PHILIPS
RESISTANCE WELDING HANDBOOK

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Typical example of a
modern spot welding machine.

CONTENTS

PREFACE

This book has been compiled to meet a need which undoubtedly exists for a practical manual on resistance welding.

It deals with the integration of resistance welding into the general process of production and is not intended to be a technical manual for the design of resistance welding machines. As such it will be of use to Works Directors, Works Managers, Engineers, Foremen and others whose interest in resistance welding lies in its practical application to the production job. It will be a valuable addition to an all too scanty library of literature of this kind. " Philips Resistance Welding Handbook " is intended as a companion volume to " Philips Practical Welding Course " which deals with arc welding. Technicalities have been avoided, although it is assumed that the reader is familiar with the principles of electricity and magnetism and has a practical knowledge of general engineering.

The collaboration of experts in the industry has been actively sought to ensure that the work covers the entire field of resistance welding and that all phases of the process are adequately covered. The ready help and generous guidance of all those who assisted in the preparation of this book is hereby gratefully acknowledged: *G. Galle, B. G. Higgins, B.Sc., A.M.I.E.E., A. J. Hipperson, B.Sc., W. S. Simmie, B.Sc., A.M.I.E.E., J. M. Sinclair, M.B.E., N. A. Tucker, A.1 Electric Welding Machines Ltd., British Federal Welder & Machine Co. Ltd., British Thomson-Houston Co. Ltd., Buck & Hickman Ltd., Contactor Switchgear Ltd., Ingranic Electric Co. Ltd., The Institute of Welding, Mallory Metallurgical Products Ltd., New Process Welders Ltd., " Sheet Metal Industries," and La Soudure Electrique Languepin.*

CHAPTER I

SPOT, PROJECTION AND GUN WELDERS

General Definitions—Spot Welders—Spot Welder Ratings—Stitch Welders—Gun or Pinch Welders

RESISTANCE WELDING.

Resistance welding is a mechanised form of forge welding and can be described as a modern development of the art of the blacksmith (See chart on welding methods, page 207). Perhaps the process can best be defined as joining metals by pressing them together and heating the parts adjoining the place of contact by the passage of current through the contact resistance of the joint.

From this basis a whole range of machines has been evolved, from the simple spot welder used for thin sheet metal to the large flash welder capable of welding sections of many square inches, but the principle involved is basically the same in every case.

The principles employed in a simple spot welder are indicated in Fig. 1 which shows the primary and secondary windings of the transformer, the movable and fixed electrodes, and the work pieces to be joined together.

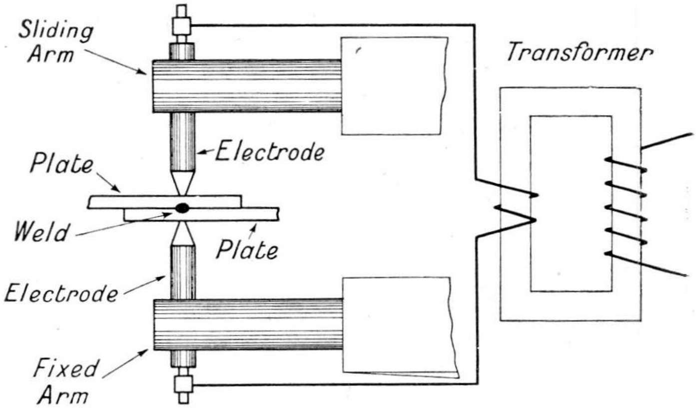


Fig. 1. Diagram of simple spot welder.

In the welding operation a current at mains voltage flows through the primary winding of the transformer inducing a secondary voltage of 2-8 volts in the secondary winding. One of the electrodes is fixed, usually the lower one, whilst the other is movable. These are closed on the work piece under pressure and for a pre-determined length of time the current heats the material and the pressure of the electrode tip forges the weld.

This, basically, is the method of operation of all spot welding machines, but so as to make the process suitable for practical operations, a number of refinements and methods of control are introduced.

The first type of machine to be described is a spot welder of the bench or floor type. This machine is provided with a single-phase transformer having a number of primary current tappings known as " heating speeds " and a secondary output of 2-8 volts. The arms are operated by a simple mechanical movement, either by hand-lever or, more often, by foot pedal. A suitable spring pressure device is fitted and the time is either controlled by an adjustable trip switch or automatically by a timer. Other types of spot welders are operated either by pneumatic or hydraulic pressure, or they are motor-operated. They are described in greater detail in the section dealing with spot welders.

Spot welders having arms separate from the transformer are known as gun or pinch welders and these are also described in detail in the appropriate section. Generally speaking the difference between a gun and a spot welder is that in the former case the welder is taken to the work whereas in the latter the work is taken to the welder.

The stitch welder is a spot welder having mechanically operated arms, generally driven by electric motors, to produce a large number of spots in close proximity, giving a sewing machine effect. The principle involved in this machine is of course identical with the single spot welder, but the mechanical details and method of construction vary considerably.

Another development of the spot welder is the projection welder (Fig. 2) in which a number of projections are raised on the workpiece. The following can be taken as a definition of projection welding : a resistance-welding process for joining metal parts, at least one of which has been provided with projections which form the only points of contact between the parts. During the welding process these projections are generally collapsed.

The next type of machine is known as the seam welder (Fig. 3) which differs from the spot welder in that instead of the electrodes being fixed with the current always flowing through the same contact points, a pair of rollers is used between which the work passes. These rollers can be either manually, mechanically or electrically operated ; usually one roller only is driven. The definition of seam welding is as follows :—A spot-welding process in which a series of consecutive spot welds can be made without manipulation by the operator (other than moving the workpiece along between the electrodes) for each individual spot-weld. One or both welding electrodes may have the form of contact rollers.

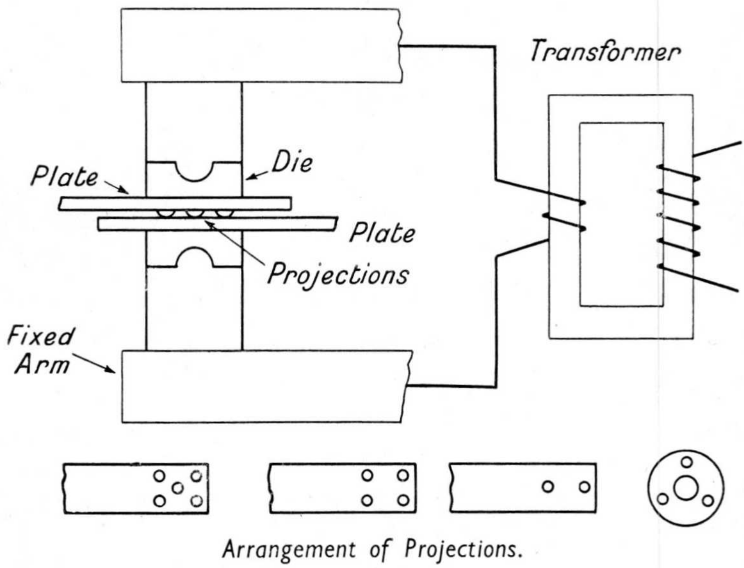


Fig. 2. Illustrating the principle of projection welding.

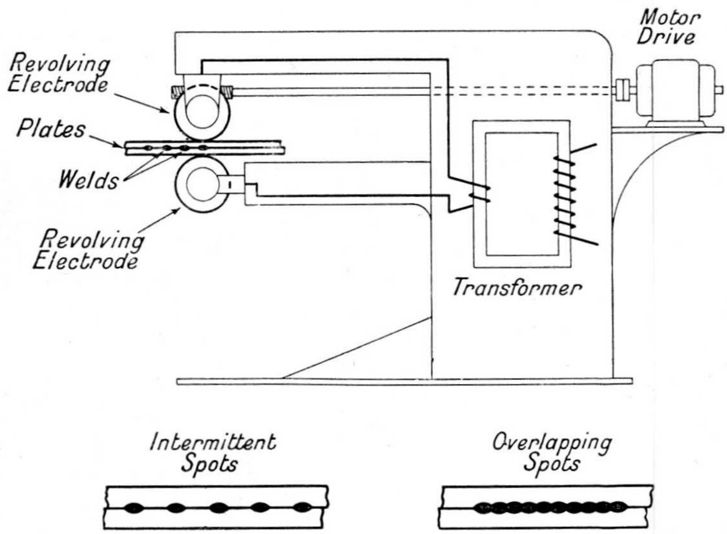


Fig. 3. Illustrating the principle of seam welding.

The next type of machine is known as a butt welder (Fig. 4) and butt welding can be defined as follows :—A resistance welding process in which the parts are butted together and pressure at the place of contact is maintained until the weld is complete. Butt welders are either manually

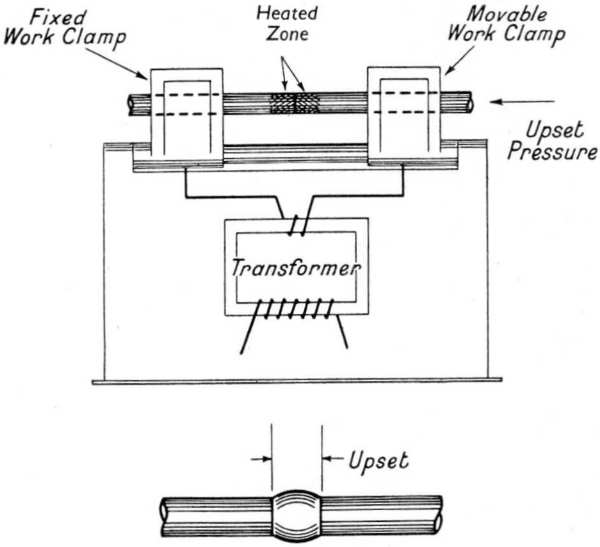


Fig. 4. The principle of butt welding.

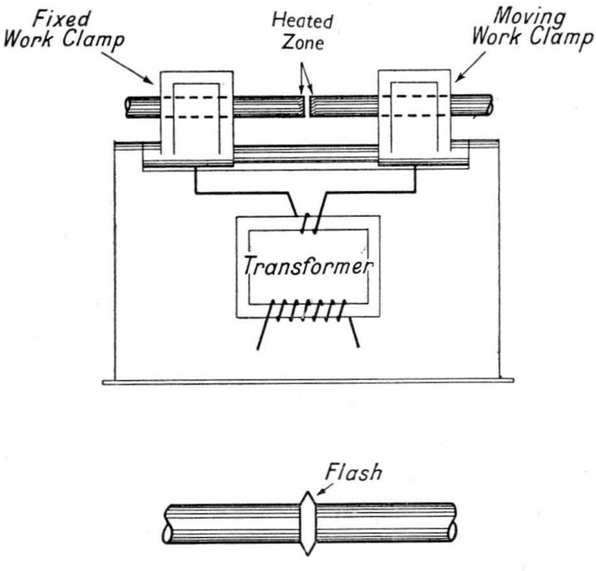


Fig. 5. The principle of flash-welding.

operated or power driven by means of electric motors, or they are hydraulically or pneumatically operated ; but whatever the method of operation, the principle remains the same.

Closely allied to the butt welder, but with a somewhat different sequence of operation, is the flash welder (Fig. 5) and flash-welding can be defined as follows :—A resistance welding process in which the contact resistance is kept at a high level, by applying a small pressure (welding pressure) during the period in which current passes. After the temperature of the parts adjoining the place of contact has reached a suitable value, the current is switched off, and the pressure between the parts to be joined is increased (forging pressure).

Whilst the details of operation are different for each of the main types of machines dealt with here, the basic principles of operation remain the same, namely, the use of high currents and low voltage to heat the material and the employment of pressure to forge the material together.

The following are the chief factors which determine the capacity of a machine, and they can be varied according to the gauge and type of material which the machine is designed to weld.

Secondary voltage (generally 2-10 v. except in special cases).

Secondary current (varying from a few hundred amps. to many thousands).

Time of current flow (varying from less than ½-cycle of the A.C. supply to one minute).

Pressure on material (varying from a few lbs. to several thousand lbs.).

Resistance welding offers an ideal method where a large number of parts have to be welded, particularly for light material, although it must not be thought that only sheet metal is suitable for resistance welding. Machines, such as heavy flash welders, have been built to deal with 15 sq. in. material ; also large butt welders for dealing with heavy steel plate. Sometimes it is found that both resistance welding and arc welding of sheet metal and of heavier steel plate can be efficiently and economically combined.

Resistance welding also has the great advantage that unskilled labour can be used, which is an important consideration. It is also particularly suitable for female labour, and as many thousands of women are now employed as resistance welders the question of female labour is dealt with in some detail in Chapter XIII.

In the following pages the main types of modern resistance welding machines are dealt with in greater detail, and in this connection one point should be emphasised. Whilst earlier types of machines operated on the same basic principles, considerable technical advances have been made in design and methods of construction in recent years. If, therefore, unsatisfactory results have been obtained in the past, resistance welding should not be dismissed as unsuitable for any particular application until the problem has been examined in the light of present day knowledge, and with regard to the results which can be obtained with modern equipment.

SPOT WELDERS.

A spot welder is a machine for making individual welds between two or more pieces of metal consisting of either separate or overlapping spots.

The method of operation of a typical spot welding machine is as follows (see Fig. 7) :— When pedal A is depressed, the moving arm B is lowered and the electrodes are brought in contact with the workpiece. When pressure is applied the contactor is closed and the current flows between the points ; the workpiece is heated and the pressure forms a weld referred to as a " spot weld." When pedal A is released the current is broken by the contactor and the electrodes are parted to enable the work to be removed.

The following detailed description of this type of machine will be more readily understood if reference is made to the numbered diagram, Fig. 7.

(1) **The body or casing of the machine.** In older types of machines this was of cast iron, but most modern machines are built with a steel frame with sheet metal casing or with a welded steel plate body.

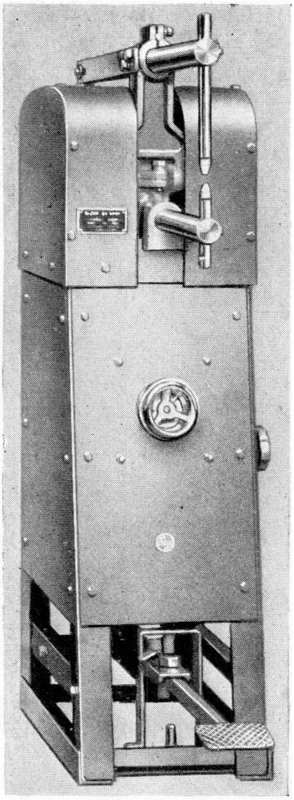


Fig. 6. Modern type of manually operated spot welder.

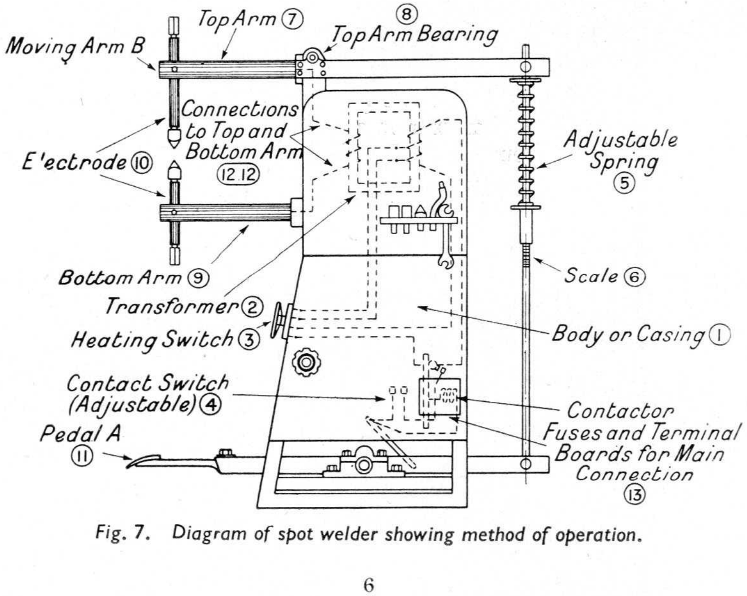


Fig. 7. Diagram of spot welder showing method of operation.

(2) **The transformer.** This consists of a single-phase primary winding suitable for mains voltages, and is generally arranged so that the machine can be connected to 400 or 440 v. supply. It is fitted with a number of current taps known as heating speeds. The transformer used in this type of machine is always single-phase. A heavy secondary winding with a voltage output of 2.8 v. is fitted, which is usually a single turn of heavy section. The transformer is generally of the single coil primary type with single loop secondary and air-cooled. In larger machines the secondary winding is sometimes water-cooled.

(3) **The heating speed or tap switch.** This is generally operated by a hand-wheel and gives a number of heating speeds. This hand-wheel turns an arm which makes contact with studs to which the primary tappings are connected.

(4) **The contactor or trip switch.** In the case of a contactor operated machine a relay (4) closes the contactor circuit when the pedal is depressed.

When a trip switch is used, the sequence of operation is slightly different. When the pedal is depressed, the trip switch closes and the mechanism of the switch is such that it remains closed for a short period which may be varied by adjustment, after which the spring or mechanical trip opens the switch ; thus the welding current is arranged to flow for a given period, according to the nature and thickness of the work.

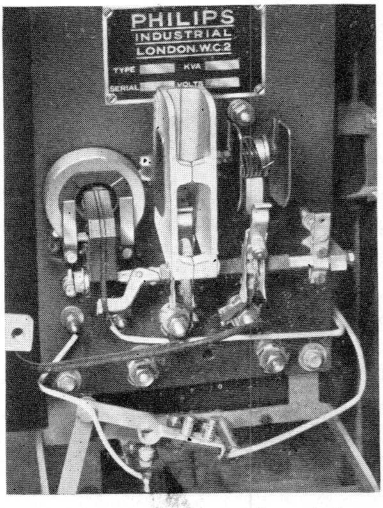


Fig. 8. Contactor relay switch.

(5) **The spring which affords variation of pressure on the workpiece.** This is generally accomplished by means of a collar and a knurled and serrated nut, the adjustment of which alters the spring pressure.

(6) **A scale which indicates the point of adjustment.** In some cases this is marked in lbs., but on most machines it is provided with divisions so that the spring pressure can be adjusted to a known point.

(7) **The top arm.** This moves on the bearing (8).

(8) **The bearing for the top arm.** This is generally either white metal or gunmetal lined.

(9) **The bottom arm.** This, in the machine illustrated in Fig. 9, is of the fixed type, but in some types of machines it is fitted to a face plate so as to permit adjustment in all directions.

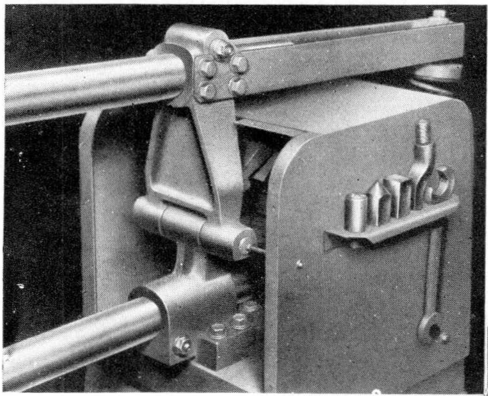


Fig. 9 (left). This machine has cotter type fixing of all moving parts ; thus split collars are avoided and dirt is excluded from the secondary connections

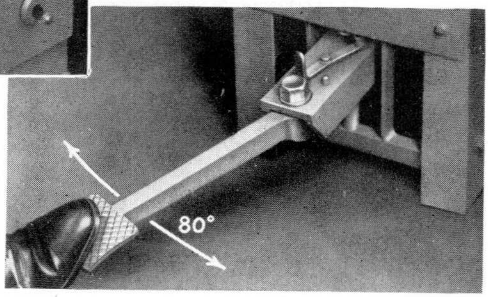


Fig. 9a (right). In this machine the foot pedal can be adjusted to any position in an arc of 80° to left and right.

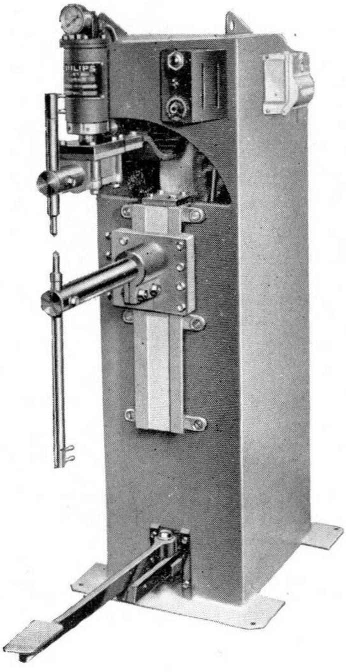


Fig. 10

(10) **The electrodes or stakes.** In smaller machines these are sometimes solid, but in most modern machines they are water-cooled and fitted with removable tips or points.

(11) **The foot pedal.** This is for operating the machine. In the type illustrated in Fig. 9a it is adjustable in the horizontal plane.

(12) **Secondary connections.** These are the connections from the transformer to the arms. On most types of machines they consist of flexible copper laminations.

(13) **Fuses and terminal boards.** Used for mains connection.

This type of spot welder has been described and illustrated in some detail as, if the operation and principles are thoroughly understood, the methods of operation of larger and more complicated machines will present no difficulties, and it will not be necessary to repeat in detail the first principles.

One of the latest types of manually operated spot welders, instead of employing mechanical leverage, employs hydraulic operation (Fig. 10). This machine operates basically in a similar manner to the mechanical leverage machine previously illustrated, but has definite operational advantages over previous types, since the wearing parts are reduced in number, the effort required from the operator is reduced and accurate control of pressure can be obtained.

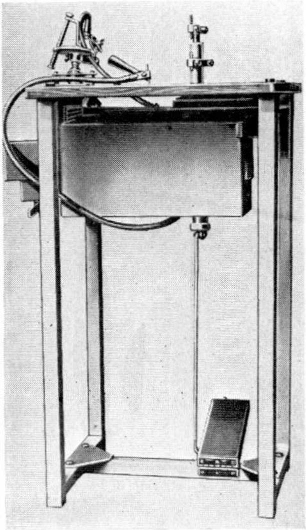


Fig. 11.

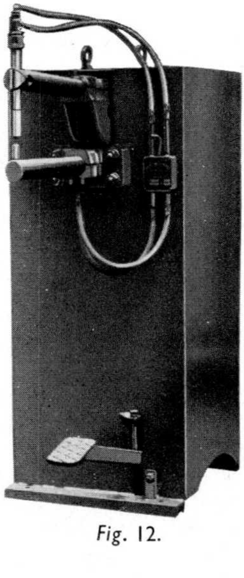


Fig. 12.

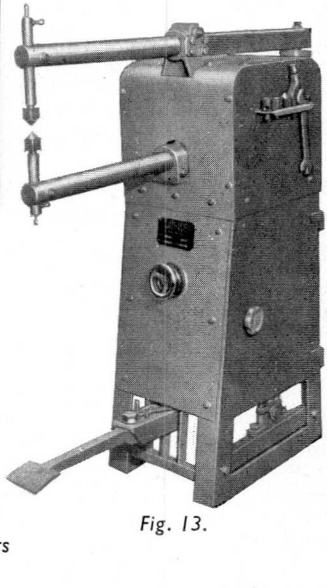


Fig. 13.

4, 14 and 20, kVA spot welders

Figs. 11, 12 and 13 illustrate typical examples of the wide range of manually operated spot welders in the market. It must, of course, be realised that machines can be supplied with longer or shorter arms, but as the arm length increases, so the welding output decreases and a machine with excessively long arms generally means slow operation and increased mechanical effort.

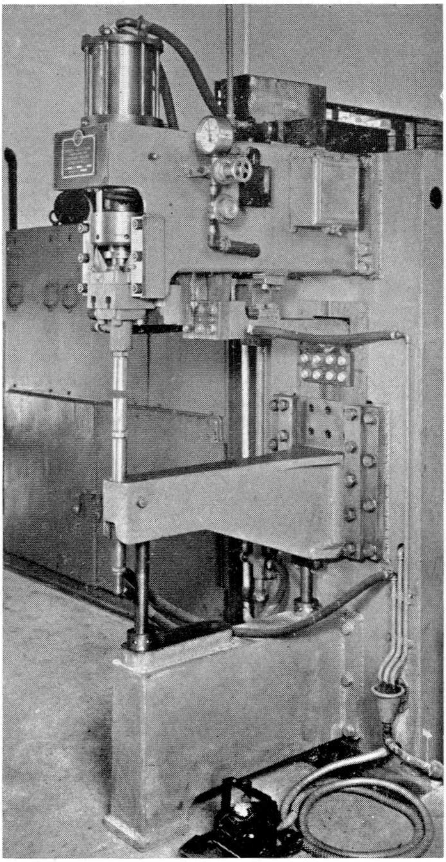


Fig. 14. A modern example of a pneumatically operated spot welder.

For sizes above 25 kVA., mechanically, pneumatically or hydraulically operated machines are mostly supplied and therefore the next step is to describe the operation and arrangements on various types of spot welders which are built in a range of sizes from 25 kVA. upwards, a very usual size being 40 or 50 kVA. Large sizes such as 75, 125, 180 and 250 kVA. are made, but these last-named and larger sizes are more often used for projection welding and are described in the chapter dealing with that subject.

The system of operation is practically identical with the manually operated machine except that pneumatic power is used, the air pressure being 60-120 lbs. per sq. inch.

The system usually employed is that of providing a piston operated by compressed air to operate the movable electrode directly. When the electrode pressure on the workpiece reaches a pre-determined value or the electrode is moved a pre-determined distance, a contact is closed which brings a relay switch into operation causing the current to flow. In those machines which are fitted with a timer the current flows for a definite period of time, usually so many cycles of the supply frequency or a number of seconds.

Most machines of this type are so arranged that the pressure can continue to be applied or increased after the welding current ceases, to give a forging effect. The piston is then either returned pneumatically or by means of a spring to the starting position. In the pneumatic type air is admitted on the under-side of the piston ; in the spring type a strong spring returns the electrode when the air relay switch releases the pressure either at a pre-determined length of travel or at a pre-determined pressure

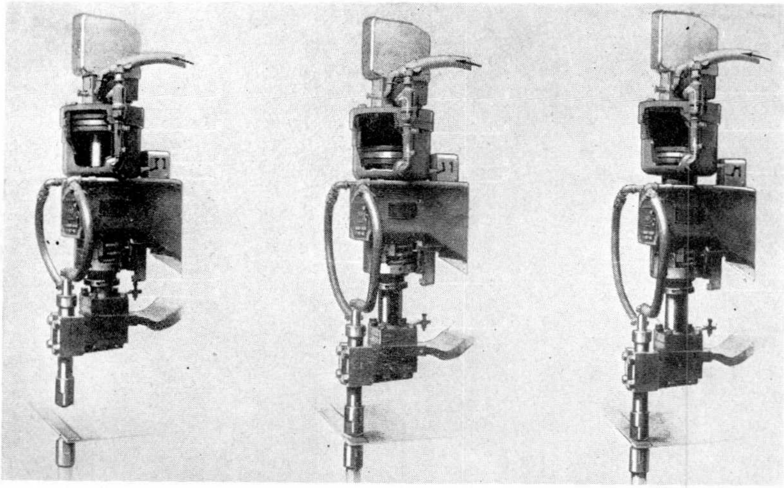


Fig. 15. *A modern pneumatic spot welder head showing piston in position.*

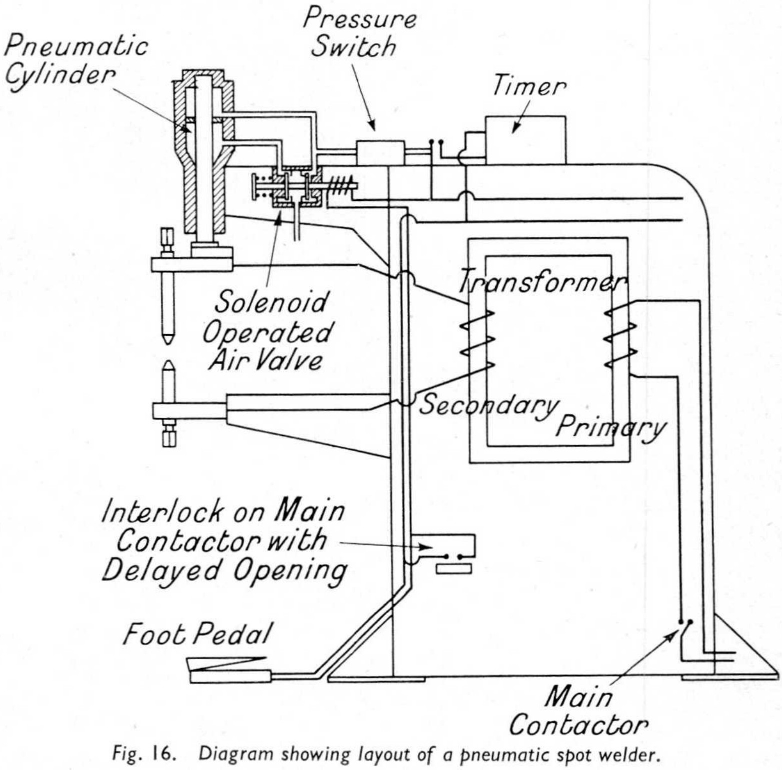


Fig. 16. *Diagram showing layout of a pneumatic spot welder.*

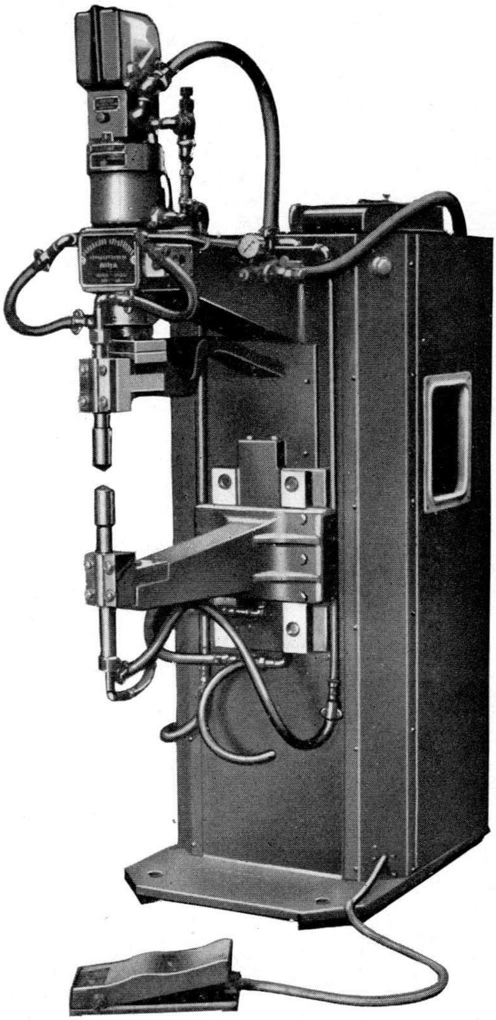


Fig. 17. A 40 kVA. spot welder.

Spot welders for light alloys, gun and pinch welders are dealt with in the respective chapters, but the following photographs (Figs. 17, 18, 19) will serve to illustrate various types of spot welders.

Hydraulically operated machines are so rare as to call for no special comment except that hydraulic power is used on the gun or pinch welder and is dealt with in the chapter under that heading. In most cases pneumatic machines are fitted with some kind of automatic timing equipment, but here again the subject has been dealt with in a special chapter devoted to this subject.

Fig. 20 shows illustrations of typical spot welded assemblies.

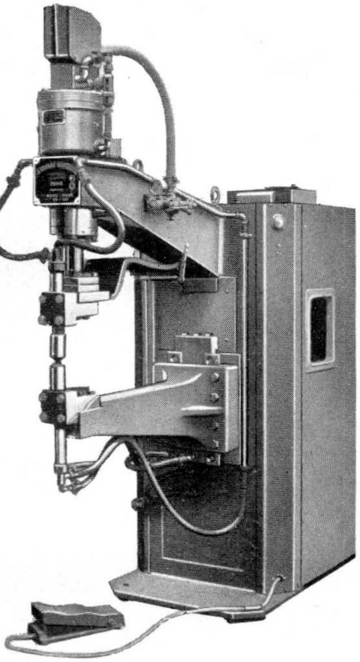


Fig. 18. 75 kVA. spot welder.

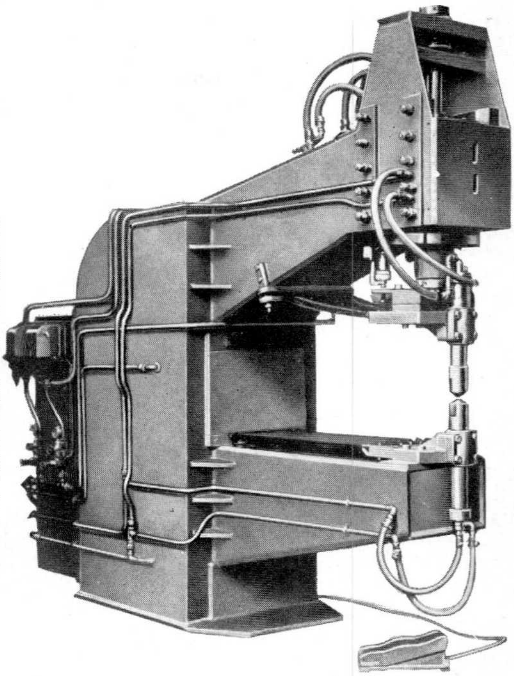


Fig. 19. 180 kVA. spot welder.

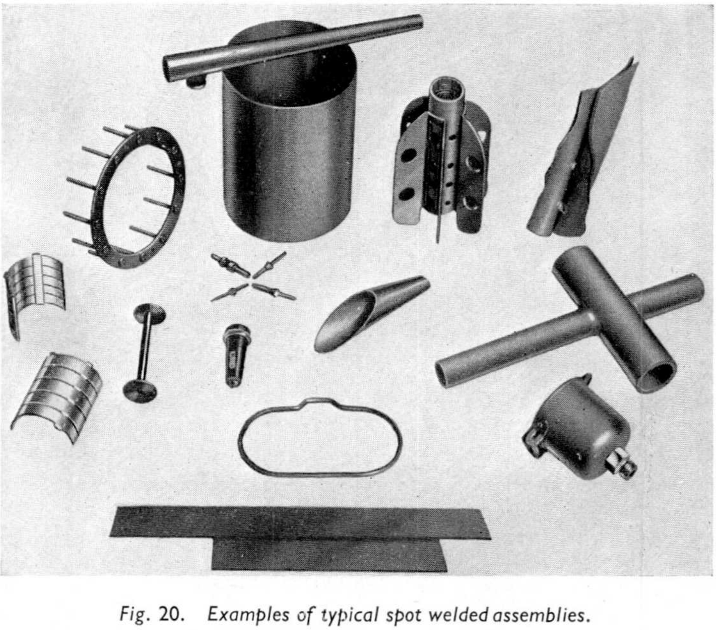


Fig. 20. Examples of typical spot welded assemblies.

PROJECTION WELDERS.

Projection welding has been defined as a resistance welding process for joining parts of metal, at least one of which has been provided with projections which form the only points of contact between the parts. The following sketches will clearly show the principles employed.

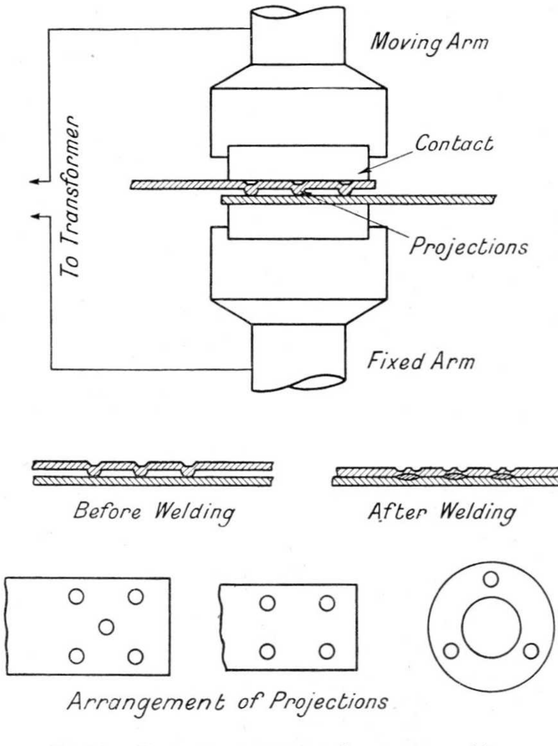


Fig. 21. Illustrating principles of projection welding.

Projection welding is carried out on machines which are really a modified type of spot welder and except that larger electrical inputs and higher pressures are employed and that special electrodes and dies are used, the principle of operation is exactly the same as that of the spot welders already described.

The advantages of projection welding, particularly for light materials, are that a greatly increased rate of production can be obtained equal to that of 3 or 4 spot welding machines, and that electrode wear is practically non-existent, as electrode tips in the normal sense are not employed. This latter point is a very important factor where large quantities of articles have to be welded. Further, unskilled labour can be used for operating these machines and, as a number of spots are welded at the same time, many articles can be welded which are difficult or unsuitable for normal spot welding.

Owing to the number of spots, projection welders are of a higher kVA. than normal spot welders. The total kVA. required is approximately equal to that required for each spot multiplied by the number of spot welds. This is, of course, only a rough rule as increased pressure and design of electrode plays a part in deciding the type of machine to be employed for any particular operation. Unlike spot welders, projection welders are generally supplied with short arms because of the high currents and pressures employed.

Undoubtedly the projection welding method has added enormously to the scope of resistance welding. The design of electrodes and dies plays a very important part and great care must be taken to ensure that overheating is prevented, that worn dies are replaced, and that the surface of the die plates is kept clean. Fig. 22 shows two types of projection welders.

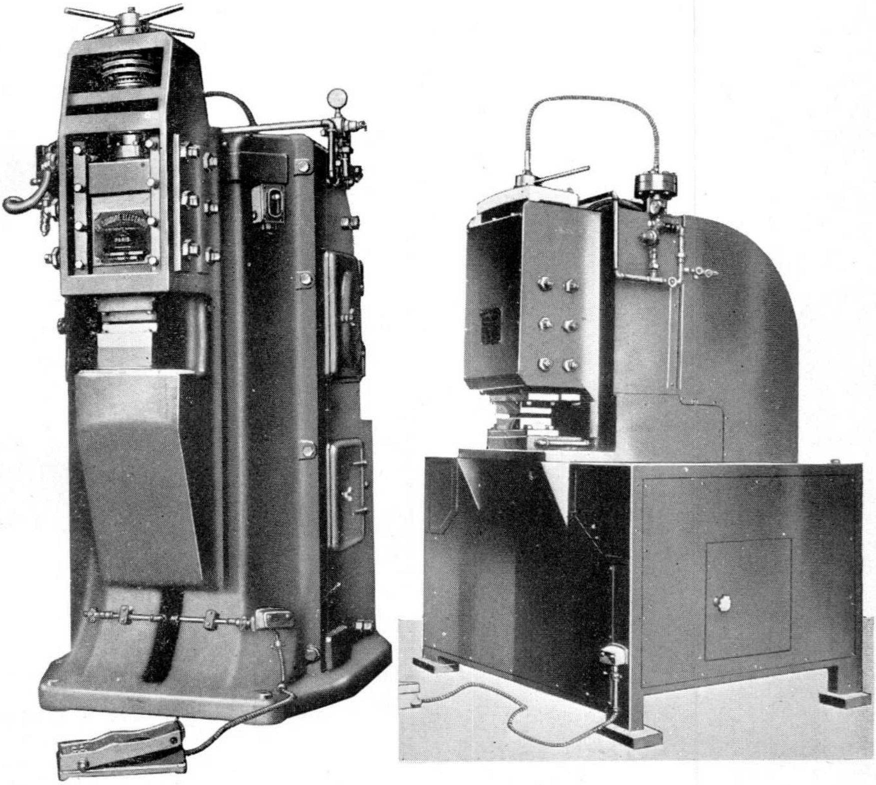


Fig. 22. A medium and large projection welder.

Fig. 23 shows a close-up view of the head of a projection welder and clearly illustrates the use of dies and electrodes. A very wide range of articles can be welded by projection, and a few typical examples are shown diagrammatically in Fig. 24.

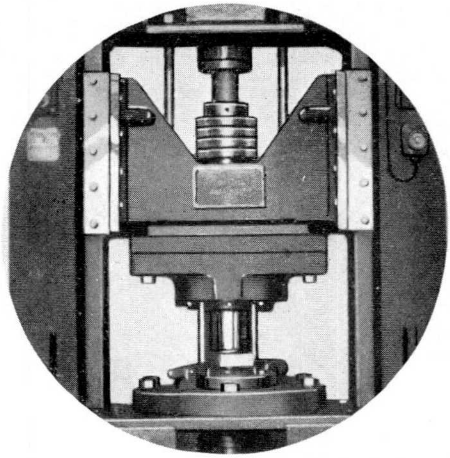
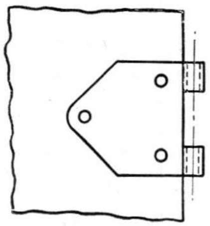
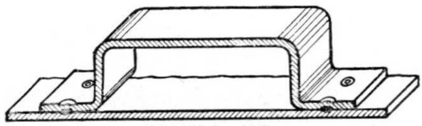


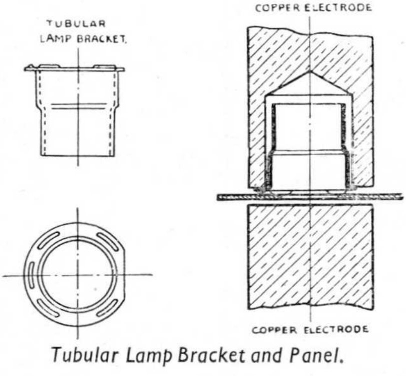
Fig. 23. Showing dies and electrodes used in projection welding.



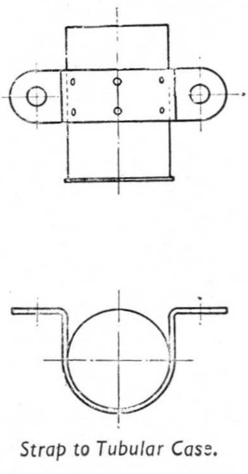
Projection Welded Hinge.



Handle to Lid.



Tubular Lamp Bracket and Panel.



Strap to Tubular Case.

Fig. 24. Group of articles suitable for projection welding.

Most projection welders, even the smaller sizes, are air-operated—the principle of operation being exactly the same as that of the air-operated spot welder. Automatic timing equipment is invariably fitted, as correct timing plays a very important part in projection welding. For the smaller machines timers controlling time only are generally fitted, but on the larger machines control units controlling time and current are installed. The use of timers for this equipment is fully dealt with in the chapter dealing with timing equipment.

Although projection welding is a simple process, to obtain satisfactory results, it is essential that the following factors be taken into account.

1. Shape of projections.
2. Number of projections.
3. Pressure to be applied.
4. Welding current.
5. Welding time.
6. Correct design of electrodes or dies.
7. Nature of material to be welded.
8. Output required.
9. Jigging and tooling.

Owing to the special nature of projection welders and the fact that individual tooling for each job is required, they are, of course, used mostly where considerable quantities of articles have to be welded ; but this does not mean to say that they cannot be used for a large variety of work. It is for this reason that the projection welder is one of the most useful machines in a mass production shop, the dies being modified or changed, when a new range of articles has to be produced. It is generally advisable, when purchasing machines for any particular contract, to install machines of excess capacity so that they will be suitable for a wider range of work. To enable the manufacturers of these machines to offer the most suitable equipment, it is essential to supply the fullest possible information. This point does not seem to be fully appreciated, as in many cases purchasers buying such equipment disclose a minimum amount of information to the makers. Information which should be made available, when considering the installation of such machines, is as follows :—

1. Material to be welded. A detailed specification of the material is invaluable, particularly if the material is of a non-standard nature. In the case of coated materials details of the exact nature of the coating should be given. Further it should be clearly stated whether the material is bright, clean or scaley. If possible, the material specification or trade name of the material should be given.

2. The minimum and maximum total thickness of material to be welded should be specified and individual thickness should be given, for example, 2 × 22 S.W.G. or 1 × 18 S.W.G. to 1 × 12 S.W.G.

3. Dimension of pieces and a sketch of the pieces to be welded clearly marked with the position and number of spots required. It is advisable to provide samples, if possible.

4. Any restriction in the size of spots should be stated.

5. The type of spot should also be considered, as in some work it is necessary to have a flush surface after welding, whereas in other jobs slight projections do not matter. In some cases the spots require to be invisible on one side after welding and in this case it is particularly important that the side which should show no mark or very slight marks, is clearly specified. In the case of enamelling or other process in which the appearance may be affected by the spot welds, it is very important to indicate clearly the nature of this finish.

Projection welders can only be supplied for use on alternating current and it is necessary to have a compressed air supply available. In some cases, where this is not available, the machines are supplied with a self-contained air compressor and receiver, or a hydraulic drive unit may be provided.

STITCH WELDERS.

Stitch welders, which have been described as the sewing machines of the resistance welding industry, are either pneumatically or mechanically driven to produce a very large number of spots in rapid succession. They are chiefly used for light material and machines have been constructed to give up to 300 spots per minute or even more.

The first type to be described is the pneumatically operated machine.

The method of operation is as follows :—When the foot control lever is depressed, the head oscillates at a pre-determined number of times per minute. At each closing of the electrodes the current flows for a short period, generally 2-3 cycles, after which the points part, the workpiece is moved along, the sequence being repeated whilst the foot control continues to be depressed. The moving electrode is lifted by a return spring or a double acting air piston, but a spring is more usually employed, as it permits of more rapid return.

These machines are fitted with an automatic timing equipment controlling the time of current flow. Perfect synchronisation is necessary, as obviously if the current does not flow during the period of contact and is not accurately broken after a very short timing period, disappointing results will be obtained.

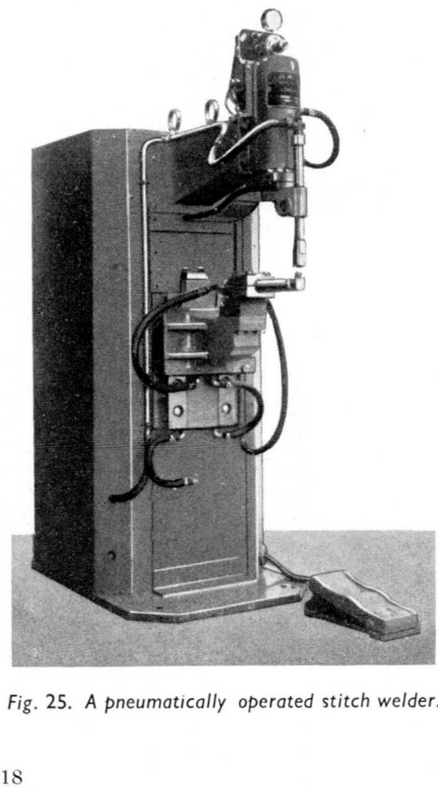


Fig. 25. A pneumatically operated stitch welder.

Owing to the very short welding times and the speed of operation, stitch welders give the most satisfactory results on clean bright material. Another important point in the operation of stitch welders is that the electrode tips should be maintained at a fixed size by means of a simple gauge, the electrodes being changed as soon as wear takes place ; this avoids overloading the machine or burning the material.

When it is realised that over 200 complete operations may take place per minute, it will be seen that the wear on the points, particularly if the material used is slightly dirty, can lead to difficulties. This does not mean that stitch welders are unreliable or a difficult type of machine to use, but as they perform in minutes what normal machines perform in hours, the wear and tear factor is higher. In modern machines this has been taken into account by suitable design and materials, but careful attention to maintenance, etc., will avoid many difficulties that may be experienced ; this matter is dealt with more fully in the appropriate chapter.

As stitch welders are frequently required for extremely light gauge material and by works having no compressed air supply available, many makers manufacture motor-driven types of stitch welders which have all the advantages of speed, etc., of the air-operated model, but are considerably simpler in construction. The required pressure on the points is low, but the high operating speed necessitates first class materials and construction.

The following is a brief specification of a motor-driven type of stitch welder.

A geared-down electric motor drives a moving head by means of a crank or eccentric, and the current is synchronized at each point of contact by accurate timer control. These machines are of comparatively simple construction and, provided a few elementary precautions are observed, give trouble-free service.

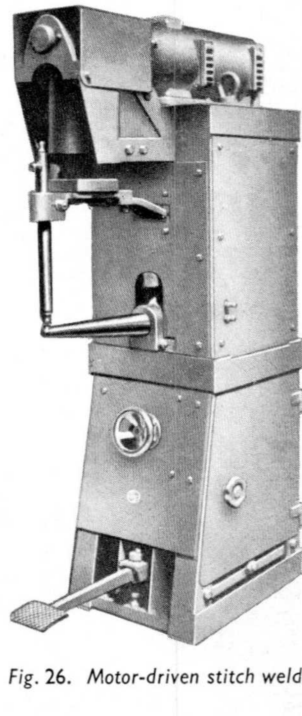


Fig. 26. Motor-driven stitch welder.

GUN OR PINCH WELDERS.

Gun, or pinch welding, is one of the most useful forms of spot welding, particularly when used in conjunction with jigs and fixtures for mass production.

This type of equipment can be divided into two main types :—

1. The air-operated gun or pinch welder.
2. The hydraulically-operated gun or pinch welder.

The first type is chiefly used in this country whilst on the Continent and in the U.S.A. the hydraulic type is extensively used in addition to the air-operated type. In France a preference is shown for the hydraulic type.

Fig. 27 shows a typical example of air-operated equipment consisting of portable air-operated gun, contactor panel, timing panel, welding transformer and air relay switch.

The gun or pinch welder is made in a large variety of types from very light machines weighing only 3 or 4 lbs. to massive machines positioned by means of a counter-balancing device or individual crane. Between these two extremes there is a wide variety of types.

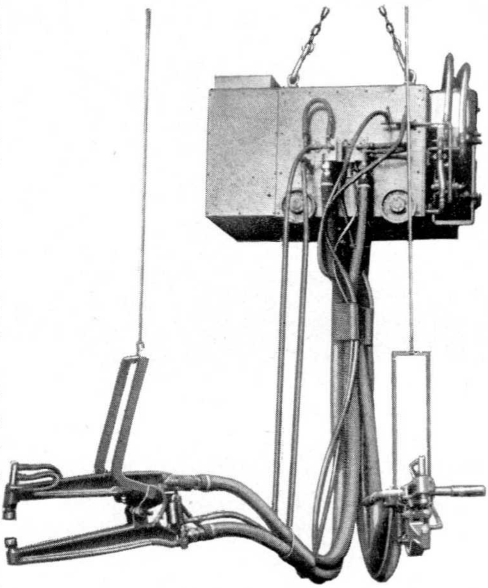


Fig. 27.

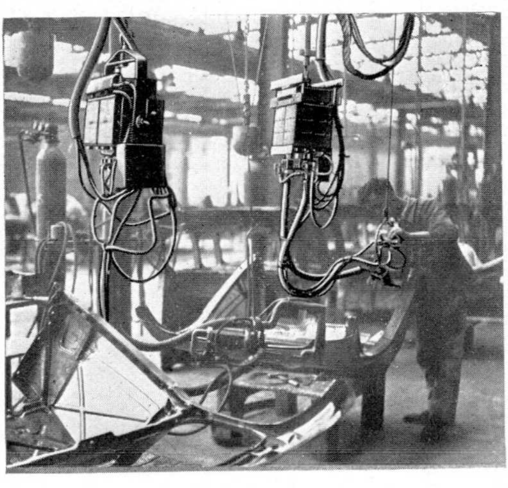


Fig. 28. A gun-operated welding outfit of the air-controlled type.

A brief description of the items comprising this equipment will enable the reader to understand clearly the principles employed, which are common to all types of gun or pinch welders, although mechanical details will vary slightly with different makes and capacities, etc.

The welder illustrated in Fig. 28 consists of aluminium box castings fitted with a brass cylinder of approximately $3\frac{1}{2}''$ dia. in which the air piston operates for applying the pressure. Some makers fit their pistons with piston rings, but it is common practice to use cup leather washers instead of rings and these are found to be extremely satisfactory and to result in much less wear than when metallic rings are used; furthermore, the low cost of renewal is a distinct advantage over the type using piston rings.

The valve for the admission of air to the cylinder is usually incorporated in the handle of the gun and is operated by pressure from the operators' thumb. The gun is connected to the other parts of the apparatus by secondary leads consisting of multi-strand tinned copper cable, these leads being water-cooled. The diameter of the leads is $1\frac{1}{4}$-$1\frac{1}{2}''$ and the cooling system employed is shown in the following diagram.

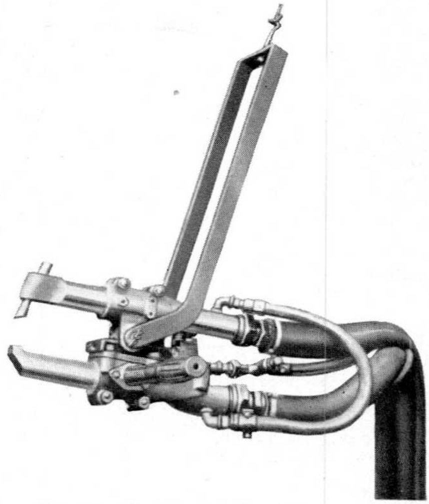


Fig. 29. A commonly used gun or pinch welder.

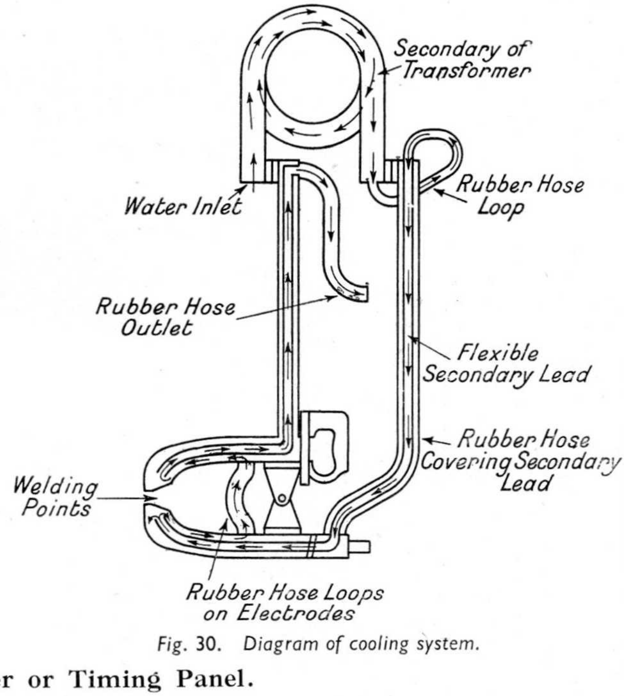


Fig. 30. Diagram of cooling system.

Controller or Timing Panel.

This is usually of the magnetic induction type with a time range from 5 cycles to 3 seconds, but other types of timers are employed and are dealt with in the chapter dealing with timers. The method of using this equipment is that a timer is set so as to give a fixed time for carrying out a definite welding operation and to ensure that the transformer is energised for a given period for each weld. By this method uniformity of production is obtained and individual responsibility for correct timing removed from the operator so that operators of gun and pinch welders need not be highly skilled.

Contactor Switch.

The contactor switch is used to control the current of the transformer, and is generally fitted with arc chutes and is electrically operated by means of a magnetic coil. The energising of this coil is controlled from the timing panel.

Welding Transformer.

It should be noted that the out-put of the secondary has a considerably higher voltage than that employed for spot welders of the normal type, the voltage being from 14-16 v. as against 4-8 v. on standard machines. The reason for this is, of course, the voltage drop in the secondary leads and the inductive losses when the leads are in close proximity to heavy steel objects.

Fig. 31 shows a typical example of a resistance welding transformer used for gun welders and fitted with water-cooled secondaries.

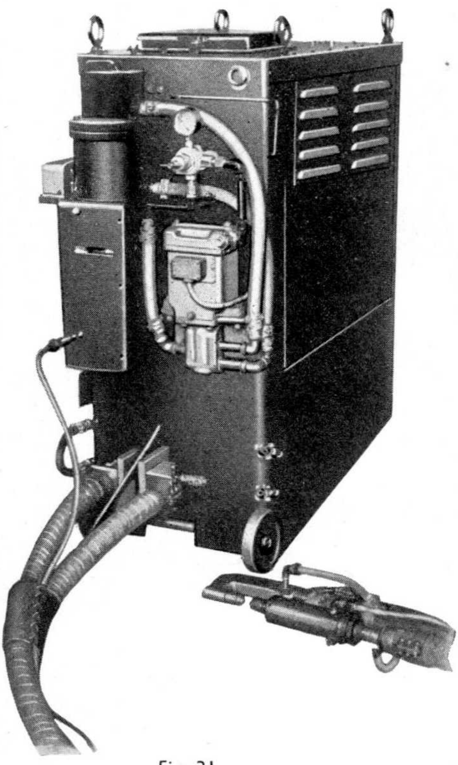


Fig. 31.

Air Relay Switch.

This switch either has a diaphragm or small plunger actuated by air fed direct from the air cylinder of the gun. The object of the air switch is to control the cycle of operation by initiating the operation of the timing panel and switching circuit on this apparatus. The air switch is spring loaded with an adjustable spring and, by varying the spring tension, the air pressure at which the switch operates can be adjusted to commence the weld at the correct electrode pressure.

Cycle of operation on Gun Welders.

Simply explained, the cycle of operation for carrying out a single spot weld is as follows :—

1. Air (generally 80-100 lbs. pressure) is admitted to the air cylinder, the piston of which is depressed and the electrode closes on to the work.

2. The air relay switch is closed at a pre-determined electrode pressure by means of air fed from the gun cylinder.
3. This completes the circuit of the timer panel which operates the contactor controlling the main supply to the welding transformer, so that the transformer is energised for a fixed period of time.
4. The contactors close and the primary current passes for the period of time mentioned above.
5. The operator then releases the air valve on the gun, the electrodes open and the machine is ready for repeating the cycle of operations.

In some machines the control valve will permit repeat action to take place automatically as long as the operating trigger is depressed. Such equipment makes possible speeds up to 180 welds per minute.

In another type of gun welder the piston, instead of being air-operated, is operated by hydraulic power, obtained either from an electro-hydraulic converter or from hydraulic mains. Except for the substitution of hydraulic pressure for air power the method of operation is exactly the same.

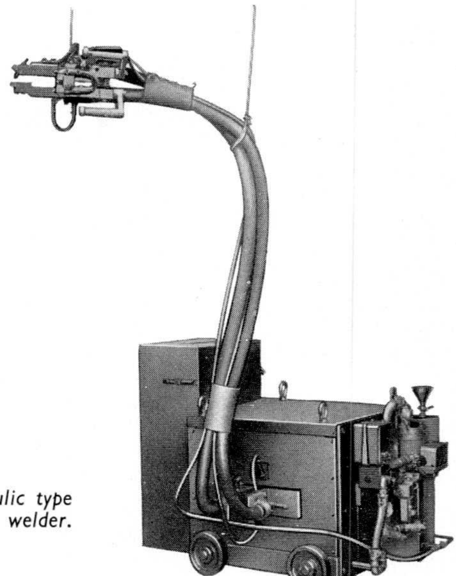


Fig. 32. Hydraulic type of gun or pinch welder.

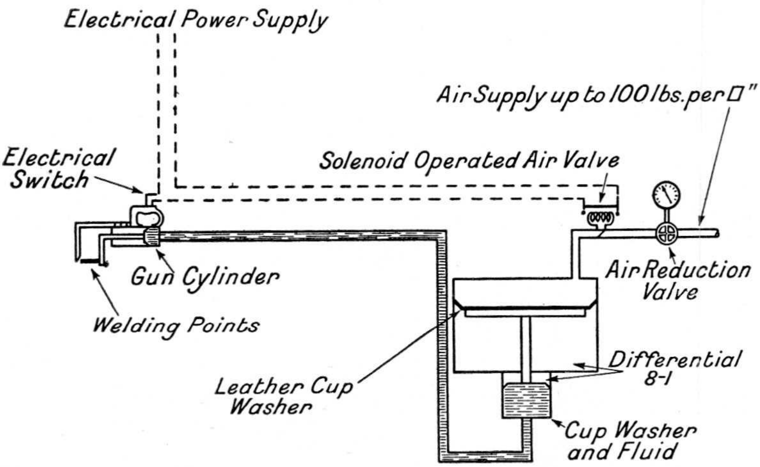


Fig. 33. Diagram showing arrangements and connections of this type of equipment.

Amongst the advantages claimed for hydraulic equipment are :—

1. A special air supply is not necessary.
2. The connecting leads are lighter.
3. For certain types of work hydraulic pressure is more suitable than air pressure.

A third type of pinch or gun welder is manually operated by means of compound levers and cranks. It is chiefly used in light sheet plate welding but is not very common.

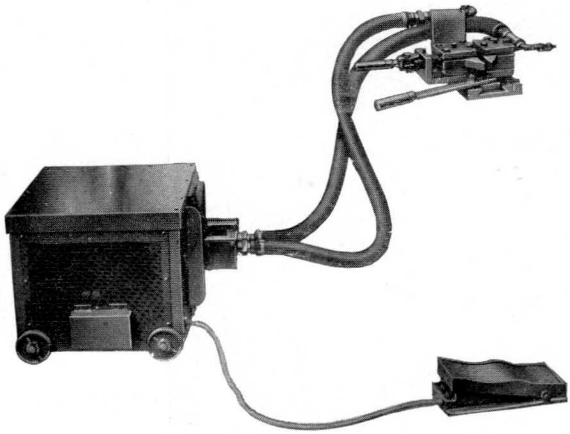


Fig. 34. An example of the manually operated system by means of compound levers and cranks.

Figs. 35-42 show various examples of air and hydraulically operated gun welders and some special plants in which the principle of gun welding has been employed. These illustrations will show that this class of welding is by no means limited to sheet metal, but can be used for structural steel work, heavy plate, etc.

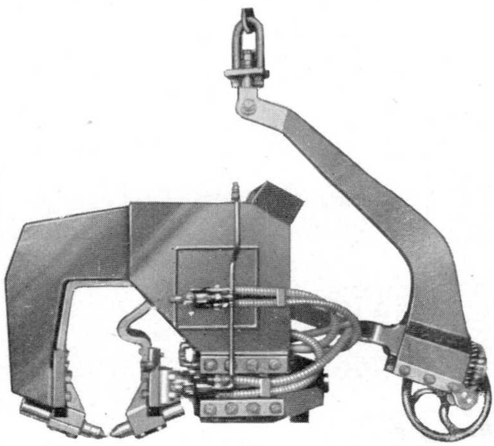
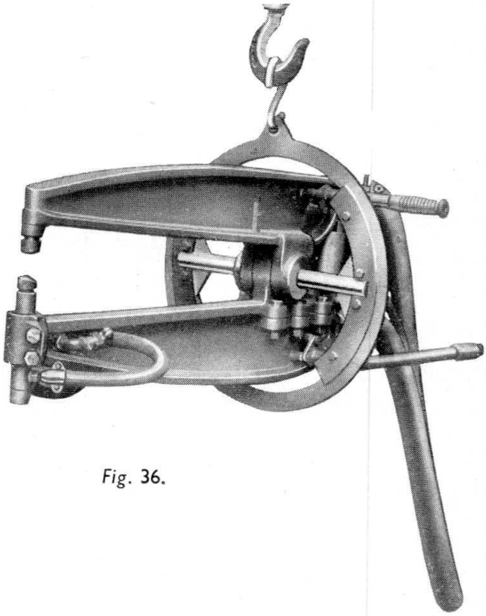


Fig. 35.



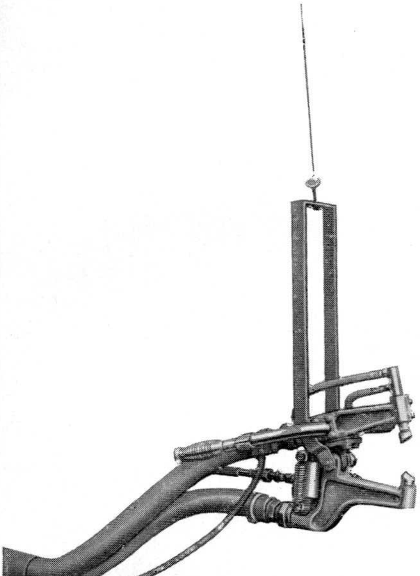
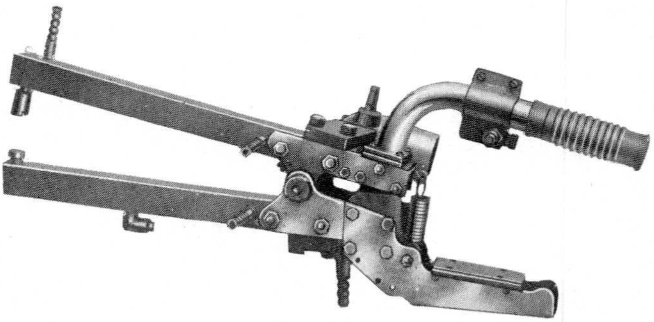
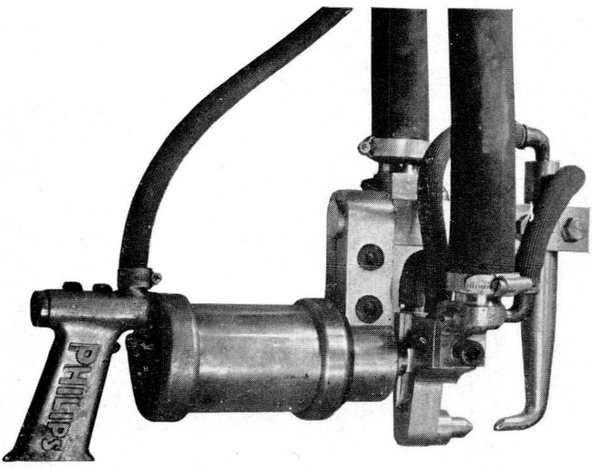


Fig. 36.

Fig. 37.

Fig. 38.





Examples of air and hydraulically operated gun welders.

Fig. 39.

Examples of air and hydraulically operated gun welders.

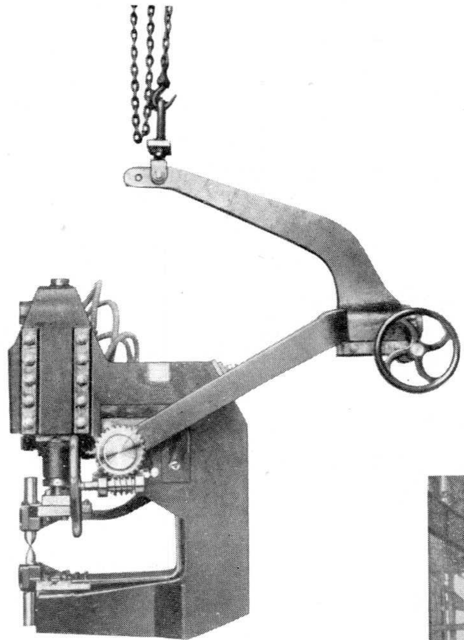


Fig. 40.

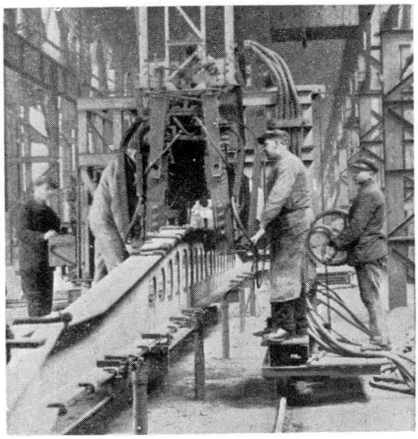


Fig. 41.

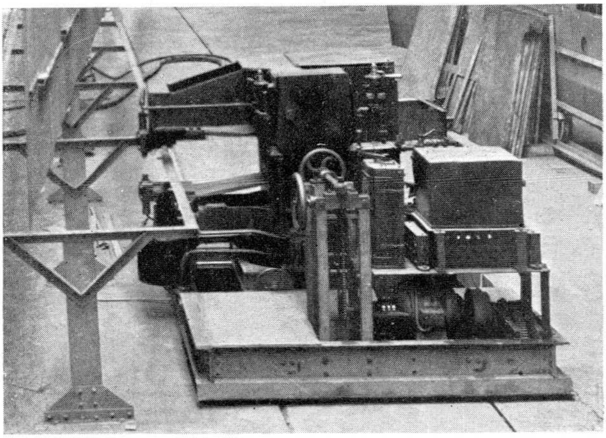


Fig. 42.

Owing to loss in the secondary leads and the nature of gun welding equipment the kVA. of the transformer is decided by the thickness of the material to be welded and the secondary cable length.

The following table provides data of the size of equipment required for various gauges of material with different lengths of secondary cable when welding mild steel under normal operating conditions.

Two Thicknesses of material S.W.G.	Secondary Cable Length.	Transformer kVA.
22	3 ft.	20
22	6 ,,	20
22	10 ,,	30
18	3 ,,	20
18	6 ,,	20
18	10 ,,	35
16	3 ,,	20
16	6 ,,	35
16	10 ,,	40
14	3 ,,	35
14	6 ,,	40
14	10 ,,	60
10	3 ,,	40
10	6 ,,	60
10	10 ,,	75
8	3 ,,	60
8	6 ,,	75
8	10 ,,	100

The above are calculated reckoning the effective cross section of the secondary leads to be $\frac{7}{8}''$ diameter high conductivity copper fully water-cooled. The secondary volts 14 to 20. As compared with pedestal machines there is an efficiency loss as high as 40% depending on the length of the secondary lead. This is also due to the small cross section.

Gun welders should be considered when large numbers of sheet metal components have to be welded which are awkward to handle or difficult to bring to the machine. Gun welding is very extensively used on automobile body and chassis manufacture and there is no doubt that this system can be employed to a large extent in the fabrication of many articles.

Chapter II

SEAM WELDERS

By G. GALLE*

Introduction—Basic Principles of a Seam Welder—Pulse or Beat Control—Roller Track Width—Heat Control—Seam Welding Methods—Welding Data

The seam welding machine tool is used for resistance welding of overlapped sheets by means of a series of spot welds.

Four controls are necessary for the technique of spot welding, these are :—

1. Welding electrode pressure.
2. Welding electrode diameter.
3. Welding current.
4. Welding time.

Six controls are necessary for the technique of seam welding, these are :—

1. Welding electrode or roller pressure.
2. Welding roller track width.
3. Welding current.
4. Welding time.
5. Time between welds.
6. Welding speed.

BASIC PRINCIPLES OF A SEAM WELDING MACHINE.

The seam welding machine (see Figs. 43-46) comprises a welding transformer, encased in a suitable frame. This transformer generally has a single turn, heavy current, water-cooled secondary, of which one side is directly connected to a heavy sectioned bottom arm. A current carrying bearing is mounted at the other end of this arm. The welding roller is directly mounted on the bearing spindle. The upper welding roll, is capable of being lifted or lowered to contact the lower roll and means are provided to control the contact pressure. The upper welding roll is carried on a

*British Federal Welders Ltd.

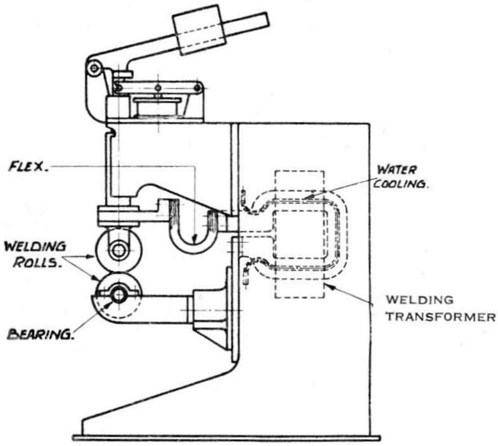


Fig. 43.

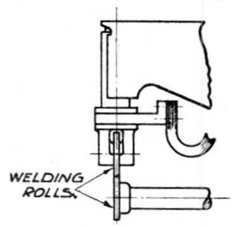


Fig. 44.

POSITION OF ROLLS FOR CIRCUMFERENTIAL WELDING.

similar spindle and bearing as the lower roll, but part of the connection from this bearing to the other side of the transformer secondary has to be flexible, to allow for the movement of the top welding head.

Means are provided for driving the welding rolls at the correct welding speed and to maintain a constant width of face on the welding rolls. The supply to the welding transformer primary is pulsated at a suitably controlled beat, so as to give a series of welds as the material to be welded passes between the welding rolls.

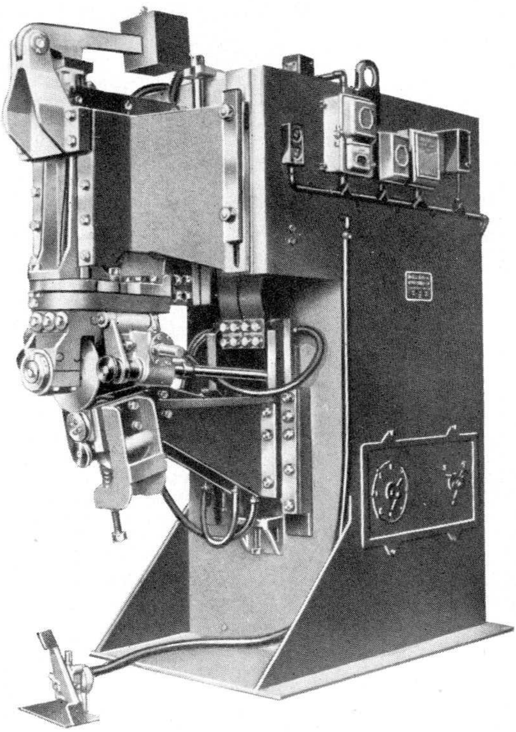
The welding rolls can be disposed either longitudinally (Figs. 43 and 46) or circumferentially (Figs. 44 and 45).

The following procedure is required to make a seam weld :—

1. The overlapped sheets to be welded are placed in between the welding rollers, which have a controlled pre-set width of track.

2. A controlled pre-set mechanical pressure is applied to these rollers, clamping the sheets together.

Fig. 45.



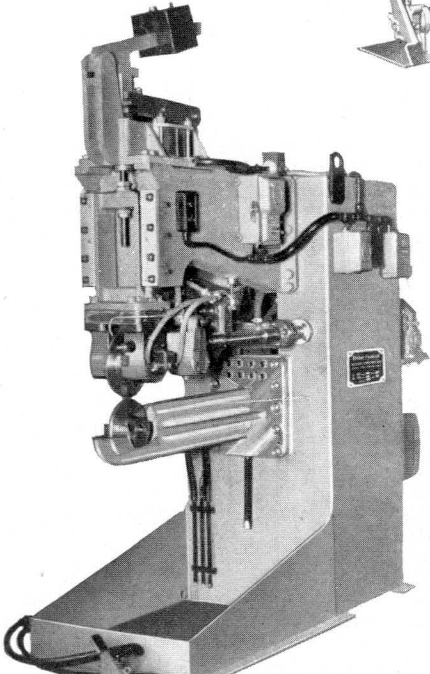


Fig. 46.

3a. A controlled pulsating welding current is allowed to flow through the sheets to be welded at the point of contact of the rollers.

3b. At the same time that this current starts to flow, it is necessary to rotate the welding rollers, in order to pass the sheets being welded through the rollers at a controlled speed.

THE WELDING ROLL PRESSURE.

There are three methods in common use, which are outlined below :—

1. Dead weight.
2. Spring pressure.
3. Pneumatic pressure.

1. A good example of the dead weight method is shown in Fig. 47.

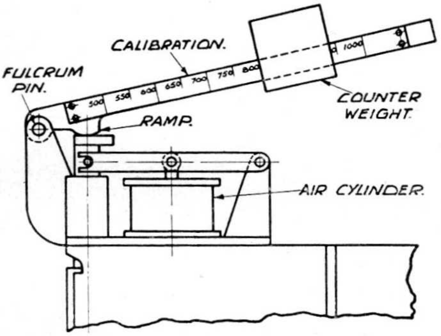


Fig. 47. *Diagram showing dead weight method.*

The weight can be moved along a calibrated lever, which applies pressure to the upper welding head at the bearing point. The head, lever, and weight are returned to the loading position by means of the single acting air cylinder. A very easily controlled and extremely constant electrode pressure is obtained by this method.

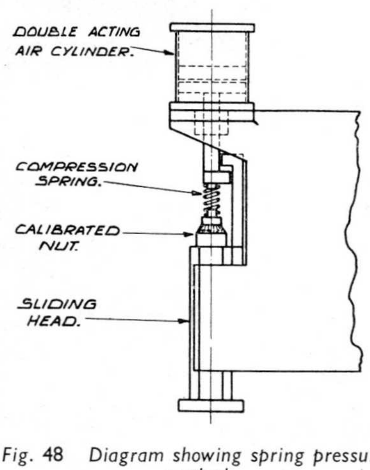


Fig. 48 *Diagram showing spring pressure method.*

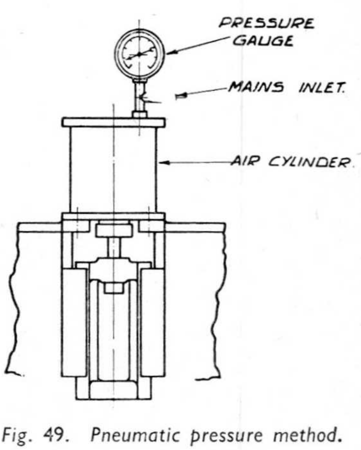


Fig. 49. *Pneumatic pressure method.*

2. Fig. 48 shows a good example of the use of a spring ; in this case a double acting pneumatic air cylinder lifts the head when the air pressure is on one side and compresses the spring which applies pressure to the head, when on the other side. The cylinder is made large enough, so that it always completes a definite stroke, and the welding pressure is adjusted by means of a calibrated nut adjusting the spring compression.

3. Fig. 49 shows the typical pneumatic method which is very simple, consisting only of a double acting cylinder. Air pressure on one side of the piston lifts the welding head, and applies the actual welding pressure when on the other side ; this pressure can be controlled by a reducer valve in the air line and the welding pressure can be read directly on a specially calibrated air gauge. This method is quite good, but unfortunately fluctuations in the main air pressure affect the welding pressure directly, and hence the electrical resistance at the weld.

THE WELDING SPEED.

Mild steel seam welding is normally confined to sheet thicknesses between 12 and 22 S.W.G. It has been found that 12 g. can be welded at between 1 and 2 feet per minute and the limit to the welding speed for the lighter gauges is restricted by the speed at which the components to be welded can be fed through the welding rollers, and by the number of spots per inch obtainable at this speed. For these lighter gauges, 10 to 20 spots per inch is a good range.

The normal 50 cycle frequency in the electric supply in this country can be used for the faster welding speeds. This periodicity gives 100 pulsations per second and thus welding speeds of between 25 feet per minute at 20 spots per inch, and 50 feet per minute at 10 spots per inch can be used. If by means of mechanical handling it is possible to use a speed of over 100 feet. per minute, then it is desirable to increase the frequency of the supply.

These speeds are, of course, normally too fast for ordinary handling. Possibly the average machine welding speed range is 15 to 100 inches per minute ; this means that for 5 spots per inch at 15 inches per minute and 20 spots per inch at 100 inches per minute, a pulse or beat of 75 to 2,000 times per minute is required to cover the whole of the welding speed range.

There are three main methods of driving the welding rolls and obtaining control over the welding speed.

1. Friction driving on one or both of the welding roll peripheries.
2. Shaft driving one of the roll shaft spindles.
3. Mechanically drawing the components to be welded through idling rolls or under a single idler.

1. Figs. 50, 51 and 52 show good examples of a " Knurl " driven roll.

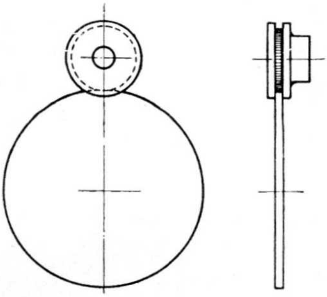


Fig. 50.

The knurl wheel is driven by either a variable speed motor, or a constant speed motor and a variable speed drive, and a gear box, so that the peripheral speed of the knurl wheel and consequently the welding roll, can be pre-set to run at any speed between 15 and 100 inches per minute.

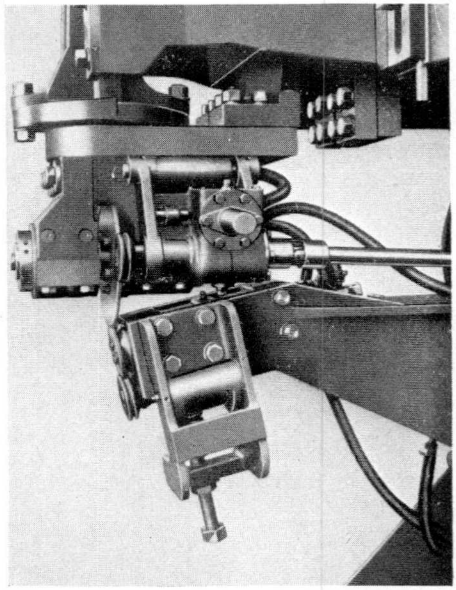


Fig. 51.

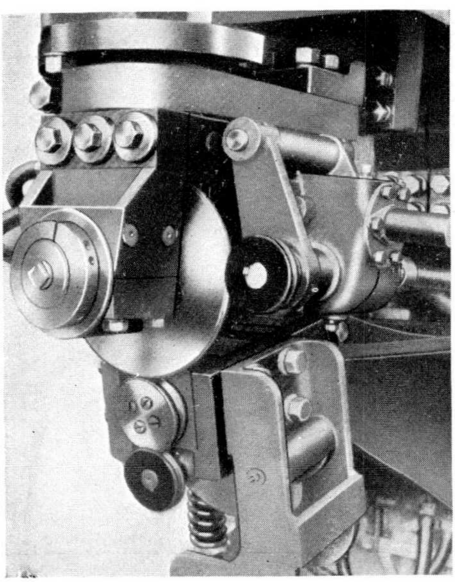


Fig. 52.

This method of driving the rolls has one important feature. When the welding rolls wear down in diameter after a certain time, the peripheral speed still remains constant regardless of the roll diameter. The welding speed can be easily and accurately calibrated directly from the motor variable speed control, or the variable speed drive.

2. The shaft driven method is self explanatory. The general method of driving the shaft is the same as with the peripheral method, with the exception that the shaft is driven at such a speed that the periphery of the welding roll can be controlled between 15 to 100 inches per minute.

The calibration of this method is of limited accuracy, because, as the welding roll decreases in diameter, the welding speed also decreases. A further disadvantage over the peripheral drive method is that only one roll can be driven and the other must be an idler, as the peripheral speeds may vary as the rolls wear. This difference in roll speed causes puckering on the welded faces of the sheet.

3. Drawing methods are generally used for a single purpose machine. Figs. 53 and 54 show a typical example of the single roll type. The roll is an idler and the components to be welded are clamped to the motor driven mandrel and table which is driven from either side by a reversing motor. The components to be welded can be loaded and unloaded at either end. This method again can be accurately calibrated in a similar manner to the knurl driven method.

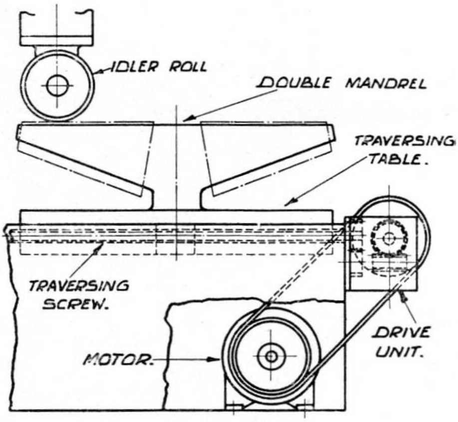


Fig. 53.

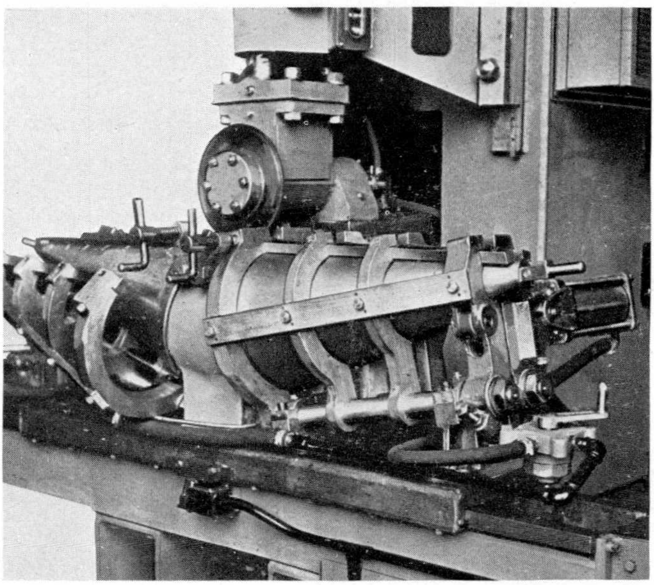


Fig. 54.

THE PULSE OR BEAT.

It has been found that if the spots per inch are too frequent, distortion of the components to be welded is the result; also if the spots per inch are correct, but the welding current " time on " is long compared with the " time off," similar distortion results.

There are three main methods of pulse or beat control, viz. :—

1. Thermionic tubes.
2. Rotary pulsator.
3. Mechanical interrupter.

1. The thermionic tube control is described elsewhere in this book. Not only can the pulsations per minute be accurately controlled, but also the " time on " against the " time off " can be controlled within limits.

Fig. 55 shows a typical oscillogram of the welding current with this type of control.

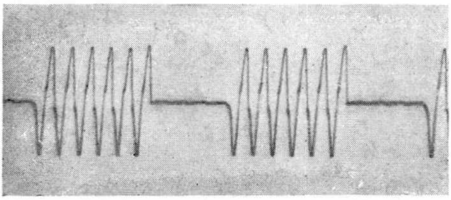


Fig. 55.

2. The rotary pulsator usually takes the form of a rotary induction regulator and is driven either by means of a variable speed motor, or a constant speed motor with a variable speed drive. This regulator is connected in series with the welding transformer and during one revolution both bucks and then boosts the voltage to the welding transformer. There is no control of the period of buck or boost, but generally the two periods are equal.

Fig. 56 shows an oscillogram of a typical welding current, the buck current is generally 25% of the boost. This 25% current value is too low to make a weld.

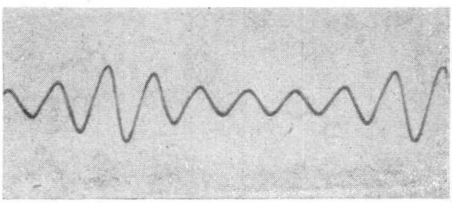


Fig. 56.

3. The mechanical interrupter is generally a variable speed motor-driven cam shaft operated switch, with a control over the cam "on" and " off " period. Sometimes this switch is used directly to break the welding current and sometimes to pilot a high speed contactor.

Fig. 57 shows an oscillogram of a welding current made on this type of unit.

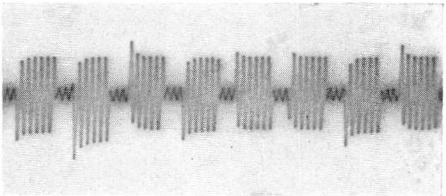


Fig. 57.

A permanent resistance has been put across the contacts of the switch to help the break. The loading current of this resistance can be clearly seen.

WELDING ROLLER TRACK WIDTH.

The mechanical pressure in pounds per square inch at the point of contact of the rollers to the sheets being welded is extremely high, generally between 4,000 and 12,000 pounds per square inch. The current density in the copper rolls at this point of contact is generally between 50,000 and 500,000 amps. per square inch. Consequently, due to these two severe conditions, the roll faces tend to mushroom at the weld. This mushrooming, or spreading, causes not only the current density to decrease, but also the pressure in pounds per square inch decreases. This in turn causes a decrease in welding heat. Consequently it is very important to maintain a constant roll track.

There are three main methcds of controlling the width of the welding track, these are outlined below :—

1. Knurl wheels.
2. Mechanical automatic trimmers.
3. Routine roll changing.

1. Fig. 58 and Figs. 51 and 52 on page 33 show a typical spring loaded knurl combined drive, cleaner and trimmer. This knurl wheel not only turns off the mushrooming as it rotates, but the serrated driving face constantly cleans the welding face. This type of roll needs no attention and can be run without being removed for the whole of its life.

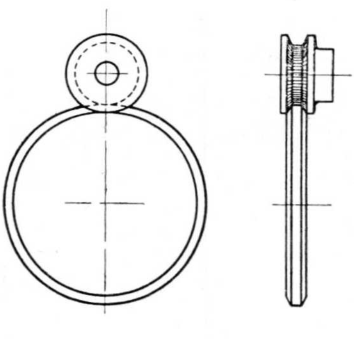


Fig. 58.

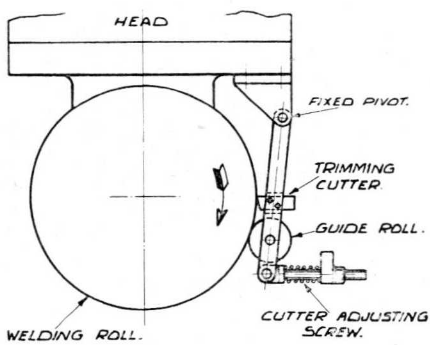


Fig. 59.

2. The mechanical automatic trimmer and cleaner is clearly shown in Fig. 59. A small hardened steel idler roller stops the " U " shaped adjustable cutter exactly in the correct trimming position, and pressure is applied to the trimmer by means of the spring. The small roller runs on the " trimmed " part of the welding roller.

3. The third method is of course self explanatory and although it is used extensively it means constant roll changing and is never entirely satisfactory as a roll rarely has a life of over three hours without increasing 15% in track width.

WELDING HEAT CONTROL.

There are three main methods of welding current control—all are on the primary side of the welding transformer.

1. Thermionic tubes.
2. Primary tapping.
3. Induction regulator.

1. The thermionic tube control is dealt with more fully in a separate portion of this book and consists of primary current wave form control. It is infinitely adjustable and no taps whatsoever are required on the welding transformer. On close examination of Fig. 55 (page 35), parts of the sine wave can be seen to taper abruptly. This was caused by the thermionic control.

2. The primary tapping method is possibly the most common. The lowest secondary open circuit voltage is obtained by use of the full winding in series. The highest voltage is generally twice this figure. Some 12 steps are generally made between maximum and minimum secondary voltage and are obtained by series or parallelling part of the winding and omitting other parts by means of a suitable selector switch.

3. The third method is sometimes used, particularly when the heat has to be controlled actually during the weld. A remotely controlled induction regulator is used in conjunction with a tapless welding transformer. An infinitely variable, stepless, instantly adjustable control is obtained.

TYPICAL EXAMPLES OF SEAM WELDING.

An excellent example of seam welding is the drum or keg weld. Fig. 60 shows the cylindrical body rolled and overlapped in position ready for the longitudinal seam weld. The arrangement of suitable welding rollers are shown on the right.

Fig. 61 shows a pressed dished end ready for driving into the welded body before circumferential, or end welding. The arrangement of suitable welding rollers is again shown on the right.

Fig. 62 shows another arrangement of the dished ends, they are reversed and welded on the inside, the length of the welder arms must, of course, be capable of reaching the bottom end of the body. It is impossible to weld the second end by this method.

Another example is what is referred to as the " butt seam weld," it has practically only one application and that is tube welding. Fig. 63 shows the main principle.

Strip is formed in some six to eight stages into a continuous tube, two final forming rolls butt the edges to be welded together just underneath the welding rollers. A heavy welding current is passed over this butt by the welding rollers.

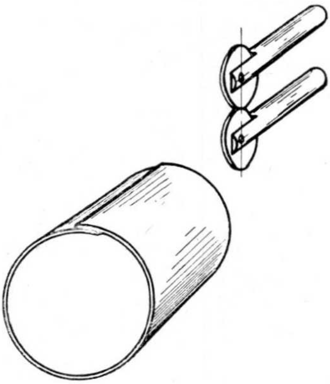


Fig. 6C.

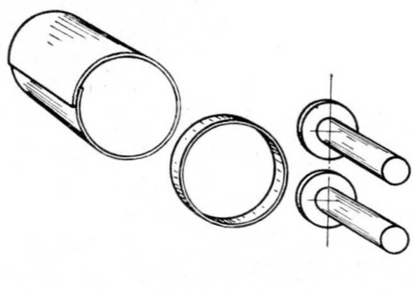


Fig. 61.

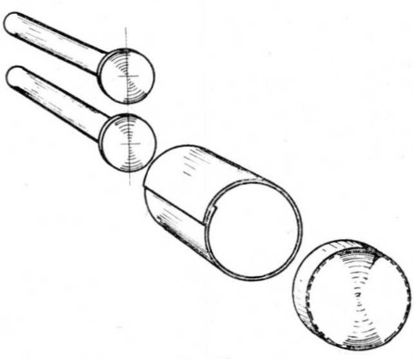


Fig. 62.

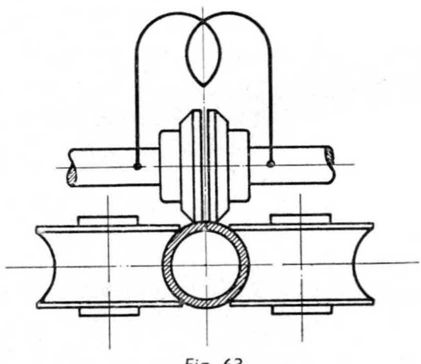


Fig. 63.

A third example is outlined by Figs. 53 and 54. It is sometimes referred to as the mandrel type seam welder. The bottom electrode is in the form of a mandrel mounted on a moving table, this table is generally driven by a screw and nut. The screw itself is driven by either a variable speed motor, or alternatively by a constant speed motor having a variable speed drive and gear box. The top roll is an idler. The particular example shown is for welding cones. During the period that one cone is being welded, the welded cone is being removed from the other end of the mandrel, and being replaced by the next cone ready for welding.

STEP-BY-STEP SEAM WELDING.

One of the disadvantages of the ordinary machine is that during the period that every spot is being made, the rollers are moving. This feature is more pronounced when welding the heavier gauges, as it is necessary to have a longer welding time for each spot. Fig. 64 shows a series of welds showing the resultant distorted spot form.

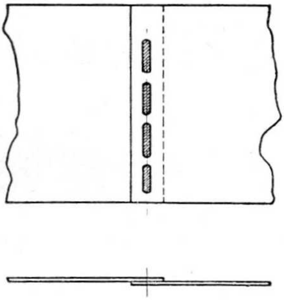


Fig. 64.

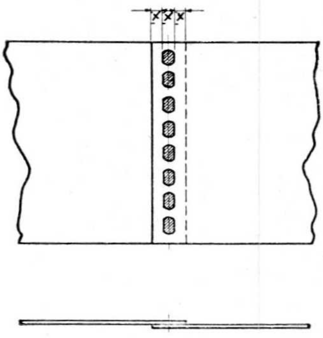


Fig. 65.

The step-by-step method was adopted to correct this distortion. It also has other advantages and one disadvantage. The welding speed is relatively slow.

Fig. 65 shows the resultant even spot.

There are two main methods of step-by-step welding :—

1. A Geneva drive.
2. A ratchet drive.

1. Fig. 66 shows the principle of the Geneva drive.

In this example the driving shaft is rotated by a variable speed motor, or alternatively by a constant speed motor with a variable speed drive, and gear box. One revolution of the driving shaft rotates the driven shaft one-fifth of a revolution. The meshing of the Geneva ensures that the ratio of time the driven shaft is moving, to the time it is stationary, is less than unity.

The driven shaft is coupled to the rollers either by a friction or shaft drive. This type of drive is very smooth in operation, and is, of course, entirely free from snatch. It has one disadvantage, although the spots per minute can be controlled, the spots per inch are constant.

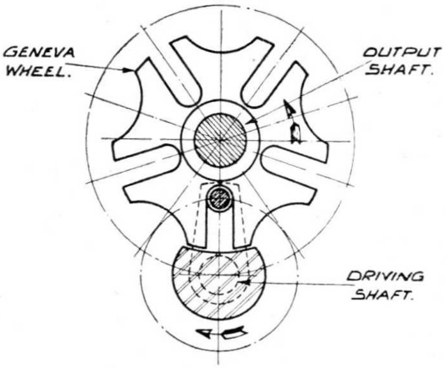


Fig. 66. Geneva Drive.

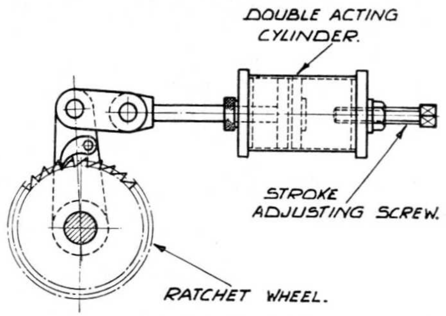


Fig. 67. Ratchet Drive

2. A good example of the ratchet drive is shown in Fig. 67.

An air cylinder operates a ratchet and pawl. The stroke of the air cylinder can be controlled to rotate the ratchet wheel 1, 2, 3 or 4 teeth. The welding time for each spot is controlled by a Timer. On completion of this time, the air cylinder makes one stroke and returns. As soon as the Ratchet Wheel has stopped moving, the Welding Time starts its second time and so on. The Ratchet Wheel is shaft connected to the Welding Roll in a similar manner to the Geneva output drive. By this method, not only are the spots per minute controlled but also the spots per inch, within limits.

WELDING DATA.

The table below shows suggested general data for seam welding mild steel sheets of between 12 and 22 S.W.G. The welding speeds, roller track widths, spots per inch and roller pressures mentioned are general averages of a great number of different welds.

The beats per minute refer to a fifty-fifty ratio, in other words, say 5 cycles welding and 5 cycles off.

Mild Steel S.W.G. Size.	Weld Speed inches per min.	Roll Track Width inches.	Spots per inch.	Beats per min.	Roll Pressure lbs.	Welding kVA. Throat Clearance.		
						12″	24″	36″
12	15	$\frac{5}{16}$	5	75	1100	70	80	90
14	20	$\frac{5}{16}$	7	140	1000	70	80	90
16	40	$\frac{1}{4}$	9	360	900	60	70	80
18	60	$\frac{1}{4}$	11	660	800	60	70	80
20	80	$\frac{3}{16}$	13	1040	700	50	60	70
22	100	$\frac{1}{8}$	15	1500	600	40	50	60

EXAMPLE.

It is required to weld two 16 SWG. Sheets. The machine will be set for :—

40″ per minute welding speed.

$\frac{1}{4}$″ roller track width.

9 Spots per inch.

360 beats per minute.

900 lbs. roll pressure.

70 kVA. will be required if the arm length is 24″ clearance.

MATERIAL FOR WELDING.

It is essential for good Seam Welding to have a minimum over-lap. The dimensions from the edge of the weld to the edge of the sheet should never be smaller than the width of the weld. (See Fig. 65.) It is also essential that the surfaces of the sheet should be perfectly clean. Rusty, or scaly sheets must be pickled, shot blasted or sheet edge ground and welded within a few hours.

MACHINE MAINTENANCE.

Production can be seriously affected by badly organised maintenance. The welding rollers are possibly the most hard worked part of the machine and take some time to change, particularly on the longitudinal Welders, where the bearing spindles and water ways generally have to be dismantled.

There are some copper alloys specially manufactured for these particular conditions, which have a welding life six or seven times as long as ordinary high conductivity Copper. This special material costs considerably more than ordinary copper, but the resultant saving of six or seven changes in production time adequately recompenses the production engineer.

A current carrying welding roller spindle and bushes are possibly the next most hard worked part of the machine. A good quality graphite grease should be forced into these bearings every 4 hours of production. The bearings should be completely dismantled and examined for high spots every 50 hours of production. Care should be taken to ensure that the correct cold water pressure is continuously applied to various water cooled parts of the machine.

CONCLUSION.

Production engineers should be careful to watch that the seam welder is not overloaded. If the roller track width is allowed to spread to a width beyond the range the machine was designed to operate, the transformer will automatically draw an overload from the mains and will over-heat.

Chapter III

FLASH AND BUTT WELDERS

By J. M. SINCLAIR, M.B.E.*

Butt Welding—Principles of Flash Welding—Typical Machines —Applications—Flash Butt Welding

The term " butt welding " is widely used in describing an end to end weld without overlap, such as the joint in two lengths of bar, rod, tube or plate. In other words, where a flush joint is required then the term " butt weld " is used. The phrase is common to all forms of welding, viz., oxy-acetylene, electric arc and electric resistance, but it is the last-mentioned process which is described here.

In the development of resistance welding the butt weld was the forerunner of all other processes in that when the possibilities of heat generation by low voltage electric current became known, it only required a forging action combined with heating to complete the butt welding process. Heating electrically and forging mechanically combined together in various types of machines became known as butt welding, the principle of which is illustrated diagrammatically in Fig. 68.

The simple form of butt welding as shown above, therefore, consists of two clamps or vises connected to the secondary of the transformer, the one clamp being fixed and the other movable, mounted on a slide through which the forging or upsetting pressure is applied. When the parts are clamped the movable head is pushed up until the ends meet. The current is then applied and when the proper temperature has been reached further pressure is applied on the movable head thereby forging the weld.

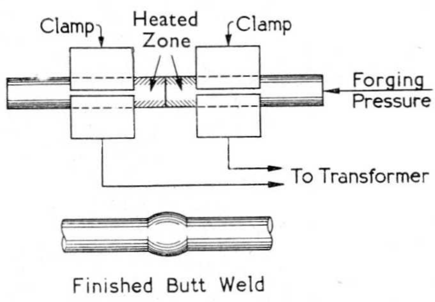


Fig. 68. Principle of butt welding.

This form of butt welding was common practice for many years and is widely used for wire and rod of light gauges and in non-ferrous welding such as copper wire and strip, and its many applications simplified forging and assembly operations by uniting the metal parts rapidly and economically in a manner superior to any other welding process at this period of development.

*A. I. Electric Welding Machines Ltd.

FLASH WELDING.

From the early process of butt welding was developed the automatic flash-butt weld, or as it is generally known the "flash" weld, thereby opening up a tremendous field of application in industry. This new process lent itself to automatic control of the two vital factors heat and pressure, and their accurate control extended the application to sectional material and finished parts where, by means of the localisation of heat application, the problem of distortion through heat dissipation was avoided.

The principle of flash welding is shown in Fig. 69. The flash weld differs from the ordinary butt weld in that the two parts are clamped, and simultaneously with the current application a very light pressure is applied to the moving electrode causing an arc between the contact faces. The heat generated from this arc is so intense that it burns away the end faces uniformly on both sides so that if the arc is maintained by a "creep" movement of the movable electrode a high temperature is rapidly obtained.

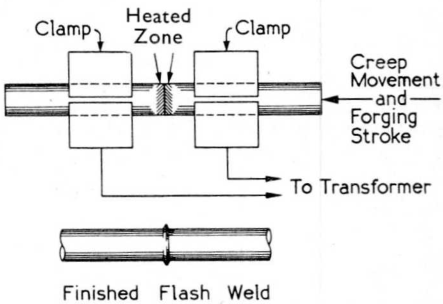


Fig. 69. Principle of flash welding.

The current is switched off and the "creep" of the movable electrode is transformed instantly into a sharp blow, this action forcing the molten metal to the outside and forging the plastic or weldable metal behind the molten zone into a perfect weld, leaving a sharp fin or extrusion instead of the "bulge" on the butt weld described earlier. The chief advantages in flash welding are: extreme localisation of heat, rapid automatic operation, and low current consumption.

From a metallurgical standpoint the flash weld is favoured by the fact that during the operation the weld metal which ultimately is forged is efficiently protected from oxygen penetration and atmospheric contamination by the arc itself and by the zone of molten metal directly in front of it.

Fig. 70 shows the conditions existing during the progress of the flash weld; the localisation of heat, which is of the utmost importance when flash welding thin sections, will be noted. The actual temperature at the metal face in contact with the arc or "flash" is much higher than that used in butt welding, but again it should be remembered that this overheated or oxydised metal is entirely extruded by the rapid forging action throwing out all impurities to the outer surfaces and clear of the main structure, thereby leaving the weld free from oxide and other gas inclusions which might cause porosity. The sharp fin of extruded metal is the result of a thermal peak engendered by the retention of heat at the welding face because of conductive lag through to the comparatively cool metal behind the plastic or weldable zone. The rapidity of the forging stroke or blow also gives a much better weld structure and finally the small upset or fin is more easily removed when a flush finish is required.

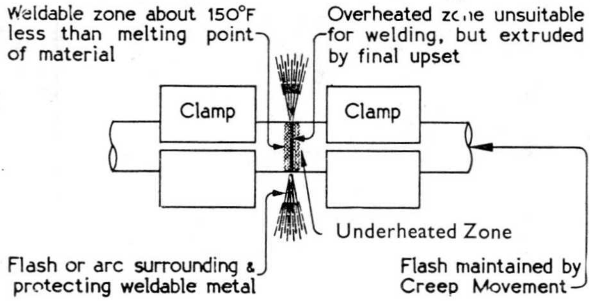


Fig. 70. Diagram of conditions during flash welding.

In brief, therefore, the simple form of flash welder, Fig. 75, comprises two welding heads or jaws, one fixed, usually the left hand head, and the other or right hand head movable and mounted on a slide giving a direct approach to the fixed head and actuated by a hand operated toggle mechanism. Each welding head incorporates a jaw or clamp in which the parts to be welded are held, and as both heads are connected to the transformer secondary the work, when clamped in the machine, completes the secondary circuit.

The transformer in the flash welder is rated according to the area of the section to be welded and the speed of welding required. The forging pressure is applied by hand operated lever or wheel in the simpler form of machines, and, in larger machines, by hydraulic or pneumatic power, or in some cases by a motor driven cam. Various methods of control have been developed for the power operated machines whereby a "creep" movement is given to the welding head, followed by an instantaneous forging blow at the end of the weld cycle. In other words, the complete weld is represented by the total movement or stroke of the moving clamp, and this total stroke (see Fig. 71) is divided into creep or flash, and upset or forging. The relative times depend on the size of stock being welded.

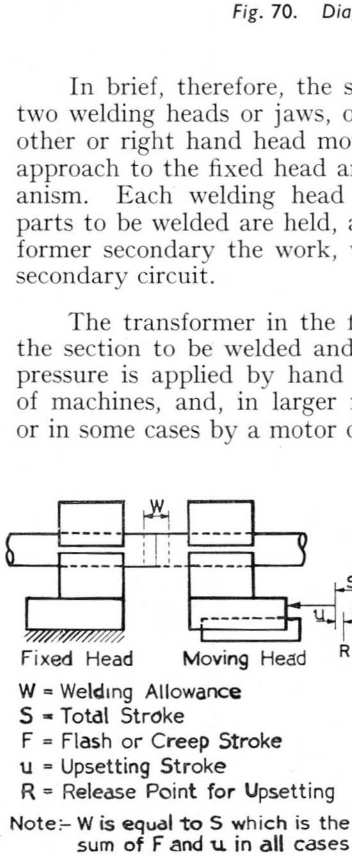


Fig. 71. Stroke diagram.

Two other factors are considered in flash welding, these are the time or flash period and the intensity of the welding or flashing current. On machines where fluid pressures are used for upsetting, the flash period is controlled by a restraining action. On cam operated machines this is predetermined by the speed of rotation of the cam. The current intensity is determined by tappings on the primary winding of the transformer.

Low carbon steel forms the widest application for flash welding and tensile tests show a strength equal to that of the original metal. A high degree of ductility is retained with the result that the material may be cold worked after welding with absolute safety. Sectioning and spinning operations are now carried out after welding, in many cases right across the weld face, without evidence of cracking even under the most strenuous treatment.

Stainless steels and alloy steels can also be satisfactorily welded, as can high carbon steels, although in some cases normalizing by post-heating is necessary, depending on the duty of the welded assembly. In non-ferrous metals flash welding can be applied in aluminium and its alloys although much higher current values are required.

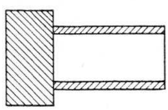
For bronze and copper, butt welding as described earlier is more suitable than flash welding. There is little or no plastic state in copper below the melting temperature, consequently machines required for this purpose have special features, such as high currents and specially applied forging pressure.

WELDED PARTS.

For efficient flash welding equivalent sectional areas and shapes should, if possible, be given to the component parts at the weld point.

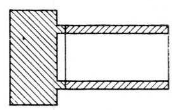
Fig. 72 shows a tubular section intended to be welded to a solid plate or wall of metal ; here the heat generation will be more rapid on the tubular portion than on the large mass of metal in the plate and imperfect welding will result.

Fig. 73 shows the same assembly prepared for flash welding, a short spigot of similar area to the tubular section being arranged on the solid end, which thereby provides an ideal condition for flash welding. Solid sections of uniform shape and area may be flash welded without preparation, such as the solid ring section A and connecting rod B in Fig. 74.



Weld to Wall
(unsuitable)

Fig. 72.



Weld to Wall
with spigot
(suitable)

Fig. 73.

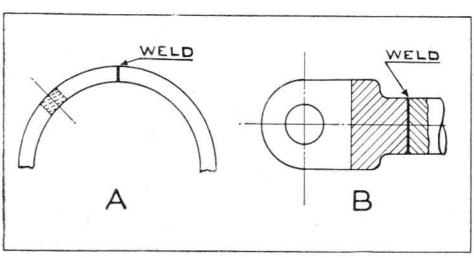


Fig. 74

Production demands of the automobile industry have substantially widened the field of application for automatic flash welding and many intricate forging operations have been simplified by its use. Fig. 76 shows two parts of an axle housing and a flash welded housing, while Fig. 77 shows the axle tube assembly set up in the welder. In this instance change in section would have meant machining down a considerable quantity of material or alternatively the forging would have been extremely difficult, whereas by flash welding the tube to the axle end the forging became

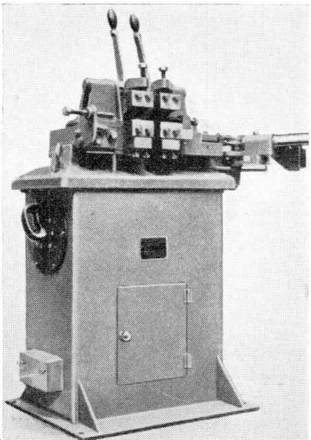


Fig. 75 (left). *Simple form of flash welder.*

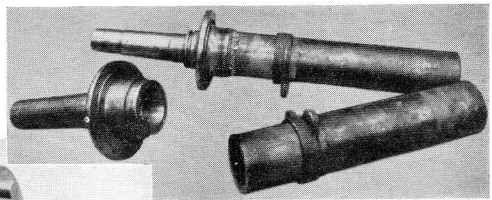


Fig. 76 (above). *Two parts of an axle housing and a flash welded housing.*

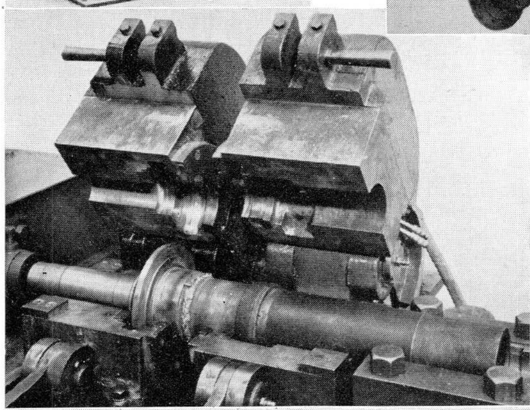


Fig. 77 (left). *Axle tube assembly set up in the welder.*

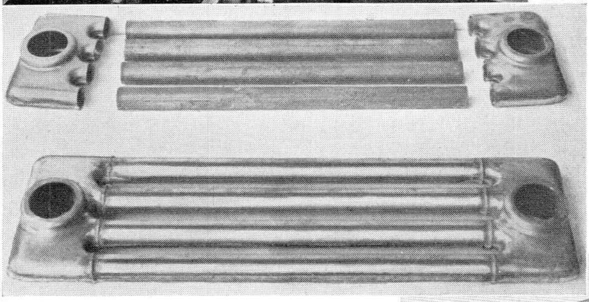
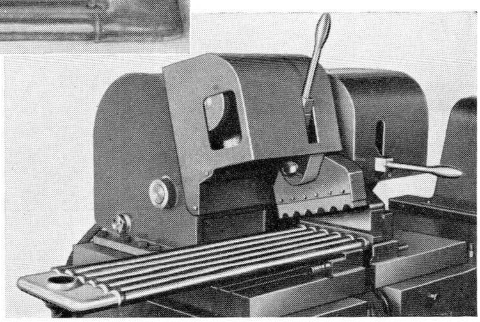


Fig. 78 (left). *Steel radiator parts prepared for assembly by flash welding.*

Fig. 79. (right). *Flash welding the radiator parts shown in Fig.* 78.



a comparatively short and simple one and the machining was confined to a short length. This welding operation on the 0.35 carbon steel axle tube, which was 4 sq. in. in sectional area at the weld point, was completed in 25 seconds. The cost of current for the operation was less than one penny. The inside fin or extrusion is removed by a power stripper fitted on the welder, and this operation is completed in 4 seconds immediately after the welding operation and while the metal is still hot. The outside extrusion is removed by grinding in the normal way.

It will be noted that the electrodes or dies are machined to suit the parts being welded and special alloys are now available which give long life and reduced maintenance of the electrodes. An end stop is arranged on the reduced portion of the axle tube and as the stroke of the machine is controlled to precision limits the overall tolerance on this particular job after welding was within plus or minus ten thousandths of an inch. This shows that welded assemblies can now be produced to very fine limits.

Fig. 78 shows steel radiator parts prepared for assembly by flash welding. The four welds at one end are done simultaneously as is shown in Fig. 79, the time involved being 8 seconds, and the results are entirely satisfactory.

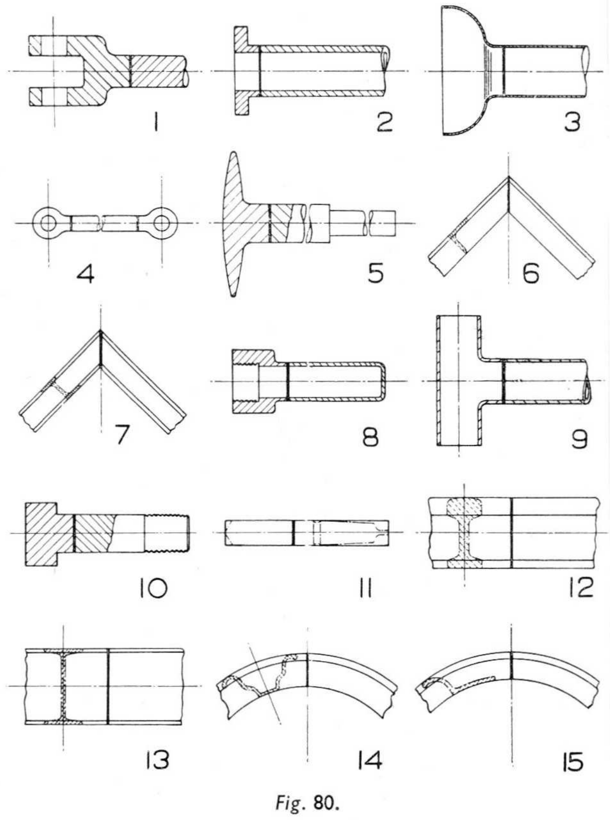


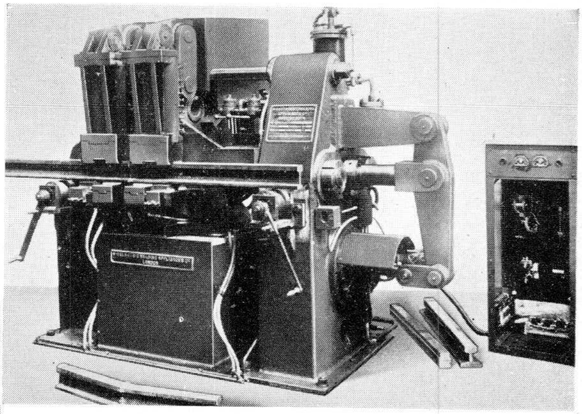
Fig. **80.**

Fig. 80 shows typical assembly operations carried out by flash welding and the economy and high production speeds obtainable by the process can be judged from the table detailed below, which gives the welding times and current consumption for each assembly.

No.	Assembly.	Weld Area.	Time.	Current Consumption.
1	Connecting Rod	3 sq. in.	35 secs.	3 welds per unit
2	Flange	.5 sq. in.	6 secs.	36 ,, ,, ,,
3	Housing	1 sq. in.	12 secs.	20 ,, ,, ,,
4	Tie Bar	1.25 sq. in.	14 secs.	15 ,, ,, ,,
5	Buffer end	12 sq. in.	3 mins.	3 units per weld
6	Angle Frame	.75 sq. in.	9 secs.	28 welds per unit
7	Metal Casement	1 sq. in.	12 secs.	20 ,, ,, ,,
8	Adapter	.5 sq. in.	6 secs.	36 ,, ,, ,,
9	Tube Tee Piece	1.5 sq. in.	15 secs.	12 ,, ,, ,,
10	Bolt	1 sq. in.	12 secs.	20 ,, ,, ,,
11	Drill Blank	.75 sq. in.	9 secs.	28 ,, ,, ,,
12	Track Rail	10 sq. in.	2.5 mins.	2 units per weld
13	Beam	4 sq. in.	45 secs.	1 weld per unit
14	Motor Wheel	1.5 sq. in.	15 secs.	12 ,, ,, ,,
15	Heavy Rim	2 sq. in.	25 secs.	8 ,, ,, ,,

Part No. 8 is a component which would normally be machined from solid bar, and obviously this would entail considerable machining time and waste of material. By welding a turned head to a body drawn from a blank considerable time and material is saved. Similarly with Part No. 10. The head can be turned from bar and the shank portion made from smaller stock which is simply screwed and parted off to length, again with saving of machining time and material. In both these examples the two parts to be joined have the same cross section at the weld point, so that the best conditions for welding exist.

It will be appreciated that there are countless components used in all branches of the engineering industry that are made by machining from solid bar or other stock, and where such parts are made in quantity there is every likelihood that the use of flash welding would reduce production costs and, what is more important to-day, would speed up production while reducing waste.



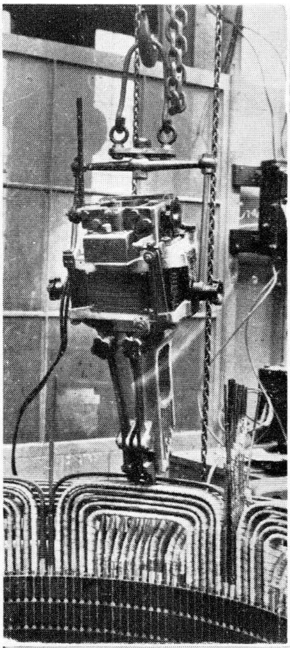
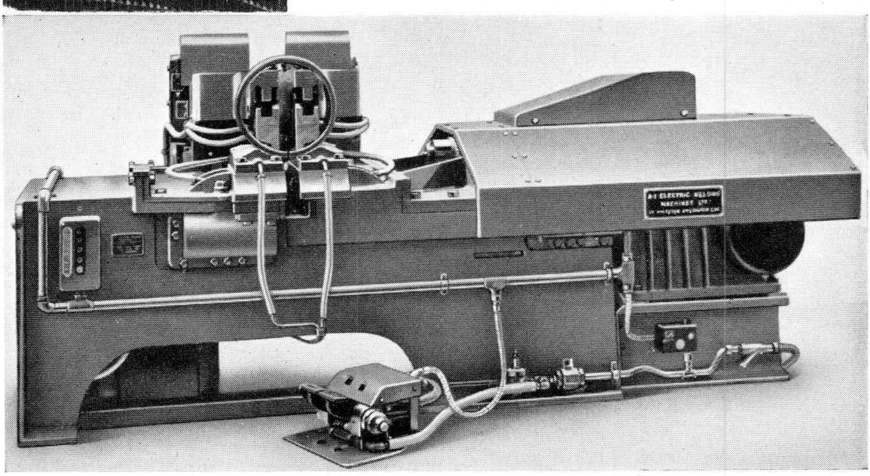


Fig. 81 (left). *Portable butt welding machine welding joints in stator windings.*

Fig. 82 (*below*). *High speed automatic flash welder.*

Fig. 83 (*above*). *Flash butt welder for rail sections.*



Mention has been made of butt welding non-ferrous metals such as copper, and Fig. 81 shows a portable butt welding machine developed for joints in stator windings. This application successfully overcomes the laborious method of sleeving and soldering the joint and, further, the conductivity of the welded joint is almost identical with the parent metal, a factor of great importance to the electrical industry.

Fig. 82 shows a high speed automatic flash welder for steel bands with a production speed of 5 welds per minute. The entire operation is fully automatic even to the release of the clamps and the re-setting of the machine after the welding operation is completed. These steel bands are then sectioned for motor car wheel rims, the sectioning operation being done across the weld, thus indicating the high degree of strength and ductility obtained.

WELDING HEAVY SECTIONS.

For welding heavy sections a flash weld which is rather different from that already described has recently come into prominence. It differs from the straight flash weld in that pre-heating is given to the section prior to the ultimate action and forging upset ; this method is generally known as flash butt welding.

On heavy sections were it attempted to flash weld from a cold condition a high transformer capacity would be necessary and a fairly long flash stroke which involves a substantial welding allowance. For these heavy sections, therefore, flash butt welding has been applied with success. The two lengths of stock are placed in the machine and clamped in position by power-operated jaws and a pre-heating flashing operation by a reciprocation of the moving head is given automatically. With each reciprocation a certain quantity of heat is given to the ends and when the temperature has risen for the flash to be maintained by the secondary voltage selected, then no further reciprocation takes place and there is a short progressive flash movement, after which the final release of forging action takes place. A special feature of this machine is the fact that the change over from pre-heating to final flashing is fully automatic.

By this process sections having an area of, for instance, 10 sq. ins. can be welded in 3 minutes inclusive time, while the welding allowance need only be $\frac{5}{8}''$, that is $\frac{5}{16}''$ per side. The economy in transformer capacity by pre-heating is substantial.

Flash butt welding has given to industry a method of welding without equal in low working costs and rapidity, while the strength obtained is consistently comparable to the strength figure of the parent metal.

Mild steel when flash welded requires no further treatment, but in dealing with high carbon steels it is necessary to normalize by post-heating the welded joint, particularly if it will be severely stressed in service. A typical example of this condition is the flash butt welding of track rails. This operation is carried out to eliminate expansion points and so reduce noise. Fig. 83 shows a flash butt welder for rail sections, the weld being completed in 3 minutes for a standard 95 lbs. per yard running rail. The operation is automatic and is done by unskilled labour. After welding the joint is normalized by post-heating to 850° C., and then normally air cooled.

On test these welded joints then withstand a tup test of 3 drops of 7 foot-tons, and one drop of 20 foot-tons on the weld, supported at 3 feet centres. The stringency of such a test indicates the high degree of strength obtained in flash-welded joints.

The range of flash butt welders now available is such that sections from the smallest wire up to 40 sq. in. area can be flash butt welded. Still larger machines are being considered in the heavier branches of industry and it would appear that the applications of the process are unlimited.

CHAPTER IV

PRACTICAL RESISTANCE WELDING

Layout of a resistance welding shop—Servicing and maintenance of machines—Practical hints on the use of resistance welding machines.

LAYOUT OF A RESISTANCE WELDING SHOP.

The first consideration in planning the layout of a resistance welding shop is whether this shop is to deal purely with the resistance welding process or if other processes such as preparation and finishing are to be carried out as well. Another point is whether only one type of resistance welding is to be carried out or whether it is to be a mixed shop employing spot, seam, and butt welding machines. Further, will the shop deal with a limited series of articles or contracts or should the layout be such that a large variety of work can be undertaken ? Whatever type of shop has to be laid out, the work should be planned to flow through the shop as a continuous process.

The type of shop to be considered here is a general shop capable of dealing with a large variety of work, both of the spot and seam type, and so equipped as to undertake design, maintenance, bending and shearing, spraying after welding and inspection and despatch.

Such a shop provides for a stores and receiving section, marking-off and preparation section, the necessary shears and rolls, a number of spot and seam welders, a spraying section, an inspection and despatch section, a self-contained air supply and all tools and equipment necessary for use as a unit.

The initial procedure in such a shop would be for all material either partly prepared or in the rough to be booked in at the stores and then issued to the marking-off and setting-up section. Having been marked off it would be sheared or rolled to the required shape and passed to the welding operators.

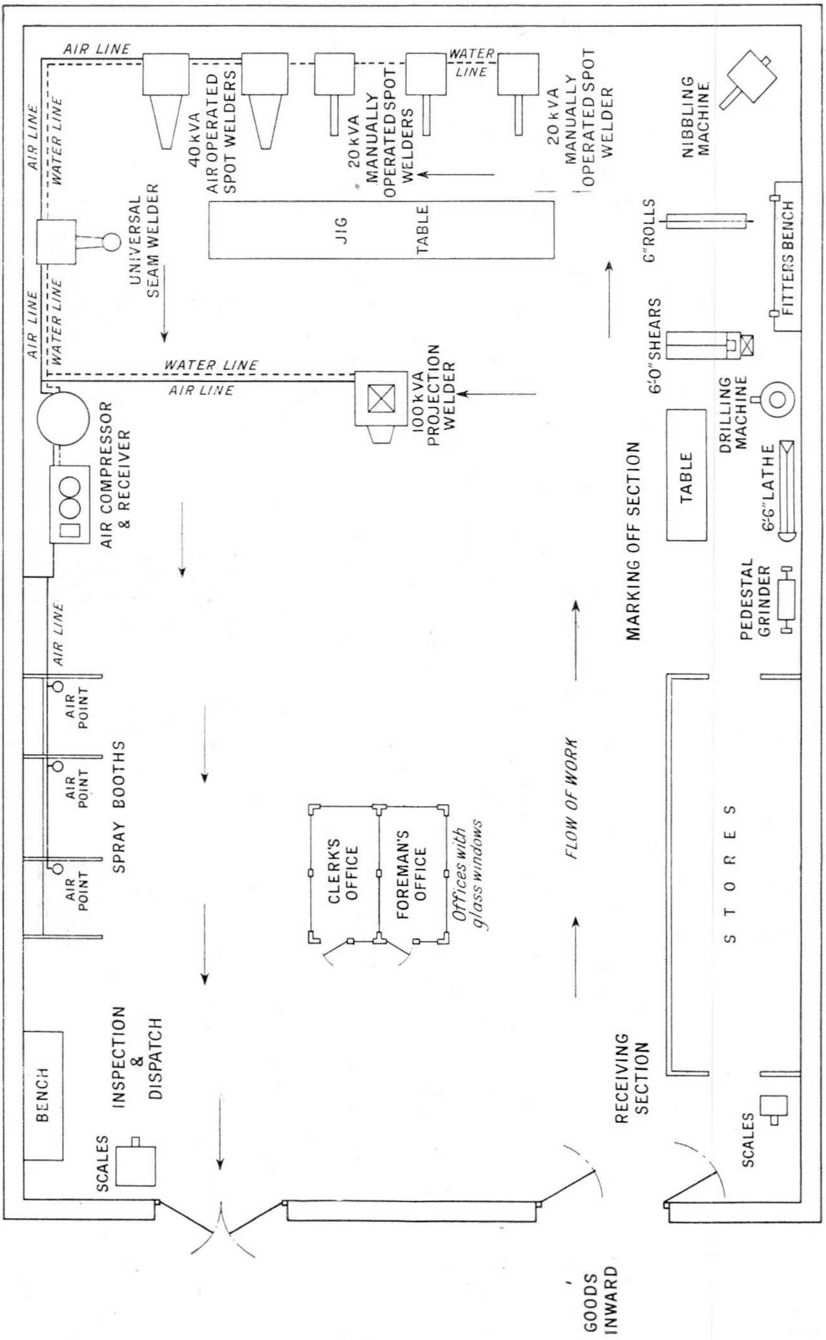


Fig. **84.** *Layout of shop.*

The detailed equipment used in such a shop is dealt with later, but mention should be made of the advisability of having all work, unless of an excessively bulky nature, conveyed to the machine operators in portable bins or racks. If a variety of articles are being welded, the painting of these bins in different colours or with different coloured lines is of assistance in planning, as all similar articles are put in the same coloured bins and these can be tied up with the job ticket. It will be noticed that the layout of the shop includes a spray booth, as it is extremely useful to be able to finish many of the articles in the welding shop, particularly where the production does not justify a special finishing shop.

Dealing with equipment and machines in progressive order, the first items are the stores and scales. In these stores will be kept all the sheet metal material and small parts that have to be welded and in order to keep check on the quantities and materials, etc., all material entering the store should be weighed. This material is then issued either direct to the machines in the appropriate bins in the case of material received ready for welding, or in the case of material that has to be cut or prepared, to the operators at the marking-off table.

It will be noticed from the drawing that the drilling machine, the grinder, and the lathe are situated near the marking-off table, as is also the fitters bench, but these machines are chiefly intended for maintenance in the shop with occasional use for correction or dealing with any special items before welding.

Having been marked off and the position of the spots accurately shown (unless jigging or automatic stops are employed, which depends, of course, on the quantity of articles to be welded), the material is then taken to the shears or rolls, after which it passes to the appropriate machine for welding. If any painting or protective treatment is to be undertaken, the work is then conveyed to the spray booth and after that direct to the inspection and despatch. It is a good principle to weigh the material before despatch so that the record can be compared with the amount of material received.

As the shop in question is a general shop, it has been shown equipped with one or two 40 kVA. pneumatically-driven spot welders and one universal seam welder. The pneumatic spot welder would be of the double-acting type suitable for an air pressure of 80-100 lbs. and having adjustable electrode stakes and adjustable lower arms. As the machines are intended for a wide range of work, they would be equipped with suitable timing equipment. The maximum pressure obtainable on this machine should be not less than 1,200 lbs. and the operating speed not less than 5,000 spots per hour. The machine would be of the single and repeat operation type.

The seam welder would be of the universal type and should have arms of not less than 36″. Unless a large amount of seam welding was anticipated, a normal type of machine would be installed, but if the shop was expected to carry out a large volume of seam welding, then a heavier type of machine would be better with both wheels motor-driven and a synchronous or current modulator type of timer.

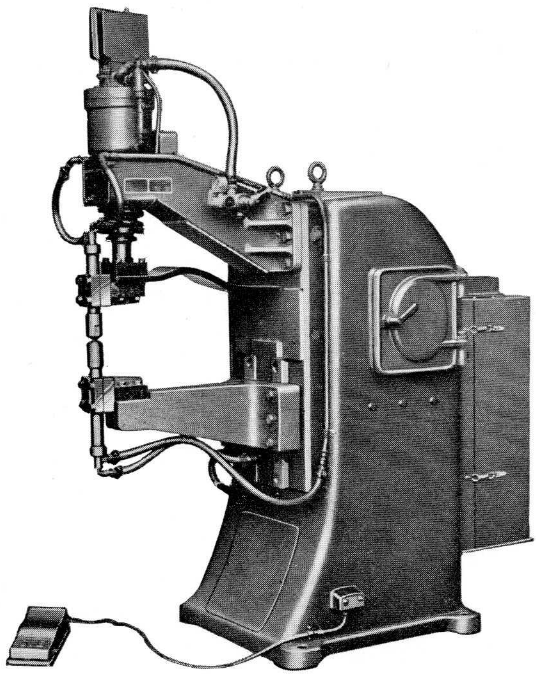


Fig. 85. A typical spot welder for use in a general shop handling a wide variety of work.

The question of the exact type of seam welder to be installed requires careful consideration and can only be decided after reviewing the type of work likely to be done in the shop.

In the layout (Fig. 84), a 100 kVA. projection welder is shown, and this type of equipment is extremely useful for mass production work. As this machine has a large capacity, the site in the works should be selected so that there is ample space for the delivery and despatch of welded articles. For this reason the machine is shown separate from the operating line and in the centre of the floor.

Fig. 86 shows a suitable type of projection welder. In most cases the flow of work for the projection welder would be direct from the stores or marking-off table to the projection welder and then to the spray booths or inspection and despatch according to the nature of the article, although in some cases the items might require operations from the shears, rolls or nibbling machine.

Another very useful piece of equipment is the jig table which is shown in front of the spot welders situated between the projection welder and the battery of air-operated and manually operated spot welders. The purpose of this table, which should be of substantial construction, is for the loading of jigs with an equipment by loading operators, the procedure being in most cases to use three or more jigs, which, as soon as they are loaded,

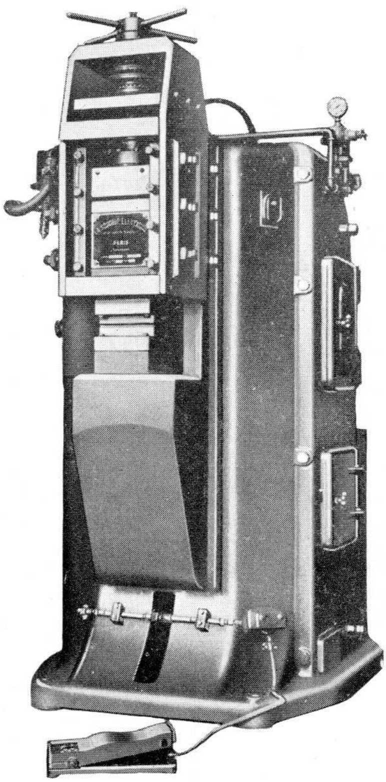


Fig. 86. Projection welder.

are passed to the machine operator who returns the empty jig, after welding, to the table. If the rate of production is very high, a special operator is employed to transfer the jig from machine to table. The jig is then loaded by female operatives or boys who are seated or standing at the table, and then passed to the machine operators, either on trolleys or in bins. In this way a constant flow of work with great speed of production can be obtained. Care should be taken in positioning the jig table so that the minimum movement of jigs is required, but, of course this table must not be placed so close as to impede operators' movements. Another important point is the table height, as if the table is used for standing jig loaders, then an additional 6″ or 9″ in height will prevent undue fatigue of the workers. If, on the other hand, the nature of the component is such that the operators can load seated, a lower table will be required. If the work varies a great deal, then a table with adjustable legs is well worth considering. A steel-topped table is preferable but this is largely a matter of personal preference. The table can also be used for jig loading for the projection welder, unless it is found desirable to employ a separate table for this purpose, but in the layout drawing only one table is shown.

The foot-operated spot welders would be of the 20 kVA. manually operated type, fitted with 24″ arms and not less than 4 heating speeds. As they are likely to be employed on a large variety of work, they should be fitted with one of the simpler types of timers.

Dealing with the other equipment, the guillotine may be a comparatively simple one, but the capacity should be not less than 6 ft. wide and suitable for material up to about 14 S.W.G. The manually operated guillotine is quite suitable for the ordinary shop. The bending rolls should also be not less than 6 ft. in width and a single gear manually operated type will be found quite satisfactory unless a large amount of rolling has to be done, in which case a power-driven machine should be installed.

A machine which is extremely useful in a resistance welding shop is a motor-driven nibbling machine with a capacity of from 1/32nd to 5/16th in. in mild steel. This machine should give burr-free edges. A self-contained motor-driven type is preferable but, of course, not essential.

The lathe, drilling machine, grinder and fitters bench being chiefly required for maintenance purposes need not be of the heavy duty type,

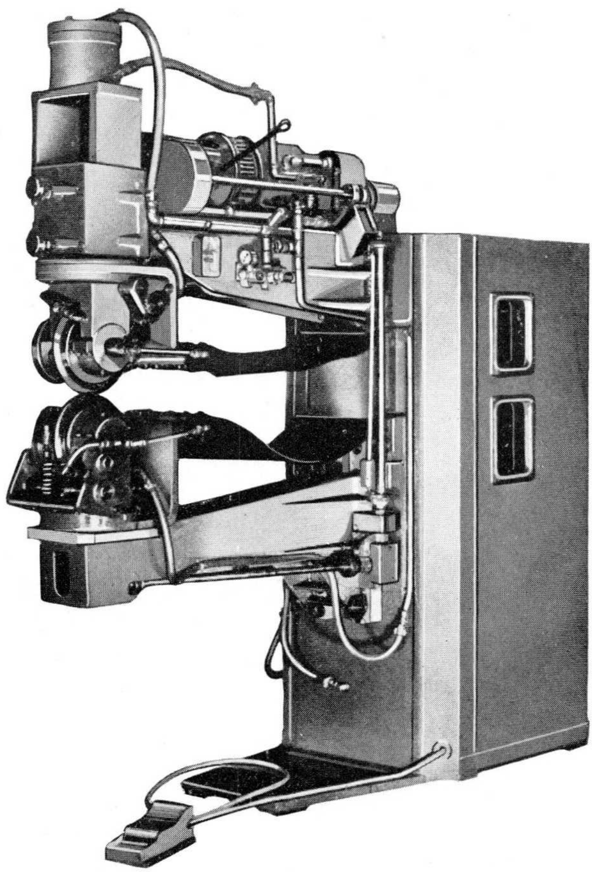


Fig. 87. Recommended type of seam welder.

but the vertical drilling machine should take drills up to Nos. 3 Morse Taper and the machine should be of the floor pedestal type preferably with 6 speeds. Whether this machine is fitted with self-contained motor or independent motor is entirely a matter of personal preference.

The grinder should be of the 6″ double end motor-driven type, preferably pedestal-mounted. Ball or roller bearings should be specified.

As the lathe is only required for maintenance, a 6″ engine lathe of reasonable quality is suitable and as this machine may be used for special electrodes from time to time, a machine with a hollow spindle of not less than $1\frac{1}{8}$″ bore should be chosen.

The paint-spraying plant can be of any suitable make, but the gun should be selected to work off the air supply from the pneumatically operated machines. The question as to whether a pot or suction type gun should be supplied, would depend on whether only occasional or continuous spraying will be undertaken. As these spraying plants are being operated from the main air line, it is essential that air strainers and cleaners be installed.

Details of servicing tools and servicing arrangements are given on p. 60, but it may be mentioned here that it is essential that a complete set of spanners be available in close vicinity to each machine. These can either be mounted in a rack on the machine or on the wall adjacent to the machine and it is sometimes advisable for them to be secured in position by a bar and padlock, the key being held by the maintenance mechanic.

The marking-out table will generally be constructed by the works themselves, but if possible, a metal-topped table should always be used. This table should preferably be zinc-covered and of a height not less than 3 ft., unless the marker-off is exceptionally tall, in which case 3″ to the height adds considerably to his convenience. The edge of the marking-off table should always be rounded.

The fitters bench should be of the normal type, but fitted with 2 vises and a drawer underneath for containing small tools, etc. A portable table of the all-steel type, fitted with one 3″ and one 6″ vise and drawers underneath, could be substituted to advantage for the fixed type of table.

On referring to the layout it will be noticed that the compressor plant is situated near the spray booth. The air compressor must be of ample capacity so as to allow of additional machines being installed, in fact it is wise to have it too large than too small. When selecting the compressor size the capacity should be sufficient for the maximum number of air operated machines the shop is likely to install over a long period. The air compressor should be fitted with an unloading valve and the air receiver must, of course, comply with Home Office requirements regarding construction, safety valve, etc.* The air cleaner should be fitted on the main air supply line and the air pipes should slope slightly and have a suitable drain-cock fitted at their lower end. If the air pipes are extended all round the shop then a number of drain-cocks should be fitted at suitable points. The air pipe should be painted a distinctive colour and all points so placed as to be easily accessible. One or two air plugs for plugging in air lines for operating small air tools or blow-guns are an extremely useful fitment for conveniently obtaining air supply in the shop.

The electrical installation requires special consideration as resistance welding machines provide an out-of-balance load and some supply authorities have a prejudice against this.

If the supply is 3-phase, 3-phase mains should be run around the shop with distribution boxes for each machine and one or two spare boxes installed for future installations. This will enable the welding machines to be connected across the outers of the 3-phase supply and by alternate connections the total machines can be roughly balanced over the phases, although in actual practice considerable out-of-balance will still occur. By connecting the machines to the outers of the 3-phase, the minimum interference will be caused on the lighting supply.

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*See also Factory Act, 1937.

The type of wiring to be selected depends chiefly upon circumstances and whilst cleat wiring is particularly satisfactory, most supply companies will require the normal conduit systems. Whatever system of installation is used, the supply cables should run at about 3-4 ft. above floor height and the distribution boxes should be of the busbar type and fitted with high rupturing capacity fuses.

As the current will most likely be purchased on a kVA. basis the question of power factor correction will probably have to be taken into account, or in any case, even if purchased on a unit or kW. basis, the supply company will most likely specify a minimum power factor. For power factor correction of resistance welding machines mass correction is to be preferred unless series condensers are installed, but for a general plant it is best to install one main correction unit.

As the shop has a fair number of machines installed the question of cooling water has to be taken into consideration and, dependent upon supply conditions, it has to be decided whether the machines shall be cooled from the mains and the water allowed to run to waste or whether a cooling tank and circulating system shall be installed.

If it is decided to use a header tank and circulating pumps then the circulating pump should be installed in duplicate so that pumping troubles do not occur. The header tank should be fitted with a ball-cock so that evaporation and leakage losses are automatically replaced. One or two indicators should be fitted in the system to check water circulation. For further remarks on cooling arrangements see page 181.

The lighting of the shop should, of course, be adequate. It is advisable for lighting points to be placed over or in the vicinity of each machine and the lighting over the marking-off table should preferably be of the mercury or sodium type. Natural lighting should, of course, be employed as much as possible. In the vicinity of the machines one or two plug points should be installed so that maintenance and inspection are facilitated and portable tools can be used by the maintenance staff.

If the floor of the shop is of concrete or stone, then wooden duckboards should be provided for the machine operators.

When laying out a new shop, the advice of a resistance welding engineer who is experienced in the planning of such shops, may not only save a considerable amount of initial cost, but a correctly laid-out shop, involving the correct positioning of machines, etc., can have a considerable effect on production and will amply repay the time spent on careful planning.

Too many resistance welding shops have simply had machines added to them as the size of the shop increased, instead of being carefully planned from the start. If only one or two machines are being installed at first, the shop arrangements should be planned to deal with the ultimate maximum extension for the space employed.

SERVICING AND MAINTENANCE OF RESISTANCE WELDING MACHINES. PRACTICAL HINTS AND TIPS.

Undoubtedly the successful operation of resistance welding machines, whether a large number or comparatively few machines are operated, is dependent upon the service and maintenance, and investigation has shown that most of the difficulties experienced in resistance welding could have been avoided, if correct maintenance and servicing had been carried out. It is, of course, realised that a firm using perhaps half a dozen machines cannot build up an elaborate service organisation, but the problem can be overcome.

The suggested procedure for a small factory will be dealt with first. In this case it is advisable to appoint one person who should have some mechanical and, if possible, electrical knowledge, to be solely responsible for the maintenance and servicing of the machines ; in this way the set-up of the machines is not altered by the operator or unauthorised persons and a simple card can be issued to record the setting, so that it is at once apparent, if any unauthorised person has interfered with the machine. This is more important than at first apparent in view of the practice of operators, if permitted, of varying settings to suit their own ideas, making it almost impossible in many cases to elucidate the exact cause of faulty welding, as no record is available of the setting used.

Having selected the person to be responsible for the machines, it is advisable, unless he has had previous experience with the machines in question, for him to undergo a short course of instruction in the principles involved in these machines. This facility can generally be arranged with the suppliers of the machines and the time so spent will be more than repaid.

For the user of 6 machines and under it is advisable for electrodes to be purchased from the machine maker or through the special electrode services that are available. Spare electrodes properly labelled should be kept for each machine. These should be locked up, the key being in the possession of the party responsible for maintenance.

The maintenance engineer obviously cannot do satisfactory work, unless he is provided with the necessary tools and equipment, and the mechanic servicing the machines and responsible for their condition should be issued with a leather satchel containing the following tools :—

(1) 1 1-lb. engineer's hammer.
(2) 1 12″ Stillson wrench.
(3) 1 pair of pipe grips.
(4) 1 pair of heavy rubber insulating pliers.
(5) 1 pair of small long-nosed pliers.
(6) 1 heavy screwdriver.
(7) 1 insulating screwdriver.
(8) 1 small plate screwdriver ($\frac{1}{8}$″).
(9) 1 oil-can.
(10) 1 roll of insulating tape.
(11) 1 $\frac{5}{8}$″ cold chisel.
(12) 1 $\frac{1}{4}$″ dia. punch.
(13) 1 copper drift.
(14) 1 test lamp.

The frequency with which electrodes are changed will depend upon production, but a good practice is to change them twice a day, care being taken that the electrodes are of the original diameter and shape. Profile gauges are helpful for this purpose. In the case of large users of machines it is generally advisable to vary the procedure, although of course the principles laid down for the small user still apply. In this case one person should be appointed and held responsible for the quality of the work obtained from the machines ; he should also be responsible for the tool set-up for the machine. The tools and welding electrodes for the machines should be kept in a normal small tool stores and they should only be issued on a requisition signed by the person in charge. The works' maintenance service such as works millwrights and electricians will be held responsible for all electrical or mechanical service and also for machine movement, installation of new equipment, etc.

Blue prints should be kept recording electrode design and sheet metal patterns should be made of special electrodes. These blue-prints should be compiled into a standard list of electrodes available and given code numbers so as to enable particular set-ups for assembly to be obtained from the stores by reference to the code number of the electrode used. The electrodes should either be purchased in bulk from suppliers against a code number or manufactured in the tool-room against drawings and specifications. Generally speaking, both courses will be adopted, although relief can often be given to the tool-room by purchasing electrodes from those firms specialising in their manufacture.

The mechanic of the maintenance department, who is responsible for the general maintenance of the machines should be issued with a list of tools identical with that suggested for the small user, but it is advisable to equip him as well with a mobile bench on casters, this bench having a vise and a series of drawers containing spare electrode parts, replacements for machines and various minor details, so that quick service can be given and journeys to the small tool stores avoided. This stock could be treated as a floating stock and any parts taken from it should be requisitioned from the stores so that spares, etc., are immediately available and delays in production avoided. Any electrical test or work should be undertaken by the works electrician.

The following notes regarding difficulties which may be experienced will probably be of assistance to those concerned with servicing and maintenance. One of the most hard-working components of the resistance welding machine is the contactor. Although the contactors fitted to these machines are of special design and very substantially constructed, it is necessary to overhaul them periodically and particularly to ensure that the surface of the contactors is clean and not unduly pitted by arcing, thereby causing bad contact and loss of efficiency. The rocker bar should be occasionally lubricated and the contacts adjusted so as to maintain the original cap.

A very excellent method of cleaning the contactors is to use compressed air and preferably one of the special cleaning guns which can be obtained from the suppliers of pneumatic equipment. Where a compressed air supply does not exist, i.e., the machines are of the manually operated type, but fitted with contactors, then a good substitute is an electric blower or a set of bellows such as are used for the cleaning of electric motors.

An adequate supply of spare contacts should always be available, as even with correct maintenance, owing to the heavy duty, all contactor contacts wear rapidly in operation and although many makers have fitted special alloy contacts and various devices for reducing arcing, the wear is still heavy, if the machines are used on continuous production.

The cleaning of spot welding electrode contact points is of primary importance, if satisfactory welding is to be obtained. An excellent way of cleaning the tips is to place a flat file between the electrode points, switch off the current and close the points together under pressure, revolving the file. Provided a fairly fine file or fine emery paper is used, additional cleaning will be unnecessary in most cases. Sometimes the machines would appear to be working efficiently and yet no current is passing through the electrodes. A quick method of testing and finding the location of the fault is to close the contactors of the machine with the current switched on and then short-circuit the secondary arms with a piece of bare wire ; arcing should appear at the points where the secondary voltage is available ; by moving the short-circuiting position the break or interruption of the current can be found. This method is quite safe for the secondary circuits, as the voltage is under 10 v. It must, however, on no account be used for the primary circuits.

To ascertain if there is adequate electrode pressure, a simple rough test is to watch the lower arm of the machine and to observe if there is a small amount of deflection or spring. If this is apparent, it shows that there is considerable pressure between the electrodes. It may also indicate that the head is not sufficiently rigid. Sometimes the electrodes on an air-operated machine do not open after the weld has been completed and

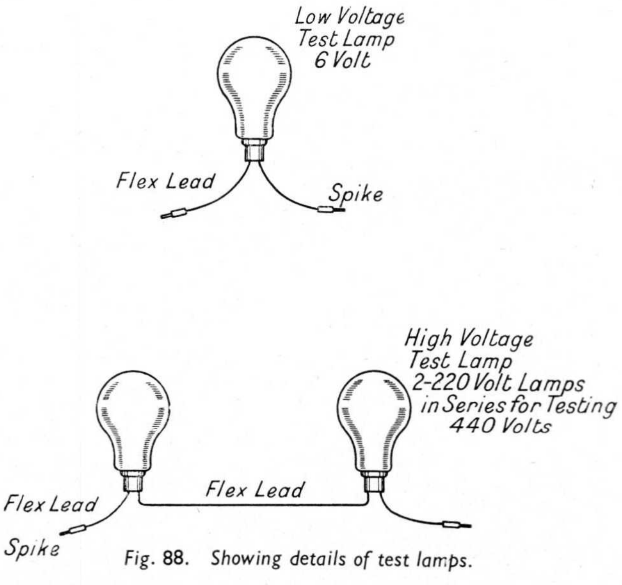


Fig. 88. Showing details of test lamps.

this indicates that the solenoid of the air-operated valve is not released or that obstruction has occurred in the exhaust port of the air pressure cylinder. An ordinary lamp with a length of twin flex, the ends of which have two spears or wire points with insulated cables affixed thereto, is a very useful instrument for ascertaining if current is available at various parts of the machine. For the low voltage circuits a 6 v. lamp can be used and for primary circuits two 230 v. lamps in series should be used. These will glow on 230 volts and not burn out on 400 volts.

One of the difficulties frequently encountered in resistance welding is that the welding material has a comparatively heavy oxide deposit, chiefly rust or corrosion and this has the effect of insulating the material thus preventing the passage of current to the part to be welded, the result being defective welds. Whilst whenever possible, only clean bright material should be used, in some cases the use of dirty material is unavoidable and in this case the parts to be welded should be cleaned with a wire brush or cleaning solution. Sometimes with deep drawn material the lubricating oil used in the drawing process causes defects, but this can generally be overcome by wiping the parts to be welded. Spot welding should not be undertaken on excessively scaly or dirty material and as previously mentioned, bright plate should be used, wherever possible. If black plate has to be used, then steps should be taken to see that this is reasonably clean.

In the event of a spot welding job necessitating very long secondary arms, i.e., 5-6 ft., considerable trouble can be experienced by inductive loss owing to the long throat depth and the material which is inserted between the jaws of the machine ; it will be found that the greatest loss occurs when the whole of the sheet is between the jaws of the machine. These inductive losses reduce considerably the efficiency of the spot welds on a long sheet and the best method of overcoming this is to increase the transformer output in direct ratio to the material between the secondary arms. This trouble is particularly likely to occur in the welding of long tubes where the secondary arm is inserted inside the diameter of the tube. In some cases the part to be welded may be inaccessible to the lower electrode and this difficulty can be overcome by the twin electrode method shown in Figs. 89 and 90.

On work requiring a smooth exterior finish, particularly work which has to be painted after welding, and where it is undesirable for an indentation by the electrode point to appear, the difficulty can be overcome by means of a copper pad or nose fixed to the lower electrode and using a pointed electrode for the upper stake.

In conclusion, the makers' instruction booklets for individual machines should be carefully studied and any special recommendations noted. The maintenance engineer can save considerable time if he compiles a notebook giving wiring diagram and details of each machine with salient

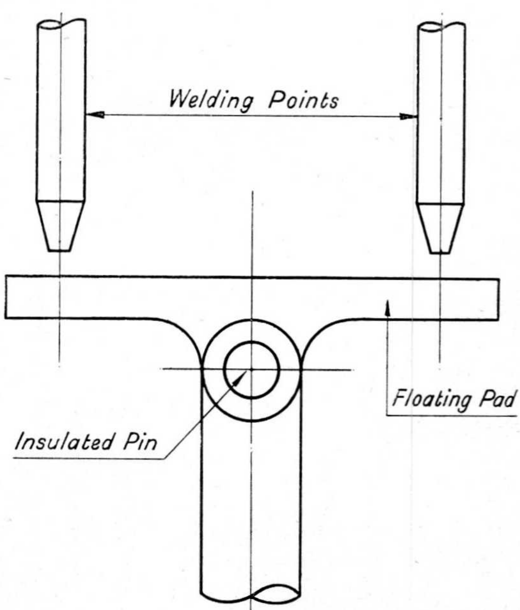


Fig. 89. Arrangement for twin spot welding.

points extracted from the maker's instructions and any other notes such as type of electrode setting for certain gauge material, etc.

Specific details on the maintenance of seam welders are given in Chapter II.

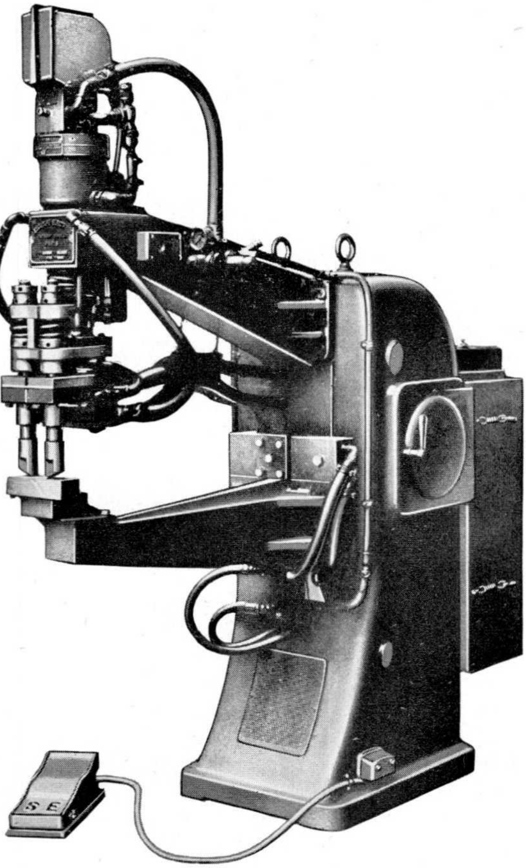


Fig. 90. Spot welder with twin electrodes.

PRACTICAL NOTES ON THE USE OF RESISTANCE WELDING MACHINES.

When the assembly of mild steel components is contemplated in quantities, it is always advisable to consider resistance welding as a means of assembly, and the following factors should then be borne in mind :—

(1) Quantity of articles to be produced.
(2) Thickness of material to be welded.
(3) Power supply available.
(4) Initial cost of equipment.

Most assemblies of sheet metal and the lighter gauges of metals used in light engineering can be resistance welded and it is advisable to consider the design of the component to be produced with a view to making the various assemblies with suitable flanges, etc., to conform to resistance welding practice. If, in the initial stages of design, resistance welding is in the forefront as an assembling method, there should be little difficulty in obtaining high rate of production, provided sufficient quantities are required to warrant the installation of resistance welding equipment. From the point of view of purchasing resistance welding plant these factors should be borne in mind because in many cases a special resistance welding machine will be more efficient in operation than a standard type built for general purpose, but in this case the initial cost of the equipment will have to be offset by the volume of production which is contemplated. Should the quantities of a certain contract be fairly low, it is sometimes advisable to purchase a general purpose machine that can be modified to suit the contract in hand and at the finish of this contract can be used for general purpose work and again modified to suit further work. For example a high capacity spot welding machine of, say, 100 kVA. can be used either as a spot welding machine or can be modified for projection welding.

When considering welding of seams by resistance welding methods such as flash, butt, roller or continuous stitch, the length of seam to be welded should be considered, as obviously a seam of say 2″ in length in twice 22 S.W.G. material, can easily be welded on a spot welding machine with continuous operation and it would not be necessary to use a flash, butt, roller or seam welding machine for this type of work. On the other hand should the seam be, say 3 ft. long, a roller welding machine would be the best proposition. Should the seam be still longer, say 6 ft., a flash welding machine might be most suitable.

All these points should be carefully considered, before equipment is purchased for any particular application.

As regards the power supply to resistance welding machines it is always advisable to contact the power supply authority, giving an indication of the consumption and peak requirements of the machine contemplated, as it is sometimes necessary to add to the estimate for equipment such auxiliaries as power factor correction condensers and balancing transformers. It will be appreciated that these auxiliaries will considerably increase the initial cost of the equipment.

The following are some examples of the use to which resistance welding machines can be put on high speed production :

(1) **Manufacture of steel drums of 18″ dia. 2 ft. in length, of 16 SWG. mild steel.**

To weld this article a one-end seam welder for welding the ends into the drum would be most suitable. These ends would be circular plate with raised flanges of approx. $\frac{1}{2}$″. The roller of the machine would be inserted under this flange and the top roller run round the circumference. There are two alternatives for welding these drums. This again must be considered in the light of previous examples. Should the production of the drums be high, a flash welding machine will weld the longitudinal seam. If production is low, a roller welder can be designed with alternative wheels for welding the end plate to the drum and also the longitudinal seam, and with this method it is obvious that production will be slow as the tooling will need to be changed for each production run.

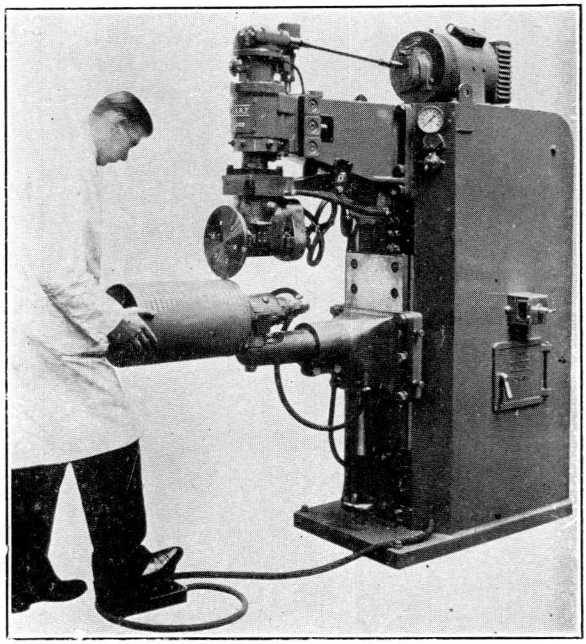


Fig. 91. Seam welding a steel drum.

(2) **The spot or projection welding of bosses or brackets to plates.**

Again, should production be low, spot welding would be satisfactory; if, on the other hand, production is high, projection welding should be used as it is possible to weld up to 10 or 15 projections simultaneously. The drawback to this application is of course that a projection machine of this size, i.e., 200 kVA., would obviously be quite unsuitable for single spot welding.

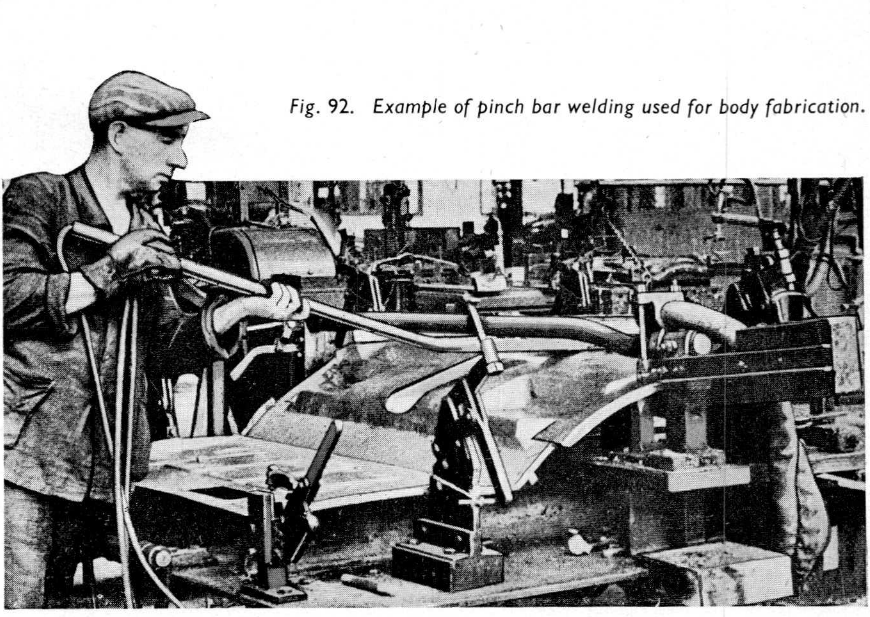
Where it is not convenient to bring the article to the machine, then the question of gun or pinch welding should be considered. This type of welding is chiefly applicable to lighter gauges, although machines have been built to deal with quite heavy plate, but this is not normal practice. Types of gun and pinch welders have been fully described in another chapter, but the type of work on which they are most usefully employed, has only been briefly mentioned.

Whilst in the past gun welding has been chiefly applied to automobile construction, there is no reason why it should not be applied to numerous other articles, even heavy articles such as tanks or constructional work in shipbuilding. Gun welding is a very useful substitute for riveting and its application to constructional fabrication is a possibility which has by no means been fully explored.

An example of the application of gun welding to automobile construction is the welding of reinforcements and stiffeners to side panels on motor bodies. It is obvious that the complete side panel of an automobile cannot easily be carried to a portable spot welding machine and therefore the best procedure is to assemble the side panel in a suitable jig with locations for the various stiffening ribs and reinforcements located round the door opening and windows. These assemblies are then welded into position without the need of carrying the side panel to a vertical welding machine. The disadvantages of this type of equipment are the considerable voltage drop due to the length of the secondary leads and their small cross-section area. To overcome this, gun welding transformers are specially designed with a very high secondary voltage, i.e., 14 or 16 v. Furthermore, gun-welding equipment has a very low power factor and the efficiency is as low as 40% in the case of very long secondary leads such as 10 ft. or 12 ft. To overcome this serious disadvantage, air-operated gun welders have been designed which are in effect miniature spot welding machines suspended on suitable balancing apparatus and runways to enable them to be applied to the work. This, of course, makes for greater efficiency, but the drawbacks to this method are the greatly increased weight and the lack of manoeuvrability. Whether these are offset by increased efficiency is a matter that should be decided by the type of equipment being manufactured. A comparison between these two methods of gun welding can be made by stating that twice $\frac{1}{8}''$ could be welded by 8 kVA. in a small portable machine whilst to obtain the same result with 10 ft. secondary leads of 1 sq. in. cross section, a welding kVA. of approximately 100 would be necessary.

It is obvious from the foregoing that the type of equipment used on structural work needs to be carefully considered, particularly from the point of view of voltage drop and the use of independent secondary leads.

Fig. 92. Example of pinch bar welding used for body fabrication.



Chapter V

THE SPOT WELDING PROPERTIES OF RUST-PROOFED MILD STEEL SHEET*

By W. S. SIMMIE, B.Sc., A.M.I.E.E., and A. J. HIPPERSON, B.Sc.

It is frequently necessary to spot-weld assemblies in which some or all of the surfaces of the components have been previously rust-proofed. The circumstances necessitating rust-proofing before assembling for spot-welding may be either when only certain parts of the assembly require rust-proofing or when the finished assembly is of such a size as to prohibit its rust-proofing treatment on production lines. Details of experimental work carried out to determine the spot-welding properties of certain surfaces representative of different types of rust-proofing processes will now be described. It should be mentioned that no attempt was made to include painted surfaces in this experimental work.

OBJECTS OF TESTS.

The objects of the tests were as follows :—

(a) To determine which surfaces permitted satisfactory spot-welding.

(b) To study the effect of the spot-welding process on the corrosion resistance of those surfaces which permitted satisfactory spot-welding.

(c) To examine the effect of each surface which permits satisfactory spot-welding on the life of the welding electrode tips.

(d) To determine the effect of those surfaces permitting spot-welding on the strength of weld produced.

SURFACES CONSIDERED.

1. **Phosphate Processes.**—The phosphate processes are normally used for coating steel and zinc base alloys, mainly for protection against corrosion. A coating of phosphate is produced on the surface by treatment in or with an acid solution of phosphates. The phosphate processes included in this series of tests were as follows : (a) Bonderising; and (b) Parkerising.

2. **Alkaline Oxidation Processes.**—The alkaline oxidation processes are used for decorative and protective purposes, whereby a black oxide film is formed on the steel surface by treatment in a strongly alkaline solution containing an oxidising agent. The alkaline oxidation process considered in the tests was Brunofix (Mark II Black).

3. **Browning.**—This process produces a black finish on steel, and involves several cycles of the following treatments : Accelerated rusting, immersion in boiling water, and scratch brushing. The surface is finally oiled.

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Thermal Processes.—The thermal process for coating steel surfaces involves the heating of the object to be coated in contact with the coating metal, which is in the form of a powder or as a coating to secure interpenetration, or with a compound of the coating metal. The process in this category which was investigated was Sherardising.

Electrodeposition.—The following electrodeposited surfaces were included in the tests : Electro-tin and electro-zinc.

Other Processes.—In addition to the foregoing surface preparations, experiments were also carried out on galvanised mild steel sheet.

TEST PROCEDURE.

For each surface under consideration, spot-weld tests were carried out on mild steel strips 6 in. wide in two thicknesses—viz., 16 S.W.G. and 24 S.W.G.

Surface Resistance.—Before the spot-welding tests were carried out surface resistance measurements were taken. For this purpose special electrode tips, each having a lead attached, were fitted. The leads were connected to a resistance measuring meter. A flat tip shape was used having a diameter of $\frac{1}{4}$ in. The resistance was measured on a single sheet by placing it between the tips and applying a constant load of 400 lbs. In the case of low resistance, values were read to an accuracy of about .25 ohm

Weldability Tests.—Concentric cadmium copper electrode tips $\frac{1}{4}$ in. dia. of a truncated cone shape with 120° included angle were used throughout the tests, with the exception of the 24 S.W.G. electro-zincplate and galvanised surfaces, where $\frac{3}{16}$ in. dia. tips were employed. The minimum electrode pressure used was 7,500 lb. per sq. in., the maximum being 18,300 lb. per sq. in. Electrode pressure was only increased beyond 10,000 lb. per sq. in. when it was necessary to do so in order to obtain consistent spot-welding conditions for the particular surface under test. In establishing the best settings for spot-welding the various sheets, the aim was towards high-current short-time welds. Table on page 70, gives a list of the best spot-welding conditions established in these tests for each surface preparation.

Only in the case of the Bonderised surface could no weld be obtained. In all other cases welds were obtained by suitably adjusting the machine settings, but in some cases extremely high electrode pressures were required.

In the case of those surfaces which permitted reasonably good spot-weldability, production runs were made to ascertain to what extent the electrode tips were fouled by the surface preparations.

Corrosion Tests.—Spot-welded samples of the various coated sheet steel were subject to corrosion tests in a salt spray bath to ascertain the extent to which the welding process had interrupted the continuity of surface protection. This test was not carried out to compare the different coatings, since the salt solution would not have a consistent effect upon the different coatings ; it was adopted as the most convenient and accelerated corrosion test available. No attempt was made to examine the damage which the inside surfaces had suffered in the proximity of the spot.

Spot-weld Detail for Coated Sheet.

PREPARATION	BONDERISED		SHERADISED		BROWNED		BRUNOFIXED		PARKERISED		ELECTRO-TINNED		ELECTRO-ZINC		GALVANISED	
	1/16" sheet	24G sheet	1/16" sheet	24G sheet	1/16" sheet	24G sheet	1/16" sheet	24G sheet	1/16" sheet	24G sheet	1/16" sheet	24G sheet	1/16" sheet	24G sheet	1/16" sheet	24G sheet
Resistance of Single Sheet at 400 lbs. Electrode Pressure (Ohms)	9.0 .5 1.5 .25 2.5	3.0 2.5 4.75 4.25 1.5	0 0 0 0 0	0 0 0 0 0	17 12 15 11 12	1.0 1.0 1.5 1.5 .5	20 4 9 5 15	23 200 150 1 200	0 0 0 0 0.5	2.5 2.75 12.0 12.0 1.0	Nil.		Nil.		Nil.	
Primary Volts	385		386		385		385		384		385		385		385	
Current Setting Amps.	–	–	9000	9400	9000	6340	7400	7600	9000	9400	8010	16200	9000	11200	8010	8500
Welding Time Cycles	–	–	40	10	20	10	20	10	25	10	40	15	50	10	70	20
Electrode Pressure Lbs.	–	–	600	370	491	600	491	700	900	900	500	400	500	400	400	400
Electrode Pressure lbs./sq. in.	–	–	12200	7500	10000	12200	10000	14250	18300	18300	10200	8150	10200	14500	8150	14500
Dia. of Electrode	1/4"	1/4"	1/4"	1/4"	1/4"	1/4"	1/4"	1/4"	1/4"	1/4"	1/4"	1/4"	1/4"	5/16"	1/4"	3/16"
Tensile Tests lbs. per Spot	–	–	3240 3250	710 760	–	380 430 530	1790 1960	450	–	710 710	2840 2880	800 870	2540 2670	860 810	3450 3170	680 710
Salt Spray Tests	–	–	Slight rusting on weld	Very slight rusting	–	Severe rusting	–	–	–	Severe rusting	Slight rusting	Rapid rusting	Slight rusting	Very slight rusting	Very slight rusting	Very slight rusting
Weldability	Unsatisfactory		Satisfactory		Unsatisfactory		Unsatisfactory		Unsatisfactory		Satisfactory		Satisfactory		Satisfactory	
Fouling of Electrodes	–	–	Sparking and sticking up to 20-30 welds	Slight sticking up to 20-30 welds		Sparking & pitting of electrodes	Sparking	Excessive sparking and pitting of dies		Excessive sparking and pitting of dies	Slight sticking	Excessive sticking	No sticking		No sticking	Very slight sticking
Redressing of Electrodes	–	–	Normal		–	–	–	–	–	–	Every 100 welds		Normal		Every 50 welds	
Carbon Content percentage			.060	.040							.080	.050	.040	.055	.055	.060

Carbon Estimations.—Representative samples of the sheet used in the experiments were analysed for carbon, the values obtained ranging from 0.040 to 0.080 per cent. The highest value was obtained on the $\frac{1}{16}$ in. thick sheet which had been electro-tinned.

SUMMARY OF INDIVIDUAL TESTS.

Sheradised Sheet.—It was found that the surface resistance of a single sheet under a load of 400 lb. using $\frac{1}{4}$ in. dia. electrodes was, for all intents and purposes, zero, and that, under normal spot-welding conditions, satisfactory spot-welds could be produced. However, the coating tended to adhere to the electrode tips, causing them to stick to the metal, although this was much less pronounced after 20 to 30 welds had been made. The use of rather low welding pressures allowed a reduction in welding current, which still further reduced the sticking tendency.

Very slight rusting was obtained on the surface of the spot-welds in the salt spray tests.

Parkerised Sheet.—A series of surface resistance measurements taken on a single sheet gave values ranging from 0 to 12 ohms. It was found that when low electrode pressures were used in the spot-welding tests, the coating frequently prevented the current from passing through the sheets. The electrode pressure was increased in increments up to 18,300 lb./sq. in., and although spot-welds were then obtained, slight variations in coating thickness occasionally prevented welding. It was not possible consistently to prevent sparking from between the sheets at the commencement of the weld, due to the high surface resistance. The electrode tips soon became fouled by the surface, which rusted severely in the vicinity of the spot in subsequent salt spray corrosion tests.

It was concluded that the surface did not permit satisfactory spot-welding on large-scale production.

Browned Sheet.—Surface resistance measurements under the standard conditions for these tests was found to give values ranging from 0.5 to 17 ohms. It was impossible to obtain welds in the $\frac{1}{16}$-in. thick material, but in the 24 S.W.G. sheet welds could only be obtained occasionally. In the latter case weld strength was uncertain, and electrode tips soon became badly pitted. It was concluded that this surface preparation was unsuitable for spot-welding.

Brunofixed Sheet.—A series of resistance readings on a single Brunofixed sheet gave values from one to 200 ohms. A high electrode pressure was necessary to obtain a spot-weld, but excessive sparking occurred, and the electrode tips became badly pitted.

Electro-Tinned Sheet.—Resistance measurements showed that the electro-tinned surface under spot-welding conditions was of zero resistance, and that spot-welding could be carried out, although the tips tended to stick to the sheet after welding. A production run necessitated tip cleaning every 100 welds. The corrosion resistance of the surface was considerably reduced in the vicinity of the weld. It was concluded that, although electro-tinned sheet can be spot-welded, the sticking of the electrode tips would be objectionable in production.

Electro-Zinc Coated Sheet.—No measurable resistance was indicated by the surface resistance measurement tests on this sheet. Good spot-weldability was obtained and corrosion resistance was only slightly impaired in the vicinity of the spot-welds.

Galvanised Sheet.—The coating had the usual inconsistencies in thickness. The resistance of a single galvanised sheet under the standard conditions of these tests was zero. The electrode tips tended to stick to the surfaces during the spot-welding tests, and the tips became fouled as a consequence. The salt spray test showed that very slight rusting occurred in the vicinity of the spot-welds. Due to the fact that the electrode tips pick up and become fouled, the strength of spot-welds produced in a production run falls off rapidly, and it is recommended that the tips should be cleaned after every 50 welds.

Bonderised Sheet.—The resistance of a single Bonderised sheet varied from 0.25 to 9.5 ohms. No spot-welds could be produced in this material.

Conclusions.—The results obtained in these tests are tabulated for reference purposes in the form of a chart (on page 70). It will be noted that shear strengths and welding times are given for both thicknesses of sheet, except in the case of the Bonderised material. It is felt, however, that the shear strength value is dependent on the composition of the steel used, and the welding time on the thickness of coating. The values given, therefore, should only be used in practice as a guide to weld strength and correct machine settings.

Satisfactory weldability was obtained only with those surfaces whose electrical resistance approximated to zero—i.e., Sherardising, electro-tin, electro-zinc, and galvanising.

It was thought that the electrode tip pressure might be sufficient to break down the surface resistance of some of the other surfaces, but such was not the case.

Of the above surfaces, that which suffered most from the point of view of damage to corrosion protection in the spot vicinity was electro-tin. The other three surfaces underwent only slight damage.

Electrode redressing was normal in the cases of the Sherardised and electro-zinc surfaces. Electro-tin necessitated electrode redressing every 100 welds, and the galvanised surfaces every 50 welds.

Spot-weld strength with the above four surfaces was approximately the same as for uncoated mild steel. Weld strength in the other four surfaces was erratic, indicating that the weld sizes produced were inconsistent.

Recommendations.—From the production point of view, Sherardised and electro-zinc surfaces are recommended when rust-proofing of components must be carried out prior to spot-welding.

APPENDIX.

Further Tests on Electro-Zinc Coated Sheet.

In view of the promise shown by the zinc coating in the foregoing exploratory tests, it was decided to carry out further work on the spot-welding characteristics of this type of surface preparation. The thickness of coating was thought to be variable, and indeed two sets of plates coated by different firms both had coating thicknesses varying between wide limits, in spite of the fact that the coating thickness asked for was 0.0003 in.

The material used in these tests was as follows :—

22 and 20 s.w.g. auto-body quality pickled sheet.

18, 16, and 14 s.w.g. single pickled sheet.

Selection of Material.—It was observed when carrying out the tests that the average breaking load of the spot-welds in $\frac{1}{16}$-in. thick sheet was considerably lower than that obtained in previous tests on material of similar thickness. The steel sheets used on these tests were analysed, and the material giving the higher weld shear strength had abnormal phosphorus and sulphur contents. It appears, therefore, that the shear strength values of the spot-welds may be effected by the composition of the steel used.

The average thickness of zinc was determined by chemically removing the coating, and from the values obtained it would appear that for a required thickness of 0.0003 in. the maximum thickness obtained may considerably exceed this value. The actual thicknesses of zinc coating on the various test samples were :—

0.029	0.0009
0.039	0.0012
0.049	0.0009
0.060	0.0005
0.080	0.00024

Pressure.—A number of welds made in various thicknesses of zinc-coated sheet were sectioned and examined under the microscope. It was found that all the sectioned welds were free from gas cavities and blow-holes. A typical section is illustrated in Figs. 93 and 94. The presence of the zinc coating may be responsible for the soundness of the welds.

In one series of tests the pressure range was varied from 300 lb. to 450 lb. (8,000 lb. per sq. in. to 14,000 lb. per sq. in. tip pressure), and all welds when sectioned were free from blow-holes. Excessive electrode tip pressure should be avoided, since it causes the zinc to burn round the edge of the electrode tip.

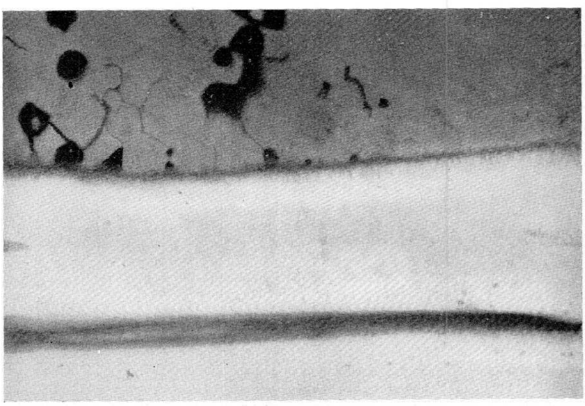


Fig. 93. Micro-section of cross-section of weld, showing absence of blow-holes.

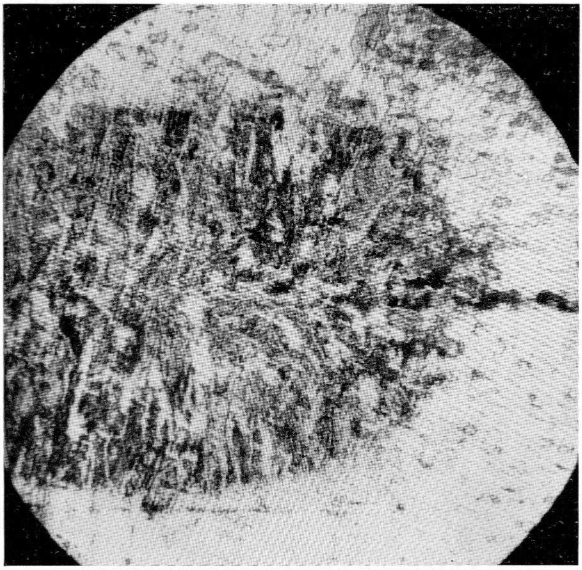


Fig. 94. Micro-structure of weld taken at a higher magnification.

Effect of Electrode Pressure on the Zinc Content of the Spot-Weld

A spectrographic examination of the material in the fused portion of the spot-welds was carried out in order to determine what effect difference of electrode pressure had on the zinc content of the weld metal. From the small number of samples examined it would appear that more zinc is retained in the material at high rather than low pressures. The nature and distribution of this zinc within the weld structure is difficult to determine, but, according to Osawa and Ogowa, as much as 18 per cent. of zinc may be retained in solid solution in steel at room temperature.

Welding Current.—High welding currents cause the coating to spit and splutter, and in the case of zinc-coated sheets a black film, thought to be a zinc-iron compound, is formed on the inside surfaces. This film may be found to spread over a considerable area surrounding the weld. The most suitable welding conditions are determined by reducing the current so that the formation of this black deposit is avoided.

Welding Time.—It appears that the thickness of coating is one of the factors which determines the welding time. In making a spot-weld in coated mild steel sheet it is necessary to allow sufficient time for the coating to melt before making the weld. The welding times are therefore longer than those used for welding uncoated mild steel.

Electrode Material.—It was found that electrodes made from cadmium copper were suitable for the spot-welding of zinc-coated sheets.

There is a slight tendency for the electrode tips to stick to the sheet at the commencement of welding, but after a few welds are made this sticking effect disappears.

Test Results.—The results obtained in this series of tests are given below. The breaking loads obtained for five test specimens are given for each thickness of material.

It does not appear to be possible to stipulate standardised welding machine settings for specified thicknesses of zinc-coated mild steel sheets. The welding time required appears to depend to some extent upon the thickness of the zinc coating. The shear strength of the spot-weld may be affected by the composition of the steel. The welding pressure does not appear to be critical.

A spectrographic examination of the weld metal appears to indicate that more zinc is retained in welds made with high welding pressures.

The use of high welding currents causes a black film to form between the sheets being welded.

Test Results on Zinc-Coated Sheets.

Metal thickness (inches).	Average coating thickness (inches).	Weld time (cycles).	Welding current (amps).	Electrode tip diameter (inches).	Gauge pressure (lbs.)	Electrode pressure (lbs. per sq. in.).	Water cooling (gals. per minute).	Breaking load (lbs. per spot).
0.029	0.0009	13	8,000	$\frac{3}{16}$	400	14,600	1	710 700 700 710 720
0.029	0.0009	13	10,400	$\frac{1}{4}$	450	9,150	1	890 960 950 950 950
0.039	0.0012	19	10,400	$\frac{1}{4}$	450	9,150	1	1,200 1,220 1,160 1,190 1,230
0.049	0.0009	27	9,100	$\frac{1}{4}$	450	9,100	1	1,370 1,420 1,330 1,410 1,390
0.060	0.0005	50	8,800	$\frac{1}{4}$	500	10,000	1	2,570 2,540 2,610 2,670 2,580
0.080	0.00024	65	8,600	$\frac{5}{16}$	550	7,150	1	3,550 3,470 3,420 3,620 3,660

Chapter VI

MISCELLANEOUS APPLICATIONS

RESISTANCE WELDING OF NON-FERROUS METALS OTHER THAN LIGHT ALLOYS.

The principal non-ferrous materials, other than light alloys, to which resistance welding might be applied are copper alloys (e.g., brass, bronze) and nickel alloys (e.g., monel, cupro-nickel). In both cases spot welding is possible and has been carried out for some years, but there is only a limited amount of information available and it would seem that actual experience is also somewhat limited. There is, however, very little doubt but, that had as much attention been given to the spot welding of these alloys as has been given to aluminium base materials much greater progress would have been achieved, and it may fairly confidently be suggested that there are fruitful fields for future development in this direction.

The butt welding of copper is a very old art in daily use in the wire-drawing industry. It is also employed with portable equipment for joining conductors in electrical machinery such as motors, generators and transformers. Spot welding of copper sheet is also possible, though apparently the present maximum thickness is about 1/16″. Owing to the high thermal conductivity a very short time of discharge is necessary. Spot welding of brass is also used, but trouble is liable to be experienced with dirty electrodes due to volatilisation of zinc from the metal.

Hess & Muller in 1941 published an account * of the welding of nickel, monel and inconel. They laid down the conditions which it was necessary to observe to obtain satisfactory high strength welds on material up to $\frac{1}{8}''$ thick. They recommend copper alloy electrodes having a conductivity of not less than 80% and the use of truncated cones rather than domed tips. Close control of energy input appears to be necessary for successful results and the time of discharge in their experiments varied from 4 to 30 cycles. Some sticking of the electrodes to annealed nickel sheets led them to recommend shorter firing times than are necessary with Monel and Inconel. The tests were made with a standard A.C. type of welder.

RESISTANCE WELDING OF DISSIMILAR METALS.

Generally speaking, the welding of dissimilar metals produces unsatisfactory results. Success can, however, be achieved in certain cases where the two materials are alloys of the same base metal, e.g., brass to bronze or duralumin to aluminium. There is, in fact, only a limited amount of knowledge on the welding of dissimilar materials and it is obvious that there is need for further research and investigation.

* *Welding Journal, October,* 1941.

An example of the welding of dissimilar metals is the renewal of cutting edges on tools such as end-mills, lathe tools, planing tools, in fact, most of the tools used in machining operations. It is obvious that to manufacture a complete tool of carbide or high speed steel would be very costly, when the actual wear in use takes place only on the cutting edge. These tools can be re-tipped by means of the flash-butt welding method. The method of operation is to clamp both pieces to be welded in a butt welding machine, allowing greater or less protrusion from the clamps according to the characteristics of the steel being welded. For example, the end of the high speed steel tip would be closer to its clamp than that of the lower carbon steel shank, thus levelling up the heat distribution and avoiding deterioration of the high speed cutting tip.

RIVET HEATING BY RESISTANCE WELDING.

One of the more uncommon uses of resistance welding is the heating of rivets. This method of heating has a number of advantages, both from the cost and technical point of view, compared with the older methods of breeze and coke fires.

The first electric rivet-heaters were introduced in Europe in 1919 and many industrial works who have a large amount of riveting to do, have installed them in place of older equipment. In electric rivet-heating the current passes through the rivet and prolonged heating does not affect it. Further the rivet is visible during the whole process and can be instantly removed from the machine. As the rivet is hotter on the inside than on the outside, oxidisation is negligible and the rivet also remains hot for a longer period than rivets heated by older methods. This is, of course, a considerable advantage, when rivets have to be placed in awkward situations. The point on the rivet is hotter than the head, thus causing better compression and permitting of easier passing through the rivet holes. Rivets which are over-heated tend to become loose and this is a disadvantage where they are employed in liquid or air-tight vessels and results in any case in constructional weakening of the joint but, as by the electric method, the rivets are heated to a constant temperature, over-heating is avoided.

General Description. The electric rivet-heater consists of a transformer, the primary windings of which have taps for regulating the current ; the secondaries consist of coils of special laminated copper arranged in such a way that ample cooling surface is presented. The connections are welded to flanges which are flexible, and to block electrodes of special copper, these block electrodes being adjustable for pressure. The degree of heating is controlled by the primary taps.

Each heating element comprises two electrode blocks, one of these blocks being fixed whilst the other, generally the lower one, is movable. When not in use, the distance between the blocks is less than the length of the rivet to be heated. The distance between the two blocks can be regulated. The movement of the blocks is controlled by a foot pedal and when this pedal is depressed, the distance between the blocks becomes wider and this permits the rivet to be placed between the blocks. Releasing the pedal fixes the rivet vertically in the space between the two electrodes ; the current passes through the rivet and rapidly heats the metal to the required temperature. In machines with more than one set of electrodes, rivets of different diameter or length can be heated at the same time. When the rivet has been heated, it is freed by pressing the foot pedal and can then be lifted by means of the usual rivet tongs. Alternatively, arrangements can be made for it to drop into an insulated rivet container.

The table on page 79 shows various models which are obtainable. These machines are of the air-cooled type, but some makers supply equipment with water-cooling. The production rates indicated for the various rivets are based upon eight hours continuous working. As previously mentioned, normally the temperature at the tip of the rivet is slightly in excess of the temperature at the head or in the body of the rivet and if the heating speed indicated is exceeded, or the pressure on the rivets decreased, the temperature will be unevenly distributed—the tip will be at white heat while the head will be insufficiently heated. Such exceptional rivet heating is obviously unsuitable for most types of work, although in some cases rivets are used in this condition. Machines are produced with one, two, three, four, or even six blocks, according to the rate of production. Some models are in mobile form fitted with wheels, others are of the fixed type. Special machines have been made with very high capacity, but of very small dimensions for heating rivets inside large tanks, boilers, etc.

Single head machines are usually supplied for operation on single phase mains or for connection between two phase or three phase mains. The machine with two and four blocks can be operated on single or two phase or even three phase mains, but machines with three or six blocks are always arranged for operation on three phase mains.

Some idea of the operating costs will probably be of interest. With gas at 8d. per therm, the cost of rivet heating is 0.212d. per lb. of rivets, or approximately 1/8 per 100 lbs., equalling about 130 $\frac{7}{8}''$ × $3\frac{1}{8}''$ rivets. An equivalent quantity of rivets can be heated with electricity at $\frac{1}{2}$d. per unit for 1/-.

It may be that the actual cost of coke or breeze is lower, but to this must be added wastage, delivery of the breeze to the forge, the need for attention to fires, lighting fires before work, the power for the blowers or fans, the reduced speed of heating and the fact that heating on a forge cannot be so easily controlled.

Dimensions of Rivets and corresponding hourly production.

$\frac{1}{4}'' \times 1''$	$\frac{3}{8}'' \times 1\frac{1}{8}''$	$\frac{7}{16}'' \times 1\frac{3}{8}''$	$\frac{1}{2}'' \times 2\frac{5}{16}''$	$\frac{5}{8}'' \times 2\frac{5}{16}''$	$\frac{11}{16}'' \times 2\frac{5}{16}''$	$\frac{3}{4}'' \times 3\frac{1}{8}''$	$\frac{7}{8}'' \times 3\frac{1}{8}''$	$1'' \times 3\frac{1}{8}''$	$1\frac{1}{8}'' \times 4\frac{1}{4}''$	$1\frac{1}{4}'' \times 7''$	Max. Material Heated per hour
240	180	100									
260	220	150	110	90							
260	220	150	110	90							24.25 lbs.
520	440	300	220	180							48.5 ,,
520	440	300	220	200	160						59 ,,
780	660	450	330	300	240						88 ,,
520	440	300	220	200	170	110	90				66 ,,
780	660	450	330	300	255	165	135				100 ,,
		300	220	200	170	150	120	100			100 ,,
		450	330	300	255	225	180	150			148 ,,
		300	220	200	170	150	130	120	80	40	132 ,,
		450	330	300	255	225	200	180	120	60	198 ,,

Chapter VII

THE SPOT WELDING OF LIGHT ALLOYS

The Problem—Types of Equipment—A.C. Machines—Magnetic Storage—Condenser Machines—Surface Preparation—Electrodes—Weld Quality — Faults — Control and Inspection — Hints to the Operator.

A separate chapter is allocated to the spot welding of light alloys since the equipment and technique used differ notably from corresponding mild steel practice. Mild steel is usually considered as a readily weldable material, in that a wide variation in welding conditions and technique may be tolerated. Whilst this is generally true, it has been widely interpreted to mean that little control is needed to obtain acceptable welds. It is no wonder that users of mild steel spot welding rarely appreciate the need for a carefully controlled technique when welding aluminium or aluminium base materials for the first time. As the greatest application of light alloy spot welding to-day is in the aircraft industry, it is important that beginners should be fully acquainted with the care and control necessary to ensure the consistent production of high quality welds, and the reasons for this control.

Several years ago, the main problem in light alloy spot welding was that of machine design. Notable advances in this respect have been made in recent years, and whilst improvements in machine design are still required, the problem cannot now be considered as important as that of pre-welding surface preparation. Machine design can rarely be blamed to-day for the production of low quality spot welds, but rather the insufficient process control and non-appreciation of the importance of surface preparation, electrode maintenance, component design considerations, etc. Even the best equipment will give poor results when due attention is not paid to these matters.

PROBLEMS OF LIGHT ALLOY SPOT WELDING.

Machine design and welding technique have been largely determined by the following factors :—

(1) Inherent nature of light alloys and their surface condition.

(2) Tendency of light alloys to alloy with copper or copper base electrodes.

Materials.

Aluminium or aluminium base materials have a very high electrical and thermal conductivity. The thermal and electrical conductivity of pure aluminium is approximately five times that of low carbon steel and that of the alloy from three to five times. In spite of the relatively low fusion temperature of aluminium alloys of about 520-650° C. as compared with 1,400-1,500° C. for mild steel, a considerably greater rate of energy input is required necessitating the use of high currents and short welding times. This can be readily understood when it is appreciated that the amount of heat developed by electrical resistance methods depends upon the resistance offered to the welding current, i.e., the inherent resistance of the material itself and that of the various contacts. Light alloys have an inherently low resistance, so that for this reason alone, high currents must be used to weld the material. Materials of low resistance are invariably good heat conductors, and welding times must necessarily be short to minimise conduction losses.

A very close control must be exercised over the energy input, since only a very short plastic range exists in light alloys, i.e., the temperature, range between initial melting and final melting is small, and small variations in energy may produce relatively large variations in weld size.

The high thermal conductivity causes rapid weld solidification and increases the tendency to form shrinkage cracks and porosity. It is obvious, since fusion takes place in light alloy spot welds, that beneficial effects will be obtained by the application of a relatively high pressure after welding, which will serve to close up pores and eliminate the tendency to form shrinkage cracks on cooling. An additional improvement will also be obtained if the rate of cooling during solidification is decreased, e.g., by passing a relatively small but long duration post-heating current after the main welding current. The full advantage of using high welding, or forging pressures, can be obtained only if the electrodes have rapid follow up, i.e., if the electrodes can follow rapidly the contraction of the solidifying and cooling spot weld, so that it is always subject to effective weld pressure. The moving system of the ordinary type spot welder has a very high inertia and a high static friction. As the electrodes are normally at rest during the passage of the welding current, considerable friction and inertia forces will oppose the motion of the electrode required to maintain pressure on the weld nugget during contraction. Any system which does not permit rapid follow up, will be liable to produce cracked welds. On decreasing the rate of cooling during solidification, i.e., by means of a post-heating current, a greater time is allowed for the electrodes to maintain effective pressure on the cooling weld. A post-heating current, therefore, may be used to compensate for high friction or high inertia heads.

To summarise, light alloys require specialised high capacity machines giving close control of the heat-pressure cycle and so designed as to give rapid electrode follow-up.

Surface Condition of Light Alloys.

Aluminium alloys are characterised by the presence of a thin tenacious oxide film on the surface, largely produced by the action of air during manufacture and subsequent treatment. This film has a high electrical resistance which may be further increased by dirt, grease, paint identification marks, etc. The presence of the film in contact with the electrode will cause heat to be developed at the electrode face, which will result in rapid deterioration of the electrode, and will give discoloured surface-burnt welds. As the film is non-uniform in thickness, a considerable variation in weld size is obtained, if the sheet is welded without any surface treatment, by reason of the variations in heat developed at the sheet-to-sheet interface. The object of surface treatment of aluminium alloys is to clean the material thoroughly, by removal of dirt and oxide film from both surfaces of the sheet and thus to reduce to a minimum the amount of heat developed at the electrode-to-sheet interface, and to obtain satisfactory weld strength consistency by ensuring uniform surface conditions at the sheet-to-sheet interface. Satisfactory consistency, as a rule, will not be obtained by cleaning only the surfaces in contact with the electrodes.

Tendency of Aluminium to Alloy with Copper or Copper Base Alloy Electrodes.

Electrodes are the means of bringing about a high current and pressure concentration at the welding interface, between the sheets, and must, consequently, be capable of carrying high currents efficiently and of withstanding high welding pressures without deformation. High conductivity copper is the most widely used electrode material in spite of its relatively low resistance to deformation—the reasons for this are :—

(1) High conductivity.

(2) Tendency to alloy with aluminium is less than with most copper alloy electrodes.

(3) Ready supply and relative small cost.

Cleaning of electrode tips at definite intervals during a production run, has to be undertaken to remove the film of aluminium, which forms on the tips, causing surface heating and sticking of the work to the electrode. This alloying of the aluminium and copper is known as electrode " pick-up " and is affected by the following four factors.

Effectiveness of the Electrode Cooling.

Electrodes must be efficiently cooled in order that heat may be rapidly conducted away from the electrode tip. With badly cooled electrodes the gradual accumulation of heat at the tip will give increased " pick-up." In some instances, the cooling efficiency has been improved by the circulation of suitable refrigerants, instead of water, through the electrodes.

Surface Contact Resistance.

High contact resistance at the electrode to sheet contact increases surface heating and electrode pick-up. This may be caused by :—

(1) Improperly cleaned material.

(2) Low electrode pressure.

(3) Badly faced and mis-aligned electrodes.

Duration of Welding Current.

Relatively long duration currents give increased pick-up, since the electrode-sheet contact is maintained at a high temperature for longer periods. Increased electrode life is, therefore, to be expected with machines using short duration currents.

Conductivity of Electrodes.

Pick-up is reduced with high conductivity electrodes. Copper alloy electrodes of relatively lower conductivity, although giving improved resistance to deformation are liable to give increased " pick-up " necessitating more frequent cleaning of the electrodes.

Considerable attention must be paid to the problems of electrode design and maintenance, in order to obtain maximum electrode life and optimum performance. Further mention will be made later, on this important question.

TYPES OF EQUIPMENT.

Air operated, fully automatic machines are universally employed for the spot welding of light alloys i.e., compressed air is used as the means of applying the load to the electrodes, either directly or indirectly as in air-lock or spring loaded heads. Automatic machines are employed, so that the predetermined welding cycle may be reproduced indefinitely, independently of the machine operator.

Machines may be divided into two main types, namely, the conventional alternating current machine and the so-called " stored energy " single impulse, unidirectional machines. This latter class may be further sub-divided into the induction storage and condenser storage types. In the former, energy is stored in the electromagnetic field of a large iron cored inductance, and in the latter in the electrostatic charge of a large condenser. Machines may also be classified according to the type of welding cycle utilised. There are numerous variations in welding cycles but the following are the more important at present in use.

(1) Low pressure, during which A.C. is applied, followed by a high forging pressure and a reduced or post-heating current, i.e., the programme control cycle used with high power A.C. machines (Fig. 95).

(2) High initial pressure followed by a low pressure, during which a direct current impulse is applied and completed by the application of a high forging pressure, i.e., the " D.C. recompression " cycle mainly used with induction storage machines (Fig. 96).

(3) Gradually increasing pressure to the maximum or forging pressure, during which a direct current impulse is applied. This cycle is used with certain types of condenser storage machines (Fig. 97).

A.C. machines fitted with complicated and expensive timing devices were, until recently, the most widely used machines for spot welding light alloys. Their use involves considerable electrical drawbacks. The very high welding currents required can be obtained only by a heavy line demand on a single phase of the power supply to the primary of the welding transformer, and the heavy intermittent loading with a low lagging power factor is particularly undesirable.

The reasons for the increasing application of " stored energy " machines in the aircraft industry are :—

(1) The solution of the electrical problems by reducing the power demand and utilising all phases in a polyphase supply with almost unity power factor.

(2) A favourable load factor.

(3) The inherently short welding cycle which minimises the frequency of electrode cleaning.

Suitability of the Type of Welding Cycle.

Cycle 1. " Programme Control."

The value of this cycle (Fig. 95) has already been discussed on page 83. Mention was made of the need for having rapid electrode follow up to obtain the maximum effect of pressure on the solidifying weld. Heavy duty A.C. machines are mainly of the press type with appreciable head inertia and friction, so that the full advantage of this cycle may not be derived. The use of a post-heating current will, however, largely counteract the inertia and friction effect.

Cycle 2. D.C. Recompression.

This cycle (Fig. 96) possesses several significant features :—

(1) The use of a high initial pressure to improve surface conditions before the welding current is passed.

(2) Reduction of the high pressure during welding to increase the contact resistance and thereby develop greater heat.

(3) Application of a high forging or upset pressure to eliminate weld porosity and cracks.

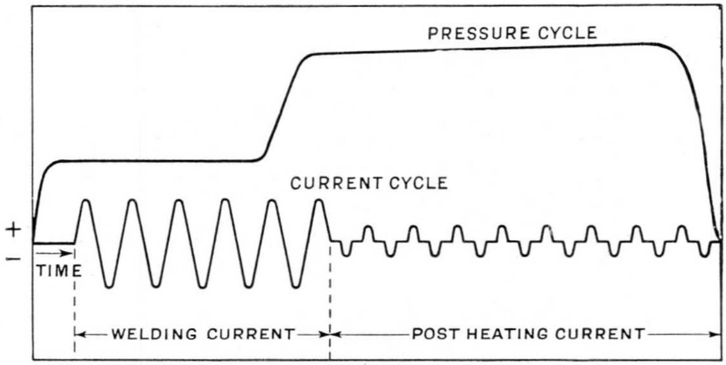


Fig. 95. Cycle I. " Programme Control."

This cycle is very good at first sight, but on further examination it is apparent that there may be several drawbacks. For instance, the initially high surface contact resistance, which is presumably reduced or destroyed by the high initial electrode pressure, is not necessarily regained by reducing the pressure during the current discharge. The high forging pressure must also be closely synchronised with the formation of the weld, if it is to be effective in reducing cracks or porosity. If the weld has frozen and cooled somewhat, the application of a high pressure will avail little in improving weld quality. Instantaneous electrode follow-up is much more effective than any recompression cycle.

Unfortunately, it is likely to suffer from the same defects as cycle No. 1, e.g., the sudden pressure changes do not facilitate ready reproduction. In addition, the initial relatively high control resistance, which is reduced or destroyed by the high initial pressure, is not necessarily regained by reducing the pressure during the current discharge.

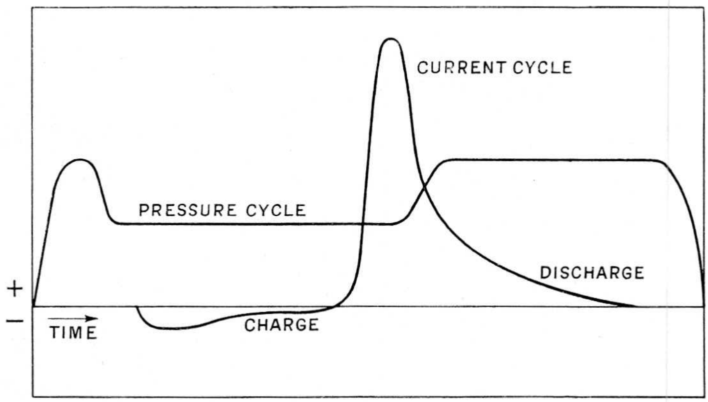


Fig. 96. Cycle 2. D.C. Recompression

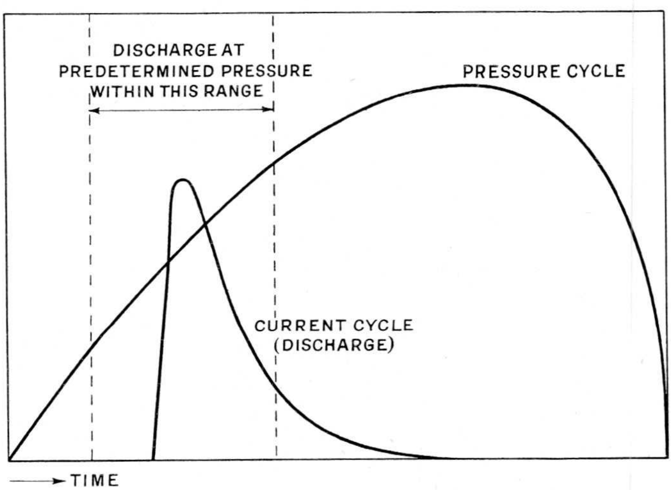


Fig. 97. Cycle 3.

Cycle 3.

The electrode pressure is gradually built up to the maximum or forging pressure. Pressure cycle reproduction is thus facilitated by the absence of any sudden pressure changes of the kind shown in cycle 2.

Pressure build-up, however, must be rapid to obtain maximum forging effect by giving instantaneous and effective electrode follow-up.

ALTERNATING CURRENT MACHINE.

The principle involved with the A.C. machine for light alloys is no different from that of the A.C. mild steel spot welder. Constructional differences do exist, however, particularly with regard to the increased machine capacity and the complex timing devices for obtaining the close control over energy input, required in light alloy spot welding.

The passage of a predetermined number of cycles of current in the primary of a welding transformer induces the same number of cycles of transformed current in the secondary or welding circuit. Special timing devices in the primary circuit control the duration of the current. A suitably tapped primary is the main control for the magnitude of the current.

The main machine variables for a standard A.C. machine are :--

(1) Welding and post-heating current. (Magnitude and duration.)

(2) Electrode pressure. (Magnitude and time of application in relation to welding current.)

Most A.C. machines are equipped with programme control ignitron panels to give close control over heat input. Only brief mention will be made of the use of ignitron and thyratron controlled circuits and their construction, since a full description is given in Chapter IX.

The machines usually employ water-cooled steel ignitrons for controlling the main supply to the welding transformer. Thyratrons control the duration of the welding and post heating current, and a thyratron controlled relay and rheostat is used to adjust the time of application of the high forging pressure.

The main control of the welding current is given by means of a tapped welding transformer primary which, in conjunction with the heat control in the ignitron panel, gives an almost infinite variation in current. Heat control is obtained by the so-called " phase shift " method, by which only a definite fraction of the current wave is passed to the secondary or welding circuit.

An accurate control of the energy output from the transformer is thus possible with ignitron and thyratron control panels. Maintenance costs are generally negligible, since there are no moving parts or contacts in the supply line. Should, however, inaccurate operation be experienced, it is no easy matter to determine the cause of the trouble, since the circuits involved are very complicated and likely to test severely the ingenuity of most workshop electricians.

STORED ENERGY MACHINES.

Inductance Storage.

Electrical energy is stored in the primary of a transformer by applying a D.C. magnetising current (see Fig. 98). When the energy stored in the electro-magnetic field reaches a certain predetermined value, the current in the primary is interrupted by a contactor, and the sudden collapse of the field induces a high welding current in the secondary. The magnitude of the welding current is determined by :—

(1) The current flowing in the primary when the circuit is broken, which may be varied by means of an adjustable current relay.

(2) The time constant of the circuit comprising the charged core and the secondary circuit, which may be altered by varying the resistance of the secondary circuit.

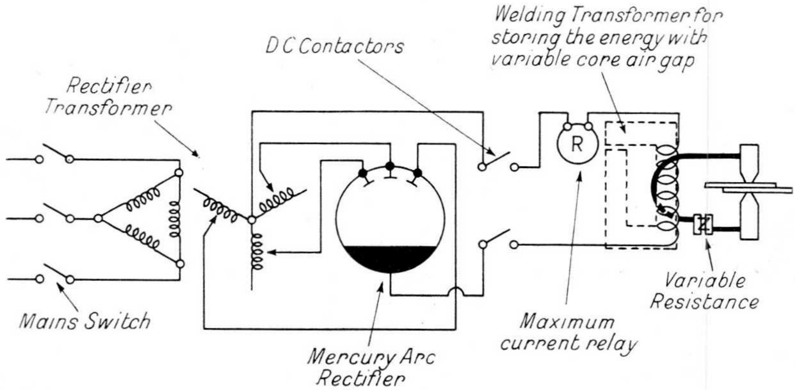


Fig. 98.

The type of welding cycle used with the machine is given in Fig. 96. The variable pressure cycle is obtained by using electrically operated air valves. Two reducing valves control the air pressure to the cylinder, to which air is admitted through electro-magnetic air valves, one valve feeds the top of the cylinder and the other the bottom. Arrangements are made for energising and de-energising the valves at the required time to give a pressure cycle of the kind given in Fig. 96. The contactors interrupting the primary circuit must break relatively high charging currents, since by this means only can the welding current be induced in the secondary circuit. Contactor wear must, therefore, be expected to be excessive, necessitating considerable maintenance and replacement.

Condenser Storage.

Equipment of the condenser discharge type represents the most recent advance in light alloy spot welding. Energy is stored in condenser banks by the application of D.C., produced by rectification of all three phases of the main supply. The energy thus stored is discharged through the primary of the welding transformer, inducing an extremely rapid unidirectional impulse in the secondary or welding circuit. The energy stored in the condenser bank is given by $\frac{1}{2}$ C.V.^{2}, where C is the capacity of the condensers and V the voltage to which the condensers are charged. The actual shape or form of the discharge curve will depend upon the quantity of energy and upon the circuit constants, i.e., upon the resistance and inductance. Fig. 99 shows an ideal form of discharge curve in which the discharge is non-oscillatory. The condition for such a discharge is given by

$\frac{R^2}{4} > \frac{L}{C}$ where L is the effective inductance

of the circuit, R the effective resistance, and C the capacity

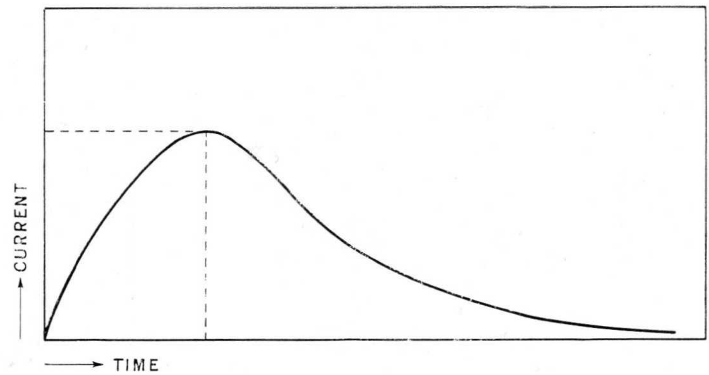


Fig. 99.

In practice, this condition is difficult to obtain, so that a truer picture of the form of the curve is given by Fig. 100 for which condition $\frac{R^2}{4} < \frac{L}{C}$.
The relationship between these constants determines the shape of the discharge curve.

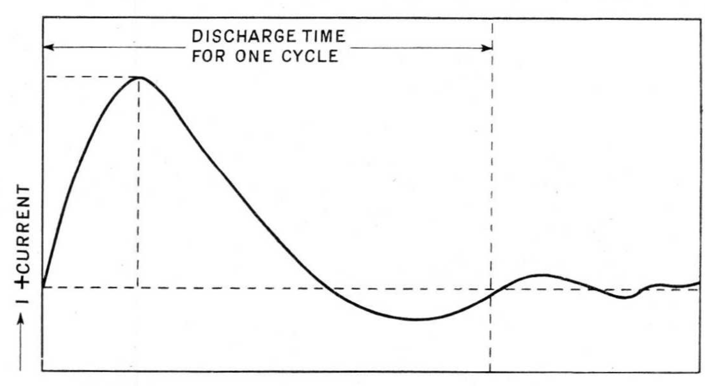


Fig. 100.

The total energy available is fixed by the capacity and the voltage to which the condenser is charged ; the turns ratio of the transformer affects the inductance and the equivalent value of the resistance and so determines the time over which the discharge is spread.

Two types of equipment may be recognised :—

(1) High voltage, low capacity type, employing paper condensers and electronic tube rectification and control.

(2) Low voltage, high capacity type, employing electrolytic condensers and mercury arc rectification.

(1) **High Voltage, Low Capacity Type.**

A schematic diagram of this circuit is shown in Fig. 101. The condenser or capacitor bank is charged by closing the line switch. When the voltage through the rectifier transformer on the bank has reached a predetermined value, the switch is opened automatically. Closing the output switch discharges the condensers through the primary of the welding transformer, which in turn causes a high welding current to flow in the secondary. The condenser bank charging and discharging circuits, voltage control, etc., are contained in the control unit. As with other discharge equipment, the machine variables to be considered are :—

(a) Condenser capacity.
(b) Charging voltage.
(c) Welding transformer turns ratio.
(d) Welding pressure.

(2) **Low Voltage, High Capacity Type.**

A typical lay-out of this equipment is shown in Fig. 102. The schematic circuit diagram is the same as that given in Fig. 101, except that the electronic tube rectification is replaced by mercury arc rectification. The type of equipment shown in Fig. 102, for welding material up to 14 S.W.G., comprises a rectifier transformer, mercury arc rectifier, condenser banks and control panel and the welding machine proper. Fifteen taps are provided on the rectifier transformer giving a voltage range from 200-500 volts for an input voltage of 400-440 3-phase supply. Condenser capacity may be 10,000, 20,000 or 30,000 m.f.d. The welding head of the machine (Fig. 103) consists of a double acting pneumatic cylinder, which first closes the electrodes upon the work piece and then compresses a spring which applies increasing pressure to the work.

The head is fitted with efficient guides to centralise the electrodes and restrict electrode deflection at high welding pressures. In this respect, it is interesting to note that the welding pressures used with this machine are much higher than those normally used with A.C. machines, so that restriction of electrode deflection is an important feature. The welding cycle employed has been fully described above, and emphasis was laid on the reproducible nature of this cycle—an important point when good weld strength consistency is required. Provision is made for predetermining weld pressure and forging pressure. In this instance, the term forging pressure relates to the maximum pressure imposed on the weld. With an air-line supply of 80 lbs./sq. in. weld pressures between 500 and 1,500 lbs. and forging pressures up to 2,200 lbs. may be obtained. Both pressures may be controlled independently of the air-line pressure, so that fluctuation of the air line pressure within limits will not affect the reproducibility of the cycle.

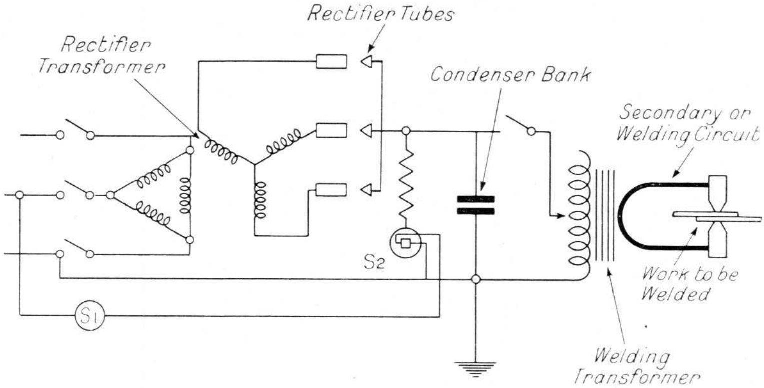


Fig. 101.

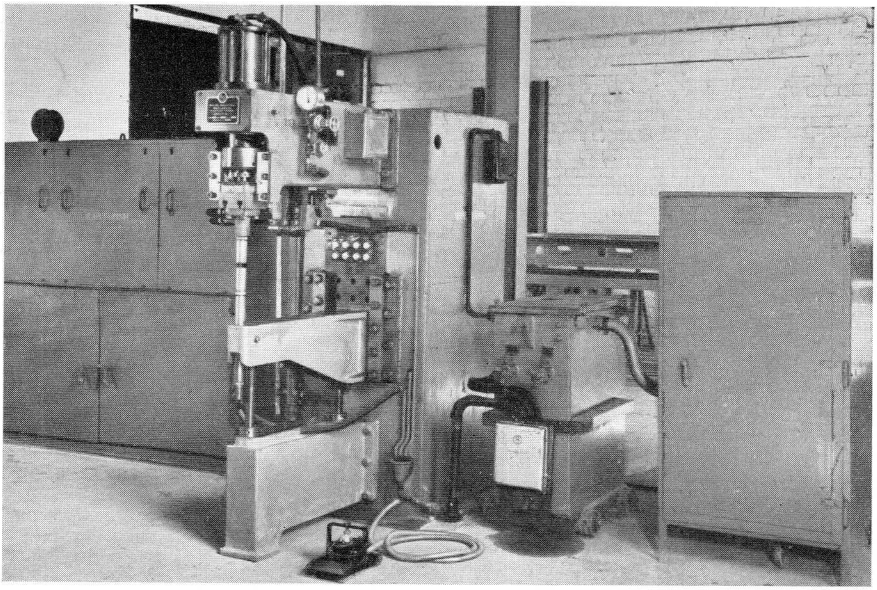


Fig. 102.

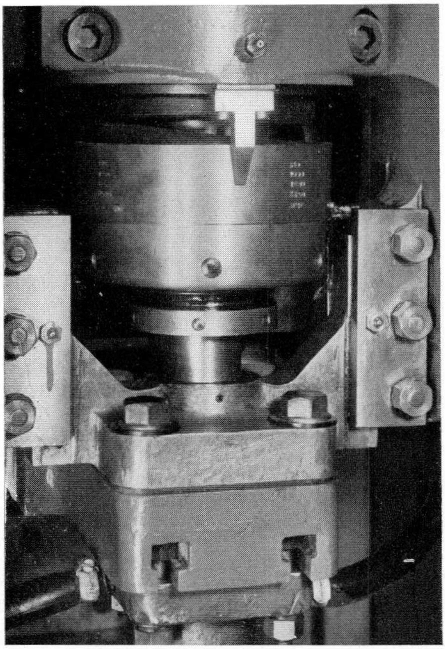


Fig. 103.

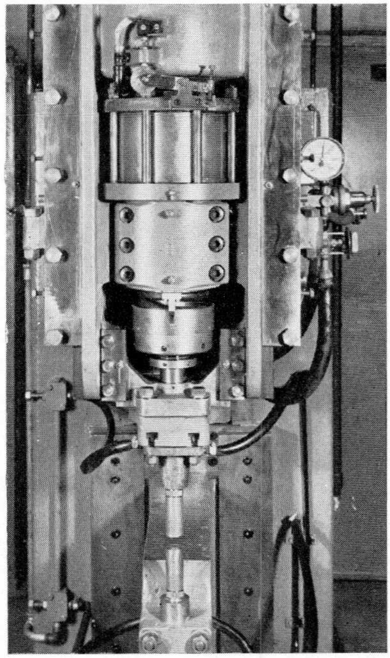


Fig. 104.

It is desirable to work with the smallest possible operating stroke, i.e., the movement of the top electrode to and from the work should be as small as possible. In certain instances, large deep sections must be admitted into the throat of the machine. The machine shown in Fig. 105 has a specially designed head for welding deep section work, being provided with the High Lift mechanism—an air-operated retractable mechanism enabling the top electrode holder and head to be moved through 6″ on the operation of a simple valve controlled by a lever. A close-up view of the mechanism is shown in Fig. 104. Under these conditions the total maximum movement may be $8\frac{3}{4}$″—the stroke normally being about 2″.

This type of machine—(Fig. 105) is designed to weld up to an included thickness of 2 × 10 S.W.G. Alclad, thicknesses which, prior to the advent of the stored energy machine, have been entirely unsuitable for welding and outside the existing machine capacities. The unsatisfactory nature of the loading on a single phase of 3 phase A.C. mains, while welding material of this thickness with a conventional A.C. welder, can well be imagined. The machine shown can satisfactorily weld material within the range 20 to 10 S.W.G., which is a good illustration of its versatility. Pressures up to 5,000 lbs. may be used.

The machines shown in Figs. 102 and 105, are all fitted with spring loaded heads, and utilise the simple, readily reproduced welding cycle (Cycle 3, pages 83 and 86). Other than the advantages to be gained from the supply point of view, electrode life may be greatly increased, e.g., the inherently short discharge time prevents appreciable heat conduction from the weld to the electrode face. Also, the use of high pressures reduces the heat developed at the electrode-to-sheet face. Electrode tip life may, therefore, be increased many times over that obtained with the A.C. machine.

CONDENSERS.

Careful treatment of condensers during operation of the equipment is essential. If the machine has not been in use for a certain period a gradually increasing voltage must be applied to the condensers, in order to make them suitable for withstanding the relatively severe working conditions. This process is known as " forming " the condensers, and relates to the reforming or strengthening of the thin oxide insulating film separating the aluminium sheets in the condenser. There are two types of forming :—

(1) Complete " forming " —to be carried out when the machine has been idle for periods of about 3 days or more and

(2) Protective forming—to be carried out when the machine has recently been in use, i.e., within the last 48 hours.

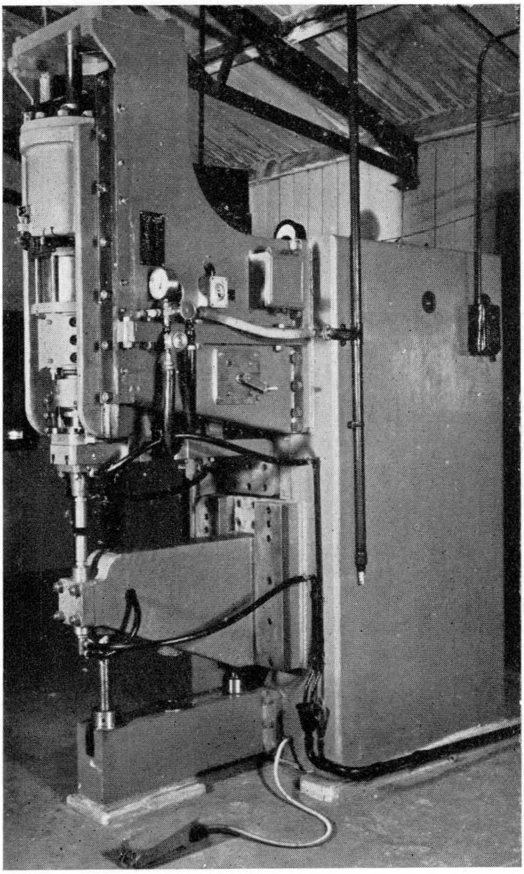


Fig. 105.

A suitable resistance is included in the forming circuit. In both cases, the forming voltage is initially low and then raised in steps by suitably altering tappings on the rectifier transformer, the only difference being that in the first case, the voltage is increased in steps of 30 volts from about 200 to 500 volts and maintained for at least five minutes at each voltage, and in the second in steps of about 60 volts with five minutes or so at each voltage, the maximum voltage attained being about 30 volts in excess of the working voltage.

By suitably planning work, so that the machine is in operation each day, forming may be greatly minimised since the condensers are then always maintained in a suitable stable working condition.

SURFACE PREPARATION.

Considerable attention has been paid recently to the importance of surface treatment of materials before welding, and it has been recognised that success or failure depends more on proper cleaning than upon any other factor. Many methods have been devised for cleaning although a limited number only are employed in practice.

The requirements for any method used are :—

(1) The surfaces of the treated material must have a low and uniform contact resistance to improve electrode life and give welds of high strength and consistent quality.

(2) The operating conditions must not be critical.

(3) The method must be simple, easily reproduced and with low operating costs.

Cleaning must be considered in two stages ; firstly, the removal of all extraneous matter, dirt, grease, identification marks, etc., and, secondly, removal of the non-uniform high resistance aluminium oxide layer. Removal of the oxide layer may be undertaken either by mechanical methods such as scratch brushing, emery, etc., or by chemical methods employing specific reagents for attacking the film. No satisfactory method exists for removing the extraneous matter and oxide film in one stage, and it is obvious that the grease would soon cause difficulties with mechanical and chemical methods. With chemical methods, it is particularly important that no grease be on the surface, otherwise the reagent will not remove the oxide uniformly and the object of the treatment would be defeated. Methods of preparation will be described in some detail.

Degreasing.

For large scale production work, trichlorethylene degreasing plants, as supplied by several well-known firms, are admirable. These plants employ the boiling liquid or vapour and are extremely efficient in action. Various other solvents, of course, may be used either in specially constructed plants or by hand wiping. The latter process must be carefully supervised, and is suitable only for carrying out on a small scale. Hand wiping of parts degreased in a vapour plant may be necessary to remove paint which is normally not removed by the vapour.

Alkaline solutions are finding increasing application as degreasing agents. Aluminium is normally attacked by alkaline solutions, but the presence of soluble silicates in the solution inhibits alkali attack, by the formation of a silicate film on the surface. All material degreased by an alkali cleaner should be wiped after treatment to remove the film and any other loose extraneous matter. Thorough washing of the material must be carried out to remove all trace of the cleaner, before treatment for removal of the oxide.

Two suitable degreasing solutions of this kind are :—

Sodium Metasilicate ($Na_2SiO_3.5H_2O$)...	(48%)	$2\frac{1}{2}$ lbs. per 10 gallons of water.
Sodium Trisilicate	(48%)	
Rosin	(4%)	

and

Washing Soda (Anhydrous Powder, Na_2CO_3)	($33\frac{1}{3}$%)	$3\frac{3}{4}$ lbs. per 10 gallons of water.
Trisodium Phosphate (Na_3PO_4) ...	($33\frac{1}{3}$%)	
Sodium Silicate (Na_2SiO_3)	($33\frac{1}{3}$%)	

Both solutions are operated at about 90-100° C.—the time of treatment being from 5 to 15 minutes.

A wide variety of similar reagents may be used with or without the addition of wetting reagents. The function of a wetting reagent is to give a surface showing no water break, by completely removing small traces of oil, grease, etc., from the surface. A good wetting reagent must not hydrolyse easily, and must be stable at the working temperature in the appropriate acid or alkali solution. Several satisfactory proprietary reagents for degreasing are available—Solvex, Zonax, etc., and manufacturers should be referred to for details of the optimum working conditions.

Degreasing is not always a simple process involving a straightforward treatment in a vapour or alkaline degreaser, and it is often necessary to vary the methods and technique, according to the condition and nature of the material. For example, formed sheets and sections sometimes have dirt, grease, and paint deeply embedded in the surface. In such cases, it may be advisable to use a trichlorethylene degreaser for removal of thick grease, etc., and then to follow it with an alkaline bath for complete removal of the oil and paint. Wiping in the alkaline bath is always advisable with dirty material. In some cases, wiping after pickling and before final drying, is also effective in reducing the contact resistance.

Removal of the Oxide Film—Mechanical Methods.

The methods most commonly used are rotatory scratch brushing, emery cloth abrasion, or steel wool. It is obvious that exceptional care must be taken with mechanical methods, to ensure the production of surfaces with a consistently low contact resistance. Indeed, the extreme care required with emery cloth abrasion or steel wool, particularly with aluminium coated material, should exclude them from practical application. However, several firms prefer to use them, because of their small initial outlay cost, at the expense of weld quality and consistency. Rotary scratch brushing is, without doubt, the best method of mechanical preparation. Care and close supervision and inspection are required, since it is difficult to prescribe or enforce a particular technique. If firms adopting this method realise the limitations and can give suitable supervision, the method will give very satisfactory results. Experienced operators can readily judge the progress of the operation by the appearance of the surface—a correctly scratch-brushed surface possesses a characteristic satin-like appearance, in which no traces of individual scratches are visible. Such surfaces possess an extremely low contact resistance (generally less than that of a chemically treated surface), and provided the correct welding conditions are used, will give welds of an extremely uniform shape and size.

Brushes generally consist of steel or nickel-silver wire and, in some cases, brass, and should be operated at speeds from 2,000 to 3,000 revs. per minute. The dimensions of the brush depend upon the nature of dimensions of the parts to be cleaned, a common size being about 4-5 ins. diameter, with a $\frac{3}{4}$-1 in. face. Brushes may be air or electrically driven, the former method being recommended. Brushes mounted on flexible shaft are ideal for cleaning large surfaces. In some cases, e.g., when cleaning long straight stringers or sheets, it is preferable to keep the brushes in a fixed position on either side of the piece to be cleaned and to arrange for automatic feed of the material.

Materials Suitable for Scratch Brushing.

Aluminium coated alloys, aluminium-manganese alloys ($1\frac{1}{2}\%$ Mn. D.T.D.213) and aluminium-magnesium alloys (B.S.S.L.46) can be scratch-brushed without difficulty, although care must be taken with the coated materials, to ensure that the coating is not impaired or removed by excessive treatment. Brass wire or fine steel brushes (diameter of wire not exceeding 4/1,000″) are admirable for aluminium coated alloys. A rather coarser wire should be used with the manganese and magnesium alloys than with Alclad alloys.

Uncoated duralumin-type alloys (B.S.5L3, etc.), are difficult to scratch-brush satisfactorily, relatively coarse wires must be used and the power unit driving the brush must have sufficient capacity to maintain high working speeds at high pressures. Brushes tend to slide over the surface in certain regions and leave large areas of oxide. In at least one instance experienced by the author, one supposedly scratch-brushed duralumin surface had such a high surface resistance, that it acted as a very efficient electrical insulator and completely prevented the passage of the welding current. Examination of the surface showed signs of tarnishing, probably indicating the presence of a mechanically produced burnished film. The difficulty of cleaning duralumin with scratch-brushing increases as the gauge thickness increases, so that with material exceeding about 16 S.W.G. chemical methods provide the only satisfactory method of oxide removal.

It is also found that certain material does not re-act favourably to chemical cleaning, i.e., very dirty Alclad material in which oil, etc., has been deeply embedded in the coating, in such cases scratch-brushing alone is satisfactory. Chemically treated material which has been over-treated, or otherwise made unsuitable for spot welding, by excessive handling or delay between treatment and welding, is best reclaimed for welding by light scratch-brushing.

The use of scratch brushing is summarised in Table 1.

Table I.—Application of Scratch-Brushing.

Use.	Material.	Whether suitable for scratch-brushing or not.	Remarks.
Pre-welding surface treatment.	Aluminium coated alloys or commercial aluminium (e.g. D.T.D. 390, B.S.S. 2L38).	Yes.	Care required not to impair coating. High capacity machines will be required to weld scratch brushed commercial aluminium.
	Aluminium manganese alloy (1½% Mn.) (e.g., D.T.D. 213 and alloys of Birmabright type, B.S.S. L.46).	Yes.	High operating speeds are essential.
	Uncoated alloys of duralumin type (B.S.S. 5L3).	Difficult.	Possible for gauges up to 16 S.W.G. Not recommended for thicknesses exceeding this.
Reclamation of over-treated parts (chemically cleaned).	All aluminium alloys.	Very suitable.	Only slight wire brushing is required.
Treatment of material not amenable to chemical cleaning. (Dirty stock, etc.)	Particularly aluminium coated alloys.	Very suitable.	No other method suitable.

The advantages of scratch-brushing are :—

(1) Very low initial outlay cost.

(2) Obviates the cleaning of large surface areas since any part can be treated without subjecting the entire surface to the treatment.

(3) Under proper control can give excellent low contact resistance surface.

The disadvantages are obvious—great care and close supervision and inspection are required to obtain satisfactory results, and the labour cost is very high. Scratch-brushing can only be recommended for small scale production work in which the process can be easily controlled.

Chemical Methods of Oxide Removal.

A large number of reagents have been recommended and used from time to time, but only a few have proved their worth in practice. The reagents at present employed in this country are—chromo-sulphuric acid pickle, R.A.E. bath D, phosphoric acid pickle and, to a lesser extent, hydrofluoric acid paste etch. Descriptions of most of these methods have appeared in the literature from time to time, and will not be repeated. A description of the phosphoric acid pickle is included as this method has been developed only recently, and would appear to be the most satisfactory pickle to date. Recently, however, a proprietary solution known as Aloclene has received very favourable reports from the aircraft industry. This solution is non-critical and is operated at room temperature.

A summary of various reagents and methods of treatment are given in Table 2.

It is convenient to discuss the requirements of an ideal reagent and to consider how far these are satisfied by the reagents used in the British aircraft industry. The requirements are :—

(1) The solution must be of a simple composition composed of readily obtainable materials and must not endanger the health of the operators, e.g., there should be no obnoxious fumes.

(2) There must be a reasonable tolerance in the operating conditions and the time of treatment must be reasonably short, i.e., the composition, temperature, and time of treatment must not be critical.

(3) Room temperature is the ideal operating temperature.

(4) The solution must be capable of easy control.

(5) The solution must produce consistently and uniformly a low resistance surface.

Solutions used at room temperature are doubly advantageous, since heating coils are not only dispensed with, but there is less danger from harmful fumes or vapours. The most important reagents used in this country, although not necessarily the most widely used, are chromo-sulphuric acid and phosphoric acid plus a wetting agent.

TABLE 2.

Data on various Chemical Reagents used for Oxide removal.

Reagent.	Composition.	Operating Temperature	Time of Treatment (according to gauge.)	Materials used.	Remarks.	Suitability.
1 Hydrofluoric paste etch.	Water, 1 gall. Gum Tragacanth, 6 oz. Denatured Alcohol, 14 oz. H.F. Acid, 1¼ lbs.	Room	1—5 minutes	Alclad, Dural D.T.D. 213	Surfaces well washed in running water after treatment. Uncoated alloys (not D.T.D. 213) must be treated with HNO_3 to remove black deposit.	Poor consistency.
2 H.F. acid solutions.	H.F. (48% conc.) 1% (by volume).	Room	20—60 seconds	Alclad, Dural D.T.D. 213.	Extremely critical solution as regards time of treatment. Uncoated alloys require subsequent treatment with HNO_3.	Gives erratic results.
3 Sulphuric Acid and Sodium Fluoride R.A.E. Bath D.	H_2SO_4, 10% (by volume) NaF, 1% (by weight).	Room	About 5—10 minutes.	Alclad, Dural D.T.D. 213.	Uncoated alloys require HNO_3 treatment to remove black deposit.	Better than 1 or 2, but still poor.
4 Chromo-Sulphuric Acid Pickle.	H_2SO_4, 15% (by volume) Cr_2O_3, 5% (by weight) (Lead lined tank).	55-60° C.	30—45 minutes	Alclad, Dural D.T.D. 213.	Not critical as regards time of treatment. Temperature should be carefully controlled within range 55-60° C. No HNO_3 treatment required with uncoated duralumin alloys.	Good all-round pickle. Time of treatment too long.
5 Phosphoric Acid and Wetting Agent.	H_3PO_4, 5% (by volume) Fixinol C., 0.5% (lead lined tank).	40° C.	5—10 minutes	Alclad, Dural D.T.D. 213.	Composition and time of treatment not critical. Dural type uncoated alloys require flash dip in 50/50 HNO_3 to remove deposits.	Very good reagent, particularly for Alclad.
6 Sulphuric Acid and Wetting Agent.	H_2SO_4, 1% (by volume) Wetting agent (e.g., Nacconal N.R., 2 gms/litre).	90° C.	5—15 minutes	Alclad, Dural	Not a critical reagent. Has reasonably wide operating range. Developed in U.S.A. Grey deposit produced on Dural, removed either by wiping or HNO_3 (25% conc.).	Good reagent for Alclad and Dural.
7 Nitric Acid.	HNO_3, 2% (by volume)	85-90° C.	10—15 minutes	Alclad or Dural.	Not a critical reagent. Excellent for Dural.	Good.

Hydrofluoric Acid Paste Etch.

This reagent is not recommended, since consistent results are difficult to obtain. It is significant that firms using this method only treat the surfaces in contact with the electrodes, and leave the interfacial surfaces untreated. The method is used from the point of view of convenience only, even to the detriment of weld quality. H.F. paste etch should be made up immediately before use. Obnoxious fumes and the irritant nature of the paste also endanger the workers' health. Solutions of hydrofluoric acid used at room temperature (1-3%), are also very unsuitable, since they are very critical in action and require a very accurate control of treatment time.

R.A.E. Bath D.

This reagent is also used at room temperature, has a relatively short time of treatment (10 minutes), but tends to be rather critical though somewhat less so than the straight H.F. solutions.

Chromo-Sulphuric Acid.

This is perhaps the most widely used reagent for surface preparation, but it is by no means ideal. In fact, it is probably true to say that its recommendation as a cleaner for preparing surfaces for painting and spot welding (D.T.D.915A), has probably resulted in its widespread use in spot welding in order to avoid duplication of pickling tanks. It is not a critical reagent and can be used for both duralumin and Alclad. The main disadvantages are :—

(1) High operating temperature, 55-60° C.

(2) Relatively long time of treatment, $\frac{1}{2}$-$\frac{3}{4}$ hour.

(3) Efficiency of pickle is affected adversely by presence of soluble ferric salts.

Phosphoric Acid and Wetting Agent.

Phosphoric acid solutions may be used at room temperatures or heated, depending upon the concentration of the solution and the time of treatment required. Solutions of about 30-40% concentration contained in lead-lined baths may be used at room temperatures. With such solutions, the time of treatment for 16-20 S.W.G. Alclad is approximately 30 minutes. For treatment at 40° C. solutions of 5-10% concentration have been found satisfactory. The 5% solution gives best results with relatively thin gauge material, i.e., 24-16 S.W.G. sheet. The time of treatment with this solution is from 10-15 minutes. For duralumin type alloys, a flash dip in 50/50 nitric acid is required to remove black deposits. All phosphoric acid solutions, whether used hot or cold, should contain small amounts of suitable wetting agents (e.g., 0.1-0.2%). Various agents are suitable for use at room temperature, but with heated solutions, reagents used should be stable at high temperatures and not hydrolyse easily. Fixinol C is an agent of this kind.

The advantages of the 5-10% solution used at 40° C. appear to be the very uncritical nature of the solution, as regards composition, time of treatment, temperature, etc. Danger from over-treatment is slight, and the surface resistance remains constant over a wide range of time of treatment.

Table 3 gives suitable pickles for materials commonly used in the British Aircraft Industry.

TABLE 3.

Suitable Pickles for various Aluminium Alloys.

Material.	Pickle.	Remarks.
Aluminium coated duralumin (D.T.D. 390, B.S.S. 2L38). and D.T.D. 213 Al.-Mn. alloy ($1\frac{1}{2}\%$ Mn.).	Chromo-sulphuric acid.	All are good. The second is probably the best from point of view of consistency and time of treatment.
	Phosphoric acid and wetting agent.	
	Sulphuric acid and wetting agent.	
Duralumin (B.S.S. 5L3).	Chromo-sulphuric acid.	
	Phosphoric acid and wetting agent.	20-30 secs. dip in 50/50 nitric acid is required to remove black deposit.
	Sulphuric acid and wetting agent.	
	Nitric acid.	

Drying and Storing Material after Pickling.

After pickling, it is important to remove the pickle completely by efficient washing and rapid drying. Washing is generally carried out, first in a cold water tank fitted with a continuous water supply and overflow, and then in a hot water tank.

It is advisable not to have this tank at too high a temperature, and to complete the drying by means of hot air in another tank, e.g., 10-20 seconds dip at 60° C. followed by air blast. Higher temperatures than this may be used if the material is merely flash dipped. Water which is allowed to dry slowly on material may produce water stains having a fairly high contact resistance. Steam distillate, or rain water, is recommended for final washing to prevent the deposit of salts upon the surface on drying. There appears to be a considerable diversion of opinion as to the maximum period that may elapse between treatment and welding, and times from 12 hours to 7 days have been advocated. Since the actual re-oxidation of aluminium in air is a very slow process, and the film cannot possibly grow to its original thickness, there should be no reason why scratch-brushed or chemically treated material should not be stored for long periods, provided the air is cool, clean and dry and there is no undue handling of material.

Sheets should not be stored for long periods in the presence of water, i.e., sheets after degreasing or chemical treatment should not be packed together while wet, since corrosive attack may take place, impairing the spot weldability of the material.

Control of Pickling.

It has already been stated that the ideal pickle is one which is not critical with regard to composition, operating temperature, and time of treatment. Unfortunately, few pickles are entirely satisfactory in all three respects, and a close control of all variables has to be made. Control of temperature and time offers no difficulties. Frequent analysis of the pickle should be made, and additions made to the solution to maintain it as closely as possible to the original composition. In order to minimise the frequency of analysis, a determination of the surface contact resistance of the treated material affords a simple, but most effective, means for controlling the pickling operation. A certain maximum resistance may be determined above which sub-standard welds (surface heating, electrode pick up, etc.), will be obtained, and below which the welds will be acceptable. Analysis of the solution need only then be carried out when the surface contact resistance exceeds this predetermined value.

In addition to controlling the actual pickling operation, care must be taken that sheets are properly degreased and all traces of alkali degreasing agents removed by adequate washing before pickling. If possible, the material should always be dried after alkali degreasing and prior to pickling. Exception to this may be made when there is no delay between degreasing and pickling. It seems hardly necessary to add that precautions must be taken to prevent contamination of cleaned material from excessive handling with bare hands, e.g., operators and assemblers should wear cotton gloves.

Schemes for Surface Preparation.

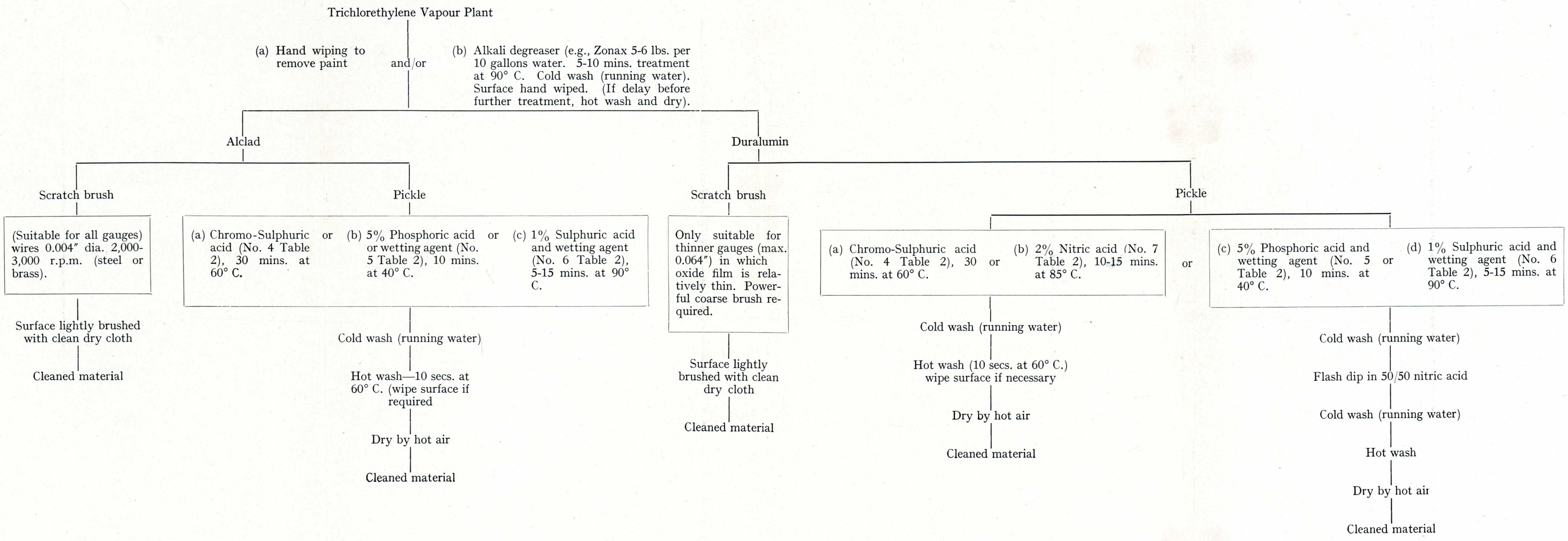
Suggested schemes for cleaning Alclad and duralumin are given in the chart opposite. Many variations are possible, depending on the surface condition of the material and degree of control required. The schemes given will be found to be generally applicable to coated and uncoated aluminium alloys.

ELECTRODES.

Electrode Materials.

The main requirements of an electrode material for light alloy spot welding are, that it should possess the maximum conductivity compatible with high resistance to deformation, and the minimum tendency to alloy with the material being spot welded.

The most common electrode material in use in this country is cold drawn high conductivity copper, which has a conductivity of about 98-100%, that of the I.A.C. Standard. Unfortunately, it anneals at low temperature, so that any heat development at the tip is likely to produce appreciable softening and mushrooming of the tip after a short time. Many electrode materials have consequently been developed containing small additions of alloying elements to raise the recrystallisation temperature, and thereby increase resistance to deformation at high temperature. Small additions of cadmium, silver, and chromium do not reduce the conductivity a great deal, although greatly improving deformation resistance. Unfortunately, most alloy electrode materials tend to " pick-up " more



Suggested schemes for cleaning of Alclad and Duralumin.

readily than H.C. electrolytic copper, so that the deformation strength improvement may be offset by the increased number of tip cleanings. Many high strength proprietary alloys are on the market, which are satisfactory for use under severe operating conditions. The conductivity of such materials is not less than 85% that of the I.A.C. Standard.

The use of H.C. copper is recommended for light alloy spot welding. Under severe working conditions in which heat development at the tip is excessive, it may be advisable to use a reliable and fully tested alloy material, in order to obtain increased electrode life. Improved life for any material is obtained by efficient cooling of the tip to maintain the tip face at a low temperature. A recent development in this direction has been the use of refrigerant cooling of electrodes, a method which is discussed in another chapter.

Types of Electrode.

Electrodes are generally of a circular cross section from about $\frac{5}{8}''$-$1\frac{1}{2}''$ in diameter, and may be of the male or female type. The former fits into a socket of the electrode holder (Fig. 106), and the latter fits over a projection or spigot from the holder (Fig. 107). The male type is commonly about $\frac{5}{8}''$-1″ in diameter and the female about $1\frac{1}{2}''$.

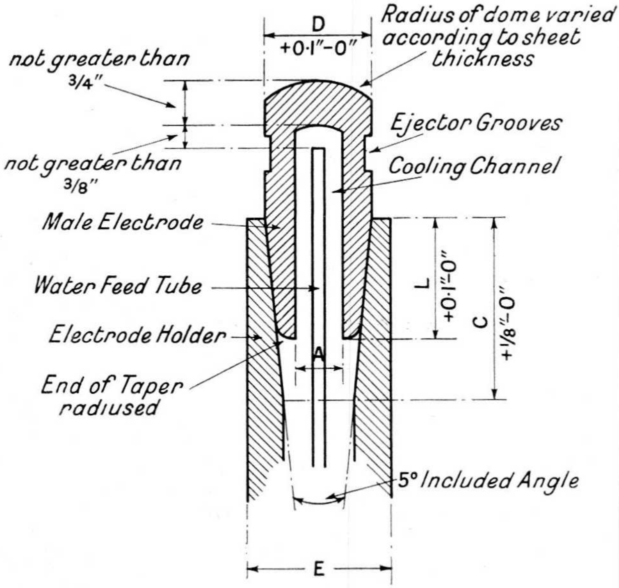


Fig. 106.

It is not generally recognised that definite requirements have been laid down in B.S.S. 807, regarding the form and dimensions of the electrode holder socket and spigot. Because of this, the more important items in this specification (issued in 1938), have been included. The two types of electrodes are shown diagrammatically in Fig. 106 and Fig. 107, in which the various dimensions have been identified. The standard dimensions are given in Tables 4 and 5, and relate to both types of electrodes.

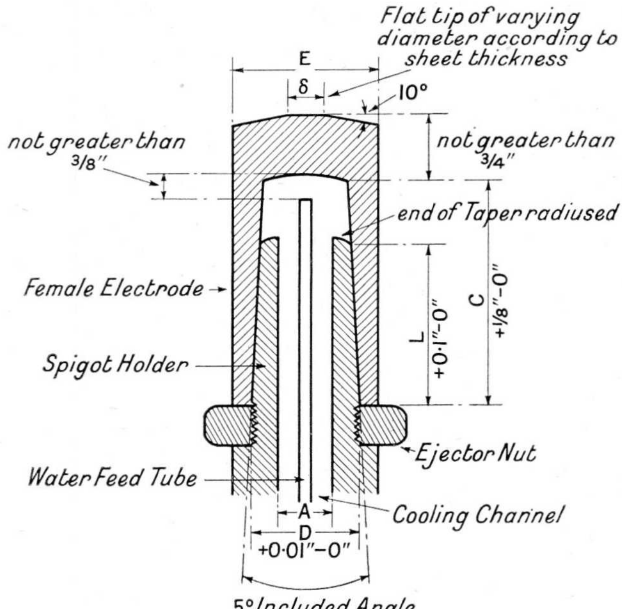


Fig. 107.

TABLE 4.

Dimensions for Male Electrode Shanks and Spigot (for Female Electrode).

Normal size of electrode (ins.)	Basic diameter (ins.) D.	Minimum length of taper (ins.).		Cooling hole diameter (in.). A.	Radius at end of tapes (in.). R.
		For straight thrust ($1\frac{1}{4} \times D$) L.	For eccentric loading ($2 \times D$) L.		
$\frac{1}{2}$	0.500	$\frac{5}{8}$	1	$\frac{1}{4}$	$\frac{1}{16}$
$\frac{3}{4}$	0.750	$\frac{15}{16}$	$1\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{32}$
1	1.00	$1\frac{1}{4}$	2	$\frac{1}{2}$	$\frac{1}{8}$
$1\frac{1}{4}$	1.25	$1\frac{9}{16}$	$2\frac{1}{2}$	$\frac{5}{8}$	$\frac{1}{8}$

TABLE 5.

Dimensions for Sockets of Electrode Holder (Male Type Electrode) and Female Electrode Socket.

Nominal size of electrode (ins.)	Diameter at large end (in.) D.	Depth of Taper (ins.) ($2\ D \times 0.5''$) C.	Recommended overall diameter for female electrode. E.
$\frac{1}{2}$	0.5	$1\frac{1}{2}$	$\frac{7}{8}$
$\frac{3}{4}$	0.75	2	$1\frac{3}{16}$
1	1.00	$2\frac{1}{2}$	$1\frac{1}{2}$
$1\frac{1}{4}$	1.25	3	2

The size of an electrode, for the purpose of the specification, has been defined as the diameter at the large end of the taper of the shank. From Fig. 106 and Fig. 107 this is seen to represent the overall diameter of this male electrode, and the maximum diameter of the socket in the female electrode. As this interpretation is not entirely satisfactory from the point of view of the female electrode, an additional column, not given in the specification, has been included in Table 5 giving the recommended overall diameter for female electrodes (column E). This diameter is equivalent to the overall electrode holder diameter for the male electrode. (See Figs. 106 and 107).

In recent years there has been a tendency to favour the use of square section female type electrodes, particularly with condenser discharge machines. These square section electrodes are generally from $1\frac{1}{4}''$ to $1\frac{3}{4}''$ side, and enable relatively larger cooling channels to be used as compared with circular section electrodes of equivalent diameter, i.e., diameter = side of square. The straight edge of the square type electrode is very helpful in locating welds in a section-to-sheet joint. An offset square section tip, with the tip on a diagonal of the square, is used for locating welds in inaccessible corners (Fig. 108).

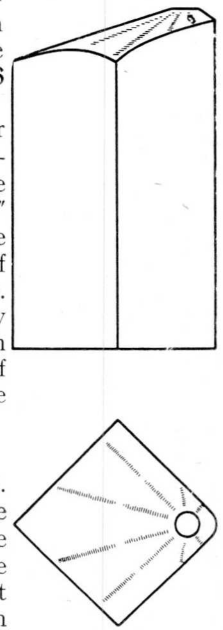


Fig. 103.

Cooling of Electrodes.

The diameter of the cooling channel given in B.S.S. 807 (Table 4), should be adhered to rigidly. It should be noted that this dimension relates to the diameter of the socket in the male electrode (Fig. 106), and for the female type to the diameter of the socket in the spigot or holder (Fig. 107). The cooling water should approach to within $\frac{1}{2}$-$\frac{3}{4}''$ of the tip face to ensure high cooling efficiency. Similarly, the feed tube should terminate at a distance not greater than $\frac{3}{8}''$ from the end of the cooling channel, in order to prevent the formation of steam pockets at this point. Considerable difference of opinion exists as to the rate of water flow for efficient cooling, and figures from 0.5 to 2.0 gallons per minute have been advocated (pressure of supply 25 lbs./sq. in.). It will be appreciated that there is a greater need for efficient cooling with A.C. than with D.C. machines, because of the inherently short welding times of the latter type. With female electrodes of $1\frac{1}{2}''$ overall diameter (Table 5), a flow of 0.5 gallons per minute is adequate for D.C. machines. For A.C. machines, the corresponding rate will be about 1.0 gallon per minute.

Offset and Special Electrodes.

Straight thrust electrodes (i.e., electrodes which are symmetrically disposed about the same axis as in Fig. 106-107), should be used whenever possible. However, the nature of the work being welded often requires the use of eccentric or offset electrodes, particularly when welding sections with narrow flanges as shown in Fig. 109. In such cases, the minimum offset must be used to restrict eccentric loading and to provide maximum copper surrounding the tip. Narrow " top-hat " sections, as well as sections with narrow flanges, may be welded using straight thrust electrodes. The cooling of such electrodes (Fig. 110), is likely to be inefficient and frequent attention will have to be paid to the condition of the tip.

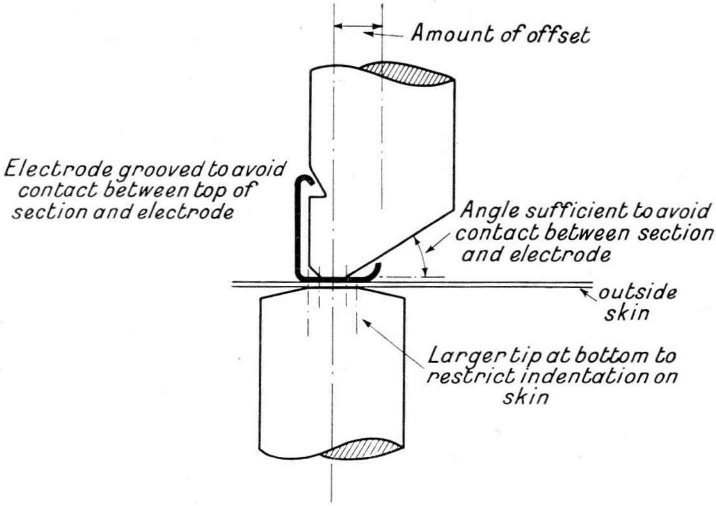


Fig. 109.

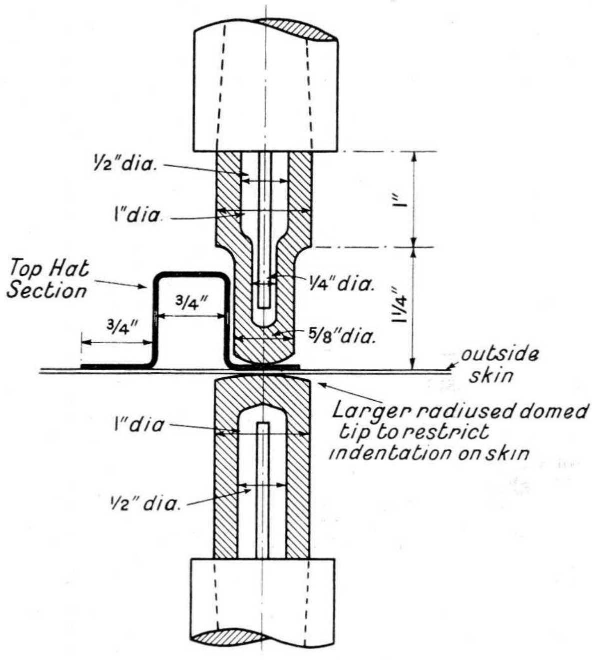


Fig. 110

As a rule electrodes may not be permitted to touch adjacent sections, otherwise shunting may occur through the section, depending on the relative resistance of the direct and indirect current path. (For instance, the side of the electrode in Fig. 109 may touch the side of the stiffener and tend to stick to the stiffener.) In many cases, however, no difficulties are experienced, and any tendency to shunt can easily be counteracted by adjustment to machine settings if required.

Attempts to reduce the amount of copper used, by fitting replaceable electrode tips screwed or brazed into the electrode shank do not give satisfactory service. This practice is strongly condemned, since it only introduces additional contact surfaces and thereby reduces the efficiency of the electrode.

Electrode Contour.

The shape of the tip face in contact with the material being welded is known as the electrode contour. Electrode tips may be either of the domed (Fig. 106), or truncated cone type (Fig. 107).

Domed Electrodes.

These are generally from 2 ins. to 5 ins. radius, the radius being varied according to the thickness of the sheet as in Table 6.

TABLE 6.

Recommended Domed Electrode Contours.

Gauge thickness S.W.G.	Radius of Electrode (ins.)
26–24	2
22–18	2
16–12	4
10– 8	5

TABLE 7.

Recommended Truncated Cone Flat Tip Diameters.

Gauge Thickness S.W.G.	Minimum Diameter (ins.)
26	$\frac{1}{8}$
24–22	$\frac{5}{32}$
20–18	$\frac{3}{16}$
16	$\frac{7}{32}$
14–12	$\frac{1}{4}$
10– 8	$\frac{5}{16}$

Truncated Cone Electrodes.

Truncated cone electrodes of 120° included angle were formerly used, but have now been replaced by electrodes of 150-165° included angle. With these electrodes, the diameter of the flat tip should be varied in accordance with the thickness of the sheet. Suitable minimum electrode flat tip diameter are given in Table 7.

Pick-up and Mushrooming of Electrodes.

As the number of welds made during a production run increases, there is an increasing tendency for the aluminium to alloy with the copper and form a thin film over the tip of the electrode. As the contamination of the electrode by this means increases, correspondingly greater heat is produced at the electrode to sheet contact, and the work eventually sticks to the electrode. Welds made with badly contaminated electrodes show excessive surface heating with 100% penetration and may be severely cracked. Frequent cleaning is thus required to remove the film and prevent sticking of the work to the electrode.

The time at which pick-up occurs depends upon many factors, the most important being, efficiency of cooling of electrodes, electrode material, machine settings, surface conditions, type of machine and speed of welding. Any factor tending to give overheating of the weld and particularly of the sheet-to-electrode contact will give premature pick-up. Recently, a considerable improvement in electrode performance with A.C. machines has been obtained, by the use of refrigerant cooling of the electrodes under carefully controlled conditions. Refrigerant cooling maintains the electrode tip face at a temperature much below that possible with water cooling. There are many difficulties to be avoided, such as moisture condensation on the tip and corrosion by the refrigerating solution. Specially designed electrodes must be used. With D.C. machines, with their very short welding cycle, there is less tendency to pick-up, and a greater number of welds may normally be made before cleaning becomes necessary. No great need for refrigerant cooling has arisen with D.C. machines, although it is to be expected that the method of cooling will be useful when welding very thick material, for which longer welding cycles will be required.

It is impossible to prescribe precisely how many welds may be made before cleaning is necessary, because of the great number of factors affecting this. Operators, or other authorised persons, must be instructed to clean electrodes immediately any sticking is detected.

Deformation of electrodes also occurs during continual operation, resulting in an increase in the diameter of the flat tip on the truncated cone, and in the formation of a flat on a domed electrode which also progressively increases in size. An increase in diameter of the flat tip produces a corresponding reduction in the current density. Weld strength will suffer a corresponding reduction and sub-standard welds will eventually be obtained. The reduction in current density may, in fact, become so great that no welds are formed. For a given setting the permissible increase in diameter must be determined. It is impossible to prescribe definitely what this increase may be, since it will depend upon the standards of weld quality required. It should, however, rarely exceed 10%. Similarly, the diameter of the flat, which forms on a domed electrode, should not be allowed to exceed the corresponding flat tip diameter (Table 7) by more than about 10%. Rather than measure the actual diameter, it is often preferable to replace electrodes after a given number of welds have been made or after a given time.

Tip Maintenance.

Responsibility for changing electrodes should not be in the hands of the operator, but another person should be appointed to supervise electrode replacements and cleaning. Resizing of electrodes should always be carried out on a lathe and not with a file as, unfortunately, so often happens. Electrode dimensions should be fully specified on drawings, so that the maintenance department can always resize the electrode to the standard dimensions required.

All electrodes should be examined to ensure that the contacting surface (of the shank for the male electrode and the socket for the female) is smooth and free from grease or dirt. Oil on the shank may facilitate the removal of firmly seated electrodes, but it also attracts dirt and other undesirable matter. On this point, B.S.S. 807 requires the surface of the shank or socket to be smooth and of such contour that, when tested with marking, the test gauge will leave a print over the whole area.

WELD QUALITY.

Standards of Weld Quality.

One of the biggest drawbacks to the development of light alloy spot welding, was the absence of any agreement on the optimum properties and quality of spot welds in material of given thickness and composition. Even to-day it is still impossible to say whether an optimum size of weld exists, although there is reason to believe that very large welds may have relatively poor fatigue strength, the welds being satisfactory in other respects.

In spite of this lack of information, weld quality should be standardised, since by this means only can the production of improved spot welds be assured. Attention is drawn to the excellent publication of the American Welding Society, "Tentative Standards and Recommended Practices and Procedures for the Spot Welding of Light Alloys," in which standards have been recognised and correlated with technique. The reader is strongly advised to read this report with care, and assimilate the information and advice contained therein.

The requirements of weld quality are based upon :—

(1) The average weld strength obtained in a series of welds, the strength being determined by a standard shear strength test.

(2) The consistency of weld strength which is a measure of the stability of the process and the control exercised.

(3) The general metallurgical characteristics of the welds, e.g., penetration of weld, presence or not of cracks, porosity, surface burning, etc.

(1) Average Weld Strength.

A very wide range of strength has been recommended by the A.W.S. for material up to about 10 S.W.G. in thickness. The upper limit of this range for material thicker than 16 S.W.G. can only be obtained in this country by certain heavy duty A.C. and condenser discharge welders. Table 8 gives the average strengths obtainable with British machines and technique, compared with the recommended American range.

This table clearly shows that British equipment can weld work to the A.W.S. minimum strength requirements for sheet up to and including 16 S.W.G., and that certain high capacity machines can satisfactorily weld material up to 10 S.W.G. in thickness. A word of warning must be made here in relation to the production of large spot welds. As most British machines cannot work to the upper strength limit, average spot weld strengths too near the limit imposed by the machine capacity must not be chosen. It is well known that welds made towards the maximum capacity of a given machine are made under inherently unstable conditions, and possess very poor strength consistency. Under such conditions, it is difficult to adjust welding technique and control sufficiently to improve consistency. There is also the very real danger of producing badly cracked and porous welds, particularly in heavy gauge sheet.

TABLE 8.

Average Shear Strengths of High Strength Light Alloy (D.T.D. 390, B.S.S. 5L3, etc.) Spot Welds.

Gauge Thickness S.W.G.	Range Recommended by A.W.S. (lbs.)	Average strengths (lbs.).		
		Heavy duty A.C. Welders	Large capacity condenser discharge machines.	Medium capacity stored energy machines.
10	2,160–2,850	—	2,300	—
12	1,790–2,520	1,400	2,000	—
14	1,280–2,050	1,350	1,700	—
16	860–1,500	1,100	1,400	800
18	550– 990	700	840	630
20	380– 670	550	640	500
22	270– 500	420	460	380
24	200– 390	300	340	260
26	160– 310	250	270	220
28	130– 260	160	200	150

Standardisation of strength consistency and metallurgical characteristics of the weld, in conjunction with shear strength, thus prevent thicknesses being welded beyond the limit imposed by machine capacity. It is recommended that average strengths to be worked to in British practice should not exceed the appropriate values given in Table 8, since it is preferable to produce welds of acceptable strength and good consistency, than welds which may have higher strength but be otherwise unacceptable.

Details of a suitable shear strength specimen for production control are given in a subsequent section.

(2) **Weld Consistency.**

Too much emphasis has been placed, in the past, on the determination of shear strength by a simple production control test piece as a criterion of spot weld quality, and there has been no insistence on the carrying out of consistency tests from the point of view of strength or metallurgical quality. The adoption of standards covering all these points by the A.W.S. is a noteworthy achievement, and it is to be hoped that British spot welding will soon be covered by a similar code of practice.

The test recommended in America requires the placing of 25 spot welds, at a given spacing, in a simple lapped joint. These welds are cut from the seam and tested singly. The consistency is deemed satisfactory, if for 21 of the welds the strength variation does not exceed 10%, and for the remaining 4 does not exceed 20% of the total average strength.

Under production conditions it is recommended that the technique should be such, that the variation in strength will not exceed 20% of the average weld strength. In this country, weld strengths are generally determined by production control test pieces, in which two or three welds are made and one or two welds tested in shear. Periodic examination of these test results should be undertaken, to ensure that the general consistency is acceptable.

(3) **Metallurgical Examination.**

Metallurgical examination must be carried out periodically and the following points noted :—

(1) Presence of cracks and porosity.

Cracks and holes in welds should preferably be entirely absent. No data is available, however, to show that the presence of small cracks or holes is deleterious. Welds must be condemned if cracks extend beyond the weld metal and holes exceed in diameter 20% of the sheet thickness.

(2) Weld Penetration.

This should be preferably from 50-65% of the total thickness, and should never be less than 20% or greater than 90%.

These are the most important points, but the examination will also reveal whether there has been any harmful surface burning, whether indentation has been heavy, and whether this has caused marked separation of the sheets. Shear consistency tests should always be undertaken in conjunction with metallurgical examination, when determining the suitability of machine settings. Photomacrographs of satisfactory welds in 24 to 16 S.W.G. sheet, welded by means of a condenser discharge machine, are given in Fig. 111.

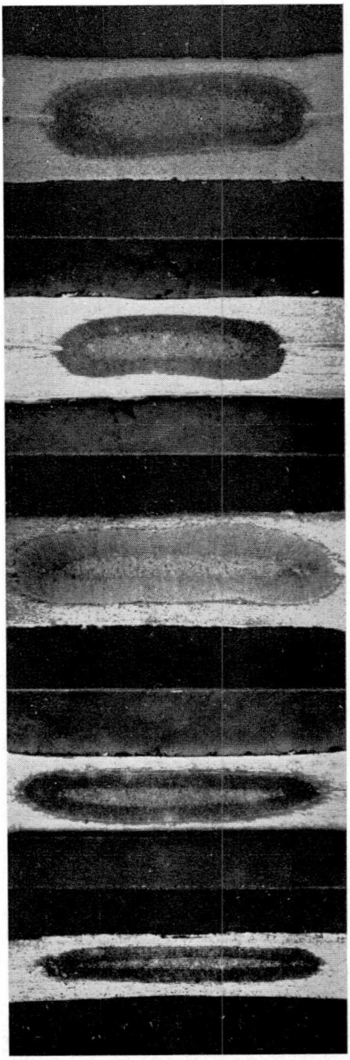


Fig. 111.

Suitable Machine Settings.

It is impossible to give specific machine settings for welding material of a given thickness, because of the individual machine characteristics and the peculiarities of a particular job. The method of surface preparation adopted will greatly affect the machine settings according to the surface contact resistance. Thus, settings for a scratch brushed surface may be suitable for a surface cleaned by phosphoric acid pickle, which gives a very low resistance, but entirely unsuitable for use with material prepared by the chromo-sulphuric acid pickle.

Settings, which may be found useful as a starting point in determining the optimum settings for a given job, are given in Tables 9, 10, and 11 for a conventional A.C. machine, small capacity stored energy inductance welder and condenser discharge welder, respectively. The settings relate to Alclad D.T.D. 390, prepared by paste etch on outside surfaces only for A.C. welder, and chromo-sulphuric acid pickle for the inductance welder and condenser discharge machine.

TABLE 9.

Machine Settings for A.C. Welder.

Gauge Thickness S.W.G.	Pressure (lbs.).		Welding Current amps.	Time cycles.		Post heat current amps.
	Weld	Forge		Weld	Post heat	
24	450	900	18,000	3	12	8,000
22	600	1,200	20,000	4	14	8,000
20	600	1,200	22,000	5	25	8,000
18	700	1,400	25,000	6	25	8,000
16	850	1,700	30,000	8	30	12,000
14	1,000	2,000	33,000	10	30	12,000
12	1,200	2,400	36,000	14	30	15,000
10	1,400	2,800	42,000	18	30	15,000

Electrodes : Domed contour according to Table 6.

TABLE 10.

Machine Settings for Inductance Welder.

Gauge Thickness	Approx. Welding Pressure (lbs.).		Maximum Current Relay Primary amps.	Left Hand Gauge	Right Hand Gauge
	Weld	Recompression			
24	250	870	175	33	35
22	250	870	195	33	35
20	310	1,000	220	40	41
18	420	1,500	300	55	56

Electrodes : Truncated cone—Contour according to Table 7.

TABLE 11.

Machine Settings for High Capacity Condenser Discharge Welder.

Gauge Thickness	Welding Transformer Turns Ratio	Condenser Charging Voltage	Rectifier Transformer Tapping	Pressure (lbs.)		Capacity mfd.
				Weld	Forge	
24	100	270	Min. 4	600	1,200	30,000
22	100	300	Min. 5	750	1,200	30,000
20	100	360	Mid. 2	900	1,600	30,000
18	100	410	Mid. 5	1,000	1,600	30,000
16	100	450	Max. 2	1,100	1,800	30,000
14	100	475	Max. 3	1,300	1,800	30,000
12	100	475	Max. 3	1,600	2,200	60,000
10	100	475	Max. 3	2,000	3,000	90,000

Electrodes : Truncated cone (included angle 160°). Diameter of flat tip varied in accordance with Table 7.

COMMON FAULTS IN SPOT WELDING.

Poor Strength Welds.

Poor strength welds may result from a combination of various factors, the most important of which are :—

(1) Current too low.

(2) Weld pressure too high.

(3) Misalignment of electrode tips, producing irregular shaped welds.

It is apparent that the sub-standard welds are produced from an insufficient energy input ; increasing the current is likely to be the most effective remedy. It may happen, however, that splashing from both the sheets may occur, before the requisite weld strength has been obtained. Increasing the electrode pressure will prevent splashing, and if it is found that under these conditions the weld is still of insufficient strength, the electrode diameter, electrode pressure, and probably the current, will require a further increase. It should be noted, that increasing the time of welding does not have such a great effect on weld strength as increasing the current. Tip misalignment (Fig. 112) will be indicated by the irregular and uneven electrode indentation on the surface and by surface heating. If this condition is observed, the electrodes should be immediately replaced and the misaligned tips returned for re-sizing.

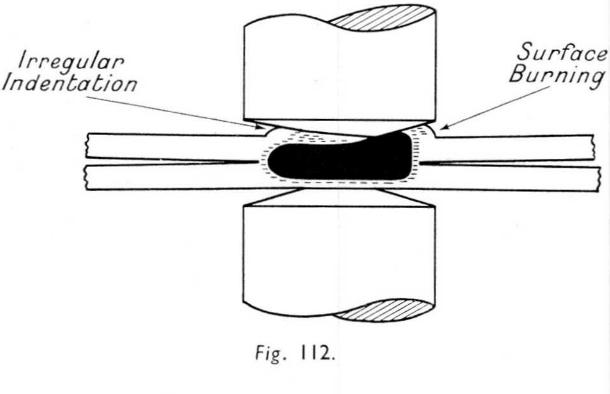


Fig. 112.

Irregular Shaped Welds.

This may be caused by :—

(1) Tip misalignment (see previous paragraph).

(2) Improper surface preparation.

High surface contact resistance always produces an irregular heat distribution. Other things being equal, the lower the contact resistance the more uniform the weld shape. It has often been stated, that an appreciable variation in contact resistance does not materially affect the average strength or consistency of spot welds made under the same machine settings. This may be true within limits, but there is always an effect on the shape of the weld. Irregular shaped welds have poor fatigue strength.

Surface Burning.

Any factor, which affects the energy input to the weld and the surface contact resistance, may be responsible for surface burning. The most important factors are :—

(1) Improper surface preparation whereby the material has too high a contact resistance.

(2) Badly cleaned electrodes, i.e., electrodes from which " pick-up " has not been removed.

(3) Misaligned electrode tips, giving excessive local current concentration.

(4) High current.

Badly burned welds show 100% penetration in one or both of the sheets (Fig. 113), and are invariably cracked and porous. Burned welds are easily distinguished by their black discoloured surface.

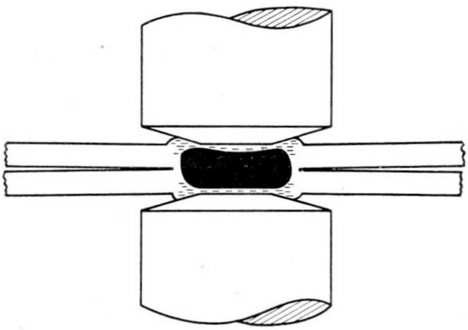


Fig. 113.

Heavy Indentation.

This may result from :—

(1) Sharp electrode contour, i.e., the use of electrodes of too small a radius or too small included cone angle (Fig. 114).

(2) Excessive energy input to weld with marked collapse of the material surrounding the weld under pressure of the electrodes, and usually associated with interfacial splashing between the sheets, i.e., expulsion of weld metal and sheet separation (Fig. 115).

(3) High electrode pressure.

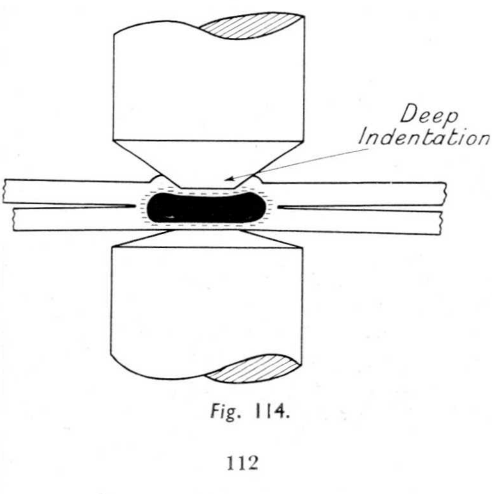


Fig. 114.

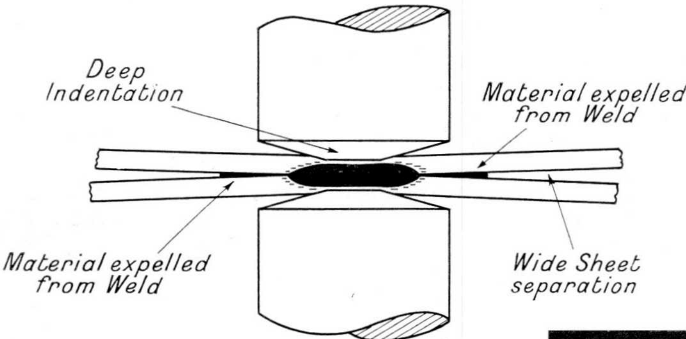
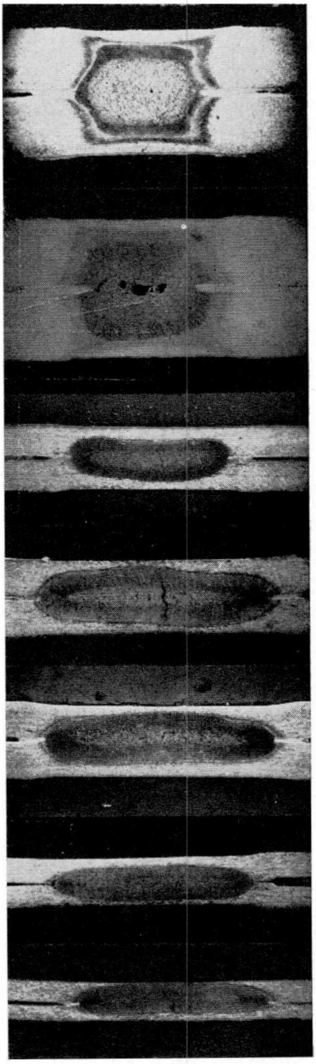


Fig. 115.

Fig. 116.



It is interesting to note that the electrode pressure may be so low, that the electrodes do not offer sufficient restraining force to the weld while it is growing, and the expanding metal bursts out between the sheets. In this instance, increasing the pressure will provide an adequate restraining force to prevent the splashing, and thereby restrict the indentation. If the pressure is further increased beyond the value necessary to stop splashing, the indentation will increase in proportion to the additional pressure increase.

In Fig. 116 photographs are given of weld cross-sections, which show most of the undesirable factors of weld quality to be avoided. Photomacrographs of suitable welds in several gauge thicknesses are given in Fig. 111.

Effect of Electrode Contour in the Welding of Sheets of Similar or Dissimilar Thickness.

Electrode contour is the most effective means of controlling the penetration of the weld and the distribution of indentation between both sheets, whether of similar or dissimilar thickness. It is often necessary to weld a certain sheet combination, so that one side is entirely free from indentation, or so that the indentation is so slight as to be considered negligible. This may be achieved by the use of electrodes of different contour, e.g., a flat electrode placed in contact with the surface in which indentation is not required, will cause all the indentation to be taken by the other sheet. It is usually not necessary to use a completely flat electrode, but for truncated cone electrodes, an electrode of greater tip diameter in contact with the requisite sheet will suffice; and for domed electrodes, an electrode of greater radius.

Similar Thickness Sheets.

With sheets which are of the same composition and thickness, a deeper weld penetration occurs in the sheet in contact with the smaller or more sharply contoured of two electrodes (Fig. 117). This is caused by the relatively greater current density in the vicinity of the sharper electrode. If the material differs in composition, the weld penetration will depend not only upon the electrode contour, but upon the relative specific resistances of the materials, e.g., when welding Alclad D.T.D. 390 to commercial aluminium of the same thickness and with electrodes of the same contour, the penetration is considerably greater in the Alclad, because of the greater resistance of this material (Fig. 118). If, in this instance, both sheets were Alclad, penetration would be similar in each sheet (Fig. 119).

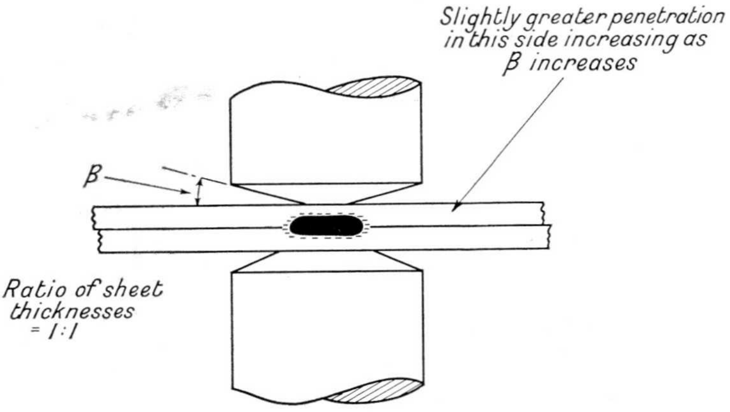


Fig. 117.

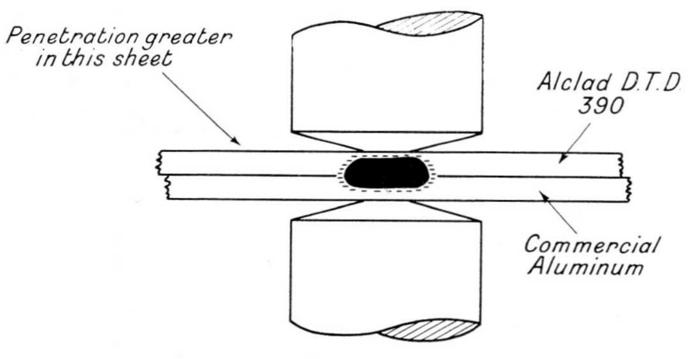


Fig. 118.

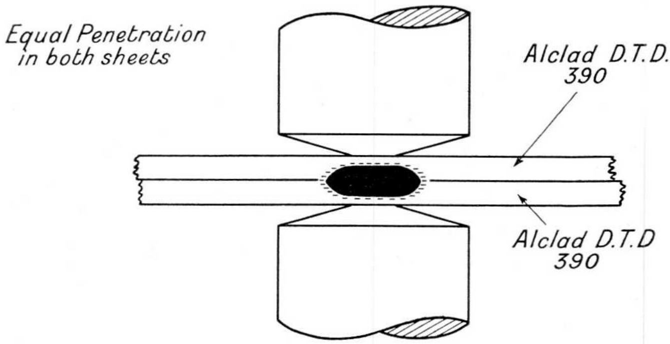


Fig. 119.

Dissimilar Thickness Sheets.

With dissimilar thickness sheets and electrodes of the same contour, the penetration is always greater in the sheet of highest resistance, whether this resistance be due to difference in thickness or difference in material composition, e.g., compare Figs. 120-121 with Fig. 118. If electrodes of different contour are used, the tendency for the weld to be formed in the thicker material may be offset by an increased current density in the thinner sheet (Fig. 122). If one surface is required to be smooth in the welding of dissimilar thicknesses, the ratio of thicknesses must not be greater than about $2\frac{1}{2} : 1$. If both sides can take an equal share of the penetration, this ratio may be greatly increased. Aluminium coated alloys may present a peculiar difficulty, because of the inherently low resistance of the aluminium layer, particularly if surface preparation is by scratch brushing.

If the sheets differ greatly in thickness, and particularly if no surface indentation is required on the thinner sheet, little or no penetration of the weld in the thinner sheet will be obtained, although it may be as great as 100% in the thicker sheet. In such instances, increasing the interfacial contact resistance is likely to be the best remedy, and this can be achieved by using a suitable pickle giving a relatively high but uniform contact resistance (e.g., chromo-sulphuric acid pickle). Similar difficulties may be experienced in the welding of very thick aluminium coated sheets, e.g., 8 S.W.G., in which it is difficult to obtain high local current and pressure concentration at the welding interface.

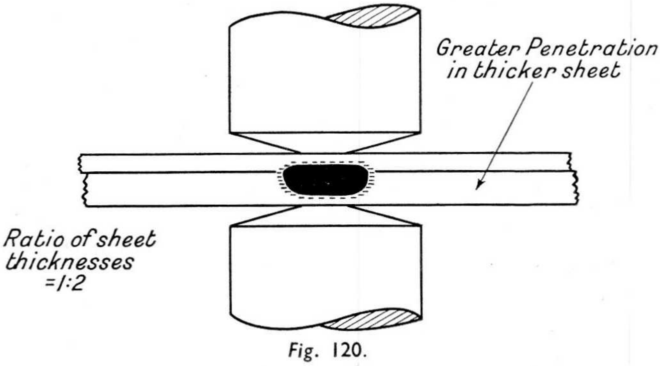


Fig. 120.

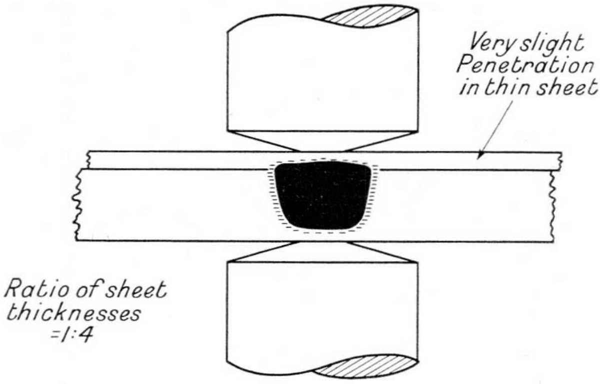


Fig. 121.

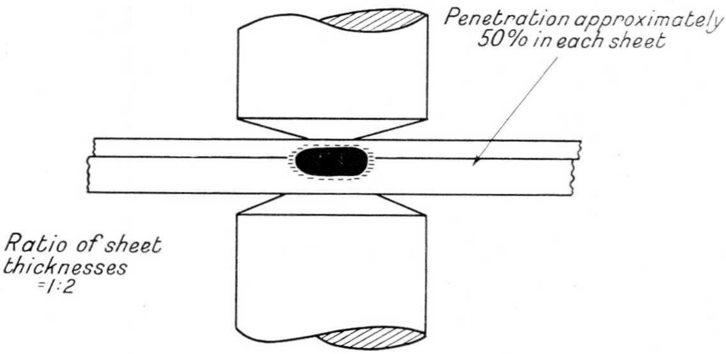


Fig. 122.

CONTROL AND INSPECTION.

With present day practice, the production of satisfactory spot welded assemblies is assured, amongst other things, by :—

(1) Using machine settings and welding technique which have been established by extensive and rigorous experimental tests.

(2) Ensuring that the established settings and technique are observed during production, e.g., by controlling surface preparation, tip maintenance, etc.

(3) Making production control tests at regular intervals during a production run.

(4) Visual inspection of finished assemblies.

It seems hardly necessary to add, that if items (1) and (2) are properly carried out, only a minimum number of production control tests are necessary.

(1) Machine Settings.

Optimum machine settings should be those which give the best weld strength consistency and metallurgical weld quality compatible with good electrode life, and simplicity of operation under production conditions.

(2) **Control of Process.**

The setting of the machine should be undertaken only by an authorised person, generally not the operator. Once settings are determined, the control of the process should be such, that these settings may be used indefinitely for a given combination of a given material. Unfortunately, variations in composition of material to a given specification and surface condition make this difficult, so that machine settings may have to be altered to accommodate these not easily controlled variables. As a rule, the responsibility for electrode tip cleaning lies with the operator, who must be fully aware of the importance of this relatively simple operation. Replacing of electrodes is generally carried out by another person. All the spot welding machines should be under his care, and electrodes changed at predetermined times to maintain tip contour consistency.

(3) **Production Control Tests.**

Control tests are based on the static shear testing of one or two welds during a production run, under the same conditions as in production, (i.e. machine settings, surface preparation, etc.), and usually at the beginning, end, and at stated intervals during the run, e.g., at two-hourly intervals, immediately before electrodes are changed, etc. The times, at which test pieces are prepared, are usually determined by agreement with the inspecting authority. Firms with poor technique and process control will be required to prepare test pieces at frequent intervals, and others with more experience may have to make only one or two test pieces per shift, when welding a given combination. Test pieces will be required, of course, for each combination welded and at the discretion of the inspector, if any variations from the established settings are made.

DESIGN OF TEST PIECE.

Suitable test pieces can be made by the placing of three welds on the longitudinal axis of simple lapped test strips (Fig. 123). The first weld made is isolated by a saw cut in one sheet, so that only the second and third welds are tested. An average strength per weld (based on the breaking load of two welds) is thus obtained. The Table on page 119 gives details of the dimensions of the specimens and weld spacings. (As recommended in B.S.S. 1138.)

Friction grip jaws are satisfactory with these test pieces. Metallurgical examination is often required, and for this it is found best to isolate two welds by a saw-cut, and only break the third and last weld made. The first weld made is discarded as usual, and the second used for metallurgical examination. When testing single welds in such test pieces, or single welds taken from a seam, stirrup grip jaws should be used with the locating holes drilled after welding to obtain axial loading of the weld.

USE OF TEST PIECE.

Production control test pieces should be used only to determine whether the weld strength obtained with the specimen exceeds the minimum strength per weld, as laid down by the designing authority. It should be clearly understood that the strengths do not necessarily indicate the individual weld strengths in the production assembly, as it is impossible for such a test piece to be entirely representative of the production job as regards spacing or edge distance. Also, it often happens that strip test pieces have to be used, to check the quality of welding in a formed or extruded section-to-sheet joint. Further, the specimen cannot take into account the mass effect in welding a large panel, such as a door or part of a wing skin. This can be simply explained as follows :—

The current and pressure concentration, possible with small test pieces, cannot be obtained in large jobs, particularly if the material is thick, so that relatively larger welds will be obtained with the control test piece. It is obvious then, that allowance can be made for these effects when fixing minimum strength figures for use with control test pieces, so that even though the strength obtained does not indicate the actual production weld strength, the production welds will be satisfactory, if the strength exceeds the minimum figure. Minimum strength figures must be chosen with care, by welding production assemblies and control test pieces under the same conditions, destructively breaking the welds in the assembly, and comparing the results with the shear strength obtained with the test pieces.

RECORDING TESTS.

Full details of welding conditions, material, composition, surface preparation, job, etc., should always be recorded in a log book.

ACTION TO BE TAKEN IF CONTROL STRENGTHS ARE BELOW THE MINIMUM.

Experience has shown that the action of inspectors, on the failure of a specimen to reach the requisite minimum strength, varies considerably, and that too much importance is attached to the function of the specimen. Spot welded assemblies have often been scrapped on the results of a single test piece. Control test pieces by themselves must, on no account, be considered as conclusive evidence in inspection as, unfortunately, is often the case. Control tests must be used in conjunction with visual examination, insertion of a thin steel blade between the faying surfaces of the joint to apply tensile force on the welds and, if necessary, destruction of one or more of the suspected assemblies

If a test piece fails to give the necessary strength, two further test pieces should be taken, and if one or both of these additional specimens fail, the material just welded should be removed for closer examination and the entire spot welding process examined for the cause of the trouble. If the technique has been closely controlled, this should not be difficult to locate.

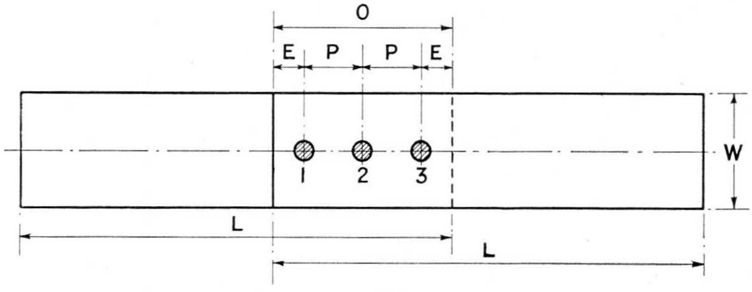


Fig. 123.

Table giving dimensions of Test piece (see Fig. 123).

SHEET THICKNESS	L ins.	W ins.	O ins.	P ins.	E ins.	HOLES FOR LOADING
UP TO AND INCLUDING 18 S.W.G.	6	$1\frac{1}{4}$	$2\frac{1}{4}$	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{17}{32}$ in. maximum dia. drilled 1 inch from end.
THICKER THAN 18 S.W.G.	$6\frac{1}{2}$	$1\frac{1}{2}$	3	1	$\frac{1}{2}$	

Visual inspection can give valuable information regarding the general weld quality, as it is possible for an experienced inspector to judge the quality of the welds by the shape and appearance of the surface indentation. As a rule, assemblies containing more than 10% of welds which show undesirable features, such as excessive surface burning, cracking, etc., should be condemned, and the process examined and corrected to prevent further occurrence.

(4) **Metallurgical Examination.**

This should be carried out from time to time at the discretion of the inspector, by preparing macro-sections of welds made on a production control test piece. Penetration, sheet separation, cracks, cavities and structure are well revealed by this method. Suitable reagents for etching polished specimens are :—

(1) 2% Hydrofluoric Acid, 24% Conc. Nitric Acid, 74% Water.

A black deposit is produced on duralumin type alloys, which can be rubbed off by the finger tip in a stream of water or dissolved by 50% nitric acid.

(2) Keller's Etch. 1% Hydrofluoric Acid, 1.5% Hydrochloric Acid, 2.5% Nitric Acid, remainder water.

The above reagents are suitable for most light alloys, although D.T.D. 213 ($1\frac{1}{2}$% Mn.), alloys of the Birmabright type (3-5% Mg.) and commercial aluminium may re-act better to treatment with $\frac{1}{2}$% hydrofluoric acid solution.

DESIGN.

This is, perhaps, one of the most important aspects of spot welding which, unfortunately, cannot be adequately covered in this chapter, and the reader should refer to the publication of the American Welding Society—" Tentative Standards and Recommended Practices and Procedures for the Spot Welding of Light Alloys." Several aspects may be recognised :—

(1) Designing to obtain maximum production speed and maximum machine efficiency.

(2) Designing to obtain maximum structural efficiency.

Parts should be designed to permit an uninterrupted vertical movement of the top electrode, in order that the maximum number of welds may be made with straight thrust electrodes. All the joints to be welded should be readily accessible to the electrodes. Flanges and sections must be of sufficient size to permit the use of straight thrust electrodes, or electrodes of minimum offset in which electrode deflection at high welding pressures is negligible.

Assembly design should also include details of weld spacing, edge distance, required minimum strength—details which should only be settled by consultation with production engineers—so that maximum production efficiency may be obtained. It is well known that spot welds, spaced nearer than a certain amount, are reduced in strength, because of current shunting, i.e., passage of part of the welding current through the previously made weld. Designers should, therefore, specify a weld spacing associated with a definite minimum strength. This shunting effect is not of great importance in thin sheets, but becomes more pronounced in heavy gauges. Tests seem to show, however, that the strength per linear inch of joint increases as the spacing decreases.

One factor in design, which is sometimes greatly neglected, is the importance of having well fitting surfaces prior to welding, so that the electrodes are not required to overcome any stiffness of sheets or section. This precludes the welding of curved sections to flat sheets or the placing of welds on radiused corners of sections and angles.

The publication of the American Welding Society already referred to gives details of recommended minimum weld spacing, edge distance, flange width, etc., and discusses joints suitable and unsuitable for spot welding.

HINTS TO THE OPERATOR.

Handling of Cleaned Material.

Wear cotton gloves, so that handling the prepared surfaces will not harm them and affect the quality of the welds produced.

Presentation of Work to Machine.

Hold the parts to be welded, so that the electrodes bed uniformly upon the surfaces, i.e., so that the axis of the electrode is at right angles to the plane of the surface.

Machine Settings.

Ensure that sufficient cooling water is flowing through the electrodes, before welding, and that the machine settings are those required for the particular job to be welded.

Do not attempt to alter machine settings on your own initiative. If you think there is any reason for doing so, always ask the person concerned.

Electrodes.

Clean the electrodes immediately you detect any tendency for the work to stick to the electrodes. If the electrode becomes badly fouled and cannot be corrected by the usual light rubbing with emery cloth, have it changed immediately, although its life may have been much less than usual.

Ensure that your electrodes are changed at the prescribed times.

Location of Welds.

Take care, when placing welds, that the electrodes are not placed too near the edge of a section or flange, otherwise heavy splashing may occur.

Keep as near as possible to the prescribed spacing for the welds and use spotlights to facilitate location if possible.

Chapter VIII

THE METALLURGY OF RESISTANCE WELDING

Light Alloys—Steel—Stainless Steel—Coated Steel —Physical Properties of Metals

The Science of metallurgy was originally concerned with the extraction of metals from ores and their subsequent refinement and alloying to produce metals and alloys of useful application. Metallurgy, as we know it to-day, covers a much wider field and has become a close adjunct of physics and engineering, including the study of composition, structure and properties of metals under a variety of conditions.

The modern engineer must be familiar with the composition and properties of the metals he is using and must understand the modification of properties possible and the metallurgical principles involved in heat treatment and other allied processes. This is particularly important from the point of view of welding processes in which metal is raised to temperatures up to and exceeding the melting point. An engineer must know how the strength of a welded joint is likely to be affected by the temperature changes, whether distortion by heat will be severe and how he can obtain improved properties by treatment of the joint after welding, etc.

In this chapter an attempt has been made to evaluate those properties which affect the resistance weldability of metals and to discuss the problems involved in specific metals and applications. It has been written, because of space limitations, on the assumption that readers are familiar with the elements of physics and metallurgy. Readers who have no metallurgical knowledge should refer to books concerned solely with welding metallurgy, e.g. Welding Metallurgy, Henry & Claussen (American Welding Society). An additional list of useful articles and papers will be found at the end of this book.

FACTORS AFFECTING RESISTANCE WELDABILITY.

Physical Factor.

The resistance offered to any electrical current passing through a metal may be divided into two parts :—

1. The resistance offered by the metal itself.
2. The resistance at the various contacting surfaces.

The resistance offered by the metal is proportional to the resistivity of the material, which depends upon its composition and condition and the length of the current path and is inversely proportional to the area of the current path. Resistivity is usually defined as the resistance in ohms of a cube of material of one cm. side.

Contact resistance is affected by—

1. The surface condition, i.e., presence of dirt, grease, oxides, etc., surface smoothness.
2. The surface pressure. For most conditions it is inversely proportional to the pressure, the higher the pressure the lower the resistance.
3. The resistivities of the materials in contact.

Fig. 124 is a diagrammatic illustration of two cylindrical bars of dissimilar composition in contact, the current being passed between copper electrode platens.

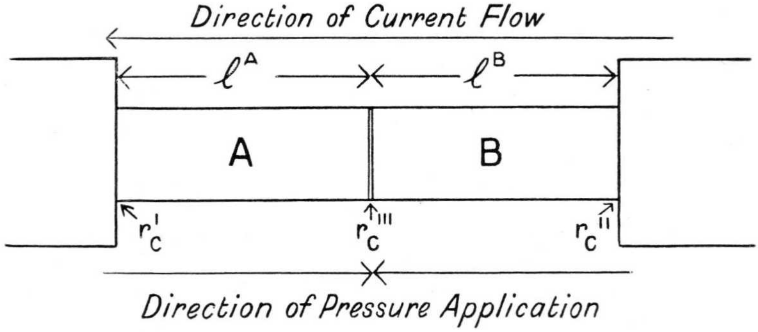


Fig. 124.

The total resistance may be expressed as follows :—

$$R = r_m + r_c \text{ where } r_m = \text{metallic resistance}$$
$$\text{and } r_c = \text{contact resistance.}$$

$$r_m = r_a + r_b = \frac{\rho_a\ l_a}{A_a} + \frac{\rho_b\ l_b}{A_b}$$ where ρ_a is the resistivity of material A, ρ_b that of material B, and A_a, A_b and l_a, l_b the respective cross-sectional areas and length of current path for materials A and B.

The total contact resistance is given by

$$r_c = r_c^{i} + r_c^{ii} + r_c^{iii}$$

so that R, the total resistance, is given by

$$R = \frac{\rho_a\ l_1}{A_a} + \frac{\rho_b\ l_L}{A_b} + r_c^{i} + r_c^{ii} + r_c^{iii}$$

The rate of heat generation due to the passage of the welding current at any instant will be given by I^2R where I is the current in amperes at that instant.

If it is assumed that any heat developed by the resistance r_c^{i} and r_c^{ii} is rapidly conducted away by the electrical conductors (dies or electrodes) carrying the current the total effective resistance will depend upon resistivity, dimensions, and welding interface contact resistance.

The natural oxides present on the surface of metals are of a non-uniform character so that the surface contact resistance may vary within wide limits. It is for this reason that such oxides are largely removed by special treatments prior to welding (particularly spot welding) in order to obtain a more uniform heat accumulation at the interface. With cleaned surfaces, pressure then becomes the main factor in determining the magnitude of the contact resistance.

With materials of high body resistance, i.e., of high resistivity or great thickness, the surface contact resistance is not so important as the body resistance in determining the heat distribution. Similarly with materials of low body resistance, i.e., of low resistivity (high conductivity) or of light gauges, the surface contact resistance is of great importance. Specific data on the resistivity of various metals is given on page 124, which shows that metals of the stainless steel type have a very high resistivity, aluminium and aluminium alloys are of low resistivity, and materials of the mild steel type occupy an intermediate position.

The energy input required to make a weld or generate a certain quantity of heat is determined largely by the resistivity of the material and to a lesser extent by the pressure of the contacting surfaces. Thus very high currents are required to weld light alloys, and currents of proportionately smaller magnitude may be used with mild steels and stainless steels.

A further important physical factor affecting resistance weldability is thermal resistivity which is the reciprocal of the more widely used term—thermal conductivity. Materials of high electrical resistance are invariably poor heat conductors, i.e., have high thermal resistance. The reverse is also true, so that good heat conductors are invariably good electrical conductors. (See page 124.)

This means that with materials of low resistivity, e.g., light alloys, heat is rapidly conducted away from the welding interface. Long welding times are prohibitive because of the excessive energy dissipation, i.e., it is impossible to obtain a gradual heat accumulation by the use of low welding currents and long welding times. There are several additional reasons why long welding times are not desirable and these will be discussed in a subsequent section.

With materials of relatively higher resistivity it is possible to have a more gradual heat build-up at the welding interface by using relatively low currents and long welding times. Although materials of the stainless steel type should be admirable from this point of view since their resistivity is high, metallurgical considerations preclude the use of long welding times.

Other important physical factors are specific heat and thermal expansion, values of which are also given on page 124. Materials of high specific heat will require more heat to raise them to welding temperature, than those of low specific heat.

Physical Properties of several Metals and Alloys

PHYSICAL PROPERTIES	METAL							
	Iron	Copper	Aluminium	Commercial Aluminium (99.5% purity)	Alloys of Duralumin type (BSS. 5L3)	Low Carbon Steel (C-0.2%)	High Carbon Steel (C-0.5%)	Stainless Steel 18/8 type
Melting Range ...	1537° C.	1083° C.	659° C.	657° C.	530-610° C.	1500-1540° C.	1440-1520° C.	1400-1420° C.
Coefficient of Linear Expansion ° C. X 10^{-6} ...	11.9 (0-100° C.)	16.6 (0-100° C.)	24 (0-100° C.) 29 (0-500° C.)	24 (0-100° C.)	23.7 (0-100° C.)	12.6 (0-100° C.) 14.4 (0-500° C.)	11.34 (0-100° C.) 14.4 (0-500° C.)	17.3 (0-100° C.) 18.4 (0-500° C.)
Thermal Conductivity Cals/cm^2/sec/° C./cm. ...	0.19 (20° C.) 0.091 (600° C.)	0.92 (20° C.) 0.86 (500° C.)	0.52 (20° C.) 0.63 (500° C.)	0.50 (0° C.) —	0.30-0.45 (0° C.) —	0.193 (100° C.) 0.109 (500° C.)	0.162 (100° C.) 0.075 (500° C.)	0.039 (100° C.) 0.0515 (500° C.)
Specific Gravity	7.87 (20° C.)	8.93 (20° C.)	2.79	2.703 (20° C.)	2.82 (20° C.)	7.9	7.9	7.92 (20° C.)
Specific Heat (Cals./° C./gm.)...	0.1075 (20° C.)	0.092 (20° C.)	0.24 (20° C.-100° C.)	0.27 (20° C. to fusion)	0.24 (20° C. to fusion)	0.155 (20° C. to fusion)	0.15 (20° C. to fusion)	0.12 (0-100° C.)
Electrical Resistivity. Microhms per cm.^{3} ...	9.8	1.694	2.87	2.845	3.3-5.3	19.9 (20° C.) 25.6 (100° C.)		70 (20° C.) 117 (650° C.)

Welding, being essentially a local heating operation, involves local expansion and contraction. In resistance welding and, indeed, in most methods of welding, this expansion and contraction takes place largely under constraint so that there is the possibility of stresses being locked up in the joint, which may be of sufficient magnitude to produce cracking. Welding technique, in consequence, has to be controlled to reduce the magnitude of such stresses.

The data given on page 124 include figures for the coefficient of linear expansion (inches per inch per degree centigrade). These show that aluminium will expand and contract whilst cooling, twice as much as a similar piece of mild steel heated to the same temperature. In addition contraction of weld metal occurs during the process of solidification. For aluminium alloys this contraction amounts to about 5% of the original liquid volume and is thus of about the same value as the change of volume of the solid on cooling from the melting point down to room temperature.

For any material, then, local heating may give residual stress which may, or may not, have to be relieved by further treatment depending upon the composition of the material and the extent of heating. In welds involving fusion, contraction during solidification may produce shrinkage cracks and porosity if means are not provided for making good the shrinkage. Thus, in spot or seam welding, the electrode or rollers must provide adequate pressure to consolidate the weld. Welding times should be short to minimise "spreading" of heat and possible distortion of the metal.

In conclusion, the physical properties of importance in determining resistance weldability are electrical and thermal resistivity, surface contact resistance, thermal coefficient of linear expansion, volumetric shrinkage on solidification and specific heat. Data available on these properties for several well known materials have been summarised on page 124.

These factors, in themselves, are not sufficient to determine completely the resistance weldability of various materials, but are the major factors affecting machine capacity. High currents and short welding times will be required to weld materials of low resistivity. With materials of high resistivity welding cycles may be used which give a gradual building up or accumulation of welding heat. It is to be expected that steels, etc., would require relatively low capacity machines for resistance welding and that light alloys and other alloys of low resistivity would require high capacity machines. Similarly, it is to be expected that means must be provided to compensate for the relatively high solidification and cooling shrinkage of aluminium and its alloys.

Metallurgical Considerations.

The study of the effect of heat on the properties and structure of metals constitutes a most important part of metallurgy of interest to all concerned with welding and its applications. Heat not only causes expansion of parts during welding but also affects the structure of the metal, depending on the temperature, the time the metal is maintained at the temperature and the composition of the metal. Rate of cooling from the welding temperature may also be an important factor. The rate of temperature build up is directly related to the nature of the welding cycle and to the composition and dimensions of the materials. The properties of a resistance welded joint are therefore determined by the composition of the material comprising the joint and the type of welding cycle used.

Effect of Welding Cycle.

Welding may be accomplished either by fusion or by " forge welding " (recrystallisation and grain growth across the welding interface without fusion) in either a short or relatively long time with a correspondingly fast or slow rate of cooling from the welding temperature. A joint produced by fusion and solidification of the melt will have properties inferior to those of a forge welded joint in the same material, e.g., compare the properties of a spot weld in mild steel with a properly flashed welded joint in the same material. In flash welding, the high upset pressure, applied after flashing has raised the joint to the right temperature, serves to remove all oxide inclusions and molten metal so that the joint is effected in metal which has not been molten. It is noteworthy that the fatigue strength and the tensile strength of flash welded joints free from inclusions or cracks and heat treated when necessary, is often only 5% or so less than that of the parent metal. Spot welds in the same material are invariably produced by fusion and show a characteristic fusion ingot or nugget. The reduction in tensile strength (tons/sq. ins. of weld) may be as much as 50%, although in this case the nature of the joint has as important an effect on the strength as the structure.

From a metallurgical point of view the best welding cycle is that which produces the least disturbance in the properties of the weld as compared with that of the unwelded material. The extent of the heat affected zone will largely depend upon the energy input but particularly on the welding time. The use of very high currents and short welding times for any material will obviously reduce the extent of the heat affected zone. This cycle is also more economical from the point of view of power consumption. Some modification is, however, necessary when welding materials such as low alloy steels, etc. Rate of cooling is of great importance with such materials—high currents and short welding times reduce the heat affected zone but increase the temperature gradient from the weld, to the parent metal and will give hardening of the weld and heat affected zone to a degree depending on the composition and the temperature gradient.

The use of low currents and relatively long welding times will reduce the rate of cooling and in some cases the hardness of the weld and heat affected zone. The most suitable solution for low alloy steel spot welds is the use of a controlled post heating current, i.e., passing a reduced current after the main welding current. Post heating cycles may be used to reduce the rate of cooling or to temper any zones already hardened. The latter method is the one used in low alloy steel spot welding and will be explained in greater detail in the section dealing with steels.

Preheating by the passage of a secondary current before the main welding current, is sometimes used in addition to the normal welding cycle. Its effect is to reduce the temperature gradient from weld to parent plate. In conclusion, welding cycles should be chosen to restrict the extent of the heat affected zone to the minimum compatible with the weld being satisfactory in all other respects. Excessive hardness and local stress may require the use of preheating and post heating currents.

LIGHT ALLOYS.

Many aluminium alloys, particularly those of the duralumin type owe their strength to heat treatment, i.e., quenching the wrought metal from a high temperature followed by ageing at room temperatures or a treatment at a somewhat higher temperature.

Heating to temperatures up to fusion point will produce appreciable softening of the metal surrounding the weld. This softening may be restricted by rapid welding. Similar considerations apply to the aluminium alloys which owe their strength and hardness to work hardening treatment. When a cold worked metal is heated above a certain temperature, known as the recrystallisation temperature, softening occurs. In the resistance welding of light alloys, the present techniques used almost invariably involve fusion in the weld. Table below gives approximate details of the effect of heat on the properties of representative light alloys which show that the properties of fused material are considerably inferior to those of the wrought and heat treated material. A joint produced by welding without fusion (i.e., recrystallisation and grain growth) would possess improved properties and with heat treatment strengths approaching that of the parent metal could be obtained. It is, indeed, unfortunate that the inherent nature of light alloys in general, high conductivity, small plastic range, tenacious nature of oxide film, etc., have so far precluded them from joining by this means. Flash welding has only a limited application to a few materials such as commercial aluminium and non-heat treatable alloys. The main difficulties are machine design and the nature of the alloys. Very high current densities are required (not less than 100,000 amps. per sq. inch of section) with rapidly applied upsetting pressures. The moving head must have little inertia or friction so that the head rapidly accelerates under the action of the upsetting pressure. Slow butt welding has not

Strength Properties of "Duralumin" Type Alloy in various conditions.

Condition	0.1% Proof Stress. Tons/sq. in.	Ultimate Tensile Strength. Tons/sq. in.	% Elongation on 2″
Wrought and heat treated	15	26.5	18
Wrought and annealed	6.0	17.0	17.8
Chill cast	9.2	10.7	1.0
Chill cast and heat treated	13.2	18.4	1.8

been used even with commercial aluminium because of the exceptionally heavy power requirement. Flashing used to reduce power demand, however, produces the undesirable aluminium oxide with aluminium alloys which tends to become entrapped in the joint. Duralumin type alloys containing up to 3-5% Copper, provide difficulties in flash or butt welding by cracking and serious reduction in strength properties at the joint.

Spot welding is the most widely applied method for light alloys and has only been made possible by the use of improved machines and welding techniques. The high conductivity requires that high current and short welding times be used to minimise conduction losses. Rapid welding is also essential from metallurgical considerations. As a light alloy weld is mainly composed of cast metal, the degree of improvement in properties by heat treatment is limited, unless a full solution treatment and ageing is possible. Production considerations preclude such treatment. The passage of a reduced or post-heating current after the main welding current is, however, used in spot welding light alloys by A.C. machines to improve the quality of the weld. This is the so-called " programme control " cycle and it is claimed that its use improves the weld shear strength by as much as 20% as compared with welds made with the same main current but without the post heating current. However, it is by no means clear whether this strength improvement results from a heat treatment effect or from the increased energy input to the welds producing welds of greater size. In addition, weld shrinkage cracks and porosity are greatly reduced. This may be explained as follows : The reduced rate of cooling will maintain the weld at heat for a longer period and thus enable the electrodes to overcome the inertia and head friction and thereby provide effective consolidating pressure whilst the weld is cooling and shrinking.

Pre-heating finds little application in the spot welding of thin gauge light alloy sheets although it is claimed that the induction storage method of welding light alloys possesses an inherent pre-heating cycle which improves surface conditions. Although several attempts have been made to determine the value of pre-heating in spot welding no conclusive results have been obtained. In the welding of heavy gauge light alloys it is conceivable that pre-heating currents will be valuable in improving the current and pressure concentration at the welding interface.

STEELS. (**Mild Steels and Low Alloy Steels.**)

With mild steel of carbon content up to about 0.18% high rates of cooling have no deleterious effects and, indeed, will tend to improve the properties of the weld and the heat affected zone by the consequent hardening. In particular impact strength is increased. There is, of course, a limit to which the hardening of the weld and adjacent metal may be tolerated, depending on the composition of the parent metal. For example, with steels of higher carbon content, or those with low alloying additions of chromium, nickel, manganese, etc., a considerable variation in properties may be obtained for different rates of cooling. In brief, the hardening effect will increase as the rate of cooling increases so that high rates of cooling may give welds of relatively high tensile strength but poor ductility.

The metal adjacent to the weld may show " quenching " cracks resulting from the volume changes associated with the formation of the hardened structure and the cooling shrinkage of the weld. Such welds may have high tensile strength but are exceptionally brittle and can fracture under relatively small impact blows.

Very short welding times (by using high currents) will naturally produce rapid rates of cooling although restricting the heat affected zone. Long welding times (with low currents) by giving a gradual accumulation of welding heat will give an increased heat affected zone but will reduce the final rate of cooling. Whether or not the former or latter type of cycle is desirable will depend upon the composition of the steel.

It has already been shown that weld hardening can be beneficial with low carbon steel, e.g., automobile grade low carbon steel ($C =$ ca. 0.05%) by improving the impact resistance. With steels of higher carbon content ($C < 0.16\%$) the impact resistance of the weld may be relatively low with rapid rates of cooling and can be increased within limits by the use of low currents and long welding times to decrease the temperature gradient.

With high tensile and low alloy steels neither cycle is capable of producing satisfactory welds because of the greater hardenability of the steel and special means must be provided for improving the ductility of the weld and adjacent metal. Briefly, the method consists of making the weld in a single impulse in as few cycles as possible, allowing a very critical and definite time " off," in which the weld cools quickly to produce a brittle transformation product, and then tempering to give a tougher and more ductile weld by means of a second current impulse of smaller magnitude than the first. This cycle has been successfully used with N.A.X. high tensile steel ($C = 0.14$, Mn 0.65, P 0.017, S 0.021, Si 0.84, Cr 0.57, Zr 0.11, Mo. nil) but the general procedure should be applicable to a variety of high carbon, low alloy high tensile steels. As it is easier to temper completely welds in thin sheet, it is to be expected that sheet thickness may limit the value and application of the method.

Mild steel is eminently suited for seam welding and a wide range of thicknesses may be welded, the only limits being imposed by the electrical and mechanical capacity of the machine. Seam welding of the low alloy steels is not practised because of the difficulty of incorporating the essential heat treatment current in the welding cycle.

Flash and slow butt welding are widely used for joining mild steel sections and flash welding has recently been successfully applied to low alloy steels. Flash welding is carried out without pre-heating (i.e., in the cold condition) for thin sections such as are used in automobile body construction. Heavy sections, however, if welded in the cold condition would require a very high transformer capacity and the material wasted in flashing would be considerable. Pre-heating in such cases is an integral part of the process and is carried out by passing a secondary current or more usually by intermittent and gradual flashing prior to the main flashing period. It is well known that flash welded joints are stronger than corresponding slow butt welded joints. This is believed to be due to the exclusion of air from the welding surfaces by the flashing and by the complete removal of inclusions from the surfaces. The fatigue strength of joints in mild steel rods of a content 0.09-0.13% has been shown to be determined by the quantity of included oxidized products and is consequently affected by the upsetting pressure and the energy used in making the weld. Welding time, pre-heating and flashing periods determine the temperature distribution in the work piece and thus also the effectiveness of the upsetting pressure. High transformer tappings produce a relatively steep temperature gradient and facilitate oxide removal by increasing the deformation resistance of the material adjacent to the weld. Tappings cannot be increased indefinitely, and a limit is reached above which welds show porosity and cracks.

Optimum flash welds in mild steel possessing no inclusions or porosity are thus produced by localising the heat and a fairly wide tolerance in welding conditions is permissible. With alloy steels there are other aspects which must be considered. The greater hardenability of alloy steels will produce excessively hardened zones adjacent to the weld. Pre-heating for alloy steels is of importance in reducing the temperature gradient from the weld zone to the parent metal and thereby reducing any tendency for cracking in material adjacent to the weld. The extension of the heat affected zone by relatively long pre-heating cycles is unimportant since heat treatment (usually oil quenching and tempering) can be carried out after welding.

STAINLESS STEELS.

The austenitic stainless steel alloys of the 18/8 type (18% Cr, 8% Ni, 0.10% C.) have an electrical resistance approximately 6 times that of ordinary mild steel, with lower heat conductivity and melting range (page 124). Considerably less heat input is therefore required to resistance weld stainless steel. Difficulties have been encountered due to the phenomenon of " weld decay " which is caused by the precipitation of chromium carbide in metal near the weld which has been heated to temperature with the range 300-900°C. The corrosion resistance of such austenitic steels is dependent upon the retention of the chromium in solid solution and any precipitation of chromium carbide thereby reduces the corrosion resistance of the metal near the weld. The extent of this precipitation increases with increase in welding time so that short welding times are essential in welding stainless steels. Short welding times not only give reduced heat affected zone but also high rates of cooling after welding. This also reduces the tendency for precipitation. In addition, austenitic stainless steels have been developed containing " carbide stabilisers," e.g., titanium and columbium. These are added in amounts sufficient to combine with all the carbon present so that no chromium can be precipitated as carbide. The titanium content must be at least four times that of the carbon. If columbium is used the ratio must be 10 : 1. In spite of these improved stainless steels optimum results are given by using ignition type timers. The inherently short discharge time of condenser discharge welding methods should find useful application in stainless steel welding. Seam welding of austenitic stainless steel is also carried out successfully provided care is taken to control the energy input and weld time.

COATED STEELS.

The principal coated steels commercially available are galvanised sheets (zinc coated), tinplate, terne plate (tin-lead alloy coating) and steel with various electro-plated coatings. The resistance weldability of these steels will obviously depend more upon the properties (resistivity melting point, etc.) of the coating than upon those of the steel.

Difficulties to be expected are the alloying of the coating with the electrodes (spot or seam) with the consequent removal of the coating from the sheet, and the alloying of the steel and the coating at the sheet-to-sheet interface. With zinc, tin, and lead coatings, it is very difficult to prevent melting of the coating although it is relatively easy to produce welds without any alloying of the coating at the sheet-to-sheet interface by means of a controlled pressure cycle to remove the melted coating before the weld proper occurs. Vaporisation of the zinc is particularly troublesome. Surface disfiguration of some sort occurs in the spot or seam welding of most coated steels but can be minimised by carefully controlling the energy input, welding time, and pressure cycle.

In resistance welding of coated steels considerable attention must be paid to the maintenance of the electrodes and minimisation of the alloying of the coating and the electrode. In this respect, electrode refrigeration may be a solution for many of the electrode problems. Further information about the welding of coated sheets is given in Chapter V.

CHAPTER IX

TIMERS

Trip Switch—Dashpot—Magnetic—Resistance Capacity

SIMPLE TIMERS.

This chapter is devoted to simple types of timing devices, more complicated types being dealt with in chapter X.

The earliest type of timing device was the trip switch type (Fig. 125) which operates as follows :—As the foot pedal of the machine is depressed, the electrodes meet and a switch controlling the main current of the welding transformer comes into operation. This switch (known as a trip switch) may either actuate an electro-mechanical contactor or the main switch can be built into the trip mechanism.

The trip mechanism usually comprises two hardened steel plates, spring loaded and set at such an angle that at a pre-determined amount of travel the switch portion becomes disengaged from the moving part of the switch and the switch circuit is broken. Various modifications have been used such as cam and trigger mechanisms which operate in the same manner. One feature common to all types of mechanism is that the switch does not engage on the return stroke of the foot pedal.

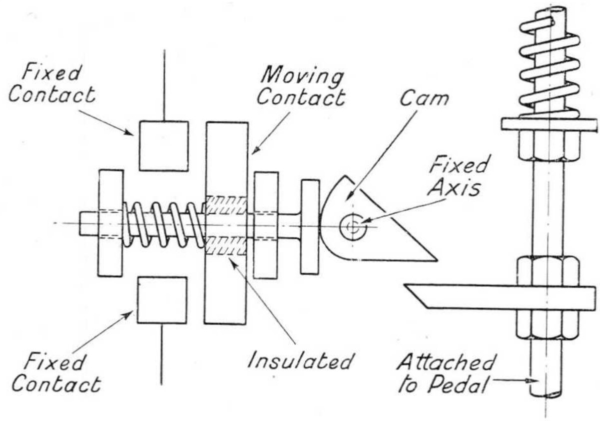


Fig. 125. Trip switch timer.

TIMERS

It should be noted that the "two stage" timing system is a modern development and that in the second stage any of the precision timers later described can be employed. This system can, in addition, be used with either contactors or ignitrons and the only limitation of capacity is that of the particular equipment selected.

This type of trip switch, although satisfactory in operation, has certain limitations as regards accuracy of time and the trip period is also dependent upon the speed and energy of the operation and is therefore unsuitable for any type of welding requiring very accurate and short periods of time.

The next development in the range of simple timers was the magnetic induction timer which consists of a magnetic relay clamped in position to one of the secondary arms of the welding machine, and operated by the magnetic field of the secondary circuit. This induces current in the mechanism during the flow of the welding current. This type of equipment depends basically upon the rise in current in the secondary circuit of a spot welding machine as the resistance of the work is broken down, and a secondary current relay known as the magnetic relay is employed. If a graph is taken of a spot welder current against time, it will be found that the current rises steeply in the first instance and as the resistance of the work being welded is broken down, there is a falling off in the current due to the rise in the resistance in the heated metal, and finally a second rise in current as the two or more pieces of material are fused together. For thin material and with a machine of adequate capacity this second peak is higher than the first one and the magnetic relay is therefore set to the required figure in the second peak. It has been found, however, that in certain conditions such as thick material where the rise in resistance of the sheet is greater than the reduction in resistance at fusion, and with a machine with bad regulation or inadequate mains supply, the second peak is not as high as the first one or even if the second peak rises to the same height, the angle of the graph is very shallow and the moment of reaching the required current value is extremely indefinite. This fact somewhat limited the development of this type of timer, but experiments have shown that whilst the time required to reach the first peak varied according to the surface conditions of the material, the time between the first peak and the conditions necessary for the completion of a sound weld was, for a given setting, constant. Therefore, the makers of this apparatus developed what is known as "two-stage" timing. With this "two-stage" timing the magnetic relay is retained for measuring the first peak in the current cycle and is adjustable for different conditions, but instead of being employed to break the welding circuit, it is used to operate an adjustable time delay device, of which a number of varieties are used, to record the time between the first peak and the required point in the second peak. Diagram Fig. 126 shows the method employed.

Another type of timer that is being used is the oil dashpot type timer. As will be seen from the drawing, Fig. 127, a current transformer is incorporated in the welding transformer secondary circuit. This current transformer secondary is connected across a special relay and the current fed into this relay coil from the current transformer bears a direct relation to the welding current.

The operation of the armature of this relay is retarded by an oil dashpot. To lift this dashpot through its stroke a certain amount of energy is required and this bears a direct relation to the welding energy. It is possible if a control is attached to the dashpot so that the plunger depth in the oil can be pre-set, to control the welding energy. As the plunger lifts, the contacts shown in Fig. 127 are operated and are arranged to terminate the welding primary current by some suitable electrical means.

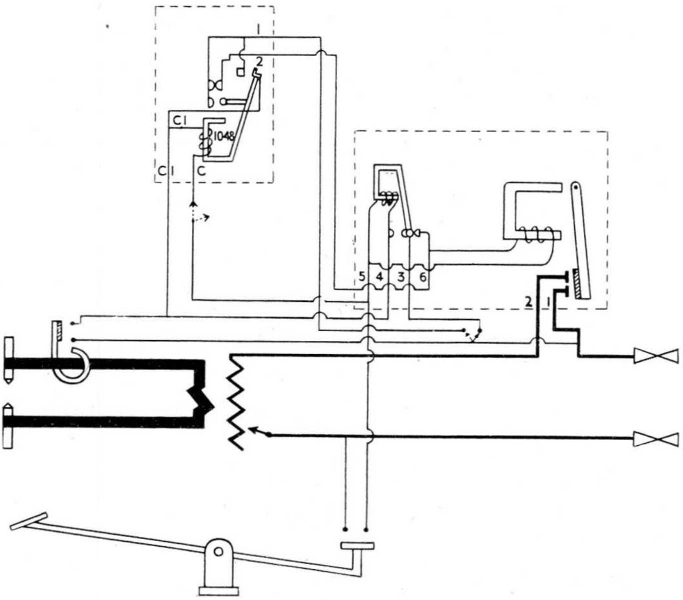


Fig. 126. Two-stage magnetic relay timer.

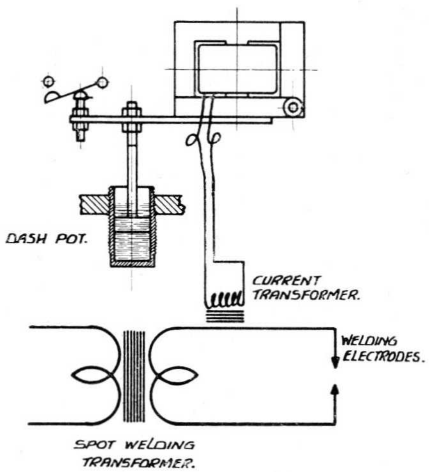


Fig. 127. Dash pot type timer.

A non-return valve of the plate type is incorporated to enable the plunger to return to the " rest " position rapidly and re-set for the next weld.

One of the advantages of this type of timer is that if for any reason the welding current is lower than normal, the welding time is automatically longer and vice versa and the weld is not affected. One of the biggest disadvantages is that the viscosity of the oil varies at different temperatures though this is overcome to a certain extent by using a very special light grade oil. Welding times of between 10 cycles and 2 seconds can be controlled within 5 per cent. provided the temperature of the oil does not vary by more than 40° F.

Moving air vane and clockwork types have also been used.

The vane timing device functions as follows :—When the magnetic circuit is energised it closes the welding contactor, which in closing compresses the relay operating spring which starts the gear train working. This gear train is retarded by the rotation of the vane. The disc will eventually establish a circuit across the two contacts after an interval of time depending on the adjustment. This type of timer has a time adjustment of approximately 0 to 10 seconds. Another type embodying the same principle has an oscillating lever with a maximum time adjustment of two minutes ; a third type has a spring escapement with an exceptionally long time adjustment.

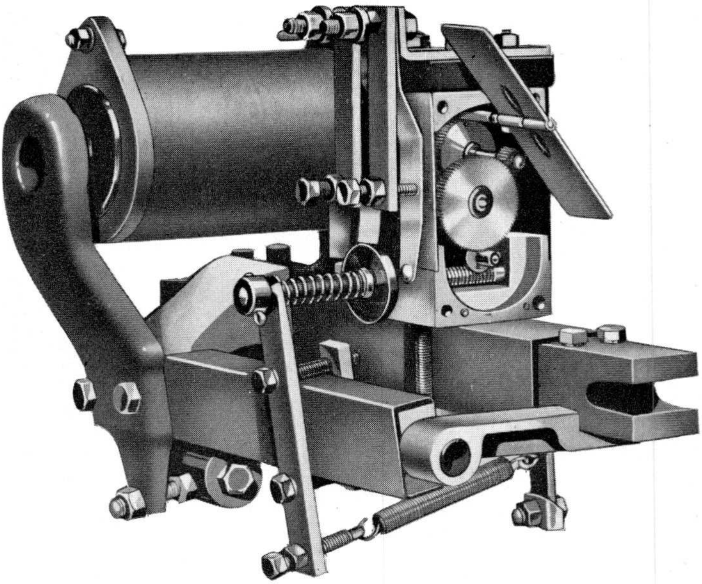


Fig. 128. Timer of rotating vane type.

MODERN TIMERS.

The timers in the previous section are of a simple type which are sufficiently accurate when high precision is not expected, but those which are purely mechanical devices are subject to all the usual defects associated with friction control—notably variation with time and temperature. Friction devices, unless of the fluid friction type, gradually wear and unless adequately maintained by constant adjustment to accommodate such wear, variation of timing inevitably takes place. On the other hand if fluid friction is employed then viscosity variations occur with change of temperature and these give rise to non-uniformity of timing.

Normally such simple timing methods are in any case inapplicable to machines of over 20 kVA., and from 10 kVA. upwards contactors are usual practice to make and break the main current—the timing device being used to control the operating coil of the contactor. The total time of operation is therefore dependent on both the timing device and the contactor, and both are subject to time variation. A.C. contactors cannot be relied upon to make and break with a consistency closer than one to two cycles on a 50 cycle supply. For a mechanical device this represents a high degree of precision, one to two cycles representing a time of 0.02 to 0.04 seconds—but for the best class of modern resistance welding work even such inaccuracies are of importance. Greater consistency is found with D.C. contactors, but even so it is unusual to rely on time controlled contactors for periods of less than 0.1 sec., i.e., 5 cycles, when extreme conditions of accuracy are required.

It will be appreciated that the inaccuracy is of greatest importance when the time settings are shortest. Thus an error of 2 cycles in a period of 1 second (50 cycles) is of very minor importance, but the same error in a total time of, say, 5 cycles is very serious, involving, as it might do, a variation of time between 3 and 7 cycles. Such variations are due to the inherent variation in pull-in and drop-out times of the contactor, and it can readily be seen that this is affected to some extent by the time in the actual current cycle at which the relay contacts close or open.

MAGNETIC TIMERS.

These timers depend on the fact that the time taken for a magnetic field to collapse depends upon the fundamental constants of an electric circuit—these constants being resistance, inductance and capacity. The time of collapse is a function of the ratio L/R.C., L being the inductance of a circuit, or in other words, its ability to store electro-magnetic energy, R the resistance which depends only on the size of wire used in the circuit, its length and the material from which it is made, and C the capacity or ability to store electro-static energy. The greater the inductance the greater the time, and the greater the product of R and C the less the time required for the collapse of the magnetic field. The method of using this fact is to arrange that the foot switch closes a pilot relay, the coil of which is then short-circuited. On this taking place the flux tends to collapse and in so doing generates a current in the coil which is in such a direction as to oppose the collapse of the field. When the field has reached a sufficiently low value the relay armature drops out and the main contactor is released.

The device is known as the " flux-decay " or induction type timer and is claimed to be reasonably accurate between 3 and 60 cycles. It is not a suitable method for long periods owing to the obvious difficulties of securing a sufficiently large value of the inductance. The time is controlled by varying the value of the resistance which short-circuits the relay coil. In addition to patterns giving single spot times of between 3 and 60 cycles there are others giving single spot or repeat spots between 6 and 60 cycles. The timing may be arranged for direct control of a D.C. operated welding contactor or special relays may be included with or without " hold-out " coils.

In one method of applying the flux-decay principle a relay having two armatures and two coils is used. The upper coil is the closing coil ; the lower coil is a holding-out coil so designed that it will prevent the top armature of the relay from closing until the current in the holding-out coil reaches a very low value. The structure of the lower portion of the relay is such that the holding-out coil operates in a magnetic circuit which is practically closed, i.e., one with a very small air gap. This circuit is highly inductive, and consequently, if voltage is applied to the holding-out coil and then removed and the coil short-circuited, current will continue to flow in the coil for an appreciable period of time, during which the relay will remain open and contacts will not close until the current falls to a very small value.

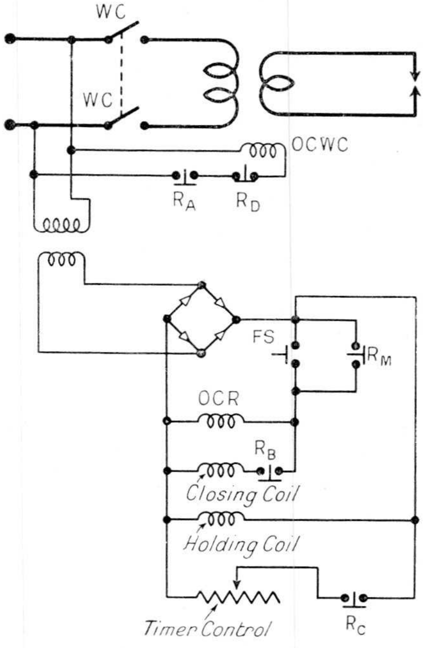


Fig. 129. Schematic diagram of induction type of timer.

The timing of the relay may be adjusted by increasing or decreasing the air gap in the magnetic circuit of the holding-out coil, which changes the value of the current at which the relay will close. Coarse and fine adjustments of the air gap are provided, but normally sufficient adjustment can be obtained by means of a rheostat connected in the circuit in the manner described below.

Fig. 129 shows an elementary schematic diagram of a flux-decay or magnetic timer. A transformer and rectifier provide a low voltage direct current for operating the timer, the sequence of operations being as follows :—On closing the foot switch relay R is energised and closes the four auxiliary contacts shown as R_a, R_b, R_c and R_m. R_a is in the line voltage circuit and on being closed the welding contactor operating coil is energised, the contactor closes and welding commences. R_m maintains the contact and ensures that the sequence continues even if the foot is removed from the foot switch. R_b closes the pull-in coil of the cut-out relay, whilst R_c short-circuits the holding-out coil through an adjustable resistance—the holding-out coil being continuously energised. The value of this resistance determines the rate at which the current and hence the flux in the holding coil die away, and until this takes place the pull-in coil does not operate. When, however, the pull-in coil overcomes the force exerted by the holding coil the relay operates, thereby opening the contacts R_d and hence the circuit of the welding contactor operating coil. Fig. 130 shows an induction type timer, and main relay with pull-in and hold-out coils on the right.

RESISTANCE CAPACITY TIMERS.

This well-tried type of timer is based upon a resistance capacity charging circuit, the principle of which is best understood by reference to a simple hydraulic analogy such as that shown in Fig. 131. In this diagram P represents a pump drawing water from a sump S_1 and pumping it through

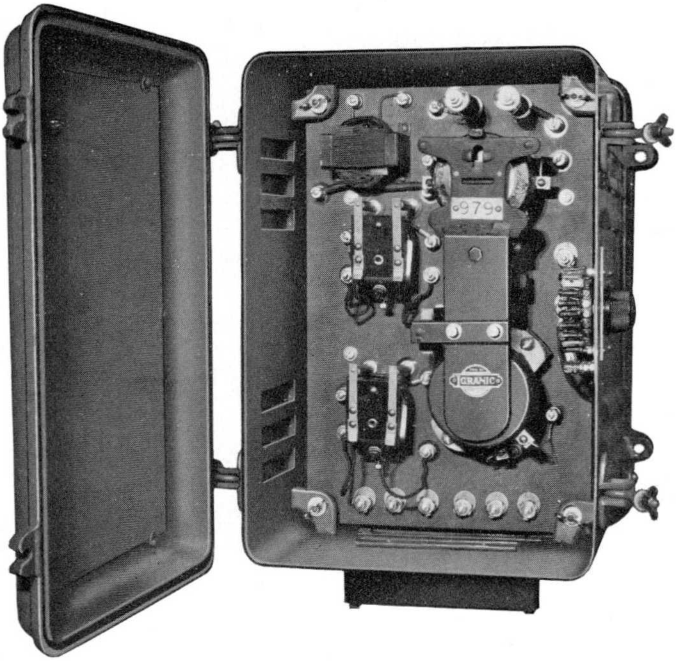


Fig. 130. Induction type timer.

the valves V_1 and V_2 to the reservoir R. Now clearly the rate at which the reservoir can be filled with water depends on the opening of the valve V_1 if we assume a constant speed of the pump. The reservoir may take 30 minutes to fill if the valve is only just open or it may be filled in five minutes if it is fully open. In other words the valve introduces a resistance into the circuit and the higher the resistance the longer it takes to fill the reservoir, that is, to build up a given store of potential energy.

Now the resistance capacity timer works in just this way—the pump being replaced by the direct current source of supply, the reservoir by a condenser, and the valve V_1 by a resistance. The coil of the welding contactor relay is connected in parallel with the resistance. When the supply is switched on the contactor closes because there is a large voltage drop across the resistance—equivalent to a big pressure difference on the two sides of the valve V_1. As the condenser charges up, the voltage across the contactor falls until it is insufficient to hold in the contactor, just in the same way as when the potential head of water reaches its maximum, the pressure exerted by the pump on one side of V_1 is equal to the pressure due to the reservoir head on the other side and no flow takes place. The operating time can be altered either by changing the resistance or by changing the capacity which is equivalent to altering the setting of the valve or changing the diameter of the reservoir tank so that it takes more or less water before it reaches the limiting head determined by the pressure available from the pump.

A simple diagram of connections is shown in Fig. 132. The control circuit operates at a low voltage direct current and this is provided by the

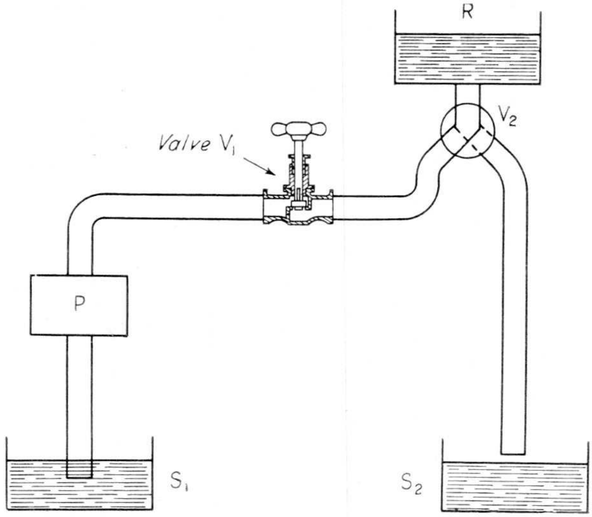


Fig. 131. Hydraulic analogy of resistance capacity timer.

transformer and rectifier shown. When the welding control switch, generally a foot switch, is operated, a large charging current flows and the voltage drop across the time control resistance is sufficient to cause the contactor to pull in. The charging current falls off and after a certain time, de-

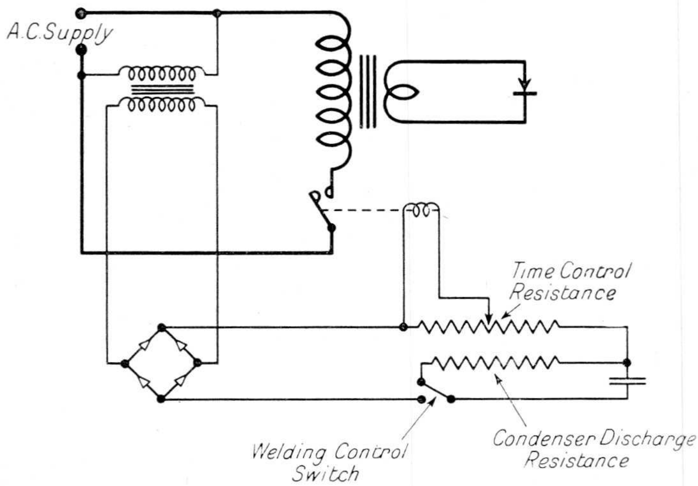


Fig. 132. Elementary circuit of resistance capacity timer.

pending on the constants of the circuit, the current is so small that the voltage drop across the time control resistance is insufficient to retain the contactor, which then drops out and the welding cycle is completed. The condenser discharge resistance shown dissipates the charge in the condenser and so prepares it for a fresh cycle of operations which is initiated by the closing of the welding control switch. The changing over of this switch to the discharge position is equivalent to changing the valve V_1 in Fig. 131 to the position shown by dotted lines and so discharging all the water from the reservoir to the sump S_2.

Inaccuracies are introduced by the variation of the drop-out voltage of the contactor and temperature rise effects, which modify the value of the contactor coil resistance and the value of the time control resistance. Variations of the supply voltage also introduce inconsistencies. When the contactor is a large one it is usual to interpose a relay or relays to keep the value of the direct current to a small amount. This also restricts the size of the auxiliary transformer and rectifier, which otherwise tend to be unduly cumbersome.

This timer is reasonably accurate for spot welding within the limits of 2 and 100 cycles and in some types, timing periods up to three seconds can be arranged. The timers may also be adapted to give repeated cycles of time on and time off for continuous spot welding.

An illustration of a resistance capacity timer incorporated in one unit with a contactor is shown in Fig. 133. Automatic and non-automatic operation are controlled by the left-hand switch ; the right-hand switch cuts out the timer. In the centre is an indicating lamp which lights up during the welding period and below this is the graduated dial of the time control resistance. By modification of the circuits of resistance capacity timers so that the timing period does not start until appreciable current is flowing in the welding transformer the useful feature can be obtained that mill scale on steel sheet is broken down and the timing period delayed until true contact is established.

A schematic diagram for a resistance capacity timer is shown in Fig. 134. The method of operation is as follows :—When S is closed the transformer is energised and a D.C. voltage appears at the rectifier terminals. On closing the foot switch F.S. current flows through the operating coil of the contactor B (O.C.B.), auxiliary contact B_1 closes and so permits the release of the foot switch without interruption of the further sequence of operations. Auxiliary contact B_2 also closes and current passes through the operating coil of the welding relay (W.R.) which is then closed. On closure of the welding relay the main welding contactor closes and welding commences—the fact being indicated by the lighting of the lamp in parallel with the welding relay operating coil.

Fig. 133. Resistance capacity timer with welding contactor.

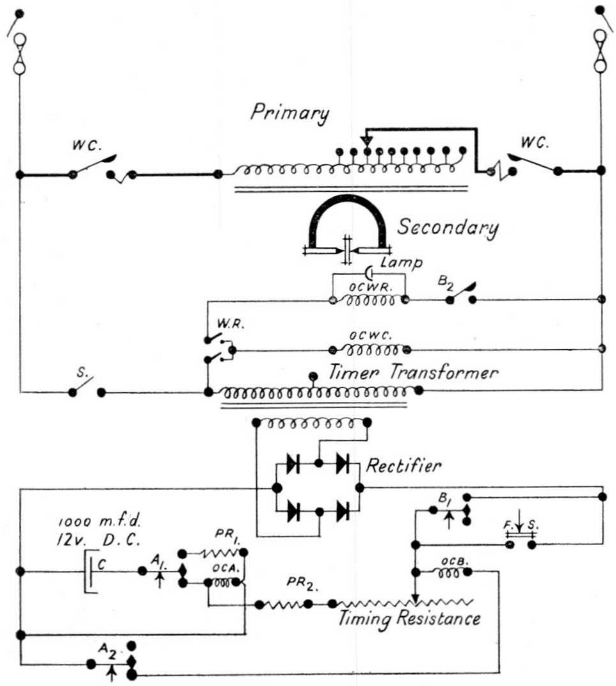


Fig. 134. Schematic diagram for resistance capacity timer.

The condenser C now charges up through the timing resistance—the value of which determines the rate of charge. When the charge is complete current flows through the operating coil of relay A (O.C.A.) and contacts A_1 and A_2 are changed, the former placing the discharge resistance PR_1 across the condenser and the latter opening the circuit of contactor B operating coil and so opening B_2, the welding relay and the main contactor. The opening of B_1 interrupts the current through the operating coil of A, so A_1 and A_2 return to their normal position and everything is re-set for a fresh cycle of operation.

A.C. ELECTRONIC VALVE TIMING CONTROL.

The electronic valve timer is similar in type to the resistance capacity timer, with the exception that a vacuum type valve is used to replace the metal rectifier found in the straight resistance capacity timer. The electronic timer of this type is more independent of voltage variations than the straight resistance capacity type and is sufficiently rapid to give up to 100 welds per minute at the minimum time setting.

One type of electronic timer is arranged to give both time and current control, i.e., by the use of a current transformer the timing current is shortened or lengthened according to changes in the welding current due to variations in surface resistivity of the materials to be welded.

The electronic timer can also be arranged as a repeating type giving variable timing between welds in addition to welding time control over a range of 6 to 80 cycles.

The use of a hard vacuum type of valve limits the current which can be handled by this type of timer and it is necessary to use an intermediate relay between the timer and welding contactor when heavy contactors are employed.

This limitation is removed when the mercury vapour electron tube is used as these are capable of handling much heavier currents. The usual method of control is to apply a grid control voltage to block the flow of current through the valve. The timing range can be extended over a period of 0.1 to 5 seconds by a suitable variable resistance. The welding contactor is essentially of the D.C. operated type. By using three timers of this type a modified form of " woodpecker " control can be obtained.

Many combinations of constant time, time and current, repeating control and variable cycle control can be obtained by the use of the timers described in this section. The basic principle of flux-decay or the more common resistance capacity circuit is used throughout the combinations so that in all cases the inherent faults of these basic methods are present to some degree. Similarly the combinations are all used with welding contactors to control the heavy primary currents of the welding transformer.

To obtain freedom from the variables due to contactor operation and more especially to deal with heavy currents, it is necessary to have recourse to thyratron and ignitron controllers described in detail in Chapter X. Nevertheless, the low cost and reliable action of the magnetic, resistance capacity and electronic valve timers enable them to fill a wide field of usefulness on machines between 5 and 100 kVA., where extreme accuracy is not essential, and where the number of operations does not exceed 150 per minute. The comparatively high cost of thyratron and ignition controllers militates against their more general use and ensures the continued operation of the simpler, if somewhat less precise, equipment described above.

CHAPTER X

ELECTRON TUBE CONTROL

By B. G. HIGGINS, B.Sc., A.M.I.E.E.*

Advantages of tube control—The thyratron—The ignitron—Principles of timing circuits—Contactor timer control for spot welders—Water-flow switch—Heat control by phase shift—Synchronous Ignitron Control—Circuit operation.

ADVANTAGES OF TUBE CONTROL.

Electron tube control has found a very wide field of application in the control of resistance welding machines, largely due to the many advantages which result from its use. The chief points in its favour over the more usual types of control are as follows :—

(1) No moving parts in the main power circuit.

(2) No contactor tips requiring maintenance and replacement.

(3) Increased speed of operation, resulting in greater output from the production line.

(4) All welds are of exactly the same duration.

(5) Flexibility of control, giving easy change in the length of the welding time and, in the case of seam welders, the " off " time also, from one cycle (0.02 sec.) upwards.

(6) Ease of controlling the welding heat within fine limits, by means of phase shift control, thus avoiding the necessity for a large number of taps on the welder transformer.

(7) Negligible maintenance.

(8) Silence in operation.

Flexibility of control, the ability to vary the " duty cycle " (ratio of " time on " to " time on plus time off "), and to obtain " on " times as low as one cycle gives electron tube control a great advantage over a rotary modulator type of control, in which the duty cycle is inherently fixed at 50 per cent. Further, " cut off " of current flow takes place within a quarter of a cycle with tube control, but with a modulator, " cut off " of current flow never takes place, since the current rises slowly to a maximum and falls slowly to a minimum, which is usually about 30 per cent. of the maximum. In this case, 30 per cent. of the maximum welding current is always flowing, and this current produces heat at the electrodes which merely serves to overheat and distort the work. For most classes of work complete cut-off of current for a certain percentage of the welding cycle is essential, and this condition can readily be satisfied by using tube control.

* British Thompson-Houston Co. Ltd.

For those spot welding applications which do not require welding times below five cycles, and in which the welding kVA. is easily within the capabilities of a contactor, difficulty may be found in justifying the cost of an " all-tube " control panel, particularly if very fine adjustment of the welding heat is not required. In this case, a " contactor timer " equipment will solve the problem ; such a control consists of a contactor which is timed by an electron tube timer. The welding heat is then controlled by varying the length of the welding time and by changing taps on the welder transformer.

ELECTRON TUBES.

The two chief types of electron tubes involved in the control of resistance welding machines are the thyratron and the ignitron, and these two tubes will now be described in detail.

The thyratron (Fig. 135) is essentially a three-electrode tube consisting of an anode, a grid, and a cathode, either of the filamentary or the indirectly heated type. These electrodes are enclosed within an evacuated glass envelope, and a few drops of mercury are added to provide the mercury vapour for sustaining the arc, by means of which the current flow through the tube is maintained. As in all other electronic devices, the electron flow is from cathode to anode, the electrons being attracted by the potential of the anode, which is positive with respect to the cathode. (Conventional current flow is usually regarded as being from anode to cathode.)

The effect of a voltage, which is negative with respect to the cathode, being imposed on the grid, is to prevent current flow in the anode-cathode circuit. Assume that the anode is positive, all potentials hereinafter being with respect to the cathode. For a given anode potential, there exists a " critical " grid voltage (Fig. 136), and when the grid potential is below this value, i.e., more negative, no current will flow. If, however, the grid voltage is raised above this critical value, then current will flow in the anode-cathode circuit, provided the anode is positive.

Once this anode current is established, the grid is powerless to control or limit the current, provided the anode remains positive. This is because the positive ions form a sheath around the grid, and prevent its negative potential affecting the current flow. The actual value of the current which flows through the tube is decided not by the grid voltage of the tube, but by the resistance of the external circuit, the tube having a substantially constant voltage drop of about 20 volts across it, irrespective of the amount of current flowing.

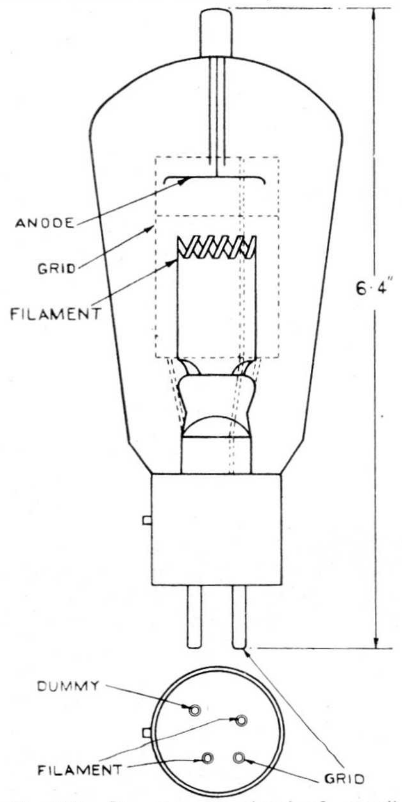


Fig. 135. Diagrammatic sketch of a small thyratron.

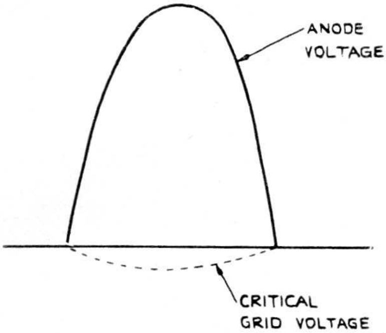


Fig. 136. Critical grid voltage curve for thyratron.

If now the anode voltage is reduced to zero or made negative, the current flow ceases and the grid regains control. If the grid voltage is now sufficiently negative, the grid can prevent the flow of current when the anode is made positive again.

If, then, the thyratron has its anode supplied with an alternating voltage, the arc is extinguished when the current wave goes through zero, i.e., once every cycle, and the grid can therefore regain control and prevent another current flow restarting when the anode becomes positive again on the next cycle.

Thus one thyratron can control a D.C. load, when its anode is fed with an A.C. voltage, the tube being made conducting or non-conducting depending on its grid voltage. Similarly, two thyratrons connected in reverse parallel, i.e., the anode of one connected to the cathode of the other, can control an A.C. load.

Thyratrons are available which can handle up to 12.5 amps. mean and 75 amps. peak at a voltage of 10,000 volts peak. From this it will be seen that in order to handle the high welding kVAs. demanded by the industry to-day, it would be necessary to operate the thyratron at its maximum anode voltage, since the thyratron is virtually a high voltage, low current device. This was done in the past, but the advent of the ignitron, which is a high current " low " voltage tube, rendered the use of high voltage circuits unnecessary. The ignitron is described below. Thyratrons are also available in a variety of smaller sizes for control duty, a typical tube at the other end of the scale being the B.T.19 tube, which is rated at 0.5 amp. mean, 2 amps. peak, at a maximum voltage of 1,000 volts inverse peak.

THE IGNITRON.

The ignitron (Fig. 137) is essentially a 3-electrode tube consisting of an anode, an igniter and a mercury pool cathode, and these electrodes are enclosed in an evacuated envelope, which may be of glass or of steel. The igniter, which is made of semi-conducting material, is conical in shape, and is permanently immersed, tip downwards, in the mercury pool cathode. A current impulse through the igniter produces a " hot-spot " in the mercury pool, and hence a source of electrons.

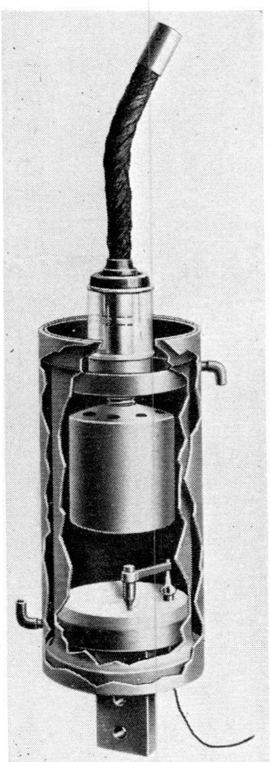


Fig. 137. Sectional view of BK.24 ignitron.

If the anode is positive with respect to the pool cathode, then these electrons will be attracted to the anode, and current will flow through the ignitron.

The glass ignitrons are fan-cooled, while the steel tubes are provided with a water-jacket, and are water-cooled.

Owing to the fact that the ignitron cathode is a mercury pool, the tube can handle currents of several thousand amperes for short periods of time without damage. The maximum current that the tube can carry for a certain period is largely dependent on the temperature of the surrounding envelope and connections—excessive local heating in the region of the glass-to-metal seals will cause failure of the seals through cracks developing. Since the steel tube envelope is at cathode potential, there are only two glass-to-metal seals, namely, the igniter seal and the anode seal—the cathode connecting lug being integral with, and welded to, the steel envelope. However, the envelope being at cathode potential, the clearances between the anode and " cathode " are less than in the glass ignitron in which the mercury pool and the igniter are the only parts of the tube at cathode potential. This means that the steel tube is more likely to " arc back " at excessive currents, i.e., a local hot-spot forms on the anode due to mercury being spluttered on the anode, and this acts as a small cathode, allowing the tube to conduct when the anode is negative with respect to the cathode. This liability to arc back increases with current and with inverse voltage, so that a further limitation is set on the maximum current the tube can carry for a given period of time.

It will be readily appreciated, however, that the ignitron has a very much greater " overload " capacity than the thyratron, since if the thyratron peak current is exceeded for even one or two cycles duration, then permanent damage will be done to the hot cathode: whereas in the case of the ignitron with its mercury pool cathode, the latter cannot suffer harm, and local heating is not likely to cause damage, in so short a time, unless the peak current is very seriously exceeded.

A typical ignitron which is used in welder control service is the BK.24, which is rated at 140 amps. mean, 4,000 amps. peak, at 440 volts R.M.S., which is equivalent to two such tubes handling a maximum of 1,200 kVA. at six per cent. duty cycle. As the peak current is reduced, so the maximum permissible duty cycle is increased. A larger ignitron, the BK.34, is rated at a maximum current of 355 amps. mean, 7.800 amps. peak, at 440 volts R.M.S., which is equivalent to two such tubes handling a maximum of 2,400 kVA., at a maximum duty cycle of 8 per cent.

From the ratings (see page 147 and Figs. 138 and 139) it will be seen that these two sizes of ignitron are capable of handling all that the welding industry is likely to require in the matter of kVA. demand.

Technical Information and Ratings of typical Ignitrons

Types A, B and C.

	A	B	C
General design—			
Tube voltage drop at 300 amp.			
(Maximum) ... ... volts	20	20	20
(Minimum) ... ... ,,	8	8	8
Net weight, lb. approx. lb.	7	10	20
Shipping weight, lb. approx. ,,	20	16	40
Cooling	Fan	Water	Water
Maximum ratings—			
*†Welder control service; ratings are for any voltage from 250-600 volts R.M.S. ...	—	—	—
Maximum demand ... kVA.	450	1,200	2,400
Corresponding average anode current ... ... amps.	10	75.6	192
Maximum average anode current ... ... ,,	15	140	355
Corresponding demand kVA.	230	400	800
*Maximum time of average anode current " T " secs.—			
At 600 volt R.M.S. secs.	7.6	5.9	4.7
At 440 volt R.M.S. ,,	10.2	8.0	6.3
At 250 volt R.M.S. ,,	18.0	14.0	11.0
Maximum surge current, peak amps. (per cent. of maximum R.M.S. demand current) ... ... amps.	280	280	280
Igniter potential (volts)—			
Maximum instantaneous allowed, igniter positive. volts.	900	900	900
Maximum instantaneous required, igniter positive. volts.	200	200	200
Maximum instantaneous allowed, igniter negative. volts.	5	5	5
Igniter current (amperes)—			
Maximum instantaneous allowed ... ... amps.	100	100	100
‡Maximum instantaneous required ... ... amps	40	40	40
Maximum average allowed ,,	1	1	1
‡*Igniter ignition time*, maximum micro-secs.	100	100	100
Igniter current averaging time ... ... secs.	5	5	5
Maximum outlet water temperature ... ... C°	—	40	40
Minimum flow gals. per min.	—	1.5	3.0

* With the use of Log-log paper, straight line interpolation may be used to arrive at other detailed ratings.

† R.M.S. demand voltage, current, and kVA. are all on the basis of full cycle conduction (no phase delay) regardless of whether or not phase control is used. For voltages below 250 volts use the 250-volt rating.

‡ Ignition will occur if either maximum required instantaneous positive potential is applied or maximum required instantaneous current flows for the rated maximum igniter ignition time.

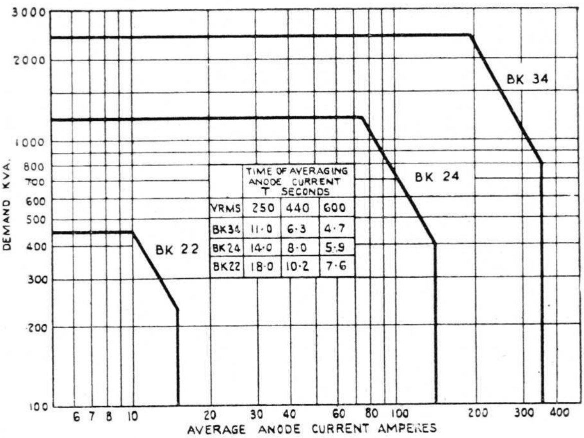


Fig. 138. *Curve showing average anode current against demand kVA. for C, B* and *A ignitrons.*

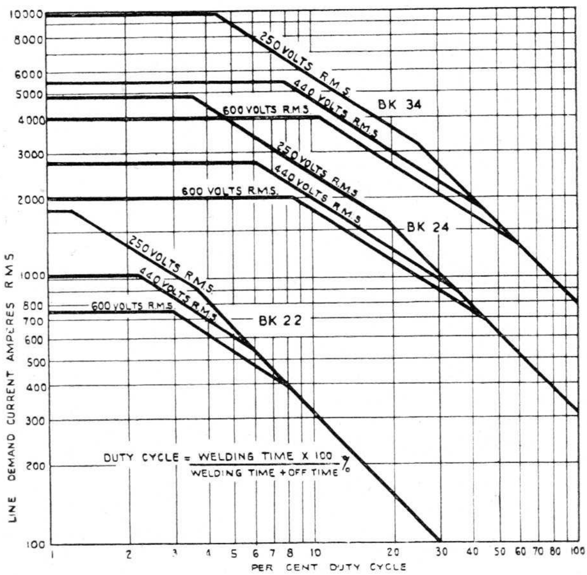


Fig. 139. *Curves showing per cent. duty cycle against line demand current (amps. R.M.S.) at various voltages for C, B and A ignitrons.*

THE RESISTANCE-CAPACITY TIMING CIRCUIT.

The fundamental principle of the resistance-capacity timing circuit has already been described. The following shows the application of the principle to tube control circuits. Fig. 140 shows such a circuit in which condenser C and resistance R are connected in series with switch S across a D.C. supply voltage. Switch S is of the two-way type, and is arranged to short-circuit condenser C through resistance R in one position ; under these conditions, condenser C is discharged, and since C and R are disconnected from the supply, the voltage across both C and R will be zero.

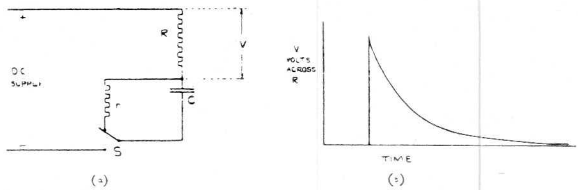


Fig. 140 (*a and b*). *Principle of resistance capacity timing circuit.*

When switch S is operated, it open-circuits the discharge path through r and then connects condenser C to the D.C. supply. Since the voltage across a condenser cannot be changed instantaneously without flow of current, it follows that at the instant of connecting C to the supply, the full supply voltage must appear across resistance R. Condenser C will then commence charging up exponentially, and as the voltage across C rises, so that across R falls, since at any instant the sum of these two voltages must equal the D.C. supply voltage, which is assumed constant. Eventually when C is fully charged, the voltage across R will again equal zero. The instantaneous voltage across R is shown in Fig. 140b.

If the value of the resistance R, or of the condenser C, were doubled, then the time taken for the voltage across R to reach zero would be twice the time shown.

When the switch S is returned to its original position, the charged condenser C is disconnected from the supply, and allowed to discharge through the resistance r. It follows, then, that if resistance r is equal to R, then the voltage of the condenser will fall exponentially at the same rate as the voltage across R fell when the condenser was charging up, and the curve for this decaying voltage on the condenser will be the same as that in Fig. 140b.

If, then, this exponential voltage is connected in series with a variable negative voltage, and the total voltage is applied to the grid of a thyratron with A.C. volts on its anode, then the thyratron can be made to conduct for different periods of time depending on the value of the negative bias voltage. The thyratron will conduct for as long as its grid is made positive with respect to its cathode ; Fig. 141a shows the grid normally biased heavily negative, such that the grid is only positive for a very short time, and the thyratron therefore conducts for a short time only. Fig. 141b shows the grid biased very slightly negative with the result that when the exponential voltage occurs the grid is positive for a longer time, and the thyratron therefore conducts longer.

This, then is the basic principle of all tube timing circuits, but variations of the principle are obvious. Therefore, it is immaterial if the exponential voltage is obtained from across a resistance which is in series with a condenser that is being charged, or if the exponential voltage is taken from across a pre-charged condenser, which is allowed to discharge through another resistance. Again, the timing can be varied by keeping the negative bias voltage fixed and varying the value of C or R : in order to cover wide ranges of time, it is often arranged to change C or R to give a different range of time and to vary the time throughout that range by altering the bias voltage. A further variation in the circuit is to vary the precharged voltage of the condenser, since the time taken to discharge the condenser from a voltage V_1 to a voltage V_2 will be longer for higher values of V_1 provided C and R remain the same.

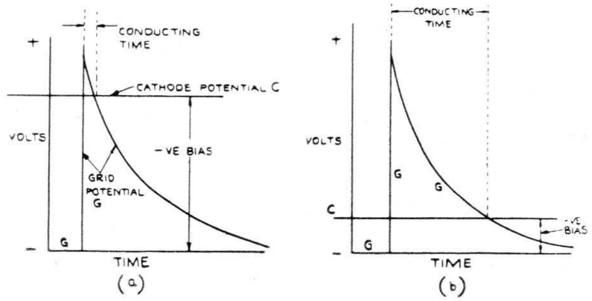


Fig. 141 (a and b). Principles of resistance capacity timing circuit.

CONTACTOR TIMER CONTROL.

The makers have developed a very large range of thyratron and ignitron panels for the control of resistance welding machines, and the chief of these will now be described commencing with the contactor timer (Fig. 142). The function of this equipment is to control accurately the duration of the flow of welding current to a spot welder, which may be air-operated, mechanically driven, or pedal-operated. The welding time is initiated by the closing of a control switch on the welding machine. For an air-operated machine this switch is usually an air-pressure switch which is arranged to close when a certain pressure exists between the electrodes; for a mechanically driven or power-operated machine this switch is frequently cam-operated, while in the case of the pedal-operated machine the switch is operated by depression of the foot pedal.

The apparatus consists essentially of a thyratron control panel comprising a D.C. timing circuit for controlling the thyratron, which in turn controls the welding current through the medium of a welding contactor. The contactor, which is mounted separately from the timer panel, is available in two sizes, 150 amps. and 300 amps.

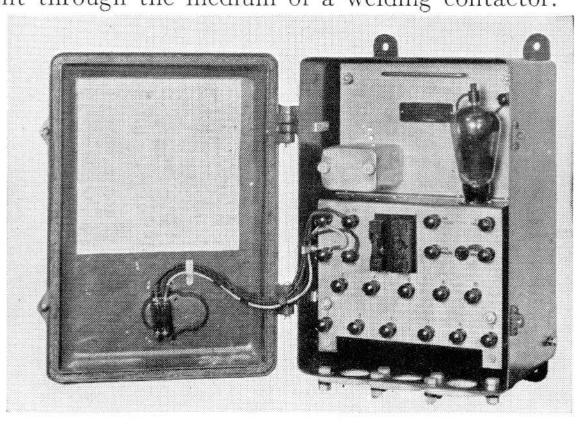


Fig. 142. Contactor timer panel.

Adjustment of the welding time is carried out by means of a separately mounted potentiometer rheostat, in conjunction with a range switch mounted on the door of the timer panel. The rheostat dial is calibrated in cycles for the "short" range and in seconds for the "long" range; the timing can be varied from five cycles to 100 cycles on the short range, and from 1 to 10 seconds on the long range.

The weld initiating relay is energised at low voltage—12 volts D.C.—so that risk of shock to the operator when using portable electrode tongs with trigger initiating switch is eliminated.

The equipment operates entirely from 50-cycle single-phase A.C. mains, and taps are provided on the mains transformer to operate on any voltage between 400 and 440 volts.

The control panel will operate up to a maximum of 150 welds per min., and will initiate the weld when the control switch closes; it is immaterial when the control switch opens. When controlling a welding machine with an air-operated head, the use of a pressure switch is recommended, since it is particularly suited to frequent operation at high speed. Further, it requires no adjustment or alteration for satisfactory operation when the air pressure is varied by means of a reducing valve over a range of from 10 lb. to 100 lb. per sq. in. The timer panel is shown in Fig. 142, and the circuit used in Fig. 143.

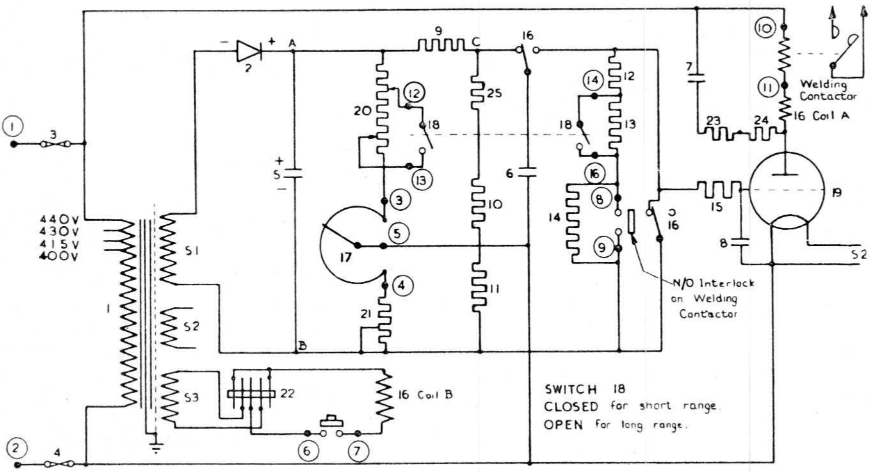


Fig. 143. Circuit diagram for contactor timer.

Description of the Circuit Operation.

The mains transformer 1 supplies the cathode of thyratron 19, the D.C. supply for the control circuit by means of copper oxide rectifier 2, and the 12-volt D.C. supply for coil B of initiating relay 16, by means of selenium rectifier 22. The control circuit voltage is approximately 330 volts, when measured across condenser 5, using a high resistance D.C. voltmeter. The top plate of condenser 5 (point A) is the positive, and the bottom plate (point B) is the negative of the D.C. supply voltage.

The timing of the weld is carried out by causing the thyratron to conduct for a certain period; the grid voltage for controlling the thyratron is derived from a resistance-capacity charging circuit, condenser 6 being charged to a certain potential and then being made to discharge to a second potential through resistances 12 and 13. Short times are obtained by short-circuiting resistance 13 by means of range switch 18. Intermediate welding times are obtained by rotation of the potentiometer rheostat 17.

When the supply is first switched on, the cathode of the thyratron will commence to heat up, and the D.C. control voltage will build up; the thyratron grid is connected through the normally closed contact of relay 16 to the D.C. negative, and is thus negative with respect to its cathode. The thyratron will therefore be held non-conducting as soon as the cathode warms up.

In order to initiate a weld, a circuit is made between terminals 6 and 7. This energises coil B of relay 16, which picks up. The grid of the thyratron is then disconnected from the D.C. negative, and at the same time condenser 6 is disconnected from point C, which is slightly negative with respect to the D.C. positive. The positive plate of condenser 6 is then connected to the thyratron grid circuit, and also through the high resistances 12, 13 and 14 to the D.C. negative. The thyratron grid is now positive with respect to its cathode, and the thyratron therefore conducts, energising the welding contactor, and also coil A of relay 16. Meanwhile condenser 6 is discharging at a very slow rate. However, as soon as the contactor closes its normally open interlock, high resistance 14 is short-circuited and condenser 6 commences to discharge at a much quicker rate. As the condenser discharges, a point will be reached when the thyratron grid is once more negative with respect to its cathode, and the thyratron will then cease conducting. It is obvious that the nearer the slider of the potentiometer 17 is to the D.C. positive, the sooner will the grid become negative with respect to the cathode, and thus the shorter will be the welding time.

When the weld has commenced, coil A of relay 16 will retain the relay closed, irrespective of whether coil B is kept energised, or the initiating switch is opened. If the initiating switch is held closed until after the weld is completed, relay 16 will remain energised, and the equipment cannot re-set until relay 16 is de-energised. Condenser 6 will continue to discharge until finally it will charge up in the reverse direction, its final voltage being that between the slider of rheostat 17 and D.C. negative: in other words, the upper plate of condenser 6 will have swung from slightly below the D.C. positive (point C) to the D.C. negative. If the initiating switch is opened before the weld is completed, then at the end of the weld coil A will release relay 16, whereupon the equipment will re-set to its original condition.

In order to provide very short welding times, resistance 13 is short-circuited, and the upper end of rheostat 17 is moved towards the D.C. positive by short-circuiting a portion of resistance 20. This is accomplished by means of the range switch 18.

Ignitron Contactor for Spot Welders.

For those applications in which it is not necessary to have welding times lower than five cycles, but where the welding kVA. is higher than 100 kVA., and the number of welds per minute is such as to make maintenance of a magnetic contactor a frequent source of trouble, the ignitron contactor offers an effective solution of the problem of rupturing the line current.

A typical example of this type is shown in Fig. 144 and consists of two ignitrons connected in reverse parallel, complete with ignition circuits for the igniters.

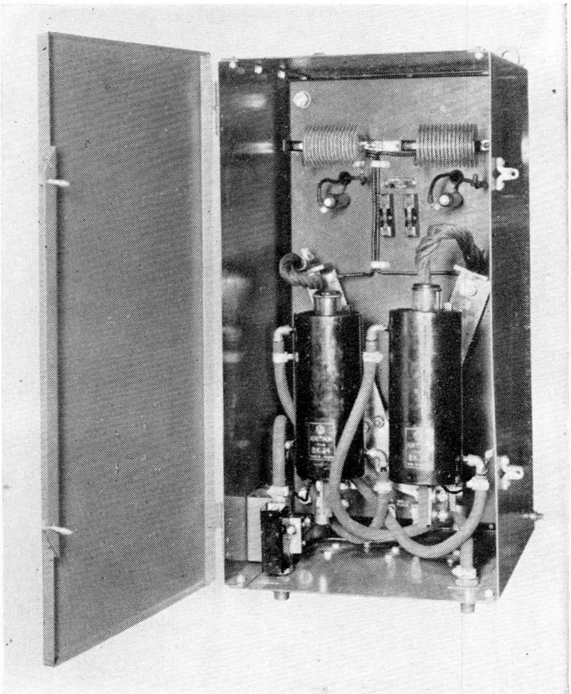


Fig. 144. Ignitron contactor.

The components are mounted on an insulating panel, and housed in a sheet metal box, suitable for wall mounting. No timing circuit is included, two control terminals being provided, across which is connected the customer's own timing device. Any suitable type of timing device may be used, but the best results will be obtained if an electron tube timer is used. The ignitrons will pass current whenever the circuit is made between the control terminals, and will cease conducting when the control circuit is broken.

The equipment uses two " B " type ignitrons, and its rating is therefore shown on page 147 and Figs. 138 and 139.

Water-flow Switch.

A water-flow switch is provided to prevent the operation of the equipment if the water flow through the ignitrons falls below $1\frac{1}{2}$ gallons per minute. The water-flow switch used is of the water flow and differential pressure type—the same as was mentioned previously in connection with the initiating of the weld on an air-operated welder. This switch is readily modified to make it suitable for operating either as a differential air-pressure switch or as a water-flow switch (Fig. 145).

Adjustment of the tripping point of the switch is carried out by screwing the throttle valve screw V in or out. The throttle valve V, which is in the middle of the larger of the two blocks, is screwed in to cause the flow switch to close its contacts with a smaller water flow.

The flow switch operates as follows :—

When no water is flowing through the flow switch the pressure on the two bellows A and B is the same, and since bellows A has less leverage than bellows B, the latter pushes the pivoted arm C to the left and opens the switch contacts. When sufficient water flows through the switch, bellows A exerts more pressure on the arm than bellows B, due to the pressure drop across the throttle valve: the arm is therefore pushed to the right and the switch contacts allowed to close. If the flow of water decreases, the pressure exerted by bellows A falls, until bellows B pushes the arm to the left, opening the switch contacts. If a blockage occurs, either on the inlet or outlet side of the flow switch, then the bellows both exert equal pressure, the arm moves to the left, and the switch opens its contacts and prevents further welding taking place until the normal water flow is restored.

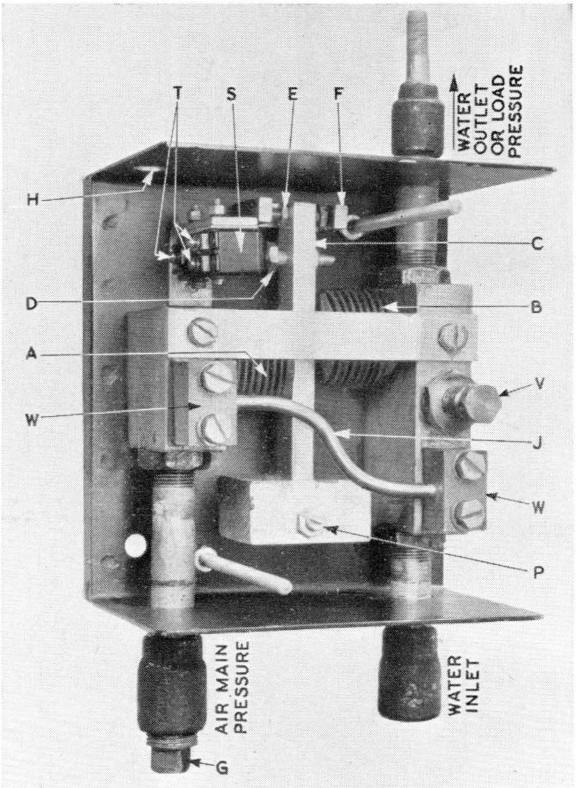


Fig. 145. Water-flow switch.

The ignitron contactor is only suitable for the control of spot and projection welding machines, and is not applicable to the control of seam welders.

Technical Description of the Ignitron Circuit.

The circuit is shown in Fig. 146. It will be seen that the two ignitrons are connected reversely in parallel, and that their igniter circuits are virtually connected in series. It will be noted, however, that each igniter and its protective resistance are substantially shunted by a metal rectifier ; the reason for this is to limit the reverse current which must be carried by each igniter. For instance, assuming that the anode of ignitron 1 is positive with respect to its cathode, and it is therefore desired to ignite this ignitron, when the circuit is closed between the control terminals, current will flow from the anode of ignitron 1 through the direct connection to the cathode of ignitron 2. Here the current path will be divided, the greater current flowing through metal rectifier 4 in a forward direction, while a small current will flow through the igniter of ignitron 2 as reverse current ; the circuit will be continued through fuse 8 to the timing device, water flow switch 9, and fuse 7, when the current will again divide ; the rectifier 3 will pass a small reverse current, but the greater current will flow through the igniter of ignitron 1 to the pool cathode, and thence through the load back to the mains. It will thus be seen that the igniter of ignitron 1 has received a heavy current impulse, and ignitron 1 will therefore fire. When load current ceases to flow through ignitron 1, it will be extinguished, and at this instant, due to the inductive load, an appreciable positive voltage will be present on the anode of ignitron 2 ; ignition of this tube will follow in a similar manner. Conduction of the two ignitron tubes alternatively will continue until the control circuit is broken.

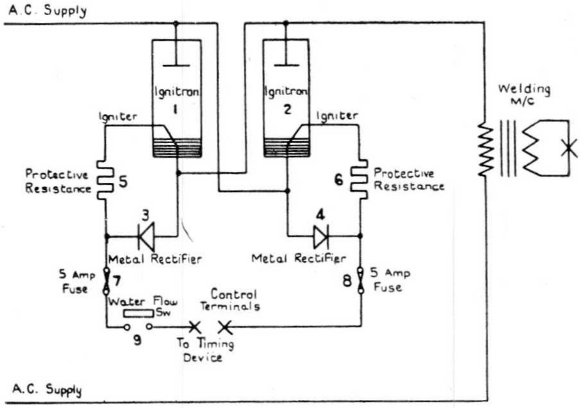


Fig. 146. Connection diagram for ignitron contactor.

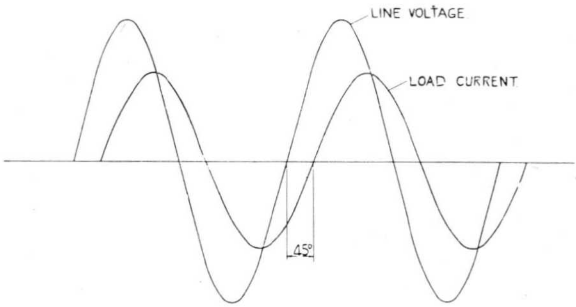
Since a voltage must exist across the igniter circuit in order to cause the current flow which brings about ignition, it follows that ignition cannot take place near the zero voltage point at which current transients in the power circuit will be most damaging. This explains why the ignitron contactor will give more uniform welds than the magnetic contactor, which can close the power circuit near the zero voltage point on the first half cycle of any weld.

The Principle of Heat Control by Phase Shift.

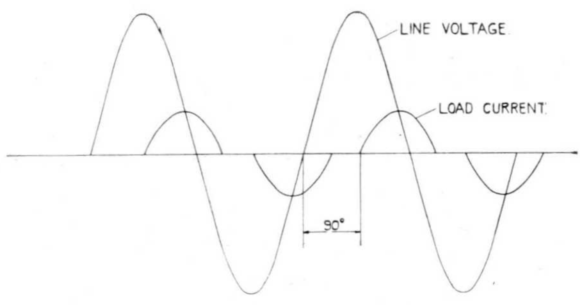
In the case of the ignitron contactor, each ignitron passes a full half cycle of current ; when the current in one ignitron ceases, the other ignitron immediately commences to pass current, and the resulting current wave will be a complete sine wave, just as would be obtained with an ordinary contactor. Each ignitron will commence to pass current at a point in the voltage wave decided by the power factor of the welder transformer. Suppose, for example, that the current wave goes through zero at a point 45 electrical degrees after the voltage wave has gone through zero (Fig. 147a.)

Now, then imagine that each ignitron is made to commence passing current not 45° after the voltage zero, but is delayed and made to conduct at a point 90° after the voltage zero (Fig. 147b). The resulting current " loop " or " half cycle " of current will no longer be a full sine wave, but will be somewhat less, because for 45° after each current wave goes through zero the current will remain at zero. This means that the effective R.M.S. voltage applied to the welding machine transformer will be less than the full R.M.S. voltage of the supply and, consequently, the welding current will be reduced, with a reduction in the welding heat.

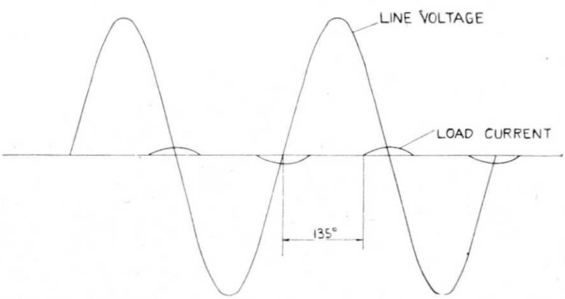
Suppose that the firing of the ignitrons is delayed still further and that they become conducting at a point 120° after the voltage zero : the



(a) Maximum heat current starts at 45°.



(b) Medium heat current starts at 90°.



(c) Minimum heat current starts at 135°.

Fig. 147. Effect of phase shift of fixing voltage on load current with welder of 70 per cent. power factor.

current wave will now be a succession of " loops " with gaps of 75° duration between the " loops " wherein the current will be zero. This brings about a further reduction in welding current and also in welding heat.

If the ignitrons are made to become conducting at a point 135° after the voltage zero, then the welding heat will be very substantially reduced (Fig. 147c). As a measure of the reduction in heat which can be obtained by this method, if full sine wave conduction, representing 100 per cent. heat, takes place at a power factor angle of 80°, then if the firing of the ignitrons is delayed to 130°, the heat is reduced to approximately 4 per cent.

This, then, is a very simple and effective method whereby the welding heat can be varied. In practice it is carried out in the following way. Each ignitron is made conducting by means of a trigger thyratron, which is fired by a peaking voltage wave. This peaking voltage is capable of being shifted in phase between 45° after the voltage zero and 135° after the voltage zero. This shift in phase is carried out by means of a phase shifting bridge, one member of which is a rotary rheostat. By rotation of this rheostat, any firing angle between the above limits can readily be obtained, and thus any value of welding heat set. Since the rheostat is of the stepless type, variation of the welding heat can be made in infinitely small amounts.

This is a great advantage over the method of altering the welding heat by changing taps on the welder transformer, for even if a machine is equipped with as many as 16 taps, it is frequently found that the heat tappings are far too coarse. Phase shift control renders a large number of taps on the transformer unnecessary, and in fact they can be dispensed with altogether. Further, phase shift control enables the heat to be altered while the welder is still on load, whereas with taps it is always necessary to shut down the machine to change the heat.

For those applications requiring welding times as short as one cycle, the contactor timer is not suitable owing to the variations in timing due to the contactor closing and opening at different points in the voltage wave. It is therefore necessary to make use of the " all-tube " control panel, embodying synchronous control. This equipment will now be described.

Ignitron Spot Welder Control.

The function of this equipment (Figs. 148 and 149) is to control accurately the duration and value of the current flow to a spot welder, the welding current being controlled by two ignitrons connected in reverse parallel in the supply line to the primary of the welder transformer. The ignitrons are controlled by two thyratrons. Phase shift control is provided to permit a smooth adjustment of the welding heat without changing taps on the welder transformer. The weld initiating control circuit operates at low voltage—22 volts A.C. Synchronous timing ensures that all welds on the same setting are of exactly the same duration. A time delay relay is provided to prevent operation of the control panel until the thyratrons have warmed up to their operating temperature. A water flow switch prevents welding being carried out if the cooling water flowing through the ignitrons falls below $1\frac{1}{2}$ galls. per min.

All the controls are mounted under a hinged cover on the door of the cubicle housing the apparatus, and both the cubicle and the control compartment can be locked. The equipment will handle up to a maximum of 1,200 kVA. when fitted with " B " ignitrons, and 2,400 kVA. when fitted with " C " ignitrons. The detailed ratings are shown on the curves in Figs. 138 and 139.

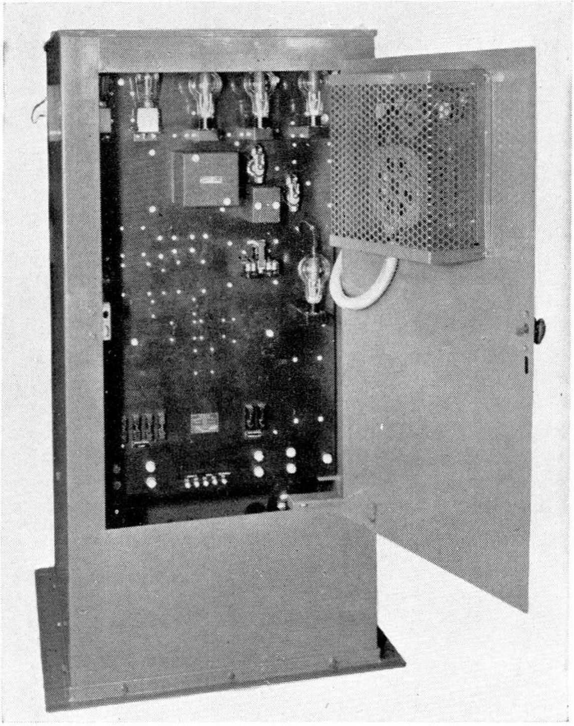


Fig. 148. Ignitron panel. Front view.

The timing range provided is from one cycle up to 24 cycles in increments of one cycle ; it is carried out in two ranges.

To illustrate the use of the rating curves, the following example is given :—

A spot welder operating on a 440-volt 50-cycle supply demands 400 kVA. from the line. What is the maximum duty cycle and the maximum welding time (conducting time) at which the ignitron panel can be operated ?

The R.M.S. line current in this case is :—

$$\frac{400,000}{440} = 890 \text{ amps. R.M.S.}$$

Fig. 139 shows that with two " B " ignitrons, operating on 440 volts, a demand current of 890 amps. is permissible, and that the maximum duty cycle allowed is 35 per cent. At 440 volts, the time of averaging the anode current for the " B " ignitron (from page 147) is 8 secs. : in other words, in any period of 8 secs., the maximum welding time (conducting period) must not exceed 35 per cent. of 8 secs. = 2.8 secs. = 140 cycles. Thus, if the welding time is chosen as 14 cycles, in any period of 8 secs., 10 such welds, preferably evenly spaced, may be made. If the welding time is 14 cycles, the " welding time plus off time " will be 40 cycles, and the " off " time will therefore be 26 cycles.

With regard to Fig. 138, note that in any period T seconds, for a certain voltage and kVA., the average anode current must not exceed the value shown. This point is taken care of in Fig. 132.

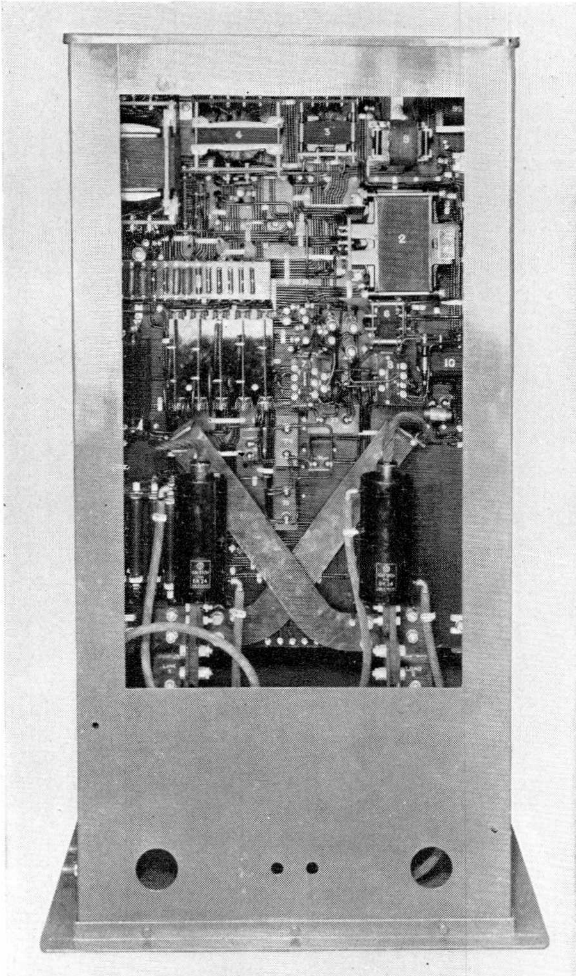


Fig. 149. Ignitron panel. Back view.

Heat Control Range.

The welding heat may be gradually varied from full heat, obtained by firing the ignitrons at the steady state power factor of the welder, giving full sine wave welding current, to a low heat obtained by firing the ignitrons at a point approximately 135 electrical degrees from the start (zero) of the voltage wave.

The phase shift is accomplished in two ranges. The low heat range enables the firing point to be retarded from 90° to 135° from the start of the voltage wave. When on the high heat range, the firing point may be advanced from 90° from the start, to a point which corresponds to the normal power factor angle of the welding machine, giving full sine wave current. If it is attempted to advance the firing point beyond the normal power factor angle of the welder, then one ignitron will fail to fire, and this condition must obviously be avoided.

Description of Circuit Operation. The Timing Circuits (Fig. 150).

The timing thyratron 90 controls the charging of the condensers 74 to 76 and 115, through resistances 24 and 25. The grid of the leading control thyratron 91 is normally held negative with respect to its cathode by the voltage between the slider of rheostat 16 (connected to grid) and the positive of the D.C. system (connected to cathode), and thyratron 91 is therefore held non-conducting.

When a weld is to be made, relay 15 is energised, and this applies anode voltage to the timing tube 90, but this thyratron is still held non-

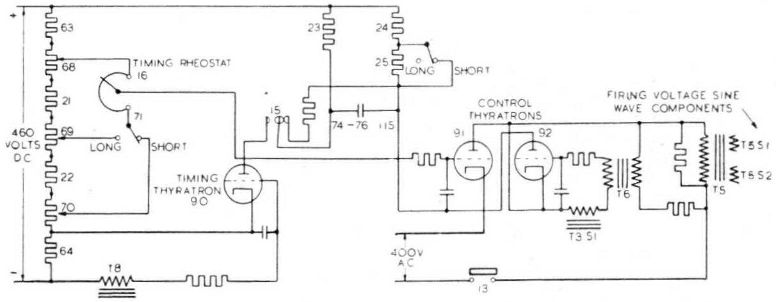


Fig. 150. Elementary diagram of timing circuit for spot welder panel.

conducting by the negative voltage on its grid derived from across resistance 64. However, when the next positive peak occurs in the secondary of transformer 8, this peaked voltage will overcome the voltage across resistance 64, and the timing tube 90 will become conducting. At this instant the grid of thyratron 91 becomes positive with respect to its cathode, since its cathode is carried negatively from the potential of the D.C. positive to about 20 volts positive with respect to the cathode of the timing tube 90 ; at this instant, also, the anode volts of thyratron 91 are arranged to be negative. Condensers 74, etc., will commence charging up, and since the grid of thyratron 91 is now positive, thyratron 91 will become conducting as soon as its anode volts become positive.

Tube 91 will remain conducting until condensers 74, etc., have charged up to such an extent as to make the grid of tube 91 once more negative with respect to its cathode. The time taken for this to occur will be determined by the position of the slider of rheostat 16 and the amount of charging resistance in circuit, as set by range switch 71.

When the condensers are fully charged, the flow of charging current through the timing tube 90 ceases. In order to prevent any change in, or " wandering " of, the potential of the anode of tube 90 with respect to the main potential divider, which might upset the operation of the equipment, the timing thyratron is maintained conducting by the provision of resistance 23, which is in parallel with the timing circuit.

The follower control thyratron 92 is made conducting by the voltage appearing across the secondary of transformer 6, as a result of tube 91 firing, which overcomes the hold-off voltage provided by the winding T3S1. Thus, for every half cycle of current passed by the leading control tube 91, the following half cycle will be passed by the follower control tube 92. These two tubes control the energising of transformer 5.

When the weld is completed, relay 15 is de-energised, and the condensers are then discharged through its normally closed contacts.

Trigger Thyratrons (Figs. 151 and 153).

The ignitrons 95 and 96 are controlled by the trigger thyratrons 93 and 94. These two thyratrons each have their grid voltage built up of four components, as follows :—

(1) A.C. hold-off voltage, sine wave component.

(2) Decaying negative D.C. component.

(3) Firing voltage " peaker " component.

(4) Firing voltage sine wave component.

1. The A.C. hold-off voltage sine wave component (300 volts R.M.S.) is derived from T4S3 and T4S4 and is 180 electrical degrees out of phase with the anode voltage of the trigger thyratron.

2. The decaying negative D.C. component is derived from the decaying voltage across resistance 41 and 42, in parallel with which are condensers 56, 103 and 58, 104 respectively. These condensers are charged up during the half cycle in which the trigger tube anode voltage is negative, so that during the half cycle in which the anode voltage is positive, the decaying D.C. component is added to the negative voltage provided by the A.C. hold-off voltage sine wave component. The function of the D.C. component is to ensure that when the anode volts are zero and going positive, a negative grid voltage already exists.

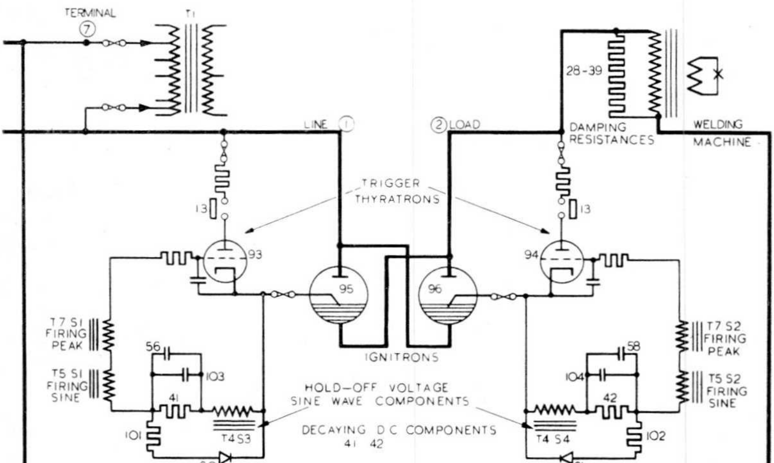


Fig. 151. Elementary diagram of ignitron circuits on spot welder control panel.

3. The firing voltage " peaker " component is derived from T7S1 and T7S2. The secondary windings of transformer T7 produce a voltage of peaked wave shape, and transformer T7 is therefore known as the " peaker " transformer. The peaker component derived from each of these secondary windings operates as a positive voltage of 200 volts peak in the positive half cycle of the trigger tube anode voltage. By itself it is unable to overcome the negative hold-off voltage derived from components 1 and 2 above, and cannot, by itself, fire the trigger tubes. It is, however, capable of being shifted in phase, since the primary winding of the transformer T7 is fed from a phase shifting bridge (Fig. 152).

The peaker component can occur anywhere between 45° from the voltage zero (maximum heat : maximum on the high heat range) and 135°

from the voltage zero (minimum heat: minimum on the low heat range). Medium heat is at 90° from the voltage zero (either maximum on the low heat range or minimum on the high heat range).

The phase shifting bridge consists of the heat control rheostat 17, resistance 66 and choke 10 for the high heat range: and rheostat 17 and condensers 79, etc., for the low heat range.

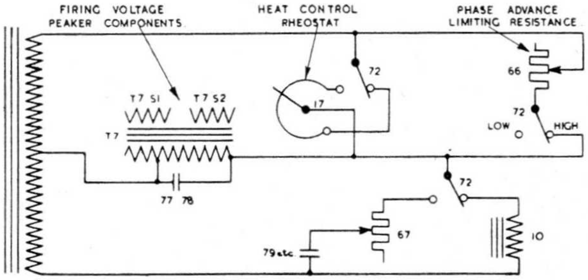


Fig. 152. Phase shifting circuit for spot welding panel.

4. The firing voltage sine wave component is derived from T5S1 and T5S2, and is 250 volts R.M.S., in phase with the anode voltage; it is therefore a positive voltage when the anode voltage is positive. When T5 is energised, the negative hold-off voltage is reduced to such a value that the peaker component is enabled to carry the grid positive and fire the trigger tube.

The firing voltage sine wave component therefore decides the number of cycles that the trigger tubes conduct, and the peaker component decides at what point in each half cycle the respective thyratron fires; the welding heat can thus be varied by shifting the phase of the peaker component.

The firing voltage sine wave components from transformer 5 are controlled by the control tubes 91 and 92, and they are in turn controlled by the synchronous timing thyratron 90.

When a trigger thyratron becomes conducting, it passes current into the igniter of its associated ignitron, which therefore immediately becomes conducting, at the same time short-circuiting the trigger tube. Oscillograms are shown in Fig. 153.

Permissible Phase Advance.

The maximum phase advance which is permissible is set by the power factor of the welding machine. If the welder has a very low power factor, and the phase shifter is set so that the peaker component is in advance of the current zero point represented by this power factor, then when a weld is initiated, only one trigger tube and one ignitron will fire. The reason for this is that when the first firing peak fires one thyratron and its associated ignitron (designated the leader thyratron and ignitron), the current will not go through zero until over 180 electrical degrees later: therefore, when the next firing peak occurs 180° after the first, the leader ignitron is still carrying current, and the second trigger tube (designated the follower thyratron) therefore cannot fire. When the leader ignitron ceases to pass current, the follower thyratron is then in a condition to fire as far as its anode voltage is concerned, but the firing peak of grid voltage has already occurred, and

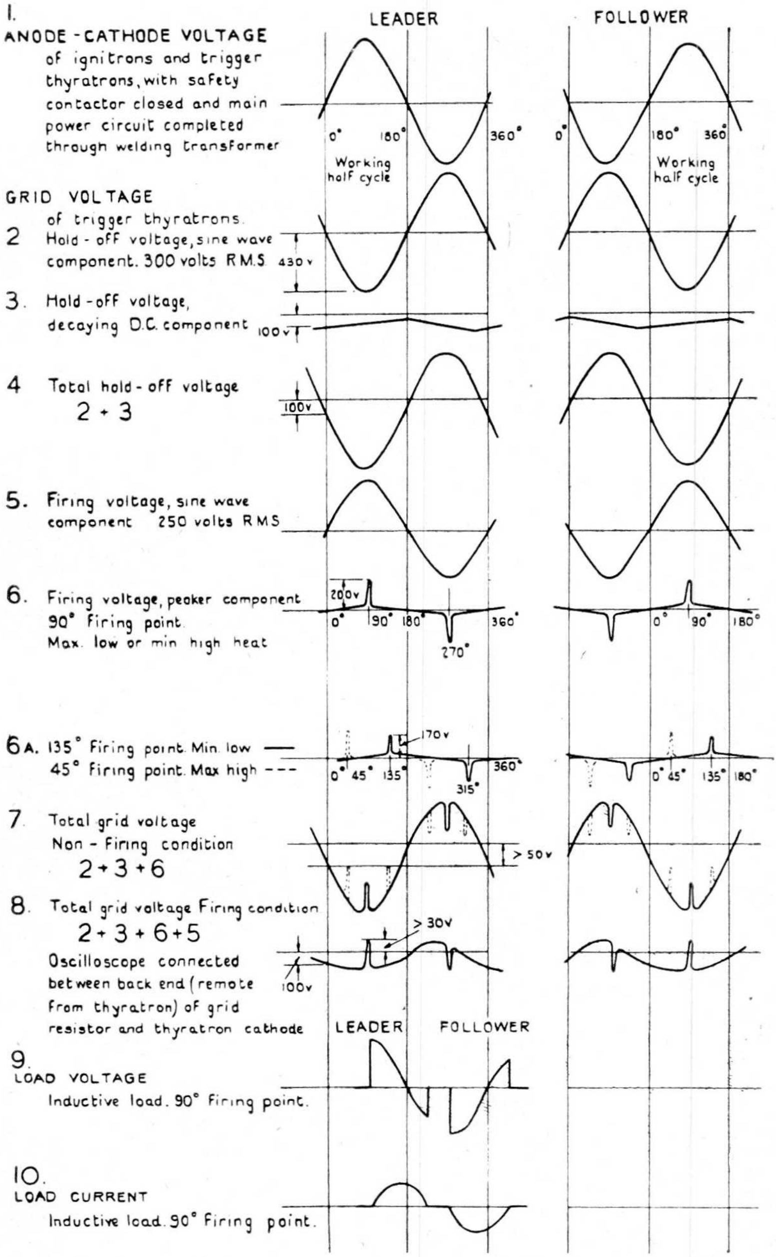


Fig. 153. Oscillograms, anode and grid voltages of ignitron trigger thyratrons to show functioning of heat control by phase shift.

the follower trigger tube cannot therefore fire. On subsequent cycles the same conditions exist, and so only one ignitron fires. Severe overload conditions will accrue, since in effect D.C. is being passed through the welder transformer which will quickly saturate.

This condition must be avoided and therefore means must be provided for limiting the phase advance on the high heat range. This is done by means of pre-set resistance 66, which shunts the heat control rheostat 17. Resistance 66 is therefore set by reducing it in value until, with the welding machine on its lowest power factor setting, the maximum (clockwise) stop on the heat control rheostat can just be reached on the high heat range without either of the ignitrons failing to fire. When adjustment of resistance 66 is carried out, due allowance should be made for variations in the power factor of the welding machine, such as may occur when using different electrodes, when altering the length of the throat of the welding machine, or the amount of material in the throat of the welding machine.

It should also be borne in mind that when the heat is set at any value by the control panel, the panel will only deliver that particular current value to the welder provided there is no change in the inductance of the welding machine, or in the value of the line voltage supplying the welding machine. Slight changes in power factor or in line voltage will, of course, bring about slight variations in the welding heat, but such variations will not upset the quality of the weld provided they are kept within reasonable limits.

Programme Control.

When spot welding is carried out on some of the aluminium alloys which are extensively used in the manufacture of aircraft parts, it has been found that increased strength is given to the welds if they are allowed to cool slowly. This is accomplished by following the welding process immediately by a post-weld heating period, during which a much smaller current is caused to flow through the completed weld. The post-weld current is usually of the order of 30 per cent. of the welding current. At the same time as the current is caused to fall to the lower value the electrode pressure is increased. A typical current cycle is shown in Fig. 154.

Ignitron control lends itself very readily to achieve the desired result, which is obtained by means of a special ignitron panel (Fig. 155). This control panel is very similar to the normal spot welder panel described above, and since it makes use of the same ignitrons its ratings are also the same. The chief difference lies in the duplication of the timing circuits and control tubes, and also of the phase shifting bridge circuit and the trigger tubes.

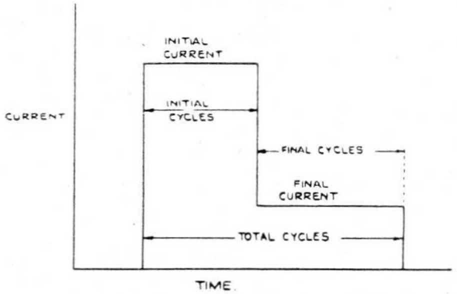
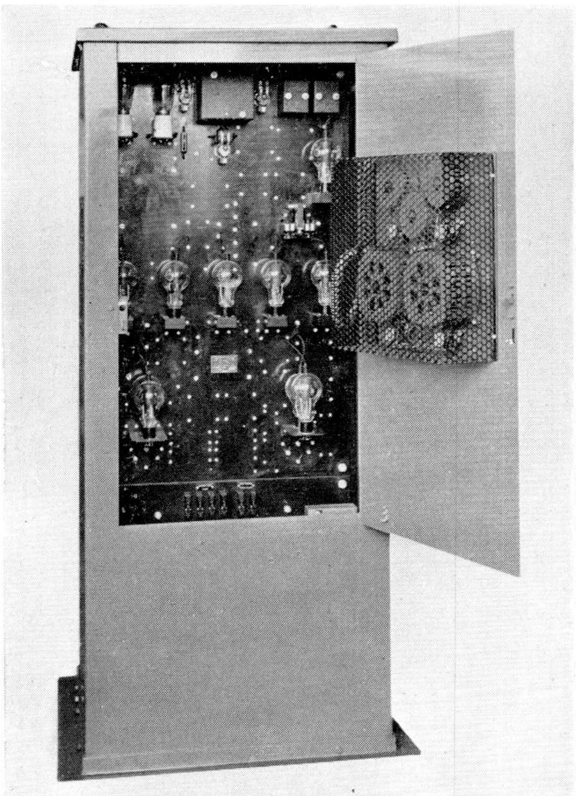


Fig. 154. Current cycle for programme control.

One timing circuit, designated the "initial cycles" circuit, controls the duration of the welding current proper, and operates in conjunction with one phase shifting bridge, known as the " initial " heat control circuit, to vary the value of the welding current by means of two trigger tubes. These " initial " trigger tubes control the two ignitrons as described above and, as far as the circuit has been described, it is exactly the same as the ordinary spot welder circuit.

However, the second timing circuit, operating from the same synchronous timing tube, but, having its own resistances, condensers, and timing rheostat, controls the conduction of two other control tubes, to energise for a predetermined number of cycles a second pair of trigger tubes. These tubes are called the " final " trigger tubes, and they operate on the same ignitrons as do the initial trigger tubes. The timing rheostat for the second timing circuit controls the " total " cycles, and the phase shift circuit controlling the " final " trigger tubes is known as the " final " heat control.

The circuit is then set up so that the initial cycles are, for example, five cycles, and the initial heat equivalent to say 100 per cent. heat ; the " total " cycles are set at, say, 15 cycles, and the final heat at 30 per cent. of the initial heat.



Fig, 155. Ignitron panel. For programme control.

The circuit operates in the following manner. When a weld is initiated, both timing circuits cause both pairs of trigger tube grids to become positive ; but, owing to the fact that the initial heat is set higher than the final heat, the initial trigger tubes are made conducting a certain number of degrees in advance of the final trigger tubes. The initial trigger tubes therefore fire the ignitrons at the advanced firing angle, giving full heat, and the final trigger tubes are short - circuited before their firing peaks occur ; they, therefore, have no control over the ignitrons.

This state of affairs exists for the duration of the initial cycles period of five cycles, at the end of which the initial trigger tubes are rendered non-conducting. But the final trigger tubes are set to conduct for a total of

15 cycles, so that for their remaining 10 cycles they are still conducting, and they, therefore, take over control of the ignitrons, firing them at the retarded firing angle, equivalent to the reduced heat. At the end of the 10 cycles of final heat (15 cycles total) the final trigger tubes become non-conducting, and current flow ceases altogether.

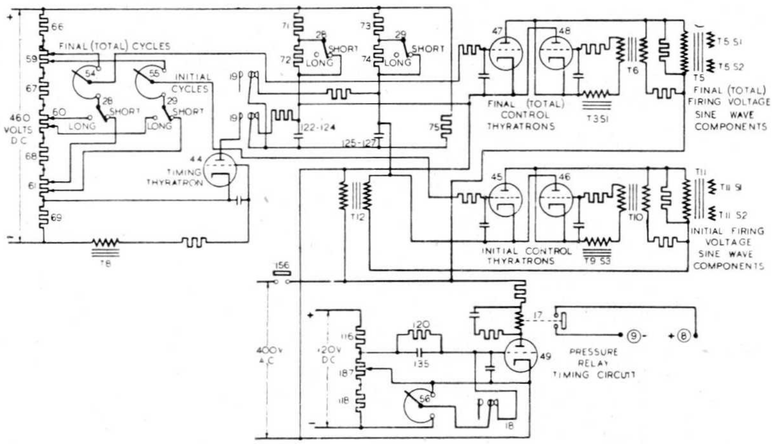


Fig. 156. Elementary diagram of timing circuits for programme control panel.

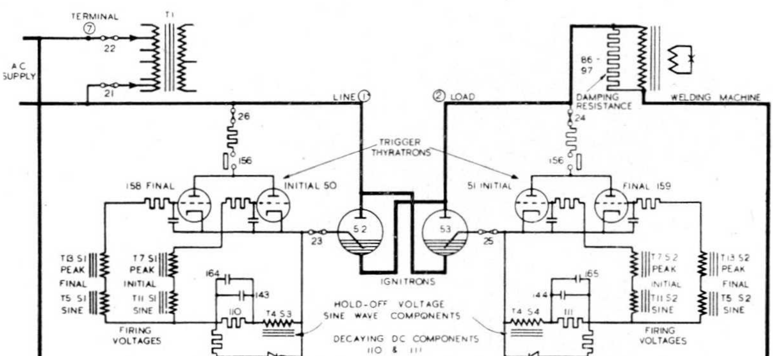


Fig. 157. Elementary diagram of ignitron circuits for programme control panel.

The panel is also provided with a separate timing circuit controlling a small relay ; by this means the relay can be made to close a predetermined number of cycles after the weld has been commenced Closing of this relay brings about an increase in the electrode pressure.

The timing circuits on the panel (Fig. 155) provide for " initial " and " total " timing periods from one cycle to 38 cycles, and the " pressure increase relay " timing circuit covers a range of from 0 to 38 cycles.

The programme control panel is shown in Fig. 155, and its circuits in Figs. 156 and 157.

A modification of the programme panel is the sequence programme panel. This is finding application in the spot welding of high tensile steels, where it is desired to give a variable off period immediately after the welding period, before commencing the post-weld heating period. The timing periods for the three timing circuits cover a range of from one cycle to 38 cycles. The rating of this panel is the same as the panel in Fig. 155. In this, the timing of each period commences at the end of the preceding period, hence the term sequence programme panel. The welding period is, of course, initiated by the closing of the pressure switch in the usual way, the pressure switch remaining closed until after the conclusion of the post-weld heating period.

Interrupted Spot Welding or "Woodpecker Control."

When it is required to spot weld very heavy sections of metal, or two sections of metal of greatly differing thicknesses, it is frequently necessary to resort to interrupted spot welding. In this process, which is also known as pulsation welding, the electrodes are brought together on to the work in the usual way; but instead of the weld being made with one "shot" of current of so many cycles duration, the weld consists of a number of short shots of current with "off" periods in between.

If it were attempted to weld a thick and a thin section together in the ordinary way, the thin section would burn through before the thick section were raised to anything approaching a welding temperature. But if the weld is made in a series of short shots, then the intervening off periods would enable the section of metal under the electrodes to attain a more symmetrical temperature gradient across the section, with the hottest point at the inner surfaces of the two sections.

As each shot of current is made, the temperature of the hottest point rises in steps, at the same time shifting gradually from the thin section towards the thick section, until the final shot completes the weld. The weld is thus made in a series of steps, or pecks, and hence the term "woodpecker control."

This type of welding can be carried out by electron tube control in two ways. It can be done by means of what is virtually a number of contactor timers, or by complete tube control throughout.

The first type of control embodies five timing circuits, which cause relays to operate in accordance with the timing set-up. The first timer controls the "on" time, and controls the welding current through an ignitron contactor; the second timer controls the "off" period; and these two timers operate alternately for a total period, which is set by the third timer. Since an ignitron contactor controls the welding current, no heat control by phase shift is provided. The remaining two timing circuits control the upset time, and the forging time respectively, the timing periods being timed in both cases from the start of the welding operation.

The "on" time (or "spot length") and the "off" time are variable between 10 cycles and 10 secs.; while the total time is variable from 15 cycles to one minute. The upset and forging periods are variable up to a maximum of one minute.

Since the equipment uses either " B " or " C " ignitrons, its rating is the same as the rating previously described.

The advantage of using all-tube control for woodpecker welding lies in the fact that this panel provides fine control of the welding heat by phase control, as previously described. A view of this panel is shown in Fig. 158

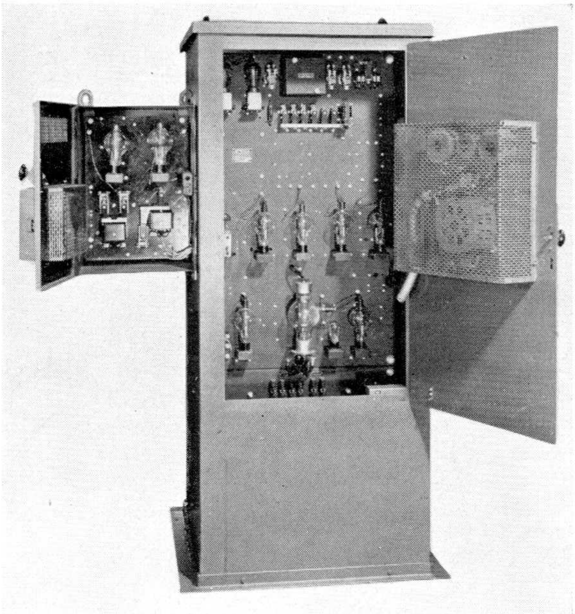


Fig. 158. Ignitron panel. For woodpecker control.

The circuit used is a modification of that used on the all-tube seam welder panel described below. This circuit enables current to flow for a certain number of cycles, and then to remain off for a certain number of cycles, this cycle of operations being capable of being repeated ad lib. The modification of this circuit used on the panel in Fig. 158 consists of the addition of a counting circuit, whereby the cycle of operations mentioned above is repeated for a definite number of times and then the flow of welding current ceases altogether. It is worth noting that in this circuit it is not the total time that is timed out as in the model described at the beginning of this section, but the number of " spots " per weld. This means that the three-timed quantities, " on " time, " off " time, and number of spots, are all independently set up. In the case of the panel mentioned at the beginning of this section, the total time must be set in accordance with the " on " time and " off " time, for the required number of spots to be made.

The all-tube woodpecker panel type (Fig. 158) is rated the same as the spot welder panel type (Fig. 155), since it uses the same ignitrons. The timing ranges provided are :—

Spot length	1 to 30 cycles.
Off time	1 to 15 cycles.
Number of spot	1 to 15 spots.

The panel is also provided with timing circuits for controlling the " upset " and forging times, the ranges being :—

Upset times ...	10 cycles to 15 secs.
Forging time ...	0.5 secs. to 28 secs.

Half-cycle Bench Welder.

There is a somewhat special type of spot welder control which is unique in that it includes the welding transformer (but not the welder) in the control panel. This equipment is designed to control a small bench welder of the pedal-operated type, such as is used for the welding of small components, lamp and vacuum tube parts, etc. The timing range is such that the maximum duration of current flow is slightly longer than one-half cycle, and the minimum duration substantially zero. Since the maximum welding time is only one half-cycle, only one ignitron is used, and this is a type " B " ignitron. As the duty cycle is extremely low, water cooling of the ignitron is not necessary.

The ignitron is fired by causing a pre-charged condenser to discharge through a thyratron which is in series with the ignitron igniter circuit. This ensures that each time the control is operated, the ignitron conducts for one-half cycle (or a fraction of one-half cycle) only, because the condenser discharges completely on the first half-cycle, and cannot fire the ignitron again until the panel has been re-set.

The firing angle of the ignitron is varied by shifting the phase of the peak in the grid voltage of the trigger thyratron ; this is accomplished by means of the phase shifting bridge, previously described.

The control panel is arranged for bench mounting and the low-voltage secondary leads of the welding transformer are brought out at the front, thus being suitable for direct connection to the electrodes of the small bench welder.

The welding transformer provided with the equipment is capable of supplying a demand of 50 kVA. ; as the duty cycle is very low, the transformer is accordingly reduced in size, being a relatively small unit.

Obviously this equipment could be used for much higher kVA.s if a larger transformer were provided, as the ignitron can handle currents up to 4,000 amps. peak (see Table I and Figs. 138 and 139). But the restriction of the maximum welding time to one half-cycle limits the application of the equipment to the welding of small components, as the heavier welds usually demand welding times in excess of half a cycle.

The equipment is of particular advantage, when welds require to be made in close proximity to glass, e.g., in the manufacture of vacuum tube parts, etc., as under these conditions it is essential to complete the weld in the minimum possible time and so prevent spread of heat to the glass.

Seam Welding Control.

For seam welding, the control is required to permit current to flow for a predetermined number of cycles, and then to cut the current off for a predetermined period, and this cycle of operation must be capable of being repeated throughout the length of the seam.

To accomplish this, the synchronous timing tube 90 shown in Fig. 150 is rearranged in an inverter circuit shown in Fig. 159, the output from the inverter circuit controlling the leading control tube. The remainder of the circuit is the same as for the spot welder panel (Fig. 151).

The operation of the inverter circuit is as follows :—

At the instant the D.C. voltage is applied, the voltage across the condenser 5 is zero, and the whole of the D.C. voltage appears across the charging resistances 2 and 3. This means that the potential for the point B is the same as the D.C. positive.

Also, at this instant, there is no voltage existing across the timing tube and the grid of the timing tube is considerably negative with respect to the cathode ; the timing tube therefore is non-conducting.

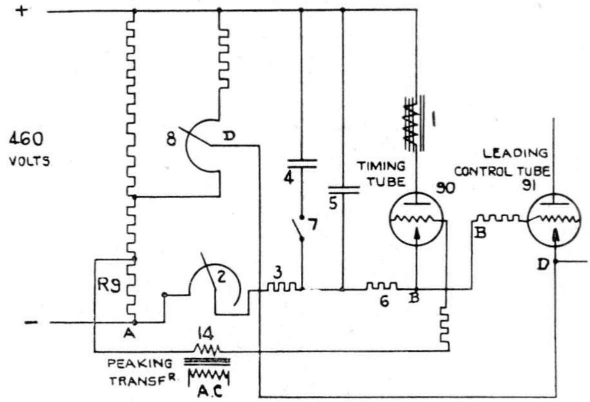


Fig. 159. Timing circuit for ignitron seam welder control.

The condenser 5 immediately starts to charge up from the D.C. supply through the charging resistances 2 and 3, and as the voltage on the condenser increases, so the voltage across the charging resistances decreases. As the potential of the timing tube cathode, point B (Fig. 160) approaches that of the D.C. negative, A, a point will be reached when the timing tube grid potential becomes positive with respect to its cathode, the grid being suddenly carried positive by the peaking voltage. This is shown at point Y. The timing tube now has a positive anode-cathode voltage existing across it, and it therefore fires at Y, discharging the condenser 5 through the inductance 1 and current limiting resistance 6. The effect of the inductance 1 as the condenser 5 approaches complete discharge is to cause the anode voltage of the timing tube to be depressed momentarily negative with respect to the cathode, and flow of current through the timing tube is thereby terminated ; this takes place at point Z. The condenser 5 will then start charging up again, and the cycle of operations will be repeated.

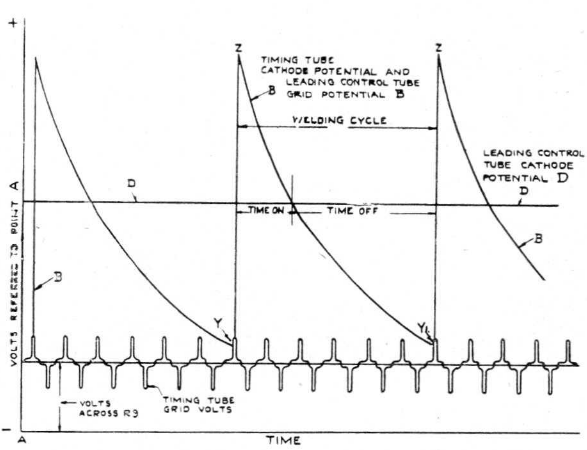


Fig. 160. Timing tube circuit voltage conditions.

It can be seen from the foregoing that the time that elapses between two condenser discharges will depend upon the values of the condenser 5 and the resistances 2 and 3. It will also be noted that the time will always be a definite number of cycles because of the synchronising peaking voltage. The time between two discharges is known as one welding cycle.

Suppose now that the condenser 5 is nearly fully charged and that the point B is negative with respect to point D: the leading control tube 91 will therefore be held non-conducting. The synchronising peaking voltage now fires the timing tube, with the result that the point B instantaneously attains the same potential as the D.C. positive (neglecting volt drop across the timing tube 90 and inductance 1), which is positive with respect to D, and hence the leading control 91 is made conducting. When the timing tube fires, the condenser discharges through the reactor 1, the inductance of which causes the timing tube arc to be extinguished; this is because the anode is momentarily made negative with respect to the cathode when the condenser is discharged, and under these conditions the tube cannot pass current. The condenser 5 immediately starts to charge up again, and the potential of the point B slowly returns to its original value, negative with respect to D, and when this condition is reached the leading control tube 91 will cease conducting. Condenser 5 will then continue to charge until the peaking voltage again fires the timing tube, and the cycle of operations will then be repeated.

It will be obvious from the above that the length of the welding cycle is set by varying resistance 2, and also by switching in extra capacity 4 by means of range switch 7; and that the length of time the leading control tube 91 conducts is set by varying the potential of the point D, which is carried out by the rheostat 8. This control is known as the ratio control, since it sets the ratio of the "on" time to the "total" time of the complete welding cycle.

The above circuit is incorporated in two types of ignitron panels, one of which is merely a more up-to-date version of the other. Both these panels incorporate the seam welding and spot welding timing circuits, and by means of change-over links the panels can be readily arranged for seam welding or spot welding. Since these panels make use of "B" and "C" ignitrons, the ratings are the same as for the other panels using these ignitrons. The timing ranges available are:—

Spot welding: One cycle to 25 cycles in two ranges, for duration of spot length.

Seam welding: Welding cycle, from two cycles to 30 cycles in two ranges. Ratio control, from zero to 100 per cent. on each range.

Seam Welding Control using Synchronous Commutator.

One of the great advantages of all-tube control is the ease with which the timing can be changed from one setting to another, since this can be done instantly by turning the appropriate rheostat from one dial position to another. This is a particular boon where the control panel is carrying out all-purpose or experimental work, necessitating a frequent change in timing set-up.

There are, however, a very large number of mass-production welding plants in operation at the present time, in which the set-up is only changed at very long and infrequent intervals, and where the control may operate for many weeks, possibly several months, on the same setting. Under these conditions of operation it may seem unnecessary to go to the complications of all-tube timing circuits for a seam welding control panel in order to obtain an advantage of which little, if any, use can be made.

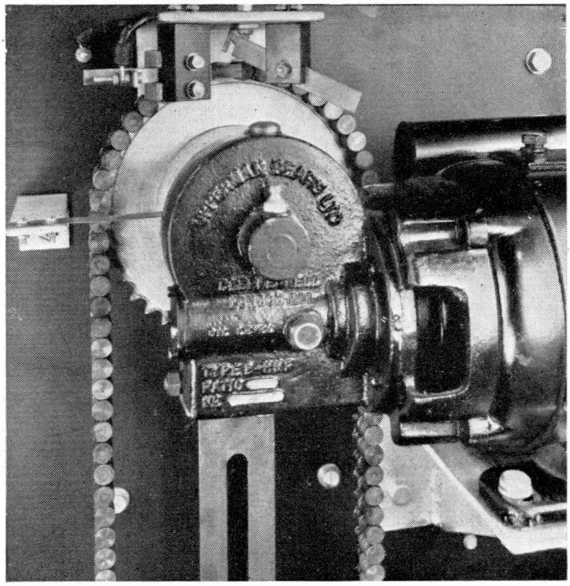


Fig. 161. Synchronous chain commutator.

An alternative and simpler method of timing the ignitrons has therefore been developed and is embodied in two ignitron control panels, one being merely a more up-to-date version of the other. In this case, the circuit is the same as for the spot welder panel (Fig. 151) as far as the trigger tubes and ignitrons are concerned, the difference lying in the method of timing the intermittent energisation of the transformer 5 (Figs. 150 and 151), which supplies the firing voltage sine wave components to the grid circuits of the trigger tubes. The timing tube, and the leading and following control tubes, along with their associated rectifiers, and other components are removed and replaced by what is virtually a synchronous commutator.

This device consists essentially of an endless length of cycle-sprocket chain, supported on two sprocket wheels, one of which is driven through gearing by a small single-phase synchronous motor. The pins of the sprocket chain are extended at one end, and on to these extended pins can be pushed small " buttons," which are made of either insulating or conducting material. A contact brush makes contact with the procession of buttons as they pass over the upper driven chain sprocket, and the chain is driven at such speed that each button represents one half-cycle of the A.C. supply. The arrangement is shown in Fig. 161 while the complete panel is shown in Fig. 162. A schematic diagram of the circuit is shown in Fig. 163.

This chain commutator is then used to energise the firing voltage transformer (T4 in Fig. 163) in an intermittent manner. By arranging the buttons on the chain in a particular manner, any desired welding cycle may be set up. For example, two cycles " on " followed by two cycles " off " would be set up with four conducting buttons placed on four adjacent pins, followed by four non-conducting buttons placed on the next four adjacent pins, this pattern being repeated for any convenient length of chain. The

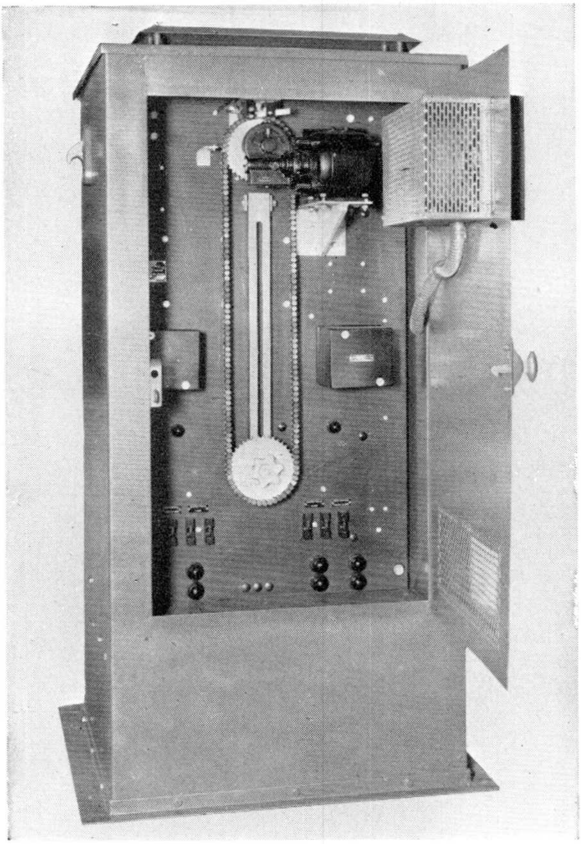


Fig. 162. *Ignitron panel.*

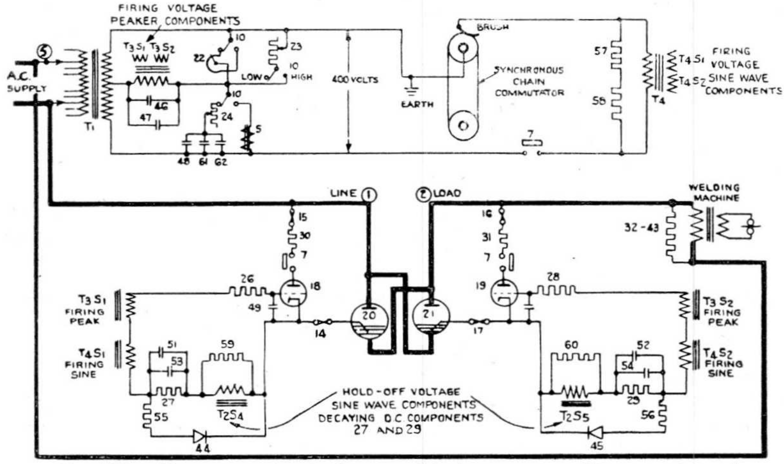


Fig. 163. *Elementary circuit diagram of ignitron seam-welder control panel.*

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number of complete welding cycles set up on the chain is immaterial, but will obviously be less for welding cycles of longer duration. The maximum chain length permits of a maximum welding cycle of 80 cycles (40 cycles on, 40 cycles off) 80 " on " buttons and 80 " off " buttons being provided. Thus, for welding cycles of 40 cycles and below, the " on " and " off " buttons can be arranged in any desired sequence to give any particular " duty cycle." The " duty cycle " is the ratio of " time on " to " time on plus time off."

The welding cycle may be set up with the chain on the upper sprocket, although if a major change in set-up is required, it will be preferable to remove the chain.

The chain can be completely dismantled and reset to give a new welding set-up in about 10 min., and this set-up time can be still further reduced, and the delay in resetting almost completely obviated by having a spare chain and setting it up beforehand. The chains can then be changed over in a matter of a couple of minutes. But obviously a set-up time of 10 min. is no great disadvantage, since changes in the set-up of the welding machine, etc., will almost certainly take longer than that length of time.

Care must be taken to see that the position of brush tip is such that the brush breaks contact with the conducting buttons when the current is at zero, so that there is no sparking at the brush.

For proper operation, it is necessary that no D.C. component be introduced in the current to the welder. That is, the sum of the " positive " half-cycles in two consecutive welds must equal the sum of the " negative " half-cycles in those same two welds. Thus, where the weld length (" on " time) is an even number of half-cycles, such as one cycle (two buttons), two cycles (four buttons), etc., each weld is balanced ; hence any two consecutive welds will be balanced, regardless of the " off " time. However, where the weld length is an odd number of half-cycles—½ cycle, 1½ cycles, 2½ cycles, etc.—it is necessary that the time off (time between welds) be an even number of half-cycles, e.g., two half-cycles off, four half-cycles off, six half-cycles off, etc., in order to give " antipolar " starting to balance the welds.

For example :—

Correct.

½ cycle on, followed by 1 cycle, 2 cycles, or 3 cycles off, etc.
1 cycle on, followed by ½ cycle, 1 cycle, 1½ cycles, or 2 cycles off, etc.
1½ cycles on, followed by 1 cycle, 2 cycles, or 3 cycles off, etc.
2 cycles on, followed by ½ cycle, 1 cycle, 1½ cycles, or 2 cycles off, etc.

Incorrect.

½ cycle on, followed by ½ cycle, 1½ cycles, or 2½ cycles off, etc.
1½ cycles on, followed by ½ cycle, 1½ cycles, or 2½ cycles off, etc.

Antipolar starting is commencing consecutive welds on half-cycles of opposite polarity ; whereas unipolar starting is commencing consecutive welds on half-cycles of the same polarity. In general it is necessary to use antipolar starting where the weld length is an odd number of half-cycles ; and preferable, but not necessary, to use unipolar starting when the weld length is an even number of half-cycles. Operation in this manner gives the closest approach to pure interrupted balanced alternating current in the transformer.

Any number of patterns can be used to complete the desired length of chain. The number of patterns obviously does not affect the output in any way. The end of the last pattern should be joined to the beginning of the first to make a continuous chain without change of pattern. If the welding cycle is an even number of half-cycles, there will always be an even number of buttons in the chain so that the special half-link providing for insertion of a single button need not be used.

Where the welding cycle is an odd number of half-cycles, if an even number of patterns is used, the total number of buttons is still even and the half-link is not used. However, if the number of patterns is odd, the half-link must be used in order to make the chain continuous without change in pattern.

The equipment makes use of two " B " or " C " ignitrons, and is therefore rated as shown on page 147 and Figs. 138 and 139.

Summary.

The panels dealt with may now be conveniently summarised as follows :

Duty.	*Figs.*	*Method.*	*Rating kVA at 440 volts*
Spot	142 and 143	Contactor timer	65 or 130
,,	144 and 145	Ignitron contactor	1,200
,,	148 to 152	All-tube synchronous	1,200 or 2,400
,,	—	,, ,,	450
Programme spot	155 to 157	,, ,,	1,200 or 2,400
Sequence programme	—	,, ,,	,,
Woodpecker spot	158	,, ,,	,,
,, ,,	—	Timer-Ignitron contactor	,,
Half-cycle spot	—	All-tube synchronous	50
Spot or seam	—	,, ,,	1,200 or 2,400
,, ,,	—	,, ,,	,,
Seam	162/163	Synchronous commutator	,,

Future Developments.

New applications are constantly being found for tube control in the welding industry, and many problems of long standing are being solved by its use. A typical example is the problem of varying welding heat brought about through changes in the inductance of the welding transformer as a result of the insertion into the throat of the welding machine of varying amounts of steel. This effect is particularly troublesome when seam welding or spot welding large steel drums, panels or tubes. As the metal is inserted into the throat of the machine, so the inductance of the secondary loop increases, resulting in a fall in welding current and heat. In order to compensate for this, it is necessary to increase the welding heat as the metal is inserted. This can be very readily carried out automatically by means of phase shift control, with the result that the welding current is kept substantially constant for wide changes in welding transformer inductance. At the same time, the welding current can be maintained approximately constant irrespective of changes in line voltage.

The electron tube has been of considerable assistance to the welding engineer in the past ; despite its laboratory ancestry, which tended to make some of the more conservative engineers somewhat reluctant to put it to good use on a production line, the electron tube has long since proved itself as a " machine tool." There is every reason to believe that its help will be even more widely sought after in the future.

Chapter XI

AUXILIARY EQUIPMENT

ELECTRODES AND ELECTRODE MATERIALS.

By N. A. TUCKER.*

The electrodes of a resistance welding machine are situated at the extremities of the secondary circuit, and by their design enable current to be conveyed to the point or points on the component parts where a resistance weld is required. Of the four factors, current, time, pressure and electrode tip diameter, which govern the correct set-up of a resistance welding machine the last-named, to which particular reference is made in this chapter, requires particular attention in terms of design, material and maintenance.

A resistance welding electrode may take the form of a small taper insert for a spot welding machine, a disc or wheel electrode for a seam welding machine, a facing for a projection welding machine, or a faced clamp or die block for a butt or flash welding machine.

INFLUENCE OF DESIGN ON THE LIFE OF A SPOT WELDING ELECTRODE.

There are five main requirements to bear in mind when designing a spot welding electrode :

1. Ease of replacement.
2. Minimum cost to life ratio.
3. Maximum number of welds per electrode trim.
4. Efficiency of water cooling.
5. High electrical conductivity.

There are two ways of making an electrode detachable for replacement purposes, one being to employ the screwed type of shank and the other to use a tapered shank. The only advantage which the screwed type holds over a taper shank is the degree of tightness to which it can be attached to the electrode holder. This degree of tightness is not essential if the electrode is correctly designed, and the taper shank has many advantages over the screwed type. These advantages include the large area of electrical contact between the electrode and electrode holder, this making for high electrical conductivity, and the shorter time required for replacement, particularly where offset electrodes are employed, due to the ease of radial adjustment.

*Mallory Metallurgical Products Ltd.

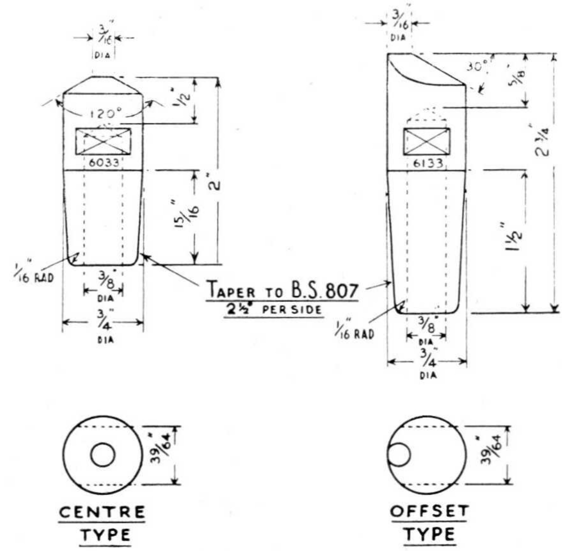


Fig. 164. Standard types of spot welding electrodes.

Taper electrodes can be difficult to remove if too small an angle for the taper is employed. On large electrodes where high pressures are normal a Morse taper can be objectionable from this point of view. These objections can, however, be easily overcome by employing materials for electrode shank and holder widely differing in hardness value, and using tapers of 5° included angle as recommended in British Standard 807.

Since an electrode is a replaceable part it is reasonable that its weight and cost of replacement should be kept to a minimum. This can be accomplished by using an electrode of minimum length and diameter consistent with efficient welding and economical tip life. British Standard 807 also makes recommendations as to the suitable length of taper for the two main types of electrodes, namely, centre and offset. The taper portion will, of course, vary in length for different diameters of electrodes and for the type of loading. A concentrically loaded tip requires only a short length of taper whereas an eccentrically loaded tip will require a much longer length to prevent bell-mouthing of the electrode holder. The parallel portion of an electrode requires spanner flats on the larger sizes but in other cases can be left circular for removal by pipe grips. A maximum length of one diameter is ample for this section and at the same time sufficient room is provided for code marking the electrode type.

From the experimental evidence on which the Advisory Service on Welding bases its recommendations in Memoranda 8 and 4a, the maximum distance between the end of the water cooling hole and the tip diameter should be not more than half an inch.

Tip Shape and Size.

The tip diameter must essentially be related to the thickness of the material to be welded, since the tip diameter governs to a large extent the size of the weld and the strength of the joint. The following relationship has been recommended and has received considerable support in this country and the U.S.A. :—

$$D = \sqrt{t}$$

where D = tip diameter in inches

t = thickness of one sheet

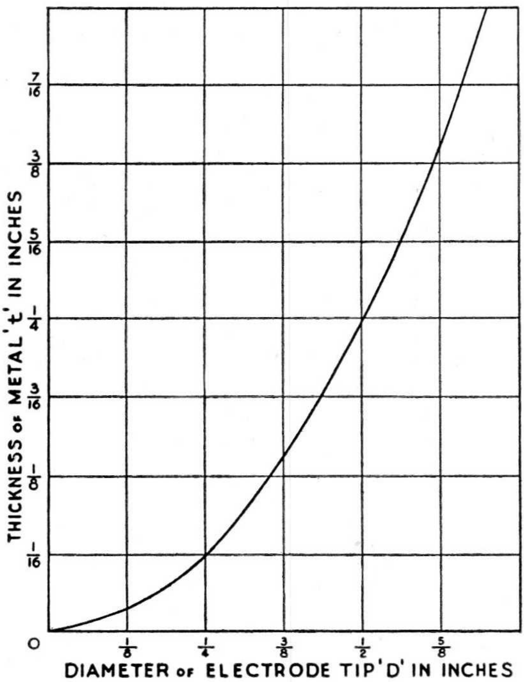


Fig. 165.

Fig. 165 and Table below show recommended electrode tip diameters for spot welding mild steel using the formula $\mathbf{D} = \sqrt{t}$.

Material Thickness " t " in inches.	Electrode Tip Diameter " D " in inches.
0 to 0.009	$\frac{1}{16}$
0.010 to 0.024	$\frac{1}{8}$
0.025 to 0.048	$\frac{3}{16}$
0.049 to 0.079	$\frac{1}{4}$
0.080 to 0.118	$\frac{5}{16}$
0.119 to 0.165	$\frac{3}{8}$
0.166 to 0.220	$\frac{7}{16}$
0.221 to 0.282	$\frac{1}{2}$
0.283 to 0.352	$\frac{9}{16}$
0.353 to 0.430	$\frac{5}{8}$
0.431 to 0.517	$\frac{11}{16}$

The chief advantage of using a flat tip is that its size may be readily checked in the course of its life, and it can be re-trimmed to its original dimensions without difficulty. The domed tip, which may have theoretical advantages, develops flats in time, and the size of tip is not readily measured. Domed tips are, however, very common in the U.S.A. The use of the correct tip diameter in relation to thickness of sheet is of prime importance since undersized tip diameters will mushroom very rapidly and electrode life will be short.

The rake angle, or twice its complement, the included angle, of the truncated cone which is formed at the tip end of the electrode, ranks in importance next to tip diameter, in its effect on the life of the electrode. The recommended included angle for electrodes used on ferrous material is 120° and under certain conditions this is found to give an electrode life of 10 times that obtained with a 60° angle, and four times that of a 90° included angle. This greatly increased life, which may at first seem outstanding, is not unreasonable when one considers the advantages derived from this design. A large included angle reduces the current density in the truncated cone, and thus heat generated in the electrode is reduced to a minimum. A larger mass of material in the tip provides better conduction of heat away from the tip diameter and also increased mechanical support for the electrode tip to resist mushrooming. Operators may at first resent this blunt nosed shape for an electrode tip on the grounds that it is more difficult to position the spots accurately. However, modern machines with vertically sliding heads enable the operator to overcome this prejudice after a little practice. Fig. 166 shows tips with included angles of 120° and 60°. These tips have "mushroomed" to the extent of 16% and 40% increase of diameter respectively.

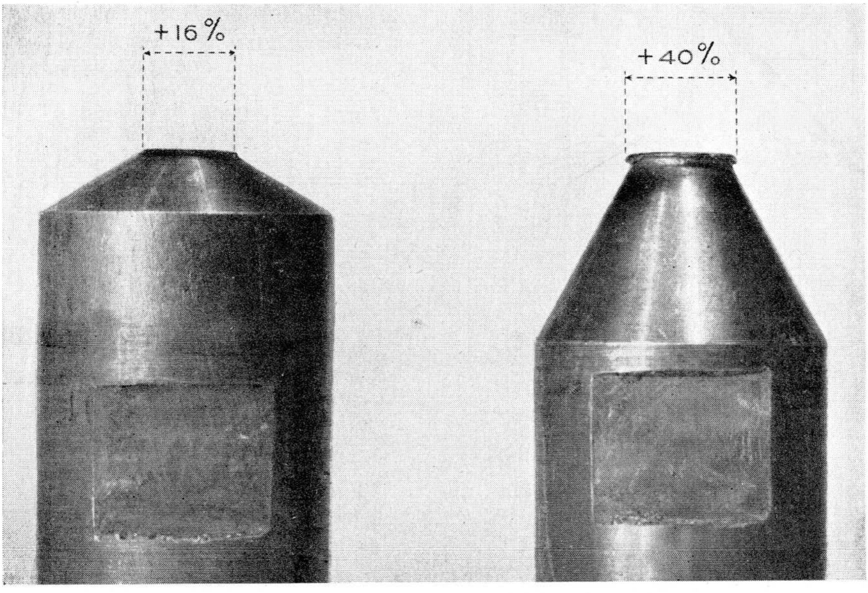


Fig. 166. Truncated cone electrode having 120° and 60° included angles.

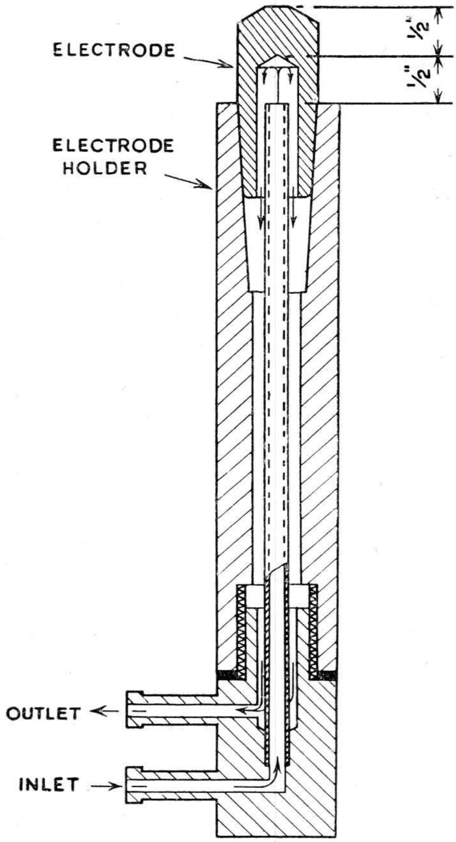


Fig. 167. Water cooling circulating system for spot welding machine electrodes and holders.

WATER COOLING.

Water cooling of electrodes is essential. The importance of this point is not always appreciated without some knowledge of the temperatures and temperature gradients involved between the welded spot and the tip face.

The temperature of the surface of the material in contact with the electrode tip depends upon the welding time and the thickness of material. Short welding times obviously produce a steep temperature gradient between the weld and tip surface, but, even so, high tip face temperatures have to be contended with. Under normal conditions this temperature may be about 500°C. In order to promote tip life it is therefore important that adequate means of cooling the tip shall be provided, without which it is impossible for any high conductivity copper alloy to withstand successive heating and cooling under applied pressure without softening and deformation. As already stated the distance from the drilled end of the water hole in the electrode to the tip face should not exceed half an inch, and furthermore the circulating water pipe or inner tube should be brought to within half an inch of the drilled end of the water cooling hole. If this latter condition is not strictly adhered to, the formation of an air lock or a steam pocket is probable, thus greatly reducing the cooling efficiency. About one gallon per minute is a satisfactory supply rate for the water cooling system and it is strongly recommended that the upper and lower circulating system for each electrode be connected in series, thus ensuring equal supply of water to both electrodes. With parallel connected water supplies to the electrode circulating systems it is difficult to ensure an adequate supply to both electrodes, and a partial blockage in one system causes all the water to be by-passed to the other electrode.

ELECTRODE MATERIAL FOR SPOT WELDING.

It is important that the correct material be chosen for a spot welding electrode, since its duty is to conduct a very heavy current from the secondary circuit into a confined area in order that the necessary heat may be generated in the components to make a weld without overheating the electrode and without generating heat in any other part of the circuit.

The Choice of the Correct Electrode Material.

From practical experience it has been determined that the electrode material for economical tip life when welding mild steels must have a conductivity of at least 50 to 60% of that of copper with a hardness of not less than 110 to 130 V.P.H. and a good resistance to softening at high temperatures. Of the possible materials which may be used the following three are probably the most common.

Copper.

Copper has the highest conductivity or lowest specific resistance of all metals except silver. Copper therefore is an ideal material from a conductivity point of view. Hard working of copper by cold drawing will increase its hardness up to a maximum value of approximately 95 V.P.H., but hard drawn copper will soften at approximately 150° C. if heated for a sufficient length of time.

Cadmium-Copper.

By adding about 1% of cadmium to copper, the hardness obtained by cold working can be increased to 110 V.P.H., with a conductivity of 85% of that of copper. By special treatment it is possible to increase the hardness to a maximum of 145 V.P.H. Cadmium-copper is a very useful alloy for spot welding electrodes always provided that welding times are kept short since this material commences to soften at about 250° C.

Chromium-Copper.

Chromium-copper, in the form in which it is produced specially for resistance welding electrodes is a precipitation hardening alloy, and it derives its greater hardness from a special heat treatment process in addition to the usual cold working. Chromium-copper, although somewhat more expensive than cadmium copper, has the highest value of hardness, the greatest resistance to softening at high temperature coupled with good conductivity, of any material so far produced for resistance welding electrodes. By the special heat treatment of this alloy a hardness value of 150 VPH. is obtained, and softening of the material does not occur until a temperature of 550°C. is reached. These factors coupled with its conductivity 80% of that of copper make it ideally suited for resistance welding electrodes.

THE INFLUENCE OF MATERIAL ON THE LIFE OF A SPOT WELDING ELECTRODE.

As will be seen from the technical data given in previous sections of this chapter the material with the highest resistance to softening at elevated temperatures will give the longest life. From tests taken under identical conditions cadmium-copper produced three times as many welds per trim compared with hard drawn copper, whereas chromium-copper produced three times as many welds as cadmium-copper. It is obvious that if extremely short welding times can be employed, such that the tip face of the electrode can be kept below 250°C., no advantage is to be gained by using chromium-copper. This, however, can only be accomplished on a few applications and where the material is very thin.

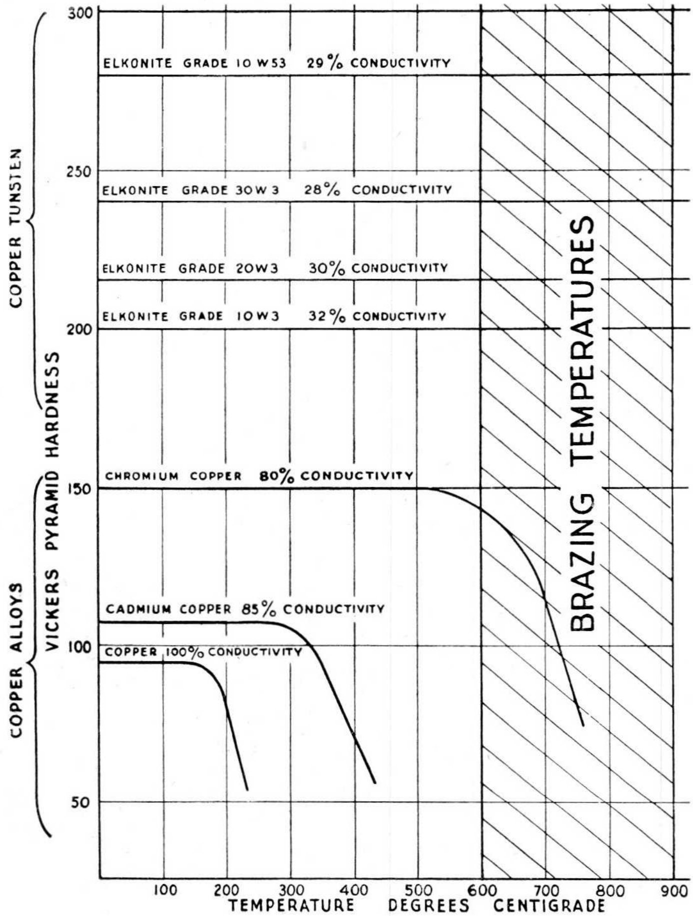


Fig. 168. The effect of heating on hardness values of various electrode materials after heating for two hours.

COST COMPARISON OF VARIOUS ELECTRODE MATERIALS.

The cost of an electrode should not be based on the price paid per foot of rod or even the initial cost of the electrode. A check on the life of an electrode should be made, and a cost determined per 1,000 welds made, for only in this way can two or more electrode materials be properly compared. Where an electrode material involves expensive alloying elements and additional labour for heat treatment processes, such a material will be several times the cost of a straight copper alloy. This does not necessarily mean that the highest priced alloy is the cheapest in the long run, and the following specimen cost analysis is intended as a guide for users to make a check test on their own particular welding application.

	Copper.	Cadmium-copper.	Chromium-copper.
Material cost	4.2d.	6.3d.	25.7d.
Machining (10 min. at 2/6 per hour plus 100% overheads) ...	10.0d	10.0d.	10.0d.
Initial cost of Electrode	14.2d.	16.3d.	35.7d.
Trimming (20 trims at 3 min. each)	60.0d.	60.0d.	60.0d.
Life cost of Electrode	74.2d.	76.3d.	95.7d.
Number of welds per trim, allowing a 20% increase in tip diameter ...	1,000	3,000	9,000
Total number of welds	20,000	60,000	180,000
COST PER 1,000 WELDS ...	3.71d.	1.27d.	0.53d.

The above is a typical cost analysis and although it does not hold good for every spot welding job it will generally be found that the results will be of the same order. It is of interest to note that the price of raw materials is in the ratio of 1 : 1.5 : 6, but when the initial cost of the electrode is considered the ratio becomes 1 : 1.15 : 2.5, while the final costs are in the ratio of 1 : 1.03 : 1.28. Labour spent on machining an electrode, and time taken to re-trim an electrode whether by machining or filing (the latter is not to be recommended) are often forgotten, but as will readily be seen they form the greater part of the life cost of an electrode. Furthermore, it will be noticed that a ratio of the number of welds per trim of 1,000 for copper, 1,030 for cadmium-copper and 1,280 for chromium-copper would provide no preference for choice of material. In actual fact the ratio of cost per 1,000 welds is more than reversed when compared with the cost of raw materials alone, being 7 : 2.4 : 1 respectively.

CARE AND MAINTENANCE OF ELECTRODES.

The electrode of a spot welding machine should be treated with just as much respect as the cutting tool of a lathe or milling machine. In all cases the quality of the work is dependent on the condition of the tool, and its life depends almost entirely upon its treatment. In the same way as lathe tools require to be removed from the tool post or holder and trimmed occasionally, so must the tools or electrodes of a resistance welding machine be removed for the same purpose.

The frequency with which an electrode must be removed from a spot welding machine for re-trimming will depend, as we have already seen, on design, water cooling, and the material from which the electrode is made. Nevertheless, the tip diameter will increase with use, and must be removed and reduced to its original size. The frequency of removal is a function of tip growth and not of the number of spot welds made or assemblies welded, except that once conditions have been established tips can be replaced at regular intervals. The recommended standard of growth allowed for a tip diameter before re-dressing is a 20% increase on diameter for Grade A welding and 40% increase on diameter for Grade B welding. Grade A applies to structures where the failure of a single spot weld would endanger the whole structure while Grade B welding is intended to apply to all other welded assemblies. This statement does not imply that there should be any difference in the quality of a Grade B weld compared with that of a Grade A, but it does mean that a greater margin or factor of safety is provided for Grade A work.

Sets of standard electrodes should be available in order that the correct tip diameter may be selected to suit the material thickness. All spare electrodes should be kept in a rack and stored safely so that the tapers cannot become damaged. Before a new set of electrodes is inserted into the holders it is worth while to wipe the tapers with a clean rag, and then apply a film of oil. This procedure will ensure that the tapers of the electrode and holder are kept in good condition and so prevent subsequent water leaks, and at the same time facilitate easy removal of electrodes whenever necessary. The removed electrodes should be sent to a central depot for re-trimming in a lathe to the correct tip diameter before going into store. Re-dressing of the tips by filing either by the operator or the setter-up should be discouraged if the user wishes to preserve his reputation and ensure good quality spot welding. An occasional clean with fine emery may be permitted where the electrode tip is found to oxidise rapidly or where pick up occurs due to welding coated steels.

ELECTRODE MATERIALS FOR WELDING OTHER MATERIALS.

The notes on design and water cooling given in previous sections apply to the welding of all materials but the same electrode alloys recommended for steel cannot be used on all materials satisfactorily. Although steel is by far the most common material spot welded, a few notes on electrode alloys suitable for welding other materials may be helpful.

Coated Steels.

The welding of coated steels always presents a difficulty and the thicker the coating the more trouble will be experienced due to pick-up on the electrodes. Steels requiring a rust-proofing treatment should be welded first and treated afterwards wherever possible. Where it is not possible to adopt this procedure, the electro deposition methods of coating should be adopted and here it is preferable to use zinc or tin. The electrodes will require frequent cleaning with fine emery paper to remove pick-up. The material for electrodes should be cadmium-copper or one of the cadmium-copper type, since these materials appear from practice to have less affinity for the coated material.

Aluminium and Aluminium Alloys.

Owing to the very low resistance of these alloys it is essential that the electrode materials be of high conductivity and in fact should have a conductivity of not less than 95% of that of copper. Materials of lower conductivity generate excessive heat at the tip surface and cause undue pick-up at the electrodes. Hard drawn copper or an alloy such as Elkaloy T is, therefore, the most suitable material for welding these alloys.

Brasses.

Owing to the comparatively high conductivity of brasses, coupled with a negligible plastic range, it is exceedingly difficult to obtain sound welds on these materials. If welding is confined to thin sheets, say below 0.015 inch, and the quality of welding is not important, then a high resistance electrode material can be used with fairly satisfactory results. One of the copper-tungsten types of electrode material such as Elkonite would, therefore, be suitable. With this method of welding, heat is generated at the surface of the material in contact with the electrode tip and this assists in raising the interface temperature to obtain a weld. Very good welds have been obtained in 16 and 14 S.W.G. 70/30 brasses with condenser machines using H.C. electrolytic copper.

SEAM WELDING ELECTRODES.

Little can be said about seam welding electrode design as so much depends upon the machine design. It is, however, very important to provide adequate water cooling to the electrodes and it is not sufficient for the electrode to be bolted to a water cooled shaft. When seam welding at 60 to 100 inches per minute welds are being made at the rate of 900 to 1,500 per minute, and the temperature gradient between the weld and wheel surface is low, resulting in high temperatures at the wheel tread. Cooling water should, therefore, be in contact with the sides of the wheel and over as great an area as possible. The wheel width should never be less than twice the tread width, and the longest electrode life will be obtained by placing the tread in the centre of the wheel width and chamfering the sides at an included angle of 120°.

The electrode materials most suited to seam welding wheels are the same as those outlined for spot welding mild steel. High conductivity is essential, coupled with a hardness of 120 to 130 VPH. and a high softening temperature.

PROJECTION WELDING ELECTRODES.

It is difficult to generalise on projection welding electrode design, since each electrode is usually made in the form of a jig to locate the component parts and will differ in design for each assembly. There are, however, a few points to be noted which apply to all projection welding electrode designs. Care must be taken to ensure that the jig cannot provide an alternative path for the current, and insulation must be used to prevent such paths being formed. The electrode dies must be bedded to make good contact over a large area surrounding the whole group of projections to be welded. Parts of the jig which require to be of steel for hard wearing purposes must not completely surround the welding current path or enter the throat of the machine to any extent, otherwise heat will be generated in these parts which will be detrimental to the jig as well as having a choking effect on the welding transformer. Lastly the current carrying parts of the electrode and jig must be adequately water cooled, particularly near the contact faces.

The main requirements of an electrode material for projection welding are extreme hardness and high softening temperature. Since it is only possible to produce materials having a high degree of hardness and high softening temperature at the expense of conductivity, it is important that the component parts to be projection welded make good contact over the whole surface to be welded. Failure to observe this condition will not only result in uneven distribution of the welding current through the projections, but in points of high resistance and burning between the components and electrode faces.

Copper-tungsten facings about a quarter of an inch thick to all die faces give excellent results where these conditions are met to the full, wear is extremely small and die faces need only to be cleaned after very long production runs. Suitable copper-tungsten materials are provided in the various grades of Elkonite and other proprietary alloys, giving hardnesses from 150 to 280 VPH. with conductivities from 28 to 35% of copper. Elkonite has an extremely high softening temperature and is quite unaffected by temperature of 700° C. and more. It is therefore suitable for silver brazing to copper alloy dies to form a facing. Owing to the comparatively low ductility of copper-tungsten however it is essential where high pressure loadings are employed that the facings be brazed to high strength copper alloys such as Mallory 53, otherwise cracking may occur due to poor backing materials.

Where the component parts of projection welded assemblies cannot be maintained accurately to shape, such that good contact is not maintained with the electrodes, or where the surface condition of the parts is not smooth, copper-tungsten alloys should not be used. In their place a material having a better conductivity, such as Mallory 3, or chromium copper should be used.

FLASH-BUTT AND BUTT WELDING ELECTRODES.

Generally speaking the electrodes of a flash or butt welding machine consist of faced clamping dies, and compared with any other resistance welding process the current density per square inch of contact area is extremely small. This condition allows the use of low conductivity electrode materials in the form of facings to the clamping dies. Hardness and resistance to abrasion and wear are the two main essentials for the facing materials. Copper-tungsten is again the most suitable material in the form of the harder grades of Elkonite.

SUMMARY.

Electrodes for resistance welding must be properly designed to incorporate good electrical contact, large included angles on spot and seam welding electrodes and adequate circulation of cooling water. Electrode materials must possess correct hardness, correct conductivity, and a good resistance to softening at high temperatures, and must be selected to suit the material which is to be welded.

Electrode Material	Hardness VPH.	% Conductivity of Copper.	Softening Temperature	Resistance Welding Process.	Material to be welded.
Hard drawn copper	95	100	150° C.	Spot	Aluminium
Cadmium-copper	110	85	250° C.	Spot	Coated Steels
Cadmium-copper (specially treated)	145	85	250° C.	Spot	Thinner gauges of Mild Steels
Chromium-copper	150	80	550° C.	Spot Seam Projection	All Steels All Steels All Steels
ELKONITE (copper tungsten material) 10W3	200	32	Approx. 1,000° C.	Spot	Brasses
20W3	215	30	Approx. 1,000° C.	Projection	Steels
30W3	240	28	Approx. 1,000° C.	Flash and Butt	Steels
10W53	280	29	Approx. 1,000° C.	Hot Riveting	Steels

CHAPTER XII

AUXILIARY EQUIPMENT (*Contd.*)

Cooling Systems—Spotlights—Pressure Gauges—Jigs and Tools

COOLING OF RESISTANCE WELDING MACHINES.

The necessity for the adequate cooling of the electrodes of resistance welding machines has in many cases not been fully appreciated ; yet if the production of sound and consistent welds is to be obtained, this question is of vital importance.

It is necessary not only to ensure a satisfactory cooling system, but the arrangements of this system must be such as to avoid difficulties. Before dealing with details it would perhaps be as well to lay down a simple test of the efficiency of a cooling system.

The best practical test is to make a succession of spot welds, 12 to 18 in number, and then to feel the electrode holder immediately on ceasing welding. This should remain perfectly cool throughout the welding operation and if the electrode holder is of a temperature that is uncomfortable to feel, then obviously the cooling system is inefficient.

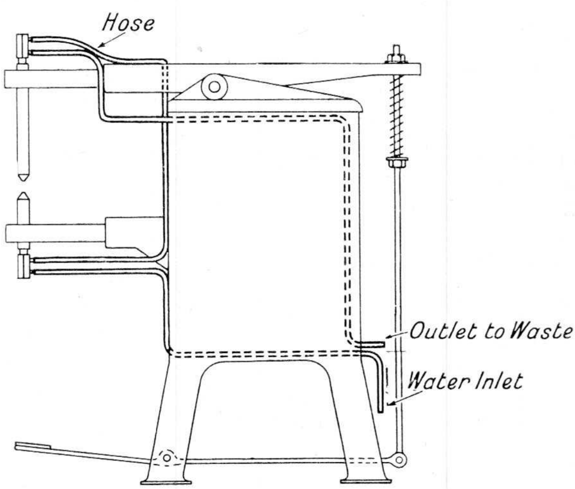


Fig. 169. Showing layout of cooling system for normal types of spot welders.

In laying out the cooling system for a machine or number of machines it is essential to avoid any arrangement whereby air or vapour locks can occur. For this reason it is always preferable to supply the water to the bottom electrode first and thence to the top one.

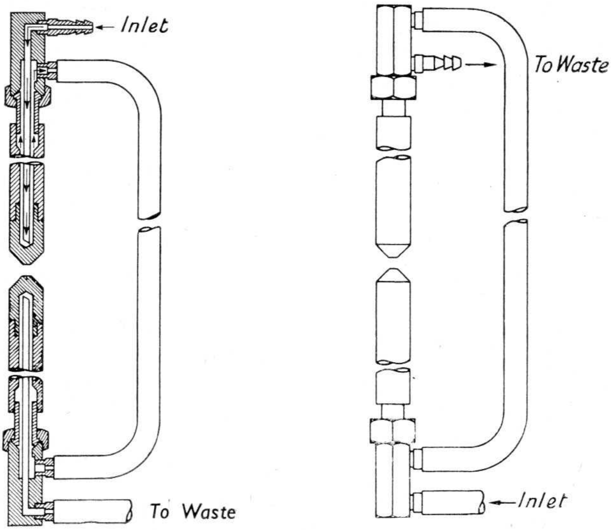


Fig. 170. Showing correct and incorrect arrangements. The faults in this drawing have all been indicated in this section.

Small single machine installations are generally run direct from the main, the exhaust water running to waste. Welders of about 20 kVA. have a consumption of 30-40 gallons per hour, but even for smaller machines it is sometimes necessary, where water is short or the cost is excessive, to put in individual supplies.

The best method of laying out a system is to have a large gravity tank for the group of machines with a water discharge into a sump or tank from which the water is pumped by a suitable motor-driven pump to the gravity or header tank of each machine. When this system is employed it is advisable to have a flow indicator to indicate the system is operating satisfactorily. This, in its simplest form, can consist of a water feed into a funnel or a vane indicator or other device showing the movement of liquid.

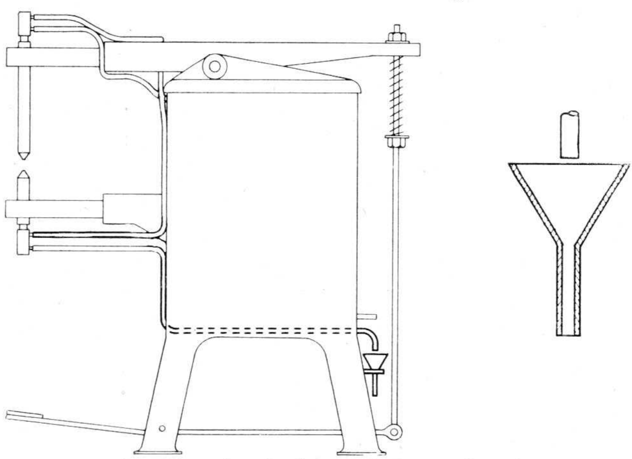


Fig. 171. Sketch of water feed into a funnel.

In large installations it may sometimes be advisable to have a thermometer pocket in the return circuit. Where gravity tanks are not possible, then individual tanks per machine can be used, a small motor-driven pump being employed to return the water.

Linking a succession of welders in a series to one water supply should be avoided at all costs, as the first machine will heat the water before it passes to the next and the last machine in the series is likely to be receiving water at far too high a temperature for satisfactory cooling. A few notes on the actual cooling details on machines will probably be of interest.

1. Cooling water should always be carried to within $\frac{1}{2}''$ of the actual welding point.

2. For those types of electrodes having an inner copper tube carrying water, this should reach to within $\frac{1}{4}''$ of the end of the electrode.

3. All water pipes should be of adequate size for the flow of water and in any case the bore should not be less than 5/16ths.

4. As the water is generally conducted from the metallic pipes of the machine to the electrodes by rubber hose, minor maintenance troubles and difficulties can be avoided by a few simple precautions as follows :—

(a) Standard 3-ply rubber hose should be used and be clipped into position with the excellent worm-operated clips which have been found to be more satisfactory than the nut and screw type.

(b) Where screw electrodes are used, these should be fitted with a fine thread, preferably a gas thread.

(c) Where electrodes are fitted to stakes or bars, copper asbestos washers should be employed.

Research has now been going on for some years on the question of cooling electrodes, but there is still a large field open in this direction. Coolants other than water have been tried and a successful line of research which has been developed for the use of machines employed on the welding of light alloys, is the use of refrigeration for the electrode tips. This has been found to reduce the oxide pick up from the aluminium sheet and also to permit the electrodes to maintain their dimensions over long runs.

Whilst the remarks in this section have dealt chiefly with the cooling of tips or points, it should be appreciated that broadly they apply to the cooling of transformer secondaries as well, as the practice of using water-cooling or liquid-cooling for transformers and other portions of the machine, other than arms and stakes, is increasing.

OTHER EQUIPMENT.

The preceding chapters have described the main types of machines and apparatus and this section is intended to deal with various equipment and accessories other than timing equipment, for use with resistance welding machines.

Pressure Gauge.

One of the most useful accessories in a resistance welding shop is the pressure gauge. The instrument illustrated is a 2-stage instrument for use on light or heavy machines, the movement working on a fulcrum, the principle being that for a lighter machine with tip pressure of up to 750 or 1,000 lbs. the end of the fulcrum is used and for heavier machines of up to 2,000 or 2,500 lbs., the near register is used.

This machine, when placed between the electrodes and the welding machine, will indicate on the dial the exact number of lbs. pressure exerted by the electrodes. This is very useful data as, in the case of air-operated machines, it will enable the air regulating valve to be set at a pre-determined pressure and the pressure can thus be easily checked. With foot-operated machines various positions of spring tension can be ascertained and data gathered to which reference can be made for re-setting the machine on production jobs.

It should be noted that the pressure shown is the total pressure between the points and not the pressure in lbs. per square inch on the weld area.

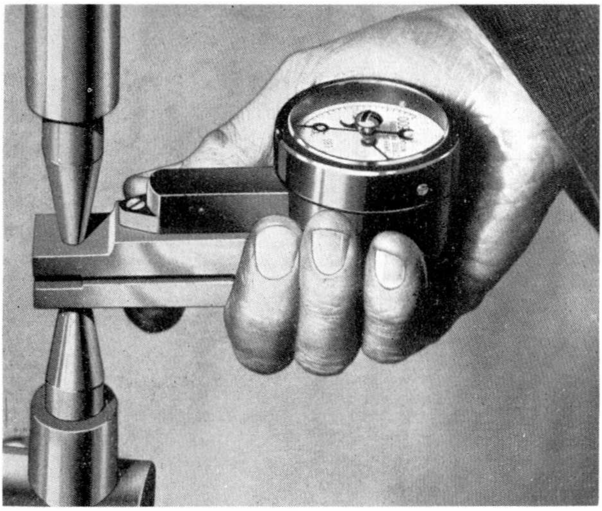


Fig. 172. Pressure gauge.

Spotlight.

This accessory is useful for positioning work and for spacing of spot welds. It ensures that untrained operators place spot welds accurately; in some cases two spotlights are mounted on the machine to enable the pitch of spot welds to be maintained. This is illustrated in Fig. 173.

The apparatus consists of a small electric bulb and lens mounted in a cylinder and so arranged that the filament is brought to a focus at a point on the work 12″ to 18″ away. A low voltage E.M.S. lamp is used, the voltage being stepped down by a suitable transformer which may either be mounted in the casing or alternatively mounted separately on the machine. The transformer is connected to 200/250 volt mains. The spotlight is mounted on a suitable arm with clamping device and this arm is affixed to the machine so that the spotlight can be centered and focused in any position.

This accessory is particularly useful for air-operated machines and on mass production, and also where the shop lighting is not too good. It has also been found very useful in the welding of light alloys, the surface of which renders the detection of marking spots under normal lighting conditions difficult.

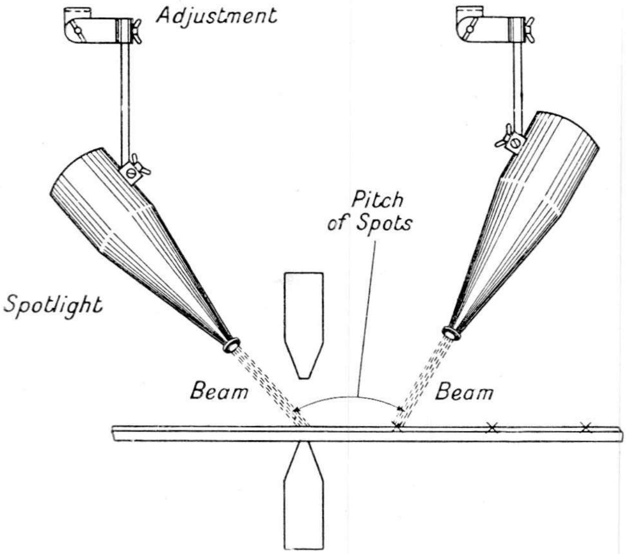


Fig. 173. Diagram of two spotlights.

Another useful accessory for machines where the water supply is difficult, is a tank fitted with a self-contained motor-driven circulating pump. For full information on this apparatus see note on the cooling of resistance welding machines in Chapter IV.

An instrument similar to a milling cutter is a useful accessory and can be placed between the electrodes with the electrodes in the down position and revolving in a clockwise direction, the small cutters in the instrument remove any burrs on the electrodes and reform the electrode to the desired contour. The obvious advantage of this is that the electrodes need not be removed from the machine and it is a means of rapidly obtaining the original contour and spot size.

A spring balancer for suspending gun welders and other portable tools is an excellent device which saves the effort of the operator in handling the welder.

JIGS AND TOOLS FOR USE ON RESISTANCE WELDING MACHINES.

Other than for comparatively simple operations, in fact, in all cases where high production is required, it is essential to use jigs and tools so as to avoid having to rely on operators' judgment regarding positioning, and undoubtedly the success that has been obtained with resistance welding as a production method lies in the correct use of jigs and tools.

The factors to be considered in designing jigs and fixtures are :—

1. The method of locating the work.

2. Fixtures should be made of non-ferrous material to avoid inductive losses in the machines.

3. The use of locating jigs for the dual purpose of locating and spot welding simultaneously (Fig. 174).

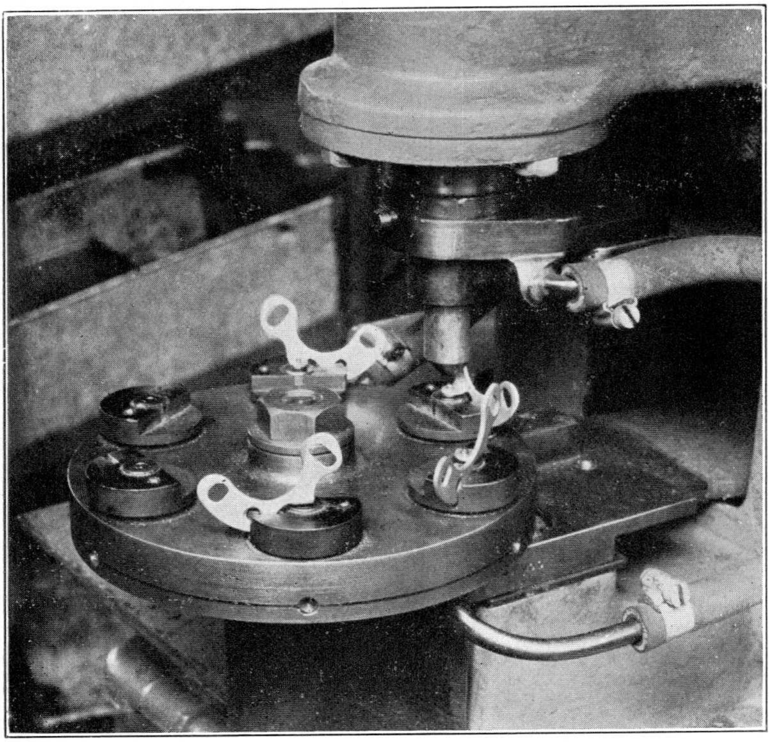


Fig. 174. Illustrating use of jig for dual purpose of locating and spot welding.

With the use of jigs for box construction, etc., accurate location is obtainable and in many cases two spots can be applied at the same time, the current passing through the locating jig to the lower secondary arm. After completion of the weld the jig can be removed from the box. This applies when jigs are made of good conductivity material such as copper or certain copper alloys. In some cases aluminium can be used.

The tools used in spot welding machines can be designed in such a way that otherwise inaccessible flanges and positions can be easily reached.

When designing jigs and tools the water-cooling of these fixtures should be considered and usually iron pipes are cast in the fixtures to enable a circuit of water to be passed round that part of the jig which would become heated during welding. Another point in designing is to ensure sufficient insulation of fixtures, when these are permanently fitted to the welding machine.

One of the most useful types of devices for spot welding is the sliding fixture to which the work is clamped and which is moved to pre-determined spots. (Fig. 175).

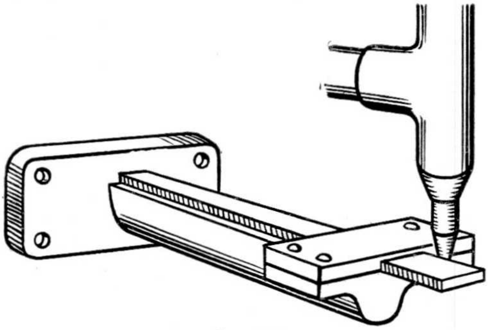


Fig. 175.

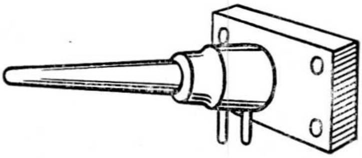


Fig. 176.

For pipe welding special lower arms are often arranged to serve the purpose of an electrode and a jig at the same time. (Fig. 176.)

Jigs for Projection Welders.

Whilst the question of jig and fixture design for spot welding is fairly simple, the correct design for jigs for projection welders requires far more consideration, as not only do they serve as location and fixing devices, but the actual projections on the work to be welded have to be accurately located with respect to one another.

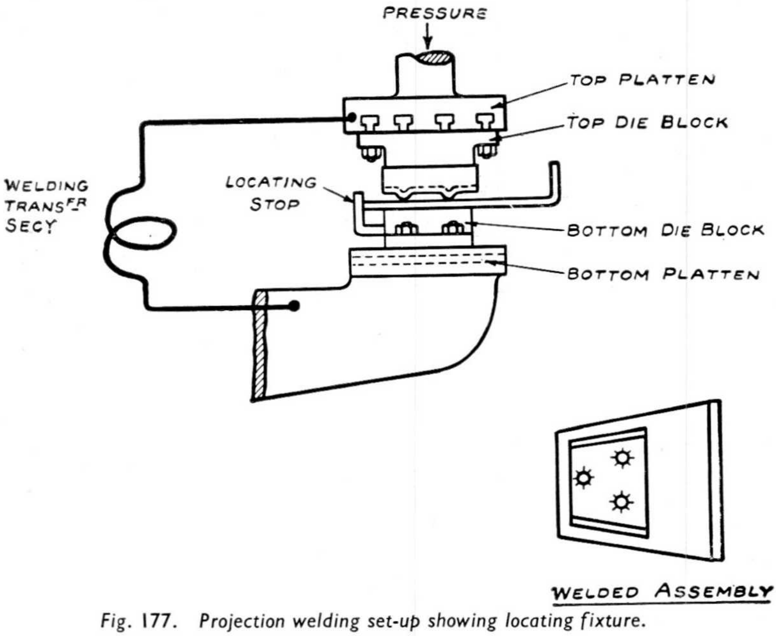


Fig. 177. Projection welding set-up showing locating fixture.

In broad outline it is good practice to follow the procedure used in fixing and designing press tools, as in effect a large projection welder is an air-operated press with location for holding work on the upper and lower tools. The upper and lower secondary arms are usually made with T slots to provide location for holding down bolts of the usual press tool variety. These fixtures are generally made of high conductivity copper with hard alloy inserts situated in such a manner that they come directly under the position of the work to be welded, where the projections are located. These inserts are renewable when wear takes place and it is found in practice that this is the best procedure for maintaining tool alignment.

Jigs and Fixtures for Seam Welders.

Apart from locating pins or limit stops, jigs or tools have not been extensively used for seam welders, as in most cases the work can be manually fed through the machine, but guide bars are invaluable.

Jigs and Fixtures for Butt and Flash Welders.

Jigs and fixtures are usually built into flash welding machines when the machine is under construction, as almost all these machines are specifically built for a certain operation and all jigs and fixtures are incorporated in the design to enable high production to be obtained and to enable the work to be located accurately. These fixtures are usually designed in such a way that they can easily be removed and a variety of fixtures can be bolted to one flash welding machine, always provided that the cross section area of the material to be welded does not exceed the capacity of the machine.

Jigs and Fixtures for Pinch and Gun Welders.

Jigs and fixtures for pinch welders serve for location or positioning only, the gun being used to tack the assembly in position in the location jig. These jigs are usually of the pedestal type and can be constructed of angle and steel sections, the assembly being lifted from this assembly jig and passed to a pedestal type of welding machine for completing the welding. The tools in the gun welder would be of such shape as to enable the key position of the assembly to be reached for tacking. These tools are designed purely for tacking purposes and the yoke of the gun is constructed in such a way that the parts subject to heavy wear are renewable.

Chapter XIII

PLANNING FOR RESISTANCE WELDING

Planning Production—Training of Operators—Costing

PLANNING PRODUCTION FOR RESISTANCE WELDING.

In using resistance welding for mass-producing metal assemblies the main factor to be borne in mind is that the time of the longest welding operation should not exceed that of other processes, in other words, the welding operation should balance operations such as drilling, fitting, etc.

Spot welding on mass production can be roughly divided into two groups : jigging prior to welding and actual welding. It is obvious that the jigging time should be equal to the welding time. In some cases it is necessary to tack assemblies in fixed jigs, then remove the jig to complete the weld, as it is very often impossible to design a jig that will locate pieces accurately and at the same time leave sufficient room for manipulation of the electrode points. In these cases it is usual to have three locating jigs, using one on the welding machine, one being loaded and one unloaded.

With regard to the actual welding operation it is sometimes found necessary to break down various operations owing to difficulties of approach or due to one machine being overloaded with work and causing a bottleneck, thereby restricting production.

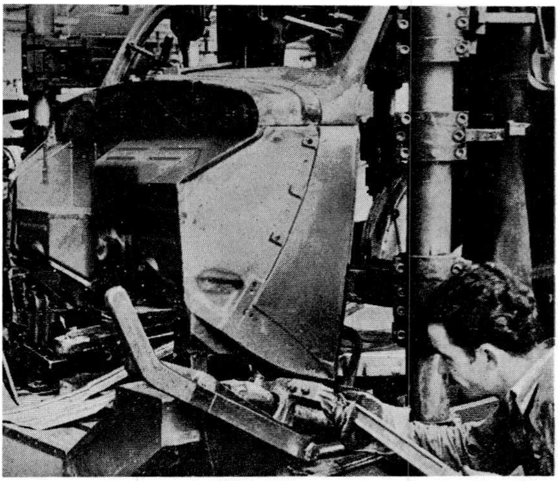


Fig. 178. Spot welding jigs.

It is usual for one machine to be tacking assemblies, whilst the final welding is carried out on three other machines suitably tooled. When planning for this production continuity of output should be aimed at with a minimum of handling of components between operations.

With bulk assemblies a high rate of production can be achieved by using air-operated gun welding machines for the initial tacking operation. These gun welders are very mobile and can be inserted in awkward corners and places that would otherwise be inaccessible to the pedestal type of welding machine. Furthermore, it will be found that to locate the assembly accurately the assembly jig will be so bulky that two men would be required to carry it to the welding machine ; obviously using the gun welder reduces the cost of production owing to less labour being employed.

Planning production for resistance welding should really start on the drawing board, as, if the product is not designed to take the maximum advantage of all the possibilities of resistance welding, then the cost of production may be equal to or only slightly below that of other methods. The first essential in designing for resistance welding production is to avoid inaccessible corners and to have flanges of adequate width to enable welding electrodes to pick them up ; furthermore it is necessary to break down the assembly into small components which can be easily handled as sub-assemblies. The sub-assemblies will be ultimately jigged in one master jig which locates the whole of the article being manufactured.

Fig. 179. Sketch of joint unsuitable for spot welding.

Fig. 180. Sketch of same joint for suitable spot welding.

Fig. 181. Sketch of incorrectly designed joint for resistance welding.

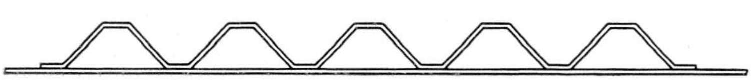


Fig. 182. The same joint designed for spot welding.

The designer of spot welding assemblies should work in close collaboration with the designer of the jigs locating the parts to be welded, as it has been frequently experienced that the jigs for locating the parts have located them in such a manner that it was quite impossible to insert welding electrodes to complete the welding operation. This matter is dealt with more fully in the chapter on jigs and tools.

An important point that is often overlooked in planning for production is that the material to be welded is not specified and cases have occurred where unsuitable material or coated material has caused considerable difficulties, whereas, if in the original planning a material suitable for resistance welding had been chosen, these difficulties would not have arisen. Particular care is necessary where coated sheets are being dealt with or where the material is likely to be of a scaly or dirty nature, in fact the invariable rule for resistance welding should be bright clean material or a de-oxidising process should be used before welding takes place.

Another point that should be taken into account is that the material or joint specified should not be in excess of the plant capacity and very often production can be increased by modifying the design to fit in with the production capacity of the machines in question. It is as well on high speed production to work no resistance welding machines on a duty cycle exceeding 65%.

The above remarks should enable the preliminary design and specification to be drawn up in such a way that the article will be suitable for the shop capacity, but there are a number of practical points which should be taken into consideration and these depend upon the type of welding that is to be employed.

Spot Welders.

Dealing, first of all, with spot welding an important point to consider in planning for production is that the number and size of spots should give adequate strength to the parts to be welded ; bearing in mind the ultimate use to which the article will be put and that a large number of spots may not be necessary, it is advisable to test to destruction various assemblies with a varying number of spot welds in varying positions to ascertain if the completed article has the required strength. This, of course, refers to normal commercial production of mild steel assemblies and not to special applications as required to War Office or Air Ministry specification.

Projection Welders.

In addition to the precautions that should be taken in planning for spot welding, a very important factor in planning for projection welding is the question of die design and the number and placing of projections. This, of course, will be determined by the capacity of the equipment being used and it is advisable to obtain the makers' recommendations on this point before designing for high production on any particular machine, except in cases where experience has proved that the operation contemplated is well within the capacity of the machine.

When designing projection welding tools it is advisable to build into the tools as many locating points as possible to align the work accurately ; also these locations should be of such a nature as to enable the work to be rapidly clamped in position and removed when welded. Good quality castings for the manufacture of these tools are essential. Phosphor bronze is generally used, and this should be completely free from blow-holes and imperfections. These castings have to carry a very heavy current and if they are defective, there is a danger of them breaking down under the current that is being passed through them. It will, therefore, be appreciated that close co-operation between the planning department and the tool-room is most important.

Seam welders.

The problem of planning for seam welding production is slightly different from the above examples, as the factor to be taken into account is the footage which has to be seamed and the length of runs required, also whether the seams have to be watertight or merely have to join two surfaces together.

In planning for seam welding the following factors should be taken into consideration. The seams should be accessible for the rollers of the machine and care should be taken that if external water-cooling is used, the water is not trapped in the vessel or component being welded. If the surfaces to be seam-welded have an oxide deposit, they should be ground, or cleaned by a de-oxidising process, before welding takes place. Many modern roller machines are knurl drive and therefore the rollers are self-cleaning ; if they are not of the self-cleaning type, there will be a danger of pick-up from the sheet being welded and this iron oxide should be removed frequently, otherwise there will be a possibility of indentation and holes in the sheet being welded.

A very important point for the planning of seam welding is that the radius of the corners shall be easily dealt with by the machines available and also that special rollers or extremely small rollers do not have to be used. A rough rule is that the design and planning should not allow for curvatures of less than $1\frac{1}{2}''$ radius.

Flash Butt Welders.

High speed production by flash butt welding methods is best obtained by using machines with fully automatic clamping and jigging with push-button control. These machines are so designed as to give constant output with very little variation in consistency. It is usual to have two operators on this equipment, one loading the machine and the other removing the welded work, this being closely followed up by the first operator inserting fresh work to be welded.

It will be found in practice that there is a large accumulation of swarf from this machine that should be removed at regular intervals of say four hours. The holding-down clamp should never be scraped or filed with rough implements, as this causes high spots in the clamping, thereby causing bad location and slipping of the clamping, when in operation. This may not seem to apply directly to planning, but actually it is important that the original planning should incorporate the correct clamping and holding-down devices as part of the original specification of the job so that most of the difficulties will be removed at the planning stage rather than the production stage. This again means that the design office should collaborate very closely with the tool-room and in the case of elaborate fixtures it is probably advisable to bring in the machine makers so that their experience in using the most suitable forms of dies and clamps can be utilised.

As flash butt welding is generally employed where a large production is required, time spent in studying this problem from all angles will be more than repaid, especially if a time study is made of the sequence of operations, including the loading, unloading and storage of the stock to be welded. This should come readily to the hands of the operators and care should be taken that the actual welding position is not too high for the operator to reach. In some cases it is advisable for the flash butt welding machine to be placed in a pit in the floor of the workshop. This enables the operators to reach the work easily and this provision in the planning of the workshop will be repaid by increased production.

Where large production by means of resistance welding methods is undertaken it is advisable to appoint an inspector of welding whose responsibility it will be to take samples of welding from the various machines and various processes, these samples to be submitted to the laboratories for tensile strength and in some cases for photomicrographs, to enable the inspector to keep a close check on the quality of output. This inspector would note the various machine settings and keep a memorandum of these and visual check-overs of the equipment which would ensure that the machine settings are kept constant for various runs of work ; in this way consistent quality would be maintained.

In conclusion the principles of planning for resistance welding can be summarised as follows :—

(1) Design suitable for the type of resistance welding to be employed.

(2) Close co-operation between the tool-room and the designer.

(3) Study of the sequence of operations and movement of operators.

(4) Study of the delivery of the workpieces to the machine and removal from the machine.

(5) Progressively arranged inspection and control of the quality of output.

TRAINING OF RESISTANCE WELDING OPERATORS, MALE AND FEMALE.

One of the great advantages of resistance welding machines is that unskilled labour, either male or female, and particularly boys and girls, can be used for the operation of most resistance welding machines, but this does not mean that the process can be carried out without skilled supervision or maintenance, if satisfactory results are to be obtained. Further, the tendency to put operators to work without explanation as to what is required of them, is not to be recommended.

Owing to the fact that resistance welding machines are extremely monotonous to operate, labour should be selected of a mentality suited to this type of work. Then again, workers should be selected who are rapid in their movements and whose dexterity is such that they can perform the same operation over and over again at high speed.

For those works who grade or test their labour, a suitable test would be the following :—Take a board divided into 25 squares or compartments ; 25 counters or disks numbered 1-25 are placed in front of the candidate and an arrangement of these disks in the squares is shown on a suitable screen or exhibited on a card. The candidate then has to place the numbered disks in the same order as that on the card or screen and those candidates who, as a result of three tests with different groupings, can arrange the disks correctly in a time period of less than three minutes, are likely to be suitable for rapid operation.

Any similar tests such as placing disks with various size holes on various size pins can equally well be employed, the main requirement being to ascertain that the prospective worker possesses manual dexterity and co-ordination of eye and hand.

Probably the best procedure when employing labour which is totally unfamiliar with resistance welding is for a skilled operator to demonstrate the process to them. In the case of female labour it is important to point out that there is no risk of electric shock and that the sparks are harmless apart from minute pin prick burns in clothing. Protective overalls or clothing should therefore be worn.

A very important point, if the shop-floor is of concrete, is to provide wooden duckboards or wooden platforms for the operators to stand on. In all cases where practicable, the operator should work seated, adjustable stools being provided ; this, of course, particularly applies to repetition spot welding by female operators. The operators should be instructed that on no account must they adjust or set the machines themselves. Further, they should be shown specimens of good and bad spots and be instructed to call the foreman immediately the work deteriorates below the standard set.

These remarks, of course, only apply where totally unskilled labour is employed, but the system should be used wherever practicable, as it has been found that the bulk of variation in welding is due to operators either altering the machine setting or allowing the tips to become unduly worn and in the case of machines not fitted with timers, depressing the pedal for too long.

Having demonstrated to the operators the operation of the machine and the type of spot required, they should then be allowed to try the machine on scrap material, but no endeavour should be made at this stage to speed up operations. As soon as they produce satisfactory results working at their own pace, then they can be trained to produce work at the laid-down production required. The main point is that to get production, quality of welds must not be sacrificed and the operator should be trained to produce quality, leaving quantity to come with experience and increase of manual dexterity which can only be obtained by practice.

It must be realised that a lower output is far more economical in the end than a high output with a large percentage of rejects which can so easily happen where operators are endeavouring to reach a production rate which is beyond their stage of dexterity.

One of the best incentives for operators to obtain good production is a bonus scheme which provides for deduction of bonus depending upon the percentage of rejects.

Female operators rarely progress beyond the stage of operator, nor in most cases is their mentality or background suitable for training as a skilled operator or machine setter. Boys and male labour, on the other hand, if kept purely as operators, are likely to become dissatisfied and those suited for more important work should be given training in the basic principles of resistance welding, so that they can be used for setting up machines or on important operations.

Gun or pinch welders are mostly operated by male labour owing to their weight and the physical strength required for their operation. This, of course, also applies to the heavier projection and flash welders.

COSTING SYSTEM FOR USE IN RESISTANCE WELDING.

The question of the costing of resistance welding is one that requires careful consideration because, whilst the true cost of resistance welding is extremely low, if the costing is not correct, the amounts included for this process may be unduly high, or the estimates may be on a hit-and-miss basis and may give an entirely false conception.

The problem of costing resistance welding for large works, of course, presents no difficulties as the machines are generally treated under the normal costing system employed for other types of machine tools, but medium or small works who do not employ such elaborate systems, undoubtedly have a need for simple methods of costing.

The main factors that have to be taken into account are : the capital cost of the machine, depreciation, maintenance, cost of spares and replacements including electrode cost, operating costs, cost of current, operators' time, overheads.

A very good system is to have an individual card for each machine and as soon as a machine is installed in a works it is given a machine number which is entered on its card. (Fig. 183.) On this card are entered the cost price, name of maker, cost of any auxiliaries and special equipment, cost of installation, date of purchase, date of installation, depreciation period, approx. load factor, current consumption per hour. When any repairs are done or spares provided, the cost is added so that the actual cost is known of any given machine.

In the top left-hand corner is the hourly cost of the machine which is an extremely useful guide when making up estimates. This hourly cost of the machine is of course exclusive of operators' time. In the right-hand corner are given details of the production output of the machine per hour, again very useful information for estimating and planning.

Type of Machine : Serial No. : Works No. :
Makers' Name : Voltage : Freq. : Phase :
Current taken p. machine p. hour :
Date of installation :

Tel. No. :
Cost price delivered : Installation and Erection : Total Cost :
Depreciation p.a.
Appr. load factor : Running cost per hour including current and overheads,
No. of operators except operators' time..
required................. Output per hour..
Maintenance and Repair..

Date	Material or Spares				Labour			Other Costs			Remarks
		£	s.	d.	£	s.	d.	£	s.	d.	

Fig. 183. Specimen machine card.

It will no doubt be of interest to work out an example of the actual costs on a known machine. In our example we have assumed that a machine suitable for welding 2 × 14 SWG. will cost £100 :—

	£	s.	d.
Cost of machine	£100	0	0
Installation cost, say	5	0	0
Special Electrodes	2	10	0
Total first cost	107	10	0
Depreciation at 10% per annum	10	15	0
Maintenance and repairs including cost of new electrodes, say	10	0	0
Cost per hour based on a 48 hour week and at 50% load factor (50 week-year)			4.15d.
Overheads per hour at 200% on cost			8.3d.
Current consumption per hour at 1d. per unit ...			5d.
Operators' wages per hour		2	0d.
Total cost per machine hour		3	5.45d.
Average number of spots per hour, say ...			500
Therefore cost per 1,000 spots			6.11d.

This figure per 1,000 spots is a very useful figure for estimating, but a multiple has to be used to meet varying conditions of work because these very largely affect the production output of a machine.

These multiple figures for costings are, of course, best found by practical experience, but for spots with a spacing between ½″ and 1″ a multiple of 2 will probably be found necessary ; for an output with 1½″, 2″ or 3″ spots a multiple of 3 or 3.5 will be required. Similar examples of the same system can, of course, be worked out for stitch welders, but in the case of projection welders and flash and butt welders, instead of per 1,000 spots the cost would be worked out per operation in the case of projection welders, irrespective of the number of spots per operation ; in the case of seam welders, per foot run of various gauge materials. In the case of flash and butt welders the hourly cost is, of course, calculated on the same basis, but the welding costs are per operation unless the operation is one of joining sheets of the same width together, in which case an area or length of joint cost may be more convenient.

In addition to the individual machine cards a specially ruled book should be kept showing the production obtained and the hours in operation compared with the whole working hours of the works.

Machine Type	Card No.	Production Units per week ending	Hours fully employed	Hours worked by works	Operators' wages per machine per week	Hours out of action due to breakdown	Contract No.

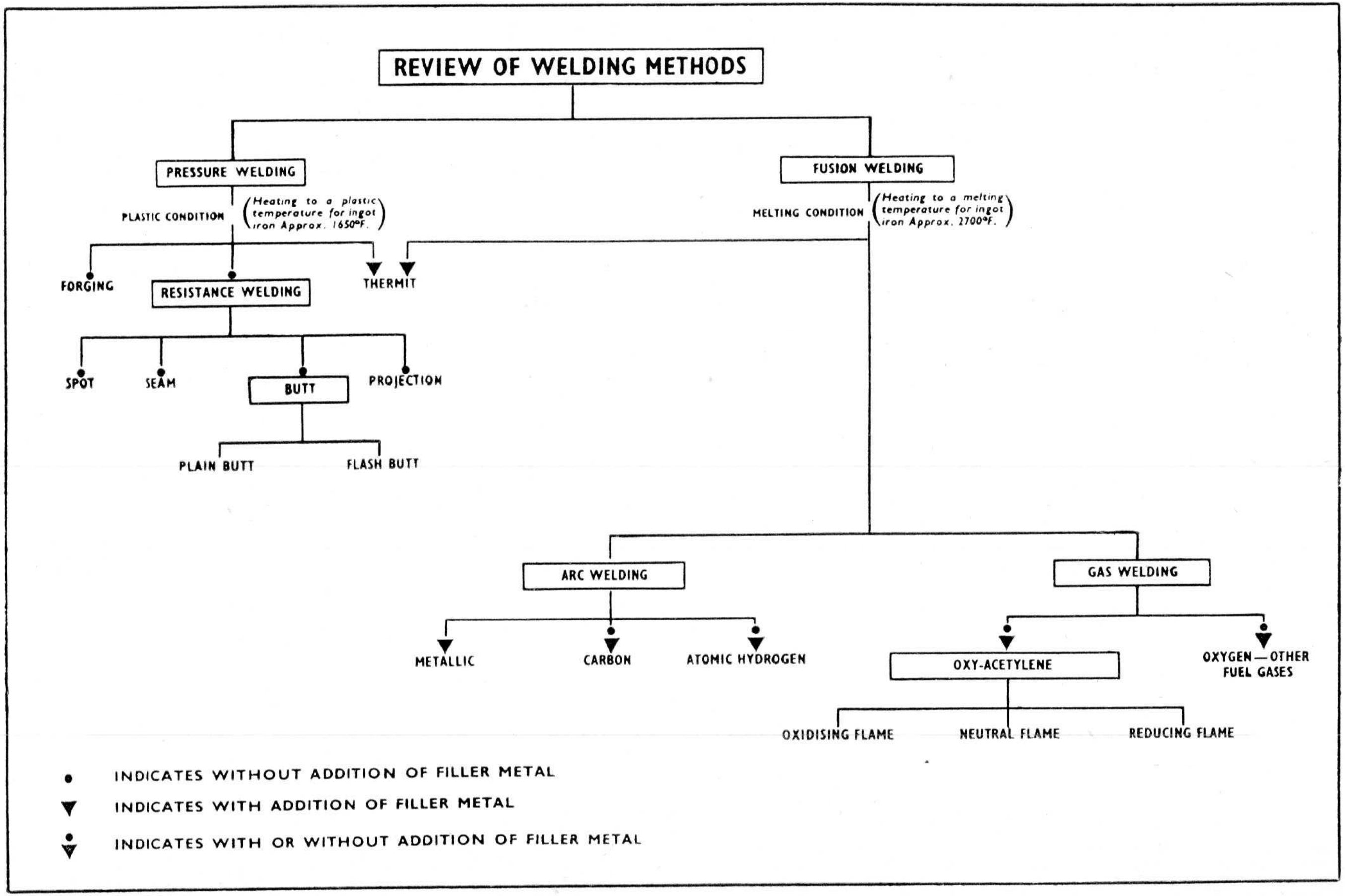
Fig. 184. Specimen of ruled book.

The purpose of this book is to enable the load factor on the machines to be judged and to ensure that machines are kept fully employed as far as possible and that the correct calculation figure is inserted on the machine card. This book also shows the actual operators' wages expended per machine per week or some other period, and the approximate value of the current used per week per machine, this only being an estimated figure except in the case of very large flash and butt welders involving several hundred kVA., in which case the value of the actual current consumption should be inserted. A column is provided for the machine card number and the column indicating the number of hours the machine is out of action due to breakdown or other causes, but not owing to lack of work, is particularly valuable as it enables a bird's-eye picture of the efficiency of the machine to be obtained. It is advisable to keep this column in a different colour ink from the other figures, preferably red or some other easily distinguishable colour.

The total figures are periodically checked against the job costings or the costings of any particular contract and revised, if necessary, so that the correct cost figure is always reasonably up-to-date.

It is a very good practice, when a contract is undertaken, to prepare an estimate based upon these card figures and at the end, or at regular periods during the contract, this estimate is checked against the actual cost of the contract. Such continuous checking of estimated as against actual costs should result in extremely accurate estimating, provided no abnormal conditions have arisen, and if an estimate shows any great variation over a number of contracts, then obviously the system is not being correctly applied and steps should be taken to remove the error, due allowance of course being made for exceptional circumstances or a run of bad material or articles difficult to weld.

The use of such a costing system will not only enable competitive tenders to be put in, but will be found invaluable when discussing contracts in which costings or other forms of price control are involved.


REVIEW OF WELDING METHODS
PRESSURE WELDING
PLASTIC CONDITION
(Heating to a plastic temperature for ingot iron Approx. 1650°F.)
FUSION WELDING
MELTING CONDITION
(Heating to a melting temperature for ingot iron Approx. 2700°F.)
FORGING
RESISTANCE WELDING
THERMIT
SPOT
SEAM
BUTT
PROJECTION
PLAIN BUTT
FLASH BUTT
ARC WELDING
GAS WELDING
METALLIC
CARBON
ATOMIC HYDROGEN
OXY-ACETYLENE
OXYGEN—OTHER FUEL GASES
OXIDISING FLAME
NEUTRAL FLAME
REDUCING FLAME
INDICATES WITHOUT ADDITION OF FILLER METAL
INDICATES WITH ADDITION OF FILLER METAL
INDICATES WITH OR WITHOUT ADDITION OF FILLER METAL

Selected List of Books and Pamphlets in the Library of the Institute of Welding.

(Arranged as follows: (A) publications devoted solely to the subject; (B) handbooks containing sections on the subject).

(A)

American Welding Society.
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