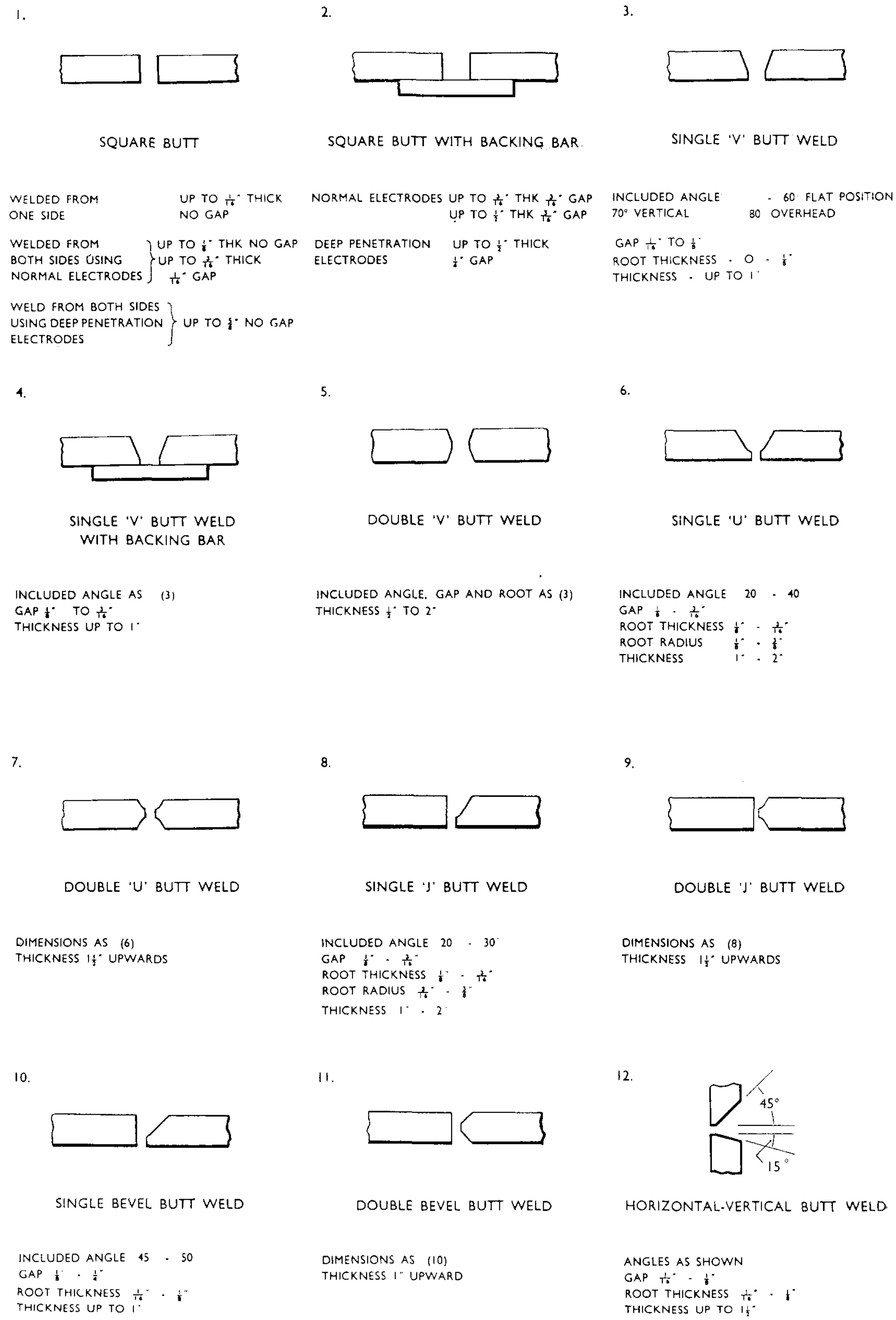


FIG. 1—BUTT WELDS FOR MANUAL WELDING

ARC WELDING IN THE CONSTRUCTION AND REPAIR OF SHIPS

THE WELDED JOINT IN SHIPS

BY

F. BROOKSBANK, M.A., A.M.INST.W.

The Author is the Field Manager of Quasi-Arc Limited, and acknowledges the permission of the Directors to publish this article.

At one time there was considerable doubt expressed on the effectiveness of welding as compared with riveting but now, with so many examples to quote in practice, the welded joint has proved its value in increasing the efficiency and economy of any type of fabrication or structure. In shipbuilding, after some initial setbacks due largely to inexperience in welding design, progress has been very rapid and, in spite of the high capital expenditure involved, most shipyards in this country have been reorganized so that the process of welding can be utilized to its full extent.

It is interesting to review the particular advantages which are inherent with the welded ship since they provide the pointers for the future of British Shipbuilding :

(1) Higher structural efficiency mainly due to the elimination of holes which are essential to riveting practice

(2) Reduction in dead-weight by the elimination of lapped surfaces and using the direct connection provided by the welded butt joint. This allows for increased carrying capacity and, therefore, decreased cost of operation

(3) Automatic sealing of all joints thereby eliminating the need for caulkers

(4) Smoother hull surfaces giving a worthwhile saving in propulsive power required

(5) Speedier building by the use of prefabricated sections and the smaller number of components to be handled

(6) Cheaper construction by the reduction in labour force and the saving in material.

Due to the continual rise in the cost of labour and materials, shipbuilding in this country will only maintain the lead by greater productivity which can only be achieved by making full use of the latest processes.

To design for welding, due account must be taken of the stress-carrying capacity of the various types of welded joints, their behaviour under load and the practical factors involved in making them. Not the least important aspect is the design of the welds themselves since design can make or mar an efficient and economical structure. It is fundamental that in order to build anything efficiently the connection should be sound and this is precisely the case with welding. Anything that can be done to improve the ease of making the welds and ensure their efficiency will be repaid many times over.

The two main categories of welds are butt welds and fillet welds but there are many different types which can be selected.

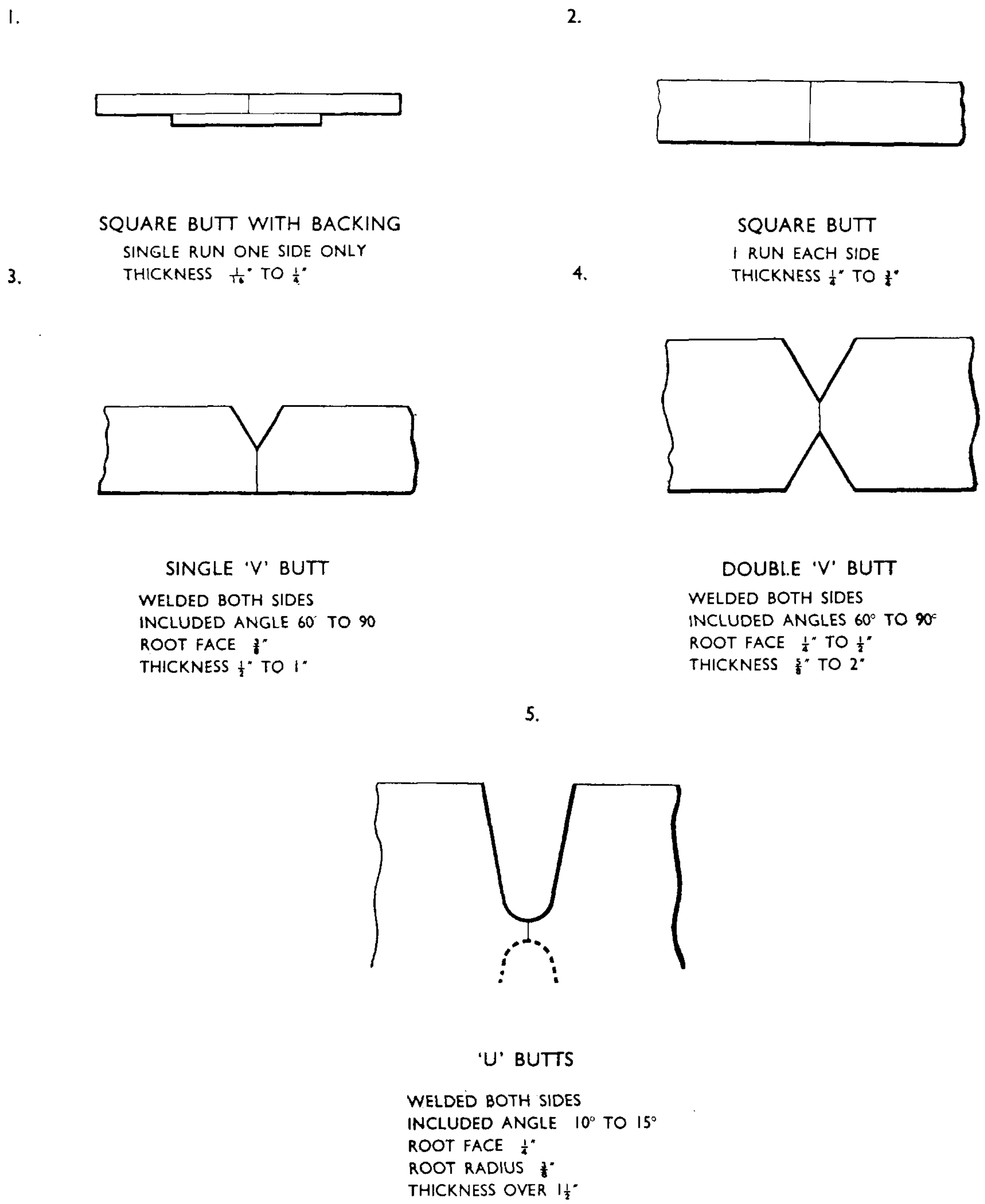
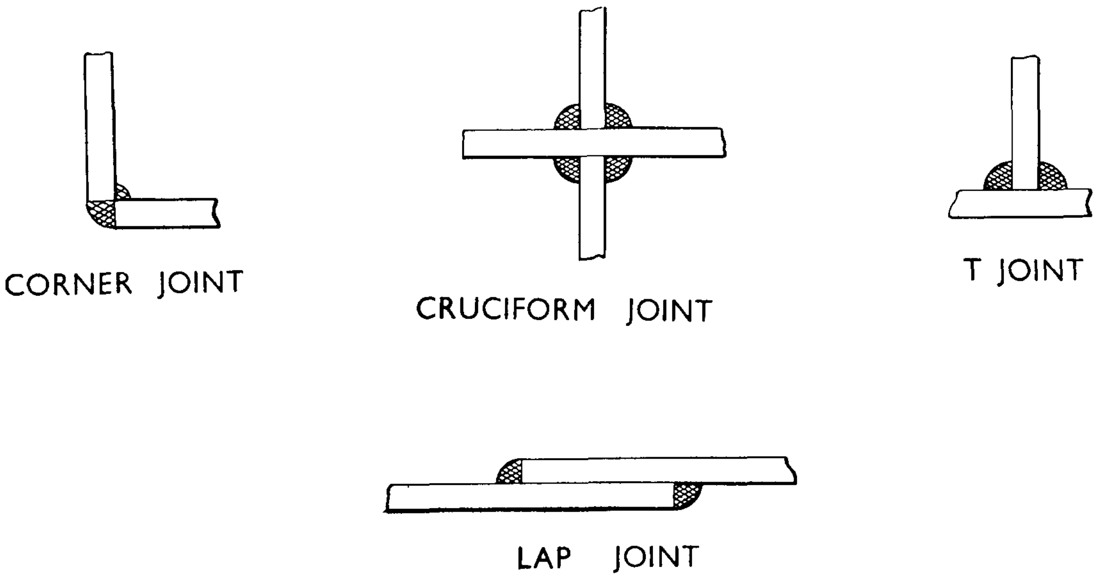


FIG. 2—BUTT WELDS FOR AUTOMATIC WELDING

Butt welds are made between the edges of abutting plates and are generally described according to the way these edges are prepared. FIG. 1 shows examples of various types designed to meet various requirements for manual welding and examples of butt welds for automatic welding are shown in FIG. 2.

Fillet welds are made between plate surfaces which are usually at right angles but the angle between the plates may vary from 60 to 120 degrees for load carrying. Generally no edge preparation is required provided mating edges are reasonably true and smooth. Various types of fillet welds are shown in FIG. 3.



FILLET-WELD JOINTS

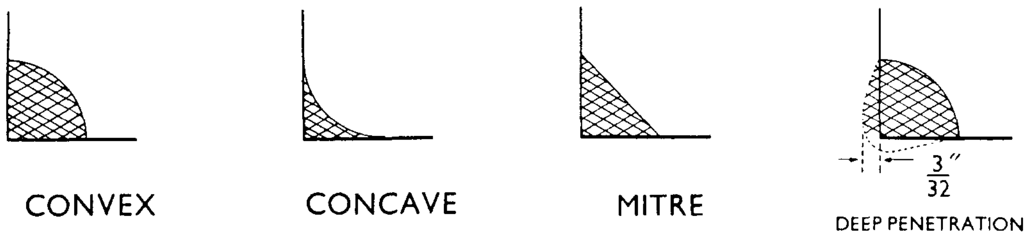


FIG. 3—TYPES OF FILLET WELDS

It is very important that the dimensions of butt welds, i.e. thickness, included angle, root face, root gap and root radius should be combined in such a way as to ensure that full penetration can be obtained and the joint is a practical proposition at the same time as being economical.

The selection of the type of weld to use on any particular joint will depend on a variety of factors and circumstances, the chief being :—

(i) Accessibility for welding
(ii) Position for welding
(iii) Shop or site welding
(iv) Thickness of material to be used
(v) Electrodes or process to be used
(vi) Power available
(vii) Type of edge preparing equipment available
(viii) Loading on the weld.

Since the number of variations and procedures is very large, it is recommended that a chart of standard welds and procedures should be prepared and rigidly enforced in the shipyard or maintenance ship taking into account all the above factors.

The stressing of welds can be very complicated but simple design rules have been evolved (Ref. *Design of Welds* by Quasi-Arc, Limited) which give reliable results within the practical tolerances of making the welds.

Essentially the loadings can be of a static or a dynamic nature and the treatment of welds under these forces is very different.

For butt welds under static load, provided full penetration is obtained and the same stress is allowed by specification as in the parent metal, no design is necessary since the welds will have at least the same cross-sectional area as the parent plate. For fillet welds, the critical section, as far as stress is concerned, is the throat thickness and this dimension, which for right angled fillet welds is taken as 0·7 × leg length, is used for design. With deep penetration fillet welds, provided the penetration of $\frac{3}{32}$ in. is achieved, $\frac{3}{32}$ in. can be added to the leg length for determining the size of welds.

Under dynamic loading and particularly where fatigue conditions apply, the shape of the joint and the soundness and smoothness of the weld are more important than the cross-sectional area of deposit. A convex fillet weld is better than a concave fillet weld for static load but for fatigue loading the reverse is true. Thus the aim should be to ensure that the flow of stress is as smooth as possible with eccentric connections and notch effects reduced to a minimum in order to avoid stress concentrations which are the primary initiations of fatigue failure. Rounded corners to hatches in place of rectangular is one example in point.

Having ensured that the design of the weld and welded joints are correct, it is important that the information should be passed to the shop or yard usually by means of symbols on the drawings ; B.S. 499 : 1952 gives a suggested scheme. In the shop, particular attention should be given to the preparation of the plate for welding and the fit-up of the joints. Bad fit-up, although possible to deal with by manual welding (for repair work, etc.), increases both the welding cost and the skill required by the welder. It is useless to consider using automatic welding or to establish procedures and piecework rates, etc., if consistent fit-up and plate edges cannot be guaranteed.

Welding has come to stay and will play an ever-increasing part in the construction and repair of all types of structures and fabrications. It is essential, however, that to build better and cheaper structures, ships, etc., it is to the foundations that we must look and ensure that the fundamentals of good welding design and practice are applied.

ARC WELDING PROCESSES USED IN SHIPBUILDING

It is now fifty years since covered electrodes for the manual metal-arc process were introudced into this country ; a very large amount of research in welding has taken place since then, but the process is still the most important of all those in use in industry.

Progress in manual metal-arc welding has taken the form of gradual improvement and growth of existing applications rather than spectacular new applications. Within the last decade, however, its scope has been considerably widened by the increasing use of low-hydrogen electrodes, making it possible to weld steels that are difficult to weld with normal mild steel electrodes, and giving greater assurance of safety in the fabrication of mild steel where heavy sections and/or a severe degree of restraint are inherent in the construction. More recently still, experience has shown that the use of iron powder in electrode coverings offers great possibilities of economy. Ease of welding, ease of slag removal, neat weld appearance and above all the high welding speeds are all atractive features of iron powder electrodes.

In the field of plant for manual welding, the principal advance has been the introduction of metal rectifier sets. These equipments have many advantages over rotary equipment, operationally because of the more stable arc, and economically because of their higher efficiency and the fact that very little maintenance is required.

Welding can be carried out much more quickly in the flat position than in other positions. This fact has led to the introduction in recent years of positioners and manipulators which enable many types of job to be quickly turned or tilted so that all the welding can be carried out in the flat position. This is another way in which productivity in manual arc-welding has been improved by extension of existing processes.

For automatic arc-welding there are two main processes : the open-arc process using a continuous flux covered electrode and the submerged-arc process using a bare wire electrode and granulated flux powder. The processes are about in equal use in this country ; the open-arc process being more used on outside work and the submerged-arc process being more used in shop work.

The continuous covered electrode generally used for the open-arc process consists of a core wire wound round by auxiliary wires and coated with a flux covering. The auxiliary wires protrude slightly above the covering and serve to conduct the welding current from the welding nozzle to the central core wire. As the welding current is introduced to the electrode near to the arc region, considerably higher currents, of the order of three times those used for manual metal-arc welding, can be used, with a corresponding increase in welding speed.

As in manual metal-arc welding, the flux covering of the electrodes can be used as a medium for adding alloys to the weld metal, so that the open-arc process can be used for welding a wide variety of steels and for the deposition of wear-resisting hard surfaces.

In the submerged-arc process, a lightly copper-coated electrode wire is used in coil form and the currents used are of the order of four times those used for manual metal-arc welding, with a corresponding increase in welding speed. The arc operates below a layer of granulated flux powder and this flux powder is completely anhydrous. Only a portion of the flux powder layer is fused during welding and this forms a glass-like slag which is easily removed from the weld metal.

The type of automatic welding machine which is in most general use is the portable self-propelled machine running on rubber-tyred wheels or on a special track.

For horizontal-vertical welding, a special guiding wheel arrangement, crabbed to keep the welding nozzle in correct alignment with the joint, is fixed to the machine. When using the submerged-arc process for horizontal-vertical fillet welding, accuracy in pre-setting the angle of the electrode wire is essential because the blanketing layer of granulated flux makes it difficult for the operator to make any correction during welding.

The high speed of automatic welding is its most attractive feature but automatic welding heads alone can only partly achieve the advantages which automatic methods of welding make possible. Only if their use is considered together with the provision of really efficient means for the precise positioning and rapid movement of the work can the full benefits of automatic welding methods be obtained.

The use of automatic welding affects production rates and methods extensively and it must, therefore, be properly introduced in the production scheme, which may itself need re-organizing with the use of automatic welding : a greater volume of work has to pass in less time through a given production space and provision must be made for its efficient handling. Much of the advantage of fast welding speeds would be lost if it took longer to set up a job for welding than formerly, or if delays should occur in the movement and flow of work.

One of the most interesting welding processes introduced within the last five years is that using a continuous electrode which is deposited within a protective shield of gas, either of argon, or a mixture of argon with oxygen or of carbon dioxide.

These processes have opened up a new field of welding and their use will be reviewed in a later article.

A new process, described more fully later in this article, uses a continuous covered electrode in conjunction with CO_2 gas-shielding giving results which are both operationally and metallurgically superior to either flux-shielding or gas-shielding used alone. Known as FUSARC/CO_2 this process can be used to very great advantage in modern shipbuilding, where reliable methods of automatic prefabrication are of great and ever-increasing importance.

THE CHOICE OF MANUAL ELECTRODES FOR SHIP CONSTRUCTION AND REPAIR

Essentially, there is little difference between manual welding electrodes designed for use in ship construction, and those intended for repair work.

Certainly in shipbuilding, more latitude is possible for flat position welding where skid prefabrication methods are used, but positional type electrodes are required for the incorporation of such fabricated units into the composite ship. In repair welding, the ship structure exists so that the preponderance of work involves positional type electrodes.

In both spheres, the employment of planned welding sequences such as ' cascade ' welding and centre point outward progression methods are required ; in building for the final assembly work, and in repair to minimize the effects of welding under general conditions or restraint.

To a very large extent, therefore, the types of electrodes used in ship work are common to both building and repair.

Probably the best yardstick in evaluating the various classes of electrodes is B.S. 1719 : 1951 which classifies the electrodes into groups in accordance with the type of covering, the welding position, and current conditions for usage. This classification system will be used throughout in electrode references.

Ship repairs in general are the consequence of the effects of wind and wave upon a composite multi-stressed skin and its internal components. In basic analysis, therefore, the ship proper can be sectionalized into three divisions : hull, framing and appendages, internal structure and superstructure, engines and propulsion gear.

Manual welding electrodes suitable for carrying out repairs to the various components associated with these several locations are generally available, but the precise choice is to some extent governed by the chemical composition and existing condition of the parent plate to be welded, the geometry of the joint to be made, and the position in which welding is to be executed. As the great majority of repairs are welded *in situ*, either a general purpose electrode of the E217 class such as Radian, or a universal electrode of the E316 class like Vortic, conforming to Lloyd's Register approval, is suitable for the usual run of mild steel applications such as hull repairs, general shell work, centre keelson, ships' floors, intercostals, and other units such as tank top and tank margin structures, knee brackets and shell framing, etc., also such appendages as bilge or stabilizer keels and such stream-lining as fin or eddy plates and balance or box type rudders, etc.

Where shell plating is exposed to salt water corrosion in way of the welded joints, it is preferable that the weld metal should match the parent material as near as possible in chemical composition ; slight variations would not affect the issue greatly but if, for example, the plating of a box rudder was repaired with an austenitic electrode, the net result under service conditions would be the induction of electrolytic corrosion. The stainless steel, being nobler in the galvanic series, would be unaffected, and the attack concentrated on the mild steel plating either side producing accelerated corrosion. Undoubtedly the better procedure is to weld with mild steel electrodes.

Where shell plating is heavily corroded, it is not always possible to bare to clean metal surfaces, and a fluid slag type E316 electrode such as Vortic, which has a driving arc, is preferable to burn through the residue of the rust deposit. Shell butts in, for instance, a replating contract, would also require the E316 positional type Vortic electrode, although sometimes a similar electrode with quiet arc action is preferable, such as Vordian (E317). Again, if longitudinal seams are to be welded instead of riveted, while the same electrode would suit the application, somewhat better results in the horizintal-vertical position joints would be achieved with Vertispeed, again E317 class, which electrode has proved eminently suitable for joints of this type. Where extensive damage has occurred involving tank top plating, it is often economic to seal weld the butt joints from the overhead position in the double bottom tank before using a deep penetration electrode of the E125P such as Weldeep, to secure full penetration through from the upper side. This procedure will usually permit straight edge welding and eliminate the expense of edge preparation provided the thickness of plate is not too great in relation to the electrode size. Repairs to the cellular understructure in the double bottom tankage would preferably require the use of an E3XX positional type electrode. Repairs to 'tween decks and internal structures, also bulkheads, such as deep tank, oil bunker and various divisions between fore and after peaks, will require either E2XX or E3XX electrodes dependant upon whether the connection is to tank top, shell or decking.

Another electrode in this group, Victor (E317), has proved particularly suitable for work where cabin, state room or bath accommodation is being modified. The average electrode used with vertical-upwards technique gives a convex finish in butt and corner welds which is not necessarily an advantage for the subsequent enamelling of the plate surfaces ; Victor on the other hand, produces with vertical-downward welding technique, a smooth weld with a swept concave finish which lends itself much better to decoration.

Where framing is to be welded in position to replace shell plating, a positional type electrode of either E3XX class or E6XX class can be used, irrespective of whether the connection is continuous or intermittent space fillet welding. If the sections are massive or plating heavy, the E616 type would be preferable, such as Ferron (New Type) or Ferron 35 electrodes, whereas in other cases Vortic or Vordian types would meet requirements. Hull repairs under restrained conditions such as the insertion of butt welded patch plates would preferably require the E616 class electrode, Ferron, which because of its fine-grained weld metal structure has a high crack resistivity.

In repair work it is rather unusual for X-ray clear standards of weld metal to be stipulated, but if the circumstances arise there is little doubt that the class E616 electrodes, Ferron and Ferron 35, would best answer the purpose. Similar applications, such as the welding of Oxter plate fracture or renewal of plating in the fore peak tank top or tank top flat, would likewise require this electrode or even in certain extreme circumstances the medium tensile counterpart, Ferron 35.

Work on the main or strength decks involving the connection of superstructure such as mild steel deck-houses, pump houses, tank or hatch coamings, derricks or samson posts and streamlined bridge front casings, would be carried out with either the positional E3XX type or general purpose class E2XX electrode dependent upon the application.

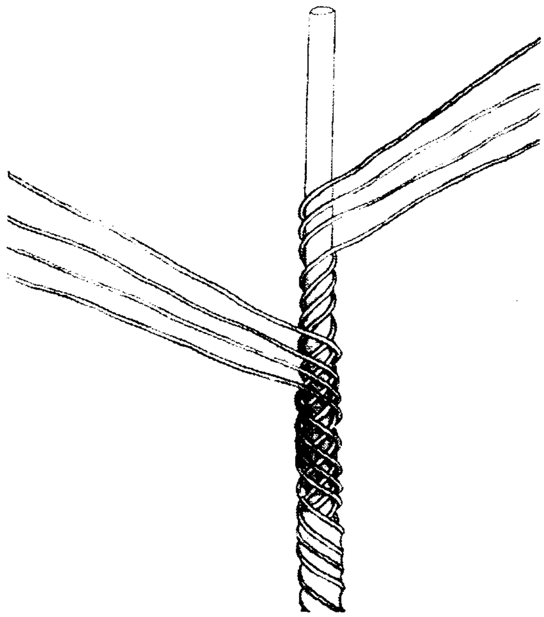


Fig. 4—Continuous Covered Electrode Process

Deck auxiliary equipment such as winches, deck cargo line pipes and mountings, would be dealt with in accordance with the nature of the material. If cast iron is involved, suitable cast iron electrodes for such work are Ferroloid No. 1 where a machinable finish is required, Ferroloid No. 2 for strength welding and Ferroloid No. 3 if high duty irons of the meehanite class are involved. Such electrodes would also apply in the case of engine-room equipment for either steam, turbine or Diesel propulsion. If, for example, engine columns are of cast iron then studding with either Ferroloid No. 2 or No. 3 would be preferable. Alternatively, for the welding of cast steel columns Ferron 35 would be more suitable.

Cast irons are also extensively used for Diesel cylinders where repairs to the internal bores can be carried out with similar electrodes. Boiler repairs both to shell, smoke box and fire box tube plates and to the combustion chamber proper would require a positional type electrode such as the E3XX class, either Vortic or Vordian can be used, the main essential being to ensure cleanness of the plate surface. Water side corrosion work likewise can be built up with either of these types. The main consideration in boiler repair work is the sequence of welding in a rigidly restrained structure, and in this connection if difficulties are experienced with either of the two electrodes mentioned it may be worth while resorting to the E6XX class with its greater high crack resistance of the weld metal deposit.

Engine-room auxiliary equipment such as feed pumps, circulating pumps for tankage, oil transfer pumps, salinometer pumps, etc., require treatment in accordance with the chemical composition of the material, whether of cast iron, steel or corrosion-resisting material of the non-ferrous class. Pump buckets, for example, are often made in phosphor bronze in which case Bronzoid No. 1 electrode, depositing a 6 per cent tin bronze, would be suitable. This electrode would be suitable also for building up eroded propeller blade tips of the phosphor bronze class, and also for the welding of fractures in stern tube bushes. Where non-ferrous materials such as monel metal or various types of stainless steels are used in auxiliary equipment, Mirroid or a selected Chromoid electrode would meet the requirement.

In the case of valve gear, often the faces and seats are built up with austenitic weld metal and the Chromoid series of electrodes would again meet the requirement in general.

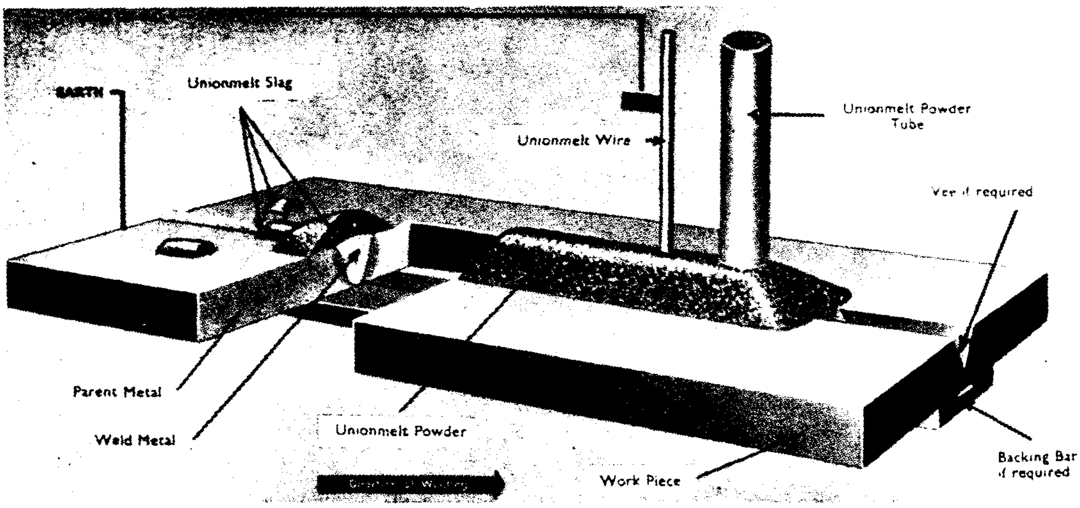


FIG. 5—SUBMERGED ARC WELDING

Shafting, whether for steam engines or other types of propulsion, is usually built up with mild steel electrodes to secure a machined finish, using the appropriate class of weld metal in accordance with the chemical composition of the steel, but wherever doubts arise a medium tensile basic type electrode of the E616 class, Ferron 35, would be suitable, provided subsequent stress relief measures were applied.

The advent of the rutile/iron powder electrode of the E9XX class is comparatively recent in regard to ship repairs, but the all-positions high speed and heavy deposition characteristics of Ferromax (E917) electrodes will no doubt prove attractive in the near future.

AUTOMATIC WELDING PROCESSES FOR SHIPBUILDING

Continuous Covered-Electrode Visible-Arc Process

This process (see FIG. 4) accounts for nearly half the fully-automatic welding of steel practised in Great Britain. Its principal advantages compared with submerged-arc welding are the visible arc, and its greater metallurgical flexibility, which allows a wider range of materials to be welded and enables electrodes with greater tolerance to rust, dirt and poor fit-up to be developed.

Considerable developments are being made in many aspects of the process. New and improved welding heads, both stationary and carriage-propelled, together with a wide range of manipulating gear, are part of the rapid growth towards the concept of a completely mechanized welding installation. In shipbuilding, very extensive use is made of self-propelled machines running on rails or on the plate itself ; the long, straight joints in flat plate, or plate curved in only one dimension, enable great economies to be effected by this method. Boilers and similar vessels are welded using a roller-bed to turn the workpiece under a stationary welding head.

Submerged-Arc Welding

Fully-automatic submerged-arc welding (see FIG. 5) employing a bare wire electrode deposited under an overburden of granulated flux, has been in established use in Great Britain for 23 years. At present it accounts for about 60 per cent of all automatic welding of steel.

Developments in the use of the process with new equipment and fully

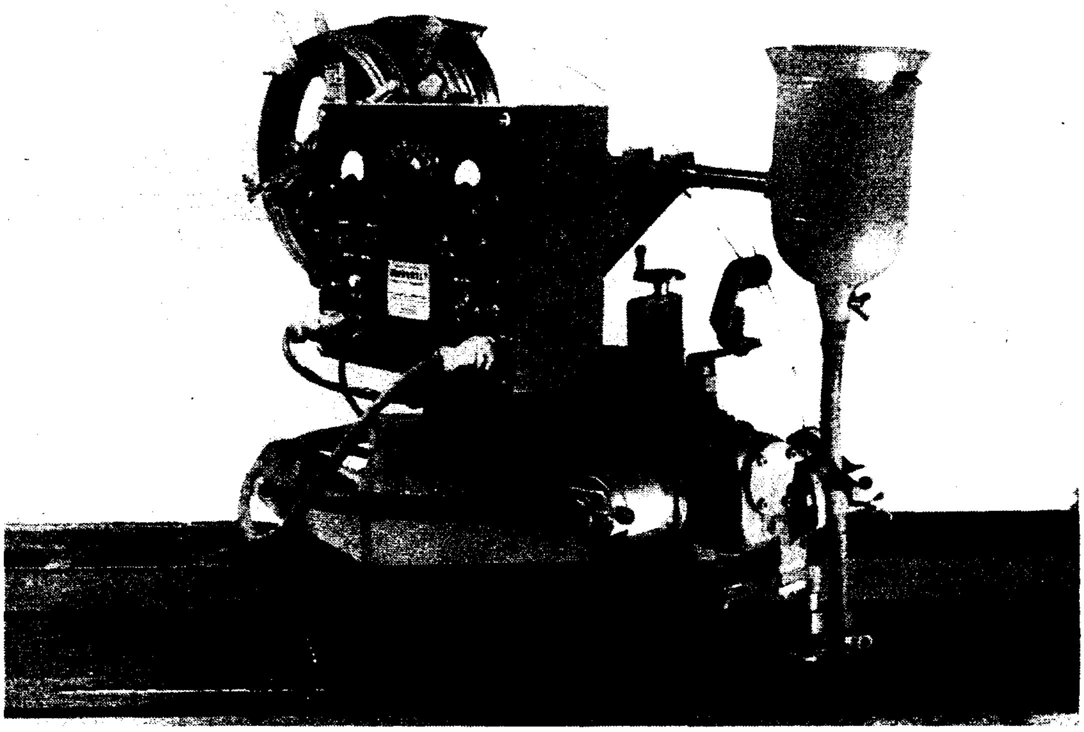


FIG. 6—PARALLEL WELDING

mechanized welding installations are taking place with the same rapidity as in continuous covered-electrode welding. There are also extensive developments in technique which are directed mainly towards higher welding speeds by the simultaneous use of two or more electrodes operating in the same weld pool.

There are three essentially different techniques :—

(i) *Parallel welding* in which two electrodes are connected in parallel to the same power supply, offers an increase in welding speed of about 50 per cent compared with a single electrode (FIG. 6).

(ii) *Multi-power welding* with two electrodes involves the use of two power sources and two welding heads, each with its own arc-control system. The capital outlay is heavier than for parallel welding but, as a compensation, the welding speeds are significantly faster. Metal can be deposited 2-2½ times as fast as with a single electrode, and about 50 per cent faster than with parallel welding.

(iii) *Series-arc welding* employs two separate welding heads, with the two electrodes connected in series across the poles of a single A.C. or D.C. power supply. The arc is thus formed between the two electrodes, and not between the electrodes and the workpiece. This arrangement results in shallow penetration over a wide area, and consequently has particular application to hard surfacing and metal-cladding operation.

New Process Employing both Flux and Gas Shielding

With the success of the gas shielded processes for welding, attempts have been made to use a cheaper gas than argon for shielding the arc. CO_2 was a logical choice, since it is a principal component of the shielding gases produced by many covered electrodes, notably the basic types.

With mild steel, however, the bare wire/CO_2 process does not produce the high grade welds which are now demanded and it has operational limitations including spatter and frequent cleaning stops which largely offset the saving in gas cost.

CO_2-shielded welding of mild steel has, however, been carried out with continuous covered electrodes with excellent results. In flux-covered electrode processes, basic low-hydrogen fluxes give the best metallurgical properties, but have only moderate operational performance ; rutile fluxes have good operating characteristics but give a lower level of metallurgical quality in the deposit, especially at high currents. Mitchell and Freeth[1] have described a recently introduced process combining the metallurgical quality associated with basic electrodes with the operational characteristics obtained from rutile electrodes. This process employs a continuous covered electrode of the wire-mesh reinforced type, designed to operate in conjunction with CO_2 shielding. The shielding gas serves the function of reducing the partial pressure of hydrogen in the arc atmosphere and evokes welds of high metallurgical quality to be obtained with a flux which is primarily of the rutile type, giving the desired operating characteristics and deoxidation control. Weld profiles in the flat and horizontal-vertical positions are good, with excellent slag detachability, no obnoxious fumes and a relative freedom from spatter. The electrode will operate satisfactorily on both A.C. and D.C.

Both metallurgical and deposition properties of the electrode are retained at currents considerably greater than those normally used with continuous electrodes operating in air and for this reason the process shows considerable economic advantages.

This new process is applicable to the whole range of applications for which continuous covered electrodes are already established and offers in addition important new features. One is the ability to make fillet welds of excellent shape and metallurgical properties at fast welding speeds. Hitherto with the normal rutile-type continuous electrodes that can be used for fillet welding, the current, and hence the welding speed, had to be severely restricted to maintain adequate quality of the deposit. Other new features are closer control of penetration, easy slag and low spatter loss.

A self-propelled CO_2 continuous electrode welding machine set up for horizontal-vertical fillet welding is shown in FIG. 7.

AUTOMATIC WELDING EQUIPMENT FOR SHIPBUILDING

Portable Self-Propelled Machine

The small self-propelled welding machine, comprising a welding head or torch mounted on a portable machine carriage designed to run on rails or on the plate surface, has proved to be versatile and popular as a production welding tool. It is a machine that may be used on its own or in conjunction with some work-holding jig.

The machine can be effectively used on shipyard work where many long, straight welds have to be made, joining large areas of plate ; it is easy to move the machine from a completed job to another already prepared for welding.

Whereas many users prefer the type of machine that runs directly on the plate surface and that can be guided by the welding operator, others prefer to use a track, which can be accurately aligned with the joint before welding begins. At the same time, machines that are completely self-guiding are being utilized for making horizontal-vertical fillet welds joining stiffeners to bulkheads.

[1] E. J. Mitchell and W. E. Freeth: *Welding and Metal Fab* 1956, Vol. 24, pp. 431–438.

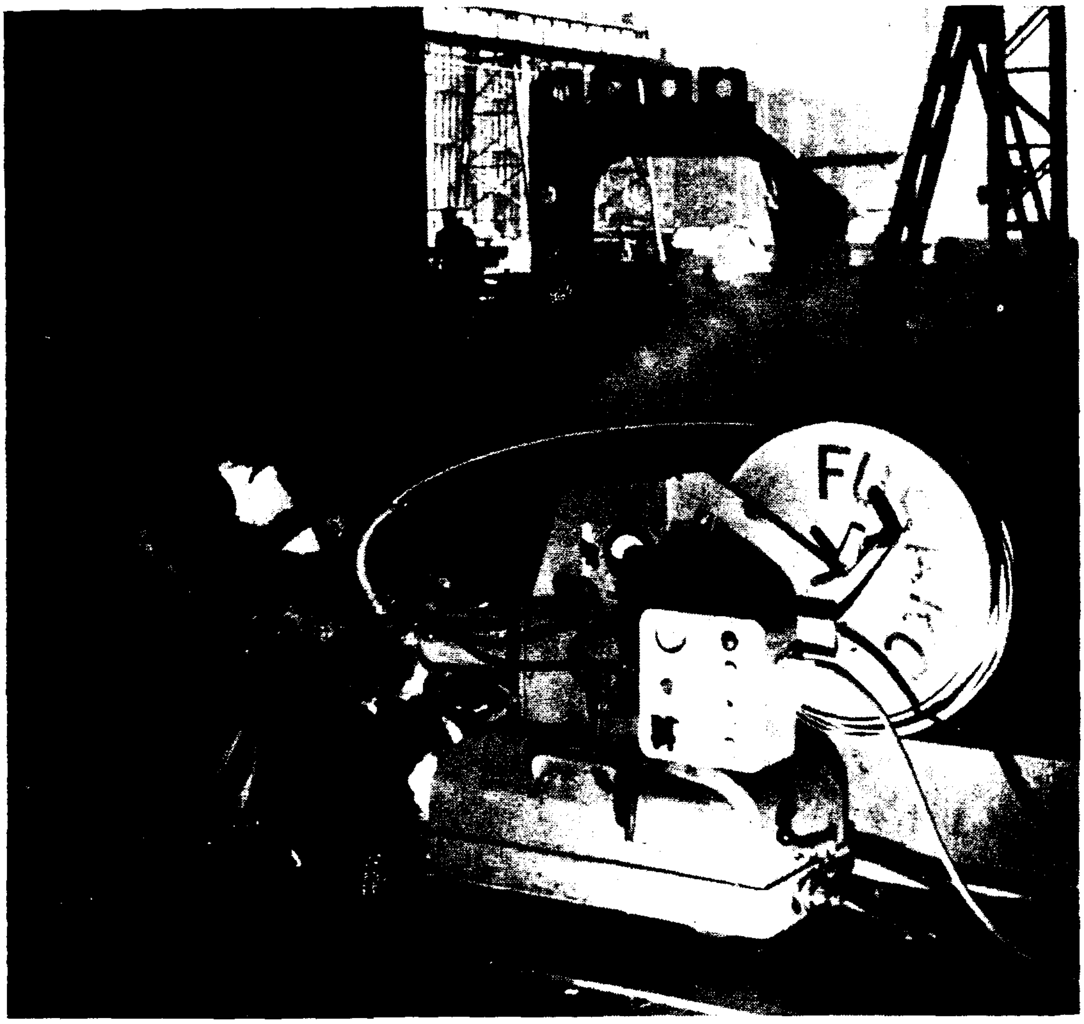


FIG. 7—SELF-PROPELLED WELDING MACHINE

The FUSARC self-propelled machine is fitted with hand steering, and is usually run directly on the plate. With the arc visible there is little difficulty in keeping the machine correctly aligned with the joint. Normally, the operator sits on a small three-legged stool mounted on castors, as shown in FIG. 8. A fume extractor eliminates the possibility of fumes being blown in the operator's face, or obscuring his vision of the line of the seam.

Gantry Installations

There is a limit to the efficiency of portable equipment where welding is carried out over a large floor area. Time may be wasted in waiting for the services of a crane to lift the machine from one job to another ; the lengths of welding and control cables may become unwieldy ; or the welding power unit may have to be moved frequently. With submerged-arc welding, the recovery of unfuzed welding flux is an additional operation, and the operator has also to be constantly filling the hopper on the machine. With automatic visible-arc welding the removal of fumes outside the shop may present a major problem with portable machines.

The advantages of a gantry installation having a span of up to 40 ft or more are obvious. The gantry, running on rails, can have an unlimited traverse for the full length of the shop. Two or more welding heads can be carried for

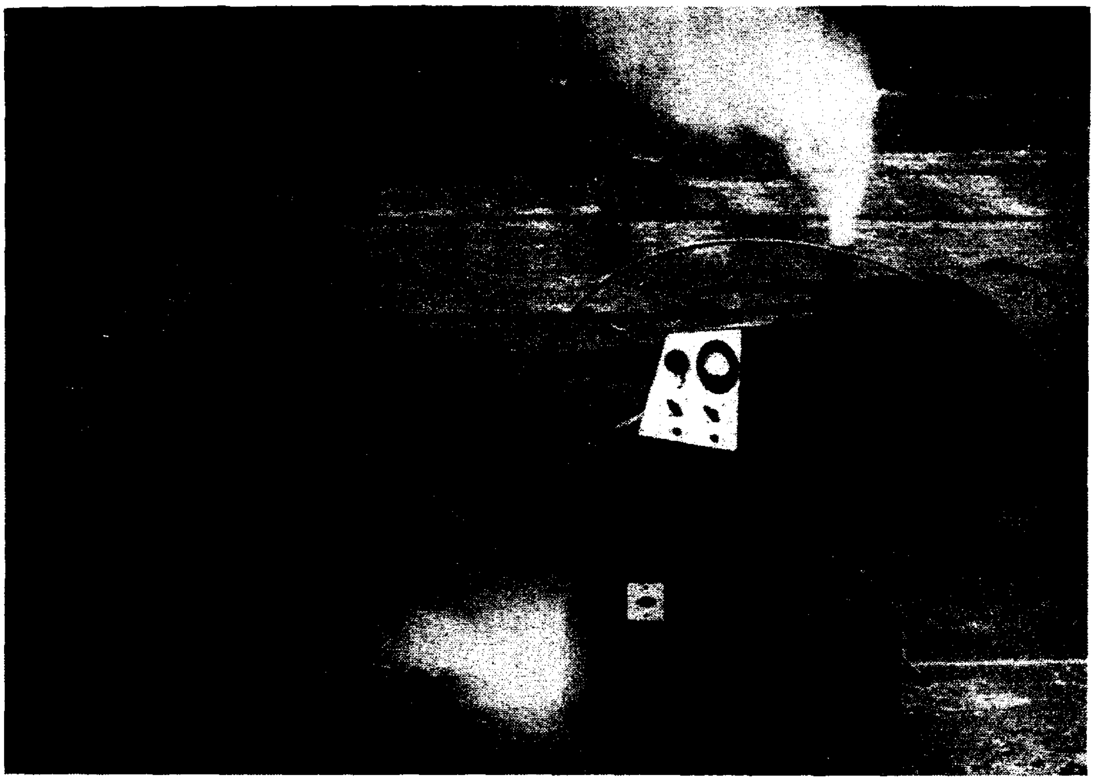


FIG. 8—' FUSARC ' SELF-PROPELLED MACHINE WITH HAND STEERING

making a number of welds simultaneously, and there is complete independence of crane lifting facilities for positioning each head. In addition, all ancillary equipment can readily be accommodated. There is no need to have welding control cables lying across the floor. In fact, the welding power supply equipment can be mounted on the gantry itself, with the mains supply provided by bus bars positioned high up against the wall of the shop.

In shipyards gantry machines are being favoured, particularly where more than one welding head can be operated simultaneously. In fillet welding stiffeners to bulkheads, the welding head can be automatically guided off the stiffener, so that one operator can easily control a number of heads mounted on a single gantry. With submerged-arc welding, it is a very real advantage to be able to carry a flux hopper of sufficient capacity to permit continuous working throughout an eight-hour shift. With the suction unit also mounted on the gantry, unfused welding flux is picked up behind the completed welds as the machine moves along.

The high utilization factor of up to 80 per cent, obtainable with a machine such as that illustrated in FIG. 9 is one of the main economic arguments in its favour. Thus the output of welding on ships' stiffeners at a welding speed of 2 ft/min would total about 900 to 1,200 ft per shift, whereas a portable self-propelled machine would be expected to operate at an overall duty cycle of only 50 per cent, giving an output of about 400 ft in the same period.

TRENDS IN MODERN ARC WELDING PLANT

Plant for Manual Welding

The inherent simplicity of A.C. equipment, which enables it to be produced at low cost, is one of the main reasons for the development of the wide range of very satisfactory electrodes for A.C. welding that exists today. Electrodes

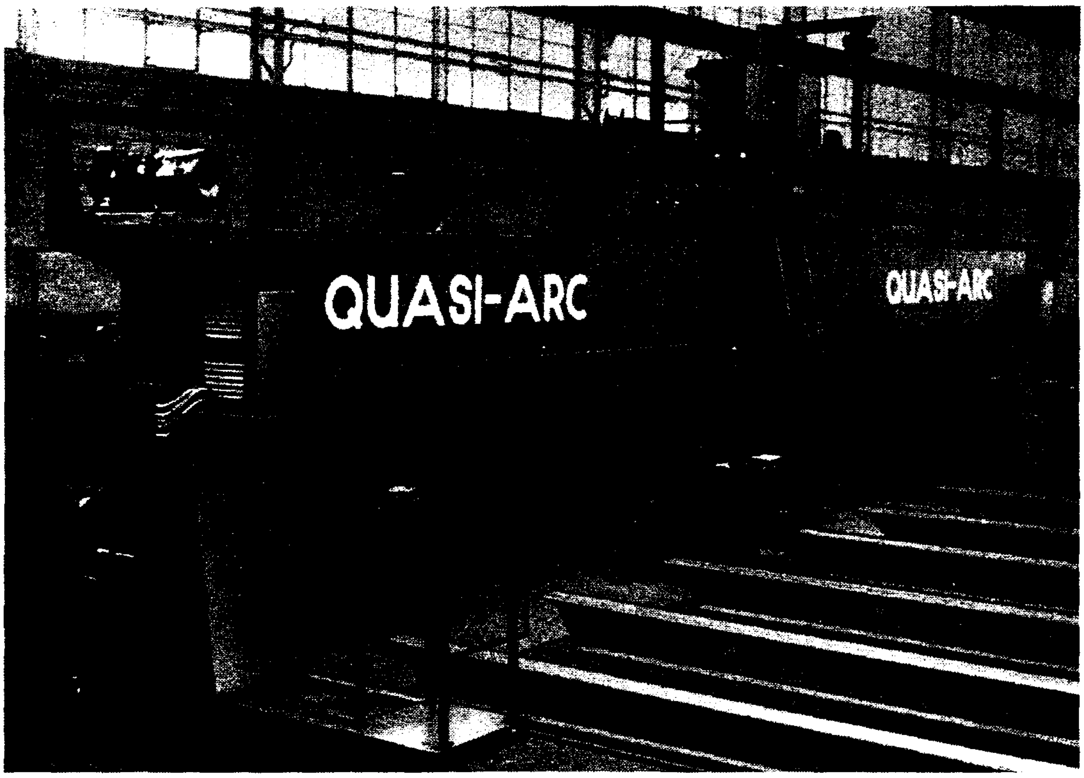


FIG. 9—THE GANTRY MACHINE

of this type have now been firmly established for a number of years, so much so that the design of A.C. equipment has largely become standardized and in consequence there have been few outstanding developments.

The method of current control most widely used for the British oil-cooled sets is by a tapped series reactor. Stepless current control by means of a series saturable reactor has been tried, but it has been found that distortions of wave form at low currents give unstable welding conditions unless a large amount of iron is used in the reactor. The resulting high cost of this type of control has, therefore, so far precluded its general use.

With the wider use of A.C. for welding, there has been a tendency towards the use of higher open circuit voltages, and a number of safety devices, designed to reduce the voltage applied to the electrode to a low value whenever welding is not actually in progress, have been developed. One device of this kind is shown in FIG. 10.

There has been relatively little development of D.C. welding generators during recent years. Owing to the variable nature of the load and the particular type of load characteristics needed, the requirements for good welding performance are quite different from those of any other type of D.C. generator, and their determination involves long and complicated studies of dynamic characteristics under a large number of welding conditions.

During the past five or six years, however, there has been a steady introduction of the selenium metal rectifier, as a power source, into the welding field. This transformer-rectifier type of welding set has a number of advantages over the conventional D.C. motor generator. For example, the rectifier set has substantially higher efficiency, requires less maintenance, is lighter in weight, silent in operation and less subject to changes in output voltage due to temperature rise. The introduction of this type of welding power source has been a logical development of the welding transformers used for A.C. welding.

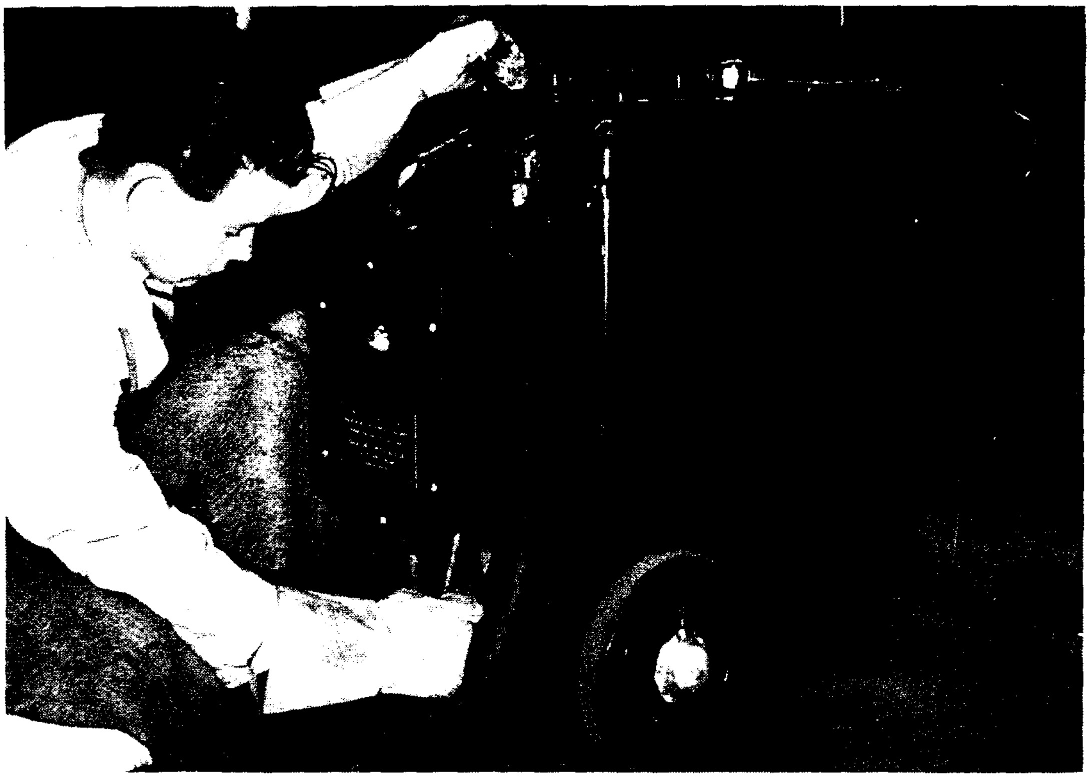


FIG. 10

It has been made possible by the availability, as a result of intensive development in this field, of reliable light-weight rectifiers capable of carrying high currents.

To facilitate production, rectifier plates are commonly made up in groups or stacks of individual cells. Each stack is usually a full-wave rectifier with numbers of cells connected in series and parallel, and to meet specific current requirements numbers of stacks may in turn be connected in parallel.

Most of the rectifier welding sets used up to the present time have been of the fixed open circuit voltage type, with means of stepless control of current over the full range of the set. Different values of current are obtained from variations of the A.C. input to the rectifier by means of a series reactor of variable impedance.

Stepless variation of reactor impedance has been achieved by the use of a moving core choke or of a saturable reactor, and the rectifiers used so far fall into two main groups distinguished by the incorporation of one or other of these methods of current control.

Plant for Automatic Welding

The rapid expension in recent years in the use of semi-automatic and automatic processes has had three main effects on the development of power supply equipment. Firstly, it has led to the development of larger power units suitable for use at the much higher duty cycles encountered in automatic welding. Secondly, it has revived interest in D.C. power plant, because many of the automatic processes now in use need this type of supply. Thirdly, for D.C. supplies, it has led to the development of power sources with characteristics other than the conventional drooping kind used for manual welding. Developments of this kind, as well as affecting transformers and D.C. generators, have also included rectifiers; and sets capable of giving maximum currents of 1,000 amp and more are in use today under arduous conditions.