# Welding in Marine Engineering

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No catalogue of work which is being done in the marine field has been considered but an attempt has been made to bring to notice a few features in metallurgy, welding processes and methods which are of major importance in the construction of marine machinery. The principles have general application and form the basis of good design.

## 1. INTRODUCTION

Welding processes have not really changed in principle, but those in common use have been improved, whilst others have been developed to the stage of practical application.

Similarly with electrodes; the number of grades for welding mild steel has been drastically reduced and one now expects a type to be equally satisfactory for all position welding on either a.c. or d.c., and even to meet X-ray requirements.

Researches into the behaviour of welded joints has done much to take the mystery out of welding and both the metallurgy of welding and the design are now on a sound scientific basis.

Mechanization of the welding and handling operations has been necessary and has of course made possible design changes both as regards the general conception and detail fabrication for the betterment of the product.

## 2. METALLURGICAL FACTORS

### 2.1. *Fatigue*

To the marine engineer this is one of the major problems to be considered in any design. However, as main engines are subject not only to self-induced vibrations, but also to those induced from the hull, the magnitude of the forces cannot always be calculated and adequate allowances must be made to cover these. Then again, not all engine parts are subject to dynamic loading heavy enough to warrant special design considerations and sometimes the bedplates, which are generally lowly stressed by being designed for small deflexion, may only necessitate static loading features.

The design treatment for dynamic conditions is based on the fact that ferrous materials subjected to alternating loading will carry a limited load satisfactorily for ever, but should that limiting load be exceeded only slightly the life of the structure becomes finite, and when still further exceeded may become quite short.

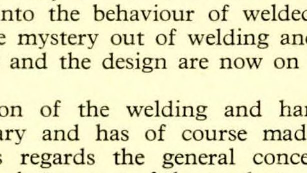


FIG. 1—*Basic fatigue curve*

This is usually expressed in a curve plotted for stress against the number of reversals of loading and looks like Fig. 1.

It is usual engineering practice to accept a million reversals of stress as the practical limit and if the test specimen lasts that time it will be good for ever. So if the marine structure is likely to be subjected to the order of $10^6$ reversals or fluctuations of stress in its lifetime, then the working stress must be kept below the value where the curve flattens out.

That represents the general case but there are a number of very important factors which apply to welding, such as the form of weld, quality, surface finish, metallurgical and mechanical notches.

#### 2.1.1. *Surface Finish*

Generally speaking, whether it be plate or weld metal, the better the surface finish the higher the fatigue limit. So that rough welds, heavily reinforced welds, or badly flame cut plate edges, may reduce the fatigue strength by up to 20 per cent.

#### 2.1.2. *Weld Quality*

Within the limits of plate and weld metal strength generally used in marine engineering, i.e. up to 40T/sq. in., the fatigue limit is proportional to the tensile strength. One would however be ill advised to use the higher tensile material with a view to improving the fatigue strength of the joint, due to the fact that the higher strength materials contain a larger percentage of carbon and therefore are more susceptible to variations in quality across the joint due to welding. This variation will cause notches in the metallurgical sense which can produce stress concentrations and therefore reduce the fatigue strength of the joint.

Strangely enough slight porosity in the centre of the weld will not necessarily reduce the fatigue strength. Similarly, a slight lack of fusion at the root of a double prepared butt joint can have little effect. Slight surface porosity, discontinuities, cracks, undercutting, or a rapid change in section at the weld reinforcement, can seriously affect the joint strength. It is therefore most essential that the under side of a weld should be as smooth as possible, and lack of root fusion, such as can readily occur in butt welds in pipes, should be eliminated as far as possible. Under the circumstances no additional reinforcement on the outside of the weld will be of benefit, as this will rather tend to further aggravate the effects due to rapid change of section. A number of techniques have been devised to produce good root runs which behave satisfactorily under these conditions, whilst the outside surface can readily be improved either by welding technique or by grinding the surface of the weld to a smooth contour.

#### 2.1.3. *Heat Treatment*

Stress relief of the finished weld has shown no increase in fatigue limit. In fact, if the heat treatment reduces the static

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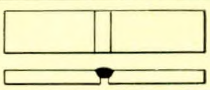
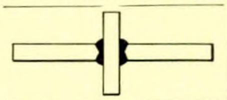
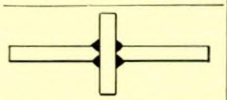
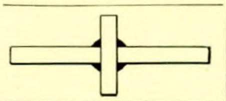
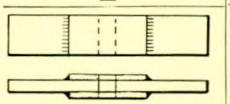
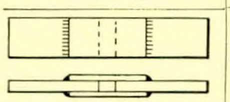
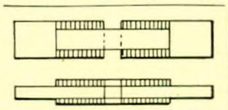
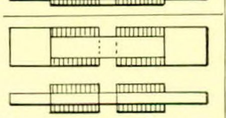
tensile strength, there is every likelihood of the fatigue limit being reduced too.

*2.1.4. Detail Design*

Undoubtedly the most important single factor is the detail design of the welded connexion. The following table published by the Institute of Welding (Table I) amply indicates this and can be taken as a reliable guide in design.

TABLE I.—STRENGTH OF WELDED JOINTS IN MILD STEEL UNDER FATIGUE LOADING

Maximum stress range for $2 \times 10^6$ cycles, tons per sq. in.

| Type of joint | Description | Alternating push pull | Repeating tension |
|---|---|---|---|
|  | V-butt, root sealed, machined flush | ±9·0 | 7·0±7·0 |
|  | V-butt, root sealed, as welded | ±7·0 | 5·75±5·75 |
|  | V-butt, root unsealed, as welded | ±5·0 | 4·0±4·0 |
|  | Cross joint, plates fully bevelled, complete fusion at root | ±5·5 | 4·75±4·75 |
|  | Cross joint, plates partially bevelled, incomplete fusion at root | ±3·7 | 3·5±3·5 |
|  | Cross joint, no preparation, plain fillets | ±2·25 | 2·0±2·0 |
|  | Lap joint concave end fillets | ±3·4 | 3·25±3·25 |
|  | Lap joint, plain end fillets | ±2·8 | 2·6±2·6 |
|  | Lap joint, concave side fillets | ±3·7 | 3·5±3·5 |
|  | Lap joint, plain side fillets | ±2·6 | 2·5±2·5 |

*2.2. Creep*

When steel is operated at elevated temperatures, other characteristics of the material must be taken into account. As the operating temperature rises, the U.T.S. of the material falls, but the more important feature is that it loses its yield point and instead it gradually stretches all the time it is loaded. Therefore the design conception must not be what factor of safety can be used, but how long must the job last, and to choose the working stress accordingly.

To determine the properties of mild and alloy steel under these conditions, large numbers of tests have been conducted. Creep testing which necessitates loading batches of specimens over long periods shows that material which would be ductile at room temperatures will fail with low ductility under creep.

Therefore considerable reduction in working stress must be accepted and the higher the working temperature the lower the stress.

This has prompted the use of alloy steels containing molybdenum, which greatly improves the creep properties.

The commonest alloys contain $\frac{1}{2}$ per cent Mo, 1 per cent Cr, $\frac{1}{2}$ per cent Mo, and $2\frac{1}{4}$ per cent Cr, 1 per cent Mo.

*2.2.1. Heat Treatment*

Heat treatment has an important effect on the creep properties. With alloy steels the best results are obtained in the fully annealed condition. This is seldom possible in welded drum or pipe work. However, stress relief under controlled conditions in the furnace is usually called for.

The treatment consists of heating to 650 deg. C. (1,202 deg. F.)-700 deg. C. (1,292 deg. F.) and holding at that temperature for two hours for each inch of maximum thickness for alloy steels and 600 deg. C. (1,112 deg. F.)-650 deg. C. for one hour per inch of thickness for mild steel and allowing to cool in the furnace.

The method adopted with pipes depends on conditions. Furnace treatment is preferred, but in cases where that is impossible either local stress relief or flame annealing is adopted.

*2.2.2. Local Stress Relief*

Local stress relief is easily carried out by induction heating. The pipe is lagged locally with asbestos and wound with turns of asbestos insulated flexible cable on either side of the weld. A heavy current at 50 cycles is passed through the winding, which induces eddy currents in the pipe wall, causing it to heat up. The rate of heating is controlled by the value of the current flowing, while the temperature is measured by thermocouples fastened to the pipe before lagging and winding. In the case of important steam pipes a recording pyrometer is used to record the heating and cooling cycle of each joint.

*2.2.3. Box Heat Treatment*

The alternative method, which can give an equally good result, employs a lagged split box which can be placed round the joint after completion and heated by circulating a gas/air mixture through the box. The method has the disadvantage that it cannot be used for heating during welding although it can be used for preheating and then removed for welding: while with the induction method the temperature can be maintained during the welding period by adjusting the current and on completion of the weld the stress relief treatment can follow without interruption.

*2.2.4. Flame Annealing*

In the case of small pipes such as superheater or boiler tubes, particularly when they are gas welded, flame annealing is desirable. This consists of flame heating an area including the weld to above the upper critical temperature, holding it for a minute or two and wrapping with asbestos to reduce the rate of cooling. This treatment is essential for mild and low alloy tubes which are gas welded to reduce the large grain size characteristic of this process. The higher of the low alloy steels sometimes require a double heat treatment. That just described is followed by stress relief at 650/700 deg. C. This latter requires furnace, box or induction methods. In the case of small tubes induction heating at 50 cycles will generally not be successful due to the low eddy loss in a thin wall tube, and a higher frequency becomes essential. This will generally be ruled out on shipboard due to the amount of plant required.

*2.3. Brittle Fracture*

Just as at high temperatures, so at low, mild steel exhibits different characteristics.

It has been known for many years that the notch brittleness of steel increases with reduction in temperature and that the fracture exhibits an increasing proportion of crystalline structure.

Various investigators have proposed forms of tests for this purpose, including special shaped tensile and bend tests loaded at various speeds.

Material which has good strength and ductility as measured by the conventional tensile test might have a low impact value when measured at a low temperature.

The Charpy type impact test is used as a practical method of evaluating the relative quality of the steel, but the way in which it should be interpreted is still a matter for argument. However, the method of quoting a figure for energy absorbed at some arbitrary temperature has practical application.

A typical impact curve shown in Fig. 2 shows the energy absorbed with the vee-notch Charpy test. From that it is clearly seen that the value drops rapidly with reduction in temperature. Tests have of course been conducted to determine the safe values for given conditions and material specifications are framed on these.

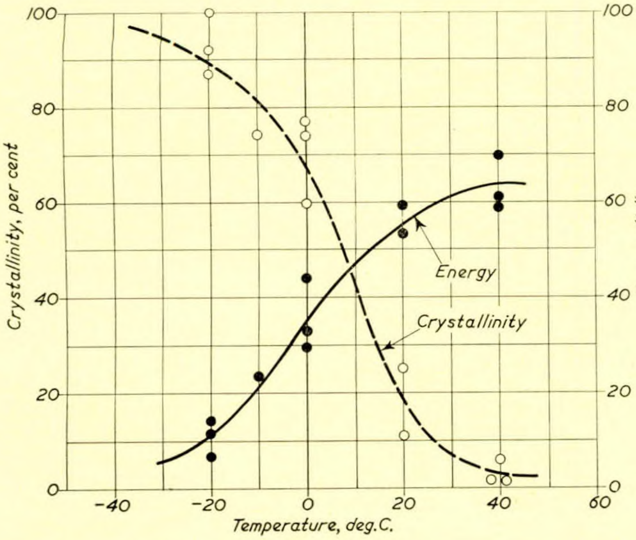



FIG. 2—*Typical impact curves*

The temperature at which the accepted minimum impact value is obtained is called the transition temperature and the lower this temperature the better the material is suited to low temperature conditions.

As a notch is essential to start a fracture of this nature, this aspect should be kept in mind and notches or abrupt changes in section avoided in design. Similarly, during construction, weld or flame cutting defects which produce stress raisers might be dangerous.

Whilst there is not a constant relationship between energy and percentage of crystallinity in the fracture, it is interesting to note that as the temperature drops so it increases.

The main factors which control the transition temperature are the carbon/manganese ratio, degree and method of de-oxidization and the final rolling temperature of the plate.

A range of steels has been standardized by the British Standards Institution with impact values quoted for given temperatures, so that in designs where controlled material of this type is desired it is a simple matter to specify the grade required. (See Table II.)

### 2.4. *General*

In all three aspects of metallurgy discussed the avoidance of weld and base metal cracks is most important. This is directly so in the case of fatigue and brittle fracture and of a secondary nature in the case of creep, apart from its direct effect on the initiation of a fracture. Creep is a matter of concern to the marine man when dealing with steam pipes and drums and, if cracks are present, secondary effects such as erosion add to the difficulties.

With these factors to consider the importance of material choice is obvious. Not only must it satisfy the mechanical requirements but it must be of weldable quality. Often this latter property will determine the grade of material used. Obviously, use will not be made of a material which is prone to cracking just for the sake of a slightly higher strength.

Conversely, a material which depends on heat treatment for its strength may well be weakened by welding along the heated zone in the vicinity of the weld, and the strength reduced to that of annealed material. This more often applies to non-ferrous metal and the more common complaint lies in the use of steels which harden locally on welding.

Much has been done to investigate hardening in low alloy steels. The absorption of nascent hydrogen produced from electrode coatings and absorbed by the hot steel causes fissuring in the heat affected zone. The solution to the problem is to avoid the use of electrodes which are potential producers of hydrogen. Such a range is available and proves extremely useful for heavy constructions.

That is the next factor which has to be considered, namely the mass effect. Heavy material increases the rate of weld cooling and hence the degree of hardening which takes place, and therefore the risk of cracking.

The other factor which adds further to the difficulties of heavy plate welding is the fact that, in order to maintain the tensile strength of the material, the steel maker has to increase the carbon and manganese over that required for the same strength in a thinner plate. This increased carbon means a greater hardening for the same rate of cooling and, as the cooling rate goes up too, the welding risks multiply.

Preheating to reduce the rate of cooling and hence the degree of hardening is a solution.

Post-heating, which will reduce the hardening produced, will of course not help the cracking problem, as this takes place at an elevated temperature and once formed cannot be corrected by heat treatment.

In general, British steels need not present any welding difficulties providing the foregoing is understood. The amounts of carbon and manganese present seem to meet most ordinary requirements and the limits on phosphorus and

TABLE II.—NOTCH DUCTILE STEEL FOR BRIDGES AND GENERAL BUILDING CONSTRUCTION (SUITABLE FOR WELDING)

*Extract from B.S.* 2762:1956.

IMPACT PROPERTIES

| Quality | Temperature, deg. C. | Temperature, deg. F. | Charpy—V Minimum average, ft. lb. | Charpy—V Minimum individual, ft. lb. |
|---|---|---|---|---|
| ND I | 0 | 32 | 20 | 15 |
| ND II | −15 | 5 | 20 | 15 |
| ND III | −30 | −22 | 20 | 15 |
| ND IV (plates) | −10 | 14 | — | 45 |
| | −20 | −4 | | 40 |
| | −30 | −22 | — | 35 |
| | −40 | −40 | — | 25 |
| | −50 | −58 | — | 20 |
| ND IV (sections) | −10 | 14 | 45 | 35 |
| | −20 | −4 | 40 | 30 |
| | −30 | −22 | 35 | 25 |
| | −40 | −40 | 25 | 20 |
| | −50 | −58 | 20 | 15 |

CHEMICAL COMPOSITION

The steel shall contain:

| Element | Grades ND I and II, per cent | | Grades ND III and IV, per cent | |
|---|---|---|---|---|
| | Min. | Max. | Min. | Max. |
| Carbon | — | 0·20 | — | 0·17 |
| Silicon | — | — | 0·10 | 0·35 |
| Manganese | — | 1·50 | — | 1·50 |
| Sulphur | — | 0·060 | — | 0·050 |
| Phosphorus | — | 0·050 | — | 0·050 |

sulphur called for by inspecting authorities are well chosen so that trouble is seldom met on that account.

## 3. MANUAL ARC WELDING

Hand arc welding is still the most generally used process in the marine shop. At one period there was a tendency to have too many grades of welding, with a multiplicity of materials and testing methods. The changes which have taken place over the last ten years have not been spectacular but have rather been to channel the types into limited quality ranges. Now it is realized that it is really no more difficult to make a good job than a poor one and, what is more important, it takes no longer and is therefore no dearer. We have therefore two general classes of electrodes, namely rutile and low hydrogen types in common use.

### *3.1. Rutile Electrodes*

These electrodes having rutile as the main ingredient in the covering are easy to use and give a weld of good appearance. In their various grades they are made with advantages for special applications, such as their suitability for positional welding. They are made for the normal mild steels and are approved by the classification and inspection societies. They may also be used for classed pressure vessels and some give good X-ray quality welds.

Due to their limitations, such as susceptibility to cracking in the weld metal as a result of contamination from base metal impurities and hydrogen pick-up in alloy steels or heavily restrained sections, there is a demand for an electrode with characteristics to meet these stringent conditions more adequately.

### *3.2. Low Hydrogen Electrodes*

To meet these conditions the lime base type electrode with controlled ingredients to give low hydrogen qualities has been developed and is finding increasing use as service conditions become more difficult. This type of electrode has a sound dense weld metal which shows up well under X-ray examination.

In use it requires a little more skill on the part of the operator and slightly different operational techniques. Sometimes it may have an inferior surface finish.

Positional welding is generally more difficult than with the special rutile types. The earlier types were best when used with d.c. but the popularity of a.c. equipment has made electrode makers turn their attention to a.c. varieties of these electrodes. Similarly, constant attention is being directed to improving both their operational properties and the surface finish of the welds.

### *3.3. Other Electrodes*

A period has been passed through when the search for higher welding speed was attempted by the use of larger electrodes, until today there has been a return to a position where the 5/16-in. diameter electrode is the largest size in common use. The larger the electrode size the greater the welding current required and whilst welding equipments were readily available, cables and welding pliers become the limiting factors. If they are made big enough to carry the welding current without overheating, they become unwieldy and exceed the optimum practical size.

The search for speed is still on, but now along the lines of limited electrode core wire size, with a coating containing a large percentage of iron powder, which when melted, augments the steel from the core wire. This shows a deposition rate of over 100 per cent based on core wire and deposits a greater length of weld in a given time. In this development ease of manipulation and surface finish have not been lost for a given quality of weld metal. At the moment these have a limited application and as the economics are not outstandingly in their favour there is no great swing towards their use.

Another method, with a limited application, but with basic attractions, is the use of deep penetration electrodes. For the engineer, to have to cut away metal during plate edge preparation just to fill it up with steel made more expensively, has no real attractions.

Electrodes are available which can penetrate 3/16in.-¼in. into mild steel when the plate edges are square cut and butted together. This means that 100 per cent fusion can be made on ⅜-in. and possibly ½-in. thick plates without the necessity for chamfering the edges of the plate. Furthermore, as no metal has to replace what would normally be cut away, the number of electrodes required is reduced. Unfortunately it is not so easy as that, because the ability to secure 100 per cent fusion depends on a number of factors, the controlling of which cannot always be ensured. These factors are welding current, arc length, rate of travel, angle of electrode to the work, variations in butted joint and the base metal itself, as it eventually constitutes a larger percentage of the weld than in the other techniques.

However, despite all these difficulties, these electrodes are in common use in the engine shop for tank manufacture and the like, and giving every satisfaction.

## 4. WELDING EQUIPMENT

Welding, requiring an intermittent power and not always at the full machine rating, would have left the user much in the hands of the manufacturer when buying equipment had it not been for the standardization done by the manufacturers and users in conjunction with the British Standards Institution.

The agreed machine sizes and ratings provide the user with machines which meet practical requirements for a minimum expenditure.

Equally important is the guidance given on cable sizes, coupled with the ease with which these sizes are available from manufacturer's stocks.

### *4.1. D.C. Motor Generators*

Although these are not so popular as they were some years ago there are still many in use. At one stage in electrode development d.c. power was more commonly required for their satisfactory deposition and in the case of single operator welding sets, an a.c. squirrel cage motor drives a reverse compound wound generator built into the same casing to provide the necessary drooping volt/ampere characteristic for the maintenance of a stable arc. In another design the effect of armature reaction is used in a cross field arrangement to give a static characteristic with a steep slope under welding conditions.

In the case of multi-operator machines, of which many were installed in shipyards, large d.c. low voltage generators are driven by a.c. motors, located in central sites and coupled on the low voltage side to the welding areas by heavy copper bars. Each operator has his own regulating resistance for current selection to meet the individual job requirement.

### *4.2. Welding Transformers*

With the advent of electrodes suitable for a.c. welding, similar arrangements were made as described above, namely the use of either single or multi-operator units.

The multi-operator equipment is generally three-phase, step-down transformers suitable for three, six, nine or twelve operators. Each has his own regulator, the size of which depends on the type of work being done. For engine work the 300 amperes size is common, but a smaller number of larger ones can be used providing the total connected current does not exceed the transformer rating. These are generally oil cooled and of robust construction suitable to heavy duty.

Naturally the multi-operator set has merits where the welding is concentrated in limited areas with numbers of men working together. Under these conditions the best electrical conditions are met.

If only a limited number of men work together or considerable movement of operators is frequently occurring, then the single operator set is preferred. These are self-contained units consisting of a transformer and tapped reactor for current selection or, in the case of the continuously variable current type, a moving iron core within the windings to provide variable reactance and hence current control. This equipment can be either air or oil cooled and both are equally satisfactory.

*4.3. Rectifiers*

The main use for new d.c. plant today is for alloy welding, as many of the electrodes for both ferrous and non-ferrous metals are made for d.c. operation. Therefore after so many years of non-rotating welding equipment it is only natural that engineers think along these lines when d.c. is required and the transformer of special design coupled to a modern rectifier meets the requirements.

These are air cooled and, as metal rectifier ratings generally fall rapidly with increase in temperature, the addition of a fan to assist cooling keeps the size and cost down.

Their dynamic characteristic does not depend on flux changes in the magnetic iron as in M.G. sets so the response is quicker. This advantage is reflected in the case of welding and reduction in splatter loss.

## 5. AUTOMATIC WELDING

Automatic arc welding machines have been available for more than twenty-five years but hand welding is so simple and the range of electrodes so extensive that there has been no major interest in machine welding in marine engineering until comparatively recently.

Now the quality of the result and the availability of equipment makes machine welding essential. Pressure vessels, even those made in the small factory, are now invariably machine welded, while the general marine fabricator is being attracted more and more by the possibilities of the various processes.

*5.1. Open Arc Process*

The function of the automatic welding machine is to simulate the process of hand welding by feeding an electrode into the arc at the speed at which it is consumed, thereby maintaining a constant arc length and traversing along the seam by relative movement of the job and electrode. A mechanically controlled process of this nature would be expected to give consistent results at a higher duty cycle than the hand welder. One of the main difficulties in the development stage was the method of feeding the welding current into the core wire when using a continuous coil. The most popular way is to wind a spiral of smaller gauge steel wire round the core and to fill the spaces with flux. The electrode is then fed through the machine in which a contact nozzle is arranged near the arc so that the welding current is fed through the spiral into the core wire and at the same time guides the electrode wire in to the weld joint. This permits higher welding currents to be used than would be possible without overheating hand welding electrodes, with a corresponding increase in melting-off rate and consequent welding speed.

*5.1.1. Arc Control*

The usual method of arc voltage control is to take the voltage across the arc and use it as the reference voltage for the servo-mechanism in the head, whether it be all electric or electro-mechanical.

The design of this equipment varies appreciably both with regard to the method of control and the mechanical appearance. In one type a slipping and reversing clutch drives the weld feed rollers from a constant speed motor. After the motor speed is set approximately, the voltage across the arc operates a relay which first of all energizes the clutch in the forward direction to feed the wire down until it touches the plate, reverses to draw out the arc, and then flutters so that the clutch drives sufficiently to feed the electrode into the arc at the rate consumed.

Various twin motor or generator systems, with constant and variable excitation proportional to the arc voltage, have been employed to give the correct electrode feed characteristics.

More recently the application of thermionic tubes to provide the power source for the wire feed motor, with the arc voltage as the control medium, have also proved successful.

All of these types are generally applicable to any form of machine welding process and are sometimes interchangeable for a.c. and d.c. without modification.

*5.2. Covered Electrode/$CO_2$ Process*

One of the difficulties of producing covered electrodes for automatic welding lies in the practical difficulties of getting enough covering on the electrode wire. As the covering acts both as a fluxing material and a producer of arc shielding gas, the separate provision of shielding gas has been used successfully in automatic welding in a specialized form for twenty odd years. More recently coiled covered electrode wires have been developed for use with a supplementary $CO_2$ gas shield, with surprisingly good results.

Fillet welding and the necessity for accurate positioning of the electrode has influenced users to prefer the open arc process with the possibility of visual control of the arc position. The deposition rate for this process opens up new possibilities for fillet welding, particularly in the horizontal/vertical position. Admittedly, the size of standing fillet is limited to 5/16in. length if a good shape is to be retained, but this, when the extra root penetration obtained is taken into account, covers quite a lot of work at present undertaken. For sizes larger than that the choice lies between tilting the job into the vee position, and building up in a series of runs in the same way as positional hand welding.

*5.3. Submerged Arc*

In this process welding is done under a blanket of granulated welded flux, using a bare wire electrode. No difficulties exist in feeding the required current into the welding wire but arrangements have to be made to feed continuously an adequate supply of powdered flux ahead of the arc and to pick up the surplus unfused flux, either automatically or by hand afterwards. The necessity for the coverage of the weld zone with granular flux may determine the type of joints which can be undertaken.

Originally, the possibility of using bare electrode wires with very heavy welding currents gave the promise of thick plate welding without joint preparation in the case of butts, in one run from each side. Whilst this has been done, the metallurgical influence of the base metal due to the proportion melted and becoming the weld, coupled with high joint restraint, has given joints not always acceptable for Class 1 vessels and the change to multi-run techniques is general.

There are also simpler controls available for use on single purpose machines, which in no way need be less efficient than some of the more elaborate systems.

Variations of the process either to increase the welding speed or to help to overcome practical difficulties in assembly or setting up have been devised. The tandem arc system is one of these. In this two electrode wires are fed through the single head, at a spacing determined by the requirements and supplied with current from a single source. According to the conditions, either increased speed or reduced risk of burn-through can be achieved. If the twin wires are positioned across the seam a much wider and flatter weld can be obtained.

On the twin wire arrangement with independent power sources a wide variety of welding conditions can be obtained. One of these is suitable for the deposition of surface layers of dissimilar metals with a minimum contamination from the base metal.

## 6. GENERAL FABRICATION DESIGN CONSIDERATIONS

The main welds in pressure vessels are butt welds and are of regular form, namely longitudinal or circumferential, and suitable welding machines have been made for a number of years and are therefore fairly well developed.

The position is very different with general fabrications. In these there are fewer butt welds and more fillets. Furthermore, the vessel designer always visualizes machine welding and designs accordingly. For the satisfactory machine welding of frames the designer should also have the welding process in mind at an early stage of the design, so that full advantage can be taken of the process. It must always be remembered that the benefits of the speed of machine welding can easily be lost by excessive setting-up times producing a low overall duty cycle. Therefore as many welds as possible should be made at one setting and the arrangements on the welding machines should provide for quick positioning of the welding head. The next factor to be considered is the size of fillet welds and whether they will most efficiently be made in the vee or horizontal/vertical position. As pointed out before, the maximum size of fillet which can effectively be made in the latter way has a 5/16-in. leg length. Some advantage may be obtained from the greater penetration obtainable with automatic over hand welding, so that this should be taken into account during design. The amount of hand welding required during assembly and finishing off is also an important factor influencing the overall economics. Distribution of labour on the job is also important and it may be found that the man who is tack welding could be profitably employed in finishing off during the assembly stage, to an extent that might make final machine welding uneconomic.

Then again, quite apart from deciding whether the head or the job should move during welding, there is also the possibility of using welding machines with portable tracks set up on the job in the assembly bay. In this case setting up the machine for welding may take a long time but that time is offset against that saved in lifting the job.

In other works it boils down to a suitable design welded by the method which shows the highest duty cycle.

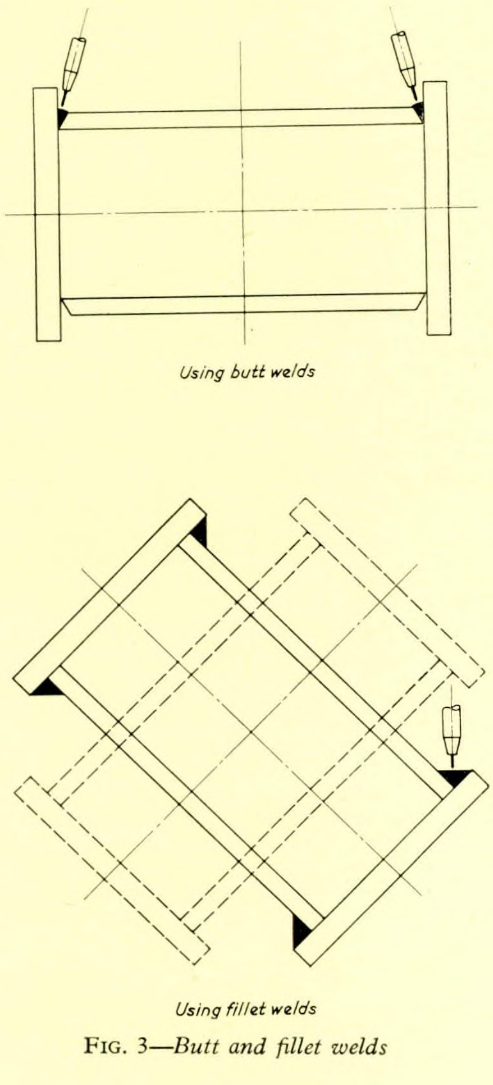



FIG. 3—*Butt and fillet welds*

### 6.1. *Fillet and Butt Welds*

Apart from the overall design conception, the detail joint design can be quite important.

For instance, the choice between fillet weld, which might be adequate, and a prepared butt between the web and flange of a girder, is a good example. The fillet weld requires that the girder be tilted to the vee position for gravity welding by either lifting twice or using a manipulator, while the prepared butts can be done in the flat, possibly with no special tackle, providing the head can be moved on the machine to the two welding positions, thereby saving handling time.

Fig. 3 shows an example of this.

### 6.2. *Fillet Weld Considerations*

Design for welding as applied to engine frames necessitates the application of normal stressing methods. The treatment means determining the major loads, their magnitude and direction, and placing the material in the best position to carry them. In this way an analysis of the basic requirements can be made and catered for economically. Weld sizes should be calculated when the loads are known. Care must be taken to differentiate between static and dynamic loading, as already discussed. The welding process imposes few limitations and the ideal design for load carrying members usually meets practical construction requirements, the most important one being the provision for accessibility during welding. This can often be circumvented by the sequence of assembly but of course must be considered in the design stage.

The strength of a fillet weld is determined by the throat thickness, although for convenience of measurement the size quoted on the drawing is always the leg length. In the case of hand welding, apart from the use of deep penetration electrodes, three fillet shapes are met in practice but one usually assumes that the throat is 0·7 of the leg length (Fig. 4). In the case of automatic welding, which can consistently produce something better than this, a determination has to be made of the effectiveness of these welds. In hand welding as in

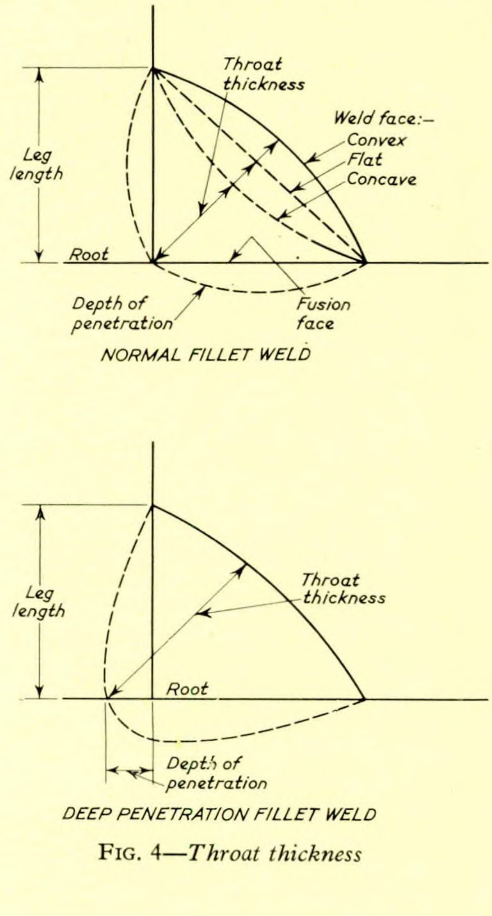
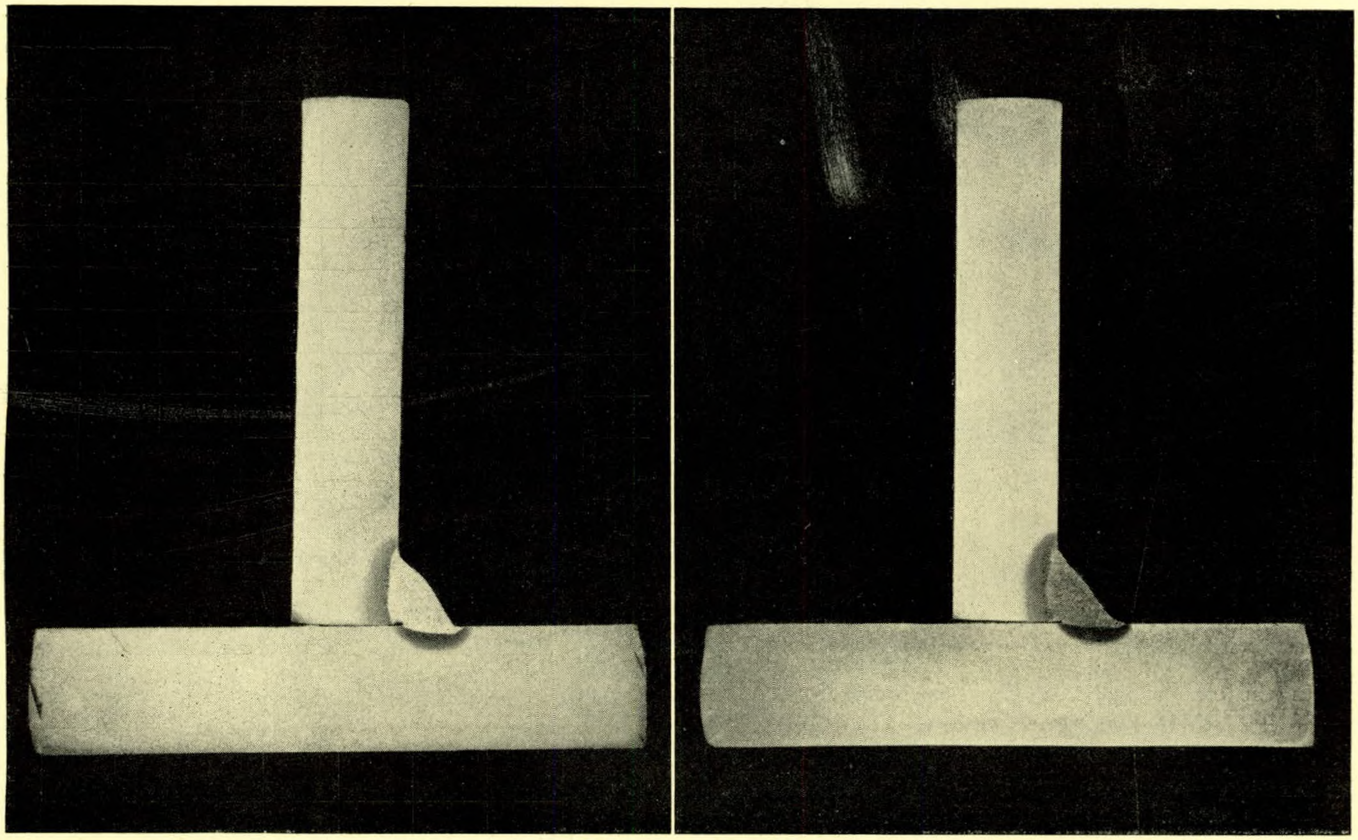
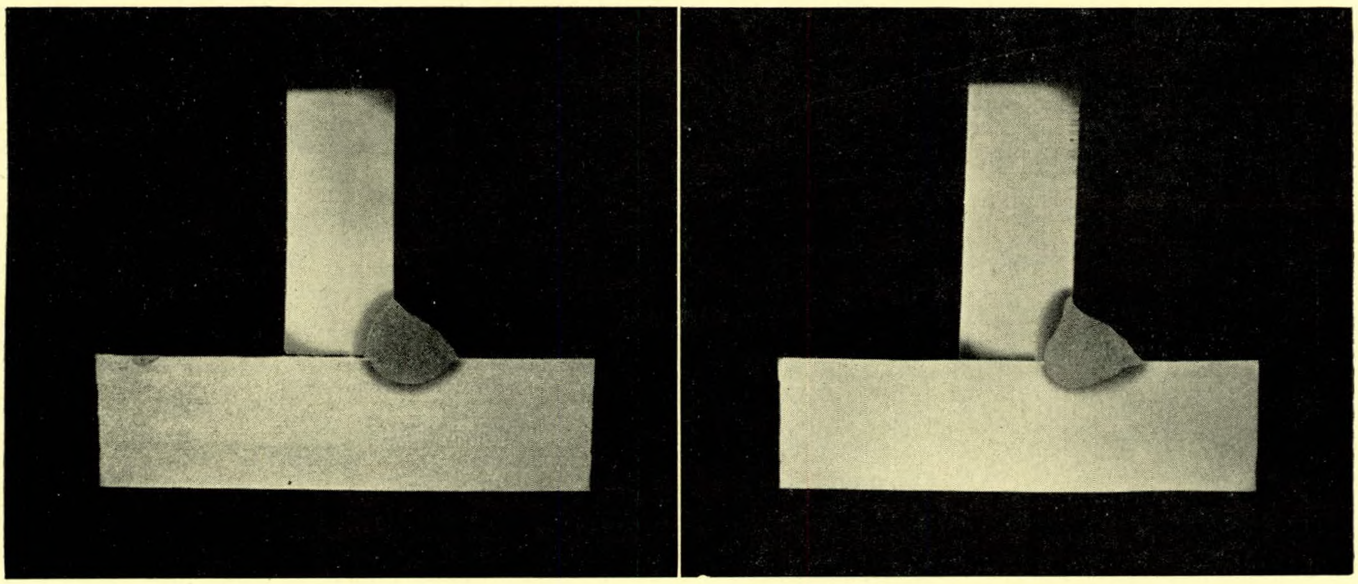



FIG. 4—*Throat thickness*



*Rutile type electrode* *Low hydrogen electrode*

*Hand welding*



*Submerged arc* *Fusarc/$CO_2$ process*

*Automatic welding*

FIG. 5—*Macrophotographs of single-run fillets*

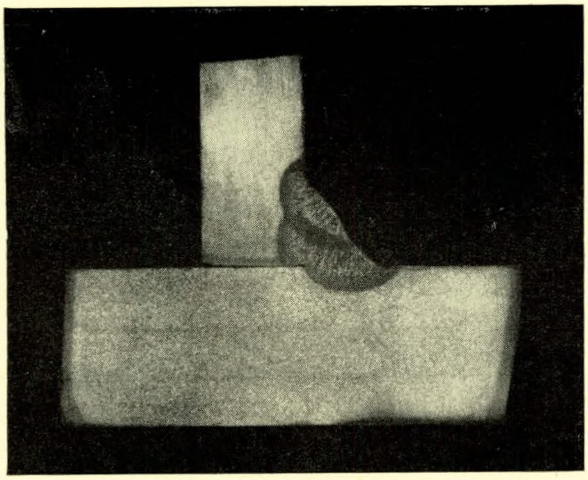
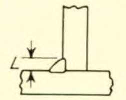
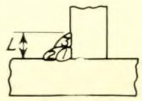
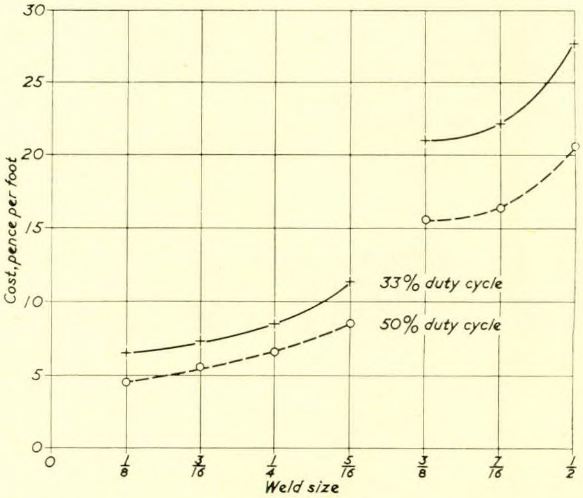


FIG. 6—*Three-run fillet weld*

TABLE III.

| Weld size L, in. | Welding procedure | Electrode: Size | Electrode: Run length, in. | Electrode: Current | Labour and material, cost/foot, pence: 33% Duty cycle | Labour and material, cost/foot, pence: 50% Duty cycle |
|---|---|---|---|---|---|---|
| 1/8 |  | 10g | 12 | 110 | 6·4 | 4·6 |
| 3/16 | | 8g | 12 | 160 | 7·2 | 5·3 |
| 1/4 | | 6g | 12 | 200 | 8·6 | 6·2 |
| 5/16 | | 4g | 12 | 270 | 11·3 | 8·3 |
| 3/8 |  | 3×6g | 16 | 200 | 20·9 | 15·4 |
| 7/16 | | 3×4g | 20 | 270 | 22·0 | 16·1 |
| 1/2 | | 3×4g | 16 | 270 | 27·7 | 20·4 |




machine welding the greatest fillet weld which can be made in one run is a 5/16-in. standing fillet. But, as can be seen from Fig. 5, the machine weld has a considerably greater thickness and is correspondingly stronger. The shape and form of the weld also varies slightly with the type of electrode or process used.

In the case of hand welding the optimum speed for making these welds can only be exceeded by sacrificing weld shape or finish and the little advantage gained by welding in the vee position must be balanced against the relatively expensive handling.

In the case of standing fillets an increase of weld size above 5/16-in. necessitates an increase from one run to three runs of weld metal, as illustrated in Fig. 6. Practical considerations usually entail the use of one size and type of electrode in any joint, when the three-run technique is adopted, but ensures good weld shape which is generally desirable for engine parts. Naturally welds made in this way are more expensive than single runs welded in the vee position (Fig. 7) but the overall cost will then depend on the ease with which positioning can be obtained.

Weld metal is much more expensive per pound than steel plate, so the weld sizes should therefore be kept to a minimum and not chosen to look right, but should be calculated and proportioned according to the loads carried.

In addition to the foregoing special case the following simple principles must be observed. The weld area goes up as the square of the size and above a certain minimum size the cost of welding is approximately proportional to the area. This is clearly illustrated in the curves for cost of labour and process materials for making simple fillet welds (Table III).

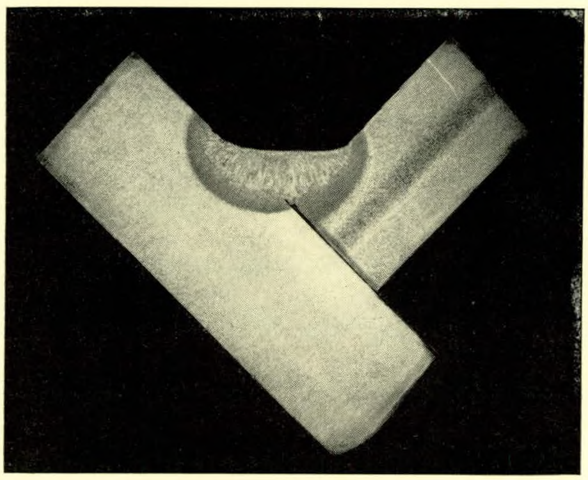


FIG. 7—*Single-run "Vee" fillet*

Engine frames and columns are basically a series of deep web girders built up from plates and bars. In design they may be either single or double web girders. Theoretically the webs in the double web design will be half the thickness of the single web and if these are attached to the flanges with fillet welds the individual welds will also be half the size. This can be a considerable economy as half size welds only take on quarter of the weld metal and, even allowing for double the welding length due to the two webs, the total welding is halved (Fig. 8).

The question of accessibility for welding should not be overlooked as this can increase the welding time and in this the single web construction has merits in some designs.

In the attachment of stiffeners the volume of weld metal required can be applied as a single small continuous fillet or as short intermittent welds of a larger size. Generally speaking and as already shown, if the continuous fillet weld can be made in one run it will be cheaper than the intermittent one requiring three, and therefore only if the continuous single run weld is more than required should intermittent welding be called for, because the smaller welds made with smaller electrodes are so little cheaper.

There is also the metallurgical aspect to be considered. The effect of a small weld and too little heat input into the base metal may cause weld cracking or even base metal cracking in the case of alloy steels. Therefore tables of recommended minimum weld sizes with respect to metal thickness are provided in various codes of practice or standard specifications.

TABLE IV.—MINIMUM SIZE OF SINGLE RUN: FILLET WELDS (B.S. 1856).

| Thickness of thicker part | Minimum size of single run fillet welds, in. |
|---|---|
| $\frac{3}{8}$ in. up to and including $\frac{3}{4}$ in. | $\frac{3}{16}$ |
| Over $\frac{3}{4}$ in. up to and including $1\frac{1}{4}$ in. | $\frac{1}{4}$ |
| Over $1\frac{1}{4}$ in. | $\frac{5}{16}$ |

The adoption of space welding calls for a little care in its application and should be even and regular. It may be staggered or in line on either side of the stiffener and must always be returned round both ends of the stiffener to the extent of the individual length of weld.

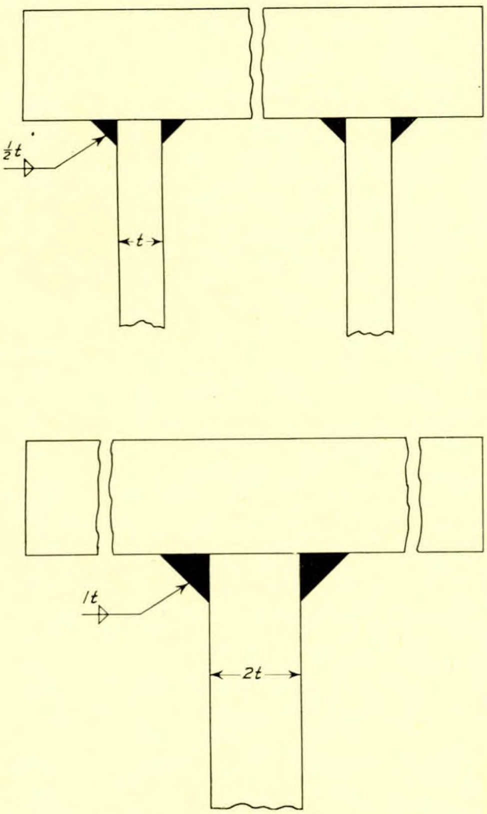



FIG. 8—*Single and double web girders*

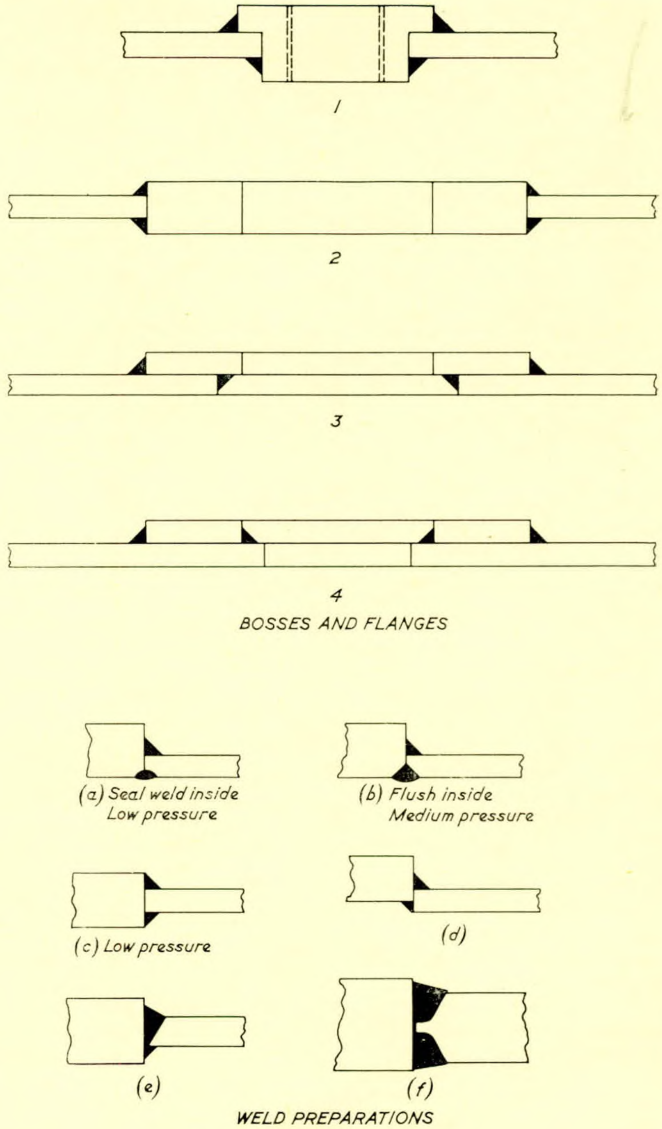



FIG. 9—*Bosses and flanges*

*6.3. Cruciform Joints*

This is a common detail likely to be met in all forms of welded construction.

The first point to watch is that the ribs or plates are continuous so that loads are directly transmitted, also that there is no misalignment which might introduce serious bending in the joint. A word of warning is sometimes issued with regard to this construction when direct tension is transmitted across the joint. Danger arises should the plate happen to be laminated and tear down the centre.

*6.4. Bosses and Flanges*

The design of these depends largely on the service. With correct design these details are used for oil, air, water and steam. There are so many variations that it will be impossible to discuss all, but rather to illustrate the commonest bosses and flanges in combination with selected welded joint designs. The choice will be determined by the service; for instance, the type of fittings suitable for lubricating oil tanks must primarily be free from cavities which might retain scale or dirt and could get worked out and into the bearings. For that type 1, Fig. 9 is suitable when used in conjunction with welds *a, b, c,* or *d*. The choice of *a* or *b* could be, in the case of a drain boss used in the inverted position, to provide a reasonable inside surface in the tank, with the inside weld readily visible for welding.

In the case of small standard flange connexions, type 2 is generally best. Used in conjunction with welded joint *a* it makes a suitable tank bottom connexion. Modifications *b, c* and *d* can be used up to about 200lb. per sq. in., whilst *e* and *f* suit the more severe conditions.

For larger flanges types 3 and 4 are more applicable. Type 3 is the most common but 4 has the merit of having both welds on one side and saves either overhead welding for one weld or turning over.

*6.5. Facings*

The practice of designing raised faces for machining in iron and steel castings has been followed in welded fabrication practice, despite the fact that it may not be the most suitable way. In Diesel bedplates, however, it is common practice to machine the whole of the top face and only pump facings which may be required on the side of the bedplate are welded on. These are rectangular and fillet welded to the main structure (Fig. 10(a)).

In the cases where the facing comes in the flange of the girder it may consist of a doubler welded on. Care must be taken to avoid two dangerous conditions which can arise in

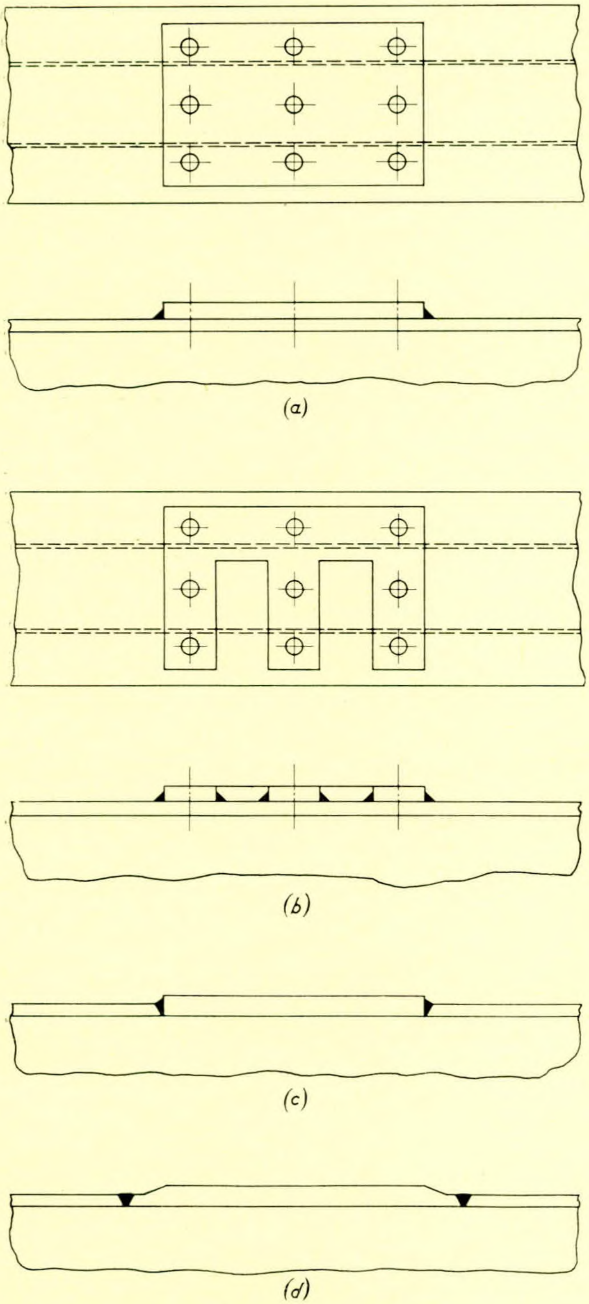



FIG. 10—*Bedplate facings*

marine work. It may happen that a facing is required on the top of, say, a Diesel bedplate in which considerable bending exists between the adjacent columns. If the facing is long and only welded round the edges, separation can occur in the middle during the alternations of stress in the bedplate girder and if through bolts are used in the pad, the stress developed might fatigue the bolts. The cure is, of course, not to increase the bolt sizes but to reduce the facing length by using separate narrow strips in way of the bolts or shaped as shown in Fig. 10(b) to reduce the space between welds, and so reduce the amplitude of the movement of the pad at the bolts. The other method is to avoid the laminated plate construction and insert locally a single thick plate, butt welded to the adjacent flange (Fig. 10(c)).

In the extreme case where the fatigue loading is high the ideal method is to fit a shaped facing in which the ends are reduced to the thickness of the girder flange (Fig. 10(d)).

This condition is unlikely in marine work, where most of the structures are designed for small deflexions under service conditions, and the working stresses are therefore likely to be low.

### 6.6. *Steel Castings*

Many of the shapes with which one is familiar are difficult to produce from rolled material and there is the temptation to incorporate castings for the intricate shapes. In Diesel beds and turbine cylinders, castings in low carbon weldable quality steel have been used successfully. The edges which are attached to the rolled steel plates and sections are usually machined to ensure sound, sand-free metal.

At the present time there appears to be a drift away from this practice and to design structures which are entirely of steel, flame cut, pressed and forged.

## 7. FABRICATION METHODS

As mentioned earlier, fabrication methods have developed greatly over the last ten years and considerable thought has been given to the layout of shops to ensure straight line production, with the consequent reduction in transportation and movement of parts up and down the shop.

Methods are very often production planned and processed before being put into the shop so that the product is produced in the most efficient manner. Detailed studies should be made to determine the economics of the various methods of manufacture.

For example, bar frames and rings are used in many forms in fabrications and can be made from rolled bar or flame cut from plate. This information should be presented either as a graph or in tabular form to show when the changeover from flame cutting should take place, having regard to the relative inside and outside size and thickness.

The same can be true of the actual welding process as there may be a choice between fusion and resistance welding and the factors which determine the choice should also be readily available for the designers.

### 7.1. *Material Preparation*

The choice between cropping and sawing in the case of bar and rolled sections may be decided by the suitability of the finished cut rather than by the economics of the methods of cutting, any advantage obtained by cropping may, for instance, be offset by the possible extra setting up and welding time. The same is true in the cutting of plates to size by flame or guillotine and for plate edge preparation. Again, as many material preparation operations are best carried out by men who are specialists in the particular machine work, demarcations have changed, and the old jobbing system of giving the skilled man the drawing and asking him to make one is dying out.

Probably the most developed tool in the welding shop is the machine flame cutter. The tracing method may be from a drawing for small quantities and metal or wood templates for repetition work. For quantity production multiple burners cutting 6 to 8 parts off the template at one time are readily operated by one man. Optical tracing heads are now in common use, tracing from either scale or full size drawings with a remarkable degree of accuracy. Naturally electronics have found their way into this field and the computor with magnetic tapes may soon be used to make the machine completely automatic.

### 7.2. *Assembly Techniques*

The assembly techniques must vary with the design. If the essential plates are accurate, then they can be used for jigging the plates attached to them, and providing correct contraction allowances have been made the job should finish to size. In the other general type of design allowance can be made for adjustment of the important dimensions at a late stage of construction.

For heavy work the assembly area or floor is covered with

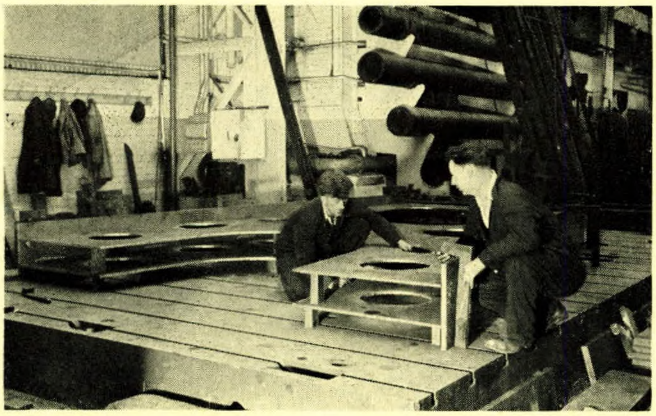


FIG. 11—*Column assembly*

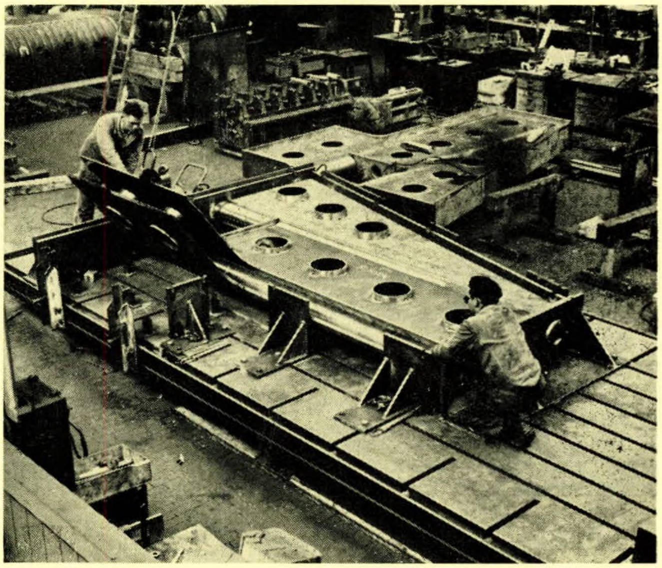


FIG. 12—*Sulzer column (jig assembly)*

slotted cast iron floor plates on which the base plan of the job can be marked out to facilitate assembly. The dimensional accuracy of the double web plates determines the ease of assembly as they control both the size and shape of the column. Spacers representing the overhang of the flanges are positioned on the blocks. One web is placed on these, followed by the side, top and bottom flanges. Some permanent and some temporary spacers on top of the bottom web enable the top web to be dropped on (Fig. 11). Tee headed clamps hold the flanges square in position and in contact with the webs, which can then be tack welded. Facings for crosshead guides, ribs and stiffening tubes are then fitted and welding is completed.

In another design of fabricated engine, jigs are used for assembly on similar floor plate arrangements. These consist of fabricated brackets bolted to the cast iron beds and arranged to locate the plates or sub-assemblies in their correct relative position (Fig. 12).

After assembly and tack welding, sufficient of these brackets are removed to release the fabrication which can then be welded, partially by machine and finished off by hand. Allowances are made during cutting for welding contraction.

In this design considerable loads are carried by the columns so that the welds may be highly stressed and prepared butt welds have been deemed necessary. By so proportioning these, advantage can be taken of making them all in the down hand position with a limited amount of turning and without the necessity for expensive manipulator gear, as discussed in section 6.1. In fact, as the welds are of proportions to warrant machine welding a case can be made out for welding with a machine using a portable track, lifted on and positioned for each weld as shown in Fig. 13. Sometimes it is convenient to use a combination of machine and hand welding in such cases and the base run of weld metal is put in manually. Here too, exists a case for the twin arc method of welding, which enables a wide flat weld to be produced when the disposition of the plates forms a naturally wide joint preparation.

The manufacture of entablatures is comparatively simple and consists first of all of clamping the base plate down on the bedplate, using similar square headed C clamps fitted into the bedplate slots and wedges to hold the plates in position. In this design no separate jigs are required as the spacing bars

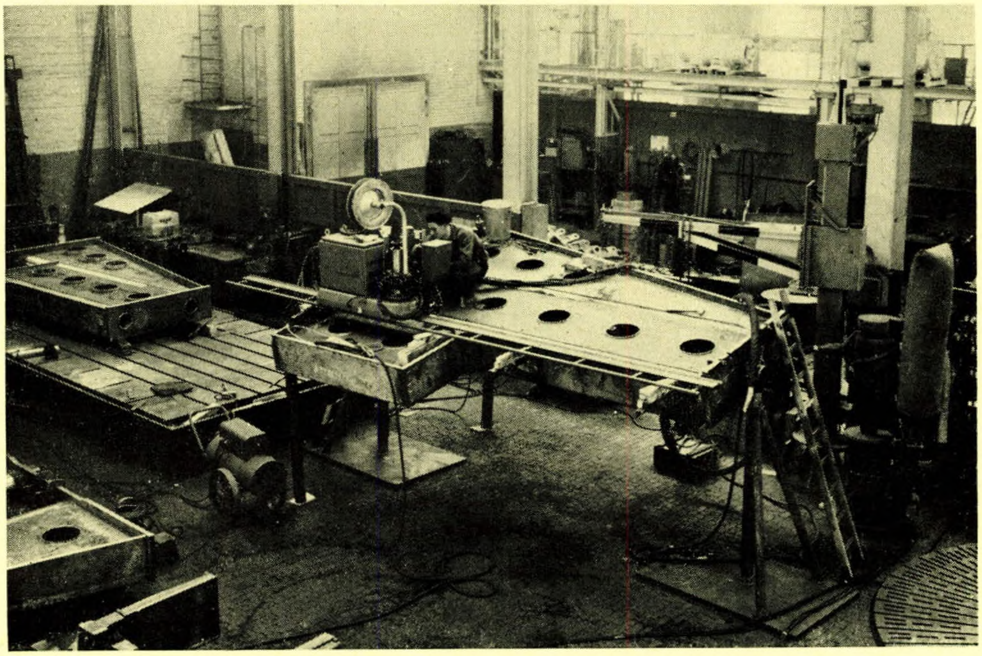


FIG. 13—*Sulzer column (automatic welding)*

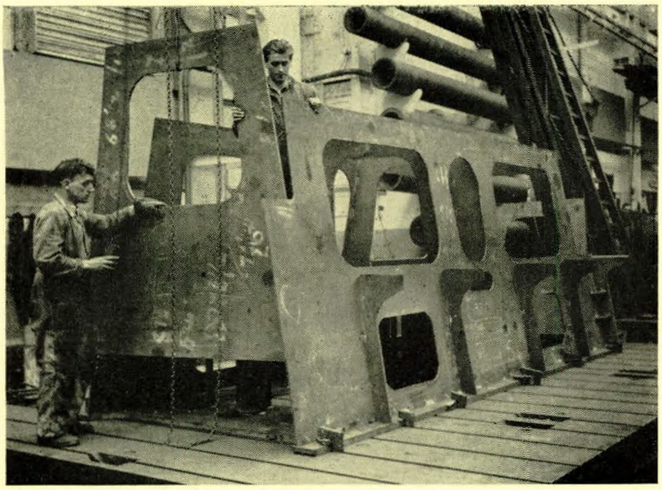


FIG. 14—*Entablature assembly*

FIG. 15—*Sub-assembly of cross girders*

which are machined to length and fitted with tap bolts determine the exact height of the centre platform. The necessary stiffeners are welded in position at an early stage while there is easy access to the inside. The next tier of plates are then positioned across the intermediate platform and as these are accurately cut to shape the side plates are automatically located. This is clearly shown in Fig. 14. It is now a simple matter to have the remaining plates, including the top and the camshaft platform which rests on the flame cut ribs attached to the side plates, tack welded on.

The construction of the bedplate is simplified as far as possible by breaking it down into sub-assemblies. First of all the transverse girders are assembled with the premachined bearing housings, the top and bottom flanges (Fig. 15) and the radial stiffeners. These are completely welded and as some of these welds are in important load carrying areas it is considered desirable to ensure that these are sound and free from cracks. This is done by inspection, using magnetic crack detection methods. These cross girders are assembled one at a time, starting from knee plates bolted to longitudinal girders, which are pre-set at the appropriate distance apart to facilitate assembly (Fig. 16). This provides a level surface to work from and the knee plate gives the squareness of the setting of the initial cross girder. The sump plate marked off and cut to size is next positioned against the cross girder and the second girder lined up against the opposite end. After tack welding this process is repeated according to the number of cylinders required. Care must be taken to make sure that all the bearing housings are in line and within the machining tolerance permitted. After this the remaining plates are assembled in a natural sequence. Sufficient welding is carried out on the job while it remains in the inverted position to ensure stability during turning over before fitting the top longitudinal flanges, after which welding can be completed in a sequence starting from the centre outwards.

This type of design does not lend itself to much sub-assembly or prefabrication but that illustrated in Fig. 17 is designed with that in view. The transverse girders are double

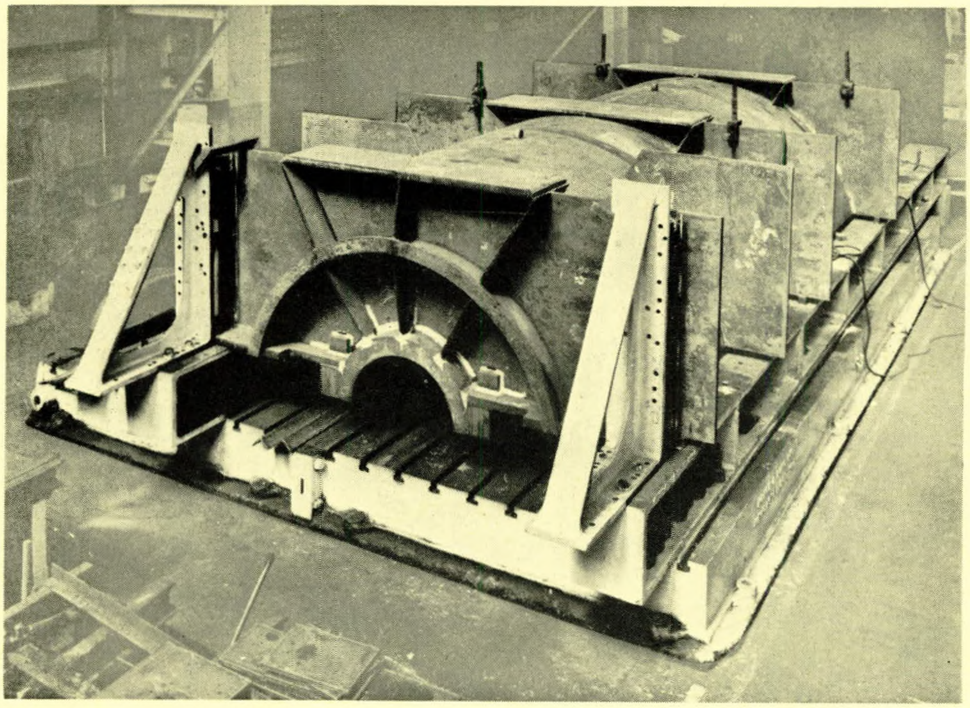


FIG. 16—*Bedplate assembly*

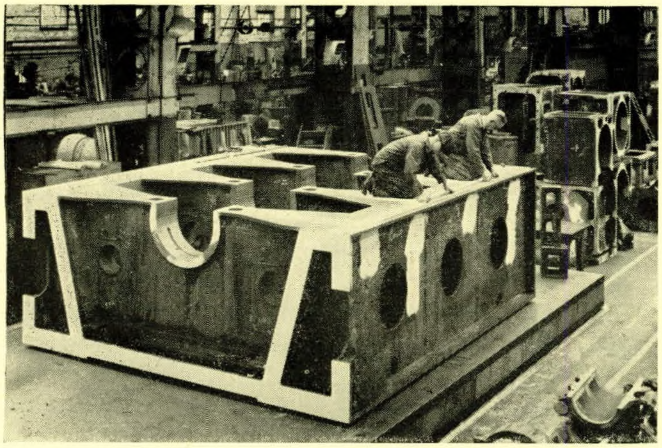


FIG. 17—*Sulzer bed*

web design and to obtain adequate inside welding the assembly sequence is most important. In the case of the cross girders the centre section is built and welded as a unit, while the two wing sections can also be sub-assembled. These, with flanges, are then assembled and the welding completed. Similarly, the longitudinal girders, which are double web design, are assembled and welded so that the final assembly consists of an assembly of prefabricated longitudinal and transverse girders.

This breakdown does much to simplify handling and the spread of work enables a greater concentration of welders on the job without unnecessary interference between individual workmen. It also has advantages when machine welding is undertaken due to the breakdown into more readily handled parts and the greater accessibility of the welds.

Turbine cylinders and reduction gear boxes can be assembled in the same type of shops. These are usually built upright from the floor plates and locally supported by temporary staying, which can be removed after welding. Examples of these are shown in Fig. 18.

### *7.3. Positioning and Manipulators*

In some instances the positioning of the job can readily be done by crane and the economics are governed by the number of lifts required, but the use of manipulators is increasing and a range of standard types are available on the market.

The commonest type consists of a stand on which a rotating and tilting table is mounted. In the heavier ones both these operations are motorized and when used with automatic welding heads the rotating table is turned at a controlled welding speed. The most successful engine fabrication designs are those which take advantage of the features of manipulators and have the welds positioned so that a minimum handling and setting up is required.

The designer must therefore know their elementary principles and limitations. This can be readily illustrated by the positioning of the welds of a simple cylindrical vessel, diagrammatically shown in Fig. 19.

The ability to tilt the job through 135 degrees makes it possible to weld both sides of the flanges in the down-hand position in one setting, as well as bosses, branches, longitudinal or radial stiffeners, both inside and out and various flange designs. On the other hand, lack of forethought in the design stage can easily double the amount of handling.

For large jobs these manipulators become heavy and require large motor power to operate them. Balancing is achieved in some types for both hand and power operation.

The double trunnion arrangement with a cradle carrying a rising and falling beam with a turntable in the middle is a good example of this type. By raising and lowering the beam the job can be balanced in one plane, thereby reducing the power required for tilting.

The roller beds used for automatic welding pressure vessels are also manipulators and are probably the most used type. The designs are usually flexible, consisting of units which can be used separately for short or light vessels and in multiple for the longer jobs. For circular welding of circumferential stiffeners on shells in the vee position or for fillet welded end rings, provision in special cases can be made for tilting a section of the roller bed to 35-40 degrees. The angle

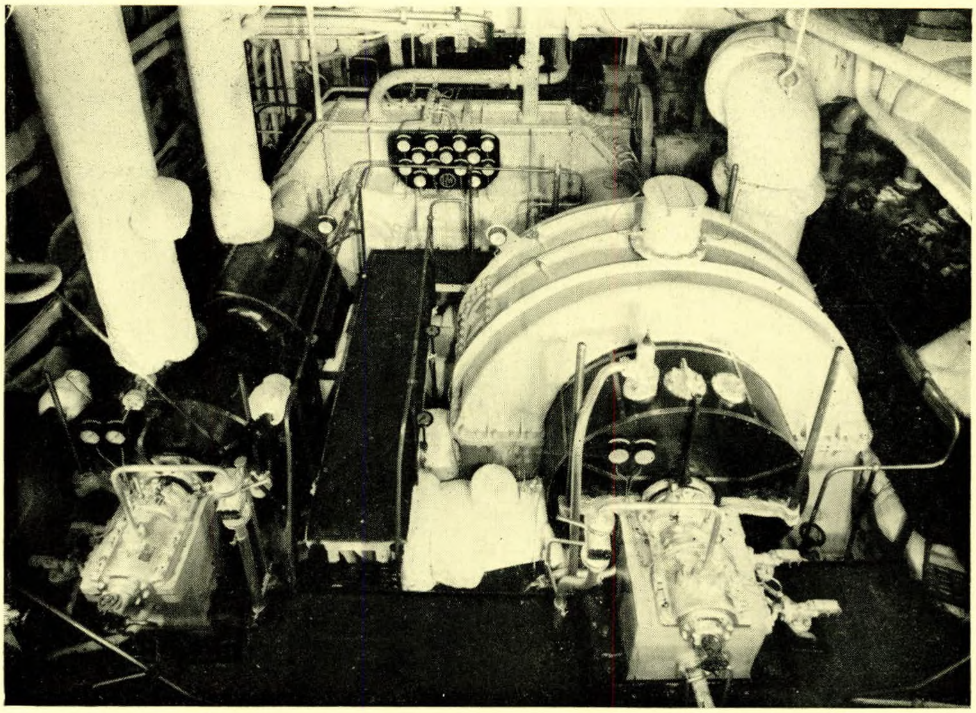


FIG. 18—*Turbine and gear*

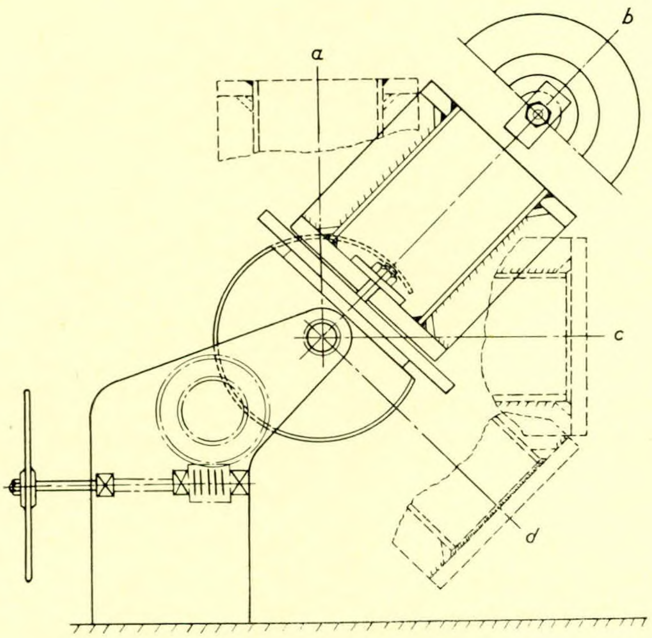



FIG. 19—*Manipulator sketch*

is limited, otherwise the height of the welding position would be prohibitive.

Another type of manipulator with a wide variety of uses, particularly for hand welding, consists of a pair of rings spaced suitably apart and rotated on two pairs of rollers. Loading of the manipulator is either by splitting the rings or from the end. With these, odd shaped or rectangular tanks can readily be positioned on any side for convenience of welding. Fig. 20 shows these in use for gas and arc welding.

Repetition and like work can often be manipulated by using the fabrication itself with the addition of bolted-on trunnions, which form the axis of rotation. To use this system effectively, very careful design is required to ensure that maximum welding can be done in the plane of rotation.

*7.4. Pressure Vessel Welding*

As has been shown, the automatic welding machine consists of a head which feeds the welding wire into the arc, and if this moves relatively to the welding seam at the correct speed satisfactory joints can be welded.

The choice of whether the head or the job should move depends on circumstances.

One necessary requirement is a steady support for the welding head so that the control medium has a reasonable chance of maintaining a steady arc. Sometimes this is best done by mounting the head on a fixed arm and moving the job.

Fig. 21 shows a simple example of this in the form of a machine for longitudinal and circumferential seam welding of pressure vessels such as starting air bottles.

First of all the shell plate is planed to size with the necessary weld preparations and rolled to shape. As this machine has no facilities for inside welding the minor weld preparations are located inside and the welding done manually, after attaching the test plates to the end of the shell longitudinal butt. It is then placed on the roller bed, with the seam at the top, and the welding head is set for the start of the weld. Push button controls start the arc and the longitudinal travel of the bogie at welding speed.

The surplus granular flux is sucked up by a vacuum cleaner and the slag chipped and cleaned from the surface of the weld. This process is repeated until sufficient runs have been made to complete the weld. In this class of work usually four runs per inch of thickness are used. The welded seam is now examined by X-rays and if satisfactory the test plates are removed, heat treated in the same manner as the finish vessel will be, but in an earlier batch, so that the test results will be available as soon as possible. The vessel ends are now fitted, welded inside and put back on the machine for circular welding by rotating the rollers which carry the drum under the welding arc. On the completion of the automatic welding, pads, standpipes and mounting brackets are welded on, generally by hand. The next operation is stress relief, which necessitates heating in a furnace to between 600 deg. C. (1,112 deg. F.) and 650 deg. C. (1,202 deg. F.) for mild steel for one hour for each inch of maximum thickness of the vessel, and allowing to cool to 250 deg. C. (482 deg. F.) in the furnace. After hydraulic testing, and assuming that all the test pieces

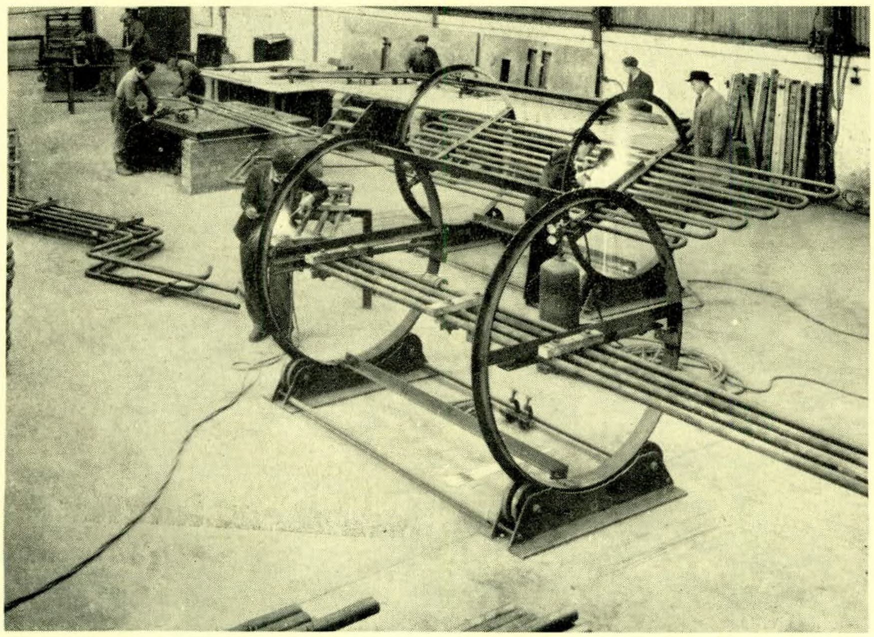


FIG. 20—*Ring type manipulator*

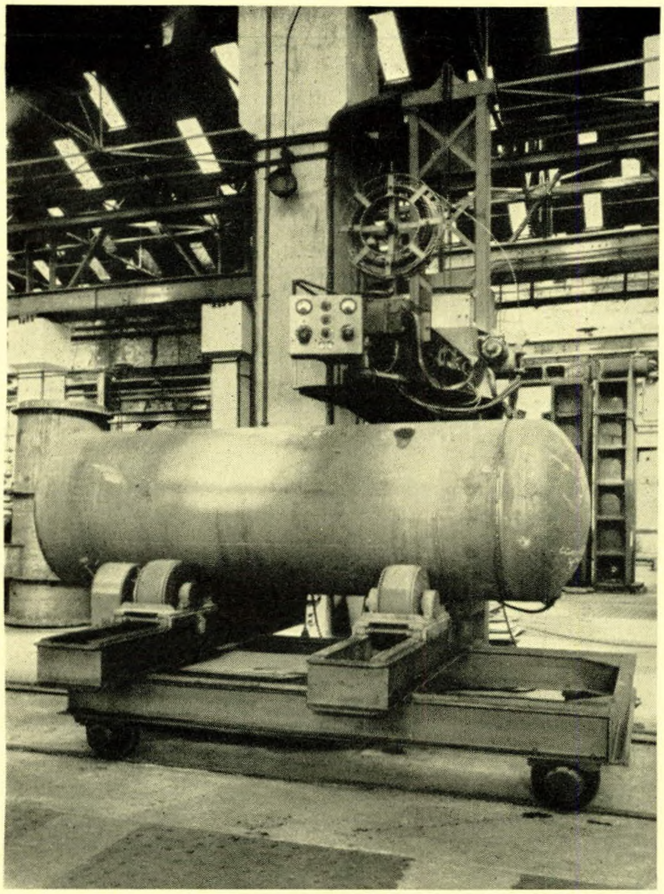


FIG. 21—*Automatic welding air receivers*

have already been approved, the vessel is ready for installation in the ship.

Steam drums and similar vessels are all made in the same manner. Often arrangements are made on the welding machines for the inside seams to be done on the machine, usually by mounting a welding head on a cantilever arm which passes inside the drum.

*7.5. Light Plating*

In marine work "light plating" is an important aspect of the business and usually deals with much of the ancilliary work, including funnels, uptakes, ventilators, tanks, exhaust pipes, expansion joints, silencers and changeover valves.

In the case of funnels, welding has been used even for mild steel, to ensure smooth, easily painted surfaces with freedom from lap joints, where corrosion is likely to occur. The process is also most suitable for the streamlined shapes which are now popular. In passenger ships aluminium alloys have been used for this purpose as well as for some superstructures and welded with the comparatively recently developed inert gas arc welding process.

All classes of installations require oil storage tanks and the like for engine room use and are often tailor made to fit in cramped spaces. It is usual to design so that the plates are self-jigging, with the welds as accessible as possible for welding with the minimum of handling. As much inside welding as possible is done before putting on the closing plate and if the welder has to go inside a suitable exhausting fan draws off the fumes from the inside. Consideration must be given to the pads and facings which should be premachined and drilled before welding-in for economy. It is important that standardization is adopted wherever possible and this applies particularly to pipe flanges.

Welded constructions can often be used to advantage when weight saving is important. A good example of this is in the changeover valve used in the Diesel exhaust line to switch from exhaust gas boiler direct to the silencer. Another advantage of this construction is the adoption of premachining on the valve lid and seats. This method only requires simple machining operations which give greater accuracy for a much reduced manufacturing time.

*7.5.1. Spot Welding*

Although the bulk of the work can be done by arc welding it may not always be the cheapest. Spot welding is a very useful process and applicable without elaborate equipment and process controls to sheet metal work. The process necessitates two overlapping surfaces which can be compressed between the machine electrodes so that a measured quantity of electricity can pass across the joint and make a button type weld. These can be spaced closely or widely according to requirements.

The generation of welding heat is proportional to the square of the current, the duration of flow and the resistance of the junction between the sheets. The contact resistance varies with the cleanliness of the sheets, but with adequate mechanical pressure between the electrodes and reasonable cleanliness, consistent spot welds can be made. The easiest way is to use air pressure in a pneumatic cylinder to apply pressure direct to the contacts, and by varying the air pressure, control the total load. This can be interlocked with the timing control so that until the required pressure is reached the timing does not commence. This is commonly by thyratron timer and is provided with a delay which holds the pressure long enough after the weld is made to allow it to solidify. The value of welding current is selected by tappings on the welding machine transformer. Therefore, by controlling all these factors, repeatable results can be obtained automatically. Table V gives data for mild steel welding.

Such a machine is shown in Fig. 22 making 16-g. mild steel air trunking.

The lap joint necessary for the application of the process in this case acts as a stiffener as well.

The practical application requires a minimum overlap of sheets, the amount depending on the thickness, and sometimes in the case of corners on the shape, of the electrode holders available. In the example shown, inclined holders with offset electrode tips enable welds to be made close in.

Fig. 23 gives some of the common joints applicable to this work; the advantages and disadvantages of the various joints can be readily visualized. Both (*c*) and (*d*) can be welded from the outside. The lap joints (*a*) and (*b*) on closed trunks must be threaded over the lower arm. Doubling plates,

FIG. 22—*Spot welding machine*

TABLE V.—DATA FOR SPOT WELDING TWO EQUAL THICKNESSES OF LOW CARBON, MILD STEEL SHEET

| Sheet thickness | | Electrode tip diameter, in. | Electrode load*, lb. | Welding current, in amperes weld time in cycles (50 c/s) | | | | | | Average shear failing load†, lb. | Approximate diameter of fused zone, in. | Minimum edge distance, in. | Minimum weld pitch‡, in. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | B | | A | | C | | | | | |
| In. | S.W.G. | | | Current | Time | Current | Time | Current | Time | | | | |
| 0·022 | 24 | $\frac{5}{32}$ | 190 | 5,000 | 5 | 5,000 | 10 | 5,000 | 20 | 530 | 0·15 | $\frac{1}{4}$ | $\frac{3}{8}$ |
| 0·028 | 22 | $\frac{3}{16}$ | 275 | 8,000 | 5 | 6,500 | 10 | 5,000 | 25 | 800 | 0·18 | $\frac{1}{4}$ | $\frac{7}{16}$ |
| 0·036 | 20 | $\frac{3}{16}$ | 275 | 8,000 | 10 | 6,500 | 15 | 5,500 | 30 | 1,100 | 0·18 | $\frac{5}{16}$ | $\frac{1}{2}$ |
| 0·048 | 18 | $\frac{7}{32}$ | 375 | 9,000 | 10 | 7,500 | 20 | 6,500 | 40 | 1,400 | 0·22 | $\frac{5}{16}$ | $\frac{3}{8}$ |
| 0·048 | 18 | $\frac{1}{4}$§ | 500 | 10,500 | 15 | 9,000 | 25 | 8,500 | 40 | 1,550 | 0·25 | $\frac{5}{16}$ | $\frac{3}{4}$ |
| 0·064 | 16 | $\frac{1}{4}$ | 500 | 9,500 | 15 | 8,000 | 20 | 7,500 | 50 | 2,200 | 0·25 | $\frac{3}{8}$ | $\frac{3}{4}$ |
| 0·080 | 18 | $\frac{5}{16}$ | 770 | 12,000 | 20 | 10,500 | 30 | 9,000 | 50 | 3,700 | 0·31 | $\frac{1}{2}$ | 1 |
| 0·104 | 12 | $\frac{5}{16}$ | 770 | 13,000 | 20 | 11,000 | 40 | 9,500 | 80 | 5,400 | 0·34 | $\frac{1}{2}$ | $1\frac{1}{4}$ |
| 0·125 | — | $\frac{11}{32}$‖ | 1,400 | 15,500 | 20 | 13,000 | 40 | 9,500 | 100 | 7,400 | 0·37 | $\frac{1}{2}$ | $1\frac{1}{2}$ |

* 10,000 lb. per sq. in. tip area up to and including $\frac{5}{16}$-in. tip diameter.
15,000 lb. per sq. in. tip area for $\frac{11}{32}$-in. tip diameter.
A Normal recommended condition.
B Limiting condition for most efficient use of energy.
C Limiting condition for low currents and long times.

† Specimen width $\frac{3}{4}$ in. for 24 S.W.G.
1 in. for 22 S.W.G.
$1\frac{1}{2}$ in. for 20 to 12 S.W.G. inclusive.
2 in. for $\frac{1}{8}$ in.

‡ At closer pitches, increased current or time is required to offset the effects of current loss through previous welds.
§ $\frac{1}{4}$-in. tips are commonly used in practice, though $\frac{7}{32}$ in. is nearer to $\sqrt{t}$ (where $t$=sheet thickness in inches).
‖ An included angle of 140 deg. is recommended for $\frac{11}{32}$-in. diameter tips.

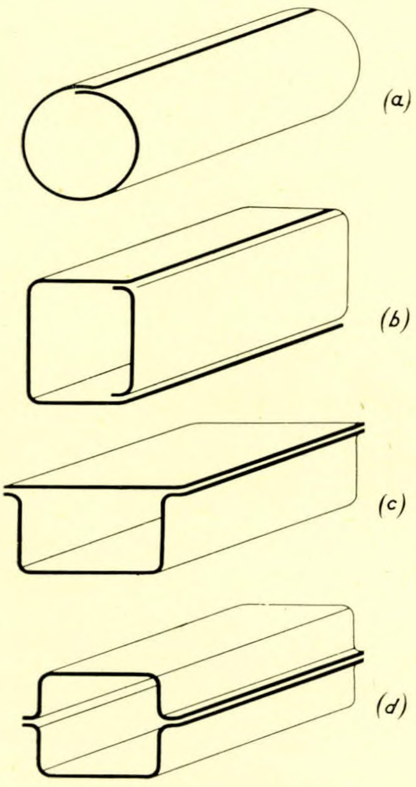



FIG. 23—*Forms of spot welded construction*

fixing straps and jointing sleeves are examples of some of the details which can be welded using the same process.

*7.6. Ferrous Pipes*

Pipe work is important in all classes of machinery and whilst in the past details were often developed according to the application, leading to a multiplicity of equally suitable arrangements, there has been a good deal of thought given to standardization and rationalization. There have been standards, for example, for pipe flanges, but the standards vary according to the industry, although the service is the same. It has therefore been left to the user to do his own sorting out. In addition to sorting things out to suit the home market, the shipping man may find himself anywhere in the world and often up against the lack of international standards. Taking British Standard flange tables as an example, these are tabulated in 50lb. per sq in. steps, and to avoid complications in the shops and fitting out a limited number of these should be adopted. For instance, some arbitrary figure should be accepted as the top limit for low pressure so that all pipes, whatever the service, within the range can be similar. This will simplify pipe stocking and enable flanges and fittings to be made in quantity and have the bolt holes jig drilled.

Similarly, the range of weld preparations and weld sizes can be limited, thereby ensuring greater consistency and less risk of wrong sizes being used. It can also effect considerable economy in design and specification for manufacture. Just as the bolt holes are predrilled, so the flanges can be faced prior to welding for some low pressure applications.

The simplest type of flange used is the slip-on flange and up to about 100lb. per sq. in. working pressure no weld preparation is generally required. With increased working pressure the flange is prepared with a single or double J-groove preparation. This type is also used with low alloy steel piping-up to the highest steam temperatures.

For thick pipes the welding of slip-on flanges may not be considered desirable due to the risk of basal cracking in the weld metal, and the neck type flange, making a butt weld with the pipe is preferred.

In the case of flanges butt welded to pipes, they can be

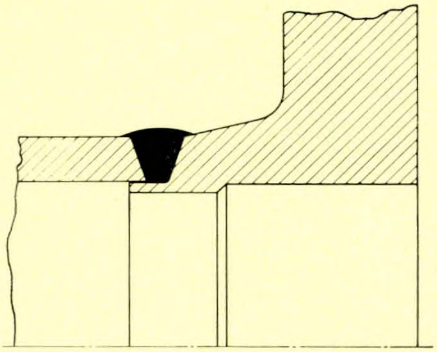


FIG. 24—*Butt welded flanges with temporary backing rings*

provided with temporary backing rings, which can be machined off after welding and ground smooth on the outside (Fig. 24).

*7.6.1. Fuel Pipes*

Smaller pipes with nipples required for fuel pipe connexions can be subjected to severe fatigue due to the pressure pulses not only trying to burst the pipe but tending to straighten each bend in the pipe, and when subjected to pulses at injection frequency of a marine Diesel, can soon exceed $10^6$

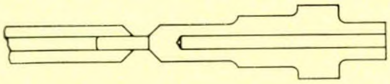


FIG. 25—*Fuel pipe nipples*

loading cycles. The nipple is made with an integral locating pin to centre in the pipe bore and act as a backing bar for gas welding. In manufacture the nipple is partially drilled and then finally drilled through to complete a notch free bore at the junction between nipple and pipe (Fig. 25).

*7.6.2. Butt Welding Pipes*

Butt welds in pipes without access to the inside present a more difficult problem and three main techniques have been adopted.

Arc welding with small gauge electrodes manipulated to interrupt the arc at a steady frequency has proved satisfactory for duty on boiler tubes and the like, but is a specialized and highly skilled operation.

The second method uses a wide weld preparation and gas welding using the key hole technique for the first run, so that the root of the weld is melted through and filled as the welder progresses. In the case of thick pipes arc welding may be

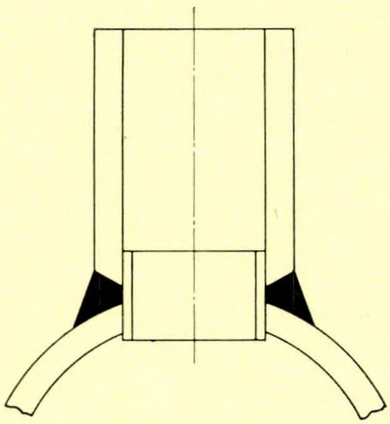


FIG. 26—*Tee connexions*

used to complete the job, while for boiler tubes or pipes up to ¼-in. wall thickness gas welding is used throughout.

As it is easier to make a satisfactory joint by one of the above methods in a flat butt weld than a butt weld forming a tee joint, resort is often made to the welding of short steel ends on the pressure pipes by the method shown in Fig. 26. In this, a short length of pipe is shop welded on a temporary backing ring at a distance which permits machining out the backing ring. The long pipes can then make a plain butt weld with the stub ends by one of the methods described and so ensure a higher overall job efficiency. The same method is sometimes used in flanged and bolted pipe arrangements, advantage being taken of this requirement and a flange joint arranged near enough to the tee joint to permit the fitting and machining out the temporary backing ring.

Drain bosses and thermometer pockets can be provided for high quality work by premachining the boss (Fig. 27) with

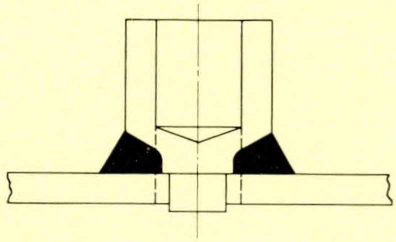


FIG. 27—*Drain and thermometer bosses*

the weld preparation and locating pin of such dimensions that the final drilling of the bore removes the weld root and leaves only sound metal in the joint.

One of the newest developments uses a shaped backing ring, which fits in the joint root gap with a D-section in the pipe bore. On fusing with the argon arc the whole ring melts, forming a smooth penetration bead. Argon gas is provided as protection for the inside of the pipe so that no scaling can occur in the bore. The argon arc process is easy to use. Completing the weld may be done by any process but the preference is for metallic arc at the moment.

With the advent of alloy steels for pipe work, due to higher operating temperatures, this process has much to commend it. In the case of low alloy steels of the molybdenum and chrome/molybdenum types, no problem exists with loss of alloying elements, and filler wire of the same composition can be used without trouble. Even for higher temperature work where austenitic steels are required, the argon arc process is easy to use.

*7.6.3. Flash Butt Welding*

This process is being used successfully to a limited extent for making butt welds in tubes and tubes to flanges. As one of the necessities is the provision of equal sections, with sensibly the same heat capacity, flanges must be of the neck ring type. The machines are of stationary types and quite bulky and require heavy electrical power mainly single phase, so that the job must be taken to the machine. The welding operation is quick and the weld produced excellent. In the commonest types of machine the flash produced by the expulsion of molten metal from the joint leaves a ragged ring of burnt metal which has to be removed mechanically. The removal of this from the inside necessitates access to the tube bore from one end and in practice at least one of the welded pipes must be straight to allow for the flash stripping. In the case of welded flanges this is no different for arc welding on an integral backing bar, as the bore can be machined from the open end. This flash stripping has limited the application in bent tube work such as superheaters, and machines have been developed to limit the internal flash by gaseous methods.

*7.6.4. Pressure Welding*

Pressure welding has made some progress towards obtaining a smooth bore with little restriction at the weld. The process requires a machine which grips the tubes near their ends and brings the accurately machined ends into light contact. Heat is applied by gas flames or by electric induction, and, when the forging temperature is reached, pressure is applied longitudinally to the tubes to provide sufficient deformation to make a high quality joint. The weld surface needs no further finishing operation. Heat treatment when required can be done on the same machine.

## 8. INSPECTION AND TESTING

Although a number of non-destructive tests have been applied to welding, no correlation between those and weld strength is generally possible so that each test has to be considered on its merits and used only when it shows up the type of weakness which might be undesirable in the fabrication.

Then again, as every inch of the welding cannot always be examined, something has to be taken on trust. Therefore much is to be said for procedure control in which the exact technique is laid down and tested out before the work commences. This not only proves the process but also the operator carrying out the work.

This is the practice adopted in pressure work associated with superheaters and boilers.

### *8.1. Mechanical Tests*

Probably the best example of this is the well known routine adopted for class one pressure vessels. The normal tests are plate tensile, all-weld metal tensile, bends and Izods as well as macro-examination. Such a selection of tests, including a fatigue, are illustrated in Fig. 28. The fatigue test is not a routine test but is used for the approval of a new process or equipment. A good deal of experience has gone in to the selection and the proportions of these test pieces. It is therefore quite important to maintain these consistently if maximum information is to be obtained from the tests.

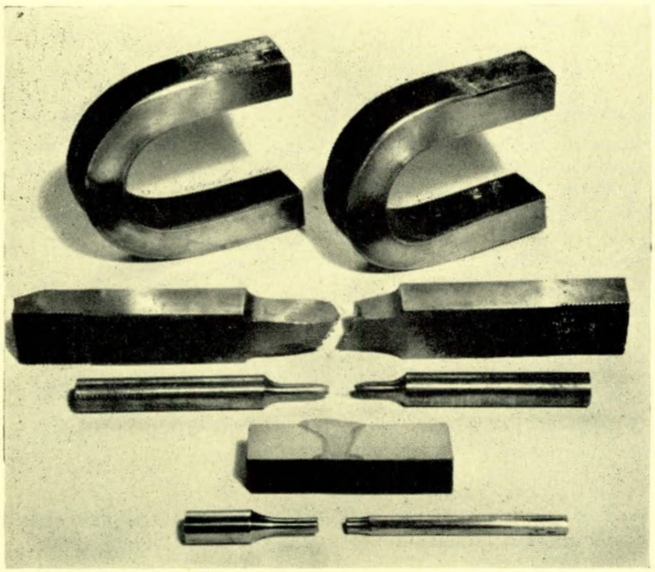


FIG. 28—*Test pieces*

### *8.2. Radiography*

#### *8.2.1. X-rays*

The X-ray process is well known and is a very useful check. Much has been said already about the importance of eliminating cracks, particularly in fatigue loaded structures, and this process as a means of checking not only gives the magnitude of the defects but also their shape, which can influence the acceptance of a welded seam.

#### *8.2.2. Isotopes*

Whilst for plate work the X-ray source is generally the most sensitive and convenient, isotopes must not be overlooked.

Particularly for site work, the inspection of pipe joints is done by inserting the isotope inside the pipe through a specially provided boss, so that it is positioned at the centre of the pipe in line with the weld. The film is wrapped round the outside and the complete exposure made at one setting. The quality of the radiograph obtained depends on the material thickness, the strength and size of the source as well as the grade of film.

The interpretation of the film is similar to X-rays and necessitates a knowledge of the weld geometry as well as a familiarity with the welding process.

### *8.3. Magnetic Testing*

Having already discussed cracks at length it is only right to give particular mention to crack detecting. The magnetic method, which virtually only shows up surface cracks and defects, is most important. The process necessitates magnetizing the area under inspection and flooding with a suspension of magnetic powder in a liquid such as paraffin. Any crack will distort the magnetic field, causing fringing at the edges of the crack and an accumulation of the magnetic powder, and if this has a contrasting colour will show up readily.

One essential for maximum effect is for the magnetic field to be normal to the crack. Fortunately the direction of possible cracking can be determined by the geometry of the joint or the rolling conditions of the base metal. The magnetizing can be done by permanent or electro-magnets placed across the suspected areas or by passing an electric current, either a.c. or d.c., through the structure in the direction necessary to produce the correct magnetic field. One should take great care with the current method to avoid arcing where the probes contact the metal surface, as this intense heating may cause local hardening and consequently stress raisers for the start of other cracks. Another weakness lies in the use of brass contacts, which if allowed to arc will penetrate the steel with similar adverse effects.

### *8.4. Ultrasonic*

As both radiography and magnetic particle testing have limitations, other methods are of interest.

The ultrasonic method which, briefly, consists of injecting a beam into the metal and picking up reflexions from any

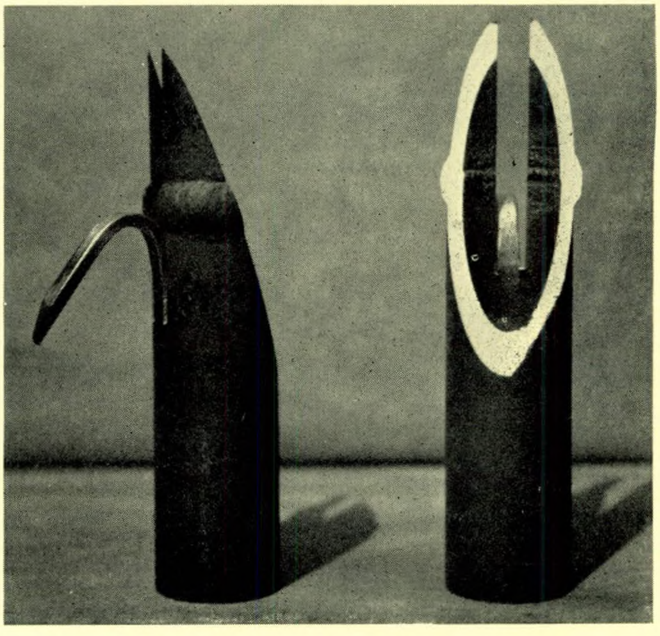
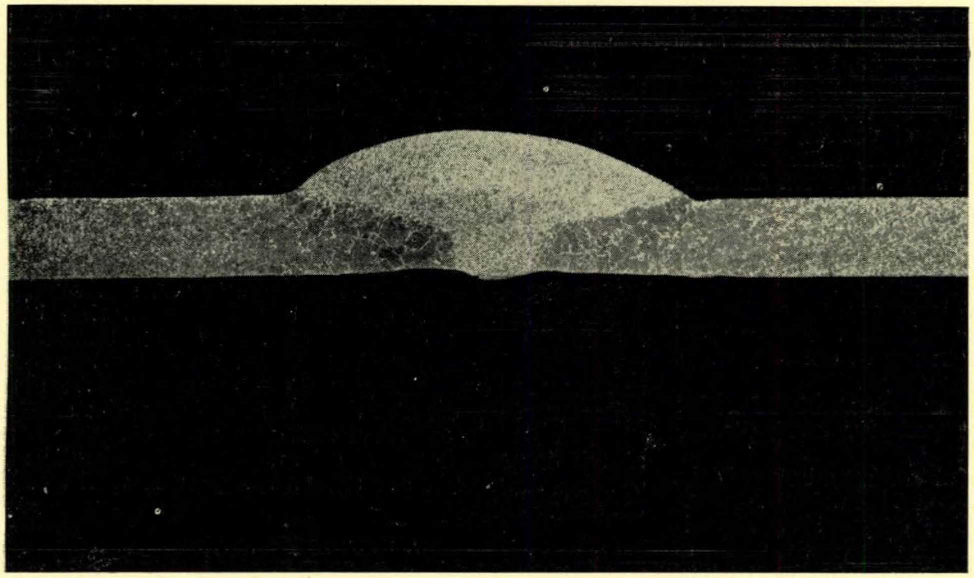
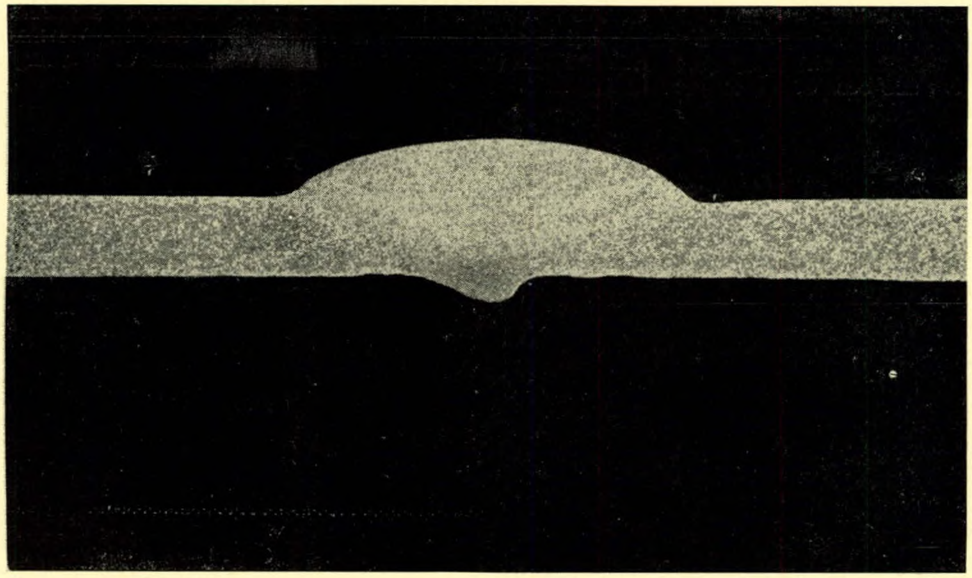


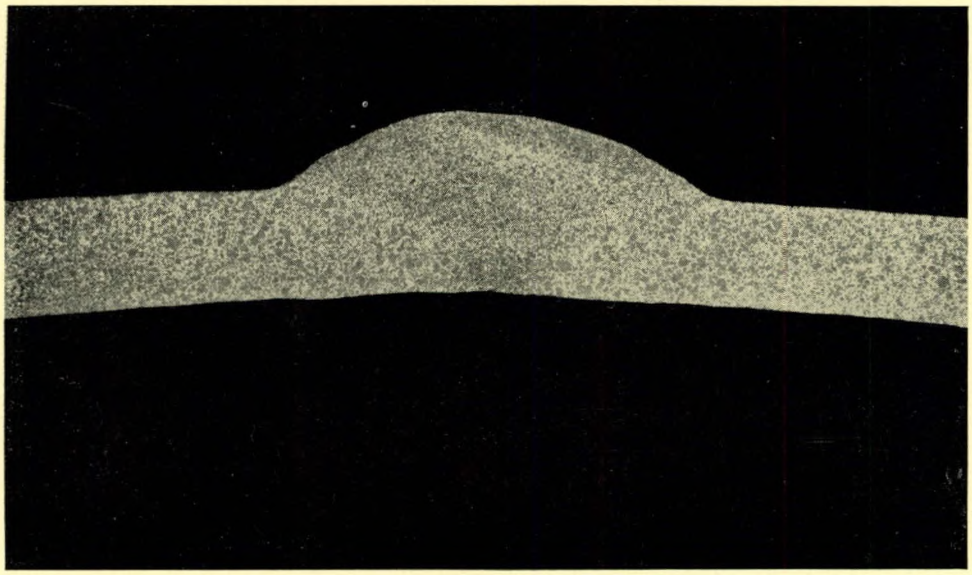
FIG. 29—*Reverse bends*



*Mild steel tubing, showing inadequate heat treatment*



*Mild steel tubing, as above but correctly heat treated*



*½ per cent molybdenum steel tubing*

FIG. 30—*Macro photographs × 3*

surface in the path of the beam and viewing on the screen of a cathode ray tube. The time taken for the reflexion gives a measure of the position of the defect. So, by ascertaining the reflexion of the reverse side of the plate, any intermediate indication must represent something in between. By this means cracks which, due to their lack of volume, would not show up on X-ray examination, can be easily detected. With this process considerable operational skill is required and adequate knowledge of the weld shapes is necessary for speedy and reliable examination.

*8.5. Special Methods: Tube Examination*

Whilst the previous methods have general application there are a number of highly developed and specialized methods worthy of note and it might not be out of place to introduce one which may affect marine work.

In tube testing a closely knit procedure control and testing technique is useful for boiler and superheater tubes, particularly for advanced steam conditions.

The procedure control consists of making a butt weld on the tube material being used and recording the weld particulars, which will be repeated on all similar joints. Now there is little point in making mechanical tensile tests on the welds, as experience shows that the strength is never in doubt. The main difficulty lies in obtaining 100 per cent penetration and good root fusion so that the test is devised to check this. The simple reverse bend prepared and tested without any expensive equipment gives the answer. One test joint cut diagonally and slotted down, as shown in Fig. 29, and bent over a simple plate former held in the vice, stresses the weld where the greatest weakness exists.

Particularly in alloy steel tubing is it desirable to have a check on the completeness of the heat treatment. So if one of the cut sections is polished and macro-etched for photography at a magnification of three, the grain size can be checked (Fig. 30). The other feature, not shown by the bend test, is inter-run lack of fusion, which may occur in positional welding of alloy steels and can be readily detected in the macro.

### CONCLUSIONS

Fabrication is gradually following the pattern of most engineering manufacturing techniques in that specialization is becoming increasingly evident, brought about mainly by the growth of mechanization. As machines are not universal, but are made for straight or circular work, the fabrications have to be channelled into these general categories. Then there is the drift away from the idea that the portable machine should be taken to the job, as greater convenience and efficiency is possible if the work is taken to the machine. All of this is only effective, however, if due attention is given to weld details in the design stage.

### ACKNOWLEDGEMENTS

The author wishes to thank Mr. J. R. Mackay, Managing Director of Richardsons Westgarth and Co., Ltd., for permission to present this paper and also for the use of illustrations.

He is also indebted to Mr. E. W. Cranston, Wh.Sc., of Sulzer Bros. (London), Ltd., and the Institute of Welding for illustrations.

# Discussion

MR. S. ARCHER, M.Sc. (Member) said that the author had given a broad survey of current welding practice in marine engineering, with here and there a hint of future lines of development, for which he for one was very grateful. Incidentally, this was the most comprehensive paper on the subject since Mr. H. N. Pemberton's Thomas Lowe Gray Lecture six years previously to the Institution of Mechanical Engineers. The Institute were indeed fortunate to have this addition to their TRANSACTIONS.

The difficulty with a subject as wide as that embraced by Mr. Dorrat was to know whether to deal relatively briefly with a great many aspects or perhaps, at greater length, concentrate mainly on two or three facets with which one was particularly acquainted. As a welding engineer of all-round experience, Mr. Dorrat seemed not to have been faced with such a choice, for although he had been commendably concise, it would, he thought, be agreed that he had covered his subject more than adequately.

In his introduction, the author claimed that much of the mystery had been taken out of welding and both the metallurgy and design aspects were now on a sound scientific basis. This might indeed be so, but seemingly there were still many people not yet acquainted with it, judging by the numbers of cracked welds in bedplates, entablatures, pistons, gear wheels and so on, which were unfortunately brought to the notice of Lloyd's Register of Shipping from time to time. Incidentally, the vast majority of such cracks occurred in the welds and only a very few clear of the welds.

It was to be hoped that these people would study Mr. Dorrat's paper with particular care and with mutual benefit to themselves and their clients.

He would like to raise a few points which had occurred to him in reading through the paper.

On the subject of creep, people did not seem to be very united about the merits of ½ per cent Mo steel. Lloyd's Register were now limiting its application to 950 deg. F., since there was evidence that it suffered from excessively low ductility at rupture.

Then there was stress relief, a vexed question on which much had been written and said. He would like to quote one well-known engine builder who unfortunately suffered from many failures with cracks in welded entablatures over a period of years. It did not seem to matter what was done: these cracks still occurred. The structure was such that the combustion loads were taken by the welded joints, and under these conditions there was, of course, fatigue loading. Nevertheless, at a certain period stress relieving was resorted to, and this produced beneficial results. However, this was not the only change made: there were amendments to one or two design features too. Yet it did appear that, in general, stress relieving, while it would not necessarily improve the fatigue strength of a well-designed structure, might nevertheless save a somewhat inferior design from disastrous trouble. He would just like to put that view to Mr. Dorrat.

A typical transition curve for steel was shown under "Brittle Fracture" in Fig. 2, page 71. It was clear that the transition temperature itself would depend upon how it was defined relative to those curves; for example, 15 ft. lb. and 40 ft. lb. at 0 deg. C. or the temperature at which the energy fell to 50 per cent of that above the transition range, had all been suggested as criteria for transition temperature. It was fortunate that in general, except possibly for refrigerating plant, marine engineers were not unduly worried by transition temperature considerations.

On page 69, under "Weld Quality", the author emphasized the importance of a smooth finish to the under side of a weld and proper root fusion. He would like to show a few slides demonstrating what could happen when these precautions were not observed.

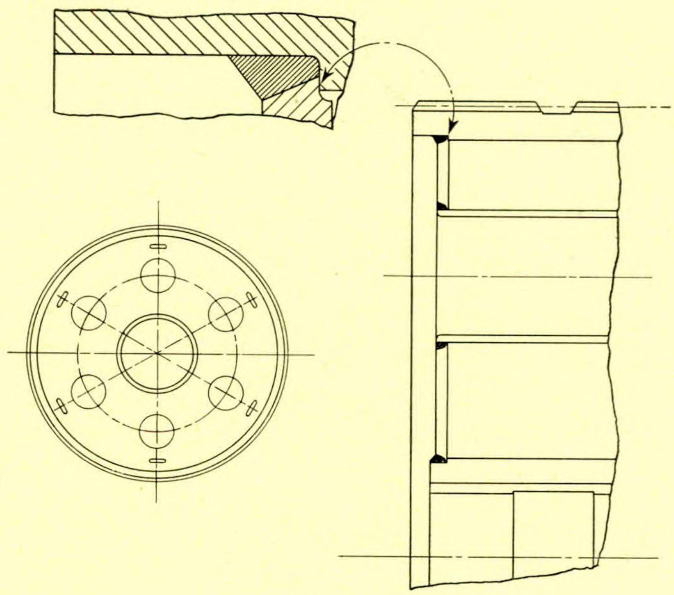


FIG. 31

Fig. 31 showed a fully fabricated first reduction gear wheel. As members would note, the welded connexion between the rim and the web plates was made by means of a weld from one side only of the plate, and there was a very awkward notch just at the root of the weld. Unfortunately, in this particular design many of the wheels were cut on a hobbing machine which suffered from—should he say?—old age. There were therefore considerable undulations on the teeth and as the pitch line speed was high, there was heavy additional dynamic loading, possibly two or three times the normal dynamic loading, coming on these teeth. In consequence, the material was subjected to stress waves of a very high frequency, and in service no less than six ships had to have the wheels renewed, three of which were classed with Lloyd's Register.

There was another factor which appeared from a subsequent examination. The material of the web plates was in some cases rimmed steel. They had been machined to form the register with the rim, and when this was done the good material was removed to expose the core of the plate, where there were heavy segregations. That was another bad factor.

Fig. 32 showed a sulphur print of the section of the

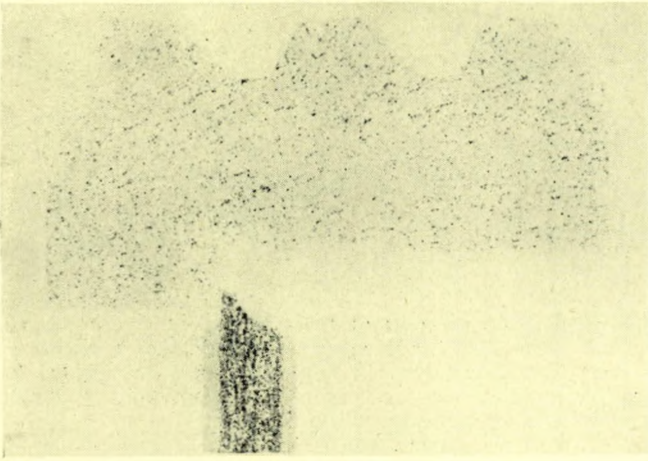


FIG. 32

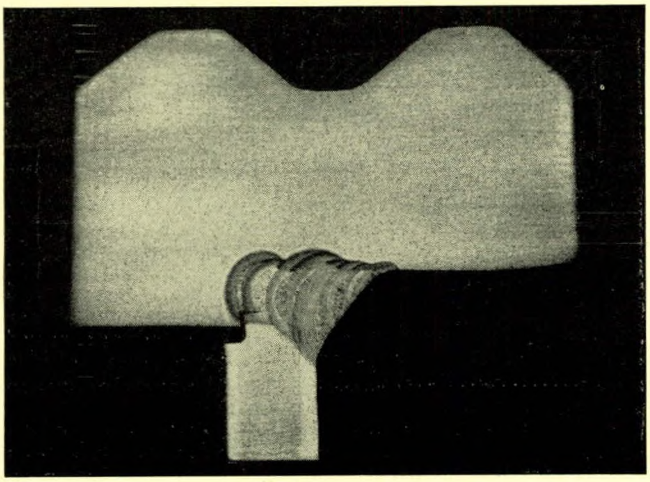


FIG. 33

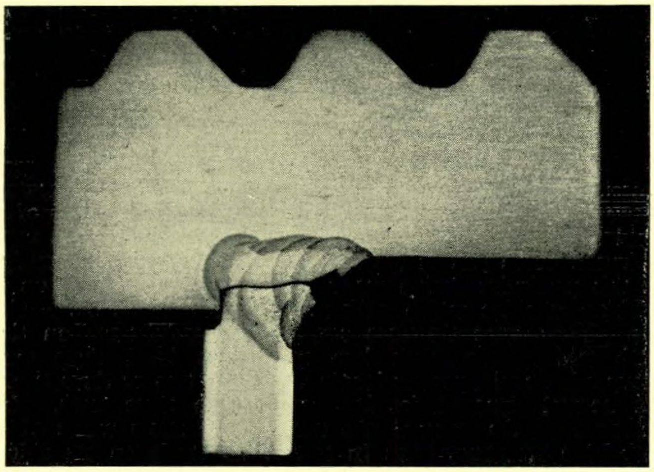


FIG. 34

rim and the web plate on which could clearly be seen the rimmed steel structure.

In some cases the cracks developed circumferentially right through the middle of the weld. In other cases they spread out and a crack developed axially through the rim. The rim was of about 0·32 per cent carbon steel, preheated to 300 deg. F. with subsequent stress relief. In the process of assembly, the material had been allowed to heat up and cool down repeatedly in order to crack detect the welds. He wondered whether that might also have been a factor in starting some of the minute root cracks.

Fig. 33 showed a section where the crack was just commencing at the notch at the root of the weld.

Fig. 34 showed the crack complete. The extent of the cracking varied and in some cases it travelled almost the full circumference of the wheel.

On page 71, under "Low Hydrogen Electrodes", the author had taken considerable trouble in describing the properties and advantages of these electrodes. He seemed, however, to have missed out the vitally important precaution of maintaining them dry—presumably because this was so obvious to him.

He would like to ask the author one or two questions on fabrication.

With regard to intersecting welds, certain engine builders preferred to stop their welds in order not to have intersecting joints; others claimed that the resulting stress concentration and possibility of notching could produce a worse result than having the welds continuous. What was the author's personal opinion? There seemed to be some divergence of practice in this respect.

The need for preheating would vary with the carbon content, the mass of the parts concerned, the welding current and the size of run. But for what sort of section would the author consider preheating was essential? For example, what would he think was essential for hand welding and for machine welding respectively in a large Diesel engine bedplate? It was a difficult question to answer, but there seemed to be a diversity of practice here also.

On edge preparation, he thought the importance of alignment could not be over-emphasized. He presumed each manufacturer would have certain tolerances to which he would adhere, but perhaps the author would give some idea of the tolerances recommended by his firm for structures of this kind.

A number of new ideas for flame preparation of welding grooves had been put forward recently. Some of them employed an air blast to blow the molten metal out of the groove; others relied on the force of the arc alone. It was claimed they could be used for the removal of defects in weld repairs, and it seemed a very convenient process. Had the author tried these methods and were there any snags to them?

One or two flash butt welding processes had been approved by Lloyd's Register since the war. The cleaning out of the "flash" on the inside of the joint was an important question. It seemed that it might not always be possible to use mechanical methods, as suggested by the author, and he understood air blast had been used in some cases. There was, however, the possible danger of air hardening, and he would like to know the author's experience, if any, in that respect.

He instanced engine builders who deliberately prefabricated bedplates in sections so as to be able to stress relieve them in the size of furnace available. He thought there was a tendency with welding to go on adding to the size of a component, so that in the end one could not get it into a stress-relieving furnace, whereas in a casting one might be limited.

The importance of weld design had struck him very forcibly in connexion with Table I where the fatigue results were given. It came out very clearly that the fatigue strength of the cruciform connexion (the fourth down) with complete fusion under alternating push-pull was ± 5·5 tons per sq. in., and this might go down to ± 2·25 tons per sq. in. with plain fillet welds (the sixth down); in other words, the push-pull alternating fatigue strength was improved two and a half times by using a full strength weld. This was one reason why Lloyd's Register's new rules for fabricated Diesel engine structures required that the joints should be made by strength welds where they were subject to the main combustion and inertia loading.

There had recently been a case where lack of preheating with too high a carbon content had led to a failure of three generator armature shafts. These were not very highly stressed. Admittedly, they had alternating first order bending, due to the weight of the flywheel, with possibly some misalignment due to the lifting of the pedestal bearing to reduce crank web deflexion. But the total reversed bending stress was only about ± 4,500 to 5,000lb. per sq. in. (nominal), which would not have been expected to cause failure. These three shafts failed in just about $10^7$ revolutions in each case (see Fig. 35), and the material was subsequently examined. It was found that the tensile strength in the vicinity of the welds was about

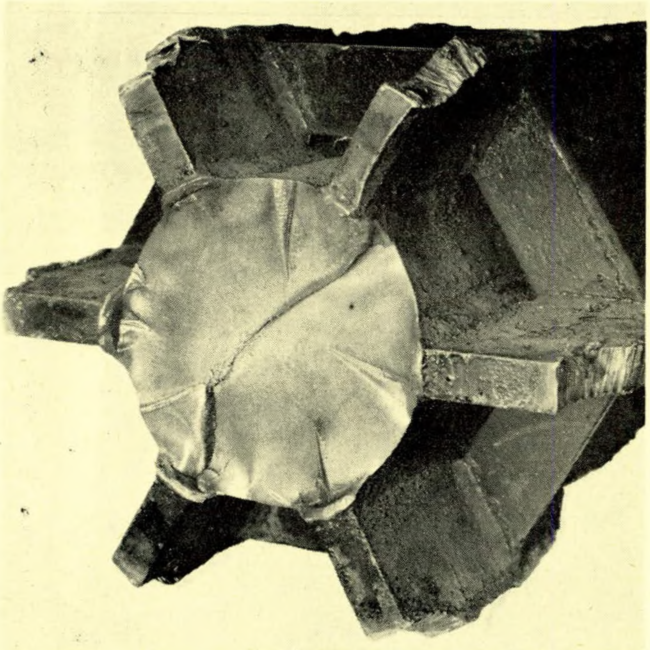


FIG. 35

40 tons per sq. in. No preheating had been used, so one could not really wonder at the welds cracking. The fillet welds securing the axial spider arms to the shaft (Fig. 36) were taken round the end of the stiffeners, as recommended by Mr. Dorrat, he thought, in considering intermittent welding on p. 77. Some people said at the time that that was bad, but he himself thought it was more probably the effect of the high carbon and the lack of preheating which did the damage. He would like to hear Mr. Dorrat's views.

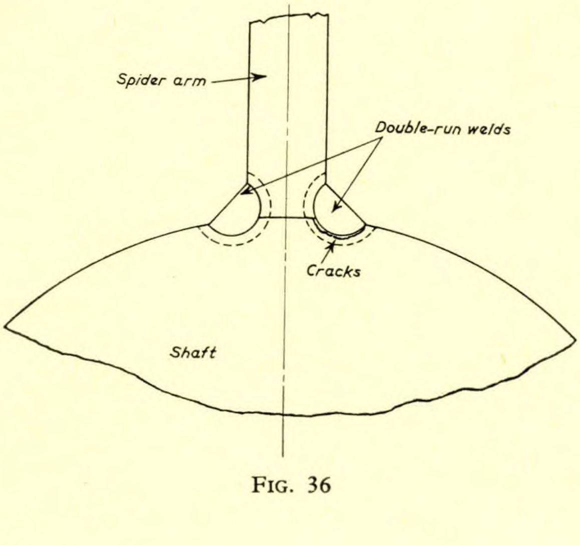



FIG. 36

Mr. Dorrat had said in one place in the paper that there was a temptation to employ castings for the more intricate shapes. He himself rather disagreed with the author's implied preference for welding here. It was his experience that good steel castings would give superior performance, especially under dynamic loading and where access for welding was difficult.

He would like to hear a little more about heat treatment and stress corrosion cracking in relation to boilers and pressure vessels generally. It did seem that if one had a very high locked-up stress in a pressure vessel or pipe, stress corrosion cracking could become a factor under certain high temperature conditions.

Finally, he would like to endorse what Mr. Dorrat had said on the importance of procedure control. They were quite convinced about that at Lloyd's Register, and he felt sure some of the troubles with dynamically loaded welded structures would never have occurred had there been adequate procedure control and had this control been maintained.

MR. H. E. DIXON said that one of the advantages of a lecture that covered a wide subject in a short time was that it gave contributors to the discussion the opportunity of raising points on which they would have liked greater detail. He had attempted to resist the temptation, but hoped the author would excuse him if he asked for a little more information on one or two points or put questions designed to draw him out and obtain a clearer indication of the author's personal views.

At the start of the paper, research work was mentioned which had put both metallurgy and design on a sound scientific basis. This was to some extent a fair statement but there was still a lot more one needed to know about weld metal, even mild steel weld metal. Why were the properties so different from those, for example, of a casting in a similar material? A good deal was known but there was still much to learn.

Higher and higher standards were being required in the welding of thick steel for reactor vessels and they had still much to learn, not only in construction methods but also in controlling weld quality.

The period of empiricism in welding research and development was passing and a more analytical stage had now been reached.

Information on metallurgical considerations was given in various parts of the paper, and this was of particular interest to himself. On fatigue the author had said that for the materials in which he was interested the fatigue limit was proportional to the tensile strength up to 40 tons per sq. in. This was a reasonable comment with the qualifying limitation of up to 40 tons per sq. in., but there was no doubt at all that with alloy steels the position was very complicated. In high tensile steels the fatigue strength was by no means proportional to the tensile strength. Surface finish had a much bigger effect and, using high tensile steels under fatigue loading, did not give the advantages which might be expected from the high tensile strength. Mild steel had much in its favour under fatigue conditions.

Table I, giving the strength of various welded joints in mild steel under fatigue loading, could be taken as a useful indication of the relative merits of various designs but the actual values given for repeating tension and alternating push-pull were open to argument. There were many factors which influenced fatigue strength for particular types of joints so that the assignment of actual values could be misleading.

Mention had been made of the creep behaviour of steel and the development of alloy steels containing molybdenum for creep resistance. It was worth noting that even for mild steel, differences in deoxidation treatment could significantly affect creep behaviour.

The author had discussed stress relieving and heat treatment in general. It was not very long ago when there were considerable arguments about the benefits of stress relieving, whether relief of stress was more important than associated metallurgical changes. There could be no doubt today that the removal of residual welding stresses by heat treatment was of vital importance when brittle fracture was a problem. It was not an operation that could be carried out haphazardly and good process control was required to obtain maximum benefit. Local stress relieving methods were not necessarily a satisfactory alternative to methods in which the entire component was raised to a uniform temperature, and a note of warning should be given.

Mr. Archer had given a very interesting example of a fatigue failure and stress relieving treatment with design changes which sufficed to put things right. He was still not sure stress relieving treatment had a significant effect on fatigue strength or whether the design changes had resulted in the improvement.

In nuclear power there was particular interest in the welding of thick mild steel plates. It was not good enough to specify Class 6 electrodes for the construction without defining the exact electrode. A vast amount of testing was necessary to confirm the optimum electrode for a particular steel. Mr. Archer had rightly mentioned control of electrodes, drying and handling procedures.

This led to the next point: construction. Far more attention must be paid in construction to process control; a knowledge of the suitability of the welding conditions, and that the conditions were not critical, so that small variations in current or welding speed, etc., would have negligible effect, was of prime importance, and of greater importance than the ability to X-ray the weld after the job was completed. Radiographs of welds in very thick plate could be misleading; he hoped he would not be misunderstood, but more emphasis should be placed on process control and the adherence to a properly established welding schedule to produce first-class welds. With plate 3- or 4-in. thick it was a most difficult problem to decide what an X-ray picture meant. It was only by having done a considerable amount of preparatory test work to establish the conditions that a reasonable assessment could be made with the assurance that the job was acceptable.

In some cases one could apply X-ray with reasonable chances of success. In other cases, the manufacturing considerations were such that one had to produce a joint in which there might be thickness variation, or some awkward feature that made X-raying difficult. In such cases, one must rely largely on process control. Magnetic crack detection was useful but it could only indicate surface defects, so again it came back to the need for very good process control.

He would like to hear Mr. Dorrat's comments on process control, X-ray and non-destructive testing methods in some detail, if possible.

MR. R. E. G. WEDDELL said that it gave him very real pleasure to be invited to take part in the discussion, largely because the author and he were old friends and over twenty-five years ago were working together on the development of the engineering of welding. The author was a master of his subject and in the paper he had just delivered was contained a most comprehensive summary of modern welding developments, which, though they had particular reference to the marine field, were equally applicable to other branches of engineering where the craft of welding played an all-important part.

Welding was comparatively new and, indeed, the applications of welding such as were seen in the paper were almost in advance of the general conception of welding as it existed today. The newness of welding tended to cause its abuse rather more than its use. This might seem a strange thing to say, but this country was all too short of Dorrats, with the result that, in general, the application of welding, and the implications thereof, were not fully understood. The Institute of Welding, through their new School of Technology, were endeavouring to overcome this state of impasse but this would take time. It was for this reason that he commended to all users of welding throughout the industry the paper they had just heard. It contained sufficient food for thought to occupy all of them for some time. The comments in the paper were such that they provided to all progressive engineers such stimulation of thought that, if the implications were considered, the craft of welding should have a real leap forward such as it had not known for many years.

He would like to congratulate the marine engineers who, after all, were the only real engineers, for bringing to the notice of other members such an all-important subject so adequately expressed.

Perhaps he might comment on one or two of the points raised.

In the short paragraph on detail design (page 70) lay the secret of the success of welding, and far too little emphasis was placed on the strength of welded joints and so on, also accessibility, with the result that some of the designs with which production was faced were, to say the least of it, impossible. He commended this paragraph to all welding designers!

As Mr. Dorrat had pointed out, all welded design was intimately connected with metallurgy, and a careful study of this, as applied to welding, was absolutely necessary for all engineers.

In passing, it was very interesting to note the use of manual welding as opposed to automatic welding. In fact, the economics of the application of automatic welding made it necessary for all welding firms, however large, to have a nucleus of skilled (all position) manual operators.

As Mr. Dorrat had said, fabrication methods had developed greatly over the past ten years; fundamentally the principles were the same as they were many years ago, but with the advent of production planning and precisioning, new conceptions had had, of necessity, to be thought out. He would draw the attention of all to the various suggestions regarding manipulation, layout, with which the paper dealt so fully. To his way of thinking, the secret was space, and his ideal of a fabricating shop was one of wide open space with all the services either underground or suspended from the stanchions. In this case, of course, the application of shipyard welding plant was considerable throughout all branches of engineering.

His interest in the craft of welding was of necessity that of application, so he would ask members to excuse his commenting on the various specialist details, but he could not conclude without once again drawing the attention of all engineers to the food for thought which this paper provided.

MR. H. CAPPER, B.Sc., said that a paper of this kind, covering a wide field, gave a chance for the specialist to air his views on various particular aspects of it. First of all, the paper was very valuable as an excellent example of a summary of information which would take a tremendous amount of time to extract from literature on the subject, although some of the points made were really standard practice.

However, it could not be expected that such a paper would go too deeply into specialized items, but he intended to enlarge on one which was so important that it should perhaps have been given a little more consideration. This was the question of corrosion fatigue.

No mention had been made in the paragraph on fatigue of the influence of corrosion, which he did not think could be disregarded when dealing with marine machinery. Although one might think it was well tucked away down in the engine room, it must be remembered that large quantities of salt laden vapour in the form of air were blown into the engine room spaces all the time.

Considering Fig. 1, the ordinary fatigue curve without corrosive influence was as shown. If log $N$ was plotted as the ordinate, the point of inflection was sharper and the curve became asymptotic, regardless of the number of cycles of stress. But if a corrosive environment were introduced around the same material, the curve was different. In this case, one was not interested in the number of reversals of stress but rather in the time that the corrosive medium was at work; instead of $N$ (the number of reversals) therefore, $T$ (time) was

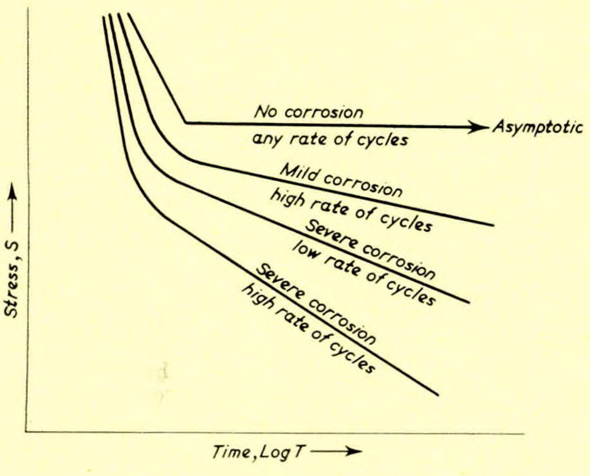



FIG. 37

substituted which did not alter the shape of the fatigue curve where no corrosion was present. When corrosive conditions prevailed, however, the shape of the curve was altered, as indicated in Fig. 37. It would be noticed that as soon as corrosion was introduced, the curve did not become asymptotic and there was no definite fatigue limit. A series of curves for the same material under different conditions of corrosion and rates of stress reversal would probably fall as shown, the worst condition being severe corrosion, say, in sea water with a high rate of stress reversal.

It was therefore very important to bear in mind the effect of corrosion when considering machinery for marine applications. This was certainly the case in Diesel engine frames, even though one might regard the corrosion fatigue in this case as following the upper type of curve, having mild corrosion and a high rate of stress reversal.

This factor was important when considering an ordinary type of fillet joint such as that illustrated in Fig. 8, of which there were many in a Diesel engine frame. The unwelded area shown represented a space into which salt laden air was drawn as the joint moved elastically in service. Once such an electrolyte had been drawn in, the conditions were those associated with crevice attack and could be severe. He thought that cracks which formed in this way were usually the result of corrosion fatigue and this had been found to be the case when some submarine engine frames had been examined. More failures of this sort should be examined metallurgically with this in mind.

He suggested that the corrosive effect would be eliminated in these joints if the exposed ends of the T fillet joints were sealed where possible with a run of welding to prevent the ingress of air. Of course, such conditions did not obtain in a prepared fillet weld such as that illustrated in the fourth type in Table I, which was best in this respect.

He would also like to enlarge on some other points in this paper. With regard to heat treatment (paragraph 2.2.1), the best condition for creep resistance was the normalized condition, and one must try to put in this condition whatever was subjected to creep, although this was not always possible. For pipework with 1 Cr, $\frac{1}{2}$ Mo material, it was best to have it normalized but with the higher alloy steels, such as $2\frac{1}{4}$ per cent chromium, 1 per cent molybdenum, one must temper as well as normalize, because they were of the air hardening variety.

He was glad Mr. Dorrat had mentioned butt welding of pipes. The inserts referred to, which he himself had always known as E.B. root inserts, were put into the root in the form of a shaped ring round the pipe joint and welded with an argon arc torch with argon gas backing. They were extremely good and very easy to use. Welding on top of them for the main runs was a simple matter once one had a sound root.

The new pressure butt welding was briefly mentioned. The best machine had been developed by the Admiralty; it was fully automatic and gave a weld which was better than a Class 1 weld every time. There was no flash on the inside at all, and the contour was extremely good. By now he thought the machine should be on the market.

MR. R. E. MATE thought Mr. Dorrat was to be congratulated on a very adequate summary of the application of welding to marine engineering, but the writer would have liked to see rather more space devoted to the fabrication and welding of pipework which formed such a large part of the manufacture of any marine installation.

In connexion with pressure welding, a process which had been developed over the last few years, it would be interesting to know from Mr. Dorrat whether any satisfactory method had yet been developed for the non-destructive testing of butt welds produced in the manner described in this section of Mr. Dorrat's paper. It was clear that as there was no weld metal forming the joint in a pressure welded connexion, X-ray or gamma ray techniques would be of little value. It seemed possible that ultrasonic examination might be satisfactory, but the author's views on this would be appreciated.

He would be interested to have the author's views on the practical application of automatic welding techniques to the welding of pipe flanges of either the slip-on type or the neck welded type, as an aid to production. The adoption of automatic welding of flanges in this way implied that the flanges must be welded to a pipe in the straight, before bending, and it would be interesting to have the author's views on the economics of such a proposal, bearing in mind the practical difficulty of bending pipes to predetermined shape and dimensions after the flanges had been attached.

He would agree with the author that the type of butt welded flanges indicated in Fig. 24, which provided for a backing ring, which could be machined off after welding, was probably the best arrangement so far devised for the satisfactory attachment of this type of flange. It was implied, however (in paragraph 7.6.2), that gas welding should be used at least for the root run on butt welded joints, but there would appear to be no valid reason why metallic arc welding should not be employed for the whole weld, if a backing ring of the type indicated in Fig. 24 were provided, since any basal cracking would be removed when the backing ring was machined away.

# Author's Reply

Mr. Archer had rightly pointed out the need for the application of knowledge already available on the use of welding and the bridging of the gap between research and practice. In this, the Institute played an important part.

The failure of the fully fabricated reduction gear wheel exhibited a number of factors which might be responsible either singly or collectively for fatigue failure. In this instance, probably the main reason was metallurgical, due to root cracking during welding; this being accentuated by welding 0·32 carbon steel to the exposed core and the rimming steel used for the disc. On the other hand, all conditions were favourable for fatigue failure due to the indeterminate loading introduced by the vibration from the badly cut teeth, the notch effect and the stress concentration induced by the joint design. As the cracks started from the root and did not appear at the surface until after service, magnetic inspection could not prove that none existed. Whilst heating and cooling might spread the cracks, it was less likely than fatigue or unsuitable electrodes to start them.

The desirability of avoiding the intersection of welds was a difficult question to answer, as very much depended upon the conditions under which these were used. For instance, there were many cases, particularly in oil and pressure tight structures, where their avoidance was impossible.

The need for preheating depended on circumstances such as class of material, thickness of sections and type of electrodes being used. From experimental results of investigations on the types of mild steels used in marine engineering and in the thicknesses usually met, it appeared that preheating could be dispensed with, but it was common practice, to give a greater margin of safety, to preheat sections of the order of 3-in. thick.

In new constructions generally, and in those particularly described, the need for grooving did not arise and therefore the author could not speak from experience of any of the new grooving processes.

Very much the same was true of the flash butt welding processes. The general marine engineer seldom had quantities which warranted the introduction of these specialized processes and these problems were therefore outside the scope of the paper.

The welded spider was a very interesting example of the necessity, not only for correct weld preparation, but also for the correct design conception of the welded job as a whole. No doubt, the under bead cracking started the main fatigue crack through the shaft, but the stress concentration due to the abrupt change of section where the ribs joined the shaft was a point that should have been adequately considered in the design stage.

Mr. Dixon's contribution was very much to the point and widened the scope of the contents of the paper. Actually, in dealing with this subject one had, of necessity, to restrict the scope and in so doing probably took a narrower view of the subject than was warranted. Mr. Dixon had rightly pointed out that this narrow view might be dangerous and no doubt had in mind the future when different types of machinery might be used for marine work and therefore the problems would be other than those already described.

The question of procedure control was, as Mr. Dixon said, becoming increasingly important. It did appear to be the wrong attitude to rely on the inspection of welds only after they were completed and then with methods which were not always adequate for their purpose. Obviously, the best practice was to ensure as far as possible that all operations were in line with requirements and the adoption of procedure control practice went some way towards this. Where this practice had been used, experience showed that increased efficiency as well as greater consistency had been attained.

The paragraph mentioned by Mr. Weddell had particular reference to the section dealing with fatigue loaded structures, but as he said it had wider implications. The design of weld preparations deserved more careful study than many realized and this must bear relation, due to the state of the art, to the process being used, the location of the joint, the welding position, the accessibility, and whether the work was being shop or site welded and whether manipulators were to be used.

If the designer understood the physics of the arc, he was more likely to produce effective designs, and so a word in this connexion would not be out of place. The heating effect of the arc was mainly associated with the anode and cathode drops so that most heating took place either at the electrode tip or in the weld crater. The proportions were to some extent under the control of the electrode designer by the choice of core wire, disposition and type of coating.

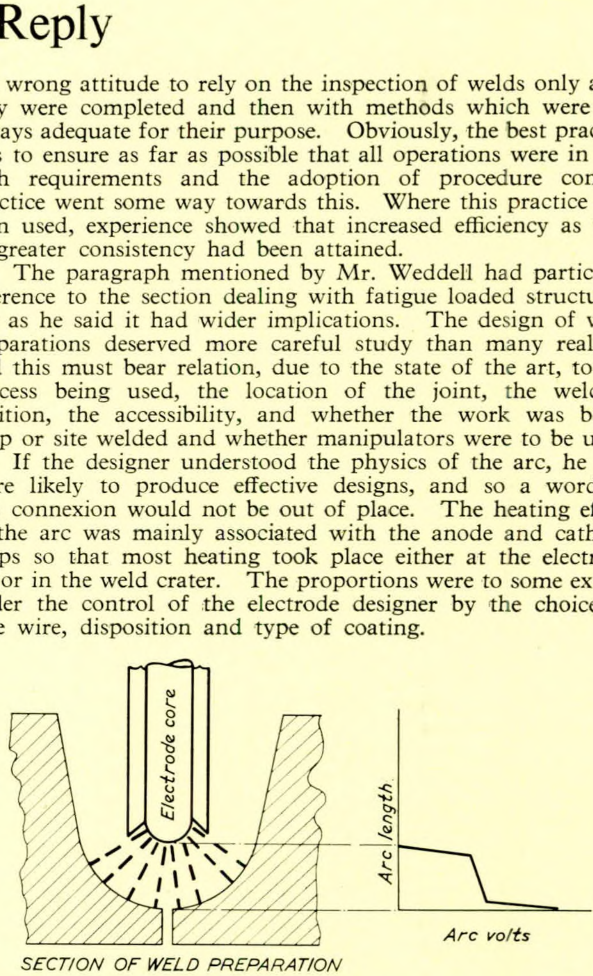



FIG. 38

Referring to Fig. 38, where the arc voltage was plotted diagrammatically against the arc length, it could be clearly seen that a considerable voltage drop took place over a very short distance from the electrode tip, whilst comparatively few volts were accounted for across the arc core and the remaining similar high drop took place over a very short distance in the crater. It could be readily appreciated that physical lengthening of the arc would only increase the arc core voltage and had little effect on the overall voltage, and as the contribution of the core to the heating effect either on the end of the electrode or the crater was comparatively small, little benefit could be expected by variations from optimum arc voltage conditions.

In the case of a.c. electrodes, these voltage drops and heat effects were roughly equal, but with d.c. advantage could be taken of the asymmetry of voltage distribution to give deep penetrating effects with suitable electrode coatings. The arc struck at a point which in the case of arc welding was continually moving over the spherical molten end of the electrode and produced a semi-spherical arc crater. For ideal arcing conditions it was therefore best to start with a radius at the bottom of the weld preparation.

In many cases a compromise was satisfactory and this enabled them to use a straight cut edge for the weld preparation. It must not be forgotten, however, that any deviation from this ideal gave a risk of lack of root fusion, as could be seen from examinations of the macrographs of the typical hand welds shown in Fig. 5.

Another important factor was the symmetry of the joint. Good root fusion could not generally be obtained with a single bevelled edge preparation as this would naturally melt quicker than the solid plate, resulting in uneven root fusion and possibly some slight slag troubles. From that it would be seen that satisfying the ideal conditions was not too easy even in the simplest of joints, and when this had to fit in with the general framework of design there could be quite a number of complications and a compromise must be accepted as inevitable.

The author was indebted to Mr. Capper for his very valuable contribution. As explained earlier, in writing a paper of this type, it was difficult to know just what to include and what should be left out but, as Mr. Capper said, the aspect he had raised was an important factor in marine practice and avoiding trouble from this source could be reduced by "returning" end fillets, a practice which had been advocated for even the simplest of stress conditions.

Mr. Mate's views on pressure welding and subsequent welding inspection were very important. The limitations of their inspection methods were shown up unfortunately only too well by these welds. In this, the importance of procedure control could not be over-emphasized and in producing the correct welding technique a method of inspection which had proved extremely reliable was the old-fashioned one of chipping off the weld re-enforcement. Due to the nature of the process, any weakness that was likely to occur was in the centre of the weld and chipping this tended to show up any such weakness by cleavage of the chipping. As this was not absolutely a non-destructive test, it might not be considered desirable to use it as a routine method of examination and was, therefore, like all other methods of examination, not perfect.

The machine welding of all types of pipe flanges was easy enough providing the relative movement between the automatic head and the pipe could be achieved. The usual difficulty was due to the number of awkward shaped pipes which had to be handled. This made the rotation of these pipes difficult in the case of neck ring flanges with butt welds, whilst in the case of slip-on flanges a more ready solution might be obtained by fixing the pipe with the flange horizontal and arranging to rotate the automatic head round the pipe at the appropriate angle to throw up the fillet weld on the back and then to turn the pipe over with the joint side uppermost and the head arranged to rotate round the job in the vertical position. The decreasing use of slip-on flanges prepared on the back as well as the front, plus the greatly improved machine fillet welding techniques, might help towards making this operation economic.