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Some Aspects of the Manufacture of Large Seamless Steel Tubes and Hollow Forgings

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Synopsis

The paper describes the manufacture of large seamless tubes and hollow forgings by hot piercing and hot drawing, and cold drawing. The advantages of these processes are indicated whether the product is a plain cold drawn tube or a complex steam receiver or boiler drum with integral ends. Details are given of the necessary control of raw materials and the precautions to be taken during billet heating and working, to ensure the production of sound concentric forgings. The wide range of steels to which these processes are applicable is outlined. Diagrammatic illustrations are given which show various stages of the processes.

Introduction

In order to produce satisfactory large seamless tubes and hollow forgings from various steels, particularly alloy and stainless types, many precautions, both metallurgical and mechanical, are necessary to ensure success. The metallurgical and mechanical problems are so interwoven as to be, practically speaking, almost inseparable. During the past ten years great strides have been made in the production and utilization of new alloy steels, many of which have considerable strength at high temperatures and possess marked resistance to corrosion and to scaling. To process such steels new manufacturing techniques have been evolved and old ones improved. This progress has been made possible to a large extent by the collaboration of the metallurgist and the engineer. The process used for the hot working of steel into the tubes and forgings referred to in this paper is a special one consisting of hot piercing and hot drawing. Four plants, each consisting of a vertical press and a horizontal draw bench, are used for these operations and each plant has a different capacity as regards the finished size and weight of forging that can be produced from it. The size and weight ranges covered in steps by the four plants are from 4-inch outside diameter to 54-inch outside diameter and from 100lb. in weight to 20 tons. The paper is a description of the process with some details of the problems arising from its use. The production and properties of cold drawn tubes are also described.

Hot Piercing and Hot Drawing

The process of hot piercing and hot drawing has been used for about 50 years and is still an efficient method for the production of seamless tubes and hollow forgings. It is essential that the broad principles of the process be made quite clear as they have an important bearing on some of the aspects of metallurgical control.

The raw material may be ingots, forged billets, or rolled billets of various sections. Almost any of the standard sections such as squares (with rounded corners), gothics, hexagons, octagons, rounds, etc., prove suitable provided their across corner dimensions or diameters are such as to allow the material to fit snugly into the circular bush for the piercing operation. The sections selected for the various products, whether ingots or billets, are arranged to allow an adequate amount of hot work to be carried out during processing, so as to ensure a satisfactory structure in the final product.

Hot piercing is the first stage and Fig. 1 shows the hot piercing process in diagrammatic form, the letters indicate the various items, and the arrows show the directions of movement. The piercing punch, the circular bush and the bush bottom are warmed and lubricated before piercing. Gas tar or black lead mixed with a carrier have proved suitable as lubricants and are regularly used. The hot solid billet is placed in the circular bush and the piercing punch is forced vertically into it so as to leave a hollow bloom with a solid end of a predetermined thickness. The solid end is necessary to enable the subsequent hot drawing operations to be carried out, as it has to take the thrust of the drawing bar.

The second stage of the process is the horizontal hot drawing, and this is shown digrammatically in Fig. 2. Here again a key is given to the lettered items and arrows indicate the movements. The drawing bar is warmed and lubricated before drawing. Immediately after the piercing operation, the hollow bloom, whilst still at a forging temperature, is placed on the bar in the draw bench and forced through dies to reduce the thickness and diameter. The number of dies used varies according to circumstances such as thickness, length, temperature, etc., but it is usual to use two or three at a time. If the desired dimensions of the forging are not attained during the first hot drawing operation it can be re-heated to a forging temperature and again forced through another set of dies to reduce still further the thickness and obtain increased length. The hot drawing operation can be carried out as many times as is necessary to meet required dimensions.

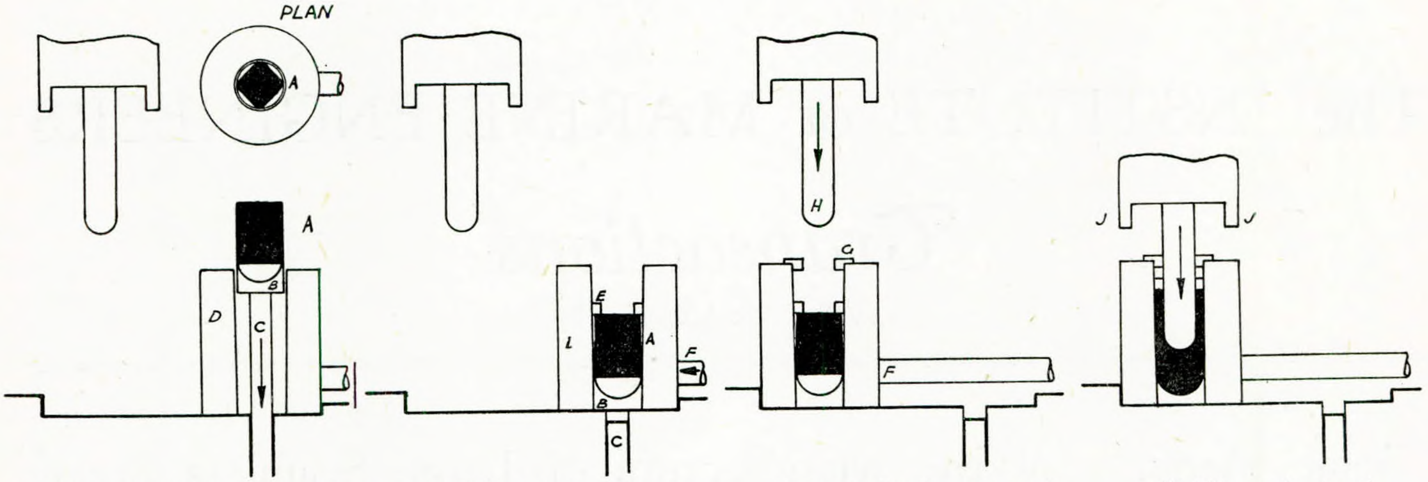
The hot working operations, namely, the piercing and the first drawing involving a considerable amount of forging, are completed in a very short time. The largest of the four plants with which the author is associated is capable of handling billets up to approximately 20 tons each in weight and the time taken to process such a billet, including its removal from the furnace to the piercing press, withdrawal of the pierced bloom from the press, its removal to the draw bench and completion of drawing, rarely exceeds 7 to 8 minutes. Billets of smaller weights are more easily handled and their processing time accordingly less.

The process offers certain advantages, a number of which are detailed below :—

(1) It is economical as regards the weight of steel used and the finished yield obtained.

(2) It is severe on the material and any inherent defects are revealed quite readily. In this respect it acts as an inspector of the material.

(3) The hot work is carried out rapidly and this fact results in the forging operations being completed at a uniform temperature well above the transformation range, thus eliminating uneven stresses during forging and when cooling. This fact

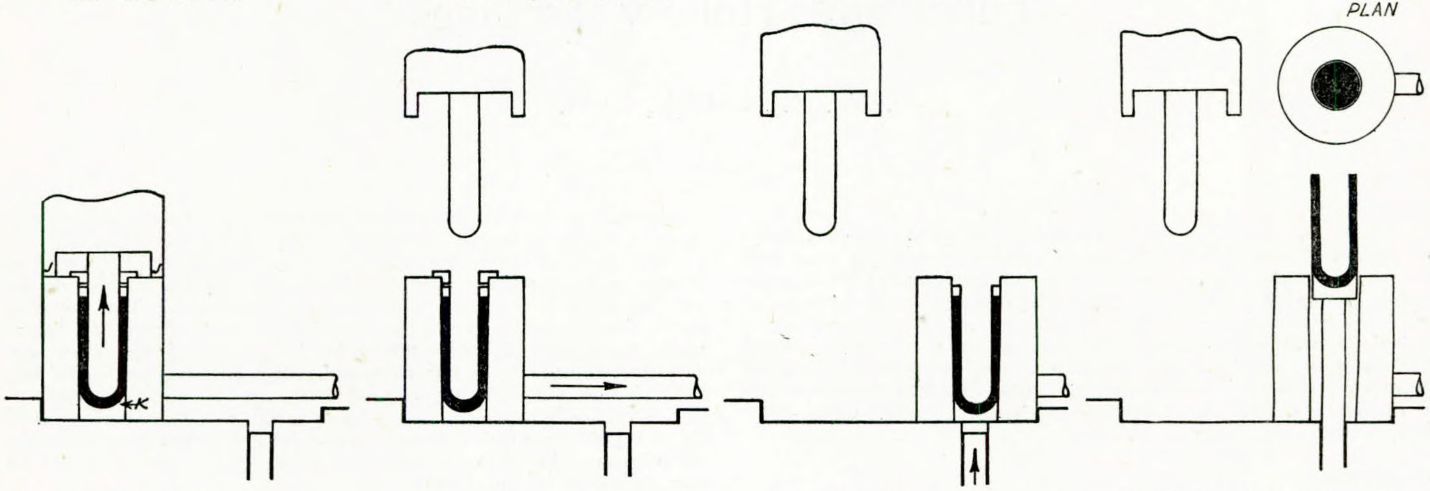


(*a*) Billet on bush bottom and ejector ram being lowered.

(*b*) Billet in bush and traverse ram ready for operation.

(*c*) Matrix directly under punch which is about to descend.

(*d*) Billet partly pierced.



(*e*) Billet pierced to a definite base thickness.

(*f*) Punch withdrawn.

(*g*) Matrix moved to ejector position.

(*h*) Pierced billet ejected.

FIG. 1.—*The hot piercing operation*

A—Billet.
B—Bush bottom.
C—Ejector ram.
D—Bush or matrix.
E—Floating guide ring.
F—Matrix traverse ram.
G—Top guide ring.
H—Punch.
J—Adjustable stops.
K—Base thickness.

is of particular advantage when dealing with alloy and special steels.

(4) The dimensions which can be worked to are such that the machining away of surplus metal is reduced to a minimum, in other words the black forgings can be produced to almost finished sizes.

(5) The shape of the section of the finished forging may be round, square, "D" shaped etc. Although all the hollows are circular in section after the piercing operation, their shape can be altered during subsequent drawing operations. Some sections regularly produced are shown in Fig. 3.

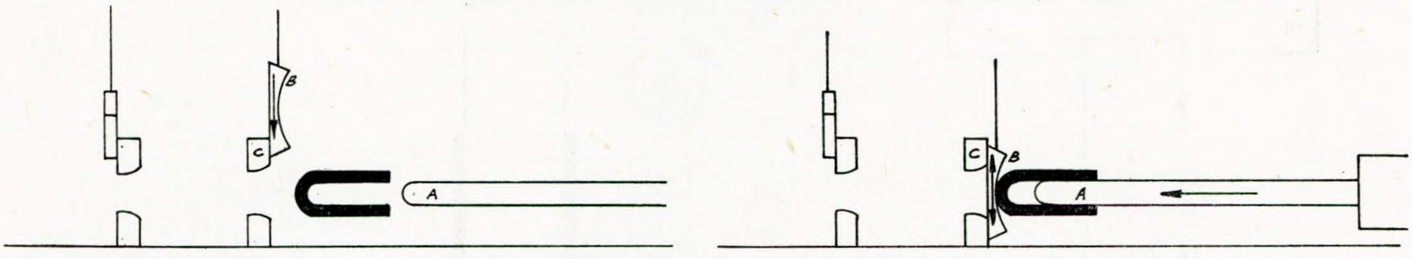
(6) A completed forging has a solid end integral with its walls.

The completion of the process described results in a hollow forging having a solid end integral with its walls and ready for any further operations. Whatever further work is given depends on what the final product is to be. There are many requirements from this stage and as it is not possible to give the details of all of them, procedures are given for two main types of product, namely, forgings for plain cold-drawn tubes, and forgings for boiler drums, steam receivers, etc.

Cold Drawing

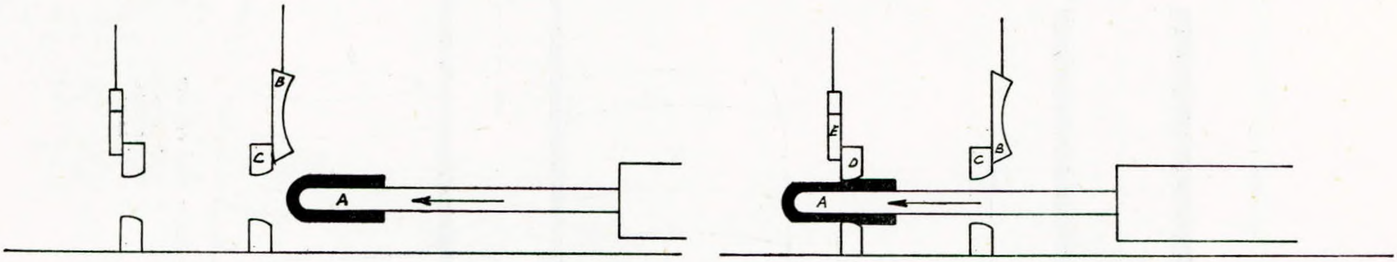
If the forging is intended to finish as a plain open-ended cold-drawn tube it is prepared as follows:—

The solid end is cut off and the open end discard removed. The body of the forging is then softened by heat treating at temperatures suitable to the type of material under consideration. The scale resulting from the heating for forging and heat treatment having been removed by pickling in acid, the clean freshly pickled bore and outside surfaces are examined and any defects present removed by grinding or other suitable means. One end of the tube is "nozzled" by reducing its diameter in a special shaped die. The "nozzling" procedure is illustrated in Fig. 4. At this stage the preparation of the tube before lubricating and drawing depends upon the type of steel from which it is made. If it is a stainless or non-rusting type, special lubricants are used and the drawing carried out as described below. If the tube is made from steel which will rust it is allowed to do so, after which it is lubricated, placed on the drawing bar and given the first cold drawing pass through a die which reduces its wall thickness and increases its length. Since in cold drawing what matters is the relative movement of tube and die, it is convenient on large sizes to push the die over the tube as shown in Fig. 5. After cold drawing it is removed from the bar by reeling, a cross-rolling process that expands the tube off the bar, and this operation is illustrated in the lower part of Fig. 5. This first drawing pass is given to obtain straightness so that the tube can be machined concentric. The machining is carried out not only for concentricity, but to remove any surface imperfections which may be present on the hot drawn surface, and to allow a thorough inspection to be made. After machining it is again softened, pickled, rusted if applicable, lubricated, and given a further cold pass. As many cold passes as may be necessary are given with softening, pickling, examination, etc., between the passes. Sometimes consecutive cold passes are given i.e. no softening, pickling, or rusting is carried out between the passes, but in such cases special pro-



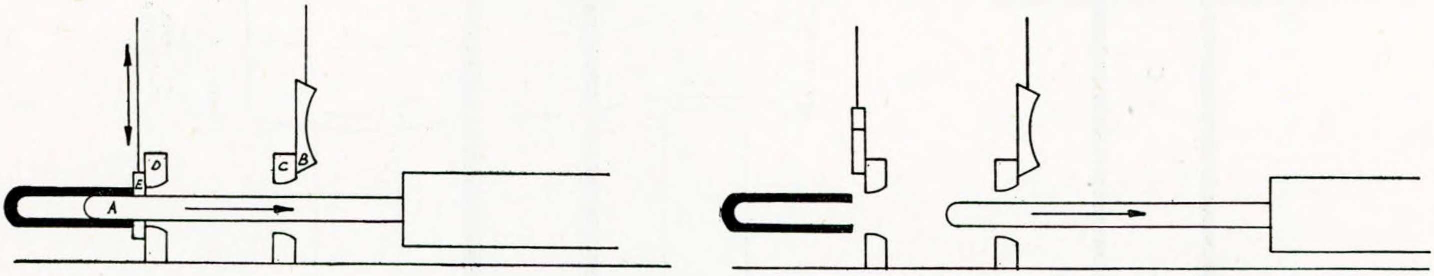
(*a*) Forging in position for insertion of drawing bar.

(*b*) Blank die lowered and bar being pushed into forging.



(*c*) Forging on the bar and blank die removed.

(*d*) Forging drawn through first die and partly through second die.



(*e*) Forging completely drawn, stripping device inserted, bar being withdrawn.

(*f*) Forging drawn and bar completely removed.

FIG. 2.—*The hot drawing operation*

A—Drawbar.
B—Blank die.
C—First drawing die.
D—Second drawing die.
E—Stripping device.

cedures are adopted for lubricating the tubes. The steel hardens during the cold drawing, and unless special methods of lubrication, such as lead coating or phosphate coating plus a lubricant are used, it is necessary to soften before giving a further cold pass. To give consecutive passes is quite a problem because of the increase in hardness that occurs during the cold drawing, and this means that more power will be required to give the next pass. Greater pressures will be created between the tube and the tools and more frictional heat will be developed, which means the risk of the lubricant breaking down is considerably increased due to the higher temperatures and pressures. If the lubricant does break down and the tube comes into contact with the drawing tools "pick up" occurs, i.e. the small areas that come into contact with each other, weld together. To avoid pick up it is essential that the lubricant does not break down and the methods adopted to enable consecutive passes to be given are as follows :—

Tubes made from ferritic steels are phosphate coated by immersing them for a given time in a bath containing a hot solution of special salts. Chemical action takes place and the bore and outer surfaces of the tubes become coated with phosphates. These coatings, although very thin, are firmly bonded to the surfaces and are porous. The lubricant is then applied to the coated surfaces, and owing to the porosity penetrates into the coating, in other words, a key for the lubricant is created by the phosphates. Tubes prepared in this way can be given consecutive passes, and it is quite normal to give two passes using soap as the lubricant.

Austenitic steels are difficult to cold draw, moreover, they cannot be prepared in the same way as are the ferritic steels because they resist rusting and the action of phosphating salts. The ordinary standard lubricants in successful use with ferritic steels are not suitable for the austenitic types even for a single cold pass. Special combinations of lubricant have been used successfully for single passes, and metallic coatings have proved satisfactory for consecutive passes. It is quite normal to give, say, three consecutive passes when using lead as the lubricant. When all cold work is finished the lead is removed by pickling in nitric acid, after which, final heat treatment, examination, testing, etc., are carried out.

Tubes of a very high quality finish in sizes impracticable by hot working alone can be produced economically by cold drawing. For example, it would not be an easy matter to manufacture seamless tubes, say 24-inch diameter by $\frac{3}{8}$-inch thick walls by 20-feet long, by any hot process without making a forging thicker than $\frac{3}{8}$-inch and machining away the surplus metal to obtain the finished thickness. Such production would be difficult and costly. Because of weight limitations it is often necessary to produce thin tubes or cylinders which have to work under strenuous conditions at extremely high pressures and in which the wall stresses are very high. Such tubes or cylinders have to be made from high tensile steel, and their surface finishes have to be of a very high standard, i.e. contain no laps or similar surface imperfections which would serve as local stress raisers. For example, tubes or cylinders for use in aircraft, where a saving in weight is very important, have to be as thin as possible and yet withstand arduous service conditions. Cold drawing makes such production possible. Some advantages of cold drawing are :—

(1) It is a method by which tubes can be produced in sizes that would be impossible, or at any rate uneconomic, by hot work alone.
(2) Close tolerances on diameters and thicknesses can be achieved. Eccentricity and ovality can also be kept to a minimum.
(3) The inside and outside surface finishes are very good thus facilitating repeated inspection of the tube, and ensuring that the surfaces are free from any blemishes that might in subsequent service accentuate mechanical or chemical breakdown.
(4) The process is severe and hidden weaknesses in material are

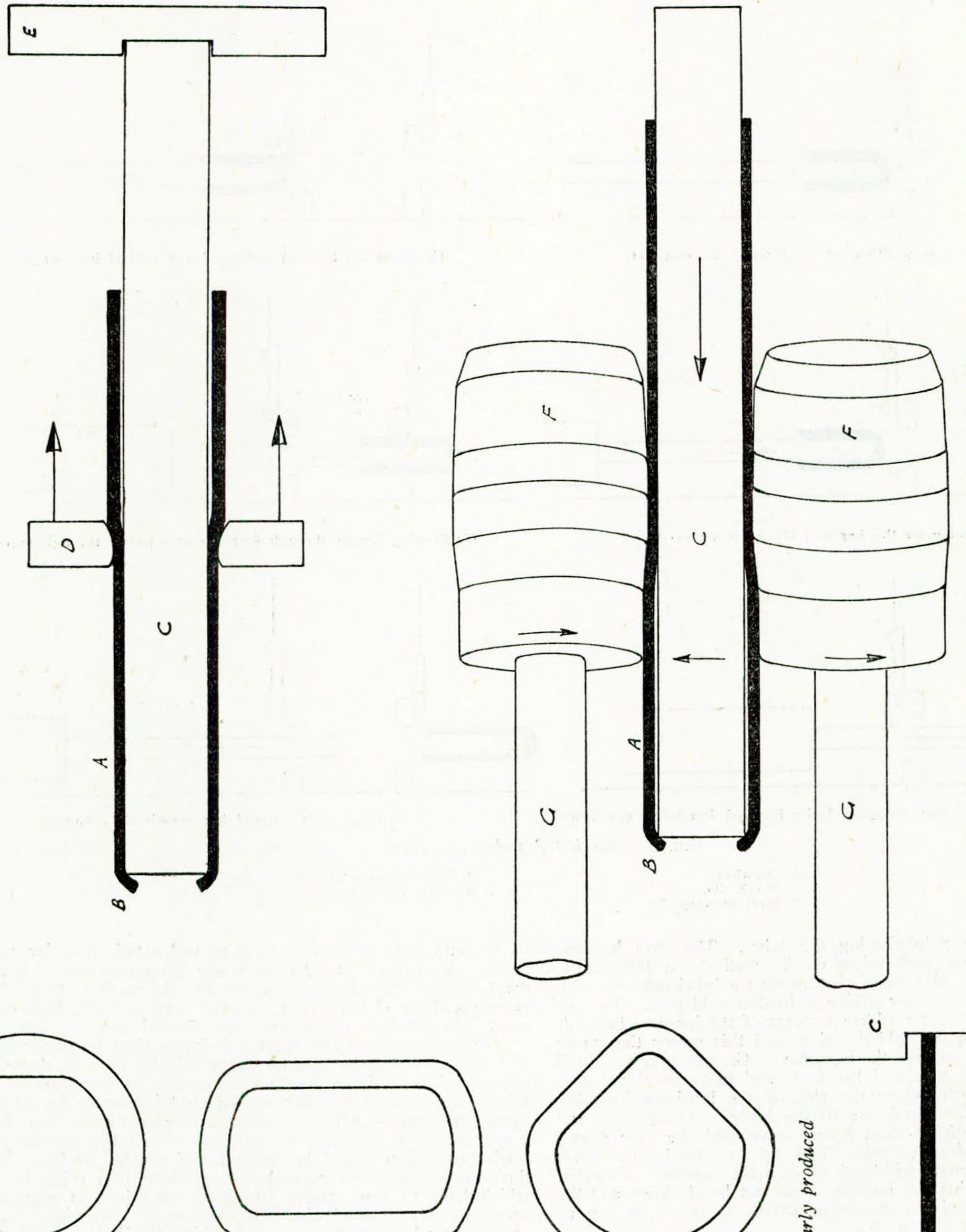


FIG. 5.—*Cold drawing and reeling*

A—Tube.
B—Nozzle.
C—Drawing bar.
D—Die.
E—Back stop.
F—Reeler rolls.
G—Roll axles.

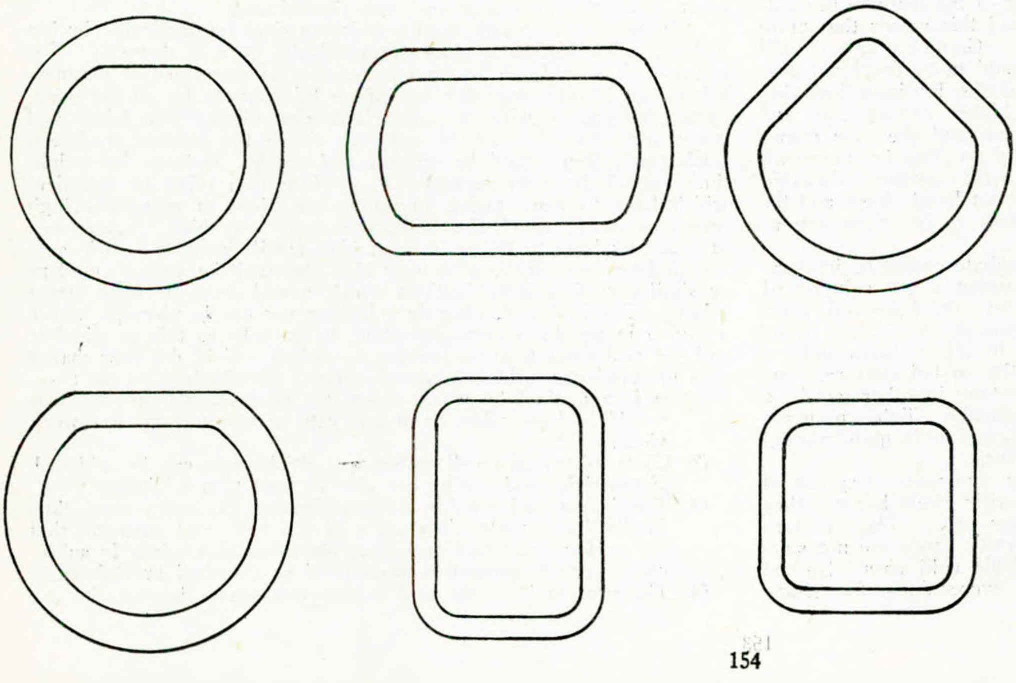


FIG. 3.—*Sections regularly produced*

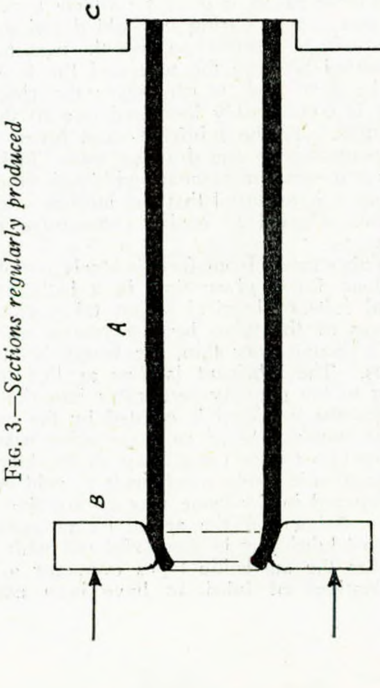


FIG. 4.—*Nozzling for cold drawing*
A—Tube. *B*—Nozzling die. *C*—Back stop.

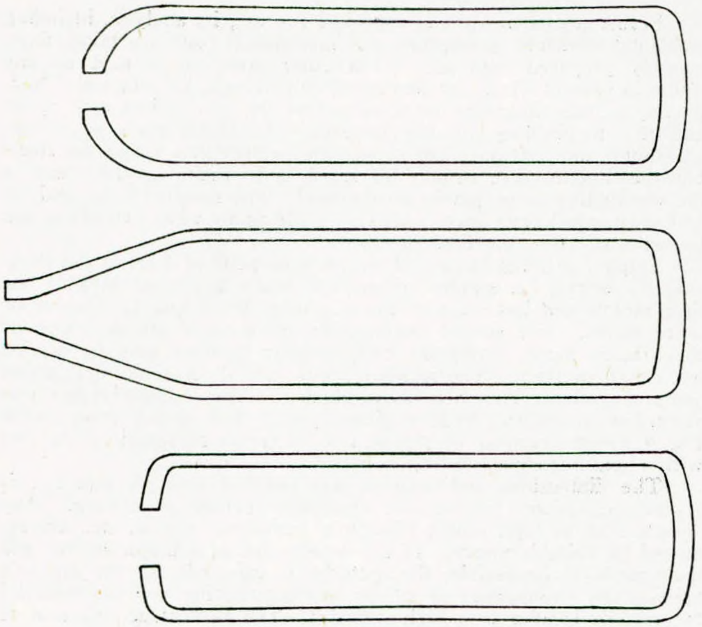


FIG. 6.—*Typical shapes of closed ends*

revealed. It is necessary to use high quality materials.

(5) Cold drawing can prove useful in many cases because of the increase in the yield and tensile strength of the material. Where close tolerances and a high yield point are required from plain carbon steels, low alloy steels, and stainless steels, this method is particularly good, giving mechanical properties that are not obtainable by hot work or heat treatment.

Production of Steam Receivers and Boiler Drums

If the forging is to finish as a steam receiver or boiler drum, the following is the usual procedure.

The solid end will be required and the open end will have to be closed in. Some shapes of closed ends are shown in Fig. 6. Any necessary boring and turning is completed before the closing in of the open end. The wall thicknesses and base thicknesses are also checked. The closing of the open end necessitates preparatory machining and further hot work using special shaped tools.

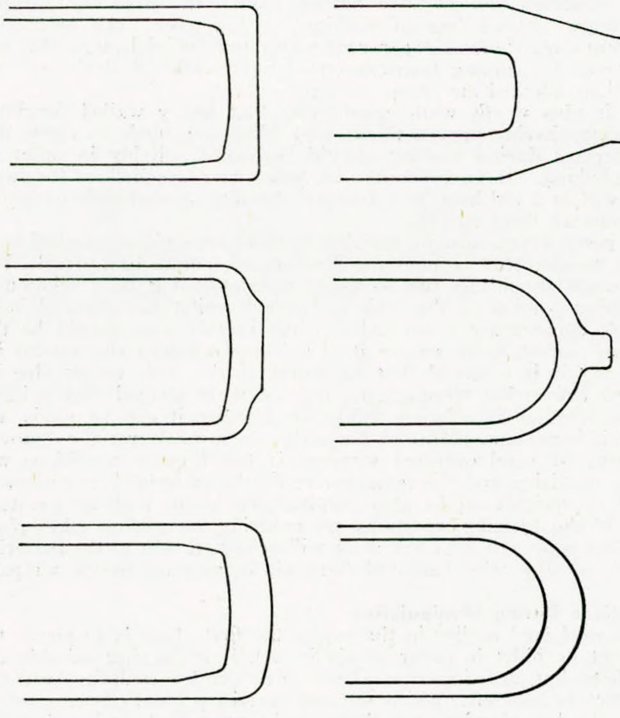


FIG. 7.—*Typical shapes of solid ends*

The forging is then heat treated to give the desired mechanical properties. The heat treatment depends on the type of steel, and the stage at which it is applied varies according to circumstances; for example, if attachments are to be welded to the main body of the forging, the ideal way would be to apply the full heat treatment after all welding is completed. This is not always possible owing to the complicated shapes of the attachments and the distortion that may occur during a high temperature heat treatment such as normalizing. The removal of the scale formed during this heat treatment would also be a problem. In such cases the forging is normalized before the fittings are welded on and a stress relieving or tempering treatment given after welding. Finally machining, inspection, testing, etc., are completed.

One of the advantages of the hot piercing process is that the solid end is integral with the walls of the forging. The solid end can be left any thickness or shape required and some examples are given in Fig. 7. Such an end has many useful applications; for example, it can form one of the closed ends of a high pressure container, or as already stated, be used for one end of a boiler drum or steam receiver. It may, of course, be machined, drilled, etc., for manholes, bolts or other fittings.

Much experimental work has been carried out on large diameter solid ends of varying thicknesses to ensure that the grain flow and the mechanical properties are satisfactory, and that they are suitable for service conditions. The grain flow of an ellipsoidal shaped end is shown in Fig. 8. It will no doubt be realized that after the piercing operation, the solid end receives no further hot work, but mechanical tests taken from almost every possible position and direction indicate its suitability for strenuous service conditions.

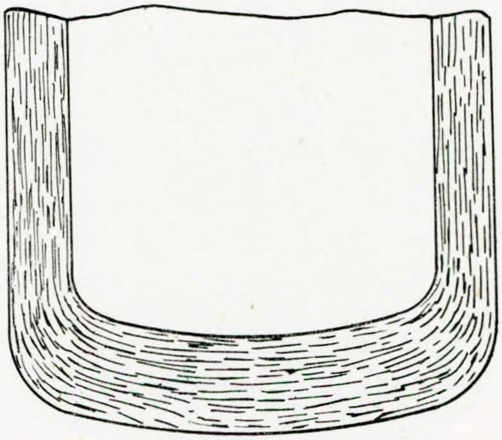


FIG. 8.—*Grain flow in ellipsoidal base*

As will be seen from the illustrations shown in Fig. 7 the solid ends are often of heavier section than the walls, and this means that when cooling from, say, a normalizing temperature the thicker portions will cool slower than the thinner ones. Under such conditions it is natural the mechanical test results will be slightly different. The actual test results obtained from material cut from the centre of the thickness of solid ends show that there is a slight reduction in tensile strength and elongation value, when the figures are compared with those obtained from samples cut from rings taken from the open ends. The slight reduction in tensile strength is due to the slower rate of cooling, whilst the lower elongation is no doubt caused by the smaller amount of hot work together with the slower rate of cooling. Such reductions in test values are quite normal when dealing with thick and thin sections, and the phenomenon is known as "mass effect". Plain carbon and low alloy steels are more prone to mass effect than are the higher alloy types such as nickel-chromium-molybdenum and 3 per cent. chromium-molybdenum. Thousands of solid ended forgings made from carbon and various types of alloy steels, including highly alloyed steels, have been in service for many years, and have given every satisfaction.

Control of Raw Materials

As almost all the products with which the author's firm is concerned are pressure vessels in some shape or form including many for high temperature service, it will be realized that strict control of the raw material is very necessary.

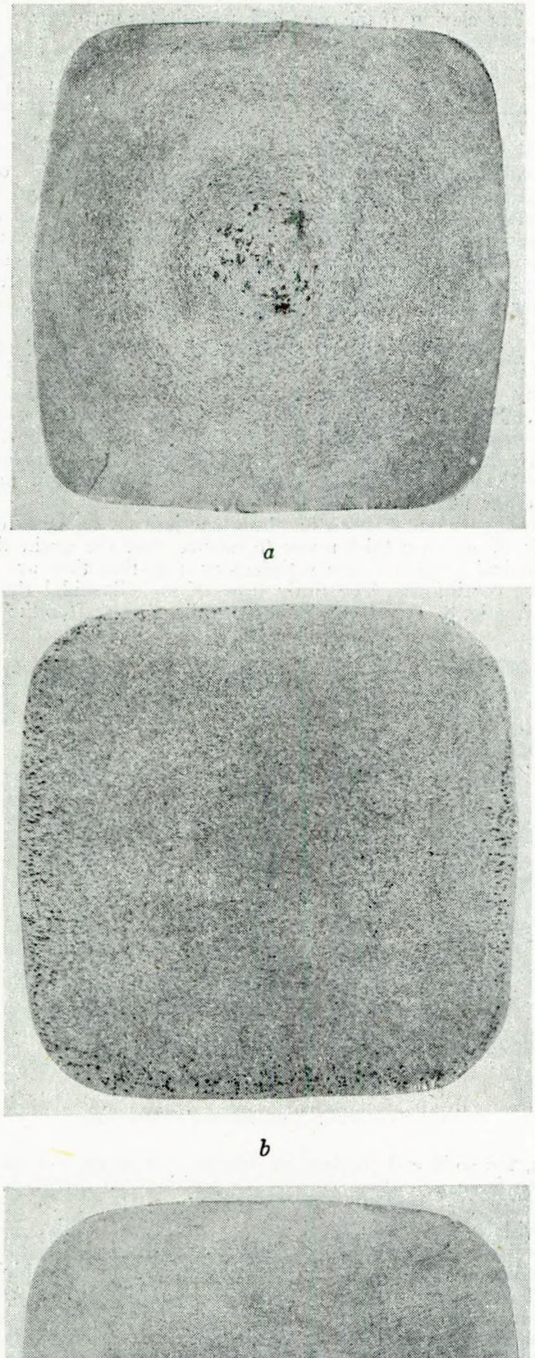


FIG. 9.—*Examples of* (*a*) *piping,* (*b*) *fringe segregation, and* (*c*) *a satisfactory specimen*

Before a cast of steel is approved for use, its analysis, including incidental elements, is checked and mechanical tests are taken from suitably prepared material. Particular attention is paid to any elements present which can be classed as residuals, i.e. not added purposely, as they influence to some extent the mechanical test values and the forgeability of the material. Residuals such as nickel, chromium, molybdenum, and copper are present in most of the steels but the amounts are usually so small as to make no difference to the workability or properties of the steel. The results of the analysis and mechanical tests give a reliable guide as to what properties can be expected from the final product.

Sulphur printing is carried out on most casts of steel at the steelmaker's works, i.e. sulphur prints are taken from the tops of the first, middle and last ingot of the cast when there are, say, twelve or more ingots. For special purposes or when there are only two or three large ingots from one cast, sulphur printing may be carried out on all of them. The sulphur prints indicate sulphur distribution and segregation. They also show whether sufficient material has been discarded to ensure freedom from piping and major segregation. Fig. 9 shows examples of piping, and of fringe segregation, together with a satisfactory specimen.

The dimensions and weights are checked and all material is visually examined for surface conditions before processing. Any defects such as laps, roaks, refractory inclusions, piping, etc., are removed by suitable means. If the defects are of a major nature and their removal impossible, the material is rejected. In the author's opinion the steelmakers of to-day are outstanding and the material they supply is of a very high standard. The percentage rejection of unsuitable material is extremely small.

Heating of Raw Materials

When heating large masses of steel there is danger of "clinking" occurring if the rate of heating is too rapid, and the larger the mass the greater is the danger. The thermal stresses set up by attempting to heat large ingots or billets rapidly may be very high, and it is necessary to charge such sections into the cool end of a furnace, the temperature of which is not more than, say, 200 deg. C. The usual method is to use a bogie type furnace. The temperature gradient of such a furnace is from approximately 200 deg. C. at the charging end to approximately 1,250 deg. C. at the discharging end, and the rate at which the material is moved through depends upon the length of the furnace and the actual temperature gradient. Normally the material is charged at the cool end, allowed to become warm, and then moved slowly through the furnace until the temperature has been increased to approximately 700 to 800 deg. C. After reaching this stage its passage through the furnace is speeded up as it is then in a plastic condition and may be heated more quickly to the forging temperature without fear of clinking. Alloy steels such as nickel-chromium-molybdenum, 3 per cent. chromium-molybdenum, etc., are more prone to clinking than carbon or lightly alloyed steels and the precautions adopted are more stringent.

It is also worth while mentioning that heavy walled forgings, or forgings having uneven thicknesses which are likely to cause uneven stresses during cooling, should be cooled suitably in order to avoid clinking. It is sometimes necessary to place hollow forgings, whilst still at a red heat, in a furnace standing at a suitable temperature and cool them slowly.

It is not a practical proposition to heat large pieces of steel to a forging temperature without the formation of quite heavy scale, but the furnace should be run so as to reduce scaling to a minimum. The major portion of the scale is formed whilst the material is in the high temperature zone, and its time in this zone should be the minimum necessary to ensure it is uniformly heated throughout its mass. As it is essential that as much of the scale as possible be removed before hot piercing, the type of scale formed during heating, i.e. whether it adheres firmly or whether it can be easily removed, is important. Most of the scale can be fairly readily removed by means of hand operated scrapers if the furnace conditions are slightly oxidizing and the temperature of the material is not allowed to cool appreciably whilst at a forging heat in the high temperature zone. If the furnace conditions are reducing, or cooling takes place in the hot zone, much of the scale will adhere firmly to the material, and only small patches here and there will be removed by the scrapers.

Precautions During Manipulation

As explained earlier in the paper, the first stage is to pierce the hot ingot or billet in order to obtain a hollow forging suitable for immediate hot drawing operations. Any faults such as eccentric walls, hot breaks, etc., which without certain precautions may occur during the hot piercing, are likely to be magnified during first hot drawing operations, and as this is the case, every effort is made to obtain a sound concentric hollow before beginning hot drawing. Many forgings have their bore diameters increased immediately after hot piercing and this is accomplished by using a drawing bar having a larger diameter than the bore of the forging. The forging is placed against a cup tool and the bar is forced into it, thus increasing its diameter. If the walls are eccentric it is easy to see that the thinnest portion, being also the weakest, will become thinner still during the expanding operation, and if any hot breaks are present they will most probably have their lengths and depths increased due to the concentrated stresses which will be set up during hot drawing.

It will be realized from the foregoing that it is extremely important to obtain a good sound concentric hollow during the hot piercing, and to accomplish this the following precautions are necessary:—

(*a*) Before piercing it is desirable to remove as far as possible the scale formed during the heating of the ingot or billet. If some scale is left adhering to the material it becomes trapped and pressed in during the actual piercing, thus automatically reducing the wall thickness at those places. If the scale breaks away from the flat sides of the material during piercing, it falls to the bottom of the bush and becomes pressed into the solid end. These effects are illustrated in Fig. 10.

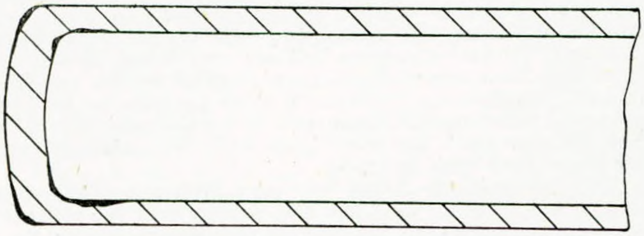


FIG. 10.—*Depressions due to entrapped scale.*

(*b*) The material must be at a uniform temperature throughout its mass. If an ingot or billet is hotter on one side than the other, the wall thickness will vary as shown in Fig. 11. If it is warmer on the outside than the inside, i.e. not sufficiently soaked, hot tears may occur due to uneven flow.

(*c*) The material when at the forging temperature, should be a good fit in the circular bush, i.e. its diameter or across corner dimensions should be such that the clearance between the material and the bush is as small as can conveniently be accommodated under working conditions. The co-efficient of expansion of the ferritic and austenitic types differs quite appreciably and this fact is taken into account when determining the sizes required. Some effects of ill-fitting material are shown in Fig. 12.

(*d*) The loads imposed on the piercing punch must not be sufficient to cause bending of the punch. This may occur when using a small diameter punch to pierce heat resistant material and eccentric forgings will be the result.

(*e*) The top and bottom faces of the material should be cut quite square, i.e. at 90 deg. to an axis through the length. If the faces are not 90 deg. it is certain that a long side will be the result, with some waste of metal when the open end discard is removed. It is also possible that some eccentricity will occur due to the punch wandering and bending. This effect is shown in Fig. 13.

(*f*) It is obviously necessary that the tools be truly aligned. The piercing punch and the bush must have a common axis or all the forgings will be eccentric. As there is some float in the crosshead of the press carrying the punch, guide rings are necessary to locate it centrally in relation to the bush. The clearances allowed on the guide rings should be as small as is conveniently possible.

(*g*) Hot breaks may be caused bv attempting to give more work than the material is capable of absorbing. They may also be due to the tools being too cool, or unsatisfactory application of the lubricant. Breaks may, of course, be caused by hidden defects such as massive refractory inclusions, porosity, laps, etc., in the material, or by using incorrect forging temperatures.

Range of Materials Manipulated

Practically all types of steels can be satisfactorily manipulated by this process, including some which are extremely difficult to forge by any other method. Non-ferrous alloys such as bronzes, aluminium bronzes, high nickel alloys, silver, etc., have also been successfully pierced and drawn.

The types of steels which have been processed can be classified as follows:—

Group 1.

Carbon steels.

Low alloy steels, such as carbon-molybdenum and chromium

FIG. 11.

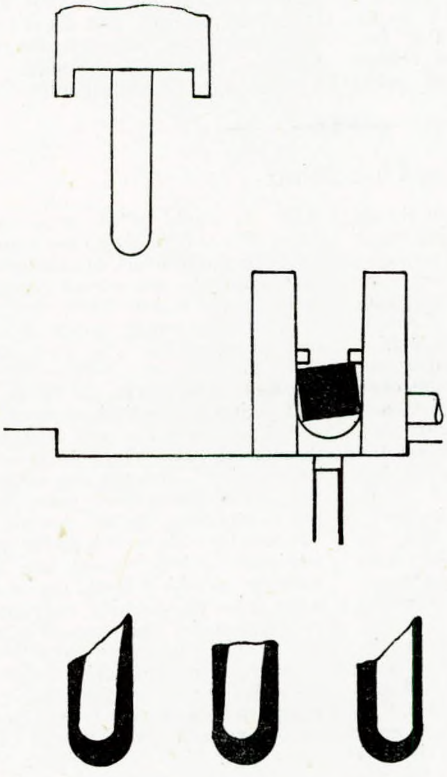


FIG. 12.—*Ill-fitting billet lying askew in the bush bottom*

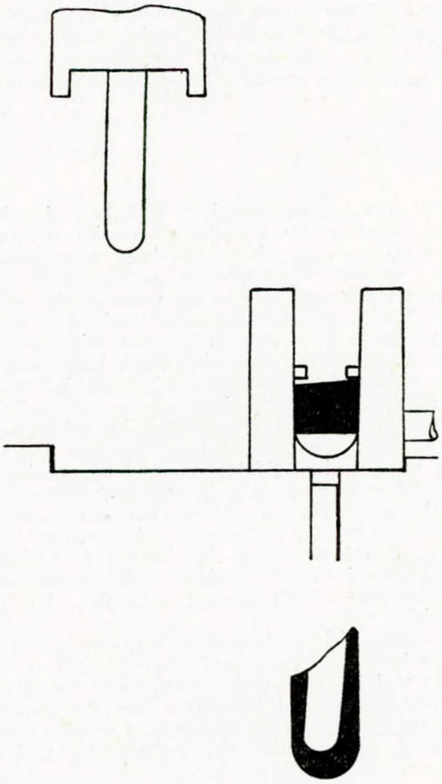


FIG. 13.

molybdenum types for use at elevated temperatures.

Other low alloy steels including carbon-manganese, chromium-molybdenum and nickel-chromium-molybdenum steels.

Group 2.

Higher alloy steels including chromium-molybdenum, nickel-chromium-molybdenum, manganese-molybdenum and high carbon-chromium bearing steel.

Group 3.

Heat resistant chromium steels and stainless irons.

Group 4.

Austenitic stainless steels of practically all types including heat resisting and corrosion resisting steels.

Group 5.

Special steels such as those used in jet engines and gas turbine air heaters and heat exchangers.

These steels include the cobalt-bearing types.

Broadly speaking, each type of steel requires its own particular forging temperature and precautions. The amount of hot work which can be given, the cooling and heating problems, scale formation and resistance to de-formation vary according to the type of steel. Brief particulars of these factors are given below.

The carbon steels, low alloy steels, etc., under Group 1 are readily hot and cold worked. The temperature range in which they may be forged is quite wide, being of the order of 200 deg. C. and they easily scale during heating. After forging, no special precautions are required during cooling unless the forging has thick and thin sections or is extremely massive.

The higher alloy steels under Group 2 work quite well either hot or cold, but require special care during heating and cooling, particularly if the sections are large ones. Most of these steels air harden to some extent, many of them quite strongly, and unless the heating and cooling rates are properly controlled clinking may occur. The forging temperature range for these classes is still quite a wide one, being of the order of 150 deg. C. Scale readily forms, but to a smaller extent than with the steels under Group 1.

Group 3 includes the high chromium steels and stainless irons. Considerable attention is necessary during the hot working of these steels as they are quite strong at the forging temperatures. Great difficulty is experienced in cold working the high chromium steels unless small amounts of nitrogen are present in the steel. The nitrogen prevents to a large extent the excessive grain growth which occurs in such steels when heated to forging temperatures, and this fact materially assists cold drawing operations. Scale does not readily form as such alloys are to a large extent heat resistant, and owing to their strength at high temperatures the forging range is restricted to about 100 deg. C.

The austenitic stainless steels mentioned under Group 4 are extremely difficult to hot work and are not easy to cold draw. Most of these steels contain added elements such as tungsten, titanium, columbium, molybdenum, silicon, etc., to give them special properties, and their structures are often complex. It is this complex structure which causes trouble during hot working. By altering the balance of the nickel and chromium contents it is possible to obtain a structure practically free from ferrite, and such a steel hot works much better than one containing austenite plus ferrite. As such steels are strongly heat resistant, scaling is not a problem, neither is the cooling and heating of this material. The resistance of these steels to hot-deformation is very marked and they do not take kindly to large amounts of hot work per pass. The forging temperature range for these steels is quite a narrow one being approximately 80 deg. C. It is very desirable that all forging is done within a range of, say, ±50 deg., and as this is so, it will be realized that the hot piercing and hot drawing process is ideal for such work.

Up to the present time no large tubes or hollow forgings have been produced from the cobalt-bearing high-temperature service steels mentioned in Group 5 by piercing and drawing. Satisfactory hollows of up to approximately 3-inch diameter have been made by extrusion and afterwards successfully cold drawn. Although these steels have complex structures and are very strong at the forging temperature, their forgeability is good, provided suitable temperatures are used. Much power is needed to make the material flow but no exceptional difficulties were met with during the production of these small diameter tubes, and there is no doubt that tubes of considerably larger sizes could be made.

The author is not certain why steels with such complex structures should forge so well, but it is thought that the changes that occur during heating to the forging temperature render the steel single-phase. As one would expect, the forging range for steels of this type is quite narrow, and here again it is desirable that the hot work be completed within a small temperature range. Such steels stiffen up rapidly and become almost unforgeable if the temperature drops, say, 50 deg. below the normal forging temperature. Extrusion is a very rapid forging operation and seems to offer the best chance of making tubes from such steels because all the hot work can be completed within a very narrow temperature range.

Many details associated with the various procedures have been omitted as it is not possible to give them all in a paper of this nature. It will be realized that the position as regards tube making is constantly changing, and in order to keep up with modern developments, continual research is essential. It is hoped it may be possible to add to this paper at some future date.

Discussion

Mr. W. J. Ferguson (Member) said the author had given a simple exposition of what was a major production undertaking with many inherent complications. Some had been mentioned, but the Institute now had a unique opportunity of getting further information. One of the many items produced by the process—the boiler drum or steam receiver in which the solid end was retained—was an item of major interest to engineers. The author had said that a slight reduction in tensile strength and elongation must be expected on samples cut from the solid end as compared with samples taken from the open end. Some idea should be given of the order of this reduction, and to what extent it could be remedied by subsequent heat treatment. The information would be helpful because the paper stressed the fact that any required thickness could be provided at the end, but obviously there was no point in adding unnecessary material. Incidentally the mass effect would be increased by an increase in thickness. It was necessary to know to what extent the inferior material properties should be offset by increased thickness of the solid end. It appeared that the author would recommend full heat treatment in the case of all important forgings but perhaps he would confirm this.

In the case of large important forgings it was customary to take tests from both ends in order to get a check on possible variations at the top and bottom of the ingot, but a vessel with a closed end presented difficulty, and he would like the author's comment. It might be said it was quite unnecessary to take tests from both ends of the vessels under notice, but if the author took this view then no doubt his opinion would be backed by the experience of consistent test results, details of which would be of interest. Perhaps what worried the engineer more than a slight reduction in tensile strength and elongation was the difference in structure of the solid end and shell. It would be of value to have a metallurgical opinion on the effect this was likely to have during service.

The question of sulphur printing would seem to be very important when the hot piercing method was employed. In the case of large drums it was often necessary to use a complete ingot, and in such cases it would appear advisable to take a sulphur print from each ingot.

Rear-Admiral (E) G. H. H. Brown, C.B.E. (Vice-President) said that owing to the limitations of his knowledge of the subject he was afraid he could not add anything very useful to the discussion, but there were one or two points on which he would like a little more information. In connexion with the cold drawing process it appeared that some importance was attached to rusting the hollow billet before drawing, in the case of steels which were of rustable type. Presumably this was intended to serve as a vehicle for carrying the lubricant, and he would like to know more about that, and also whether anything could be done to accelerate the process where more than one drawing operation was required.

Where the steel was of a non-rustable type the author had said that special lubricants were used. No doubt those lubricants were of a graphitic type which might lead to some diffusion of carbon in the outer layers of the tube, particularly where steels were of the austenitic low carbon type. He would like to know more about that also, because it was a matter of importance to be able to prevent or remove the high carbon layer.

The author had mentioned a large amount of experimental work that had been done. He himself recalled some trouble that had occurred about twenty years ago in connexion with the manufacture of gas cylinders. Difficulty was experienced owing to the formation of splits in the walls while under test. This occurred when the grain flow of the original billet was in the same direction as that of the piercing operation, and attempts were made to get over this by piercing at right-angles to the grain flow, but this proved no more successful. Eventually the problem was solved by subjecting the heated billet prior to piercing to a twisting process through 720 deg. of angle, and that overcame the difficulty.

In connexion with the production of steam receivers and boiler drums the author had stated that it was in the thicker portions that the reduction in tensile strength and elongation occurred. Presumably the reduction in elongation was due to the greater grain size of those thicker portions.

Dr. L. W. J. Newman (Visitor) said he was somewhat diffident about raising a point which interested him in the manufacture of steel tubing because the subject was of so specialized a nature. He was concerned with the design and development of pressure vessels of a special kind, namely rockets, not the guided missiles of press button warfare, but the everyday type of rocket used for throwing lines for the purpose of life-saving, for assisting in the take-off of aircraft, and the many other uses for which rockets were now being employed. Rockets had to be produced in very large numbers, particularly in war-time, so that cheapness and ease of manufacture were a prime essential. The accuracy of the usual steel rocket depended to no small extent on the straightness and uniformity of the tube which was subjected to surface temperatures of the order of 2,000 to 3,000 deg. F. He would therefore like to ask the author the following questions:—

Could the usually quoted tolerances of wall thickness be decreased so that a designer could produce designs with a minimum of excess weight, for upon the amount of weight depended the efficiency of the rocket as a weapon, if not as a pressure vessel? The avoidance of expensive machining operations to achieve that uniformity was most essential.

Could tubes which had been drawn by cold drawing passes be relied upon to retain their straightness under the conditions of temperature and pressure of the rocket, or would the locked-up stresses re-assert themselves and the tubes take up the form they had before straightening?

Dr. H. Harris (Visitor) said that he could not agree with the author when he described the process of drawing as being severe on the metal. Perhaps this difference of opinion might be compounded if they were to discuss what was implied by the term "severe". In practice any appreciable hot work on steel could be termed a severe operation, but in a paper of this type comparison should be made with alternative methods of making hollow forgings before deciding whether any particular one was severe on the steel. It that was done they would find the Chesterfield process was much kinder to the steel than was rotary piercing or radial rolling. Rotary piercing was very largely used in this country for tube production, and radial rolling had been developed in Germany for the production of large bore shells. He would rather decry a process which was unduly hard on the steel. One of the highlights of the Chesterfield process was the relative ease with which steels could be formed into the shapes Mr. Naden had mentioned.

Another point was the diagrammatic illustration of the grain flow in an ellipsoidal base of one of the boiler drums. Apparently the grain flow was at right-agles to the original flow in the rolled billet used. It was difficult to understand what the movement of the metal was that resulted in this orientation of the structure, and he would like Mr. Naden to explain how this particular grain flow arose.

The author had said that before cold drawing, the solid end resulting from the piercing operation was removed, and one end was subsequently nozzled to provide support during the cold drawing operation. There would be many people who, like himself, were wondering why it was necessary to take the solid end off, and why the solid end itself could not be used in the subsequent cold drawing operation to withstand the strain.

On the question of cold drawing he would like to ask the author to give some idea of the average reduction per pass that was normally achieved during cold drawing, and whether there was a theoretical limit to the degree of cold drawing that could be imposed without danger of the cold drawn material cracking before the internal stresses were removed by heat treatment.

The author had given sufficient information to make it possible to realize that he was dealing with a process of some considerable merit. The only statement in the paper with which he himself emphatically disagreed was when the author stated that for welded attachments to boiler drums the ideal was to give the drum a full heat treatment. By that was meant the normalizing treatment. If that statement had been one of major importance to the scope of the paper he would have asked leave to explain the error into which the author had fallen, but in the present circumstances he would merely content himself with pointing out that the statement was actually not true in fact.

Engineer Captain H. Moy, R.N. (Visitor) said that the author had drawn a lot of notice to the effect of scale, how it affected the finished job and how a small reduction of 100 deg. C. in the furnace could cause trouble through scale sticking. What he would like to know was whether any work had been done on scale formation on a time-temperature basis. Had they any knowledge whether time at a given temperature was a function of the thickness of the scale formed, and if so whether there was an optimum time during the process of heating up the ingot when the minimum scale was formed. Perhaps the author would elaborate this point.

Mr. G. H. Harford (Visitor) said he would like to ask Mr. Naden one question on the subject of boiler drums. In this paper the author had clearly shown that economy of steel, and manufacturing time, had been achieved by the process used at Chesterfield. He would like to know whether this would lead to the economy of cost, compared with the riveted drum, or whether it was only competitive with the more orthodox method of manufacturing solid forged drums.

Mr. J. B. R. Swan (Visitor) said that he himself had been associated with the production of one of the most important anti-submarine weapons in which tubes made by the author's firm were used. These tubes were about 7-feet long and 12 inch in diameter, and the limits on diameters and ovality in any one tube and between tube and tube were 0·030 inch. Some 10,000 feet of these tubes were made by the process just described by the author and the tolerances were achieved without any machining, which was a remarkable performance.

There was just one question he would like to ask the author. Had he ever thought of using centri-cast billets for the first forging process in order to get uniformity and freedom from inclusions?

Capt. (E) J. G. C. Given, C.B.E. (Member) said he would like to ask one or two questions. The first one was in connexion with control of the material. The author had pointed out the desirability of keeping out all porosity, and later on in connexion with different classes of steel had insisted on avoiding massive inclusion. Had the author any quantitative yardstick by which he would assess inclusions and porosity, or was it purely a matter of judgment and experience? In other applications such as rotor forgings the question whether one could allow any porosity or any degree of inclusions was rather a difficult one, because if anything were allowed at all as revealed by polishing or any other method, it was very difficult to state any quantitative yardstick by which one could say "This is what you can accept, and this is what you cannot accept".

The other small point was in connexion with the author's mention of the phosphate treatment in cold drawing. He said that was used entirely as a vehicle for the lubricant. It had been claimed in the application of this treatment to highly loaded gear teeth that the phosphate in itself had some inherent virtues of its own. He would like to know whether the author had found that in cold drawing work.

He would also like to know whether any theoretical research work had been done on the whole problem of lubrication in cold drawing. If the author knew of any such work it would be interesting to hear of it.

The Author's Reply to the Discussion

Mr. Naden, in reply, said that Mr. Ferguson made special reference to forgings in which the solid end was retained, namely, boiler drums or steam receivers.

There was a possibility of a slight reduction in the tensile strength and the elongation on samples cut from the solid end when compared with samples cut from the open end. The reasons for this were quite natural ones, namely, for purposes of production the solid end was generally made considerably thicker than the wall of the forging, and after the hot piercing, received no further work such as the wall did. This meant that before the forging was heat treated the grain size of the solid end was larger than that of the wall. After the normalizing heat treatment which was applied to refine the structure of the whole forging there was not much difference as regards grain size between the solid end and the wall, but it was this difference coupled with the smaller amount of hot work which were the factors responsible for the slight reduction in elongation value. The reduction in tensile strength was due to the slower rate of cooling of the solid end from the normalizing temperature.

The reduction in tensile strength might be up to approximately 2 tons per sq. in., whilst the reduction in elongation might be up to 5 per cent. It would be noted that the difference of 2 tons per sq. in. mentioned was well within the 4-ton range usually specified for such forgings. It should be made quite clear that the differences mentioned were maximum, and that the actual differences met with in practice were generally less than those quoted, in fact, it was true to say that in the majority of cases the differences in mechanical test values were insignificant.

As regards increasing the thickness of the solid end to compensate for a small reduction in tensile strength, an allowance of approximately 7 per cent would be quite sufficient.

A full heat treatment, namely, normalizing and tempering, was recommended for all such forgings whether they were made by hot piercing or any other method.

As regards the taking of mechanical tests it was usual to leave a tit on the solid end which could be cut off to provide the test material after heat treatment. Fig. 14 showed the method of taking the tests.

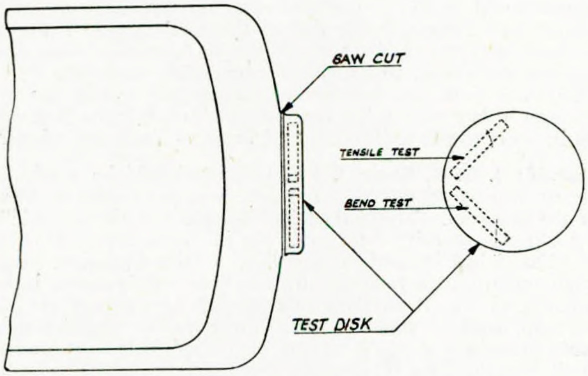


FIG 14.—*Method of taking tests from solid end*

Mr. Ferguson stated that what was most worrying was the difference in structure of the solid end and the wall. He himself wished to make it clear that the difference in the structure between the solid end and the wall was only slight after normalizing. The major difference was a slightly larger grain size in the solid end, and this was not likely to lead to any troubles whatsoever during service, in fact, from the point of view of "creep" the larger grain size should be beneficial.

It was rather difficult to understand why sulphur printing should be mentioned as being very important when the hot piercing method was employed, as he believed it was important whatever method was used to manufacture such a forging. Where large forgings were made which necessitated the use of a whole ingot, it was standard practice to obtain sulphur prints from each ingot.

The main points raised by Admiral Brown were in connexion with cold drawing and carbon "pick up".

One of the major difficulties in cold drawing was to keep the tools, i.e. the die and drawing bar, from coming into contact with the tube, as if this happened, "pick up" or tearing occurred. It had been found that cold drawing could be carried out much more easily if there was a porous carrier firmly bonded to the tube which was able to absorb and hold the lubricant. Rust was such a carrier and materially assisted cold drawing. When dealing with steels which would rust much importance was attached to the rusting procedure. The usual practice was :—

(1) Soften the tube by heat treatment.
(2) Pickle to remove the heat treatment scale.
(3) Wash well to remove any loose sludge and traces of acid.
(4) Allow to rust.
(5) Lubricate.
(6) Cold draw.

The procedure described was carried out between each cold pass.

Generally the rusting of the tubes was accomplished by spraying them with water, after which they are allowed to dry in a warm atmosphere. If necessary the rusting could be accelerated by spraying with a solution of sal-ammoniac.

By using a phosphate coating to act as a carrier in place of the rust, consecutive passes could be given. This was because the phosphate coating was porous and was much more tightly bonded to the tube than was the rust. The use of the phosphate method also allowed a much better surface finish to be attained as some intermediate annealings, picklings. and rustings were avoided. This process was now being regularly used for the cold drawing of tubes made from many of the ferritic steels.

When cold drawing steels which could not be rusted, namely, austenitic stainless types, it had been found necessary to use special lubricants, many of which contained graphite, or a metallic coating such as lead, because the lubricants which could be used successfully for the rustable steels had proved unsuitable for the stainless steels.

The diffusion of carbon into austenitic steels when using graphitic lubricants was important, but this subject was now well understood and precautions were adopted to prevent, as far as possible, carbon "pick up" taking place. When graphitic lubricants were used it was not possible to eliminate carbon "pick up" entirely but it was possible to reduce the "pick up" to very small proportions so that the penetration was not more than 0·002 inch. It was also possible to remove the thin layer completely. In order to ensure the graphite was applied uniformly on the tube before drawing it was usual to mix it with a carrier such as soap or oil. After drawing, the thin layer left on the tube could be readily removed by using degreasing agents such as trisodium phosphate or trichlorethylene. The degreasing agent dissolved the soap or oil, thus removing the graphite at the same time. This process must be carried out before the softening heat treatment was applied as it ensured that no carbon was present which could diffuse into the outer layers of the tube during heat treatment. After heat treatment the tube was pickled and this resulted in a thin film of metal being removed as well as the heat treatment scale. Many examinations had been carried out on low carbon austenitic steel tubes which had been subjected to the process described. and it had been proved that such tubes were free from the effects of carbon "pick up".

It was worth mentioning that graphitic lubricants were also used for the hot working of austenitic stainless steels, and here again, it was necessary to remove the graphite before heating the tubes for further hot work or heat treatment.

Admiral Brown made reference to certain difficulties which occurred many years ago in connexion with the manufacture of gas cylinders, but he himself regretted he was unable to offer any explanation.

The question of the reduction in tensile strength and elongation of the solid end of steam receivers or boiler drums had been dealt with fully in his reply to Mr. Ferguson. He himself believed the reduction in tensile strength was due to the slower rate of cooling of the solid end, and that the reduction in elongation was due to the slighly larger grain size of the solid end plus the fact that this end did not receive as much work as the wall of the forging.

Dr. Newman raised points in connexion with the tolerances of cold-drawn tubes, having in mind the accuracy and uniformity necessary when they were to be used for rockets.

Cold drawn tubes could be made to very fine tolerances as regards wall thickness, ovality, and straightness, but as would be expected, to produce tubes to really close tolerances meant special care at all stages during processing, which in turn meant extra cost. No sizes or thicknesses of tubes were mentioned by Dr. Newman, but if the diameter thickness ratio was reasonable, he believed that tubes could be provided to very fine tolerances, certainly near enough to avoid any machining being necessary, and suitable for the intended purpose.

The question regarding the distortion of cold-drawn tubes due to the temperatures and pressures met with under service conditions was not easy to answer, and only a trial would prove the point.

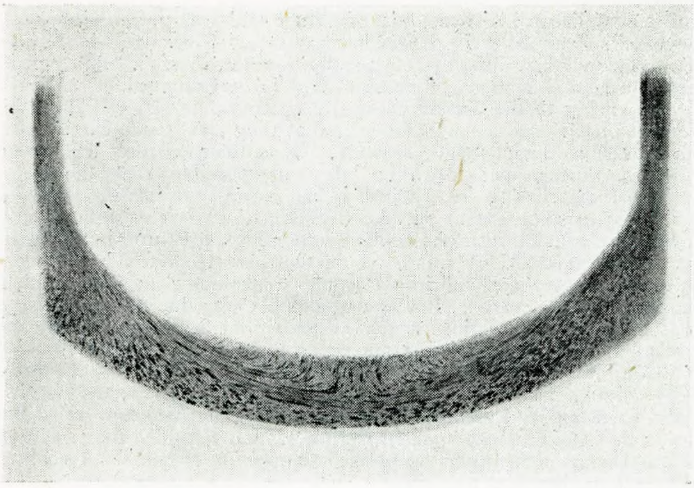


FIG. 15.—*Photograph illustrating grain flow in the solid end*

Some distortion would undoubtedly occur but to what degree would depend to a large extent on the final condition of the tubes before being put into service, i.e. the conditions of stress remaining in the tubes. The manner of processing the tubes had a large bearing on the residual stress and this in turn affected the distortion problem. He believed there was a distinct possibility of supplying cold drawn tubes which would meet the stated service conditions.

He agreed with Dr. Harris when he said there were more severe processes, namely, rotary piercing and radial rolling, than the hot piercing and hot drawing method which was used at Chesterfield. He himself had stated that the Chesterfield process was severe because he had compared it with the conventional hot forging method used in many steel works for the manufacture of hollow forgings, and he still believed the process was severe. If, however, the many processes which were used for hot working steel were graded according to their severity, then the Chesterfield process was certainly not at the top of the list.

The easiest way of dealing with the question of the grain flow of an ellipsoidal end was to illustrate this by means of an actual photograph (see Fig. 15). The effect of the piercing on the grain flow would be clearly seen. There was a band where the flow was practically at right-angles to the original direction of flow, but the band in this particular case was relatively narrow, the reason being that this base end was taken from a comparatively small forging which had a much thinner base than those referred to in the paper.

During the piercing operation the top of the billet in contact with the end of the piercing punch and the bottom of the billet in contact with the bush bottom became "frozen" i.e. fairly rapid cooling took place in these areas due to contact with the tools, and consequently the steel did not flow so readily. The effect of the "freezing" was shown in the photograph and because the base was thin the "frozen" areas were relatively large. If the base had been much thicker the "frozen" areas would not have been any larger, but the area of maximum flow, i.e. in the centre of the thickness, would have been considerably deeper but not so well defined.

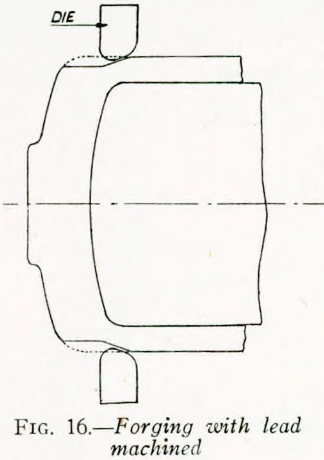


FIG. 16.—*Forging with lead machined*

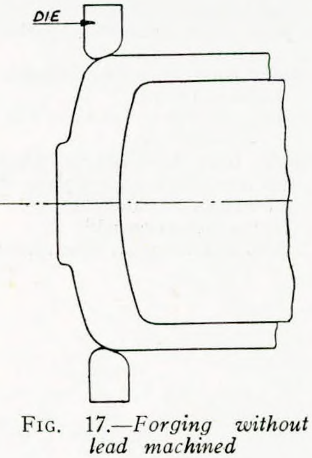


FIG. 17.—*Forging without lead machined*

The solid end could be used to take the thrust of the drawing bar instead of a "nozzle" provided a "lead" was machined on the forging as shown in Fig. 16. This procedure was adopted for certain types of work, namely, thin walled gas cylinders. If cold drawing was carried out without machining a "lead", the solid end would distort badly and most probably crack. The tools might also be damaged. Fig. 17 illustrated the relative positions of the solid end without a "lead" and the die at the beginning of cold drawing. As would be seen the effect was practically equivalent to pushing a solid piece of metal through the die. Quite apart from the foregoing it would be expensive to machine "leads" on all forgings which were intended to finish as plain open ended tubes and, for the reasons given, it was more economical to cut off the solid end and "nozzle" the tube to provide a "lead" for cold drawing.

Regarding the average reductions per pass which could be applied during cold drawing it was only possible to give approximate values as there were a number of things which had a bearing on this point, for example, the type of material, its condition, i.e. whether fully annealed or only tempered, and the wall thickness. Generally speaking, the deciding factor was the wall thickness, and assuming the tubes had been properly softened and prepared for cold drawing the reductions per pass which could be given were as follows:—

For thicknesses up to ¼ inch, 25-35 per cent.
For thicknesses between ¼ inch and ½ inch, 20-25 per cent.
For thicknesses between ½ inch and ¾ inch, 15-20 per cent.
For thicknesses between ¾ inch and 1 inch, 10-15 per cent.
For thicknesses of over 1 inch, up to 10 per cent.

He was not able to state a true theoretical limit to the degree of cold drawing that could be applied without danger of the cold drawn material cracking before the internal stresses were removed by heat treatment. He himself would welcome information on this point. Occasionally, cold-drawn tubes had split whilst lying on the floor awaiting heat treatment, but generally the splitting was not due to heavy cold reductions, as in most cases the known safe values were not exceeded, but in some cases the reductions had been well below the safe limits. At other times when the stated values were slightly exceeded, no cracking whatsoever occurred.

For practical purposes the limits suggested above had proved satisfactory, but in certain cases these values had been exceeded without meeting with trouble, but such heavy reductions were not recommended.

Dr. Harris disagreed with the statement that the ideal way to heat treat boiler drums was to give a full heat treatment, i.e., normalizing after all attachments had been welded on. This statement was made having in mind the fact that such a heat treatment eliminated the changes in structure that occurred in certain zones during welding and would leave a completed article with a uniform structure. He himself still believed this was really the ideal way, but at the same time realized that it was not often possible or even necessary to do this in practice. It was usual to normalize the drum before the attachments were welded on, and then either stress relieve the complete article if this was possible, or locally stress relieve where welding had been carried out. Drums subjected to this procedure had given every satisfaction in service.

Capt. Moy raised a most interesting point as regards the formation and effect of scale. He himself believed that quite a lot of practical work had been carried out as to scale formation on a time temperature basis in many different works under specific conditions which only applied to a particular plant. There were a number of variables besides temperature which affected scale formation, and probably the major one was the furnace atmosphere, i.e. whether strongly oxidizing, mildly oxidizing, or reducing. It was difficult to generalize as regards scale formation, but under any given set of conditions it could be controlled. There was no doubt that the build up of scale was a function of time and temperature and any increase in either of these increased the amount of scale formed. As stated previously, it was not possible to generalize and give an optimum time, irrespective of other conditions, for the heating of ingots or billets to a forging temperature when the minimum scale would be formed. It was only possible to do this when dealing with a known set of conditions for a particular plant.

It was, of course, possible to generalize to a certain extent and say that the material must be in the furnace only long enough to ensure it was uniformly heated throughout its mass, and that the atmosphere must not be strongly oxidizing.

Mr. Harford asked whether the fact that the economy in the use of steel and manufacturing time which had been achieved by the process used at Chesterfield would lead to economy of cost compared with the riveted drum, or whether it was only competitive with the more orthodox method of manufacturing seamless drums.

In his own opinion a drum made by the Chesterfield process had certain advantages and was competitive with one made by any process whatsoever.

Mr. Swan raised the question of using centri-cast billets for the first forging process in order to obtain uniformity and freedom from inclusions. The use of such billets had certainly been considered and their use might prove advantageous for certain products. It was not thought that this method would give freedom from inclusions or uniformity as regards structure and composition. A further point was that it would be necessary both to bore and turn such billets before they could be processed.

Capt. Given raised points about the control of material. It was certainly desirable to obtain sound material, i.e. free from porosity, and also material free from inclusions. Unfortunately there was no easy method by which one could readily assess the quality of the steel as regards porosity and inclusions, and at the moment the acceptance of steel was based on such things as the appearance of the cut surfaces after the discards had been removed, sulphur prints, analyses, mechanical tests, and a general examination of the material. In special cases, supersonic testing was carried out but the results obtained were not easy to assess as such an instrument was very sensitive and the testing must be carried out by a skilled operator who had built up his own scale of values and was able to interpret the results obtained with reasonable accuracy. This method of testing was slowly becoming more generally used but it was a lengthy process when large sections of material had to be examined.

Referring to the use of phosphate coatings, he believed the real virtue of such coatings was the fact that they acted as a carrier for the lubricant during cold drawing. No other virtues had been observed during cold drawing. It was possible that the very nature of the coating, i.e. because it had a high phosphorus content, prohibited to some extent the local welding of two faces which were in intimate contact with one another under high pressure, but he was not sure of this. There was no doubt that gear teeth which had been phosphate coated and lubricated would wear less than those which had not been so treated. It was thought this was due to the porosity of the phosphate coating which ensured that a complete film of lubricant was present at all points of contact.

Considerable theoretical and practical work as regards the problem of lubrication during cold drawing was being carried out by Tube Investments Research Department, Birmingham, but the work would take quite a long time to complete. He felt sure that the Research Department would be pleased to pass on to Capt. Given any information they had available.

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MEMBERSHIP ELECTIONS

Date of Election 12th July 1948

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Ernest Cross
Alexander Ian Henderson Dalgleish
Joseph Jean Sylvan Desjardins
Charles Louis Eaton
Laurence William Edwards
Matthew McAllaister Flack
Lionel Arthur Frampton
Leslie Walter James Harding, A/Sub-Lieut.(E), R.N.
Robert Frederick Holloway
Tom Isherwood, Ch.E.R.A., R.N.
William Charles King, Ch.E.R.A., R.N.
John Thomas McAvoy
William Hugh Mathews
Sukhbir Singh Mathur
John Osborne
Thomas Leslie Palmer
Ronald Clifford Pearson
Kocherlacota Ramakrishna
William Roberts
Andrew Eric Stewart, B.Sc.
Capt. James Peter Thomson
Antony Owen Frank Vernon, Sub-Lieut.(E), R.N.
Henry Stephen Wood

Graduate

Desmond Quinn

Students

Ian Coleman Howarth
John Lloyd Frederick Prickett

Transfer from Associate Member to Member

William Dornan
Charles Alfred Herbert, Ch. Eng., R.F.A.

Transfer from Associate to Member

William Kenneth Gwynne Allen
Alexander Macdonald
Justus Schwersenski
Harrie Thompson Spearpoint

Training of Apprentices Intending to Become Marine Engineers*

Mr. T. W. Longmuir (Member) said that in introducing this discussion he would confine his observations to the training of apprentices who were now serving in a workshop with the definite intention of going to sea as engineers at the age of twenty-one.

For the past twenty years he had known about a large number of schemes all designed to improve the training and increase the status of marine engineers, and yet there was very little difference in the training given today from that given forty years ago.

In some details there was an improvement, but in others there was perhaps less interest shown in the apprentices, especially in the workshop. He would refer to the definite improvement in the facilities for technical training later.

The first fact to be accepted was that the majority of young engineers chose a sea-going career as an alternative to remaining a fitter or turner, and not as an alternative to a position of an executive engineer in a power station, or a designer or works manager. Therefore their background was almost the same as that of the artisan, and not that of the professional engineer, or the engineer officer in the Navy. In other words it was a craftsman's training that was given and from the point of view of the employer and the ship owner this was the correct thing to do.

The first essential result of training was that the young sea-going engineer must be able to work with his hands. It might be years before he was called upon to occupy an administrative post.

Table I gives information obtained by taking a representative cross-section of marine engineers who began their apprenticeship between 1932-37.

Table I. Training of Marine Engineer Apprentices

Workshop		Educational	
Type of works in which apprenticeship was served	per cent	Age leaving school	per cent
Marine engineering repairs	50	14 - 15 years	20
General engineering	46	15 - 16 „	20
Building marine engines	2	16 - 17 „	50
Other	2	over 17 „	10
Number of apprentices employed in works	per cent	Type of school attended	per cent
1 to 10	36	Elementary	23
10 to 20	10	Secondary	53
20 to 30	10	Junior Technical School	20
30 to 50	8	Others	4
50 to 100	6	25 per cent obtained First School Certificate	
100 to 250	6		
over 250	12		
System of works training	per cent	Years attendance at night classes	per cent
Attached to a fitter	84	None	12
Picked up information from anyone	12	One	4
Organized instructional classes	4	Two	18
		Three	30
		Four	20
		Five	12
		Special courses	4
		4 per cent. obtained Ordinary National Certificate	
		4 per cent obtained Higher National Certificate	

Consider first works training. 64 per cent served their time in works having less than fifty apprentices, and in 46 per cent of the cases there were twenty or less. In only 20 per cent was a system of class instruction possible; in fact only 4 per cent were given instruction in craft training.

In nearly all works there was some system of moving the apprentices from shop to shop and from shop to ships to enlarge their experience. In many works all, or nearly all them have 3 to 6 months in the drawing office. The usual basic plan was about two year's fitting, one year's turning and two years spent in the pattern shop, foundry, drawing office, and on outside work.

In some firms they spent three months in the transport department on the maintenance of petrol and small Diesel engines. In very few shops did the potential marine engineer have the opportunity of gaining practical experience on electrical work, ship work, or boiler repair work. This might be the result of Trade Union demarcation rather than the fault of the management.

In general the boy was taught his trade by being attached to a fitter who should be able to give him good advice. He himself believed this system to be an excellent one, provided only special men were chosen to act as tutors.

He believed that a boy should not go out of the shop and work on an actual ship until he was capable of working by himself, and then only after about four years workshop experience. One advantage of being taught by a fitter in preference to class instruction was that the boy learnt to develop initiative, an essential characteristic for a successful marine engineer, but a boy would not derive additional benefit by remaining with one fitter longer than six months.

In almost every works the personnel supervisors took an individual interest in the apprentices, and so far as was possible endeavoured to arrange for their correct training. Another source of help might be the shop stewards, some of whom did take an interest in the boys training, and help and advise them on their work and evening classes.

While considering shop training one must not lose sight of the fact that the apprentice who was eventually going to sea was employed to earn money for his employers, and that after he had finished his training he would not work for the firm who had trained him.

In discussing the much debated question of technical training for marine engineers he would deal only with the marine engineer who could be classified as "sea-going" and would remain at sea, and not the engineer who went to sea in order to gain experience which would enable him to secure a position on shore.

There were a large number of persons connected with technical training who maintained that a special training for marine engineers was not only unnecessary but wrong and that a good engineer would make a good marine engineer. With this he agreed, but this discussion was at present concerned with the apprentices who would go to sea as engineers and yet might be outside the category of good engineers.

Of those apprentices tabulated in Table I, 66 per cent had three or more years attending evening classes, yet only 8 per cent obtained National Certificates; 30 per cent did not attempt the examination, but 50 per cent tried and failed. There must be a fault somewhere. The high percentage of failures was due in part to the night class system then in vogue and the information was often given by tired teachers to sleepy students. This problem was partly solved by part-time day release of students for one day each week. Some firms granted this privilege for two years and he would like to see it extended by all firms to the age of twenty-one provided the student made steady progress. This part-time day release raised many problems especially when taken in conjunction with the five-day week.

One problem was the question of Saturday classes. It had been suggested by some employers and students over twenty-one, that Saturday should be the day for classes, or that instruction should be given on Saturday morning instead of one or two evenings. The objection to this was that by the end of the week the teachers were in no condition to give an extra day to students, also the majority

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* Discussion at a meeting of the Education Group on 7th November 1947 introduced by T. W. Longmuir.

of instructors required Saturday for preparation and marking homework.

Another aspect of the part-time day release was the question of increasing the number of subjects. It was stipulated by the majority of employers and agreed to by the Trade Unions, that the apprentice was given one day a week on pay on condition that he also attended on one or two evenings.

His own opinion was that the night class should be optional up to the age of seventeen. One evening was sufficient from the ages seventeen to eighteen, and that a boy of nineteen suffered no hardship by doing two evenings a week provided homework was limited to three or four hours a week. Part-time day release made it possible to increase the number of subjects for marine engineers. English should be taken for the first and second years: electricity and naval architecture were the obvious choices in addition to the usual mathematics, applied mechanics and heat engines up to the third year level. In the fourth and fifth years, marine engineering knowledge, and treatment of feed and boiler waters should be included and the subject of heat engines extended to include modern marine practice.

The most difficult problem to be solved was that of the 60 per cent who, even with part-time day release could not obtain a National Certificate at the end of their third year.

It could be seen from Table I that the rate of progress expected of the ordinary student could not be obtained. He thought the solution lay in having two National Certificate courses, one which would take two years after the first year, and another which would not be completed for three or four years after the first year—the first year examination being used to separate these two classes. Surely it was the amount of knowledge a man had when he went to sea that counted, and not the rate at which he acquired that knowledge, and also the slower some students assimulated knowledge the more they retained.

Another suggestion which he would put forward for improving the present technical training, was to admit to the technical schools students at the age of sixteen instead of seventeen and to devote the major part of this pre-national certificate year to mathematics, the subject which lagged behind the others. These classes would be held in the technical schools or in junior evening institutes and would be directly under the control of the technical institute regarding staff and the teaching of technical subjects. This class would include boys from all trades.

He would suggest that technical training meant more than obtaining a National Certificate. To be a good marine engineer, character was essential, which was something that the student might possess and the teacher could bring out, and it would stand him in good stead when things went wrong at sea.

For this reason teachers should be picked with care. Classes must not be too large and the teacher must not have so much to do that there is not time to know the class individually.

He had not mentioned the Marine Engineering College which was to turn out the "exceptional" marine engineer. Under present conditions he could not foresee any major alteration in the system of training for many years to come, but he was convinced there were numerous ways in which the existing conditions could be improved. Also economic conditions and not educational standards would continue to be the criteria of selection.

He had not mentioned such schemes as graduate apprenticeships, student apprenticeships, the sandwich system, dockyard training and University courses, all of which were ideal for marine engineer training, but unfortunately the excellence of this training produced a state of mind which was not conducive to gaining sufficient seagoing experience to become a chief engineer.

When examining the figures of Table I it must not be assumed that marine engineers were drawn from a low strata of technical learning. They were not below the average of all the engineers in the country provided craftsmen were included in the term "engineer".

Mr. D. Carmichael (Member) said that the author was speaking about education in the technical colleges, and that the teachers should know each student well enough to be able to follow his educational developments. One of the difficulties he had found when he attended evening classes at a technical college during his apprenticeship was that there were usually fifty to sixty students in the class and as the teacher's time was so fully occupied, personal attention to each individual pupil was not possible. He hoped that under a new education system they would be able to reduce the size of these classes.

Mr. S. Cundill (Visitor) stated that Mr. Longmuir had given a lot of figures about training, but some of them were from schemes which were not up to date. His firm trained between 300 and 350 apprentices and trainees and he had the pleasure of supervising their training. All boys were started in an apprentice training department, which was in charge of a foreman, with a number of older fitters as the instructors. The boys stayed in that department for six to eight months and were then moved through the shops for fitting, erecting, turning and other experience; all the moves throughout the firm's various works were made by him, and no boys were allowed to stay in a particular department for longer than the time specified. He sent out a list every two or three weeks giving the names of the apprentices to move, the date from which the moves were to take effect, and the place to which they were to move, no matter whether it was in the same shop or a different shop or works.

In the past, boys had to ask their foreman when they desired to move, and in that way good boys were victimized as they were most useful to their charge hands and foreman, whereas the inefficient ones were allowed to move round freely. The apprentices were now moved from a central point, and a report was received from the foreman monthly for each boy for the first year, and after that, following every move. This was in the form of a questionnaire report form on which the foreman concerned had only to mark A, B, C or D to each question; by this means the boys were graded and the result added to the boys' record cards. These cards were kept in the boys' personal folders and made a very useful record at the end of their apprenticeship.

His firm had at present 170 boys attending the part-time day release scheme at the Technical College, mostly on the National Certificate course and a few on the External Degree course. The boys attended one day and two evenings a week (three evenings on the degree course) but some of the evening classes were tutorial, so that a good boy could get most of his homework finished during the time he was at school.

To run such a training scheme called for the co-operation of everyone from the managing director to the foreman, charge-hands and men, and he was pleased to state that he was receiving the necessary co-operation from everyone.

Lt.-Com'r (E) A. J. T. Shoring, R.N. (Member) said that for the past two and a half years he had been associated with the training of apprentices, being Senior Engineer at the Royal Naval Artificer Apprentices Training Establishment at Torpoint, Cornwall, and as such, was responsible for the practical workshop training of the apprentices. He said that he hesitated to contribute to the discussion after hearing Mr. Longmuir's remarks regarding the Marine Engineering College because, to a large extent, the artificer apprentices had that set up. He had noted the various items which Mr. Longmuir had stressed and he thought that in the Naval system they had included many of these things. He mentioned firstly the artisan background and the artificers' craftsmanship and technical training going side by side.

Regarding instructors, he had no experience of industrial schemes, but he considered that they should stress the importance of having the right type of instructor as they had to make good citizens of the boys as well as engineers. At Torpoint the complement allowed one instructor for every twelve apprentices, and normally there were about 750 apprentices under training. There was a set syllabus of instruction which included progressive practice work and test jobs and the boys progressed, in time, through the fitting shops and later to the machine shops and so on. From the beginning, the apprentices tackled the jobs themselves, with the instructors to demonstrate to them and advise and correct them. The result was that the boys' ability and initiative were developed right from the start. A test job was set at the end of each term. Each job had a comprehensive marking scheme and the boys had to secure 40 per cent marks for a pass; failure meant the possibility of the candidate being kept back for a term.

Going over his experiences, he said that as an artificer apprentice he had been trained for three years at the Royal Naval Artificer Apprentices Training Establishment at Portsmouth and had then been transferred to Chatham, where for eighteen months he had worked in the dockyard and found that dockyard apprentices who had been entered as the result of the same entrance examination as himself, but trained under the journeyman principle, were not so far advanced in their training as his term of artificer apprentices.

It was his experience that the boys were tired at night and did not seem to assimilate knowledge in evenings classes. The timetable for artificer apprentices had recently been revised so that they were away from the workshops during part of the day for lectures, having only one full day per week in the shops and a 45-hour "instruction" week.

The terms were of four months duration and in the first term the apprentices spent 25½ hours in the shops and of the remaining 19½ hours 13½ hours were spent in the school, 3 hours at organized games, 2 hours at physical training and 1 hour squad drill. In the second term and onwards they had 27½ hours in the shops and the balance in school or technical lectures. In the past, artificer apprentices were entered upon the result of a competitive examination held by the Civil Service Commission. The Admiralty were setting the examination in future, and boys with School Certificate were granted exemption. The apprentices were not allocated to branches—electrical, ordnance, engine room or air until the completion of the third term, and the engine room artificer apprentices were allocated to trades—Fitter and Turner, Boilermaker, Coppersmith or Enginesmith—at the end of the fourth term.

During the basic training they had four months woodworking, four months fitting, five weeks coppersmithing, and two and half weeks respectively in the sheet metal shop, welding shop, tool room and enginesmiths' shop. During the fourth term they had nine weeks on lathes, followed by three weeks on milling machines and two weeks on shaping machines followed by the examination.

Their policy was to keep a very careful watch on these boys in order to discover their suitability, and thus avoid putting square pegs in round holes. The boy's preference as to branch and trade received consideration but was not the deciding factor. The general practice was to give the basic training at Torpoint, and the following two years and eight months at H.M.S. "Caledonia", H.M.S. "Collingwood", or at the R.N.A.S., Arbroath. The school syllabus consisted of mathematics, science, electrics, English history, adult education, woods, metals, and blueprint reading, with one afternoon a week for organized games, physical training and squad drill. They also taught them to take charge themselves. He thought the great advantage of the organized games was the development of character and *espirit de corps*. The boys were also encouraged to organize games themselves.

He thought that one or two points could be taken up by industry, if only the allocation of apprentices to selected instructors, and the formation of the class. A lot depended upon the integrity of the man selected. He considered that given specially selected instructors on very favourable rates of pay, the best type of craftsman could be recruited and the best possible instruction afforded the apprentices. He did not know much about the schemes in the commercial world, but he did not think that the status of the marine engineer would improve, or proper training be given until there was a training college.

Mr. H. McQueen (Visitor) said in referring to the figures given in Table I, especially the figure of 84 per cent attached to a fitter, that if they were authentic he would like to congratulate the marine engineers as he had not seen such figures before. He stated that most marine engineer apprentices in manufacturing works were left to their own devices, and were expected to produce articles for sale with a profit. He added that he served eighteen months in a maintenance department whilst apprenticed but even then was not allowed to pull engines to pieces to the extent implied above. He thought that if the boys had their training in a marine manufacturing works they were in a false position.

Mr. G. W. B. Raimes (Member) said that he would heartily endorse Mr. Longmuir's remarks on craftsmanship in the training of marine engineers. He thought that the subject of English, as mentioned by Mr. Longmuir, was very important indeed. He considered that if the boy got a good knowledge of English and could express himself adequately, and could understand what he was reading, then he was on the right road. He thought that proficiency in this subject was essential to the increase of status of marine engineers.

As regards training the boys in the shops he was afraid that there was still a great deal left undone. Mr. Longmuir had mentioned that after employing and training a marine engineer apprentice the employer did not get much benefit, but it was a fact that many marine shops did get the benefit of cheap labour from this source.

He thought the boys who went to sea were above the standard of the average boy who was content to remain in the shops as a mechanic.

A marine engineer need not necessarily have a very high degree of mathematical ability, though this would be required in design work or other jobs away from the sea, and men with this knowledge generally gravitated to these positions in any case. What was required was a good grounding in fundamentals.

Mr. W. F. Jacobs (Member) said he found that there was little difference between the present training and that of forty years ago. He suggested that five years apprenticeship in the ordinary engineering shop was too long if the boys were properly trained. Too much reliance was placed on picking up information from the men without correct instruction. Referring for instance to filing—how many boys had been shown all the types and grades of files and how to use them for the various jobs? The same question applied to using most tools. Such detailed instruction could be given in short talks by a suitable man to the boys at the start. Full information should also be given on turning, of the type involved in repair work.

If training was done on these lines, the shop time could be reduced to three years, but another two years should be spent either at a technical college or as an engine room apprentice at sea without officer rank.

He thought the idea of the Marine Engineering College was a good one; alternatively some instruction should be given to the boy before he went to sea on ship operation in general. Even typewriting should be taught, to enable the budding engineer to cope with the numerous forms with which he would have to deal. He considered that the young engineer should have an adequate knowledge of mathematics, physics, and electrotechnology before he went to sea.

Lt.-Com'r (E) A. J. T. Shoring then said he was in agreement with the suggestion that the time for training could be reduced. Before the war the artificer apprentices spent four and half years at the training establishment, followed by one year at sea under training as fifth class artificers. The period of sea training still remained, but the time for apprenticeship had been reduced to four years. The time spent in the workshops was further reduced by the introduction during the senior terms, of a six weeks course in practical electricity and a nine weeks course in internal combustion engines. However, in effecting such a reduction, it was found essential to have adequate instructional aides and demonstration facilities.

Mr. D. M. Reid (Visitor) said that he thought Mr. Jacobs's remarks were very much to the point, and that craftsmanship was over-emphasized, and that more practical knowledge was gained in the first two years at sea than in the five years in the shops. He suggested that most of those five years could be more profitably employed in gaining technical knowledge, which was more difficult to attain in later years.

In his opinion the status of the marine engineer on board ship was lower than it should be; he suggested that this unfortunate position was partly due to the fact that craftsmanship had been overstressed, and that the engineer was apt to be regarded as a craftsman, and nothing more.

Mr. H. S. W. Jones (Associate Member of Council), said that, his experience of teaching men with National Certificates was that some of them had once known the work and had forgotten it; some of them had never known the work and others had gaps in their technical knowledge which did not warrant their exemption from Part A of the Ministry's examination. There were instances of men who, although exempt from Part A by reason of their holding a National Certificate, had elected to take a Part A course as a refresher.

He hoped that Mr. Longmuir did not advocate apprentices completing their technical education before they went to sea. By the time a man had been at sea for a few years he was ready and willing to learn things which had little or no interest for him in his apprenticeship days.

Mr. W. Laws (Visitor) said that he was in general agreement with Mr. Longmuir's remarks. They found that the young engineer who came ashore to study for the Second Class Examination who was already in possession of an Ordinary National Certificate was in an advantageous position. But in the course of the discussion the point had been made that marine engineers might be divided roughly into two categories—those who intended to make marine engineering their life's career, and those who went to sea for a few years for the sake of the valuable experience thus gained, during which time they hoped to secure an Extra First Class Certificate with the intention of leaving the sea while still relatively young, and getting a good shore job.

This had led him to speculate as to whether something in the nature of a City and Guilds Craft Course in machine shop engineering and workshop practice with appropriate ancillary subjects of calculations, drawings, etc., might not be more appropriate to the first category who would probably never aspire to obtain an Extra First Class Certificate.

In the past he had heard Mr. Longmuir make some uncomplimentary remarks from time to time about the value of National Certificates because he had found that students coming to him holding such Certificates still had a great deal to learn. Apparently he was becoming converted to the idea that National Certificates had some value.

Mr. C. W. Tonkin, B.Sc. (Associate Member) (Chairman) said that Mr. Longmuir had raised points which had always been present in the minds of industrialists on the score of apprentice training.

He referred to the firms who were not willing to release their apprentices for part-time day classes as they considered they would go to another firm in the end. In this connexion it was worth noting that whilst many ex-apprentices left the Naval Dockyards, on the other hand, there were many who stayed.

He considered that the firms did benefit from their apprentices and that they were getting good service whilst these young men were in their employ.

He said that the lack of electrical training for the apprentice going to sea was as much due to tradition as to trade union restrictions. He added that the time factor was the difficulty in providing such extra training.

He then referred to the industrial instructor, and to the danger which existed where a boy was attached to an instructor. He was sorry to see that the analysis applied only to the years 1932-37, and added that since that time a number of firms had introduced training shops, and this idea had undoubtedly spread to others. He referred to the apprentice who was attached to a mechanic in a commercial firm, and suggested that very frequently that mechanic might be engaged on piece work or some similar form of payment; such a man might not do justice to his duties as an instructor. He suggested that really good instructors were very difficult to obtain, and they must be offered some incentive. Whilst agreeing heartily with part-time day release for technical training he regretted that statistics did not appear to bear out that part-time release was resulting in increased percentage awards of National Certificates. He thought that the figure was still round about the 50 per cent mark. He felt that a new National Certificate taking three to four years was not desirable, as the two different standards would lead to confusion in the minds of industrial people. He then referred to the dislocation of education during the war period and said that it was hoped that part-time day release would result in more apprentices reaching a good standard.

In referring to the teachers and size of classes, he said that it was still impossible to obtain sufficient suitable teachers, and thought this was partly due to the salaries. These were paid in part by local authorities, and in turn it involved the ratepayers. He thought that the teachers' scale of salary would remain during the next three years at something considerably below what the corresponding man would receive in industry. The type of man they were wanting was not the man who was just attracted by the salary scales, but the type who, as a result of his enthusiasm for teaching, still followed this profession in spite of the salary. Many of those already in the teaching profession could earn considerably more in industry. He thought the question of the size of class was a very important factor.

With reference to the question of time for training he thought the possibilities in this respect had been brought home to them very definitely during the war years in the training of service personnel. On the question of training service personnel in such a short time he suggested that the training given during the war was particularly specialized, but that the training of apprentices went beyond the handling of tools, and the necessary experience could not be gained in six months. He did not agree that the training could be given in less than three years.

Mr. Longmuir had raised the point about substituting the City and Guilds type of examination for the National Certificate examination. It was true that there had been a strong tendency to shuffle all engineering students into the National Certificate course. He thought that an alternative to the National Certificate course would be on the lines of the City and Guild type of course for craft certificates.

Mr. Longmuir in reply said that when he suggested that the topic for discussion might be "The present training of Marine Engineering apprentices", he did not think that he would be the one selected to open the discussion. He was pleased that the opening remarks had induced so many speakers to give their views on this subject. He said that he had given facts as they existed to-day and had not considered the ideal conditions of the future. Several speakers had stressed the advantages of training schemes, but in preparing the opening remarks he had examined various shop training schemes but had failed to find one that could be applied to the smaller repair firms with less than 50 apprentices, yet more than 75 per cent of sea-going engineers came from this type of shop. The fact had to be faced that under present conditions apprentices were employed to make a profit for their employers and all schemes of training had this as the ultimate object.

Mr. Cundill's firm had an excellent scheme but it was much more difficult for the repair firms situated in sea ports to run similar schemes, as the apprentices were attached to several small shops scattered over a large dock area, often several miles apart.

No one could have more co-operation than he himself received from the firms in the London docks. These firms did try to assist their apprentices in every possible way but it was almost impossible to devise a unified system of training.

Lt.-Com'r Shoring's remarks were most welcome but it must be remembered that a Boy Artificer had numerous advantages over the boy trained in the smaller private yards. Firstly, the profit motive was absent, secondly, the boys were trained for a specific job, and thirdly, those in charge insisted that the boys had a minimum standard of education and intelligence before they were allowed to begin their training. He agreed with Commander Shoring that once a National College or a national training scheme was established the status of the marine engineer would improve.

In reply to Mr. McQueen, he said that the 84 per cent referred to in the table were attached to a fitter for some period of their apprenticeship. This was the usual procedure in ship repair firms.

Mr. Jacobs' remarks confirmed several statements made during the opening of the discussion. The actual workshop training for a boy who attended part-time day classes during the whole of his apprenticeship was reduced to four years.

While he agreed with some of Mr. Reid's remarks his own experience of young engineers at sea was that those with the best workshop training were the ones who became most efficient in the practical running and upkeep of the engines.

In reply to Mr. Jones and Mr. Laws, he said that they both knew that any opinions he had expressed about the holders of a National Certificate did not apply to the boys who were trained at the right school. He believed that if all lads went to sea with a National Certificate the standard of junior engineers would please the most exacting of chief engineers.

Replying to Mr. Tonkin he said the figures in the table were obtained over a number of years. 1932-1937 was taken because after 1938 other factors than the desire of becoming a marine engineer influenced those who entered the workshops. He had not advocated two standards of National Certificate. Under the present system a large number of students did take four years by having to repeat one year of the course. He felt sure that Mr. Tonkin would agree that a four-year progressive course was better than having to repeat one year of a three-year course. It was Mr. Laws who had suggested a City and Guilds course, which might have a lot to commend it. The fact that an intermediate certificate could be obtained at the end of two years' study acted as an incentive to continue for the final certificate at the end of a further two years. The reason why all potential marine engineers were placed in the National Certificate course was because the Ministry of Transport granted exemption from part "A" of their examinations for Certificates of Competency, to holders of an approved National Certificate. One other point mentioned by Mr. Tonkin, which was really outside the scope of the discussion, was the type of instructor who was not attracted by the salary scale. He assured Mr. Tonkin that no amount of enthusiasm for teaching would make up for lack of financial reimbursement.

Electric Power for Ships*

By R. F. LINSELL (Member)

This essay begins by describing the various methods by which electric power may be used for ship propulsion. It is pointed out that, in general, this power is not directly available for auxiliary purposes, and it is queried whether it would not be desirable to devise a system whereby the same generators could supply propulsion and auxiliary power. Such a system would lend itself to the use of standardized Diesel generators in a multi-engined ship, it would also enable one central power plant to drive two or more propellers—an arrangement which might be desirable in a vessel powered by a gas turbine or atomic power installation. The proposal is to use constant speed alternators in conjunction with synchronous motors driving variable-pitch propellers, the alternators also supplying the ship's auxiliary power and lighting services.

INTRODUCTION

Since the first experiments were made in electric propulsion for ships, some forty years ago, steady progress has been made in design and reliability, so that, at the present date there are many hundreds of vessels in commission using this form of drive. These range from yachts and tug boats to tankers and liners, and employ direct and alternating current.

There is no longer any doubt about whether electric drive is practicable and reliable. It is now more a question of when is an electric drive most desirable and whether anything further can be done to enhance its benefits.

Electric drive is of greatest use where the following characteristics are required:—

(a) Ease of control—including bridge control.
(b) Flexibility of layout and sub-division of engines.
(c) Ability to use propulsion power for a large auxiliary machine e.g. tanker's pumps or dredger's machinery.
(d) No necessity to reverse the prime mover.

Electric propulsion would be more useful still if the same electric power could be used for propulsion and auxiliary purposes. At present this is not convenient, for reasons which are explained later, where is also described the various arrangements now in use for electric propulsion.

The use of variable-pitch propellers driven by synchronous motors and powered by constant-speed alternators would provide a solution to the problem of using the same electric power for propulsion and auxiliary services. This system, which for brevity is referred to as the "Varpac" system, is discussed in this essay, and some of its possibilities are considered.

ELECTRIC PROPULSION

Direct current

General considerations. In general, direct current is used for shaft-horse-powers below 2,000 per screw, and where the speed and power of the screw are to be controlled independently, as in a tug. It cannot be used for larger powers owing to the ungainly size of commutators which would be required. The commutator is, in fact, a nuisance at all times, adding to the size, expense and vulnerability of the machine, requiring careful maintenance, and liberating carbon dust. However, the ease of control of direct current machines has made them popular and various propulsion systems have been developed.

Constant voltage system. For small powers, a propulsion motor can operate from a constant voltage source just like any pump motor. One installation of this kind has been made by a British company and employs three 66 kW. 250-volt d.c generators to supply power to a 240 s.h.p. propulsion motor and all ship's auxiliaries in a river tug. The propulsion motor requires a starting resistance, and is fitted with a special exciter, direct driven from the shaft extension, which strengthens the field when the armature current increases. This protects the Diesel engines from overload when the propeller slows down during a heavy tow, and while manœuvring.

The series resistance and special exciter, together with the fact that the propulsion motor is limited to 250 volts, make this system unsuitable for higher powers.

Variable voltage system. The variable voltage or Ward-Leonard system has been the most widely used in d.c. marine propulsion. In this system the motor field current is kept constant, the motor and generator armatures are electrically connected, and the generator voltage is varied by field or speed control to regulate the armature current. This has the advantage that no heavy current circuits are switched during normal manœuvres—the controller handles only the relatively small currents required by generator fields. Alternatively the generator fields can be supplied from an exciter, and can be regulated by controlling the exciter fields which are smaller still.

It is necessary to take precautions against surges of current due to rapid manœuvring; for, if the propulsion motor is stationary and the generator field is increased rapidly, a heavy current will flow from the generator until the motor back e.m.f. has built up by its increase in speed. This heavy current, flowing with full generator field will overload the Diesel engine, which by its very nature is unable to carry sustained overloads in torque, and may even stall it. These current surges may be prevented by fitting some form of protective relay or by designing the generator fields so that the generator voltage collapses if a heavy current flows. This latter is described later.

Various forms of protective relay have been used. Swiss and American companies favour a Brown-Boveri regulator, consisting of a current sensitive element which moves an arm making rolling contact on a potentiometer and weakening the generator field. British companies have used over-current relays which separate contacts bridging a generator-field-weakening-resistance. This can be done in one or more steps. The relay should properly respond to power and not current, as it does no harm to allow a heavy current to flow unless a strong generator field is also established.

Current peaks can also be minimized by manipulation of generator field time constants so that the rise of field current is sluggish.

A further protection is usually added which will respond to short circuit currents in the main armature circuit and interrupt the generator and motor field supply.

Variable voltage system with controlled current. The current limiting devices described in the previous section can be made robust and reliable but are always regarded with suspicion, and any generator which inherently limits its own current peaks is clearly desirable. Such a generator has been developed and has three windings, a separately excited field, a self-excited field and a differential series field. A differential series winding alone is not capable of cutting off the excitation sufficiently rapidly to prevent the current surge, but the addition of the self-excited winding causes a rapid fall in voltage when the differential winding starts to reduce it. The three-winding design can be applied either to the generator or to an exciter, the latter usually being more convenient.

The use of the three-winding scheme leads to a relatively simplified control arrangement which does not rely for its safety on any subsidiary gadget.

The more recently developed metadyne exciter can also be given a current limiting characteristic but this machine usually requires subsidiary circuits which lead again into complication.

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* This essay won the Sir Archibald Denny, J. Stephen and Lord Inverforth Fund Prize for 1947.

Constant current system. The variable voltage systems can control only one motor at a time. In a twin screw ship it is necessary to feed each propulsion motor from separate generators if independent manœuvring is required. In emergency, the two motors may be supplied from the same generator, but they must then run at the same speed, although one can run astern while the other runs ahead.

A vessel, such as a dredger, frequently carries deck machinery whose power is comparable with that used for propulsion. If the usual variable voltage system is used, it is necessary to switch one of the main generators to deck machinery or else install a separate generator for this purpose.

The constant-current system is being developed by a British company with the object of providing a flexible arrangement whereby a number of generators can supply power to any combination of motors being used independently. Moreover, this system still retains the virtue of the variable voltage system, that control is effected on field currents only—in this case on the motor fields or their exciter fields.

The success of the constant current system clearly depends upon the ability of the generators to hold the current steady. They do this by using a metadyne exciter whose reference field is balanced against a field proportional to the generator current. Suitable circuits are added to ensure the stability of this servo-system.

As the current is kept constant it is impossible to overload a generator (and hence its Diesel engine) unless the exciter voltage should rise. Protection against this is provided by an over-voltage relay which reduces the metadyne reference field. This system gives overload protection at all times however many generators are in circuit, as all receive their excitation from the same metadyne exciter.

Motors supplied on the constant current system are controlled by regulating their field currents. For a small motor, e.g. winch or crane, the field is conveniently supplied from a reversing potentiometer rheostat. Any given position of the controller handle then gives a certain torque to the motor and its speed is determined by the load. This is just like a steam winch, and the similarity extends further for the motor will race if the load drops off and the controller is not returned to the position. The light-load speed can be limited by fitting a belt driven exciter to the motor which will buck the field at high speeds.

A propulsion motor field is best supplied from an exciter, and the ubiquitous metadyne can be used to modify the torque control into power control with speed supervision to prevent racing in a seaway.

Auxiliary power in ships with d.c. electric drive. In all the foregoing propulsion schemes, except the constant voltage system, the propulsion generators cannot supply auxiliary requirements simultaneously. The constant current generators can supply any motor whose armature can be wound to take the large circulating current, but are not suitable for smaller motors or lighting unless they are taken out of the propulsion circuit and excited as constant voltage machines. Thus it is always necessary to provide constant voltage auxiliary generators as well as the propulsion generators. This is usually done by driving auxiliary generators in tandem with the propulsion generators and providing one or more separately driven auxiliary generators for harbour service—all of which adds to the number or machines to be accommodated in the engine-room. The tandem auxiliary generators particularly add to the confusion by increasing the length of the Diesel generator set and engine-room length is usually at a premium. One American firm tackles this problem by specially designed generators having the main and auxiliary generator armatures keyed to the same shaft and supported by one outboard bearing. The auxiliary generator has a short core length, larger diameter, and more poles than would normally be designed in a machine of its size, and the overall length of the Diesel generator set is greatly reduced.

The amount of auxiliary power to be provided varies with different ships. A trawler might require 20 to 25 per cent of its propulsion power for auxiliaries—chiefly the trawl winch. A salvage tug might require 15 to 20 per cent of propelling power, and a cargo vessel might require between 10 and 20 per cent of propelling power for auxiliaries, depending upon how many winches and how much refrigeration is installed. It is unfortunate that so many extra generators have to be installed to supply this load in a vessel already packed with electric power.

Alternating Current

General considerations. Alternating current is usually used for propulsion when the s.h.p. per screw exceeds 2,000 and where the prime mover is a turbine. It is particularly suited to turbines as the alternator is also a high-speed machine and no separate reversing turbine is then required. Synchronous motors are generally used for the propulsion motors. This requires that the propeller speed is a sub-multiple of the turbine speed, and must be controlled from the turbine throttle. Thus the alternating current used for propulsion is at variable frequency and is not therefore suitable for supplying all other auxiliary services.

Alternating current generators and motors have a big advantage over direct current machines in that they do not require large commutators. They can, therefore, be made totally enclosed without the hazard of carbon dust collecting inside the windings, and this enclosure enables them to be better protected against the inevitable leaks of steam, oil and water that are always likely to attack an open machine in a ship's engine-room.

If necessary, two or more propulsion motors can run simultaneously off the same alternator. They will of ocurse run at the same speed if synchronous motors are used.

Induction motor drive. In the early days of a.c. electric propulsion little was known about the torques experienced by a ship's propeller while manœuvring. Induction motors could be designed to have a good torque at low speeds and these were therefore used.

Later, when the manœuvring torques had been measured it was found that salient-pole synchronous motors could be given the necessary synchronizing torque, and these were adopted.

The alternators driving the early induction motors ran at constant speed which was a slight advantage, but the motors themselves were less efficient, heavier and more expensive than synchronous motors and had a poor power factor.

Synchronous motor drive. The starting torque of salient-pole synchronous motors was improved by fitting squirrel-cage damper windings in the pole faces. This enabled them to be started as induction motors and then synchronized when close to synchronous speed.

As well as being more efficient than induction motors, synchronous motors do not require such a small air-gap, and by running at approximately unity power factor, the alternator size can be reduced.

In some vessels, the variable frequency associated with synchronous motor drive has been utilized to drive main circulators and boiler fans at variable speed.

Synchronous motor drive is now employed universally for turbo-electric vessels up to the maximum power.

It is necessary to provide a supply of direct current for excitation of the alternators and synchronous motors. In ships with d.c. auxiliary supply, the excitation can be derived from the auxiliary busbars. This excitation must be increased while synchronizing the motors, and boosters are usually employed to do this. In a ship with a.c. auxiliary supply, the propulsion excitation is usually supplied from a motor generator set.

Alternating current drive using Diesel driven alternators. A few vessels have been built in Germany and at least one in America using Diesel alternators and synchronous motors, and one is being built in this country.

The American ship is a twin screw submarine tender of 16,000 tons displacement and 5,900 s.h.p. per screw. She is powered by eight 1,150 kW. Diesel alternators and also carries four 500 kW. Diesel generators. The installation in this vessel is reported to be successful and compares favourably with those of her sister ships which have direct current. The comparison of space, weight and cost for propulsion equipment is given below :—

	Space	Weight	Cost
Alternating current ...	1·2	1·0	1·0
Direct current	1·0	1·47	1·5

The success of a multi-engine a.c. propulsion installation depends very largely upon the ability of the engine governors to maintain synchronism and load sharing over the range 0-100 per cent power and 25-100 per cent engine speed. This is no mean engineering feat but appears to have been solved by the modern hydraulic governor. The governor can be given the characteristic that it will not deliver more than a safe amount of fuel to each cylinder per stroke and adjusts the "safe" valve in accordance with the speed. This prevents overload of the Diesel engines and limits their maximum torque. This is an advantage in a variable frequency a.c. drive as it reduces the chance of the engines driving the alternators out of step with their motors during rough weather or manœuvring. The torque of a turbine installation cannot be so easily limited, and its inertia is high, so that the alternators and motors associated with turbine drive must be designed for a higher torque margin and are therefore larger and more expensive than the equivalent machines powered by Diesel engines.

Auxiliary power in ships with a.c. drive. In general the propulsion alternators cannot feed the ships auxiliaries because their frequency varies. Certain auxiliaries whose speed is required to vary with propulsion power demand can be run from the propulsion alternating current supply but this is seldom practicable especially at slow speeds. Thus, separate generators must be provided for the auxiliary load. These generate direct current in almost all British ships, but many American and some German vessels have used alternating current.

Much is debated still on the relative merits of a.c. and d.c. for shipboard use. Direct current still survives, in spite of its commutators, because it is more suitable for speed variation and it is better known. Alternating current is less well known in shipping circles and admittedly is not directly suitable for cargo winches, but the simplicity of the induction motor makes it attractive where the load consists chiefly of centrifugal fans and pumps. The U.S. Navy has standardized the use of a.c. at 60 cycles, 440 volts, three phase for power and 110 volts single phase for lighting.

The proportion of auxiliary electric power required in a liner varies between 10 and 20 per cent of the propelling power. The auxiliary electric load of ships will probably increase as the "hotel amenities" are extended.

THE USE OF VARIABLE-PITCH PROPELLERS POWERED BY CONSTANT SPEED ALTERNATORS

General considerations

In the foregoing sections it has been shown that electric drive can be applied to all types of ship and for any power at present required. Hitherto, however, the propulsion plant has been treated separately and little attempt has been made to evolve one power system suitable for both propulsion and auxiliary services.

Direct current machines are unsuitable and cannot be used for the highest powers. They are more expensive and heavier than a.c. machines which are much to be preferred and would be almost ideal if only the propulsion motor could run at a constant speed. This latter requirement has become possible in recent years by the development of variable-pitch propellers to a practicable state. These can be driven at constant speed by synchronous motor, while all manœuvring is done by controlling or reversing the pitch of the propellers.

It is, therefore, postulated that the use of variable-pitch propellers powered by constant speed alternators would form a desirable drive for ships, and the possibilities of this system (for brevity referred to as the "Varpac" system) are explored in the succeeding sections.

Characteristics of variable-pitch propellers

The thrust of a variable-pitch propeller is controlled by varying its pitch while revolving at constant speed. The control station can be in the engine room or on the bridge.

The variable-pitch propeller has a maximum efficiency at one pitch only, all others are less efficient and the deficiency must be balanced against the other conveniences gained. Most ships cruise at the one "full away" speed and do not spend much time at others except when manœuvring when the convenience of bridge control would outweigh loss of propeller efficiency.

In general a variable-pitch propeller is less efficient than an equivalent solid propeller because the boss must be larger to accommodate the pitch changing mechanism. This feature is minimized by one manufacturer by making the blades of stainless steel so that they are thinner and more efficient than equivalent cast bronze blades.

The chief advantage which a variable-pitch propeller possesses over a fixed-pitch propeller is that it can give a higher thrust at a lower speed through the water. This is important in tugs and trawlers where the tow may slow the ship's speed down to only 3 or 4 knots. Under these conditions a variable-pitch constant speed, constant s.h.p. propeller will exert approximately 33 per cent more thrust than a fixed-pitch constant torque propeller. This feature might also be of value to cross-Channel vessels which often have to steam at high speeds in relatively shallow water. Under these conditions the ship's resistance increases and the variable-pitch propeller could help to maintain high speeds in shallow waters as well as being valuable in shortening the manœuvring time.

Some designs of variable-pitch propellers

The variable-pitch propeller is by no means new, but it has only recently developed into practicable designs by employing mechanisms which have been proved in Kaplan water turbines.

A Swedish firm uses a servo-piston inside the propeller hub to rotate the blades. Oil pressure for operating the servo-piston is introduced into the propeller shaft. A Swiss firm uses hydraulic power to control the blades but the servo-piston is inside the ship and operates a rod passing down the centre of the propeller shaft. A British firm, developing their designs from aeronautical practice uses a worm and wheel to rotate the blades and controls the worm from an epicyclic gear operated by a rod passing down the propeller shaft strut. An American firm has a design in which the pitch is controlled by a rod passing between the propeller boss and the rudder post, the rod being operated from the steering compartment. Many other designs have been published.

Of all these designs, the Swedish claim the largest power and the longest operating experience, having been fitted to a twin screw, 17-knot vessel of 7,200 tons gross and 3,500 s.h.p. per screw in 1944.

It is stated that all the internal mechanisms can be designed so that it is never stressed beyond 2 to 3 tons per sq. in. and that if the blade fouls anything, it is the blade and not the mechanism that will bend or break. The blades can be removed and replaced underwater without breaking any oil seals. The Swedish design incorporates a spring which will return the blades to the "ahead" position should the oil pressure fail.

"VARPAC" SYSTEM APPLIED TO VARIOUS KINDS OF SHIPS

Passenger liners (15,000-100,000 s.h.p.)

The prime movers would probably be constant-speed steam turbo-alternators and could work under good thermodynamic conditions taking full advantage of high pressure, high temperature and reheating. Two main alternators would provide power for propulsion and all auxiliary services including the "hotel" load. The main alternators would generate at 3,300 volts, while auxiliary circuits would be fed at 400 volts from transformers at load centres. This voltage would be transformed down to 110 for lighting.

In harbour one of the main alternator sets would run at partial load while the auxiliary and hotel load was high. One auxiliary turbo-alternator would be provided having a capacity equal to the auxiliary and hotel load. This would be a standby to the main alternators at sea and in harbour. No other turbo-alternators need be provided but smaller Diesel alternators would be required to supply power during boiler cleaning periods.

It should be possible to accommodate this machinery in the space usually taken up by two sets of geared turbines and the extra turbo-generator compartment would be dispensed with. The propulsion motors would be accommodated aft, and in a large vessel two screws could be driven by each of the port and starboard alternators.

The use of high voltage generation would cheapen the distribution cables. The anchor windlass and warping winch could be slip-ring induction motors. They do not run long enough for the waste of power in rotor resistances to be noticeable. Boat and baggage hoists could be slip-ring induction motors or squirrel-cage motors with double cage windings. Cargo winches would probably be d.c. motors powered from a motor generator set. Any requirements for direct current for battery charging, degaussing, radio, etc., would be supplied from motor generator sets.

Each alternator and synchronous motor would be provided with its own exciter and voltage regulator.

Cargo liners (8,000-20,000 s.h.p.)

The propulsion machinery arrangements would be similar to those described for passenger liners. The auxiliary load would contain a high proportion of refrigeration and cargo winches.

The refrigerating compressors would be driven by two-speed induction motors. The cargo winches would be run from a d.c. supply obtained from a motor generator set. The motor generator set would be driven by a synchronous motor which would be arranged to give power-factor correction while running thus easing the load on the alternator. If alternating current becomes popular in ships, the demand for a.c. cargo winches will be a problem demanding satisfactory solution. German and American firms have already started on this problem and claim some success.

For the lower propulsion powers (8,000-12,000 s.h.p.) Diesel-driven alternators might be used. These could be of any convenient number depending upon the size chosen. Some maintenance could be done at sea on idle engines although this pleasing objective is seldom realized in practice unless a special maintenance staff can be carried. It becomes more of a possibility if loop-scavenge or exhaust-piston Diesel engines are used as these have no poppet valves to be looked after.

Cargo ships (3,000-10,000 s.h.p.)

These would probably be single-screw vessels and Diesel driven. The number of Diesel alternators would be between four and eight. It would not be necessary to install more generating capacity than would supply full propulsion power and maximum sea-going auxiliary load. The relatively large cargo-winch load would be supplied by some fraction of the main Diesel alternators in harbour. Existing cargo ships must carry idle generating capacity all over the ocean in order to work cargo-winches in harbour.

The use of multiple Diesel engines might lead to lowering of costs by greater standardization and simplification of spare gear throughout a fleet.

Cross-Channel vessels (5,000-15,000 s.h.p.)

These could be powered either by steam turbo-alternators or Diesel alternators. The variable-pitch propellers would give good manœuvrability which should cut down docking time. They might also increase the speed in shallow water.

Whaling factory ships (5,000-8,000 s.h.p.+15,000 kW.)

These vessels carry a factory load of up to 30 per cent of their propulsion power. The factory is little used during the voyage to and from the grounds, and the propulsion power is not required while the factory is in use.

They would best be powered by multiple Diesel-alternators whose power was equal to propulsion plus say one third of factory requirements. This would effect a reduction of 20 per cent in installed generating capacity.

The factory machines are chiefly centrifuges, grinders and choppers and would be suitable for induction motor drive. The large winch required for hauling whales up on to the flensing deck could be steam driven as considerable boiler capacity must be carried for process steam.

The whale catchers should also be a.c. ships so that they can take power from the factory ship while lying alongside.

Dredgers (500-5,0000 s.h.p.)

Dredgers frequently carry dredging machinery whose power is comparable to that used for propulsion. They often require propulsion power at the same time as the dredging machinery is in use, for instance, to drag a suction pipe or push a cutter head.

The dredging machinery is either a bucket ladder, a suction pump, a revolving cutter head or a number of grab cranes. In general, alternating current is not immediately suitable for these drives. The bucket ladder motor, cutter motor, and grab hoist motors may be required to stall and inch, while the suction pump which may be up to 2,000 b.h.p. may be required to vary its speed. The use of hydraulic couplings might enable the other advantages of a.c. generation to be utilized without involving a higher overall cost than would be required by a d.c. installation.

The prime movers would almost certainly be Diesel engines.

Tugs (250-2,500 s.h.p.)

In this case the advantages of employing "Varpac" drive lie chiefly with the use of the variable-pitch propeller but "Varpac" enables multiple, smaller sized, Diesel engines to be used thus providing greater standby and availability.

Tugs frequently require extra power for salvage pumps, etc., and this could be easily provided in a "Varpac" vessel. Some of the propulsion power could be used for salvage work which is done while the vessel is not underway. There would be no need to install extra generators for this purpose.

Trawlers (500-1,500 s.h.p.)

Trawlers require the same propelling characteristic as a tug and therefore the "Varpac" system enables two or more Diesel alternators to power a single variable-pitch propeller.

The other requirement of a trawler is to produce up to 25 per cent of its propelling power at the trawl winch. This has to be used frequently and may be stalled for several minutes at 2½ times normal torque. This requirement could not easily be produced by an a.c. motor, and it would be necessary to provide a motor generator set to power a variable voltage d.c. motor, or else use a hydraulic coupling or variable delivery hydraulic pump.

Engine-room space is at a premium in a trawler as any space gained means longer range or more fish. Trawlers are now carrying more and more auxiliary equipment including refrigerators and these are easily driven by alternating current.

FUTURE POSSIBILITIES OF "VARPAC" SYSTEM

Gas-turbine prime-movers

Gas turbines are now being developed for marine use and are demanding some forms of reversing propeller. The use of "Varpac" drive with gas turbines will enable the layout of the prime-movers to be more flexible, not being tied to their propeller shafts. It will also enable the turbines to run at a constant speed.

It is being found that the heat exchanges and gas ductings are very bulky and almost decide the layout of a gas-turbine plant. It might be more convenient to provide one central plant instead of port and starboard sets, the one alternator driving port and starboard screws. The very natural desire for standby propulsion power could be provided by fitting Diesel alternators for harbour use and making their capacity equal to one fifth of the propulsion power. This would propel the ship at nearly half speed while still leaving power to spare for auxiliaries.

Atomic Energy

An atomic energy plant would almost certainly not be duplicated into port and starboard sets. Two turbines could be run from one atomic "boiler" but it is unlikely that two piles would be fitted owing to the large amount of protective covering required. Thus the "Varpac" drive would enable one atomic energy plant to be used for any number of propellers and all auxiliary services. Standby Diesel engines would again be fitted.

CONCLUSION

It is fully realized that the proposed "Varpac" system is at present somewhat outside the range of immediate practicability. It will take some time before the shipbuilders, who are rightly cautious, will be willing to experiment with variable-pitch propellers or a.c. ships. However, this essay is submitted as a serious attempt to indicate a possible line of progress in marine engineering.

ACKNOWLEDGEMENTS

The author has drawn freely upon available literature on electric drive, etc., and references are quoted in the final section.

The author wishes to acknowledge that similar views were expressed by a contributor to the discussion on the papers read at the Institute of Marine Engineers in June 1944 entitled "The Engining of Post-War Cargo Vessels of Low Power", Transactions, Vol. LVI, p. 88).

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THE ANNUAL GOLF COMPETITION

1. R. Harvey
2. J. S. Clayton-Marshall
3. W. Sampson
4. The prizes
7. F. Sands
5. W. Tennant and J. A. Rhynas
6. W. H. Gregory