THE MAINTENANCE AND REPAIR OF BRONZE PROPELLERS

BY

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Introduction

It is the object of this article to describe briefly the main causes of propeller deterioration, and the proper treatment that a propeller should receive if a long working life is to be obtained from this often neglected but vital part of the ship's machinery. It is probably one of the most highly stressed parts, and has to operate continuously for long periods in a corrosive medium without any running maintenance whatever. The tip regions of propeller blades move at very high speeds relative to the water, and tend to suffer wear or wastage by corrosion. A long experience teaches that roughness begets yet more roughness, and there is no more potent cause of propeller deterioration than failure to keep the surfaces in a clean and smooth condition. Moreover, a propeller is inevitably in a highly vulnerable position and liable to physical damage. The results of casual, uninformed and hurried repair and continued neglect of a propeller can seriously shorten the useful working life or even cause premature failure.

Normal Corrosion of Propeller Bronzes

A bronze propeller lying in still or slowly moving sea water would lose less than two-thousandths of an inch of surface metal every year, provided that the composition was such that insidious corrosion by dezincification was fully inhibited. The wastage by corrosion over the blade tip region of a clean undamaged manganese bronze propeller working at its design revolutions, involving relative water speeds of 50ft per second or more, would normally be greater than this by a factor of three or four. A higher factor is to be expected in the case of certain types of propellers, notably those fitted to trawlers and tugs operating under conditions that are unavoidably far from ideal. This normal corrosion results in the loss, in the first few months of service, of the initial high surface finish, and propellers in manganese bronze become somewhat rough to the touch, this being a result of the duplex micro-structure of this group of alloys; this effect is much less evident in the case of the single-phase complex aluminium bronzes of which the well-known Nikalium nickel aluminium bronze is typical.

The Causes of Abnormal Wastage

The rates of corrosion or wear mentioned above, if maintained throughout the life of an undamaged propeller, would give a useful life of 20 years or more, and the materials used to-day for propeller manufacture are well capable of ensuring this.

However, long experience of propeller behaviour indicates large differences between the expected life and the life actually achieved by different propellers

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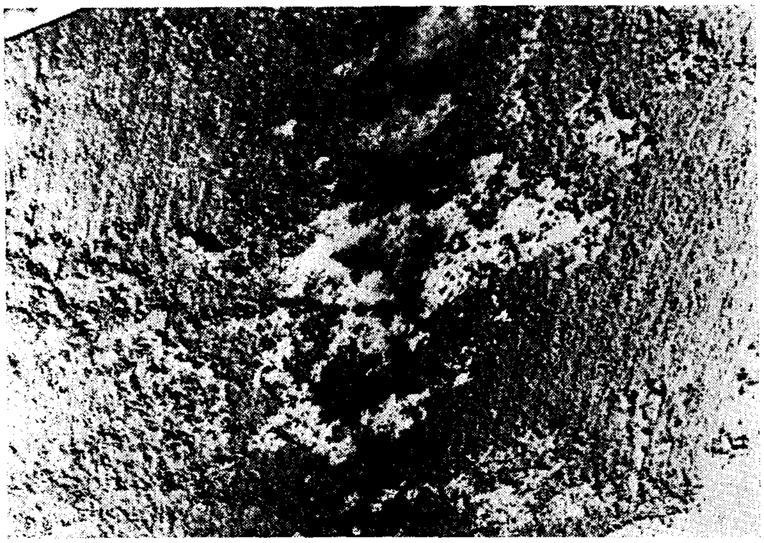

FIG. 1—DAMAGE CAUSED BY LOCALLY-REMOVED CATHODIC CHALK DEPOSIT

of virtually identical composition, differences that cannot wholly be accounted for by reference to the type of service.

It is only rarely that a short life is the result of an abnormally high rate of general wastage, and, conversely, a propeller of a well-chosen composition, that is uniformly worn after two to five years' service, will generally continue to give a satisfactory life; the majority of large propellers behave in this way. Frequently, however, an abnormal type of local wastage is observed in the form of severe pitting and small locally attacked areas between mid-blades and tips on both sides and at, and close to, the leading edges. The smaller propellers of less than 5 tons in weight appear to constitute the larger proportion of those that are found in this bad condition.

Wastage, whether general or of this far more damaging localized type, is basically a process of corrosion, and must, therefore, be expected to be largely controlled by the electro-chemical characteristics of the surface. The severe attack that can take place on relatively small anodic areas adjoining large cathodic surfaces is well known, and it has been shown that the high corrosion rates that result from such conditions are further markedly increased when the surfaces are exposed to high velocity turbulent water streams, because the activity of the local cells is maintained at a high level. Although there are other factors associated with the hull and the flow of water into the disc that are thought to affect the wear of a propeller, in the majority of cases abnormal wastage is a corrosion phenomenon.

The blade surfaces of a new propeller may develop an undesirable condition during the first few weeks of immersion in water. The new propeller is highly polished and clean, an ideal condition that, if continuously maintained, would give the longest possible life. When fitted and immersed in sea water it becomes the cathode in the hull/propeller electrolytic cell, and during a fitting-out period a thin, hard and strongly adherent coating of magnesium and calcium carbonates is formed on all surfaces. During the first few months of service this cathodic chalk film normally becomes worn away in a patchy manner near the blade tips. At these local areas, and at any other areas where for some reason the formation of chalk has been delayed or prevented altogether, particularly at and near the blade tips and the leading edges, corrosion proceeds at an abnormally high rate, being stimulated by the surrounding chalk-covered cathodic surface. In a short time these areas become sensibly depressed, and suffer a marked increase in the corrosion rate due to the onset of what may be described as microturbulence. Roughness on a scale of only a very small fraction of an inch causes minute eddies in which rapid fluctuations occur in incident angle and velocity of the water relative to the metal, an action that constitutes 'turbulence'. The successive and repeated cycles of stagnation and impingement cause a manifold increase in corrosion rate, the effect increasing as the scale of the roughness becomes larger. These small

FIG. 2—EFFECT OF PAINT SPLASHES ON PROPELLER BLADE

anodic bare patches are soon being vigorously attacked. Shallow depressions rapidly become deep pits, and in two or three years the pitting can be of such severity as to necessitate the removal of metal equivalent in thickness to many years of normal service in order to remove the roughness. The severe local pitting at areas on a propeller blade, where the white chalk film has been destroyed, is illustrated in FIG. 1.

Protection Before and During Fitting-Out

It is considered to be of great importance that the formation of a cathodically precipitated chalk film should be prevented. During a fitting-out period the conditions for this to occur could hardly be improved upon, because there is an excellent electrical connection between propeller and hull through the stationary propeller shaft, and the water is virtually stagnant.

The chalk film can be prevented from forming by excluding the sea water from contact with the propeller and this can be done by the application of a thick coating of waterproof grease to the propeller immediately before launching.

Mention should be made of protection provided to new propellers during transit to foreign parts. The propeller is covered with a coloured plastic film, and this coating should be stripped off before the propeller goes into service, care being taken that the highly polished blade surfaces are in no way damaged. In the case of a new building the coating is an adequate protection against the formation of a chalk film, and should be left in place during the fitting-out period, any bare areas being coated with waterproof grease before launching. The coating must be stripped off at the end of the fitting-out period.

The Effect of Painting and Casual Paint Splashes

A coat of paint will prevent corrosion so long as it remains intact, but no paint film has been shown to resist for long the effect of the abrasive solids in sea water, or of local cavitation caused by leading edge deformation. There is evidence to suggest that those types of paint that become pervious to sea water and ionically conducting can give rise to an increased rate of wastage at bare areas in much the same way as a chalk film can. The use of impervious paints, such as the solventless epoxies, has also been considered, but there is still a possibility of local pitting at damaged areas and there are difficulties in the way of satisfactory patching. For these reasons the use of any type of paint on propellers cannot be recommended.

Splashes of conventional anti-corrosive or anti-fouling paints on a propeller are undesirable and a propeller should be covered during hull painting. The effect of splashes of conventional anti-fouling paint on a propeller is illustrated in FIG. 2.

Routine Attention to Propellers

The formation of a chalk film cannot occur while a propeller is rotating, as it is necessary for the alkali to remain close to the cathodic propeller surface, at which it is formed, long enough to precipitate calcium and magnesium hydroxides, and for these to change to carbonates by absorption of carbon dioxide from the sea water.

However, any period of inaction affords an opportunity for a chalk film to form over the whole propeller, and the waters of some harbours and docks are more conducive to film formation than others. While that on the outer parts of blades will normally be removed during the voyage and even be reformed thinly on each sojourn in port, nearer the blade roots the chalk deposit will build up, together with fixed corrosion product and is capable of increasing the corrosion rate of bare areas nearer the blade tips.

If the longest possible life is to be obtained from a propeller it is of the greatest importance that the damaging effects of a non-uniform condition of the surfaces should be avoided as far as possible. To this end, the propeller should be cleaned and polished all over at regular intervals of not more than two years, and preferably every year. It is just as important to remove chalk and corrosion product deposits from the propeller boss and the inner part of the blades as to clean and polish the tips and leading edges. Any local pits or more widespread roughness, however slight, can in time give rise to a need for repair rather than for a simple repolishing operation.

A propeller that, through neglect, has become roughened can generally be put right by light grinding and polishing if the pits and depressions are no more than a millimetre deep. More serious damage should be dealt with only by the manufacturer, because in inexperienced hands the heavy grinding involved can lead to a loss of efficiency as a result of local alterations to pitch and edge angles, and possibly local cavitation damage and an increased rate of wear. If time does not permit this the roughness can be temporarily removed with one of the many synthetic resin fillers or putties now available.

Cavitation-Corrosion

The basic cause of cavitation will not be dealt with here. It is sufficient to say that all propellers work in a variable and complex wake stream and it is very difficult, in some cases, to avoid breakdown of flow at some point in each revolution. The larger and more heavily loaded the propeller the more this is likely to occur, although with the most modern designs of propeller the resulting erosion is relatively unimportant, and generally negligible even after years of service.

The design has clearly been very largely successful in avoiding cavitation, and is greatly assisted by discussions, during the early stages of ship design, on such matters as propeller dimensions and blade tip clearances. It is at all times good practice to examine blade surfaces carefully for indications of cavitation erosion during the early life of a propeller, because a timely modification of blade section can do much to reduce the loading at critical areas. These modifications cannot be regarded as coming under the head of a routine or maintenance polishing, and need to be done by the manufacturer under the supervision of his propeller design department.

Effect of Roughness on Efficiency

The effect of roughness on the performance of a propeller has been the subject of much research work in this country and abroad. There does not appear to be any agreement yet about it, due largely to the uncertainties associated with the translation of the results of work on models to the full scale. Practical experience, however, indicates that there is no significant

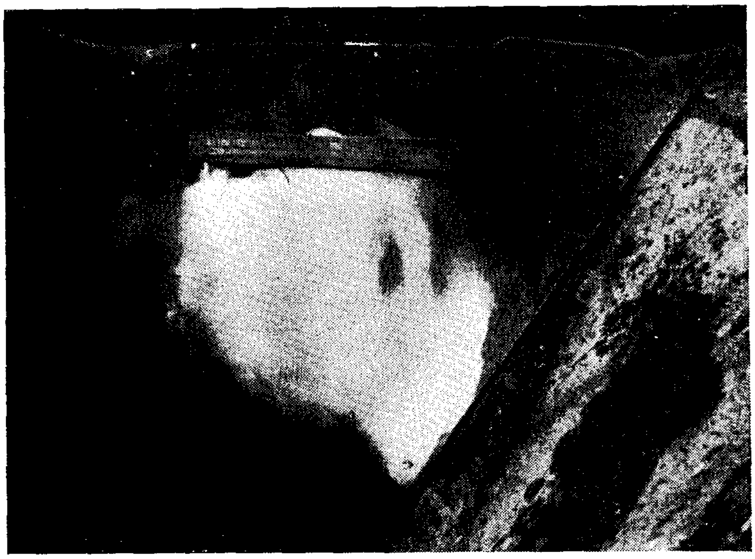

FIG. 3—TYPICAL CRACK IN PROPELLER BOSS

difference in efficiency between a new propeller and one with the normal slightly roughened surface resulting from 12 months' use. However marked roughness, measurable in millimetres, may have an adverse effect on performance because the component of drag will tend to be increased, and in the case of older ships this can cause an increase in running costs which can remain undetected.

These considerations provide another reason for regular maintenance of a propeller.

Minor Physical Damage

Minor tears, cracks, bruises and especially local edge deformation, should receive attention as early as possible, especially if the leading edges towards the tips have suffered. Deformed leading edges create a condition of disturbed flow or turbulence for a considerable distance onto the blade surfaces, tending to cause a widespread increase in general wastage or even of serious cavitation damage.

Removal of Propellers

It is convenient here to mention certain aspects of the operation of removing a propeller that come under the heading of 'Maintenance'.

The author is aware of an increasing incidence of cracked bosses of manganese bronze propellers, that more often than not has involved the replacement of the propeller. There is no doubt that this damage is an example of stress-corrosion cracking, the mechanism of which is fully dealt with in a later section of these notes. The cracks are generally, but not invariably, found to be curved concave toward the forward end of the boss, and appear to enclose a roughly circular area from 4in. to 12in. in diameter. (See FIG. 3.) The cracks are a direct result of high internal stresses induced by high temperature locally applied flames, used with the object of heating the boss to facilitate removal from the shaft. Heating with oxy-acetylene and oxy-propane is the most dangerous, and if it is absolutely necessary to apply heat to remove a tight propeller, a paraffin or air-gas burner should be used, kept constantly moving over each section of the boss between the blades, and not permitted to dwell for a moment in any one position. Only if this procedure is followed conscientiously and without hurry may the danger of cracking be avoided.

It is to be noted that the cracks do not appear until the propeller has been reimmersed in the sea, or stored in a marine atmosphere for a few weeks, and never during the period it is being handled in the dock. The evidence of the malpractice is, therefore, only brought to light at a subsequent dry-docking. No case has ever been reported of a Nikalium nickel aluminium bronze propeller cracking from this cause.

This first Part of this article has dealt with the effects of corrosion and associated phenomena and with general maintenance. Parts II and III will be concerned with procedures for dealing with physical damage.

PART II

By no means the least of the advantages of bronze for marine propellers is that inadvertent damage can be repaired easily and reliably. New metal used to replace that lost, or cut away in the course of a repair, can be virtually identical in composition, corrosion resistance and strength to that of the original propeller. It is the object of this Part of the article briefly to discuss the metallurgical principles of correct repair procedures, and to point out how these principles should be applied to the simple and urgent repairs that must occasionally be carried out by yards in various parts of the world.

A correctly executed repair is reliable and permanent, and within the limits of what can be done by hand, the operations involved are not complex nor do they demand the use of other than simple straightening tools and the heating and other equipment to be found or easily contrived in any repair yard.

Failure of Repairs

The majority of yards willing to carry out minor propeller repairs perform the operation of straightening and fairing satisfactorily, yet many repaired propellers in manganese bronze subsequently fail in service by the appearance of cracks running into the blade from the edge. It is characteristic of this type of cracking that it need not be associated with any mechanical damage, and it is a sure indication of the use of incorrect repair procedure. The errors made are not, and cannot be expected to be obvious, and if they are to be avoided, a knowledge is required which, unlike manipulative skills, would not necessarily be acquired by experience. Accidental damage to a propeller is usually known to have occured, and an early opportunity is taken to make an inspection, but cracking following a repair is a different matter. Not only is it avoidable, but because of a long delay period that occurs before the cracks appear, a propeller may be used for months with unsuspected cracks in its edges, during which period it is liable to damage of a more serious nature. If a crack exceeds a critical length, which appears to be no more than about 1in., and the cracked blade should receive a blow or heavy thrust near the tip of sufficient force to deflect it elastically, the crack can initiate a fast, low energy strainless fracture which invariably crosses the blade to the opposite side, and a large portion of blade may be lost in this way. These fractures exhibit all the characteristics of what is now well known as brittle fracture, and are known to have been initiated in propellers in both manganese bronze and complex aluminium bronze by fissures and cracks caused directly by damage, and by discontinuities present in defective welds at blade edges. Their incidence is not influenced by the type, condition or composition of the material, nor do they appear to be connected with any determinable mechanical property.

Effects of Heating

Dealing first exclusively with manganese bronze propellers, attention must be paid to certain metallurgical characteristics of the material if the repair is to be reliable and trouble-free in subsequent service.

Propeller bronzes are required to possess a high yield point and tensile strength and while perhaps very slight blade edge deformation could be knocked back cold with heavy blows against a massive hold-up, the inevitable bad edge fairing, bruising and high internal stresses created by the reversed bend do not recommend this sort of treatment at any time.

Heat is essential to render the metal soft and plastic for easy manipulation, and the comparatively low temperatures required are readily obtained even in the open with conventional heating methods.

On subjecting cast manganese bronze to an increasing temperature, the first effect of importance is encountered at about 300 degrees C. At this

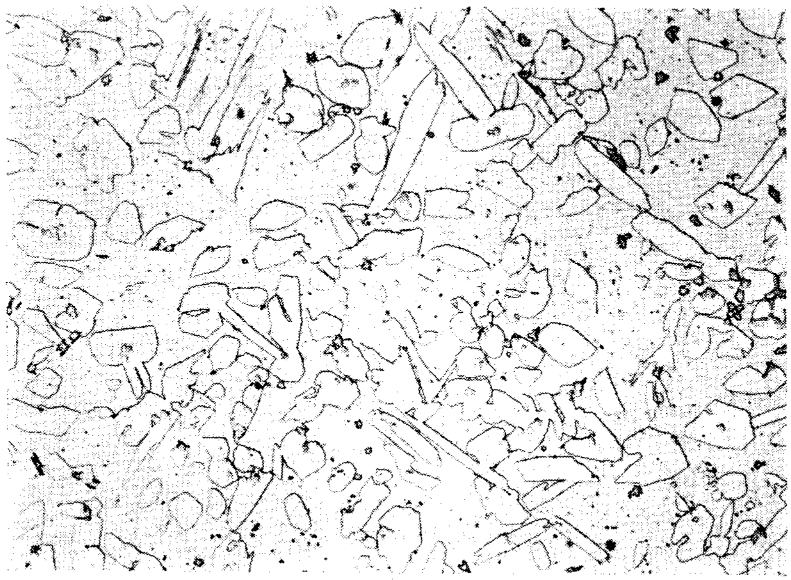

FIG. 4—P.M.B.2.C. AS CAST

temperature the material becomes incapable of withstanding a sustained load because of rapid creep, and the stress in a test bar strained in a rigid frame would be relaxed rapidly, until in a few moments only a small fraction of the original stress would remain. This is the important effect that permits of the removal of internal or locked-up stresses, and the temperature of 300 degrees C. lies within the range used for stress-relief heat treatments. On further heating, the bronze would enter the hot working range at about 550 degrees C., and become soft and increasingly plastic as the temperature is raised still further to an upper limit which for practical purposes of repair can be put at 750 degrees C.

It is to be noted that an important micro-structural change takes place on heating manganese bronze into the hot working range; in propeller blade sections the structures of the alloys currently used by the author's Company revert to the normal on cooling freely in air to room temperature. FIG. 4 shows the structure of the well-known manganeze bronze P.M.B.2.C. in the region of the tip of a propeller, and FIG. 5, the structure after heating into the hot working range and cooling freely in air. It can be seen that the only difference between the as-cast and the re-heated material is that the grain size of the alpha phase in the latter is slightly refined.

Nature of Stress-Corrosion Cracking

Manganese bronzes of any description, together with nearly all alloys and many non-metallic materials can suffer from stress-corrosion cracking when exposed to the conjoint action of a tensile stress and a usually specific corrosive environment. The basic mechanism of the phenomenon is not yet understood. The limiting stress is ill-defined, and it is axiomatic that no working stress in a propeller can conceivably reach the level attainable by internal or locked-up stresses. The specific agent in the case of manganese bronze propellers is possibly the chloride ion in clean sea-water, although there is some evidence that it is some, as yet unidentified, agent present in the less pure waters of estuaries, docks and harbours. There is invariably an induction period before cracking occurs, and the shortest period known in the case of manganese bronze propellers is 10 weeks.

As it is imposssible to avoid the corrosion factor, it is essential that a repaired manganese bronze propeller is put back into service free from the high local internal stresses that can so easily be created during repair.

Creation of Internal Stress During Repairs

When a local area of any metal is heated it expands, exerting a force on the surrounding cooler and rigid metal until it reaches the temperature at which

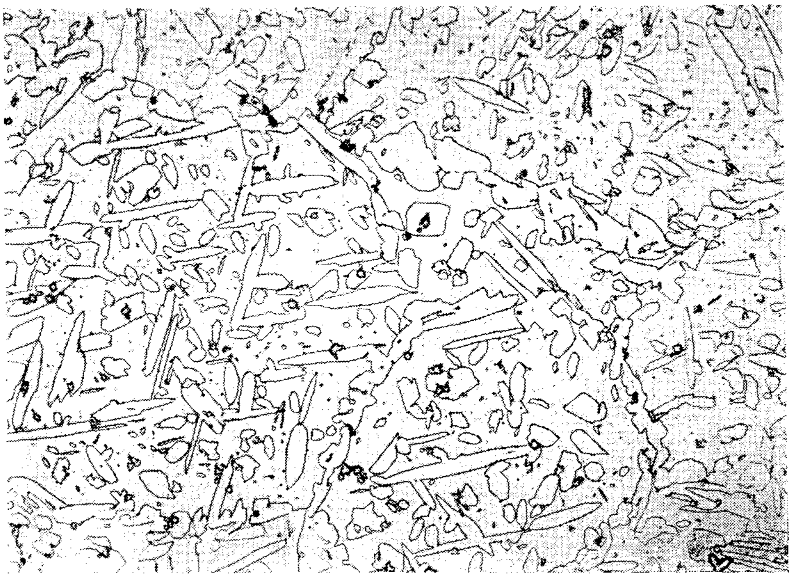

FIG. 5—P.M.B.2.C. AIR COOLED FROM 700 DEGREES C.

the compressive stresses are relieved, this being about 300 degrees C. in the case of manganese bronze. As the temperature rises, plastic flow takes place at lower and lower stresses, until at a red heat, the internal stresses can no longer exist. On cooling, the heated area contracts, and the reversed and now tensile stresses are similarly relieved by plastic flow until a temperature is eventually reached at which stress-relief becomes very slow, and at about 250 degrees C., ceases altogether. The material becomes able to withstand the increasing contraction stresses, and with manganese bronze below the temperature stated, the thermal contraction becomes tensile strain, creating internal stresses that can reach a value of over 25 tons per sq. in., or about ten times the working stress on the most highly loaded parts of a propeller.

When considering the creation of the stresses and also their removal, nothing is significant except the cooling process from about 300 degrees C. to room temperature.

Internal stresses can appear only if the 300 degrees C. isothermal forms a closed loop surrounding material above this temperature, or is markedly concave towards a free edge at the moment when cooling begins and the isothermal starts to move inwards. With certain provisos, the thermal stress developed by contraction is independent of the radius of the heated zone, but it is important to note that this must be small in relation to the far limits of the whole mass.

A small repair, such as the fairing of a dented propeller blade edge carried out in the most obvious way, is more than likely to create just those conditions liable to leave dangerous stress in the repaired area, with a high probability of cracking within a few weeks of service. Close to the heated zone, the stresses would be highest at the blade edge and parallel to it, and lowest normal to the edge. Since stress-corrosion cracking takes place under the influence of tensile and not of shear stress (possibly because the phenomenon is not a direct result of stress *per se*, but of the resulting strain), the cracks always run normal to the direction of the principal tensile stress. They start, therefore, normal to the blade edge, and propagate in a direction which tends generally to follow the boundary of the original heated area. FIG. 6 shows a typical stress-corrosion crack caused by edge repair, and the wide gap at the mouth is an indication of the high elastic stress relieved by the crack. The incidence of cracks following repairs appears to be highest when small edge deformations have been corrected. Burning-on, a particularly convenient process for the replacement of both small and large areas of blade is also liable to create high local stresses, generally followed by stress-corrosion cracking if the area involved is small.

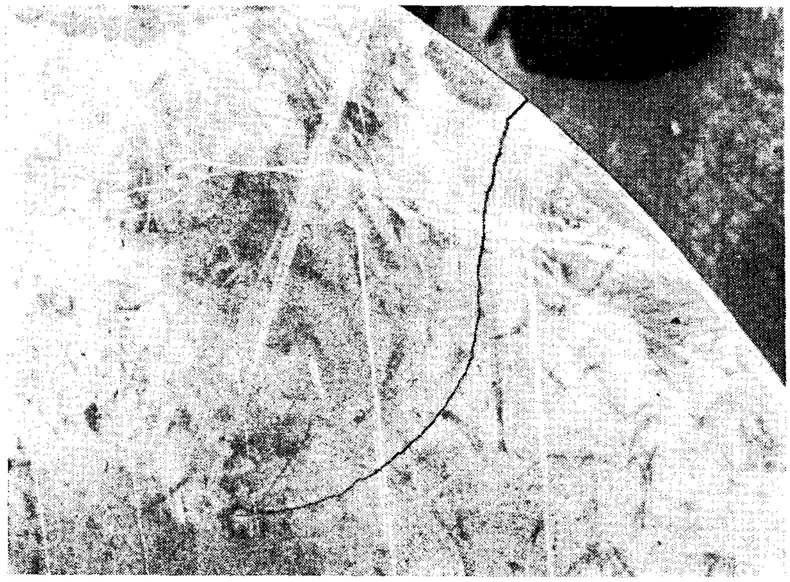

FIG. 6—TYPICAL STRESS-CORROSION CRACK CAUSED BY EDGE REPAIR

Metallic arc welding similarly can give rise to residual stresses sufficient to cause cracking, although the tendency is less marked.

Mention has already been made in Part 1 of stress-corrosion cracks in propeller bosses caused by rapid and localized heating of boss walls, and a typical crack is shown in FIG. 3.

Prevention and Removal of Internal Stress

To remove a dangerous internal stress requires a stress-relief treatment, a procedure with which all those concerned with the fabrication of structures by welding must be familiar. It involves heating the part to a temperature at which the stresses are relaxed to an innocuous level by plastic flow, and then to cool it in such a way that no new stresses can be introduced. As has been stated, internal stress in manganese bronze is effectively and rapidly removed by heating into the temperature range 300-350 degrees C., and it will be clear that to reheat to this temperature a similar zone of a propeller blade to that heated for purposes of the repair would merely re-introduce the original stresses on cooling. If, however, the isothermals for the range 300-500 degrees C. are arranged to be straight at the moment when cooling begins, and remain substantially straight during cooling down to the ambient temperature, the mass of metal will then be free from stress. If the repair requires a small area of the blade to be heated to redness, a gas flame of some type will be used, and it is obvious that the faster the zone to be worked on is heated, the steeper will be the gradients, and the more will the heated area tend to be localized. This undesirable condition can be mitigated by heating slowly, and this is the first precaution to be observed. By re-heating the outer part of the blade, including the area of the finished repair, so that the isothermal lines for the 300-350 degrees C. range will run across it, these lines will be straight enough for all practical purposes, and a substantially stress-free condition when cold will be realized. There are other more involved stress-relieving techniques that may be applied in special circumstances, but it has repeatedly been shown by experience that the simple procedure described is effective.

In the case of repairs involving welding or burning-on, the source of heat cannot be used for general heating of the blade, and stress-relief must be effected as a separate and final operation.

Nickel-Aluminium Bronze Propellers

There are certain metallurgical differences in structure and properties between nickel-aluminium bronze and manganese bronze that affect some of the procedures of which the basis has already been discussed. Nickel-aluminium bronze is basically a single-phase alloy, and in contradistinction to the behaviour of manganese bronze, the structure persists with no significant

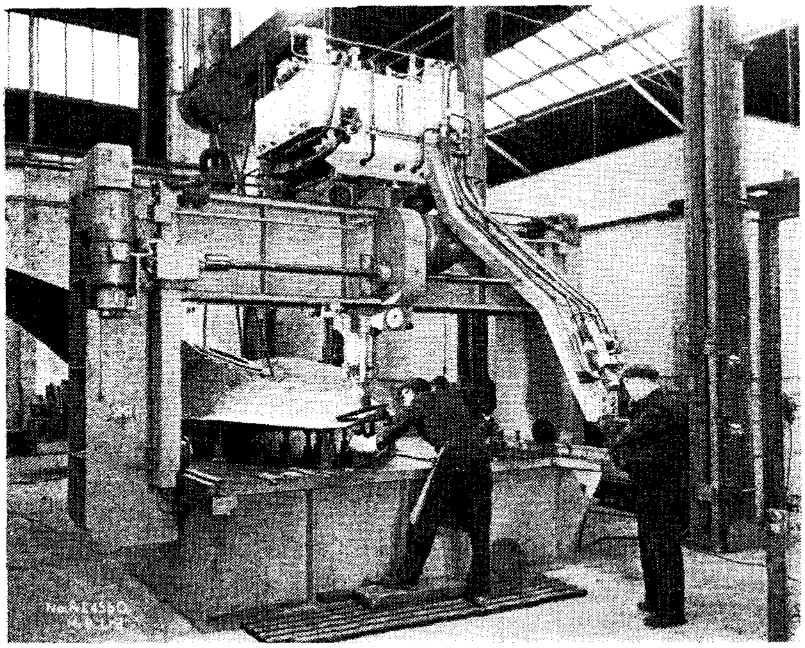

FIG. 7—PROPELLER BLADE STRAIGHTENING PRESS

change on heating to temperatures above those at which the hot working operations of repair would normally be carried out. To render the material sufficiently soft and plastic for the correction of deformation, it is necessary to heat into a temperature range lying 100 to 150 degrees C. above that suitable for manganese bronze, and because of the lower thermal conductivity, it is particularly important that the rate of heating should be slow and uniform.

'Nikalium' nickel-aluminium bronze is not liable to stress-corrosion cracking in sea-water, and it is not necessary to take any special precautions to ensure that contraction stresses are eliminated, nor to apply to a stress-relief treatment as a final repair operation.

PART III

Limitations of Dock Repairs

Repairs to propellers on the shaft present many difficulties not encountered in the works. The position of the propeller and the working conditions generally introduce considerable hazards not conducive to careful and accurate work and, in these circumstances, the first approach to the repair of minor damage should be to consider what is the least that must be done to keep the propeller temporarily in service, bearing in mind that the limitations of hand work and of heating by hand-held burners are soon reached.

Slight edge deformation may be left alone. Gashed and torn blade tips may be cut back, together with a similar cut on the opposite blade if balance is likely to be seriously upset. Cracks in blade edges however should not be left unattended for the reasons already given, and the best temporary measure is to locate the end of a crack at both back and face of the blade, and to drill a hole through large enough to include the whole crack front, the edges of the hole being finished to as large a radius as possible and smoothed off.

A slightly damaged but still usable propeller could well be a better risk in the long run and more easily put right later, if it were left alone rather than hurriedly repaired under difficult conditions.,

At the other end of the scale is the seriously damaged propeller, perhaps with deep blade deformation. In such a case, large areas of blade must be heated, sometimes in a non-uniform manner to control the return bend, and thick sections in large propellers, even in a hot and plastic condition, require forces attainable only by special purpose hydraulic presses (FIG. 7).

Stress-relief after repairs to heavy sections near blade roots generally involves the treatment of the whole propeller, and this and other considerations recommend that work of this nature should be left to the manufacturer.

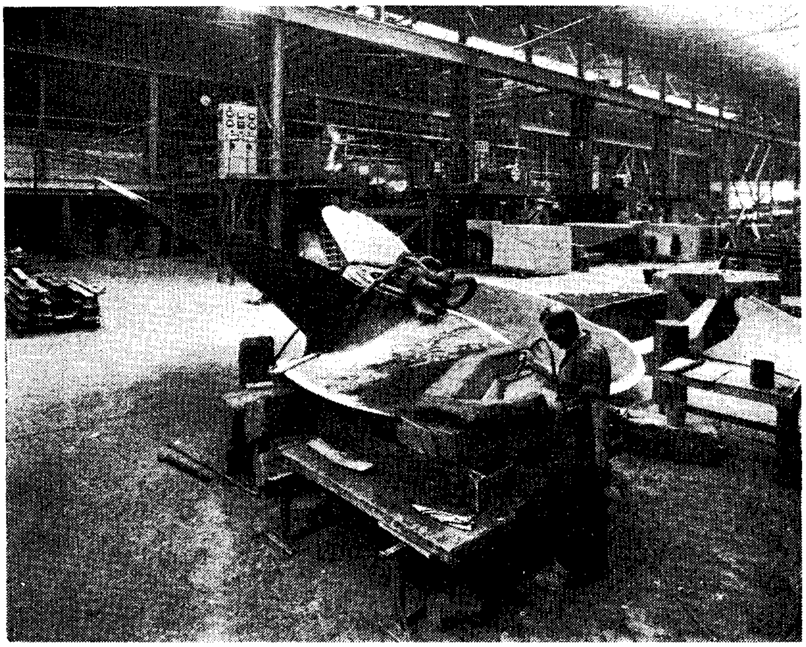

FIG. 8 — PREPARATION FOR REPAIR BY BURNING-ON

General Repair Practice

It is not proposed to detail practices that may be said to be contained in the art of the smith, the foundryman or of any other of the skilled trades that may be employed. It is assumed moreover that the propeller would be off the shaft and under cover.

The repair of the majority of damaged propellers involves at least one of three repair operations, viz.:—

(1) Straightening of deformed blades.

(2) Welding, used for local space filling, building up edge tears and cracks, and, especially in the case of aluminium bronze propellers, for replacing lost metal by welding-in pre-cast sections.

(3) Burning-on, a process in which a sand mould is built on and round the propeller blade to contain a cast section from which a replica of that lost from the blade can be produced by chipping and grinding. A surplus of liquid metal provides the source of heat to fuse the prepared edges of the parent metal, so joining the new to the old to give an homogeneous whole, see FIG. 8.

Generally, a manganese bronze propeller would require a stress-relieving treatment as a final operation after any of these three processes.

Straightening of Blades

This operation requires considerable experience if the deformed blade is to be brought back correctly to pitch and track and the edges are to be fair. Except for minor edge damage, where fairness by eye can be acceptable, a deformed blade must be marked out from the propeller drawing and the area and amount of distortion determined.

The marked out zones of distortion and the largest possible surrounding area is heated slowly into the range 550 degrees C. to 750 degrees C. for manganese bronze and 700 degrees C. to 850 degrees C. for aluminium bronze. While a proper indication of temperature should be obtained by one or other of the means referred to later, the ranges given afford sufficient margin for an estimate of temperature by an experienced eye to be reliable enough for all practical purposes. For reasons already given, heating must be slow, and it is hardly possible to over stress the importance of this point. A most effective way

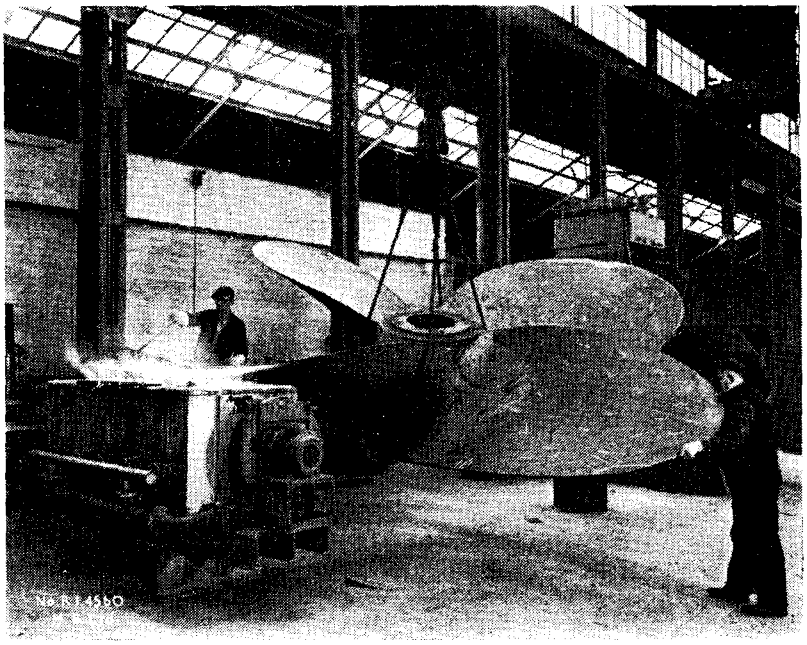

FIG. 9—HEATING FOR STRAIGHTENING BY MEANS OF A COKE BRAZIER

of achieving this is by the use of a fan-blown coke brazier, iron sheets being used to control the heating area as shown in FIG. 9. Alternatively, coal-gas, air-propane or paraffin burners giving a soft flame could be used, and any supplementary heating burners using oxygen must be kept continuously moving, because a few seconds in one spot is enough to melt a superficial layer that may contain cracks on cooling. Whatever method of heating is employed, an endeavour should be made during the early stages of heating to keep the blade edges generally hotter than the thicker central parts, and a special note should be made of this point when nickel-aluminium bronze propellers are being dealt with.

For the correction of deformation within the limits of what can be done without the use of a straightening press, strongly made long handled bending forks are used, the fork ends being provided with welded-on pads to avoid indentations in the softened metal. A range of sizes of these tools is useful, supplemented by wood or hide mallets for final edge fairing and for work on small propellers.

A common fault is to attempt straightening at too low a temperature generally a result of an endeavour to finish the work without reheating. An area about one foot square at a propeller blade edge near the tip remains in the proper hot working range for about five minutes only.

The work done is checked by a straight-edge laid down the radial lines marked on the blade, coupled with a judgement by eye of fairness down the edges. Temperature gradients through the thickness of the blade must be guarded against, since they will become evident as a drop or lift of the blade tip as it cools down.

Welding

Either metallic arc welding with coated electrodes or the gas shielded metal arc process using bare wire can be used. Carbon arc or argon-shielded tungsten electrode welding have been used to a limited extent, but the quantity of heat put into the work is an undesirable feature of these methods.

No bronze propeller should be preheated before welding whatever process is being used.

On manganese bronze, flux-coated phosphor bronze arc welding electrodes with 7-9 per cent tin give good results. This material does not give rise to any

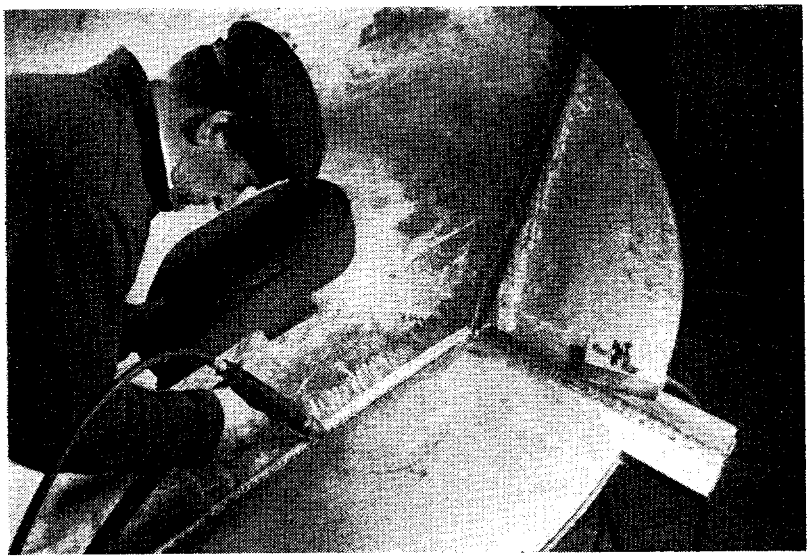

FIG. 10—REPLACEMENT OF TIP OF LARGE NICKEL-ALUMINIUM BRONZE PROPELLER BY WELDING ON PRE-CAST SECTION BY THE GAS SHIELDED METAL ARC PROCESS

brittle or otherwise undesirable inter-facial alloys with normal base metal dilution, and the strength of the de-posited weld metal is comparable with that of the material in the propeller. While the most reli-able repairs to man-ganese bronze are those made by bur-ning-on, welding is satisfactory for space filling, for the repair of small edge cracks, and for the replace-ment of small miss-ing areas near blade tips, using pre-cast sections. The use of phosphor bronze electrodes offers the advantage that the stress-relief treatment can be avoided by spreading each run of weld metal by hammering after it has been cleared of flux and has cooled. It is necessary in this case to deposit successive weld beads no faster than will ensure that the parent metal adjacent to the weld does not at any time during the operation reach a temperature higher than 200 degrees C.

Propellers in the special aluminium bronze 'Nikalium' are readily welded with flux coated metallic arc electrode, or by the shielded inert gas metal arc process, which is by far the better. The ternary aluminium bronzes containing iron or manganese may be used as electrode material in either process, but the deposited metal suffers rapid wastage of up to a millimetre in a year when exposed to high relative water velocities near the tips and edges of propeller blades. Alloys containing not less than 3 per cent each of nickel and iron exhibit a corrosion resistance comparable to that of the parent metal, and for this reason are preferable for all but temporary repairs.

The welding-in of pre-cast sections, as shown in FIG. 10, is the best and most convenient method of replacing large portions of blades lost from aluminium bronze propellers. The welding should be conducted slowly and carefully so that the time allowed between each run for cleaning and to permit the local heat of welding to be dissipated, the overall rate of working is no more than about one quarter of that of mild steel. Multi-run double-vee welds require frequent turning, but trouble from mis-alignment during and after welding and weld cracking may result from an attempt to do the work in a hurry.

In all other respects, welding procedure follows normal practice and that recommended by electrode manufacturers.

Metallic arc welding electrodes and reeled wire for the gas-shielded process are available in compositions conforming closely to those of all the special aluminium bronzes used today for marine propellers.

Repair by the Burning-On or Fusion Process

The replacement of portions of manganese bronze propeller blades by burning-on new metal is the best method available. Large areas of blades can be replaced, and even small cracks repaired by cutting them out to a narrow vee, and fusing in new metal. It is not essential that the bronze used for the burn should be identical in composition to that of the propeller, but it should at least be of the same type, and the advice of the manufacturer of the propeller should be sought on this point.

The rapid heating to the melting point of the parent metal immediately adjacent to the burn creates steep temperature gradients, and stress-relief after burning is very necessary.

Stress-Relief of Manganese Bronze Propellers

Little remains to be said about the reasons for preventing or removing thermally induced internal stress in manganese bronze propellers. The origin of the stresses and the principles involved in their removal have been discussed and the practice as described reduces to no more than ensuring that a large area of blade is heated to 300-350 degrees C. and cooled freely in air. The requirement that the limit of the zones so heated shall be more or less straight across the blade tends to make the process increasingly difficult with an increasing distance of the repair from the tip. Even at 0·75 radius, a large area of blade, varying in section thickness from ½in. up to 2½in. or more, must be heated so that at one moment, all parts are within the given temperature range. This requires considerable experience and the use of a large open coke fired furnace, supplementary gas heating burners and accurate temperature measuring equipment. Separate treatment of a blade with repairs nearer to the root than 0·37 to 0·5 radius (depending on the size of the propeller), is impracticable and, in this case, the whole propeller must receive a stress-relief treatment.

A number of older propellers are still in service, characterized by a composition containing 1 per cent. or more of tin, that require slightly different stress-relief treatment. For these propellers, the treatment temperature should be increased to 375-400 degrees C., and this temperature held for not less than 30 minutes. It is advantageous to reduce the cooling rate by covering the blade closely with asbestos blankets.

It is imperative that the lower temperature of the ranges given is reached, although to exceed the upper limit even locally does not matter a great deal. A convenient way of controlling any temperature mentioned, particularly those of the stress-relieving ranges, is by temperature indicating paints, which are applied as small spots on the opposite side of the blade to that at which the heat is applied, since they will not withstand a flame played directly on them. The paints are white or coloured, and change colour sharply on reaching a known temperature. They can only be used of course to indicate a rising temperature.

Surface contact or total radiation pyrometers are available that will cover all repair operations. The former type is cheaper and more robust, but must be calibrated for the type of surface on which it would normally be used.

A rough and ready indication of the temperature for stress-relief is given by drawing a piece of lead across the surface under fairly heavy hand pressure. Below 330 degrees C., the lead drags heavily and leaves only a light streak, but at and above 340 degrees C., it slips easily over the surface, and leaves a thick and obvious mark.

Conclusion

In this article an attempt has been made to describe the main causes of propeller wastage and damage, and to outline the principles of good repair practice. The danger of attempting repairs on the shaft, and of repair work carried out by inexperienced people has been stressed.

The failure of a propeller may involve the shipowner in great expense, and it is in his interest to ensure that whenever possible, the work of repair should be placed where it will be carried out by those with the necessary experience and equipment.