MODERN MARINE GEARS—HEAT TREATMENT

By

M. C. Oldham, F.I.M.

The following article was published in Vickers News *and is reprinted by courtesy of Messrs. Vickers-Armstrongs (Engineers) Ltd., Barrow-in-Furness. The article was written by Mr. M. C. Oldham, Chief Metallurgist.*

Warships now under construction for the Royal Navy will be the first fleet units to have British case-hardened and ground complete propulsion gear sets, H.M.S. Diana *having Swiss gears. The main objects of adopting case-hardened and ground gears are to save weight and space and to increase reliability. It is hoped that Mr. Oldham's article which deals in particular with the problem of case-hardening large gear wheels will be of general interest to naval engineers.*

During the last few years, under Admiralty sponsorship, and through the Admiralty Vickers Gearing Research Association, considerable research and development has taken place with regard to all aspects of marine gearing, resulting in the design of smaller and more highly loaded gear elements in the interest of space and weight reduction.

This work involved the replacement of a 0·4 per cent Carbon–3½ per cent Nickel steel combination for wheel and pinions as generally employed, with case-hardened (3 per cent NiCr) steel gears finished by grinding. Apart from the engineering problems involved, the adoption of such gearing introduced many entirely new metallurgical problems. Whereas in the past heat treated and tested forgings were received from the forgemaster and machined to completion, it now became necessary to provide for carburizing, hardening and tempering operations to be carried out at certain selected stages during manufacture. The case-hardening of such gears was an entirely new venture, and while the production of a case-hardened profile to the teeth periphery was not expected to present any serious problem, the distortion arising from prolonged heating at high temperatures while this was being effected, and the subsequent quenching operation, gave rise to much speculation and not a little concern, especially so far as the 6 ft diameter main wheel rims were concerned. That distortion was to be a serious problem with these large rims was underlined by the behaviour of an early experimental 6 ft diameter test gear during heat treatment.

In view of expected distortion difficulties and since no suitable heat treatment plant was available, it was decided to equip at the Barrow Works a completely new department capable of case-hardening all types of marine gears in the most up-to-date and efficient manner and with the least possible distortion.

The first step was to consider the modern techniques of employing gas as the carburizing medium, as alternative to the older method of pack carburizing, in which the work is heated at 900 to 920 degrees C. for a suitable time after being packed in boxes with a solid carburizing compound. Gas carburizing involves the substitution of a solid carburizing agent and boxes by a gas-tight heat resisting metal retort which holds the work heated to 900–925 degrees C.,

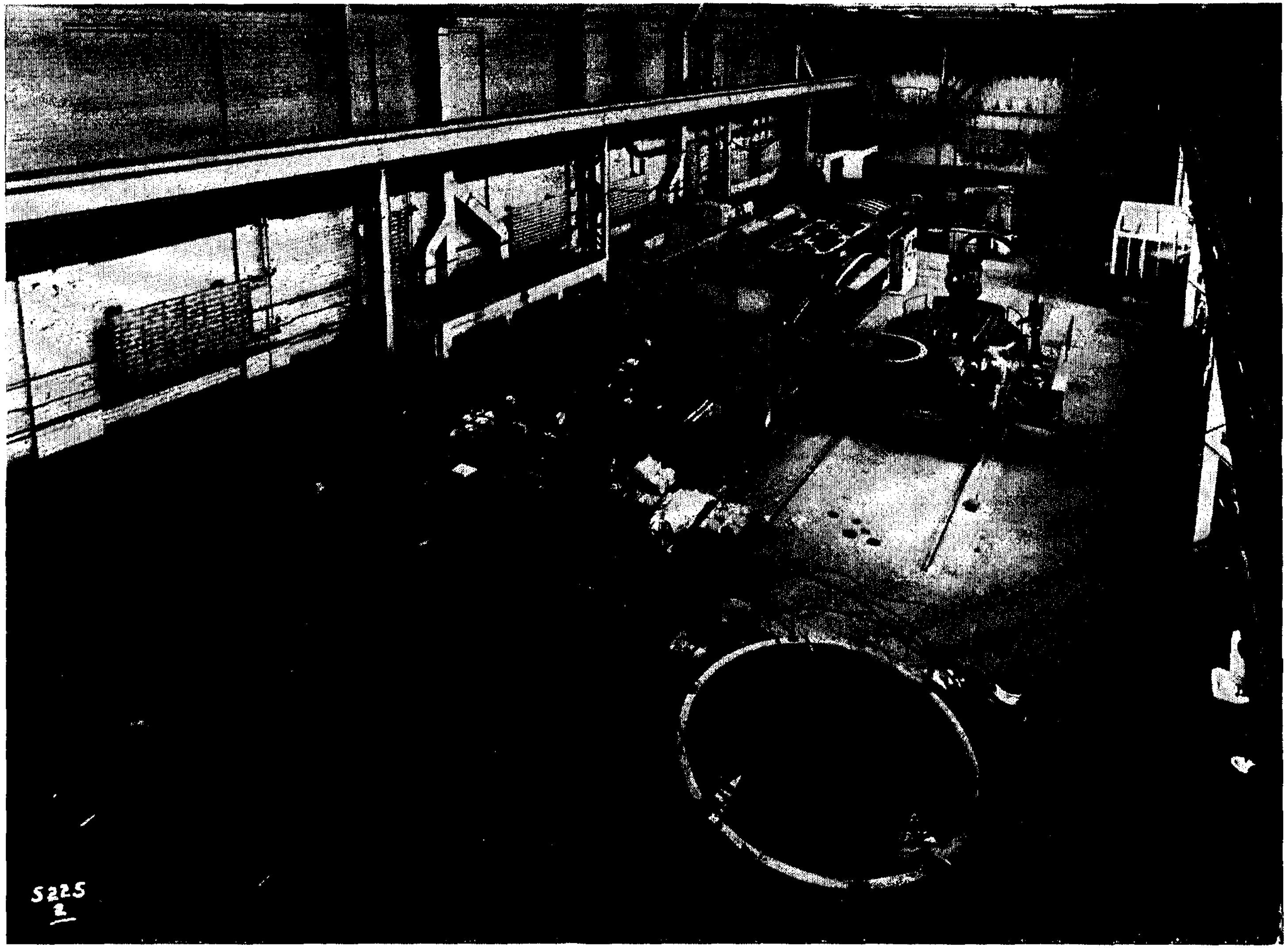

FIG. 1—GENERAL VIEW OF GEAR HEAT TREATMENT AND CARBURIZING SHOP, MESSRS. VICKERS ARMSTRONG-ARMSTRONGS (ENGINEERS) LTD., BARROW

In the left foreground is the tempering and stress-relieving furnace and further along the shop the rim and wheel furnace and through which is passed the carburizing gas for the necessary time to produce a given case depth. This process, apart from certain economic advantages, effects technical improvement as follows :—

(1) Much closer control of case depth and quality of case by suitable adjustment of the gas supply to the carburizing furnace.

(2) The time taken to produce a given case depth is less with gas than with pack carburizing, which it seemed reasonable to suppose would be reflected in reduced distortion. In any event there would be a saving in power and man-hours.

(3) The use of a controlled gas atmosphere during heating for hardening prevents decarburization and scaling, which is of the greatest importance in relation to fatigue properties of the finished gears, particularly at the unground roots.

It was decided at that time that electrical heating for the furnaces would be most convenient, but although most of the manufacturers approached were able to submit almost standard equipment for dealing with pinions, a gas carburizing furnace large enough to treat a 6 ft diameter rim was not in existence and a completely new design had to be made. Points receiving special consideration in connection with the large furnace for rims were methods of support in the furnace and of handling during transfer to the quench tank.

EQUIPMENT

Details of the equipment installed are as follows :—

Gas Preparation Unit

Ordinary town's gas is taken from the main, passed through a special catalyst heated to 950 degrees C., then through condensers, glass wool filters, and finally through silica gel driers. Passage of the gas through the gas preparation unit ensures the removal of deleterious constituents such as carbon dioxide, oxygen and water vapour and leaves, apart from hydrogen and nitrogen which play no part in the process, the active carburizing gases carbon monoxide and methane. The gas after being conditioned in this manner is now available to supply either the pinion or rim carburizing furnace.

Rim and Wheel Furnace

This furnace is of the horizontal type and has a rectangular firebrick chamber fitted with nichrome heating elements. Into this chamber fits a special heat resisting metal lining having an area originally intended for rims up to 6 ft diameter, although a 7 ft diameter rim has actually been treated. This lining has an open front end for charging purposes, and contains a double row of cast nichrome stools distributed across the floor upon which the rim or wheels may be placed. A counter-balanced door is arranged to fit into the open end of the retort and clamped to make a gas-tight seal.

The prepared gas is distributed throughout the furnace chamber by means of perforated nichrome gas pipes and passes to waste through a vent pipe to a position where it can be burnt.

Automatic and continuous temperature control is provided by means of two potentiometric controllers and recorder.

Charging Machine

To simplify the difficulty of loading heavy gears into a horizontal furnace and also to ensure adequate support while transferring hot work to the oil tank for hardening, a special charging machine is provided. This machine has four movable arms which can be run out along suitable channel openings in the loading table to pick up work and transfer it to the rim furnace where similar spaces are left between the top row of stools to accommodate the arms. Similarly, the machine can lift hot gears from the furnace, turn through 90 degrees and deposit them on a channel sectioned quench table situated in the oil quenching tank which is then lowered into the oil.

A loading table is provided alongside the rim furnace. This, together with the rim furnace, charging machine and quench tank are so related to one another that a rim placed centrally on the table will be automatically placed by the charging machine at the correct position in the furnace, and subsequently on the quench tank table.

Pinion Furnace

This furnace, of vertical pit type, has an effective work space 24 inches in diameter and 64 inches long, and fundamentally like the rim furnace is fitted with a sealable heat resisting metal lining or retort, which holds the work and is heated by means of electric elements attached to the walls of the surrounding vertical firebrick chamber. Prepared town's gas is delivered to the furnace from the gas preparation unit and is introduced into and distributed uniformly through the retort by means of perforated nichrome pipes. An hydraulically operated plug type lid normally closes the top of the retort and is secured to give a gas-tight seal by a number of hand clamps evenly spaced round the top flange. A potentiometric controller and a recorder of the same type ensure accurate automatic temperature control.

A special feature designed to keep distortion to a minimum is an arrangement for pinions to be suspended by means of special nichrome carriers from an internal flange near the top of the furnace vestibule. These carriers are arranged to screw on to the end of the pinion journal or to some suitable extension to the journal which may be parted off later when heat treatment has been completed.

Quenching Tank

Quenching for hardening is carried out in a tank 9 ft 6 in. in diameter and 12 ft deep holding 6,000 gallons of oil. A table constructed on channel sections is attached to the upper end of an hydraulically operated ram which passes up through the bottom of the tank and permits up and down motion through the oil. This arrangement was designed by us to ensure that gears after heating in the rim furnace were adequately supported during quenching and also to meet the needs of the charging machine. Continuous up and down movement of the quench table after loading gives sufficient oil velocity past the gear teeth to effect hardening.

Quenching Rig

Early experimental hardening of pinions by free quenching into the oil tank gave low hardness results and the need for more rapid cooling resulted in the development of the quenching rig which is now an important part of the equipment. This is a device in which the pinion can be suspended and into which a large volume of oil can be pumped and concentrated round the helix.

It consists of a tubular fabricated structure standing on the quench table in the oil tank and connected by flexible metal hose to a centrifugal pump situated in the pit alongside the oil quenching tank.

Normal operating practice is to lower the quench table down into the oil after inserting a hot pinion, simultaneously pumping in oil at a rate of 800 gallons per minute. The assembly remains in this position until the pinion is cool enough to be transferred to the forced air circulation furnace for tempering.

Tempering and Stress Relieving Furnace

This is a forced air circulation furnace of a well proved design capable of excellent temperature uniformity and thermal efficiency and with a working range of 0–700 degrees C. It is of the pit type with the usable working chamber size of 7 ft 6 in. diameter and 6 ft deep. The lid is designed to lift clear and roll away horizontally. A fan in the lid circulates the air continuously past the electric heating elements and the charge which is placed on stools standing on the furnace bottom, thus ensuring temperature uniformity.

The furnace is used for stress relieving operations after rough hobbing at temperatures in the range 640–670 degrees C., and also for tempering hardened gears between 150 and 280 degrees C. after oil quenching.

Vapour Blasting Machine

After hardening and tempering, all gears are vapour blasted over the teeth to remove any slight oxidation scale formed during transference from the protective atmosphere of the furnace to the quench. This machine employs a jet of water containing fine abrasive boosted by compressed air at 80 lb/sq in, the mixture being pumped from a sump in the base of the equipment and blown through a ‘ gun ’ by the compressed air on to the gear teeth.

The work is lowered in through the top of the machine and placed on a circular table capable of complete rotation and back and forward movement along rails. The operator can view the work through a glass window in the front end of the equipment and is able to hold and direct the ‘ gun ’ through long rubber gloves sealed into the panel below the inspection window.

Apart from the removal after hardening of fine scale which may contaminate grinding wheels, the cleaning up and smoothing of fine machine marks remaining in the roots of the teeth, especially those running parallel to the teeth, is very desirable in relation to fatigue properties. This process replaces the laborious hand grinding operation previously carried out.

Shrink Fitting Oven

This equipment was designed and constructed in the works to provide an effective means of heating a 6 ft or 7 ft diameter gear wheel rim for shrinking on to its centre.

It is a circular gas heated oven with a 3 ft 6 in. diameter clear space in the middle and extended 4 ft 6 in. down below floor level in order to accommodate a shaft integral with the centre during shrinking operations. Holes in the lid covering the oven allow dial thermometers to be inserted into corresponding holes in the jig, which is used to hold the rim circular during the heating and shrinking operation.

The assembly is heated to 140 degrees C., the lid of the oven is removed, and the centre with its integral shaft is lowered into the rim and allowed to cool. The rim with its centre shrunk in position is subsequently removed from the jig and finish machined and ground.

Stress Relief

The normalized and tempered forgings are received from the forgemaster and after rough machining, including rough hobbing of teeth, are stress relieved in the forced air circulation furnace at 650 degrees C. for a minimum of six hours followed by furnace cooling.

Gas Carburizing

After further machining including finish hobbing, the gears are gas carburized to the specified case depth, together with suitable test bars for official physical tests (tensile, Izod and case depth measurement) and supplementary laboratory examination.

(*a*) *Pinions*. A pinion, after having its carrier attached, and with test bars secured by wire, is suspended inside the cold furnace and the lid replaced and clamped down to give a gas-tight seal. Prepared gas is passed through the retort at 800 cu. ft/hr for 15 to 20 minutes until all air has been purged from it (to avoid an explosive atmosphere) when the exit valve on top of the lid is closed. With the plant under mains gas pressure the heating elements are switched on and the charge is heated to 925 degrees C. When this has been achieved the exit valve is opened again and prepared gas at 250 cu. ft/hr is passed through the retort for a pre-determined length of time for what is known as the ' active ' period, i.e. when carbon is being rapidly absorbed by the steel surface giving a ' case ' having a higher than necessary carbon content. At the end of this period the valve is closed, the booster stopped and heating of the charge at 925 degrees C. is continued for a further period of time under mains pressure of gas only. This ' diffusion ' period allows time for the ' case ' to diffuse further inwards into the work and for the undesirably high surface carbon content to be reduced to something approaching eutectoid composition. At the end of the ' diffusion ' period the furnace is switched off and allowed to cool off under mains gas pressure to below 200 degrees C., when the charge is removed.

(*b*) *Rims and Primary Wheels.* One 6 ft or 7 ft diameter rim or up to four 3 ft diameter primary wheels having been arranged on a loading table are transferred to the cold furnace by means of the charging machine. The test bars are placed in position on top of the work, the door lowered and clamped in position to give a gas-tight seal. The furnace is then operated generally as the pinion furnace, although with detail differences arising out of the large size of furnace and heavy weight of charge. Heating elements are separately and selectively operated to limit thermal stresses in the retort and give uniform heating to the charge. At the end of the ' diffusion ' period, and when the furnace has cooled to approximately 600 degrees C., two cylinders of nitrogen are passed through. This precaution, in which most of the P.T.G. is purged from the retort and the remainder diluted, is taken to eliminate the risk of explosion which could occur if air were to be drawn into the chamber during cooling—a possibility with a furnace of this size when distortion of joints can give rise to leaks. When cold, the gear or gears are removed, wiped free of any soot and sent for further machining operations before hardening.

Hardening

Heating for hardening of all types of gears follows the same procedure as described in heating for carburizing in that the charge, together with appropriate test bars, is heated to the hardening temperature (usually 840 degrees C.) in a static gas atmosphere at mains pressure. After the necessary soaking time at this temperature, the door seal is broken and the charge removed and quenched in oil via the quench rig or the quench table.

Tempering

Immediately after hardening and before the work is cold it is transferred to the forced air circulation furnace and tempered at 150 degrees C. Hardness testing of the tooth flanks is next carried out using a diamond hardness testing machine specially designed and manufactured for this work. The gears must have a minimum specification requirement of 650 D.P.N. Should the tooth hardness prove unnecessarily high, further tempering is carried out.

Following vapour-blasting treatment, all gears are at this stage subjected to magnetic crack testing before release for dimensional inspection, finish machining and grinding.

Physical tests to specification requirements are also carried out, together with a metallurgical (micro, etc.) examination as a final check on ' case ' condition.

After final tooth grinding, the gears are again checked for tooth hardness and freedom from cracks.

FUTURE DEVELOPMENT

It will be seen that the Gear Heat Treatment Department is very well equipped for the production of case-hardened gears, but in spite of every possible care at all stages the fundamental characteristics of high temperature treatment for prolonged periods of heavy masses of steel and associated thermal stresses make themselves evident as distortion in several forms, and this is considerable with large rims. The distortion of pinions is well within normal grinding limits, and not too serious in the case of primary wheels. With large rims, corrective practice is applied at certain stages of production which although troublesome and expensive does enable these gears to be finally produced completely satisfactory to the high standards necessarily demanded.

It can be said that technically the case-hardening practice adopted has fulfilled expectation, as such gears have been subjected to severe test running and proved highly successful.

Further and continuous developments in the metallurgical sphere are in progress. These indicate that large gear wheel rims manufactured from direct hardening steel and with the teeth induction-hardened, perform very well on running tests, and also show only slight distortion during hardening which is well within normal grinding limits. In view of the obvious advantages from the production standpoint of this method of producing a hardened gear, a new machine is shortly being installed in the Department capable of induction-hardening pinions and wheels up to 7 ft in diameter on which considerable experimental work is to be done. It seems probable, as far as can be seen, that, while pinions and small gears will continue to be case-hardened as at present, the ultimate development will be induction-hardening for the larger rims and wheels.