SHAVING MARINE GEARS ON BOARD

by

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Many Engineer Officers may have heard the term 'shaving' of gearing without knowing precisely what is meant by it. This article although largely confined to a particular aspect, that of shaving the gears in position on board, should help to remedy this.

Shaving is a process for improving the surface of the teeth flanks after the teeth have been cut by hobbing or shaping. It is used to remove the undulations left on the surfaces as a result of errors in the various mechanisms of the hobbing or shaping machine, such as worm or wormwheel and feed screw errors. It may also reduce the undulations caused by temperature changes during the manufacture, described broadly as 'daily' bands, but it is unlikely to eradicate them completely on large wheels where the wave length of these undulations tends to be large. Shaving is also used to correct small differences of helical angle between wheel and pinion and thus ensure better meshing and more even load distribution. Each of these uses tends to reduce excessive local loading that might lead to eventual fatigue failure of the gearing.

The process was first used in the U.S.A., for motor car gears, but subsequently its use was extended to marine gears in the U.S.A. and latterly in this country. Shaving or some equivalent post-hobbing process is now specified here for all gears for the main propulsion of naval ships, but only two ships are at sea with gears shaved during manufacture. A few older ships have had their gears shaved on board and arrangements are in hand to determine for which other ships in service this treatment is required.

The Shaving Process

The shaving cutter shown in fig. 1 is in the form of a helical gear of the same normal base pitch as the gear to be shaved, with deeply cut serrations in the teeth in planes perpendicular to its axis. The roots of the cutter are relieved to permit the serration of the tooth flanks. The spiral angle of the cutter is such that its teeth mesh with the teeth on the gear to be shaved when their axes are at an angle, called the crossed-axis angle, which lies between 5° and 45° depending on the cut required, the hardness of the material and the size. For example, a gear with a spiral (or helix) angle of 20° could be shaved by a cutter having a 10° spiral angle with a crossed axis angle of either 10° or 30°. This non-parallelism of cutter and work axis results in a component of sliding action along the gear tooth between the faces of the teeth. The serrations therefore move axially along the teeth.

When shaving large gears, it is usual to rotate the work and to have the shaving cutter mounted freely in bearings, the engagement of the teeth causing the cutter to rotate in mesh with the work. For smaller gears, the cutter itself may be rotated and the gear driven thereby.

There are two methods of applying pressure between the cutter and work to cause cutting action ; they are 'radial loading' and 'tangential loading'.

In the radial loading process, the cutter teeth are forced tightly into mesh with the teeth of the work and shaving takes place on both sets of flanks of the work teeth at the same time. Where it is desired to remove metal from

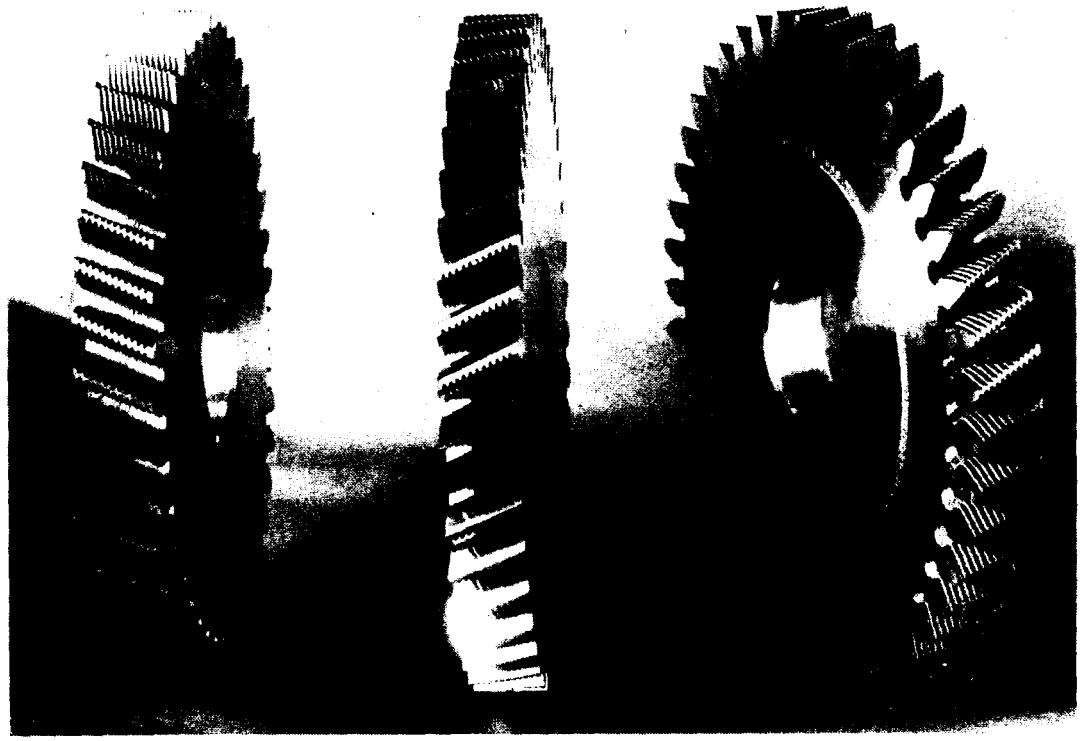


FIG. 1.—SHAVING CUTTER

one flank to correct helix angle errors a cutter serrated on one flank only is used.

In the tangential loading process the teeth of the cutter and work are engaged so that shaving takes place on one set of flanks only. In this case the teeth of the cutter must be sufficiently thin to permit this with some backlash. Loading between the teeth is obtained by applying an adjustable brake to resist the motion of the cutter when the work is rotated. For correcting spiral angles to obtain better load distribution along the helices, it is useful to be able to vary the tooth load as the cutter traverses the face of the gear.

Shaving Gears on Board

Judged by present standards, the accuracy of many of the main propulsion gears on service leaves much to be desired. A realization of the shortcomings of gear manufacture towards the end of the last war led to the formation of the Admiralty Vickers Gearing Research Association whose object was the improvement of the accuracy of gear cutting machines. One of the research items was an investigation into the possibility of reconditioning the gears of the vessels on service and as a result Messrs. David Brown were given the task of designing and manufacturing the equipment for shaving gears on board, as described in detail later.

H.M.S. Myngs

A destroyer was selected for the initial test of the shaving equipment because the gears of a destroyer could be relatively easily replaced in the event of the gears being damaged. H.M.S. *Myngs* happened to be readily available and was allocated for this test, although her gears were not in a bad condition.

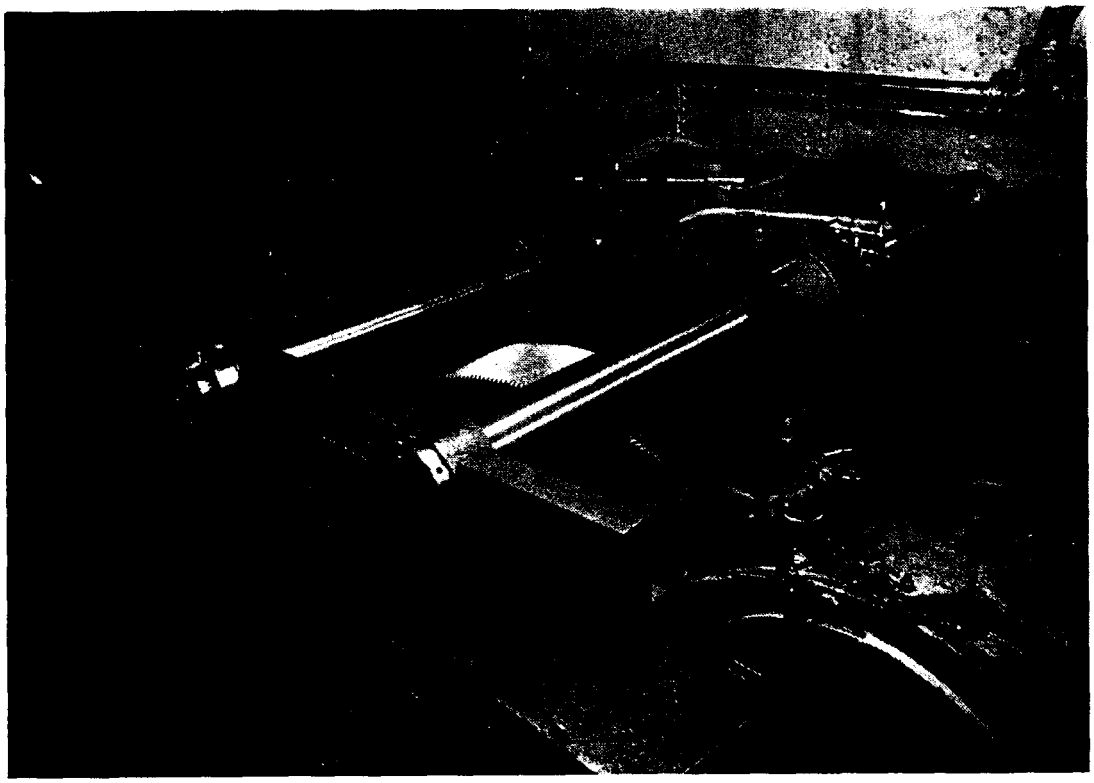


FIG. 2.—H.M.S. MYNGS' PORT ENGINE—SHAVING GEAR IN POSITION FOR SHAVING MAIN GEAR WHEEL

Portable Shaving Equipment

The wheel shaving attachment, designed to be easily adaptable for use on destroyers or any of the larger ships gear cases, is shown mounted on a destroyer gear case in fig. 2.

The frame consists of welded channel beams attached to the gear case. Mounted to this frame in a direction approximately 2 degrees to the axis of the main wheel are two tubular members, one plain and the other threaded externally. The 2° lack of parallelism is given in order to spread the wear of the cutter over a large proportion of its width. The shaving carriage, supported on these tubular members, is traversed by means of a fractional horse-power motor (0.50 h.p.) driving, through a pair of gears and a worm, a worm wheel with a threaded bore engaging with the threaded tubular member. The opposite side of the shaving carriage is supported on the plain tubular member by an eccentric bush, which when rotated by the ball handle provides ' in ' and ' out ' feed to the shaving cutter. The shaving cutter spindle is arranged with a brake and a torque arm registering ' cutting-load '. The shaving carriage may be arranged for radial-load shaving by rendering the eccentric bush and brake inoperative. The carriage is then free to rotate about the axis of the threaded tubular member, and the amount of load is varied by means of balance weights.

The attachment was designed so that when dismantled, any component would conveniently pass through the normal hatchways in a ship.

FIG. 3.—GEAR PINION IN LATHE FOR SHAVING

During shaving operations, the turbine and propeller shafts are uncoupled and the driving unit is attached to the pinion end cover flange. Power is derived from a $7\frac{1}{2}$ h.p. motor driving through a worm and wheel on to a square pin in engagement with the square hole in the end of the pinion shaft, the other pinion being temporarily removed.

Cutting oil is delivered to a nozzle adjacent to the shaving cutter from a self-contained unit, consisting of a tank with a 1 h.p. motor driven geared pump, relief valve and magnetic filter. The unit is arranged in position in the bilges at a lower level than the level of the oil in the sump of the gear case to allow a gravity drain return through a flexible pipe to the tank. A straight cutting oil ' lardedge ' is used throughout the operation. Prior to shaving, the existing lubricating system is isolated to ensure minimum dispersal of shaving cuttings, and the pinion, wheelshaft and thrust block bearings are lubricated at regular intervals by hand, sight bottles being fitted on each of the forward and after bearings.

For the electrical supply, the original intention was to use the ship's supply (220 Volt D.C.) but delay in delivery of the D.C. motors decided the use of 400 Volt A.C. Supply was therefore arranged from the Dockyard Power House to a portable transformer on the dockside and thence by cable to a junction box on the upper deck. Wires were led from this junction box to the control units in the gear room.

The pinions are shaved separately in a suitable lathe using a special attachment. In the case of H.M.S. *Myngs*, a Lang lathe in M.E.D. Factory, Portsmouth Dockyard was used with the attachment mounted on a special angle plate designed to fit on the tool saddle (*see* fig. 3). The shaving attachment consists of a spindle carrying the shaving cutter, provided with angular adjustment

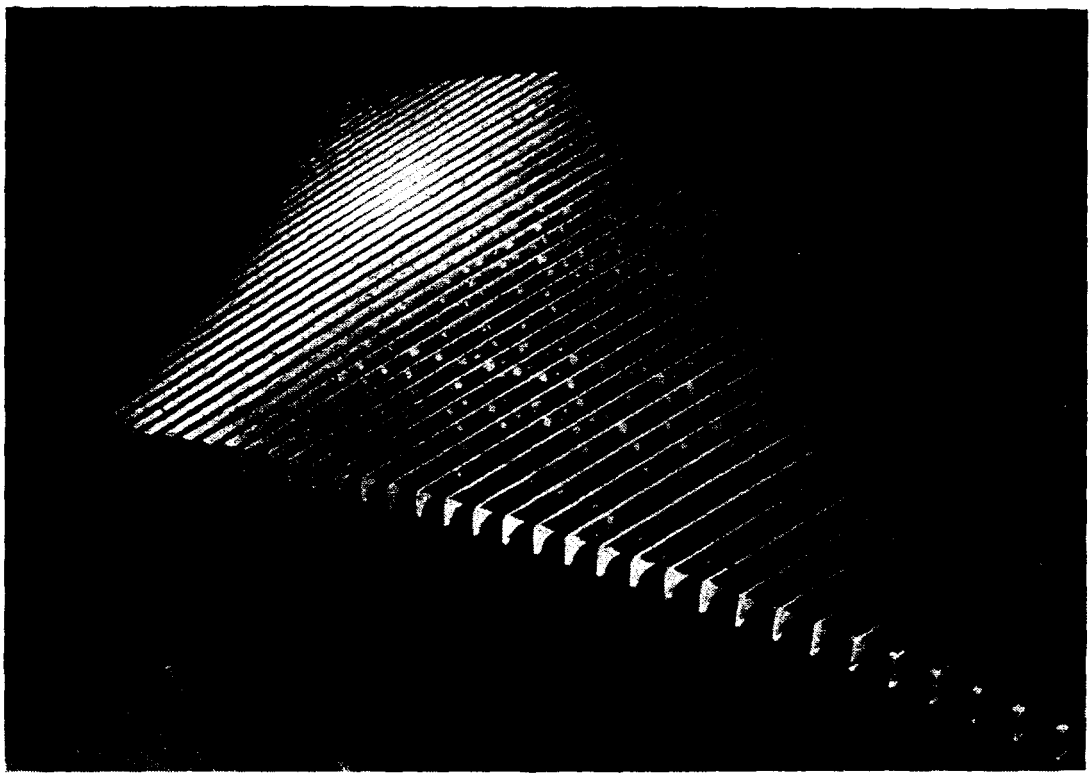


FIG. 4A.—H.M.S. MYNGS—MAIN GEAR WHEEL BEFORE SHAVING (SURFACE MARKING ON AHEAD TOOTH FACES)

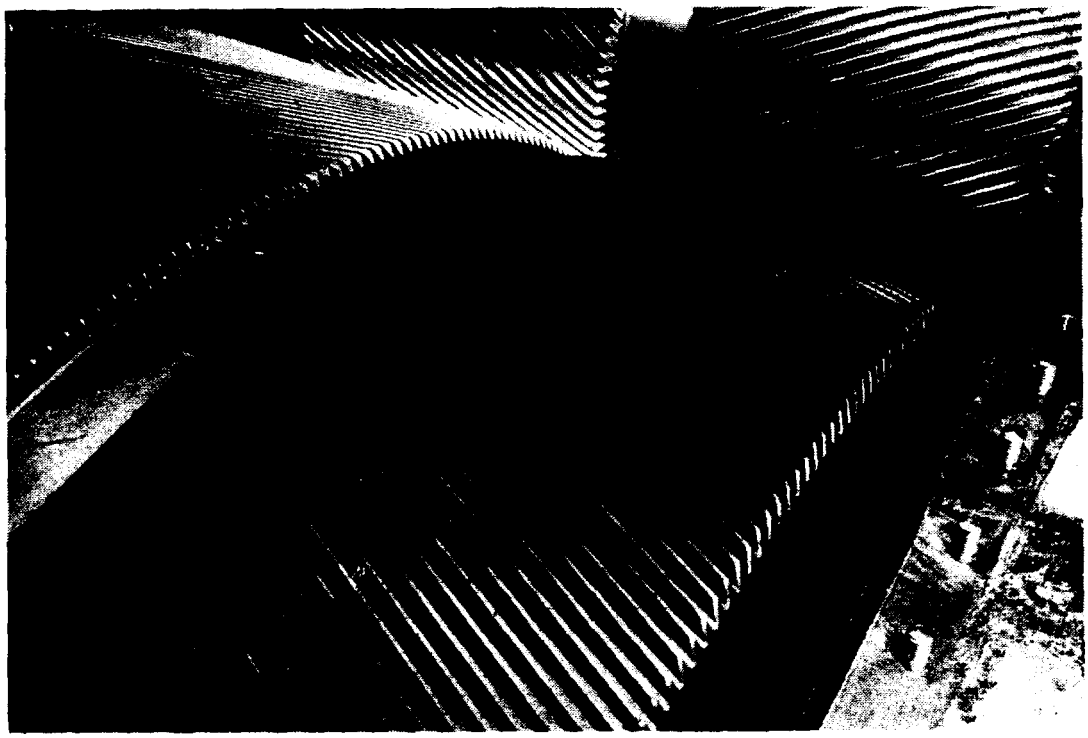


FIG. 4B.—H.M.S. MYNGS—PORT MAIN GEAR WHEEL AND PINION AFTER SHAVING

to give the necessary crossed axis angle. Brake load to the cutter is applied by means of a hand wheel operating levers connected to phosphor-bronze-lined steel brake bands, enveloping brake drums on each side of the cutter. The pinions are supported on centres at both ends, a steel recessed plate being bolted to the end containing the square hole for this purpose. Before shaving, the pinions are checked for concentricity of running in the lathe and are not allowed to have more than 0.0005 in run out on either journal.

Shaving the Wheels

Despite many delays, the wheel shaving attachment, driving unit and coolant unit were placed on board, assembled and the various clearance adjustments made in a matter of three days.

Alignment was obtained by traversing a dial indicator anchored to the shaving cutter bracket across a straight edge placed on the top of the wheel and held by suitable supports. The accuracy of alignment with the top of the straight edge attained was 0·0002 in per foot.

Radial load shaving was first attempted using a spur shaving cutter giving 30° crossed axis angle with a dead load of 60 lb. Severe vibration was experienced and this method was abandoned.

It was then decided to try the ' brake ' or ' single side ' method of shaving. With a brake load of 50 lb at the cutter tooth the Port Wheel was then satisfactorily shaved using the spur cutter at a crossed-axis angle of 30° as before. In this case, the wheel was driven by the H.P. pinion and the L.P. pinion was removed from its bearings.

No trouble was caused by shaving cuttings passing between the pinion and wheel, or entering any of the bearings.

The wheel shaving attachment, completely assembled except for the feed motor and shaving cutter head, was transported across the gear room from port gear case to starboard gear case by means of chain blocks. The change over was accomplished in two days.

The starboard wheel, when examined before shaving, was found to have been damaged on three teeth, one of which had a piece of metal missing approximately 0.75 in length and 0.25 in deep. It was doubtful what effect the wheel damage would have on the shaving cutter, but no trouble was experienced when passing over this portion. Figures 4A and 4B show this wheel before and after shaving.

Shaving the Pinions

The pinions were first cleaned up on all tooth flanks and then selective shaving was carried out where necessary to obtain even marking when meshed with their respective shaved wheels. It was found that this selective shaving operation had to be done once on each flank of the H.P. pinion and twice on each flank of the L.P. pinion on the starboard set. The H.P. pinion of the port set required four operations on one flank with two on the others while the L.P. pinion of this set only required selective shaving on one flank of one helix, the remainder giving satisfactory marking after being cleaned up. Each of these operations entailed the transport of the pinion from the lathe in the factory to the gear case in the destroyer, turning the gears in mesh to obtain the contact marking and then transport back to the factory for further shaving.

Photographs of a pinion before and after shaving are shown in figs. 5a and 5b.

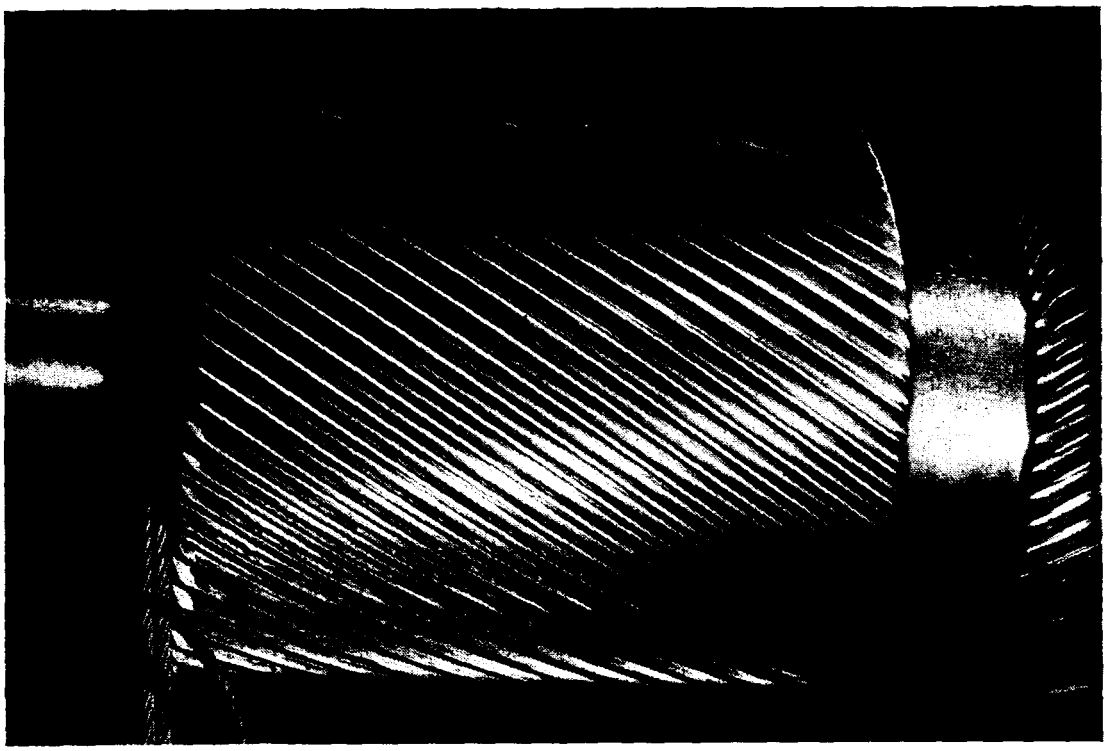


FIG. 5A.—H.M.S. MYNGS—PORT L.P. PINION BEFORE SHAVING
(SURFACE MARKS ON TOOTH FACES)

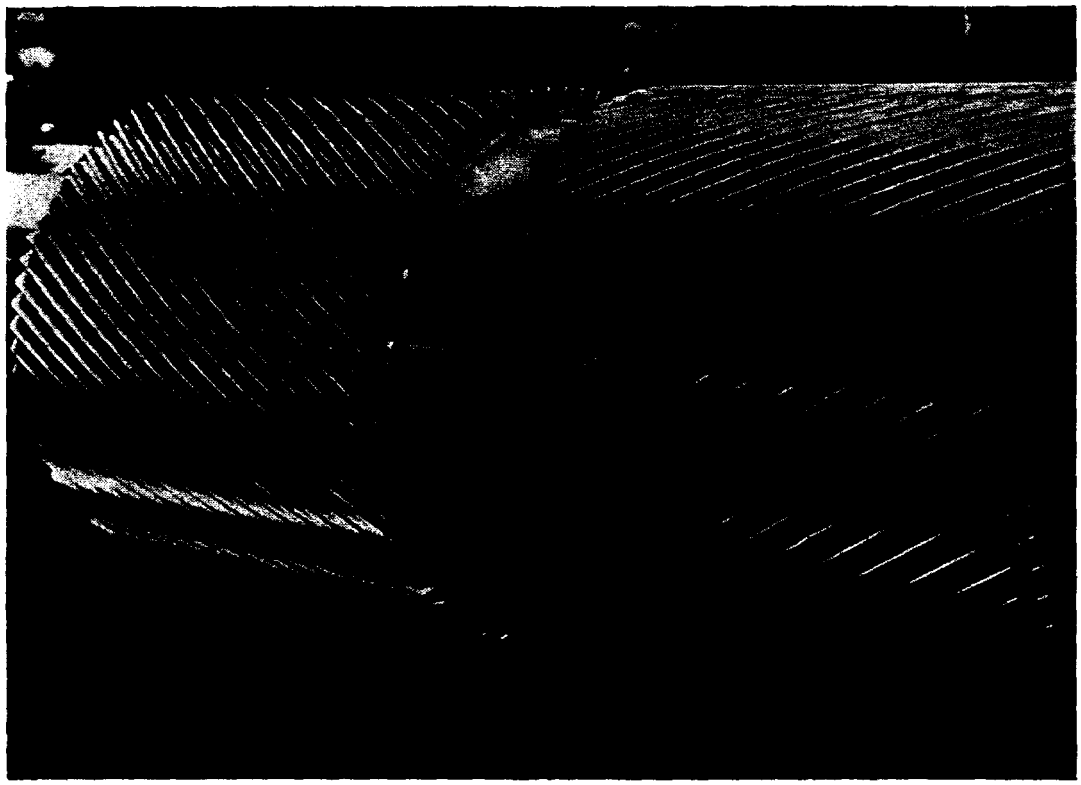


FIG. 5B.—H.M.S. MYNGS—PORT L.P. PINION AFTER SHAVING

Records

Measurements were taken before and after shaving of the sound level of the gearing for comparative purposes.

As the condition of the gears was good before shaving, it was expected that there would be very little reduction, if any, in the total noise level, and this proved to be the case.

Records were taken of the undulations of the surface along all the tooth flanks before and after shaving, these being taken with the N.P.L. design of undulation recorder.

Cleaning Gear Cases

The removal of the metallic debris from the gear case after shaving is vitally important. The procedure used was to flush the gears and gear cases with flushing oil and then thoroughly clean the sump by hand. As an added precaution, magnetic filters were fitted in the drain pipes from the sump. Very little debris was collected and they are now being removed after 12 months service.

H.M.S. Indomitable

The equipment was next used in H.M.S. *Indomitable*, but several alterations were found to be necessary. The cutting oil unit could not be placed below the gear case sump level, so a flexible pipe, fitted with a strainer and non-return valve, was led from the unit through an inspection hole to the oil in the gear case sump.

The $7\frac{1}{2}$ h.p. motor used when shaving the destroyer gears was replaced by a 20 h.p. motor with a larger reduction ratio in the worm gears driving the pinion. This motor was found necessary as tests with a brake load of 50 lb at the cutter showed that :—

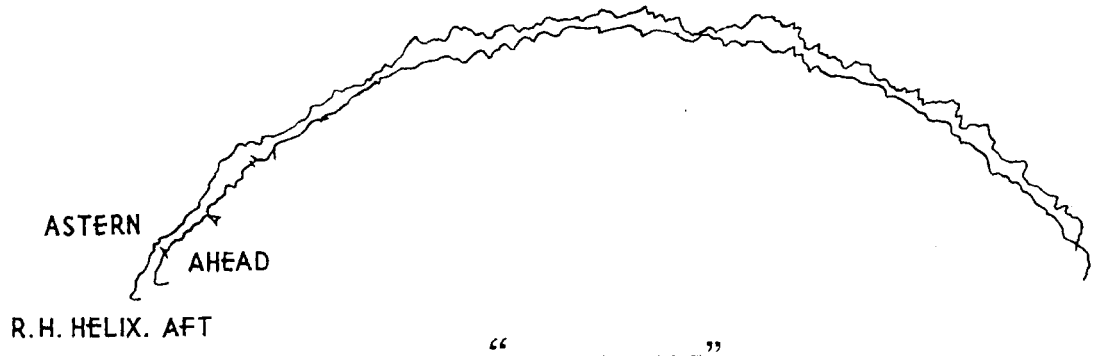
For starting, power required was 10 amps—$5\frac{1}{2}$ h.p.
To attain full speed ... 30 amps—16 h.p.
To maintain full speed ... 2 amps— 1 h.p.

Owing to the several decks over the gear rooms, it was considered impracticable to take the pinions off the ship for shaving in the factory. A lathe was therefore brought on board and welded to the lower hangar deck, immediately above the starboard gear room. Three removable plates 30 in diameter were arranged in the lower hangar deck, one over each gear room. Attached to the deck above these and in line with the three plates was a runner with chain block for lifting the pinions direct from the gear room to the lathe. The average time for meshing, transporting, setting up and shaving one pass was six hours.

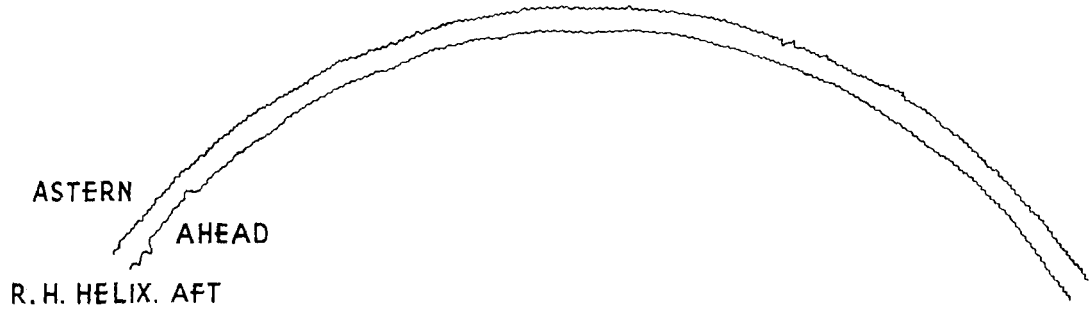
Shaving the Gears

Alignment of the direction of traverse of the shaving cutter was effected as on the case of the destroyer, but it was found that there was considerably more backlash between the shaving cutter teeth and wheel teeth at one end of the helix than at the other end. This suggested a departure from parallelism of the top diameter with the axis of the wheel. Subsequent alignments were carried out by equalising the backlash at each end of the helix, measurements being taken with an indicator in contact with the end of the brake arm.

Shaving was first commenced with the spur shaving cutter at a crossed axis angle of 30°, but it was noticed that instead of the normal cutting action taking place a tearing effect was occurring. After experimenting with various alternatives, this action could not be eliminated and it was decided that the crossed axis angle of 30° produced a cutting action that was too severe.



H. M. S. "INDOMITABLE"
CENTRE MAIN WHEEL BEFORE SHAVING



"H. M. S. INDOMITABLE"
CENTRE MAIN WHEEL AFTER SHAVING

FIGS. 6A AND 6B

All shaving after this was completed satisfactorily with the 15° cutter at a crossed axis angle of 15°. Trouble was again experienced on one of the pinions when after nine passes had been taken with the pinion running at 54 r.p.m. and a feed of 0·015 ins per rev., tearing started taking place due apparently to the cutting having reached a point beneath the work-hardened surface of the teeth. A faster rotational speed was tried without success and eventually with the speed reduced to 29 r.p.m. and using a feed of 0.02 ins per rev. cutting was found satisfactory providing the brake load was not excessive.

Two or three finishing cuts were made, employing a traverse feed of 0.07 ins, in order to impart the necessary degree of finish to the teeth.

Selective shaving operations were only required once on three flanks of the Port L.P. pinion and three flanks of the centre set L.P. pinion to obtain suitable contact between the mating teeth.

Two pictures are shown on figs. 6A and 6B of the undulation records of the centre main wheel before and after shaving as an illustration of the improvement in surface finish that can be obtained with this process.

The procedure for cleaning was the same as in H.M.S. *Myngs*, and magnetic filters have been fitted.

H.M.S. Eagle

The equipment has also been used to shave the four sets of gears in H.M.S. *Eagle*, prior to her Sea Trials. The procedure was similar and the results equally successful.

Future Use of the Equipment

The practicability of this equipment for shaving gears having been proved, arrangements are in hand to purchase two sets of the equipment for allocation to H.M. Dockyards.

The work described above has been done by Messrs. David Brown, but it is planned that Dockyard personnel should be instructed in the use of the shaving equipment and that they will be able to undertake this work in due course.

Action is being taken to ascertain the condition of the main gears of various classes of ships, and where necessary, the gears will be reconditioned at the first convenient opportunity.