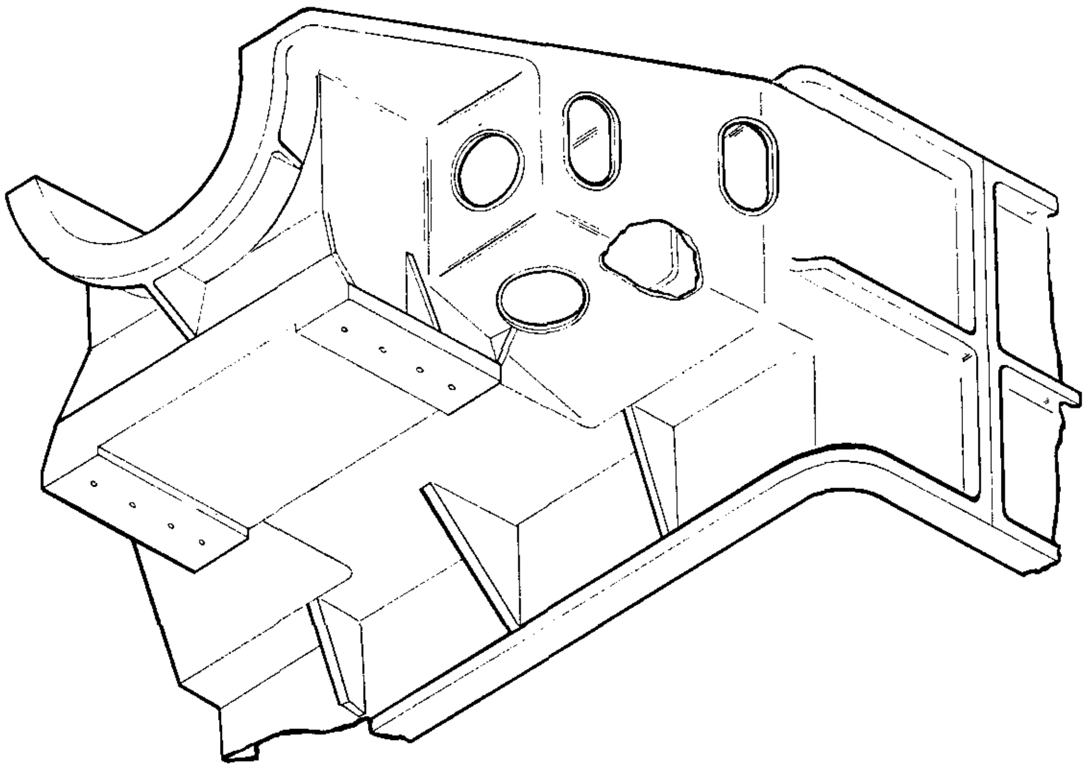

FIG. 1—L.P. TURBINE AFTER PEDESTAL—H.M.S. GAMBIA

H.M.S. LION

MAIN ENGINE BEARING TROUBLES

BY

COMMANDER J. R. BROADHURST, R.N.

In 1944 the uncompleted cruiser, H.M.S. *Defence* was accepted into reserve. In 1956 she was brought forward and towed to Newcastle for completion, and late in 1957 she was renamed H.M.S. *Lion.*

On examination of the main turbines Messrs. Wallsend Slipway and Engineering Co Ltd., the new main machinery contractors, found many things that were not to their liking. Most of these defects were attributable to the relaxed wartime conditions under which the machinery was manufactured. Among the Admiralty instructions issued for the correction of these defects was one to fit new bronze bearing shells to the main turbines and, diverting from the normal practice, these shells were to be bored circular and to closer clearances to improve their load-bearing properties.

The Contractors Sea Trials were carried out in February, 1960, and were satisfactory except that it was found impossible to maintain a good vacuum when going astern, and for this reason the astern trials were limited to under ten minutes. It was found that the vacuum was improved by the systematic elimination of air leaks at all the usual places, and by injecting the horizontal turbine condenser joint, and it was therefore considered that the problem was under control.

On opening up the main machinery after the Contractors trials it was discovered that all four L.P. turbine after bearings were wiped slightly at the forward end of the bottom half. This did not cause alarm since the turbine

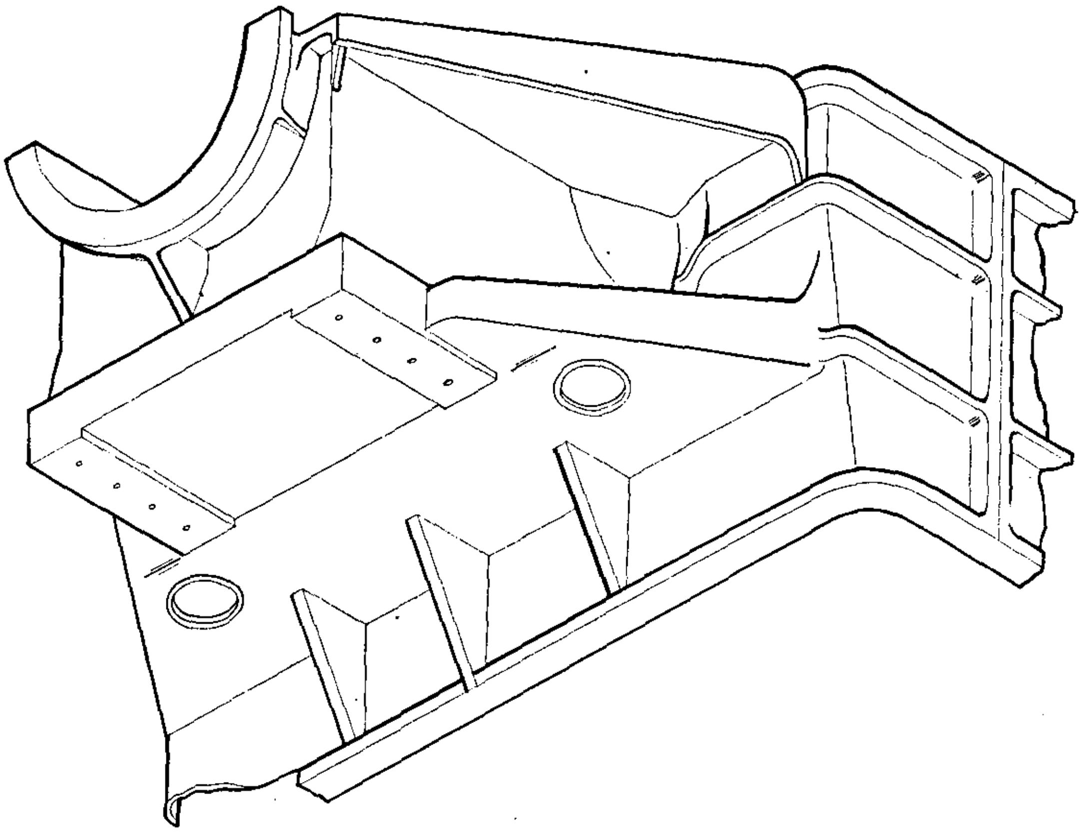

FIG. 2—L.P. TURBINE AFTER PEDESTAL—H.M.S. LION

esign was one of proved worth, and special care had been taken in the alignment of the new bearings with their closer clearances. The fact that all four ngines were similarly affected suggested some mal-operation of the machinery uring the trials, but no really satisfactory explanation was found. A possible xplanation was that excessive gland steam was used in an attempt to improve ie vacuum, and that this had caused excessive heat soakage along the rotor haft and thence to the bearing.

Therefore the defective halves were dressed up or remetalled as considered ecessary, and the engines prepared for the Acceptance Trial. This trial was 'as carried out in July, 1960, and was satisfactory for the ahead running but, s in the previous trial, the astern running was curtailed by the rapid loss of acuum. Again it was confidently expected that the vacuum problem would be ured as soon as all the air leaks had been found and stopped, and so the ship as accepted, and a determined start made on the extensive gunnery, and other quipment, trials programme.

For this purpose H.M.S. *Lion* left Invergordon on the 25th July, 1960, and in oing so carried out some intensive manœuvring which involved periods of up quarter of an hour at half astern. Nothing untoward was noted, nor in fact pected. Three hours later, just after a speed change to 208 r.p.m., vibration as noted in the starboard outer L.P. turbine. Ninety seconds later the vibration ecame severe and both forward engines were stopped, and the ship proceeded Portsmouth on the after unit.

Subsequent examination of the starboard outer engine showed that the after earing of the L.P. turbine had wiped, the safety strip had scored the journal, me blades had touched, and the rotor was bent 0·017 inches. This was bad ough, but even more alarming information resulted from the examination the other engines. It was found that the after bearing of the port outer L.P.

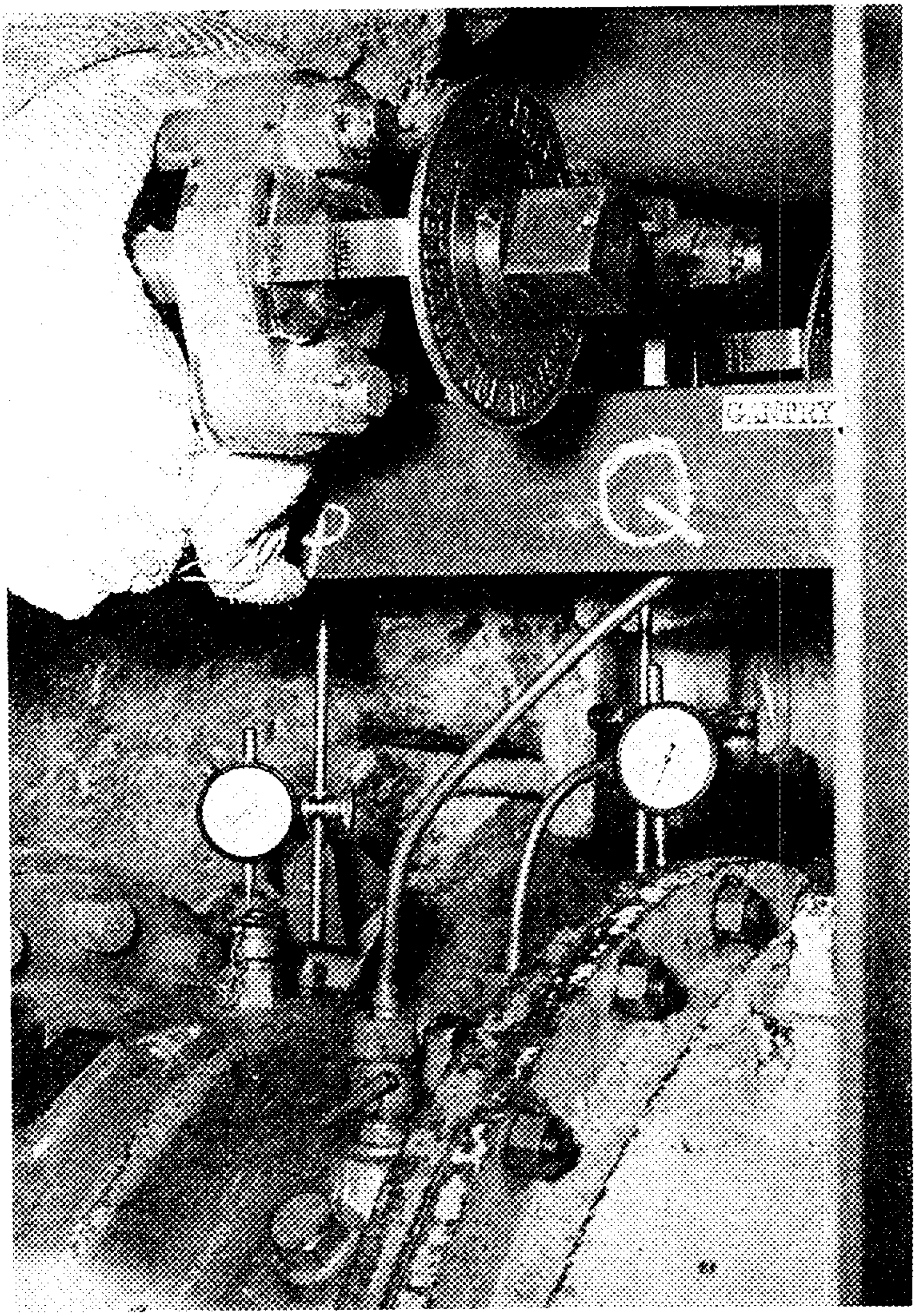

FIG. 3—L. P. AFTER BEARING SHOWING GANTRY AND MICROMETER CLOCKS

turbine was wiped right down to the safety strip, and hence had been saved by a matter of minutes, and that the after bearings of both of the after L.P. turbine were wiped.

The Investigation

It was now very apparent that there was a problem of a major magnitude early warnings of which had been explained away as teething troubles. A Board of Enquiry was convened, and meetings held to discuss and study all possible information relevant to the defect. Admiralty instructions were given for the checking of all rotors, stripping and examination of the sliding feet, metallurgical examination of the whitemetal, analysis of the lubricating oil. . . and in fact everything that might give any indication of the source of the bearing trouble. Simultaneously a design search was carried out to itemize all differences between *Lion's* turbines, and basically similar engines which had given satisfactory service. This survey showed that the design of the L.P. casing is similar to that fitted to some of the 1942 light fleet carriers and is made of steel. The design differs in several major respects from that fitted in H.M.S. *Tiger*, and the *Fiji* Class cruisers.

The 'investigation' produced a very big 'unprogrammed' task for all concerned, particularly Portsmouth Dockyard, but it was pressed on despite the large amount of negative information which resulted. The three remaining L.P. rotors appeared to be satisfactory, the whitemetal and lubricating oil was to specification, and the sliding feet although rough were in reasonable condition.

Sifting all available information, past experience, and theories, it was concluded that the failure of the after bearing had initiated the damage to the starboard outer L.P. rotor, and in consequence the major effort was directed upon the investigation of these bearings. To give early warning of failure four thermocouples were embedded into the whitemetal of the lower half bearings, these being wired to instrument panels sited on the gearcases. Also the bearings were remetalled and rebored with greater clearances, in accordance with earlier practice, this being to fit 0·01 in. shims at the butts while boring which, on removal when fitting, give an oval shaped bearing with increased oil clearance at the horns. This procedure had always given good service and was reintroduced for *Lion's* bearings to eliminate one of the variations.

The examinations carried out had produced no satisfactory explanation for the failure, and as there was a pressing need to go to sea to advance the gunnery trials, the machinery was closed up and prepared for going to sea on the three remaining shafts. To study the behaviour of the after bearings of the L.P. turbines angle bar gantries were fixed to the armoured deckhead above these bearings, and from which micrometer clocks were set to touch the bearing housings and surrounding structure. It was appreciated that these gantries were not ideal datum fixtures, but they were the best that could be devised for the job. Micrometer clocks were also fitted to the sliding feet.

By now the nature of the investigation had changed radically from the search for an obvious defect to a study of casting distortion.

Before proceeding to sea a series of basin trials were carried out on the after unit, and these showed that in general the forward end of the bearing rose about 0.018 in. relative to the after end, this tilt varying according to the operation of the machinery—and in particular to the amount of astern running. Also these trials showed that this tilt once established persisted for a long time. This suggested casting distortion by heat soakage, which would be enhanced when running astern, the astern turbine being at the after end of the L.P. rotor.

The ship went to sea on the 5th September, and after about four hours' steaming the thermocouples in the after bearing of the port inner L.P. turbine showed high readings, and the shaft was stopped. None of the normal recording equipment had showed any sign of trouble. However, on examination it was found that the bearing had wiped, and showed clearly that it had cocked sufficiently to cross-corner. This appeared to give confirmation that the source of the trouble was in the tilting of the bearing. Plotted results also showed that the bearing started to cock up before the sliding foot started to move. Further examination of the sliding feet gave nothing positive, however.

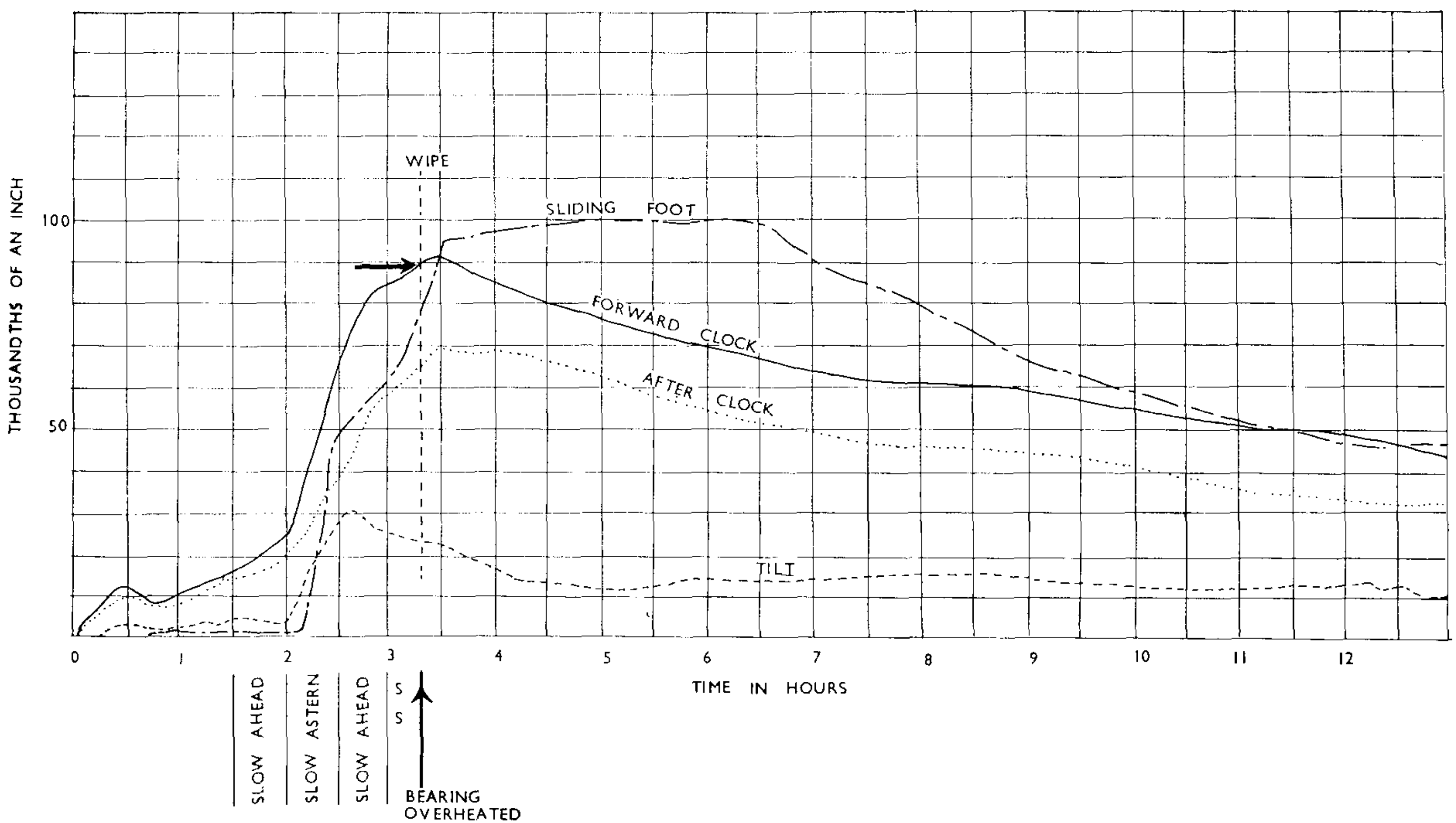

FIG. 4—PLOTTED RESULTS OF TILT OF AFTER L.P. BEARING

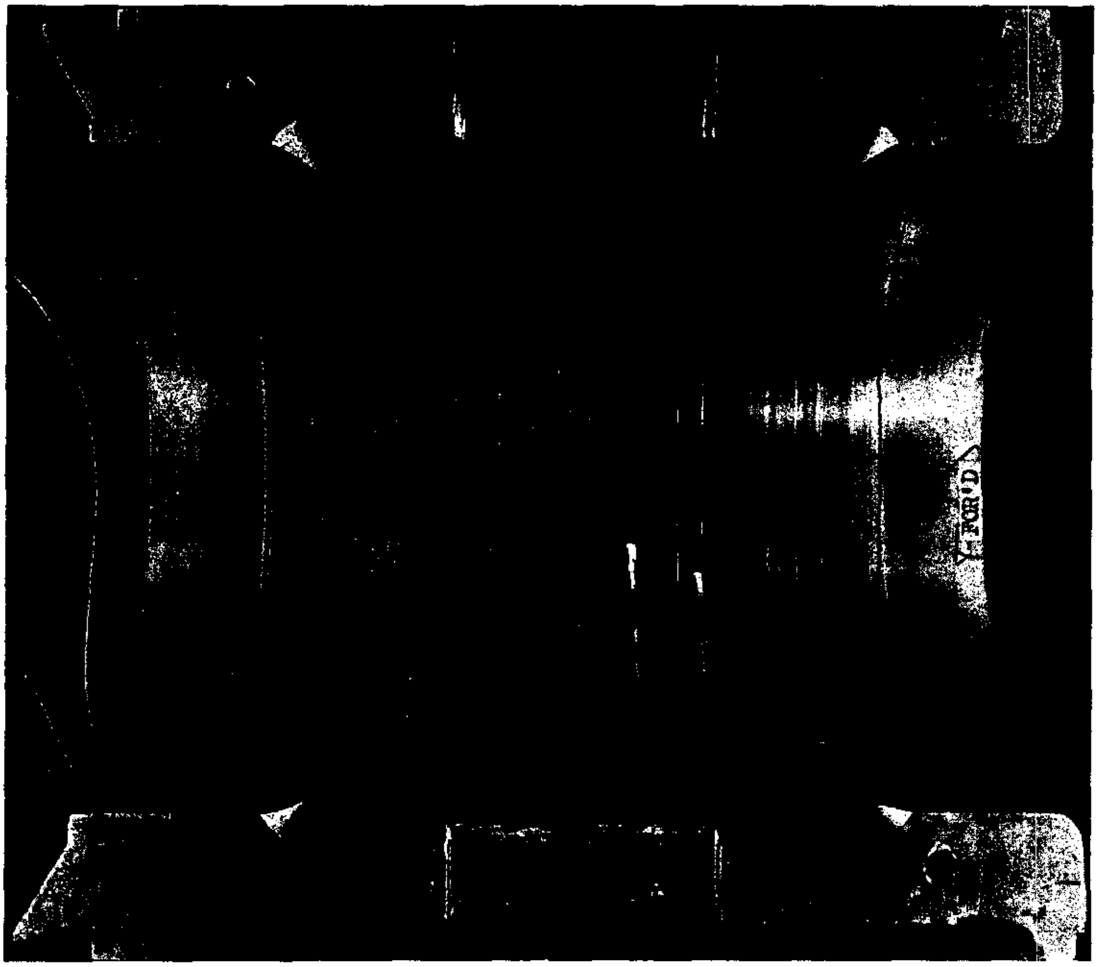

Fig. 5—Bottom Half of Starboard Inner L.P. After Bearing after Basin Trial, 10th Nov., 1960

Further meetings were held, and information and experience solicited from all sources. All suggestions made were investigated, but in general it was obvious similar troubles had not been met before.

Another series of basin trials were undertaken which resulted in more wiped bearings and a great deal of data, all of which strengthened the belief that the tilt was the cause of the trouble. It was apparent that this tilting was inherent in the construction of the steel casting supporting the bearing, and was determined by the temperature and temperature gradients prevailing. As elimination of this tilting seemed unlikely, the policy was adopted of trying to reduce the amount of the tilt to acceptable limits. At this stage, as an insurance, two designs of self-aligning bearings were undertaken, and two prototypes were made, but owing to the almost complete lack of experience of this type of bearing in turbine machinery they were to be considered only if other remedies failed.

The first big step forward was achieved by stripping the lagging off the L.P. turbine, and so reducing the metal temperature and thereby reducing the tilt by almost 50 per cent under certain conditions. This early success led to another attempt at sea trials, but these had to be given up when the after bearing of the starboard inner L.P. turbine wiped. This was an unusual wipe for it showed none of the usual signs of having originated from the forward edge of the lower half. In fact this wipe extended along the bottom half up to within half an inch of the forward edge, and showed all the characteristics of having been caused by overloading. This resulted in considerable rethinking on the possibility of double trouble. As the total rise of the bearing housing, as measured by the

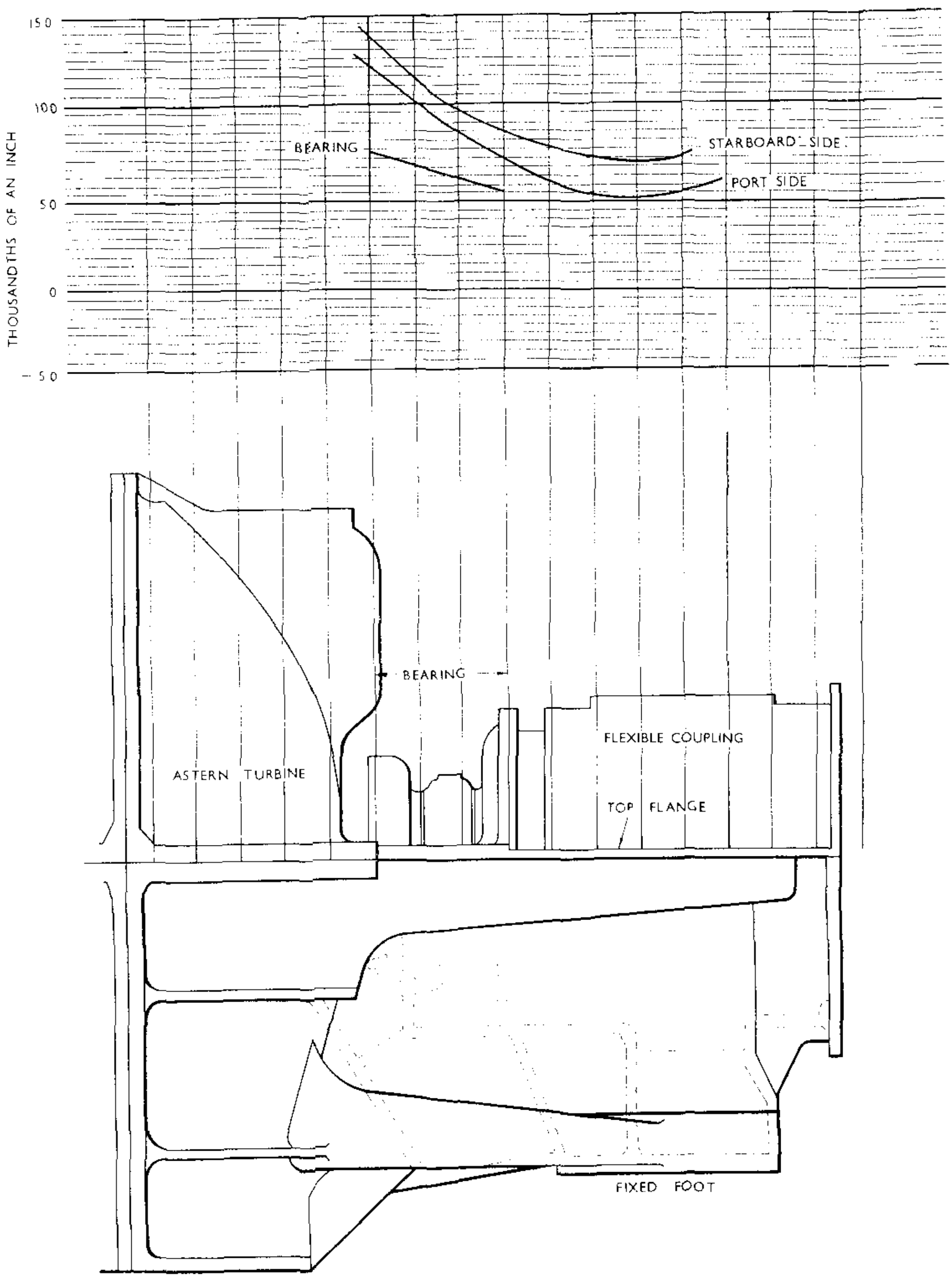

FIG. 6—DISTORTION DIAGRAM SHOWING HOT SHAPE OF TOP FLANGE OF CASTING

clocks, was about 0·1 in. it was possible that the freedom of the flexible coupling could have been absorbed thus imposing an additional load from the pinion. This load could almost double the loading on the turbine bearing.

At this point in the investigation it was decided to take the ship in hand for the repair of the damaged rotor. This was done by fitting a similar rotor removed from an L.P. turbine in H.M.S. *Leviathan*, and the work was planned to take fourteen weeks. During this period everything possible had to be done to obviate any further wiped bearings. Fortunately the after unit was still available for basin trials, and more instrumentation was set up and further trials carried out, giving particular attention to the total rise as well as the tilt. The time available, and hence the number of trials that could be undertaken, was limited and it was impossible to avoid altering several variables at each trial. This complicated the analysis of the results, but the ultimate effects were apparent in the condition of the bearings after the trials. To prevent the flexible couplings locking up during the basin trials the L.P. turbines were lowered 0·04 in. relative to the gearing when cold.

At this time it was found possible to instrument the after L.P. bearings in H.M.S. *Gambia*, and also in I.N.S. *Vikrant* (ex-*Hercules*, a 1942 light fleet carrier with similar engines to *Lion's*) which was carrying out Contractors trials from Belfast before being turned over to the Indian Navy. These ships have astern turbines at the after end of their L.P. rotors, similar to the *Lion* arrangement, and the results of their trials showed that the after bearings rose and tilted in a similar fashion to *Lion's*, but not to the same magnitude. This comparison suggests that the castings in *Lion* are more elastic than the other two ships, and are probably substandard due to the wartime manufacture. This could not be proved without cutting up the castings for the important webbing is inaccessible. However, this supposition does explain why the four L.P. turbines in *Lion* suffer from this unique defect.

Distortion Theories

Study of the results shows that the distortion is initiated by the expansion of the forward end of the lower half of the astern turbine casting, for in this vicinity the vertical rises resulting could be related to the metal temperatures. At the bearing the prevailing metal temperatures could not explain the rise, and it is considered that the casting stretches under the jacking effect of the hot end. This theory explains both the rise and the tilting action. The hot shape of the casting top flange was measured, and was found to be dished, a shape encouraged by the admission of the astern steam to the lower group of nozzles through passages formed in the actual casting.

From all this work the important factor emerged that the source of the distortion lay in the temperature of the astern steam.

' Trigger ' Theories

The most disturbing feature of the result analysis was that no definite pattern for failure could be established. The wipes occurred shortly after changing from astern to ahead, and at the maximum recorded combination of rise and tilt—but not at the maximum recorded tilt, or at any definite value of total rise, which of course, is a measure of the hot misalignment of the rotor and gearing.

Several theories were produced in an attempt to explain what ' triggered ' off the wipe in a tilted bearing, which until the time of the wipe had behaved satisfactorily. The most popular of these suggested that a wipe occurred when the rise was sufficient partially to lock the flexible coupling and thus the tilted bearing would receive a loading blow once, or more, every revolution. Another theory suggested that under certain temperature gradient conditions the differential expansions would permit a gradual rub of the lower fin packing in the after gland against the rotor, and the heat so generated would trigger the wipe. This was an attractive theory since it explains the lack of pattern, and by the wearing away of the packing is self eliminating.

Remedial Action Taken

By early December, time was running out and, in order to get the remedial work done within the repair period, Portsmouth Dockyard were given instructions to carry out the following :—

1. Fitting of a desuperheater in the astern steam pipe

2. Increasing the degree of freedom of all L.P. flexible couplings, by doubling the tooth flank clearance and lowering the L.P. turbines by 0·04 in. at the fixed foot
3. Fitting of a convection cooled habitability shield over the unlagged portion of the L.P. and astern turbine casings
4. Fitting of temperature sensitive electrical switches to the lower halves of the after bearings of the L.P. turbines.

The desuperheater consisted of a single spill type atomizer inserted into the astern steam pipe spraying water from the feed pump discharge upstream into the superheated steam. The steam pipe was sleeved internally to obviate crazy cracking as had been experienced with previous designs of desuperheaters. The output of the atomizer was controlled by a spill control cock sited near the manœuvring handwheel. This equipment was developed by the A.F.E.S. at Haslar on the basis of their knowledge of F.F.O. atomizer design. The capacity was selected to give fully controlled desuperheating between 50 and 100 r.p.m. astern. At 100 r.p.m. astern the sprayer is at maximum output, and at higher speeds desuperheating is progressively less.

The temperature switches are of the type used in aircraft engine designs, and were set to burn warning lights and to ring a bell at all control positions when a temperature of 250 degrees F. was recorded at the switch. They can be tested by a built in heater device.

Results of remedial action

Dockyard work was completed on the 10th February, and as soon as possible, a series of basin trials were carried out on both units. These trials, and the operation of the desuperheater, were very satisfactory, a most pleasing point being the improved vacuum when running astern. The after L.P. bearings still rose and tilted but not to the previous extent, but no distortion of the casting adjacent to the astern turbine belt could be measured.

On the 16th February, the ship proceeded to sea to carry out a carefully graded series of sea trials, which included a major repair trial to prove the starboard outer L.P. turbine. All these trials were carried out without incident, and to plan. A good vacuum was maintained throughout, including the full astern from full ahead trial.

Subsequent inspection of all bearings showed that they were in good condition with no signs of wiping despite the arduous nature of the trials.

Some minor limitations on astern running have been imposed as a matter of prudence, but these will not embarrass normal manœuvring practice.

General Conclusions

The apparent complete success of the remedial action was most gratifying. Whether the greater freedom of the flexible couplings, or the steam cooling, was responsible for eliminating the wiping is still an open question, but obviously both played their part. The desuperheater reduced the distortion and so made it possible to maintain a good vacuum, and hence give fair temperatures throughout the L.P. turbine.

The records taken every five minutes during the sea trials show the familiar pattern of rise and tilt, but on a lower level. This highlights the fact that the distortion has not been eliminated, and the remedial action taken has accommodated the trouble but has not cured it at the source.

The whole task was pushed through at high pressure with splendid co-operation and vigour by all concerned, and a particularly pleasing feature was the keenness, interest, and enthusiasm shown by the fitters on the job. Time after time their carefully completed work was wrecked on the next trial, but their efforts did not flag throughout this most interesting job, and they made a very valuable contribution to the final success.