A TURBO-FEED PUMP DEFECT

by

COMMANDER (E) C. R. HAVERGAL, O.B.E., D.S.C., R.N.

While H.M.N.Z.S. *Bellona* was on passage from the United Kingdom to New Zealand in the last quarter of 1946, the interesting and diverting voyage was punctuated for the Engine Room Department by a series of tiresome defects in a Weir's turbo main feed pump. The defects which took the form of recurrent impeller gland leaks and wiped tail-end bearings are, it is feared, not particularly novel, and of themselves they certainly would not provide the excuse for this article. They and their treatment are only mentioned to provide a " case history " background for the description of an unusual defect that occurred later, and its repair. It is hoped that both of these may perhaps interest other guardians of these, sometimes fickle, machines.

Checking the Alignment

At first we thought that our gland troubles had their genesis in either the " packers " or the packing, or, perhaps, in a combination of both, but as assiduous inquiry exploded this theory, it was resolved to make a careful check of the shaft and bearing alignment. This showed that the pump spindle in way of the impeller bearing housing on the same side as the suction eye, namely, the tail-end bearing, was almost $\frac{1}{32}$ in. out of line with the associated journal. Moreover, this misalignment which was the same at both the forward and after ends of this journal, suggested that the entire cover and bearing casting was laterally displaced relative to the shaft, in spite of the very thorough spigotting and dowelling provided in the design for the specific purpose of avoiding such displacement.

However, after all extraneous stresses had been removed, the readings were taken again, and they established beyond doubt that the supposition was indeed correct, and that the pump must have been in this condition since it was built. The discrepancy was probably taken up in the first instance by boring the tail end brass off centre. Methods for overcoming this defect were devised and the following dockyard work was carried out.

Manufacture of new Turbine and Impeller

The spigot of the pump cover was machined to give $\frac{1}{32}$ in. radial clearance, the bolt-holes were correspondingly enlarged, and new and carefully fitted dowels and sockets were made. The future alignment of the impeller tail-end bearing would depend on these alone, as the spigot was now, of course, useless for this application. In addition, it was deemed advisable to fit a new spindle, because it seemed that the pump must have been running throughout much of its life with an appreciable bending moment on the spindle, which might well have fatigued it.

As no spare turbine and impeller assembly was available on the Station, a new one was built by the Dockyard using the technique described in A.F.O. 2498/44.

Dynamic balancing was impossible, there being no suitable machine then available in New Zealand. We had, therefore, to be content with a static balance on " knife edges," and this appeared adequate, except for a slight tremor when the pump was running.

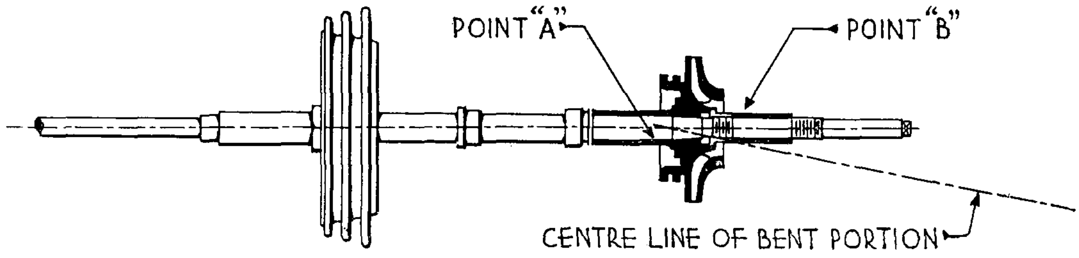

FIG. 1

More troubles

This, unfortunately, was not to be the end of the matter. One forenoon lighting-up watch, after a total of 40 hours' running since the repair just mentioned, the pump developed a very pronounced and unpleasant vibration, whereupon it was stopped and the auxiliary feed pump used in its place until the " units " could be changed over (the ship was steaming on two shafts at the time). The offending pump was then examined and it was soon discovered that the impeller tail end journal, which had been so laboriously aligned with its bearing, now had a " throw " of some 65/1000 in. when the spindle was rotated, indicating that this time the shaft and not the pump body was distorted.

Second Examination

The pump was stripped again and the turbine-impeller assembly " spun " in a lathe to locate the source of the distortion.

Clock gauging revealed the bend to be a " dog leg " one, originating about two inches towards the turbine from the blind side of the impeller (point 'A' in Fig. 1), in way of the stainless steel packing sleeve fitted there.

As the nickel-chrome steel (appropriately heat treated) from which these spindles are made (see Appendix on page 281) gives an excellent combination of toughness and malleability, it was at first decided to attempt to straighten the spindle cold, to avoid the possibility of upsetting its structure. As a preliminary to this, the tail-end stainless steel packing sleeve and the impeller, had, of course, to be removed. This curiously enough reduced the spindle " Throw " to 37/1000 in. (*i.e.*, $18\frac{1}{2}$/1000 in. on the radius). Repeated attempts were now made to jack and hammer the shaft straight again, but it proved so resistant to this treatment that it could not be set more than 10/1000 in. towards the normal, after a great deal of work. It was, therefore, decided to explore the problem from a different angle.

The impeller was remounted on the shaft, and careful readings of the longitudinal dimensions were taken and compared with the maker's drawings. This procedure disclosed that the stainless steel packing sleeve on the blind side (*i.e.*, the 'A' side in the sketch) of the impeller was $\frac{1}{8}$ in. shorter than the designed length, and that the taper in the impeller boss was not mating correctly with the male taper on the shaft, due to a slight divergence between their angles. It was, therefore, considered desirable to machine this sleeve off the shaft, and to substitute a spare of the correct length, lining the impeller boss as necessary, after lapping the two tapers together. It was this process that led to the discovery of the probable cause of the distortion, and consequently suggested a cure.

Probable cause of the trouble

While machining the sleeve, the portion of it at the origin of the bend in the shaft proved so hard that the lathe tool would not touch it. This zone was about $\frac{3}{16}$ in. in width, and occupied almost exactly a semi-circumference of the sleeve.

Deduction at once suggested that for some reason the impeller had got out of balance, and the consequent bearing load on the stuffing box neck rings, had locally heated the sleeve and the shaft underneath it beyond a "change point" in their structures. Water leaking from the gland, plus the conduction of the shaft material itself, having acted as quenching agents when the pump was stopped.

Working on this theory, it was decided to attempt partially to reverse the process of re-tempering the spindle locally in way of the overheated zone, on the assumption that if it was properly done, the shaft would resume its original structure and alignment.

Temperature Control

It was ascertained from the drawings that the material was originally tempered to 650°C., and as aluminium wire melts at 659.7°C., it provided a convenient agent for temperature control. The following two methods were employed :—

(i) Some aluminium wire about $\frac{3}{32}$ in. in diameter was wired longitudinally to a piece of two-inch diameter bolt-stave. The end of this was heated with an oxy-acetylene blow-pipe in such a way as to obtain a temperature gradient along its surface under the aluminium wire without subjecting the latter to the direct heat of the blow pipe. The object was, of course, to establish accurately the colour appearance of the heated metal at the melting point of the aluminium wire, in the relatively subdued light of the workshop.

(ii) The pump spindle was packed with fireclay reinforced with wire gauze for about 4 in. either side of the damaged zone, and a window about half-an-inch wide was left to allow direct access to this zone. Around the sides of this window a number of small lengths of aluminium wire were embedded in the fireclay in close contact with the shaft surface to give an indication of its temperature.

Of the two controls (i) proved far the most effective, (ii) being much too sensitive to the direct heat from the blow pipe to give anything but the crudest indication of the shaft temperature.

The fireclay jacket was, of course, put on to serve a double purpose, namely to reduce oxidation to a minimum, and to conserve the heat in the shaft for as long as possible. In the window itself borax was used as an anti-oxidation agent.

Re-tempering the Shaft

Heating with a large blow lamp was now started to bring the shaft temperature up to 200 or 300° C. with the object of preventing over-rapid cooling of the hardened zone by conduction. As soon as this general temperature had been attained, direct heat was applied to the hardened zone with a pencilled oxy-acetylene blow-pipe, until the previously determined " colour " temperature was reached. The area was heated twice, heavily coated with borax, and then wrapped up in asbestos cloth and allowed to cool off slowly.

What had been predicted came partially to pass, namely, when the shaft was cold again the tail end had returned 4/1000 in. towards the normal. This meant that the total throw was now reduced to 9/1000 in. ($4\frac{1}{2}$/1000 in. on the radius), and this was further reduced to $4\frac{1}{2}$/1000 in. total ($2\frac{1}{4}$/1000 in. on the radius) by lightly peening the now softened re-tempered and annealed zone.

The final correction which reduced the throw to 2/1000 in. was effected by carefully fitting the impeller securing nuts prior to " pulling them up."

The whole assembly was statically balanced on " knife edges " on completion, and no correction was necessary.

This pump has since run with insignificant vibration for about six weeks—in fact, better than it has ever run since the beginning of the present commission.

Suggested Sequence of Events

The sequence of events that led to the original defect are thought to have been as follows :—

> A wobble resulting from the unsatisfactory mating of the impeller tapers, generated a vibration of considerable amplitude at the critical speed of the assembly, which seemed to be in the vicinity of the running speed, namely at about 5,000 r.p.m. This, in turn, resulted in a whirling motion of the impeller which was only restricted by the neck rings on the suction and delivery sides, causing very considerable local overheating of the stainless steel gland sleeve and spindle at both points of contact. The fact that the shaft on the suction side did not become so overheated as the other, is probably accounted for by the considerably greater water leakage from that gland at the time. Its neck bush was, however, heavily worn and the sleeve, but not the shaft, was considerably distorted in way of it. (Point ' B ' in Fig. 1.) Support for this theory is lent by the fact that both zones of overheating occupied a semi-circumference only.

Whether deeper tempering would of itself have completely restored the shaft alignment is open to conjecture. In theory it seems that it should have done so (unless part of the distortion was due to permanent set of the shaft caused by the bend in sleeve ' A '). In practice it gave promise of supporting this theory, but it would be most interesting to the Author if someone with a profounder metallurgical knowledge would enlighten him as to the authenticity of this premise.

APPENDIX

Shaft Material :—		Shaft Material :—	
Carbon	... 0.28—0.34%	Sulphur... ...	... Under 0.05%
Nickel	... 3.3—7.5%	Phosphorus ...	... Under 0.05%
Chromium ...	... 0.5—1.0%	Remainder ...	... Fe
Silicon	... Under 0.3%		
Ult. Tensile Strength	... Over 55 tons/in	Yield Point Strength	... Over 40 tons/in
Elongation Strength	... Over 15%	Izod	... 40 ft. lb.
Quenching Temperature (Oil)	810°C.	Tempering Temperature...	650°C.
Melting Point of Aluminium	659.7°C.		

This article was submitted to the Central Metallurgical Laboratory and to Engineer-in-Chief's Material Section for their comments.

The general view is that Commander Havergal's contention that the shaft became locally overheated is probably correct. Such instances are known and the hardened edges may only be $\frac{1}{16}$ in. in depth.

On page 280 reference is made to conditions which may have acted as a quenching agent. Steel of this composition air cooling from above the critical temperature would result in an unmachinable steel, which did, in fact, happen.

The other view is that the impeller being improperly mated to the spindle caused an out-of-balance stress, thus fatiguing the spindle until it took up the dog-leg shape described. This would lead to the sleeve fouling the gland housing and so work-hardening. Subsequent tempering would relieve the hardness and possibly allow some return of the shaft to its original shape.—*Editor.*