DAMAGE AND REPAIR OF AN IMPULSE TURBINE.

The following account of the partial stripping of an H.P. turbine in one of H.M. ships, together with a brief description of the subsequent repairs, is of interest as an example of the importance of investigating the cause of any unusual vibration.

History of the Turbine.—The turbine is of the usual Brown-Curtis type, consisting of one velocity compounded stage with two rows of moving blades, followed by a number of simple impulse wheels. The history of this unit has been a somewhat eventful one, containing as it does no fewer than three cases of damage to the blading. The first of these accidents was due to improper operation, and occurred shortly after the vessel was completed; the defects were made good but, owing to the war conditions then prevailing, the ship subsequently proceeded on service without carrying out a repair trial. During the following two years no attempt was made to obtain full power, but a considerable amount of high speed steaming was necessarily experienced and satisfactory running was obtained.

The second case of damage to this turbine occurred some years later when heavy vibration developed, and, on opening out for examination, it was discovered that the first stage had been partially "stripped." The defects in this instance were due to the detachment of a number of the fixed blades in the upper half of the casing, the carrier ring, to which these blades were attached, having corroded to such an extent that in one position the dovetail had practically disappeared. It is curious to note that the corrosion was experienced at the top of the casing instead of at the bottom where water might be expected to lie; this selective action can only be accounted for by the assumption that any air within the casing tended to accumulate in the upper portion, thus causing the corrosion.

The turbine was not tested for balance after this repair, but a satisfactory trial at sea was carried out; no unusual vibration was noticed during this trial, although it was reported that the repaired turbine was less steady than the corresponding unit, thus giving evidence of some slight want of balance.

Satisfactory service was obtained from the turbine for the succeeding period of eighteen months, after which time slight vibration again became apparent. Further use of the unit at cruising speeds caused a gradual development of the vibration, but the amount was insufficient to give rise to any serious apprehension.

The third and final mishap occurred in this turbine when attempting a periodical Full Power Trial, after some six months' experience of the increasing vibration just referred to. On this occasion the disturbance became progressively more marked as the speed was raised, resulting in the fracture of the lubricating oil return pipe from the forward bearing of the cruising turbine, while lagging was shaken down from the steam pipes, and it also became necessary to lash all the valves in the vicinity of the turbine in order to prevent their movement.

It was nevertheless decided to proceed with the trial despite the somewhat disquieting circumstances, and speed was gradually increased till the power developed was but little below the authorised maximum, the total period taken for working up being ninety minutes, a normal allowance for such a set of turbines.

At this point it was noticed that three of the nuts securing the cap of the forward H.P. bearing had slackened back, and, immediately following an attempt to tighten these, the sudden appearance of a cloud of steam from the forward H.P. gland, accompanied by the fracture of a stud on the forward H.P. bearing cap, resulted in the abandonment of the trial.

On returning to harbour, pellets of blading material were found in the drain well, while the carbon packing of the H.P. forward gland was discovered to be broken and burnt, with accompanying scoring of the rotor spindle in the immediate neighbourhood of the gland. The forward H.P. turbine bearing was in fair condition and that of the remaining bearings was good. Bridge gauge readings were taken but provided no evidence that the rotor spindle was bent outside the glands, as might have been deduced from the condition of the latter.

The turbine was subsequently opened out at a dockyard, the following defects being revealed :—

Blading : First Row of first stage wheel.—All shrouding missing. Fifty per cent. of the blades broken off close to the rim of the wheel, or between this position and the reduced root section. The remaining blades were badly bent in a direction away from that of ahead rotation, and were damaged on both inlet and exhaust edges.

All root portions were found in the groove, which, however, had been opened out on the inlet side by amounts varying from 10/1000 in. to 16/1000 in.

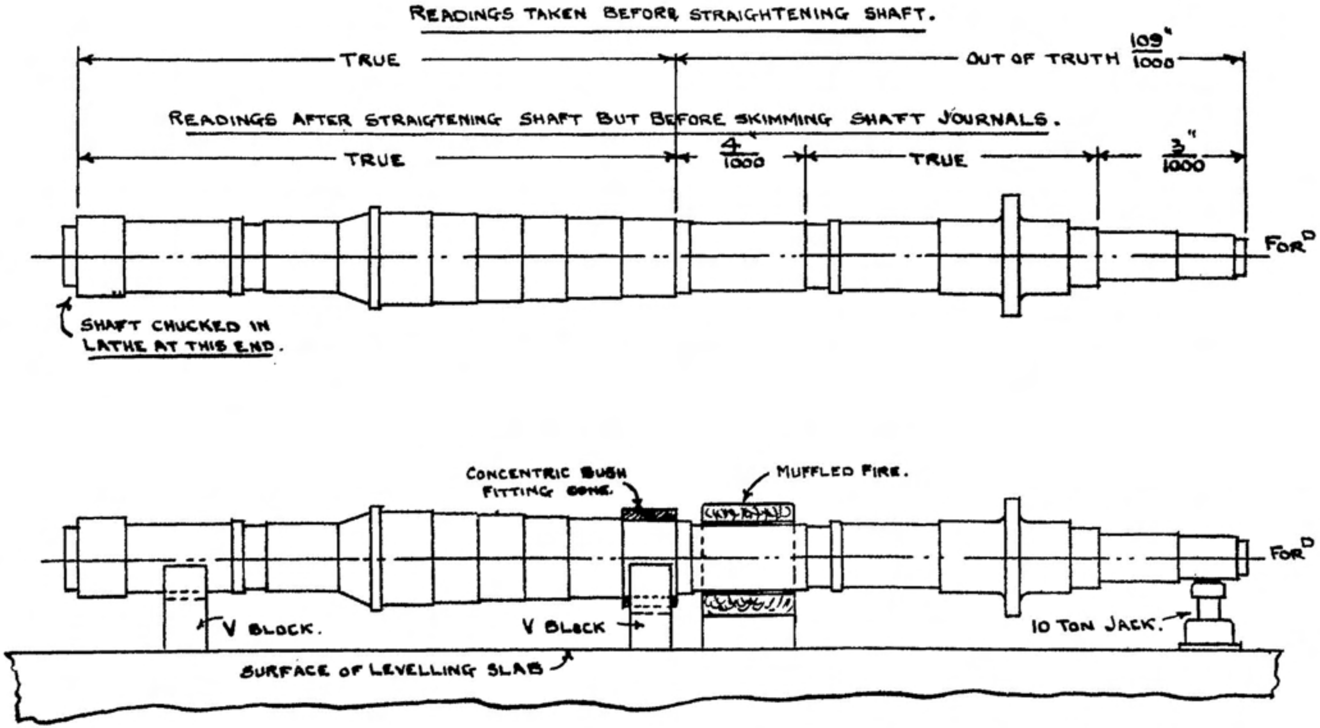
Guide Blades of first stage.—Shrouding and blading intact, but the inlet edges of nearly all the blades were badly dented and cracked.

Second Row of first stage wheel.—Shrouding and blading intact, but marked by contact with broken pieces of blading.

The blades, however, appeared slack in the groove, while the shrouding had been slightly lifted in places.

Remaining stages.—The blading was generally in good condition but slightly marked.

Nozzle Plates : First stage H.P.—The nickel steel plates were severely dented, the outlet for steam being practically closed.



SKETCH SHOWING METHOD OF STRAIGHTENING A BENT ROTOR SPINDLE.

FIGURE I.

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Cracks were found in 50 per cent. of the plates, extending in some cases for a length of $1\frac{1}{4}$ in. on both edges of the outlet edge of the nozzle.

Diaphragms.—The nozzle plates were in good condition, but the serrations on the diaphragm glands had been set over in all cases, while some of the "floating" gland rings were not free.

Forward H.P. Carbon Gland.—The top half of the packing box was found to be cracked in seven places and was badly worn in the recesses for the carbon rings, which were all broken.

Rotor Spindle.—The spindle was discovered to be bent to a maximum of 107/1000″ between the first stage wheel and the forward end of the shaft, as indicated on Fig. 1. The spindle was worn by 39/1000″ and 18/1000″ in way of the forward and after carbon glands respectively.

The exact cause of the damage in this case is necessarily a matter for some speculation, but certain points revealed by the subsequent enquiry are suggestive and indicate the probable developments leading up to the failure.

In the foregoing narrative it has been mentioned that over a period of some months prior to the accident it was noticed that the vibration of the turbine had steadily increased, thus indicating the possibility that the damage had been gradual: this theory is somewhat discounted, however, by the fact that all the blade roots were found intact in the wheel.

There is, however, little doubt that the rotor was not in perfect balance after the partial re-blading carried out some two years prior to the occurrence under discussion. This want of balance evidently could not increase unless distortion of the rotor or local change of mass took place, the probability of such changes being slight, however, in view of the fact that no high speed running was carried out after the satisfactory trial on conclusion of the repairs referred to. The cause of the increasing vibration may, however, be ascribed to gradual wear of the bearings or to loosening of the bearing nuts: the latter appears to be the more probable solution since three of these nuts were discovered to have slackened considerably during the period of working up to full power, an unlikely occurrence unless the nuts were somewhat loose prior to the commencement of the trial.

The possibility of the shaft having been initially bent is discounted not only by the successful repair trial but also by the fact that no trouble had been experienced with the carbon packing while on service.

The available evidence thus points to the damage having resulted from the gradual slackening back of the bearing cap nuts over a considerable period under the forces of vibration, due at source to the lack of balance which developed on the occasion when the turbine was partially re-bladed.

On working up to high power a number of the bearing nuts slacked back to a dangerous extent, with the result that one stud fractured in spite of an attempt to harden up the loose nuts. This defect permitted the shaft to rub heavily in the forward H.P. gland, giving rise to local heating and subsequent bending of the shaft, with the accompanying damage to the diaphragm glands and stripping of the turbine blades adjacent to the point of maximum deflection.

This accident points not only to the desirability of avoiding re-blading *in situ*, unless adequate steps are taken to ensure that a reasonably good balance is obtained, but also to the prime necessity for the thorough investigation of any unusual vibration.

One further point is stressed by the events leading up to this accident, namely the impropriety of attempting to adjust the bearings of machinery while it is at work : the wisdom of such a proceeding is always a matter of some doubt, and especially so when a heavy out-of-balance force is acting upon the bearings, as in this instance. There is a distinct possibility that the attempted adjustments actually accelerated the failure, which might have been avoided had the turbine been stopped in order to ensure the even tightening up of the loose nuts; this view is to some extent borne out by the fact that the fracture of the stud followed immediately upon the latter operation.

Repairs.—The repairs carried out do not call for any special description, but a brief account of the method adopted for straightening the bent shaft and of the degree of accuracy obtained may be of interest.

After removing the rotor wheels and diaphragms from the shaft, the after end was secured in the chuck of a lathe, a steady bearing being provided at that part of the shaft which carried the first stage wheel. Under this condition the shaft between the lathe chuck and the steady (A and B) was true within 1/1000″ while the extreme forward end, which was unsupported, was 109/1000″ out of truth (Fig. 1).

A bush was then turned to fit tightly on the shaft in the place of the steady bearing, the outside of the bush being concentric with the bore of the shaft. The shaft was removed from the lathe and set up in V blocks laid on a suitable straightening slab, one block supporting the after shaft journal, while the other was placed under the bush. A strong back was fitted for use at the latter point, and a muffled fire arranged under the shaft at the position at which the bend commenced.

The shaft was then slowly heated and at the same time revolved on the V blocks. When sufficiently hot, the fire was removed and the shaft firmly bolted down by means of the strong back, straightening being effected by means of a 10-ton jack applied under the shaft between the bend and the forward end. The operation of heating and jacking the shaft was carried out several times until the error had been practically eliminated.

The truth of the shaft was then ascertained by placing it in a lathe with the after end in a chuck, the bush being supported in a steady, leaving the forward end of the shaft free. Under these conditions the shaft was true within 3/1000″ at the extreme end. After the bearing journals and the badly scored portions of the shaft in wake of carbon packing had been machined, the shaft was revolved in supports placed at the main bearings and found to be true with $1\frac{1}{2}$/1000″.

Before the wheels were fitted to the shaft, they were secured to a surface plate and the rims tried for truth with a scribing block with satisfactory results. The wheels were then assembled by forcing them—without heating—on to their respective cones, the *edges* of the shrouding on each set of blades being faired by turning a a final operation. On completion, the sides of the wheel rims were "clocked" with a micrometer as the rotor revolved, the maximum end being 6/1000″.

Balancing.—The balancing of the completed rotor was carried out by mounting it on suitable hardened straight-edges about $\frac{5}{8}$ in. wide and oscillating it at eight different positions of the circumference. The periods of oscillation were recorded and plotted and thence the "out of balance" of the rotor was calculated, the necessary adjustment being effected by removing metal from the heaviest parts of the wheels.

In this instance the shaft with one wheel fitted on the largest cone was first dealt with, the metal for correcting the "out-of-balance" of these items being removed from *this* wheel. Another wheel was then added to the shaft, and the adjustment for the three units made on the second wheel.

This operation was repeated until the "out-of-balance" of the rotor complete with shaft, wheels, clutches and thrust sleeve was reduced to five grains per cwt. this being the limit of the accuracy obtainiable by this method. A full description of this method of balancing a rotor is given in another article in this series of Papers.

The foregoing details indicate the standard of accuracy which may be achieved in a repair of this nature, given good workmanship and the necessary plant. It is to be noted, however, that the repaired rotor falls short of the requirements for new machinery in several particulars, which may be summarised briefly as follows :—

(*a*) The shaft and wheel rims are not quite true.

(*b*) The wheels were originally arranged to be a force fit upon the shaft, the difference between the diameters of the shaft and the bore of the hub being such that a positive grip was retained even at a speed 20 per cent. greater than that corresponding to full power : forced fits of this magnitude entail the application of heat before the hubs can be forced on to the shaft. If, as was done in this case, the wheels are subsequently removed and replaced when cold, the amount of force fit becomes indefinite as the hubs may have undergone some permanent deformation, resulting in a risk that the wheels may be loose at full power.

(*c*) The shaft was straightened by the local application of heat, without being subsequently annealed all over at one operation. This is undesirable, as portions of the material will inevitably have been heated to a " blue heat " with consequent deterioration in its physical properties.

(*d*) The rotor after repair was adjusted so as to be in good static balance, and in the absence of a dynamic balancing machine this was the best that could be done: the method of balancing as each wheel is added does not ensure that the dynamic balance is satisfactory.

Conclusion.—A successful trial at 90 per cent. full power was carried out on conclusion of the repairs. The turbine ran without vibration except for a minor " bump " which disappeared at the higher speeds.

DEFECT IN A HEAVY OIL ENGINE.

A somewhat unusual defect in a semi-Diesel engine recently came to notice and a brief description is appended for information.

During an overhaul of the engine some months previous to the actual detection of the defect, it was noticed that the skirt of the cylinder liner appeared to be $\frac{1}{8}$ in. low. This was attributed to incorrect manufacture and unfortunately the liner was not withdrawn for examination. Subsequent examinations of the engine after continued running (without withdrawal of the liner) showed no extension of the drop, thus apparently confirming the above supposition.

Finally, however, on starting up the engine after periodical cleaning, heavy knocking occurred and the engine was immediately stopped. It was found that the liner had dropped a further $\frac{13}{32}$ in. thus enabling the crankhead bolts to foul the skirt of the liner in their rotation, so causing the knocking and some considerable damage to the structure of the engine.

Removal of the liner revealed the fact that the portion of the cylinder casting which supports the upper portion of the liner had fractured in a complete ring along the section indicated in the figure. The fracture was clearly of long standing and undoubtedly was the cause of the initial drop of the liner.

It appears evident that the liner was retained in its displaced position by the effects of friction at the part A and at the lower joint, this being sufficient to meet the normal axial stresses. On the occasion of the final accident however, it is probable that an overcharge of fuel on starting gave rise to abnormal pressures with the result that the liner was forcibly ejected till the skirt came in contact with the crankhead bolts.