LINING UP

SOME NOTES ON MACHINERY ERECTION

BY

LIEUTENANT-COMMANDER P. E. SPENCER, R.N.

It would be futile in one short article to try to explain all the methods of the skilled erector. The thousandths which are taken for granted on the drawing board are all-important to him, and though the designer may say ' It's a perfectly good machine, but the erectors made a mess of it ', the erector is often perfectly justified in answering ' I'd like to make the designer put this together '. Erection procedure does not appear on the drawings. Many drawings ignore the force of gravity and show shafts suspended quite a few thousandths above their bearings, or turbine diaphragms hanging in mid-air. These notes apply particularly to small geared turbines, but the logic may be applied to any piece of machinery, whether it be first erection, major overhauls, or examining ' rogue ' machines. It is assumed throughout that little, if any, of the makers' data is available.

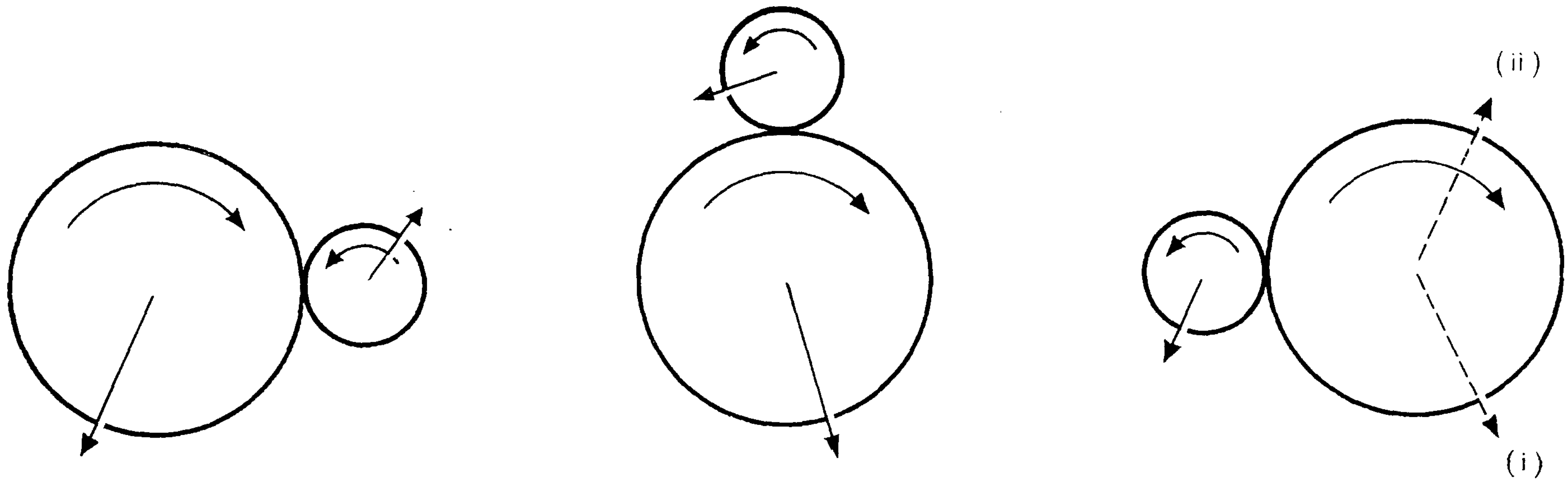
Size Up the Job

First study the drawings or the machine. See how it expands and how it is supported. Will it hog or sag when the condenser is filled ? Will the auxiliary bevel drive of a turbo generator go out of line when the turbine casing expands ? How do the diaphragms expand relative to the casing if the turbine is warmed through too quickly ?

Note where axial clearances should be and, if necessary, estimate them. There is no black art in this. There is generally an emergency thrust bearing which should take the load before the internal parts of the turbine foul the casing, but there must be sufficient clearance to avoid both thrusts pushing in opposite directions with, say, a 400 degrees F. temperature differential between rotor and casing. Bearing oil clearances should be on the drawings, but if they are not, 0·002 in per inch of diameter for high-speed shafts, 0·001–0·0015 in per inch for low-speed shafts and 0·006 in thrust clearance should give reasonable results. Turbine bearings require a little more clearance than pinion bearings to allow a greater oil flow and to remove conducted heat from the journals.

Check for Distortion

The first practical step is to make sure that the machine is not distorted. If on board ship, let go all the holding down bolts and go round the chocks with feelers. When the chocks have been shimmed satisfactorily, make certain that all lifting screws are locked back before the holding down bolts are tightened evenly. Release any large pipes and make sure that they are not straining the machine, remembering that both machine and pipes will expand when in the working condition. If a mandrel is available, make certain that the bearing housings are in line, or, if they are not, by how much they are out. Some manufacturers bore the bearing housings out of line so that concentric bearings can be used. The reason for this will be apparent later. Having established that the frame of the machine is undistorted, the mandrels can be dispensed with and the machine lined up using the actual rotating parts.



(*a*)
Pinion rises and Gear-wheel forced down

(*b*)
Pinion and Gear-wheel forced sideways

(*c*)
Pinion forced down Gear-wheel lifted
(i) torque small
(ii) torque large

Fig. 1—The Bearing Reactions, and hence the Running Positions of the Journals, depend on the Gearing Arrangement (Viewed from Turbine End)

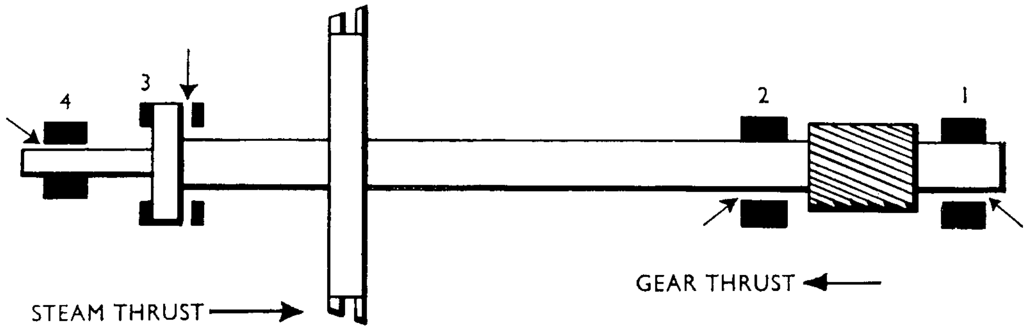


FIG. 2—RUNNING POSITION OF THE HIGH SPEED SHAFT IN FIG. 1 (*a*). ARROWS INDICATE BEARING CLEARANCES

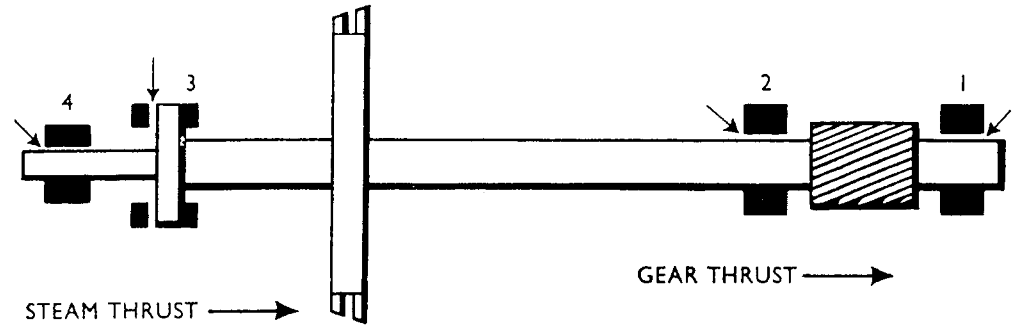


FIG. 3—HIGH SPEED SHAFT IN FIG. 1(*c*). ARROWS INDICATE BEARING CLEARANCES

Three Basic Types

There are three generic types of horizontal geared turbine, each requiring its own lining up procedure. These are shown in FIG. 1 : FIG. 1 (*a*) depicts what will be called the ' rising pinion ' type. Here the pinion is lifted by the torque reaction to the top of its bearings and forced outward by the tooth pressure, the gear-wheel is pressed down in its bearings and forced away from the pinion. The high-speed shaft of such a machine in its running position is shown in FIG. 2. The opposite or ' rising gear-wheel ' type is shown in FIG. 1 (*c*). The reaction on the pinion is down and out, and the net reaction on the gear-wheel bearings swings downwards at light load to upwards at full load. The high-speed shaft (FIG. 3) runs in the bottom of its bearings ; the low-speed shaft is generally constrained to run in the top of one bearing and the bottom of the other. FIG. 1(*b*) indicates an intermediate type where the pinion runs in the sides of its bearings.

Glands and Diaphragms

The high-speed shaft of a more complicated machine is shown in FIG. 4. The pinion runs in the tops of bearings 1 and 2, the turbine journals in the bottoms of bearings 3 and 4, and the extension shaft is forced by the bevel thrust to run in the top of bearing 6.

It will generally be found expedient to line up the high-speed shaft first, because adjustments to the turbine gland clearances are not easy, whereas the line of the low-speed shaft is usually easily adjustable. If the frame of the machine is accurately made and undistorted, little difficulty will be experienced, but if there is any distortion, the alignment may have to be a compromise.

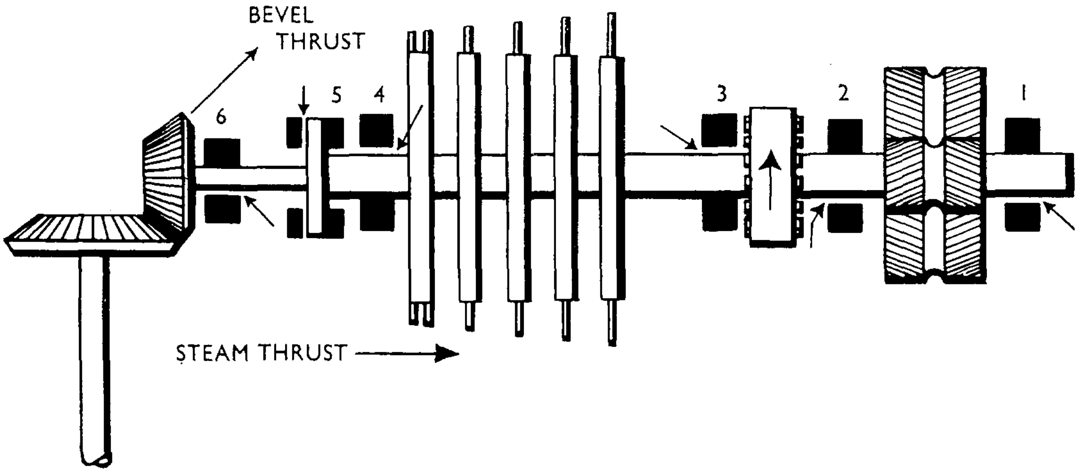


FIG. 4—HIGH SPEED SHAFT WITH RISING PINION, FLEXIBLE COUPLING AND BEVEL DRIVE. ARROWS SHOW BEARING OIL CLEARANCES IN THE RUNNING POSITION

First study the drawings of the labyrinth glands and diaphragms. Do the lower diaphragms rest on the casing, or are they supported by keys ? The upper half diaphragms are usually held up in the top half casing by keeps. The clearances between the diaphragms and the casing must be checked and adjusted. Cast iron diaphragms tend to grow and distort. If the allowance for diaphragm expansion is absorbed in this way, the labyrinth clearances may be absorbed, and the rotor will rub and be bent. Decide on the shaft line relative to the casing horizontal joint. In general the rotor centre-line should be on the same level as the horizontal joint, but it may be more convenient to use concentric bearings and run the rotor below the joint by half the oil clearance. Measure the diameters of the turbine journals, and with a micrometer depth-gauge and steel ball measure the depth of the bearing housing below the horizontal joint. The required bearing crown thickness can then be calculated. Have the rotor bearings bored, settle the rotor in them and check the diaphragm and gland clearances. Top and bottom clearances can be taken by using round leads and a spade micrometer, but if available, a series of lead strips in graduated thicknesses, laid side by side, gives a better and quicker indication. Side clearances can be taken with feelers, but if the diaphragms are loose in the casing, it may be necessary to centre them with small pieces of liner brass at their peripheries to avoid false readings.

If there are any marked peculiarities in the clearances, suspect a distorted turbine casing : in any case, it is a waste of time to proceed with aligning the gearing until the turbine internal clearances have been corrected.

Should the machine be of the type illustrated in FIG. 2, bearings 2 and 3 should have been bored low by the amount of the oil clearance, and towards the gear-wheel by half the oil clearance. When taking the gland clearance, liners, one oil clearance thick, should be placed beneath and liners, $\frac{3}{4}$ oil clearance thick, inboard of journals 2 and 3. Thus the spindle is held in its correct running position while the clearances are taken.

Pinion Bearings

Considering the turbine shown in FIG. 4, the thrust pads should be machined to give the correct axial clearances, and the thrust linered so that the rotor is forced hard towards its running position. Next, bearings 1 and 2 must be lined up. If mandrel or straight-edge readings show that all the housings are in line, the crown thicknesses can be calculated observing that when running, the

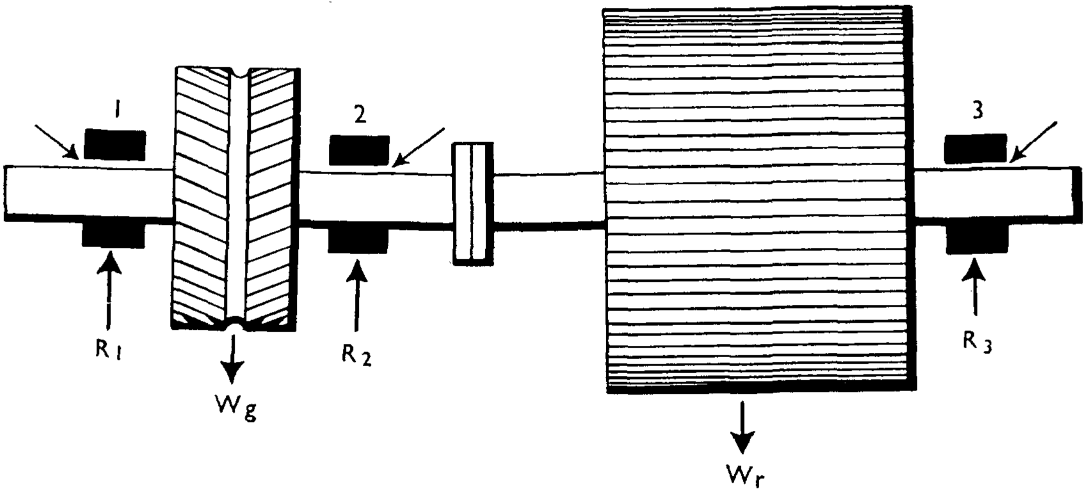


FIG. 5—LOW SPEED SHAFT OF A ' RISING PINION ' MACHINE (FIG. 1 (*a*)). NOTE HOW THE TAIL END BEARING IS RAISED TO ACCOMMODATE THE SHAFT DEFLECTION AND EQUALIZE THE BEARING REACTIONS R_1 AND R_2

pinion is lifted and forced away from the gear-wheel. When the bearings are bored, and liners are inserted under and inboard of the pinion bearings to represent the oil clearance, the couplings should line up. If they do not, then the error must be calculated from the coupling face clearances and peripheral alignment and the bearings must be rebored. Sometimes it may be easier to move the whole turbine or gearing unit.

Bearing 6 should present few problems. A bridge-gauge reading, the diameter of the journal, and the depth of the housing will give the crown thickness, the oil clearance being underneath.

The Low-Speed Shaft

It now remains to line up the low-speed shaft. With the ' rising pinion ' type, the gear-wheel runs in the bottom of its bearings (FIG. 5). With the ' rising gear-wheel ', bearing 1 runs on the top shell, and bearing 2 on the bottom shell (FIG. 6). Bearing 3 may be set to run on the top or bottom shell, depending on the weights of the moving parts relative to the driving torque.

Considering FIG. 5 in detail, the gear-wheel is forced down into bearings 1 and 2, and the lining up procedure must be such that the bearing loads, R_1 and R_2, are equal when the machine is on full load. If it is convenient to break the coupling, do so, supporting the driven shaft, and adjust bearings 1 and 2 so that the gears mesh correctly. This can be checked by using marking on the teeth, and by laying leads on the ' astern ' flank of a pinion tooth while turning the gears. The tooth flank clearance must be constant along the length, and to makers' recommendation. The marking should, if anything, be a little heavier away from the ' driving ' end of the pinion, to allow for pinion twist under load. The gear-wheel bearings should be adjusted to correct any errors. All of this can, of course, be done without breaking the coupling, but the work is more awkward.

Take bridge-gauge readings of bearing 2, and remake the coupling carefully with all bearing caps off. As soon as the bolts are reasonably tight, turn out the bottom brass of bearing 2 and harden up the coupling bolts. Test journal 2 for truth with a dial-gauge while rotating the low-speed shaft. Now lower bearing 3 until the bridge-gauge readings on journal 2 show it to be a specified amount (usually about 0·003 in for turbo generators) lower than it was with the bearing in place. Then replace bearing 2, record bridge-gauge readings, and bearing

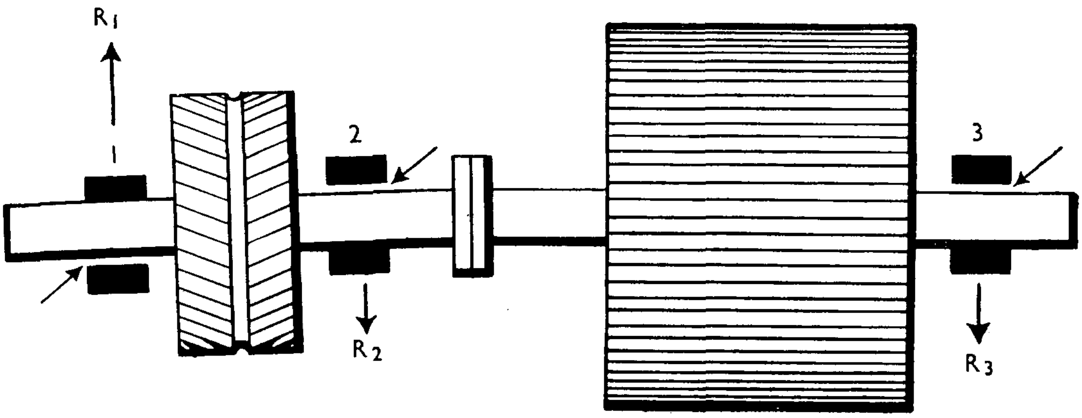


FIG. 6—LOW SPEED SHAFT OF A RISING GEAR WHEEL MACHINE (FIG. 1 (*c*)—THE MAXIMUM GEAR THRUST IS INSUFFICIENT TO LIFT THE SHAFT IN BEARING 2. BEARING 3 IS DROPPED TO KEEP JOURNAL 1 AT THE TOP OF ITS BEARING DESPITE THE SHAFT DEFLECTION

crown thicknesses, and close up the machine. This check on the drop of the shaft when removing the centre bearing is a useful one when the alignment of this type of machine is under suspicion.

This method of alignment adjusts the load on bearing 2, using the stiffness of the low-speed shaft as a spring-balance. Even if no makers' instructions exist, the drop of the shaft which distributes the load evenly between the gear-wheel bearings can easily be calculated by standard methods.

The procedure for aligning the low-speed shaft where the pinion is vertically above it (FIG. 1 (*b*)) is generally the same as for FIG. 5. The gear-wheel will always run in the bottom halves of its bearings, but will be forced to one side so that it may pay to offset bearing 3 horizontally by half the oil clearance (adjust the horizontal bridge-gauge reading of bearing 2 by a proportionate amount when the bottom shell is removed).

The Difficult Type

Finally, the type most likely to give trouble is the ' rising gear-wheel ' machine, illustrated in FIG. 6. The torque loading at full output may not be sufficient to lift the gear-wheel ; in this case alignment procedure is as for FIG. 5. But if, as shown in FIG. 6, the reaction R_1 is upwards and R_2 is downwards, alignment is tricky.

Align the gear-wheel with its pinion (remembering that the pinion now runs in the bottom of its bearings), with a liner the thickness of the oil clearance under journal 1. Again, the coupling of the machine should preferably be disconnected. Take bridge-gauge readings of journal 1 and re-connect the coupling, taking precautions against distorting the shaft. Then lower bearing 3 until journal 1 has risen by a specified amount (for calculation purposes, enough to prevent R_2 from becoming zero under full torque, but not enough to make R_3 zero at zero torque). The shaft is then in alignment. In extreme cases of this type of machine, journal 3 may have to be set to run at the top of its bearing, to prevent R_2 from reaching zero.

Vibration

Why is vibration dangerous ? If any bearing load becomes zero, the shaft is virtually unsupported at that point, and may be running above its effective whirling speed. The result will be vibration and premature bearing failure.

Any machine of the type illustrated in FIGS. 1 (*a*) or 1 (*b*) which vibrates on light load and settles down as the load comes on should be suspected of having a misaligned low-speed shaft. Any vibration at all from the type shown in FIG. 1 (*c*) should throw it under immediate suspicion.

Finally, when dealing with ‘ rogue ’ turbo generators, do not forget that unequal pole clearances can cause a force on the armature comparable with that of gravity.