Improvements in efficiency, accuracy and stability using a novel fluid film bearing

By Keith Martin PhD C.Eng FI MechE MSTLE MSAE MIMgt, Open University Lubrication Research Group

SYNOPSIS

A novel form of adjustable hydrodynamic fluid film bearing has been devised. The adjustment capability, which can be effected whilst the bearing is operating, confers operating characteristics that can be of benefit in a variety of applications. These include the ability to translate the rotational centre to any desired location, suppression of rotational centre orbits, improved stability and accuracy of location. The bearing has been subject to detailed analysis and computer modelling. Tests on practical versions have confirmed the improved performance for bearings of a range of sizes. The bearing can be substituted for a conventional type of fluid film bearing within the same available space.

1. INTRODUCTION AND BACKGROUND

Recent separate strands of research on improvements in the performance of fluid film bearings have been combined in the design, manufacture and testing of a novel journal bearing in a large marine gearbox test rig. This work may be of interest to the operators of generation plant as the bearing demonstrated improvements which they may find of benefit, and the bearing can be designed to be fitted retrospectively and packaged within the same space available for current designs of bearing. It can also be adjusted during operation in a proactive manner for optimum performance and to suit changes in prevailing conditions. The concept has been patented by BTG International (1). The background to the research and key findings are briefly outlined below.

1.1 Novel journal bearing

The first strand of research was conducted by Muhsin (2), under the supervision of Dr. D.W. Parkins, and focussed attention primarily on improving efficiency by reducing power absorbed by fluid film bearings during operation. Work was conducted on a specially designed test rig and bearing assembly. The bearing comprised 4 pads, equally spaced circumferentially, which supported the 47 mm diameter rotating journal by hydrodynamic lubrication. The lubricant was a mineral oil of ISO VG 32 supplied in the conventional manner but routed to each pad separately. Between each pad was a substantial space such that the wetted pad length was around 50 % of the total shaft circumference.

Each pad could be adjusted in terms of position, both radially and in tilt angle. By insertion of calibrated adjustment blocks and spacers the bearing pads could be reconfigured between tests to provide greater or reduced clearances and zero or converging tilt angles, or combinations of both. Loads were applied via an enveloping aerostatic bearing system incorporated in such a way that the total friction torque from the oil film shear for the 4 pads could be measured. For comparison a conventional full circular plain hydrodynamic bearing was also tested in the same manner. The clearance at unadjusted pad setting was equivalent to that of the conventional bearing.

Figure 1 shows comparative measured friction torques. For these tests the load was 600 N, the oil supply pressure 2.07 bar (30 psi) and the oil temperature rises between inlet and outlet for the conventional
bearing was 19°C, for the adjustable bearing with radial and tilt adjustments as indicated, 16°C, for zero adjustment position, 14°C. The potential reductions in friction torque, hence power loss, was of the order 30 percent. The novel bearing also demonstrated improvements in stability and radial stiffness, especially at zero eccentricity. Any radial load, including zero, could be supported at zero eccentricity.

1.2 Novel rotor bearing

The second strand of research was conducted by the author (3), also under the supervision of Dr. D. W. Parkins, and was concerned initially with improving the precision of grinding machine bearings, in particular by considering a proposed design which combined hydrostatic and hydrodynamic segments. The design was unusual in that the bearing surface rotated on a stationary journal. The journal diameter was 70 mm and the hydrodynamic segments comprised two bearings in parallel. Each of these hydrodynamic bearings comprised 4 separate pads incorporating a means of adjustment. By such means the individual pad tilt angle could be varied from zero to a maximum, i.e. contact with the bearing surface. After extensive theoretical modelling and studies, a system was developed in which the pad tilt angle could be adjusted continuously (i.e. infinitely variably) in a proactive manner during operation. The lubricant was a mineral oil of ISO VG 32 supplied to each pad separately.

The principle of adjustment involved the bearing pad being supported by a tapered pin. The pin in turn was located by a thread and when turned could translate along an axis parallel to the longitudinal axis of the journal. In so doing the pad tilt angle could be varied whilst still supporting a given load. A practical version and special test rig were manufactured and the bearing clearly demonstrated characteristics predicted by the theoretical model. This included the ability to move the position of the centre of rotation in any lateral direction. It was a simple matter to reset the centre of rotation to an initial position whenever the load magnitude, or direction, or both were altered. This included maintaining a zero eccentricity condition under radial load, and changes in load. Radial stiffness was also high in all directions, with loads applied in any direction, and variable by means of the adjustment system.

1.3 Fully adjustable journal bearing

The third strand of research, conducted jointly by Dr D.W. Parkins and the author, related to a project commissioned by DERA, funded by the Ship’s Support Agency, to design, manufacture and test in turn two larger versions of the novel adjustable bearing. Each bearing was to provide support for a Royal Navy T42 Destroyer main propulsion pinion gear shaft of diameter 190 mm running at 1500 rpm. Figure 2 shows the two novel bearings, before finish machining, designed with reference to knowledge and experience gained from the first two strands of research. The pinion shaft was normally supported by two conventional plain hydrodynamic journal bearings and each novel bearing was tested in turn whilst fitted in the place of one of these. All testing was carried out on a land based test rig comprising an electrically driven gear set supported in a steel case replicating the ship borne machinery set. The lubricant was mineral oil OEP80 for steam turbine gear application and included extreme pressure and pour depressant additives.

Figure 3 shows one of the novel bearings being installed, each of which could be fitted in the same space as the conventional bearing without any modifications to the bearing housing, bearing caps, support structure etc. For both bearings the adjuster pins were turned manually via a remote linkage, the linkage providing convenient access in relation to the construction of the particular test rig. The position of the journal centre of rotation and its orbit were monitored by inductive position transducers whose outputs were displayed by digital volt meters and an oscilloscope.
2.0 KEY FEATURES OF NOVEL BEARING DESIGN AND OPERATION

The design, manufacture and testing of the bearings have been and are being reported on in greater detail (4,5) so only brief outlines of key features that may be of interest to operators of power plant are given here. The bearing to the left in Fig. 2 comprises 4 separate pads each of which are formed within the bearing ring. The bearing surfaces are of white metal and each is fed with fresh oil via an inlet reservoir. Each pad is controlled by a tapered pin adjuster the turning of which alters the pad tilt angle. In the unadjusted position the pad bearing surfaces are circular with a radial clearance equivalent to the conventional bearings’ of 0.26 mm.

The bearing to the right of Fig. 2 comprises 4 separate pads each retained with a location spring. The bearing surfaces are of white metal and each is fed with fresh oil via 4 jets. Each pad is controlled by 2 tapered pin adjusters, the turning of which alters the pad tilt angle and radial position, separately or in combination. The pad bearing surface is of circular form and in the unadjusted position the radial clearance is equivalent to the conventional bearings’ of 0.26 mm.

2.1 Journal centre orbit suppression

The novel bearing system has been shown to provide stiffness and damping at all conditions of loading including those of zero load and zero eccentricity. This is manifest in an ability to suppress journal orbit sizes in a repeatable manner during operation, irrespective of the loading conditions. Figure 4 shows a typical orbit reduction demonstrated in the tests. In this case the shaft, running at 1500 rpm, was in its lightest loaded condition with a journal centre orbit diameter of approximately 0.14 mm, 53 percent of the radial clearance, as shown at the top of Fig. 4. Whilst running at the rated speed the journal orbit was quickly reduced in size by over 80 percent to that shown at the bottom of Fig. 4, using appropriate adjustments to the pad tilt angles. The orbit remained suppressed for all conditions of load. Both bearing types exhibited this ability.

2.2 Journal centre position

It was a simple matter to laterally reposition the journal centre orbit by appropriate adjustments to the individual adjuster pins. Figure 5 shows the repeatable and predictable results of individual adjustments to pad tilt angles, again demonstrated by both bearings. For example increasing the tilt angle of pad 4 by adjusting pin 8 moved the journal centre towards the opposite pad 2. The illustrated distances moved from the initial position in all 4 directions was approximately 0.15 mm, 29 percent of radial clearance. There was no limit to the adjustment range other than physical constraints related to clearances, shaft misalignment, gear meshing etc. Indeed, by using different radial adjustments of opposite pads, the double pin version of the bearing produced a lateral displacement of the journal centre in a controlled manner of over 2.5 times the normal radial clearance with no ill effects.

2.2 Oil temperature rises

For all tests carried out with both adjustable bearings the oil temperature rises between inlet and outlet were consistently lower than those with the conventional bearing in normal running. The double pin version was most effective in this respect as shown in Fig. 6. The single pin version was represented approximately midway between the two. The oil supply pressures and delivery system were the same for all tests indicating a less restricted flow with the adjustable bearings giving scope for further flow optimisation.
3.0 CONCLUSIONS

Results and knowledge gained from research into improving the performance of hydrodynamic bearings have been successfully integrated in the design, manufacture and testing of practical versions of an adjustable bearing system.

Adjustments can be made whilst the bearing is in operation, under all conditions of loading.

Significant reductions in friction torques and temperature rises have been demonstrated which can lead to improved operating efficiencies.

Controlled lateral positioning of rotating centres, whilst in operation, has been demonstrated under a range of loads leading to the possibility of proactive control and maintenance of given operating eccentricities, including zero, and hence greater accuracy of location of rotating components. The same feature could be of benefit in setting and maintaining equal load sharing in multiple in line bearing arrangements. It could also enable the fine adjustment of gear meshing alignment when the gears are in their hot, loaded and rotating condition.

High stiffness and damping can be achieved for all operating conditions including zero load and zero eccentricity, or both, leading to greater stability. The stiffness and damping can be adjusted in operation to tune rotor-dynamic performance in conditions of particular interest, for example the approach to and passing through critical speed regions.

The adjustable bearing can be designed to suit the space and packaging constraints of conventional forms of bearing and can be fitted retrospectively.

REFERENCES


Fig. 1 Measured friction torques (Ref.2)

Measured Torque, $T_1$ (Nm)

- $\triangle$ Zero Tilt and Zero Radial Adj. - Case Study 1)
- $\bigcirc$ -0.1° Tilt and 0.015 mm Radial Adj. - Case Study 3)

$P_s = 2.07$ bar (30 psi)
Using VG32 Mineral Oil
$T_{out} = 43 \, ^\circ C$
Load = 598 Newton

conventional bearing

novel bearing
Fig. 2 Adjustable journal bearings

Fig. 3 Installation of adjustable bearing
Fig. 4 Journal centre orbit suppression
Fig. 5 Controlled positioning of journal orbit centre

Fig. 6 Oil temperature rise