Performance tests of an 18-Inch Diameter, Leading Edge Groove Pivoted Shoe Journal Bearing

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Abstract: This article presents results from performance tests of 457 / mm (18-inch) diameter LEG pivoted shoe journal bearings supporting a 470 MVA generator rotor. Leading Edge Groove (LEG) is a method of lubrication that delivers cool oil directly into the oil film to increase bearing efficiency and has been successfully implemented in thrust bearings for more than ten years. Small LEG journal bearings have more recently been applied with favorable results. However, prior to this report, benefits for much larger journal bearings have been only projected. The test data presented in this article confirms prior projections: i.e., significant reductions in power loss were obtained, lubrication requirements were reduced by up to 46 percent, and low bearing temperatures were maintained. Performance and dynamic test data are presented which show that the application of leading edge groove lubrication to pivoted pad journal bearings can reduce lubrication system size requirements and significantly improve rotating machinery efficiency.

1. Introduction

The demand for energy in Asian countries is rapidly increasing and dynamic growth has focused on gas turbine combined cycle technology, attributed to the increased efficiency of such systems [1]. Predictions state that over a third of the generating capacity in Great Britain will be gas fired combined cycle plants by the end of the century. This trend is attributed to Privatization which makes these low cost/high efficiency systems attractive [2]. In the USA, expansion is slower and the outcome of deregulation is uncertain. Even so, the economics of competition suggests that companies with the lowest generating costs will be more successful [3]. Original equipment manufacturer competition has also established trends for low cost, high efficiency units with longer durations between maintenance outages.

Machine efficiency is degraded by power loss in the bearings. Bearing losses greatly increase with surface velocity and become especially high in large power generating units. In 1981, the British Institute of Petroleum published a report that addressed losses in turbogenerators [4], indicating that a 15 to 20 percent reduction in bearing losses in the United Kingdom's power generation equipment would contribute to savings on the order of $50 M per year.

Leading Edge Groove (LEG) technology is a method of bearing lubrication that addresses the reduction of bearing power loss. With this method, cool oil is delivered directly into the oil film of each pad. Tests of small (102 / mm), high speed journal bearings have obtained oil flow reductions of 50 percent and power loss reductions of 26 percent using LEG lubrication, while maintaining low pad temperatures as compared to flooded bearing designs. From these results, significant advantages were projected for large machines, not only in improved efficiency, but in savings possible with smaller, more efficient bearing lubrication and cooling systems [5].

With such background, the authors teamed to develop and test an LEG design journal bearing for a large electric generator application. The main objectives were to manufacture a cost effective bearing design that decreased bearing oil flow requirements and power losses, and to test the production size bearing to assure it would operate with acceptable pad temperatures and rotordynamic response. The following sections report on the results of this work.

2. Description of Tests

2.1 Operating Conditions

A set of 457 / mm diameter LEG pivoted shoe journal bearings were designed and manufactured for tests supporting a 470 MVA generator rotor. Tests were conducted on a shop rotor balancing stand using the LEG bearings, and separately with shop bearings representative of the flooded bearing designs used in production machines. Rotor dynamic measurements were obtained during start-up and run down conditions according to the balancing standards of the equipment manufacturer. For bearing performance data, the rotor was brought to a speed of 3000 revolutions per minute and allowed to reach steady state operating conditions.

Oil inlet temperature, oil outlet temperature, and oil flow rate were then recorded in two minute intervals over a 22 minute time period and averaged. Steady state measurements were repeated for a shaft speed of 3600 revolutions per minute. The lubricant was ISO VG 32 mineral oil provided at 40 degrees C.

2.2 Test Bearings

The shop bearing is a flooded design consisting of two lower chrome copper tilting pads and an upper cylindrical shell. Oil is contained in the bearing by seal rings and exits axially across the seals and radially through drain holes such that the bearing chamber is flooded during operation. These bearings were specifically designed for very low pad temperatures and minimum distortion, and have been used successfully in production machines for many years.

The focus of the LEG bearing design is to reduce power loss and oil flow while maintaining low pad temperatures. Figure 1 is a cross section of the 457 mm LEG journal bearing which has four steel pivoted pads. For this design, oil is introduced directly into the oil film through feed tubes. The bearing chamber runs in a partially evacuated condition, and oil exits without restriction. Table 1 lists geometry information for the bearings.

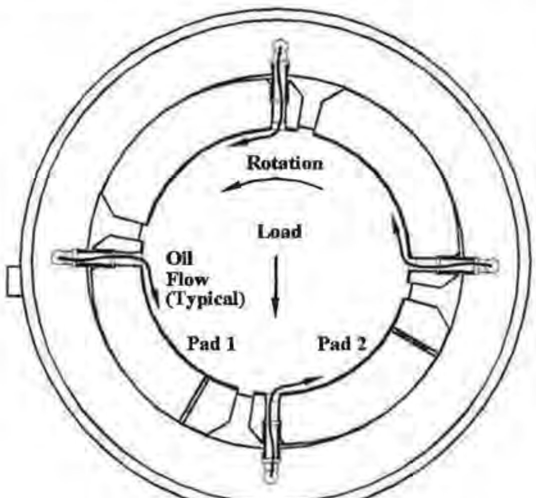

Figure 1 - LEG 4-pad Journal Bearing.

Table 1 - Bearing Geometry.

Bearing Description	Brg. Radial Clearance mm	Machined Rad. Cl. mm	Bearing Preload Ratio	Pivot Offset %
Flooded	.0180	.0180	0	55
LEG	.0125	.0165	.24	60

2.3 Test Measurements

Measured parameters included shaft speed, oil inlet and outlet temperature, oil flow, and vibration. Average oil flow, inlet, and outlet temperatures were used to calculate measured power loss based on a thermal balance. For the LEG test bearing, pad temperatures were recorded using copper-constantan thermocouples mounted along the circumferential centerline of the two lower pads, at positions 5, 50, 80, and 95 percent of the shoe arc length and at a depth of .76 / mm below the white metal/steel interface as illustrated in Figure 2 for the 80 percent location. Test measured pad temperatures are only available for the LEG design. The shop bearings did not have pad temperature instrumentation.

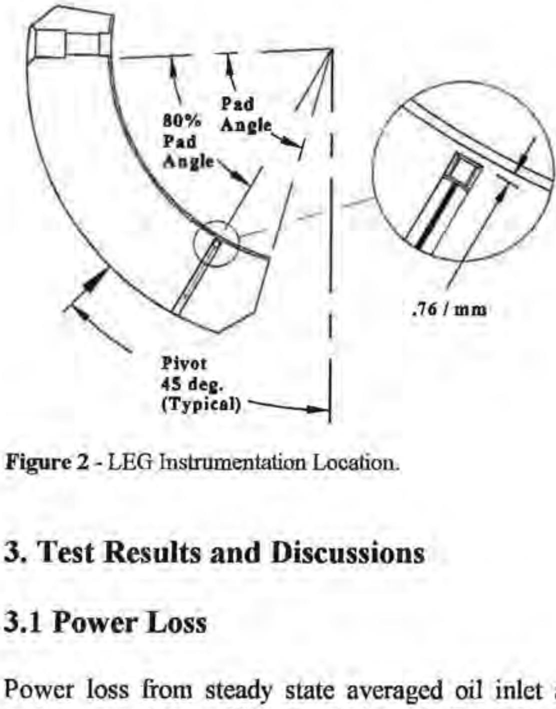

Figure 2 - LEG Instrumentation Location.

3. Test Results and Discussions

3.1 Power Loss

Power loss from steady state averaged oil inlet and outlet temperature and flow is tabulated in Table 2. The shop bearings were run with generator manufacturer recommended oil flows. The LEG bearings were designed for, and tested at lower oil flows than the shop bearings. Shop bearing tests were not conducted at lower flows because there were no pad temperature detectors to assure the integrity of the bearing at reduced flow rates.

Table 2 - Bearing Performance.

Bearing Description	Speed rpm	Oil Flow lpm	Oil In deg. C	Oil Out deg. C	Loss kW
Flooded	3000	635	40.4	55.8	288
LEG	3000	470	39.6	53.7	188
Flooded	3600	746	40.1	59.6	430
LEG	3600	470	39.9	61.3	288
LEG	3600	406	39.6	62.3	271

Comparison of values in Table 2 illustrates significant reductions in power loss were obtained with the LEG design. At 3600 revolutions per minute, the LEG had a power loss of 288 / kW with an oil flow of 470 / l · min^{-1} compared to 430 / kW with an oil flow of 746 / l · min^{-1} for the flooded design. This corresponds to a 37 percent lower oil flow, and 33 percent lower power loss. The LEG was also tested at a second lower flow at 3600 revolutions per minute. From Table 2, the LEG had a power loss of 271 / kW with a flow of 406 / l · min^{-1} compared to 430 / kW with a flow of 746 / l · min^{-1} for the flooded design. This corresponds to a 46 percent lower oil flow, and 37 percent lower power loss.

Power loss reductions on the order of 37 percent were unexpected for journal bearings. Prior tests on smaller LEG journal bearings recorded 26 percent reductions in loss for 50 percent reductions in flow compared to flooded bearings.

For two journal bearings in a generator, the table values are doubled. Oil flow would then compare 1492 / l · min^{-1} to 812 / l · min^{-1} requirements. Considering the utilization of LEG lubrication on the several other thrust and journal bearings throughout the entire train, it is not difficult to envision that significant reductions in oil flow will allow selection of a much smaller, more efficient bearing lubrication system.

3.2 Pad Temperature

When oil flows are reduced in a bearing, increased pad temperatures become a concern. This is especially true at high bearing surface speeds in large machinery where conventional bearing temperatures are already approaching typical design limits. And so, the LEG test bearings were instrumented to assess the temperatures of pads running with significantly reduced oil flows. Pad temperature profiles of the loaded pads for the LEG bearing are shown in Figure 3. The 80 percent location

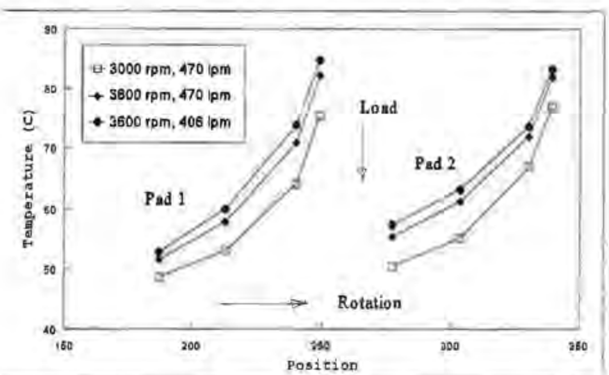

Figure 3 - LEG Bearing, Loaded Pad Temperature Profile.

detector is tabulated in Table 3 for numerical comparison. The 80 percent location is the recommended location to monitor bearing temperature as it reflects the most severe conditions of temperature and pressure.

Table 3 - LEG Bearing 80% Location Pad Temperature.

Bearing Description	Speed rpm	Oil Flow lpm	Oil In deg. C	Temperature / deg. C Pad 1	Pad 2
LEG	3000	470	39.6	64.1	67.1
LEG	3600	470	39.9	70.9	72.1
LEG	3600	406	39.6	73.9	73.7

Tests indicate that the recorded pad temperatures for both loaded pads are very low, and well within acceptable limits. As a guide, 93 / C to 105 / C are typical values used in many specifications for alarm settings. These values are very conservative as necessary to protect against unusual conditions.

Referring to Table 3 and Figures 1 and 3, the notation "pad 1" is used to indicate the first loaded pad in the direction of shaft rotation. In flooded journal bearing designs, it is typical for the second pad in direction of rotation (pad 2) to run hotter because of hot oil carried over from the preceding, loaded pad. The close proximity between the measurements of pads 1 and 2 in Table 3 supports conclusions of Reference [5]. That is, the LEG method of lubrication reduces the high temperature effects of hot oil carryover, allowing a reduction in oil flow without exceeding pad temperatures of typical flooded bearing designs.

3.3 Vibration

Another issue in regard to bearing comparisons is the effect on machine rotor dynamic response. Since the LEG design introduces cool oil directly into the pad, and because the oil flow is significantly lower than conventional bearing designs, vibration measurements were recorded with the shop and LEG bearing designs to assess the effects on the dynamics of the rotor.

Vertical and horizontal non-contact proximity probes were set up to measure vibration at both bearing locations. Vibration amplitude, response sensitivity and balance effects were analyzed. The results revealed both bearings to be stable and the rotor could be easily balanced in either set of bearings. The shop and LEG bearing designs both performed equally well with regard to vibration response control.

Figure 4 is vibration response data recorded during coast down for a certain condition of balance with the shop bearings. Figure 5 is LEG data during coast down with the same balance condition of the rotor. The data was taken at the same rotor balance condition in order to compare the dynamic characteristics of the bearings. Figures 4 and 5 represent data typical of other vibration comparisons, and show that the dynamic characteristics of the LEG and shop bearings compare well.

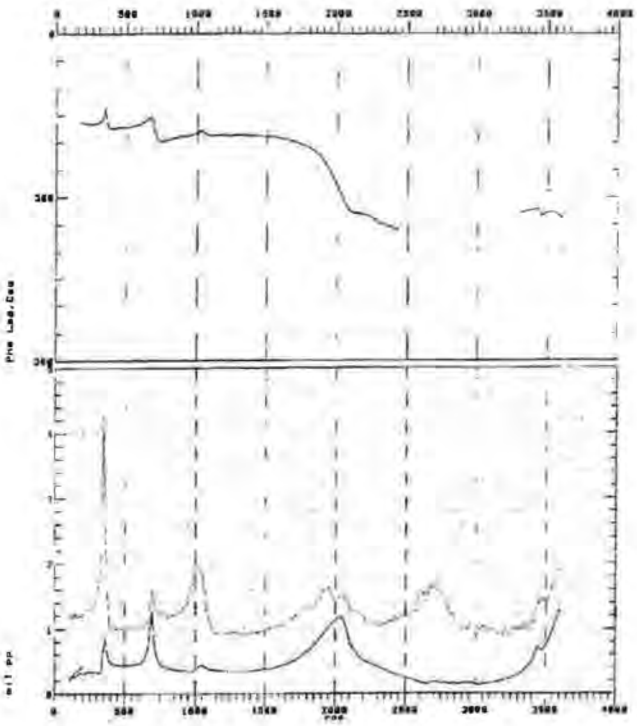

Figure 4 - Coast down, shop bearing.
(Solid line, 1X filtered. Dashed line, direct.

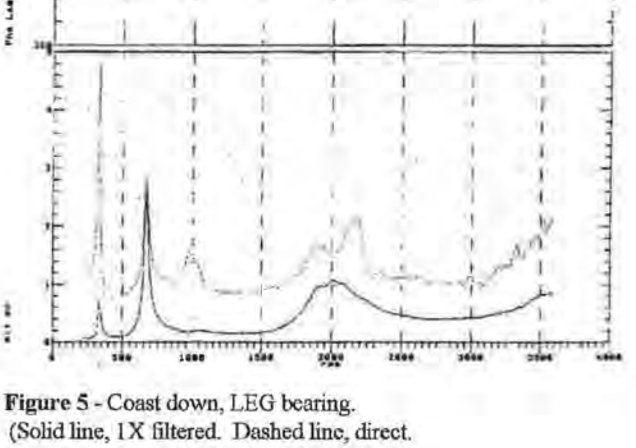

Figure 5 - Coast down, LEG bearing.
(Solid line, 1X filtered. Dashed line, direct.

Figures 4 and 5 plot vibration amplitude in mils, peak to peak on the lower scale, and phase lag in degrees on the upper scale. Solid lines are 1X filtered data, dashed lines are direct.

4.0 Conclusions

A large (457 / mm) LEG pivoted shoe journal bearing has been designed, manufactured and tested with a 470 MVA generator rotor. Results are consistent with prior tests of a smaller (102 / mm) LEG bearing. Specifically, the 457 / mm LEG design has operated with up to 46 percent lower oil flow than typical for flooded bearing designs, and has maintained low bearing pad temperatures with no signs of distress. Power loss savings were actually better than smaller bearing tests, being on the order of 37 percent lower than that of the flooded design. The reduced power loss contributes to the cost effectiveness of the design in power savings from the operation of the machinery. The significant reductions in flow allow selection of smaller, more efficient lubrication systems.

Vibration response control between the 457 / mm LEG bearing and the flooded bearing were similar. The shop and LEG bearing designs both performed equally well with regard to vibration response control. Both the shop and LEG bearing designs were stable and the rotor was easily and predictably balanced in both sets of bearings.

The performance and dynamic test data presented in this report shows that the application of leading edge groove lubrication to pivoted pad journal bearings can reduce lubrication system size requirements and significantly improve rotating machinery efficiency.

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