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"Research Note"

FAILURE ANALYSIS OF GE-F9 GAS TURBINE JOURNAL BEARINGS*

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Abstract– This paper presents a failure analysis of journal bearings used in GE-F9 gas turbines. Detailed studies including visual examination, optical microscopy, scanning electron microscopy, XRD and oil analysis were performed to determine the root causes of failure. Based on the results, it was determined that fretting, sulfur attack and fatigue were the main causes of failure.

Keywords– Journal bearing, bearing failure, fretting, sulfur attack, fatigue

1. INTRODUCTION

Bimetal bearings are constructed of two layers: backing and lining. The backing is generally steel to which a layer of bearing metal is bonded. In this type of construction the steel back provides rigidity and allows higher levels of press fit or crush for better retention. The bearing lining, however, must provide all of the bearing properties from a single layer. This requires that some properties be compromised in favor of others. Bimetal bearings are typically used for light or medium loading. The mechanisms by which bimetal journal bearings fail include fatigue, wear, fretting, corrosion, corrosion fatigue and cavitation [1-4].

2. INVESTIGATION METHODS

Failure analysis of GE-F9 gas turbine bearings having dimensional characteristics given in Table 1 was the objective of this investigation. Therefore, in the present case, samples of failed bimetal journal bearing were subjected to detailed metallurgical investigations. Depending on environment temperature (winter and summer) and cooling condition, the temperature of the lubricating oil was between 70 to 90 °C.

Table 1. Dimensions of the bearing and journal

Journal diameter (mm)	467.54-467.59
Bearing length (mm)	388.49-389.51
Vertical diameter of bearing (mm)	468.22-468.28
Horizontal diameter of bearing (mm)	468.93-468.99
Vertical clearance (mm)	0.66-0.76
Horizontal clearance (mm)	1.35-1.45
Thickness of bearing lining (mm)	2

The chemical composition of a bearing alloy was determined by the atomic absorption method. Detailed visual and stereo-binocular examinations on bearing lining were carried out. Investigation of the microstructure of the bearing material was done by optical microscope. The bearing surfaces were studied by scanning electron microscopy (SEM) on an Oxford S360 scanning electron microscope. These surfaces

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were cleaned thoroughly using acetone in an ultrasonic stirrer before examination. The hardness of different phases in the microstructure of the bearing alloy was measured. These tests were carried out on a polished specimen using a Leitz Wetzlar Vickers microhardness tester at a load of 25 g. The deposit on bearing lining was determined by X-ray diffraction (XRD) on a Philips X' Pert Pro diffractometer with Co kα radiation. The quality of the oil used just before the overhaul was checked.

3. RESULTS AND OBSERVATIONS

a) Visual and stereo-binocular observations

A visual examination of the bearing showed, clearly two black regions in the center of the upper half of the bearing, as shown in Fig. 1. The damage is confined to the upper half, with the bottom half of the bearing showing signs of normal wear.

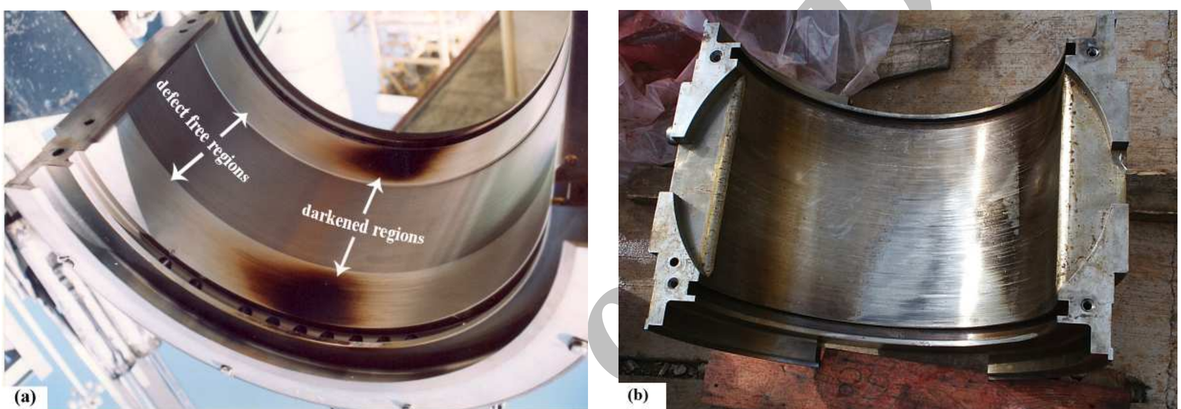

Fig. 1. a) Upper half of the bearing, b) and bottom half of the bearing

The outside surface of the upper half of the bearing backing was also damaged. It is easy to identify the severe fretting damage from the outer surface of the steel backing of the upper half shown in Fig. 2.

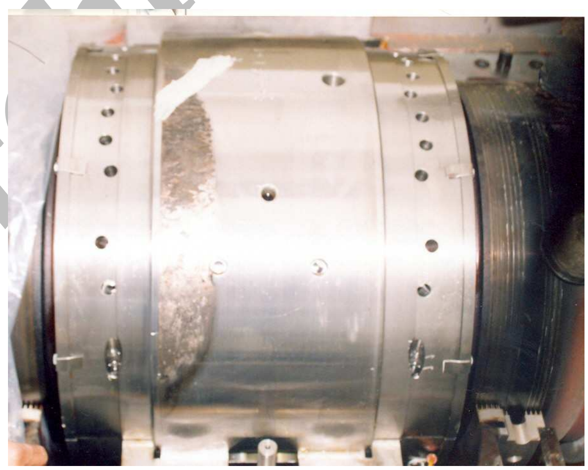

Fig. 2. Outside surface of upper half of bearing backing

Fretting of the outside of the bearing backing occurs as a result of small relative movements between mating surfaces. Movement may occur when there is insufficient press fit between the bearing and the housing. Lack of press fit can result when housing bores are oversize or when bolts are insufficiently tightened. The inner surface of housing also showed evidence of fretting.

Careful stereo-binocular examination on the surface of the bearing lining revealed some cracks on the failed (darkened) regions. No dirt or other foreign particles were found on the surface of either bearing half. The bearing surface contained no evidence of wiping or cavitation.

b) Chemical composition of the bearing alloy

The chemical composition of the bearing alloy was determined by the atomic absorption method. The results are shown in Table 2. It can be seen that the composition of the bearing material corresponds to ASTM B23-alloy 2. Tin-based babbitt alloys are extensively used for bearing material applications.

Table 2. Chemical composition of the bearing lining

Element	Sn	Sb	Cu	Pb
Content (wt. %)	88.9	7.5	3.2	0.27

c) Optical microscopy and hardness measurements

Metallographic analysis of the bearing material has been conducted. The micrograph in Fig. 3 shows a lining microstructure, where hard and small SbSn cuboids and hard Cu_6Sn_5 needles are embedded in the soft solid solution matrix of antimony in tin. There was no difference between the microstructures in the darkened region and the defect free region.

Hardness measurements were also carried out. Microhardness H_v of individual phases is as follows: matrix: 25.2; cuboids: 77.2; needles: 89.3. Metallographic analysis confirmed that lining chemical composition, microhardness and microstructure correspond to tin-based babbitt alloy.

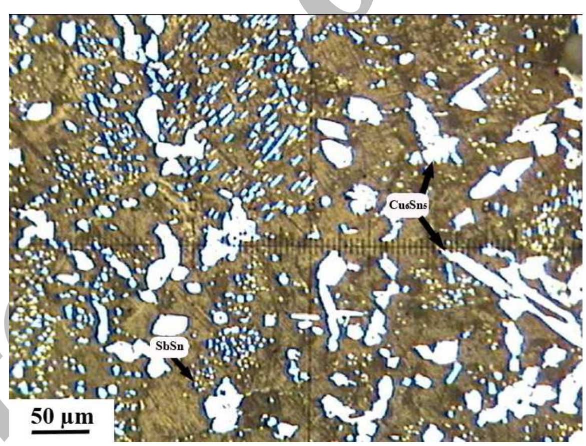

Fig. 3. Microstructure of bearing lining.

d) Scanning electron microscopy and XRD

Both darkened and defect free surfaces of a bearing were examined in a scanning electron microscope. Relatively low magnification fractographs in Figs. 4 and 5 show the surfaces of the bearing in darkened and defect free regions, respectively. It can be seen that some fatigue cracks have formed in the darkened regions. This seems to be the initial stages of fatigue damage before any loose pieces can form. Tin-based babbitt alloys have a low strength and readily suffer fatigue damage with rising temperature accompanied by alternating loads. In the present case, alternating loads are a consequence of vibration. Increasing temperature locally at the upper half of the bearing due to relative movement between the bearing and the housing has lowered the fatigue strength of the babbitt layer and caused fatigue damage. In other regions of the bearing surface (Fig. 5) there was no sign of fatigue or other damage.

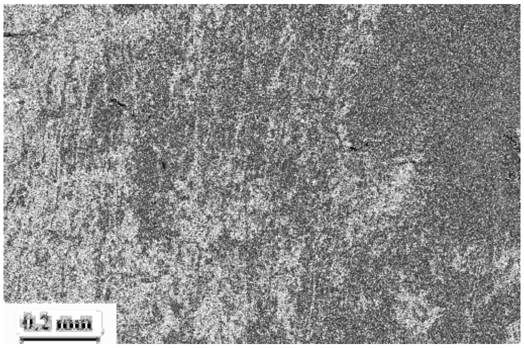

Fig. 4. Presence of fatigue cracks on darkened region

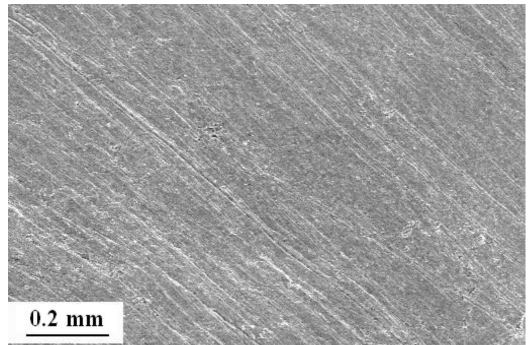

Fig. 5. Surface of defect free region

SEM-EDAX analysis was carried out to determine if there is any change in the composition of the bearing lining on the surface. The results for darkened and free defect regions are respectively shown in Fig. 6 and Fig. 7. One notable feature is the presence of sulfur at significant levels in the darkened regions. X-ray diffraction analysis was used for the specific identification of deposits. Some picks which correspond to copper sulfide (Cu_2S) picks are marked in Fig. 8. Since the surface of the bearing lining was not completely smooth, some additional noises are observed in the XRD pattern. The sulfide was formed by the action of sulfur acids in the lubricating oil on the copper in the bearing material. The decomposition of sulfur compounds in the lubricating oil usually occurs when moisture is present in the oil and when the operating temperature is high and exceeds a normal condition. In the present case, the frictional heat due to the oscillation of the bearing in the housing bore has stimulated a sulfur attack.

Additives are chemical agents added to lubricating oil to improve oil properties. Oxidation inhibitors (phenolics and dithiophosphate) and rust inhibitors (organic acids and sodium petroleum sulfonate) are among the additives which are extensive used in gas turbine lubricating oil. In contrast to phenolics and organic acids, dithiophosphate and sodium petroleum sulfonate include sulfur. It is clear that a sulfur attack can be prevented by using sulfur-free additives.

e) Oil evaluation

The lubricating oil was checked for viscosity, acidity and water content. Viscosity is the most important character of oil that should be checked. A check of the viscosity of the used oil at 40 and 100°C was performed. The acidity, as measured in the neutralization number test, is generally the second most useful information on used oil. Such a neutralization number generally gives the best idea of the degree of oxidation. A quantitative water analysis was also carried out. The results shown in Table 3 indicate that there was no problem with the oil in the normal operating condition. The result values have been compared with the recommended values mentioned in the manufacturer's instructions.

Table 3. Results of oil analysis

Character	Test method (ASTM)	Recommended value for fresh oil	Allowed changes for used oil	Measured value for used oil
Viscosity at 40°C (cSt)	D 445-96	28.8-35.2	± 10%	36.37
Viscosity at 100°C (cSt)	D 445-96	5.1-5.7	± 10%	5.83
Acidity (mg KOH/g)	D 974-97	0.2 (max)	0.1	0.165
Water content (vol. %)	D 1744-92	0.08 (max)	---	0.01

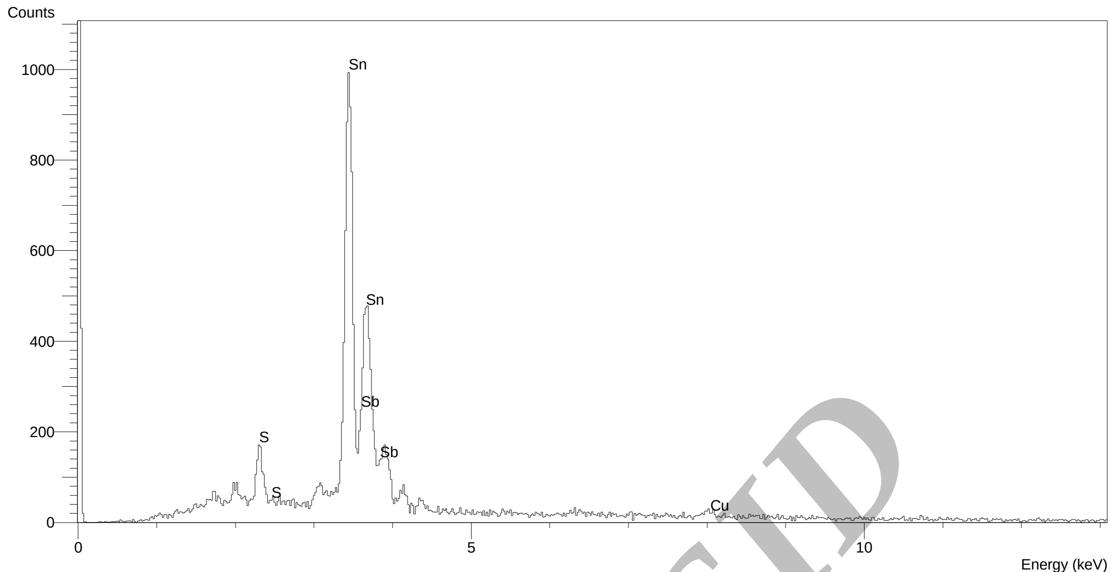

Fig. 6. EDAX analysis of darkened region

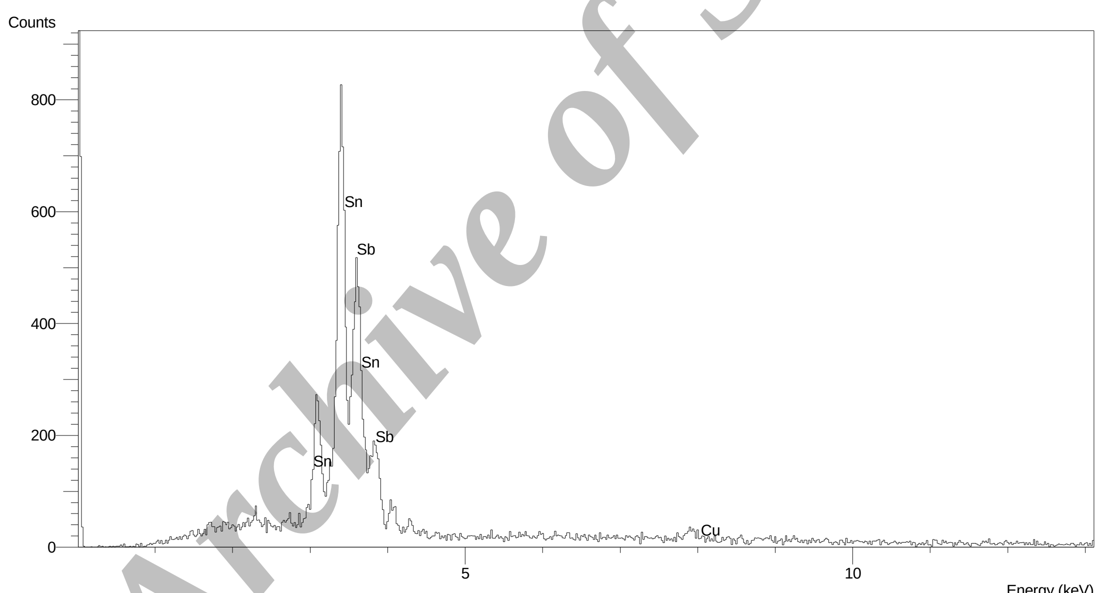

Fig. 7. EDAX analysis of free defect region

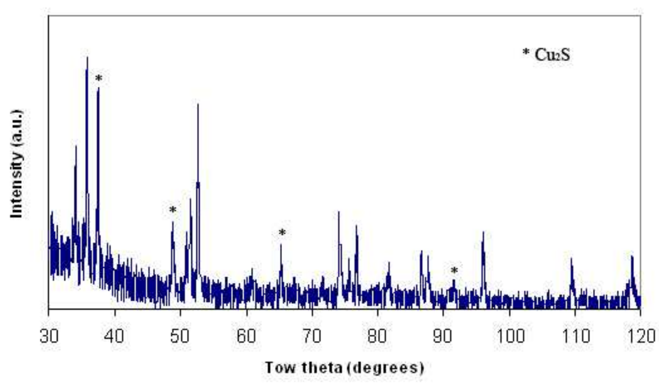

Fig. 8. XRD pattern of the sample taken from the darkened region

4. CONCLUSIONS AND REMEDIAL MEASURES

1. Relative movement between the bearing backing and the housing has been the main cause of failure. This movement resulted in the fretting of the outer surface of the bearing backing. Probably, the best measure to reduce or totally eliminate this movement is to use anti-rotation pins which keep the bearing and housing firmly together.
2. The dark corrosion product that covered the bearing surface was identified as copper sulfide (Cu_2S). The reaction of copper sulfide formation is a temperature dependent one; therefore preventing the rise of the operating temperature and changing the oil before sulfur acids accumulate to a harmful level can reduce the corrosive attack on the bearing material. Using sulfur-free oil additives is also a reliable measure which prohibits a sulfur attack.
3. The lubricating oil has had the required quality under normal operating condition; therefore it was not considered a direct contributing factor in the bearing failure.
4. The cracks that can be seen on the darkened regions are fatigue cracks before joining to each other and making loose pieces. Increasing the temperature of the upper half of the bearing due to relative movement between the bearing and housing has reduced the fatigue strength of the bearing lining and caused fatigue damage.

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