E. V. Zaretsky

A large amount of work has been performed and reported related to material and lubricant effects on rolling-element fatigue. An excellent summary of the research and the results thereof are contained in [3]. A summation of current state-of-the-art developments are summarized in [4]. Methods of accounting for lubricant, material effects on rolling-element fatigue and, hence, bearing life are presented in [5]. Reference [5], however, does not account for additive effects which may have detrimental effects on rolling-element fatigue life. The discusser would like to comment upon the authors' research and the reported results thereof in light of the previous work which has been performed by others and not referenced by the authors in their paper.

In rolling-element bearings, additives aid in protecting the rubbing contacts between the cage and the balls or rollers and between the cage and the race guiding lands. Also, it has been shown that antiwear additives can protect the ball-roller contacts in ball bearings operating under high-temperature, high-speed conditions where lubrication conditions are marginal. In the tests of [6], gross surface distress and wear were eliminated with the addition of a low concentration of a substituted organic phosphonate antiwear additive to a synthetic paraffinic lubricant. Further work confirmed that significant surface films are generated under similar high-temperature, high-speed conditions. These surface film production and an apparent increase in the elastohydrodynamic (EHD) film thickness between rolling disks as measured by the X-ray transmission technique. This lubricant and additive may be similar to that of the authors' synthetic oil and additive package D. Could the authors' comment on this?

The effects of lubricant antiwear and EP additives on rolling-element fatigue life are not well defined. When a rolling-element bearing is operating under conditions with a full EHD film separating the rolling elements, little, if any, asperity contact occurs and the life of the bearing is limited only by rolling-element fatigue. If, however, the film thickness is reduced such that significant asperity contact occurs, the life of the bearing is reduced [8, 9]. This life reduction is greater with increased frequency of asperity contact. Under these conditions, classical subsurface initiated rolling-element fatigue becomes a less common mode of failure, and excessive surface distress and smearing can become the predominant mode of failure [10]. Under these extreme conditions, surface active additives may be expected to influence bearing life by preventing some of the surface damage as demonstrated in [6]. However, under full EHD conditions where subsurface initiated rolling-element fatigue is the criterion of failure, these surface active additives should have no effect on bearing life unless the lubricant rheology is significantly altered by the additive or the presence of the surface films.

In [11], the effects of several surface active additives on several bearing steels were investigated in a rolling four-ball tester. Here it was found that either beneficial or detrimental effects on life are obtained with each of several additives depending on the choice of steel. These tests were run under very severe lubricant film conditions where significant surface film effects would be expected. The limiting life in the majority of these tests was of a surface distress type and not classical rolling-element fatigue.

Rolling-element fatigue tests were conducted with a base oil with and without surface active additives [12]. Three steel ball bearing steels were investigated in a rolling four-ball tester. Here it was determined that rolling-element fatigue is the criterion of failure, these surface active additives should have no effect on bearing life unless the lubricant rheology is significantly altered by the additive or the presence of the surface films. The test lubricant was an acid-treated white oil containing either 2.5 percent sulfurized terpene, 1 percent didodecyl phosphite, or 5 percent chlorinated wax. Nine combinations of materials and lubricant additives were tested at test conditions including a maximum Hertz stress of 5.52 x 10^10 N/m^2 (800,000 psi), a shaft speed of 10,700 rpm, and a race temperature of 340K (150°F).

In general, it was found that the influence of surface active additives was detrimental to rolling-element fatigue life. The chlorinated-wax additive significantly reduced fatigue life by a factor of 7. Rolling-element surface distress was observed in some of the tests. These tests suggest that the rheology of the base oil may have been altered by this additive. The base oil with the 2.5 percent sulfurized terpene additive reduced rolling-element fatigue life by as much as 50%. No statistical change in fatigue life occurred with the base oil having the 1 percent didodecyl-phosphite additive. The additives used with the base oil did not change the life ranking of bearing steels in these tests where rolling-element fatigue was of subsurface origin [12].

Did the authors perform any physical measurements to define the amount of elastohydrodynamic lubrication they were achieving in their tests with the different lubricant-rolling specimen combinations? How did these measurements compare with the theoretical calculation of elastohydrodynamic film thickness and roller surface appearance after testing?

The stress-life relation using the 5-ball fatigue tester was reported in [13]. In addition, results of tests in other test machines which were used to determine the stress-life relation was also summarized and reported in [13]. The conclusion presented was that, generally, consumable-electrode vacuum-melted steels produced a stress-life exponent of approximately 12, where air melted and vacuum degassed materials produced stress-life relations in the bench type test of approximately 9 or 10. There is no data in the open literature which would justify one concluding that the additives contained within the lubricants would or should significantly affect the stress-life relation in rolling-element fatigue previously reported by other investigators unless, of course, the mode of failure changed.

Fatigue tests of 6309-size deep-groove ball bearings made from two heats of AISI M-50 material produced by consumable vacuum-melting processes resulted in an average 10-percent life of 4.2 times the catalog life of 10 million revolutions. Additional fatigue tests of the same type of bearings made from a single heat of air melted M-50 material resulted in a life of only 0.4 times the catalog rating [14].

A single heat of primary air melted AISI 52100 steel was processed through five successive consumable-electrode vacuum remelting cycles. Groups of 6309 size bearings inner races were machined from material taken from the air-melt ingot and the first, second and fifth remelt ingots for evaluation; they were then heat treated and manufactured as a single lot to avoid group variables. With each remelt, a progressive reduction of nonmetallic content occurred. Endurance results show that the 10-percent life appears to increase for successive remelting with the fifth remelt material reaching a life approximately 4 times that of the air melt group [15].

Double vacuum-melted (VIM-VAR) AISI M-50 steel is commercially available. This material is processed with the first heat being vacuum induction melted. The material is subsequently vacuum arc remelted. Tests with 120-mm bearings made from VIM-VAR AISI M-50 steel [16] indicated that this material may produce fatigue lives at least seven times that achieved by normally processed CVM AISI M-50 steel.

Rolling-element fatigue tests were run with eight through-hardened bearing materials at 150°F [17-18]. These materials were AISI 52100, M-1, M-2, M-10, M-42 (similar to WH-49), M-50, T-1 and Halmo. One-half inch diameter balls of each material were run in five-ball fatigue testers. Care was taken to maintain constant all variables known to affect rolling-element fatigue life. The longest lives at 150°F were obtained with AISI 52100. Ten-percent lives of the other materials ranged from 7 to 78 percent of the obtained
with 52100. A trend is indicated toward decreased rolling-element fatigue life with increased total weight percent of alloying elements. Three groups of 120-mm bore ball bearings made from AISI M-1, AISI M-50, and WB-49 were fatigue tested at an outer-race temperature of 600°F [18, 19]. The 10-percent lives of the M-50 and M-1 bearings exceeded the calculated (predicted) AFRMA life by factors of 13 and 6, respectively. The bearings with WB-49 races showed lives less than AFRMA (predicted) life. The results of the bearing tests at 600°F correlated well with the results of the five-ball fatigue data at 150°F [18].

The above reported research appear to contradict those of the authors who report that “steel chemistry and purity did not purify any direct effect on predicted fatigue life.” Would the authors comment upon this?

Work performed by Schatzberg and Felsen [21] has shown that moisture does affect rolling-element fatigue life. It has also been common experience among many investigators that where moisture has not been a controlled variable, significant effects on life can occur. As a result, moisture should be and is considered a significant variable.

Additional References


Authors' Closure

Part I

It appears from the discussers' comments that their experience with geared roller fatigue machines is limited. After twelve years experience we are very much aware of the difficulties with these machines and believe that they are much harder to run than the 3-, 4-, and 5-ball testing machines. However, for simulating gear operations the ball testing machines are not suitable.

We have eliminated from the geared-roller machines most of the problems mentioned by the discussers. A small axial play between rollers is still possible but can be held to less than 0.005 in.

The statistical approach used by us in the test design allows us to minimize the number of tests required to give a certain level of confidence in the analysis. For these test machines and specimens the number of specimens tested must be minimized, and traditional methods using 10 or 20 specimens for each combination is not only impractical but also unjustifiable when a statistically designed experimental approach can be employed.

Part II

Mr. Zaretsky's comments clearly bring out the fact that the material and lubricant chemistry effects observed under one set of test conditions are not applicable to another set of conditions. He observed significant improvement in fatigue life in materials of higher quality under his test conditions of 800,000 psi and very low interfacial slip. We did not observe such significant improvements under our test conditions where a higher slip (3.3 and 30 percent) and a lower stress level were present. We feel also that the lubricant additive and moisture effects are significantly altered due to stress, sliding velocity, and the resulting surface distress.

All three parts of our study, taken together, clearly indicate that fatigue failure in lubrication is a complex phenomenon and is highly sensitive to material, chemical, and operating variables, and any conclusion drawn from one set of test conditions may not be applicable to a different lubricant regime.