AN INVESTIGATION INTO FATIGUE LIFE PREDICTION OF ENGINE BEARINGS

Hao Xu
Glacier Vandervell Bearings
Rugby, UK

ABSTRACT

In this study, work was carried out to investigate the fatigue life of engine bearings. A mathematical model was developed which utilises Miner’s rule to work out the total damage to an engine bearing when it is subject to all sorts of operational conditions. Given the fact that bearing fatigue rating has been traditionally tested against the specific load applied to bearings in test rigs, it was appropriate to develop a model using the specific load applied to a bearing, instead of the stress values in the bearing lining material. The model was then used to compare the life of con-rod bearings of a high performance diesel engine used on the road to that tested in the lab on test beds. The analysis showed the test procedure used in lab tests induced more severe damage than in the engine bearings in normal road use for design life.

INTRODUCTION

With the development of new engine technologies, engine bearings are subject to increasingly higher loads. This is particularly the case with new high performance diesel engines, some of which have seen the maximum combustion pressure almost doubled over the last decade. Bearing lining and/or overlay materials are so distressed that their fatigue life starts to attract more attention from bearing and engine manufacturers.

During the development stage of a new engine, all sorts of engine parts are tested on engines running in house on test beds. It is thus important to understand the severity of the test in terms of fatigue damage to engine components as compared with that to the parts in normal road uses for their designed life. The purpose of the work reported in this paper was to provide engine and bearing manufacturers a tool to achieve such an understanding for engine bearings.

Despite the long history of experimental tests employed by the industry for fatigue rating of bearing materials, there has been little work to study the problem theoretically. In 1998, Xu [1] reported his work which showed the location of fatigue site of an engine bearing which was associated with high pressure and thin oil film thickness from lubrication analysis. In the same year, Ushijima et al [2] employed an empirical approach to the problem, which added the influence of frictional power loss. The authors proposed a model using a combination of the three parameters to predict the potential for material fatigue. Recently, Holmes [3] et al employed a strain-life relationship to assess damage to bearing lining material, which used the stress and strain induced by the hydrodynamic pressure in the oil film. This is a more systematic approach. However, it has the drawback of over strengthening the system due to the structural model used. There is also a lack of fatigue data of bearing materials in the form which is suitable for the analysis.

Depending on applications, an engine bearing consists of two or three layers of metallic materials, fitted into a non-uniform supporting structure. During an engine cycle, it is subjected to a complex loading pattern which is generated by a combination of spiky gas loads and rotating inertial loads. Given these facts, it is difficult to relate test results from simple uni-axial loading tests to the fatigue problem of engine bearings. Traditionally, engine bearing fatigue tests have been carried out using a few different rigs. The most commonly used two are Sapphire and Underwood rigs. A detailed description of the mechanisms and operations of these fatigue rigs can be found in a paper by Pratt [4]. Both of the rigs record the number of loading cycles against the maximum applied load. The fatigue results are thus given as specific load against loading cycles at which fatigue occurs, i.e L-N curve as referred to in the industry. The L-N curve of a typical aluminium tin bi-metal bearing material is given in Figure 1. It follows a good linear relationship in the frame of log-log axes.

Although significant progress has been made in the
prediction of fatigue life of metallic materials, the theory is generally based on the variation of stress and/or strain values to which the material is subjected. However, given the fact that there is no fatigue data of engine bearing materials readily available in this form, it was important that any model developed should be based on the fatigue data of applied specific load against the number of loading cycles.

KEYWORDS
Engine Bearing, Fatigue, Bearing Life

THEORY
Fatigue analysis of metallic materials has been developed based on the stress strain curve of the material. In recent years, significant progress has been achieved. Many different models were developed by researchers for different conditions. One of the fundamental assumptions used in the analysis is the Palmgren-Miner cumulative damage rule, which states that the total damage to a material by a number of loading cycles is the summation of the damage caused by each individual loading cycle. It can be expressed as follows,

\[ D = \sum_{0}^{N} d_i \]

where \( N \) represents the total number of loading cycles.

For engine bearings, fatigue takes place after considerably long period of loading cycles. It was thus appropriate to consider that the bearing material fatigue was mainly stress induced. This assumption was considered appropriate since bearing lining is bonded on a steel strip which is significantly stronger than the lining material. This steel backing is used to strengthen the structure stiffness of the lining, and to maintain geometric stability during engine operation. With this assumption, the stress life curve can be reduced to a straight line when plotted on log-log axes.

\[ \Delta \sigma \propto (N_f)^b \]

In order to make use of the fatigue data of bearing materials in the specific load against the number of loading cycles, it was then decided to replace the amplitude of stress by the magnitude of the applied load. The expression for the specific load based fatigue life is then given as

\[ L = L_f (N_f)^b \]

where \( L_f \) can be defined as the fatigue strength coefficient, and \( b \) the fatigue strength exponent.

Equation (3) is a straight line on log-log axes. This relationship appears to give a good description of the L-N relationship obtained from experimental measurements, as shown in Figure 1. It is therefore considered reasonable to use the L-N approach for bearing life analysis.

RESULTS
The predictive method described in the foregoing section was used to conduct a life analysis of the connecting rod bearing of a newly developed high performance diesel engine. The purpose was to obtain an understanding of the severity of the fatigue damage of a test procedure used in a lab test as compared to the typical road use of the engine for 240 thousand kilometers of life usage. Using Equation (3), it was possible to work out the life cycles of the bearing under each loading condition. The ratio of the actual loading cycles at the condition to the predicted life cycles is then the degree of damage for the particular loading condition. The Miner rule is then used to work out the total damage for all the different loading conditions the bearing is subjected to. Fatigue of material takes place when the total damage value reaches unity. Table 1 gives a comparison of the fatigue damage to the connecting rod bearing. It indicates clearly that the engine test procedure used in the laboratory is significantly more severe than the operating conditions the bearing would experience when the engine is used on the road over its designed life.

Since the geometry of the actual rod structure is not comparable to the rod used in the test rig, it is likely that some errors will be introduced in this approach. However, when the data is used for comparative purpose, it is reasonable to expect the errors can be eliminated. The ratio of the predicted damage ratings at different operating conditions can be acceptable.

CONCLUSIONS
An analytical model for the prediction of engine bearing fatigue life has been developed. It is expressed in the form that the fatigue life of bearing material is a function of the applied maximum specific load. The relationship agrees well with the experimental data from bearing test rigs. The fatigue model was used to assess the fatigue life of connecting rod bearings of a diesel engine. It shows that the test procedure used in laboratory can induce more fatigue damage to the bearing than road use over the engine design life.

REFERENCES