IMPROVED FATIGUE LIFE CYCLE USING SURFACE FINISH AND SURFACE COATING IN A CAM-ROLLER SYSTEM: MULTI-SCALE SYSTEM ANALYSIS AND VERIFICATION

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ABSTRACT

Surface failure in the form of pitting wear is encountered in cam-roller systems. The failure appears to be initiated at micron-scale subsurface region. High stress is a result of the macro-scale requirement on the cam-roller motion event that produces high contact loads due to inertia of the roller and its follower link. Sliding of the roller and its impact onto the cam surface further compounds the detrimental effect of contact load. While conventionally a Hertz contact stress analysis can be used in ascertaining contact stress and maximum subsurface von Mises stress, it generally underestimates the stress when compared to the micron-scale subsurface stresses due to the presence of surface roughness. Contact analyses of cam and roller with rough surfaces are performed to examine the effects of two surface treatments. These involve surface finishing process in which a surface is rendered smooth, and the addition of a coating to the roller surface. Measurements of such cam and roller surfaces are used in micro-contact analysis module of Surface Distress Analytical Toolkit (SDAT) to examine the effect of surface finish and coating on maximum subsurface stress. It is found that smooth surface provides a 53% reduction in maximum subsurface stress. The analysis also shows that the addition of coating reduces subsurface stress nearly 7%. The impact of the combined treatment of the surface is an increase in fatigue life of the cam-roller system by nearly two orders of magnitude. The above findings are based on laboratory tests using six rollers without and with various degrees of finishing processes, and with and without addition of coating to the surfaces. Examination of the rollers indicates a general improvement in roller performance due to addition of coating. Most notably, the combination of finishing process and coating was found to provide the best fatigue life since the corresponding rollers showed no observable wear even after testing for 2161 hours, or the same number of cycles accumulated over about 500,000 truck miles.

Introduction

Surface failure in cam-follower system occurs due to repeated contact stress between cam and roller. Figure 1 provides examples of two failure modes on an injector cam. The primary failure mode that first occurs lies on the cam region corresponding to the portion following the maximum follower lift. This failure appears to be due to a combination of impact load and pronounced sliding between the cam and roller, leading to scuffing failure. Secondary failure appears as fatigue pits near the maximum lifting load. It is likely that the primary scuffing failure aggravates the secondary fatigue pitting failure by introducing worn particle in the cam-roller contact.

Figure 1. Surface failure regions on a roller

Systems Approach

In remedying the above-mentioned failure modes, we employ a systems approach that combines analyses at two scales. The macro scale dynamic analysis of the cam-rocker-roller system is used to establish contact force for various cam motion events. Using the result, micron-scale analysis is performed, using the Surface Distress Analysis Toolkit (SDAT) module at Caterpillar Inc., to predict induced surface and near surface stresses and surface fatigue life of the cam.

The analyses focus on the effect of surface preparation and treatment of only roller to remedy the surface failure of the cam. Initially SDAT is employed along with dynamic simulation of the cam-rocker-roller system to obtain the induced contact...
forces. These forces were used along with topography measurement of the cam and roller surfaces in the SDAT analyses.

Simulation studies for cam and roller conditions that include engineered surface roughness level of the roller with and without addition of coating were performed. Representative results are illustrated in Figures 2 and 3. Based on these the following are concluded: (1) introduction of coating decreases subsurface stress by 14 percent on an unused roller, (2) up to 53 percent decrease in maximum subsurface stress is achieved by using a smoother substrate – comparison of coated used and unused roller, (3) a combination of smoothing the substrate and addition of coating can yield up to 60 percent decrease in maximum subsurface stress, (4) smoothness and coating affect primarily substrate region within the depth of 10 mm.

**Figure 2. Maximum von Mises stress in subsurface**

**Tests**

Based on the simulation studies, six rollers were used for bench test studies. Four rollers were prepared using an advanced surface finishing process (ASF) to obtain surface topography of low roughness. Two rollers were left as ground (AG). All rollers were coated and subjected for tests under loaded engine condition.

Wear measurements of rollers tested in the lab up to 2161 hours are summarized in Figure 4. The influence of ASF process before coating is clearly evident as none of the four ASF rollers show significant reduction in coating thickness (Arm 1-4). In contrast AG rollers show significant delamination of coating as coating thickness is reduced by more than 60 percent for both AG rollers. This is in accord with the predictions made. That is, surface topography is a dominant influence in reducing scuffing and fatigue failures in a cam-follower system.

**Concluding Remarks**

A systems approach to address scuffing and surface fatigue failure has been presented. In the analysis phase of the investigation influence of macro-scale phenomenon involving dynamic response of the cam-roller system on the micron-scale behavior was established. The dynamic analysis was used to predict the contact force, from which appropriate force over a sub-region of contact zone was found through an iterative process. Simulation studies of the contact of rough surfaces revealed that near surface stresses can be reduced primarily through surface engineering of the roller in which roughness can be reduced through an ASF process. It was also predicted, and demonstrated through tests, that reduction in roughness increase the fatigue life cycle by 10 to 100 fold.

**Figure 3. Fatigue life cycle predictions**

**Figure 4. Laboratory tests showing coating thickness across the face of each roller. Arms 1 through 4 correspond to ASF processed coated rollers. Arms 5 and 6 are the AG coated rollers.**

Tests using rollers with and without ASF process verified the above predictions. Tests corresponding to cycle accumulated over 500 K truck miles showed that all coated rollers prepared by ASF before coating showed negligible loss in coating thickness, whereas those without ASF showed more than 60 percent loss in thickness.

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