INFLUENCE OF CAM SURFACE FINISH AND ROUGHNESS ON FRICTIONAL POWER LOSS IN VALVE TRAINS WITH ROLLER TAPPETS

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ABSTRACT

In order to reduce the frictional power loss and the wear in the valve train of internal combustion engines, the cam follower mechanism tends to be shifted from the sliding contact to the rolling contact such as a roller follower [1-5]. Design criteria for the valve train with roller tappets have been investigated by making obvious the effect of the cam lobe surface finish and its surface roughness on reduction of the friction loss. In particular the friction loss in the case of a cam lobe finished by shot-peening was compared with that of one finished by grinding. Also the influence of surface roughness on the friction loss was examined.

INTRODUCTION

Tribological problems have become serious for the contact between cam and follower, because the multi-valve system and the low viscosity multi-grade engine oil have been applied to improve the performance, while the oil is contaminated with soot caused by exhaust gas recirculation to reduce NOx emission. Specifically, since both the contact load and the friction force increase and moreover the oil additives is depleted, both the frictional power loss and the wear rate have become larger than ever [6, 7]. Therefore the rolling contact type cam-followers with less friction and wear are applied to the valve train in advanced engines.

Regarding the valve train with roller tappets, the advantage in friction has been evaluated for the new application of composite camshafts with sintered cam lobes finished by shot-peening instead of grinding. Both the friction losses at the contact part of cam and roller and at the other contact parts in the valve train were examined by measuring both the contact load and the friction force between the cam and roller in the OHV type valve train [2, 8, 9]. Also the changes of the solid contact between the cam and roller surfaces with surface roughness were predicted under the elastohydrodynamic and mixed lubrication regimes.

EXPERIMENT METHOD AND TEST CAM LOBES

The influence of the surface finish and surface roughness of cam lobe on the friction loss in the valve train was examined by measuring both the contact load $F_c$ and the friction force $F_f$ with a practically sized OHV typed valve train friction test rig, where forces acting on the tappet body were detected with three-component force sensors and a thin shape force sensor as shown in Fig.1. The forces $F_c$ and $F_f$ are related with the measured forces by the equilibrium expressions shown in the figure, where the angle $\alpha$ from the vertical line to the normal line onto the contact point of cam and roller are derived from the change of cam lift with camshaft rotation [2, 8, 9].

The test camshaft has an iron-base power metal sintered cam lobe finished by grinding, SG with a surface of around 0.4 micron in root mean square roughness, or blasted by shot-peening finish, SSP-F with a surface roughness of around 2.4 micron and SSP-R with a surface roughness of around 3.2 micron as shown in Fig.2. The roughness of blasted surface depends upon the size of blast particles.

EXPERIMENT RESULTS AND DISCUSSION

The experiment was conducted under the camshaft rotation speeds of 400rpm-1600rpm and the oil temperature was set at the ambient or 90 degrees Centigrade. The oil is SAE10W-30 engine oil.

EXPERIMENT RESULTS AND DISCUSSION

Figure 3 shows an example of measured diagrams of the contact load $F_c$, the friction force $F_f$ and the friction coefficient $\mu$ changing with the cam angle. It became obvious from the comparison of the diagrams among the test cam lobes SG, SSP-F and SSP-R that the influence of the surface finish and roughness of cam lobe on the contact load and friction are quite small, but the tappet clearance should be corresponded to the deviation of cam profile because the required clearance increases with the surface roughness. The cam lobe SSP-F is superior in cam lobe profile to the others. So the surface roughness should be smaller than three microns.

Also, it was made clear by comparing the torque to rotate the camshaft against the friction force between cam and roller and the torque to drive the valve train against the contact load among these cam lobes that the influence of the oil temperature and the surface finish and roughness on the mean friction torque and the mean drive torque is small.

By comparing the changes of mean friction coefficient with the rotation speed of camshaft as shown in Fig.4, however, it was found under the high rotation speed that the mean friction coefficient decreases as the surface roughness of cam lobe becomes large. As a reason why the friction decreases, it is supposed that the rough surface prevents the occurrence of skidding under the rolling contact between cam and roller because the bearing load due to the solid contact increases as the surface roughness becomes large. The skidding between the cam and roller is a slight slip motion between the contact surfaces and it generates under the acceleration or deceleration in the non-uniform rolling of roller on cam lobe [10].

ANALYSIS RESULTS AND DISCUSSION

Also the friction mechanism for the contact between cam and roller has been studied. As supposed above, the effect of interaction between rough surfaces on traction under rolling contact can be suggested as a reason why the friction characteristics change as examined above [9]. The change in the degree of solid contact between the cam and roller with surface roughness was theoretically estimated using an analysis based on elastohydrodynamic lubrication combined with mixed lubrication. The calculation conditions for contact load and camshaft rotation speed, materials and dimensions of cam and roller and properties of lubricating oil were those of present test specimens.

The bearing ratio of solid contact pressure to total contact pressure including hydrodynamic oil-film pressure exponentially changes with the surface roughness as shown in Fig.5. Only the solid contact pressure bears the whole contact load between the cam and roller under the condition where the surface roughness is larger than around one micron root mean square. Skidding is less likely to
occur between the cam and roller with cam surfaces larger in roughness than two or three microns.

CONCLUSIONS

Regarding the friction loss of a valve train with roller tappets, the following were concluded as key results of the present study.

1. The influence of surface finish and roughness of cam lobe on the friction loss in the valve train is quite small.
2. Under high rotation speed of camshaft the friction coefficient decreases as the surface roughness becomes large.
3. The rough cam surface prevents skidding of the rolling contact because the bearing ratio of solid contact is large.
4. The surface roughness should be larger than one micron and smaller than around three microns root mean square.
5. Shot-peening is more desirable than grinding as the finish of the cam lobe for a valve train with roller tappets.

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