Effect of Lubricant Inlet Pressure on the Roller Slip in Roller Follower Valve Train

Muhammad Usman Bhutta, Samiur Rahman Shah, Muhammad Usman Abdullah, Muhammad Noman Ashraf, Muhammad Khurram, Riaz Ahmad Mufti

Abstract**—** Engine valve train is normally subjected to severe operating conditions varying in nature of oil inlet pressure and operating temperature which can affect the tribological behavior of roller follower significantly and thus the overall performance of engine valve train. Little to no experimental work has been reported/carried out on the effects of lubricant inlet pressure on the roller rotational behavior and slip in a real production engine under actual operating environment. In this research work, the effects of lubricant inlet pressure on roller slip in an end-pivoted roller finger follower valve train has been experimentally investigated. The results revealed the effects of lubricant inlet pressure on roller slip clearly.

Index Terms**—** Roller Slip, Lubricant Pressure, Giant Magneto resistive Sensor, End pivoted roller finger follower.

I. Introduction

The direct acting bucket-type valve train configuration is the most common type of valve train configurations being employed in the automotive industry. However in recent days, the use of roller follower valve trains, particularly the end-pivoted configuration (Fig. 1) is becoming common in the modern passenger cars due to its improved fuel economy, higher performance due to reduced friction and improved service life of components. However, the efficiency of roller follower valve train is governed largely by the tribological behavior of rollers. The chances of fatigue failure of roller surface are minimized to a greater extent by even distribution of wear under pure rolling conditions. However, sliding of mating surfaces of cam/roller operating under marginal operating conditions can lead to wear of surfaces [1], [2]. Moreover, pure rolling of roller also helps in the reduction of engine valve train power losses by reducing the sliding friction and ensures uniform oil film at cam/roller interface. The roller slip is an actual phenomenon which is highly dependent on the engine operating conditions as experimentally investigated in detail by Khurram et al. [3].

Extensively modified test rigs have been used in the past to experimentally study the roller follower valve trains [2], [5]. The tribology of cam/roller pair is effected by many factors like contact loading, lubricant viscosity, camshaft speed, oil film thickness, operating temperatures, surface roughness, oil additives lubricant inlet pressure, etc.

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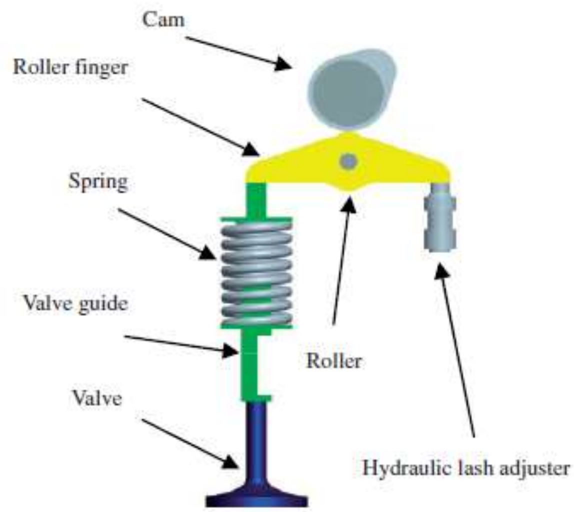

Fig.1. Under research Toyota 1NZK end pivoted roller finger follower valve train [3]

In this experimental research work, the effects of lubricant inlet pressure on the roller slip in a real production engine has been investigated in detail under actual operating environment. An advanced gasoline engine valve train Toyota INZK, as shown in figure 2 has been instrumented, for the very first time, to measure the roller slip under varying lubricant pressure using advanced sensor technology.

Fig.2. Toyota INZK Engine Head

II. Test Rig Setup

The Toyota 1NZK engine is a twin cam four cylinder engine with 16 valves. It has end pivoted roller followers with hydraulic latch adjusters. The cam-roller contact is lubricated with the help of the oil spray channel that is available in the engine head cover. The inlet and exhaust side camshafts of this engine head are identical. All the rollers have similar behavior under a given set of operating conditions as experimentally

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reported by Khurram et al. [3]. For this research work roller number 2 of the exhaust side was instrumented.

An advanced test rig shown in figure 3 was used to carry out the experiments

Fig.3. Engine Valve Train Test Rig

The cam shaft was driven by a three phase induction motor controlled via an advanced controller having Proportional Integral (PID) feedback control. An optical encoder having a resolution of 720 pulses per second was coupled at the back of the motor to provide the feedback signal to the controller. A PID controlled, plate type heat exchanger was used to heat the oil to achieve the required operating temperature. A separate controller with PID control was used to circulate and maintain the required oil pressure in the test rig. A Piezo resistive pressure transducer was used to provide feedback pressure signal for control. Heat loss was prevented by proper insulation of pipes.

III. Instrumentation and Data Acquisition System

An ultra-miniature giant magneto resistive (GMR) sensor chip (1.1 mm x 1.1mm x 0.45mm) was used to whereas a small alnico magnet was inserted in the roller race to act as a target for the triggering the sensor to measure the roller speed and slip. The roller instrumentation procedure developed and described by Khurram et al. [3] has been adopted in this study. The bench testing and roller speed measuring calibration was also done as the method described and performed by Khurram et al. [3].

The Data Acquisition System (DAQ) comprised of National Instruments (NI) hardware and software. NI software LabVIEW was sued to acquire and record the roller rotational speed and sliding data. The software was also used to control and monitor the camshaft speed, the oil temperature and the oil pressure. The hardware included an i3 computer and NI cDAQ-9174. A digital input/output module (NI 9401) an analog input module (NI 9215) and an analog output module (NI 9263) were used with NI cDAQ-9174. The sensor output signal was connected to counter channel of NI cDAQ-9174 via NI 9401 to measure the time required by the roller to complete one revolution. This was then converted into revolutions per minute. NI 9263 was used to provide power to the sensor. NI 9215 was used to read the signal coming from the pressure transducer. All the data acquisition, monitoring and control was done through simultaneous sampling.

IV. Experimental Methodology

Tests were performed at camshaft speeds of 500 rpm, 1500 rpm and 2600 rpm at oil inlet temperatures of 30^{o}C, 60^{o}C and 90^{o}C and the impact of change in lubricant inlet pressure and engine-operating conditions on the roller rotation and sliding were investigated in detail. Group IV base oil having a viscosity of 4 centistokes was used to conduct these tests. Oil Pressure was varied from 2 bar to 5 bar with an increment of 1 bar. Before the start of the each test, lubricant was heated to the test temperatures (mentioned above) and was circulated through engine head via oil pump. Lubricant temperature was maintained throughout this process. After an hour, motor driving the camshaft was switched on and was run for another hour. This was done to make sure that required engine operating conditions are achieved at each of the given test temperatures.

V. Results and Discussion

In order to fully understand traction force between cam and roller surface in roller follower assembly of the valve train, it is imperative to consider factors like contact loading, lubricant viscosity, camshaft speed, oil film thickness, operating temperatures, surface roughness, lubricant inlet pressure and the functioning of the hydraulic lash adjuster. At low camshaft speed, lubricant pressure in lash adjuster and valve spring force will play a vital role in interaction between cam and roller. While at higher speed, inertia of various components also plays an important role. It is quite evident from the previous discussions that slip occurs whenever there is a decrease in traction force between cam and roller interface and pure rolling requirements are not met.

The average value of samples collected during each test run was used to further calculate percentage roller slipat cam-roller interface. Results of percentage slippage at various lubricant inlet temperatures and camshaft speeds at each inlet oil pressure values are shown in figures 4, 5, 6 and 7.

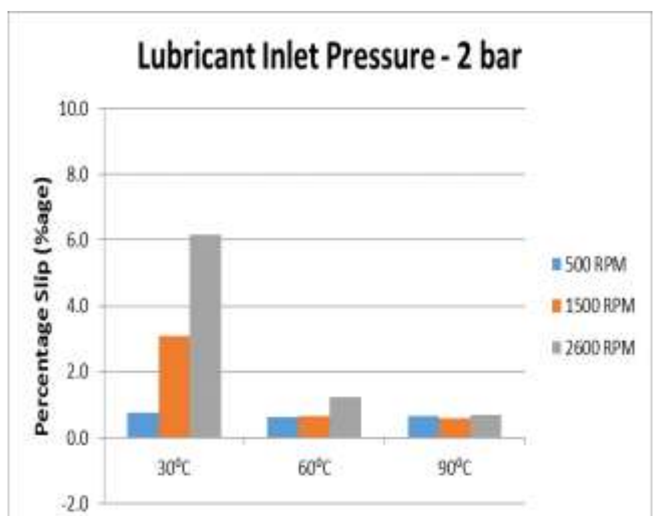

Fig. 4. Percentage Roller Slip at inlet oil pressure of 2 bar

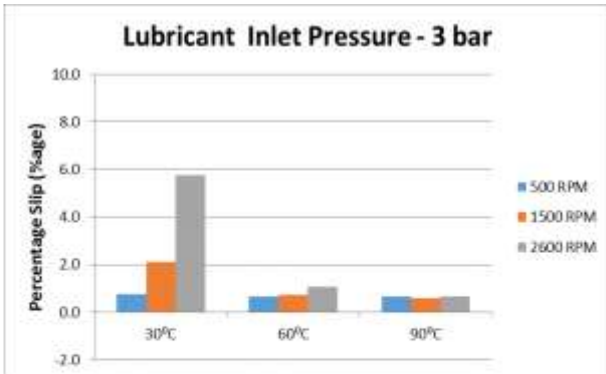

Fig. 5. Percentage Roller Slip at inlet oil pressure of 3 bar

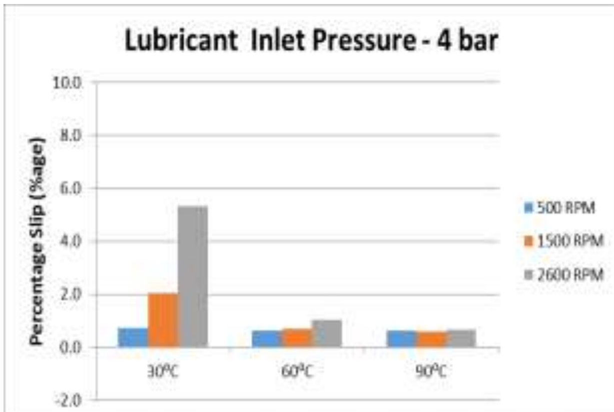

Fig. 6. Percentage Roller Slip at inlet oil pressure of 4 bar

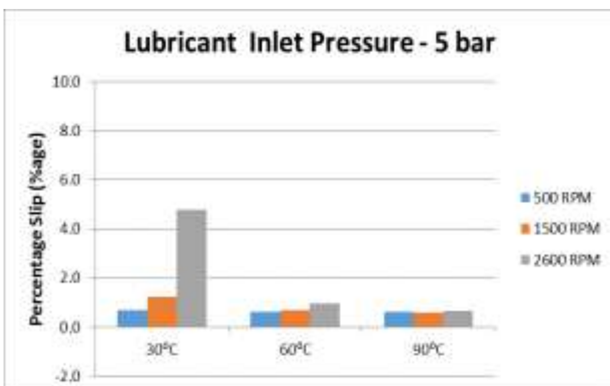

Fig. 7. Percentage Roller Slip at inlet oil pressure of 5 bar

The results showed that at the camshaft speed of 500 rpm with oil inlet temperature of 30^{o}C under different oil pressure, percentage roller slip ranges from 0.7% to 0.8% across all the test pressures which is relatively low. This low value in roller slip is due to the fact that although at low temperature oil viscosity is high but there is still a thin oil film present between roller and cam interface due to low lubricant entraining velocity under lower operating speeds. However, there is substantial increase in the percentage roller slip at higher camshaft speed of 1500 rpm and 2600 rpm. At camshaft speed of 1500 rpm, the percentage roller slip ranges from 2.1% to 3.1% with relative increase in the lubricant pressure. A further increase in roller slip values ranging from 4.8% to 6.2% was observed with a relative increase in pressure at higher camshaft speed of 2600 rpm. This increase in roller slippage with an increase in camshaft speed (1500 rpm and 2600 rpm) at low oil inlet temperature of 30^{o}C suggests that at lower temperature and high speeds, there will be less traction force at cam-roller interface under the influence of enhanced lubricant viscosity and oil film thickness which will ultimately yield in an increased roller slip. However, by drawing a comparison from fig 4- 7, one can clearly conclude that at low temperature of 30^{o}C as the oil inlet pressure is increased from 2 bar – 5 bar, there is corresponding decrease in roller slip due to improvement in traction force at cam/roller interface under the influence of rise in oil pressure.

At lubricant inlet temperature of 60^{o}C and low camshaft speed of 500 rpm, low roller slip values of 0.6% were observed across all the inlet lubricant test pressures. However, when compared with roller slip percentage values at lubricant inlet temperature of 30^{o}C, a substantial decrease in roller slip percentages was observed at higher camshaft speeds of 1500 rpm and 2600 rpm due to substantial reduction in oil viscosity and increase in the traction drive. Sliding percentage values of 0.7% were observed at 1500 rpm at all the test pressures. While roller slip percentage values ranging from 1.0% to 1.2% were noted at camshaft speed of 2600 rpm with a relative increase in lubricant pressure.

At lubricant inlet temperature of 90^{o}C, there was hardly any noticeable change in the roller slip percentage at all the camshaft speeds. Roller slip percentage of 0.6% was observed at camshaft speeds of 500 rpm and 1500 rpm while a value of 0.7% was recorded at camshaft speed of 2600 rpm at all the lubricant inlet test pressures. The reason for this decrease in the roller slip with increase in temperature is that boundary lubrication regime becomes more evident. This results in an increase in the traction force between cam and roller interface due to asperity interactions of the mating surfaces.

VI. CONCLUSION

The research was conducted to investigate the impact of change in lubricant inlet pressure on the roller slip in an end pivoted roller finger follower valve train. A state of the art experimental technique using a miniature GMR sensor developed by Khurram et al. [3] was used to measure the rotational speed of the roller and its sliding. Toyota 1NZK engine was successfully instrumented and tests were carried out at different camshaft speeds, oil pressure and oil inlet temperatures.

It is evident from the obtained test results that the maximum roller slip occurs at high camshaft speed of 2600 rpm with low lubricant inlet temperature of 30^{o}C under low lubricant pressure of 2 bar. At these operating conditions, oil film thickness is relatively high due to being more viscous along with significantly high entrainment velocity, resulting in a significant decrease in the traction force at cam-roller interface. Also, at same operating conditions, with an increase in lubricant pressure from 2 bars to 5 bars significant decrease in roller slip was also recorded due to increase in the traction drive. This indicates that with increase in pressure in the hydraulic lash adjustor forces the finger tappet-roller upwards reducing the mechanical clearance between the cam and roller. This results in an increased traction force at cam-roller contact and the reduced roller sliding. However, less roller slip was observed at high lubricant inlet temperatures of 60°C and 90°C and camshaft speeds of 1500 rpm and 2600 rpm which indicates that the decrease in lubricant viscosity with increase in its temperature results in an increased traction force at cam-roller junction The obtained results can prove to highly beneficial to further improve the tribological performance of roller follower valve train.

Acknowledgment

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Our team is working closely with numerous automotive companies on various projects. We are always looking forward for further projects and joint collaborations.