

Study of the Motion of Floating Piston Pin against Pin Bore

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ABSTRACT

One of the major problems that the automotive industry faces is reducing friction to increase efficiency. Researchers have shown that 30% of the fuel energy was consumed to overcome the friction forces between the moving parts of any automobile, Holmberg et al. [1]. The interface of the piston pin and pin bore is one of the areas that generate high friction under severe working conditions of high temperature and lack of lubrication. In this research, experimental investigation and theoretical simulation have been carried out to analyze the motion of the floating pin against pin bore. In the experimental study, the focus was on analyzing the floating pin motion by using a bench test rig to simulate the floating pin motion in an internal combustion engine. A motion data acquisition system was developed to capture and record the pin motion. Thousands of images were recorded and later analyzed by a code written by MATLAB. In the simulation, friction and lubrication analysis for reciprocating engine (FLARE) tools were adopted to carry out an elastohydrodynamic (EHD) lubrication analysis of the piston pin/bore interface and simulate the pin motion. The results showed that the motion of the floating pin was significantly affected by applied load and lubrication conditions. The experimental and theoretical results match very well.

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INTRODUCTION

Friction force is defined as the resistance to motion. Friction forces cause permanent damage to mechanical parts and that damage can be in the forms of wear, scuffing, or seizure. Since the automotive industry started, engineers have been working on reducing undesired friction forces between moving parts. The focus of this study was on analyzing the motion of one of the important mechanical parts in the internal combustion engine which is the pin that connects the small end of the connecting rod with the piston. The system that consists of pin, piston and connecting rod is one of the systems that run under a very high operating temperature, lack of lubrication, and fast speed motion. The friction is very high in this system and the combination of severe operating conditions can lead to severe damage such as scuffing on the pin bore surface. There are two types of pins. The first type is the fixed pin and this pin is fixed to the piston bore while it has relative sliding with the connecting rod. The second type is the floating pin and this pin has free motion with both the connecting rod small end and the piston bore. Through the

literature review, researchers used two approaches to study these types of pins.

The first approach is modeling and computer simulation. Shi [2] created a theoretical model consisting of a piston connected to the connecting rod via floating pin. Because of the symmetry of the pin, the simulation was run on the right half of the assembly under the conditions of free rotation and elastic deformation for the pin. The load cycle was identical to the loading cycle of the real internal combustion engine. Shi found that the pin rotated with the small end of the connecting rod swinging motion through the exhaust, intake and compression strokes because the friction force between the pin and the small end of the connecting rod was higher than the force between the pin and the pin bore. When the power stroke started, the pin stayed stationary with the pin bore because of the friction force between the pin and pin bore was higher than that with the connecting rod small end. He also explained the pin lubrication mechanism by a sucking effect which occurred when the pin rotated under the negative pressure during the stopping segment of the sequence. He showed that the floating pins had a superior scuffing resistance over fixed pins and using stiffer pins

improved the contact concentration due to pin deflection and ovalization. Ligier et al. [3] studied some of the operating characteristics of piston pin bearings, and showed that by using a simple tool it was possible to simulate the piston pin lubrication. They also showed the possibility of demonstrating the contribution of contact modeling for mixed lubrication which could occur in the piston bearings. They concluded that these bearings essentially operated in a hydrodynamic mode, very infrequently in mixed lubrication mode; also the rotation motion of piston pin and connecting rod was not the same. This study showed that the prediction of wear rate and wear position in the small bushing was possible and that prediction was helpful to optimize the surface parameters to reduce friction, wear, and seizure in these bearings. The second approach is experimental. Takiguchi et al. [4] studied the rotation motion of a floating pin and that motion helped to improve the lubricating condition on the pin bore and the connecting rod small end. It was found that at low load condition, the rotation motion disappeared. Also at high load condition a rapid rotational motion were observed and that rotation motion was caused by the friction increase between the pin and the connecting rod small end in the combustion stroke. Suhara et al. [5] developed a new method to measure the friction of piston pin/bore bearings of semi-floating pins to improve the friction and lubrication characteristics. The conclusion was that the friction force was large at the pin/bore at high engine load. The non-fluid lubrication characteristics and the lubrication characteristics became worse by decreasing the pin surface roughness. Other researchers [6, 7, 8] studied the piston pin/bore bearings in terms of scuffing resistance and scuffing behavior. They developed a scuffing criterion and different surface treatments for the pin/bore to reduce friction and eventually to increase pin/bore scuffing resistance.

Through the literature review, we could not find any work which described the floating pin motion in detail. Our belief is that understanding the floating pin motion patterns would lead to better understanding of the scuffing phenomena and it is essential to study and analyze the floating pin motion under different loading and lubricating conditions. In this paper the floating pin motion was studied in significant detail by using a bench test rig to simulate the floating pin motion in the lab, which is impossible to monitor in real engines. A data acquisition system has been developed to capture and record the pin motion. Thousands of images were recorded and later analyzed by a code written by MATLAB under different loading and lubrication conditions. In addition, FLARE tools were used to carry out an EHD analysis of the piston pin/bore interface and simulate the pin motion. The experimental and theoretical results were compared.

EXPERIMENTAL STUDY

Experimental Setup

The experimental system used to achieve the objective of this study consists of a bench test rig which can simulate the working condition of the piston pin and a data acquisition system which can capture and record the pin motion. The two parts are described in the following:

Bench test rig

Loading system

Figure 1 shows the bench test rig, which consists of the main frame that holds the piezoelectric translator (PZT) in vertical position guided by a linear bearing for free vertical sliding. The actuator was used to simulate the power stroke generated by the combustion in any internal combustion engine. It converts electrical energy directly into linear motion (mechanical energy) with high resolution and it has a very high stiffness for compression (66 kN/60 μ m). Therefore, any small displacement in the PZT can generate a high load. At the top of the PZT a fine pitch screw was used to apply a preload on the connecting rod small end. Below the PZT there is a load cell in contact with the lower end of the PZT and the top of the connecting rod to measure the compressive force applied to the connecting rod. The maximum force depends on the stiffness of the entire structure. In the bench test rig, the maximum force obtainable is 1.5-1.6 kN.

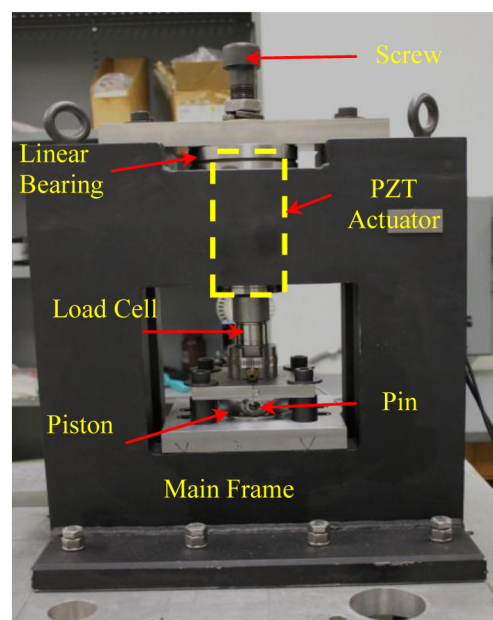


Figure 1. Bench Test Rig

In the real engine every stroke represents half of the engine cycle. In our system the swing speed of the connecting rod is controlled to be 300 rpm because the actuator needs 100 μ s to increase to its maximum load and also needs 100 μ s to return from the maximum load to the original position. The PZT loading cycle is shown in [Figure 2](#).

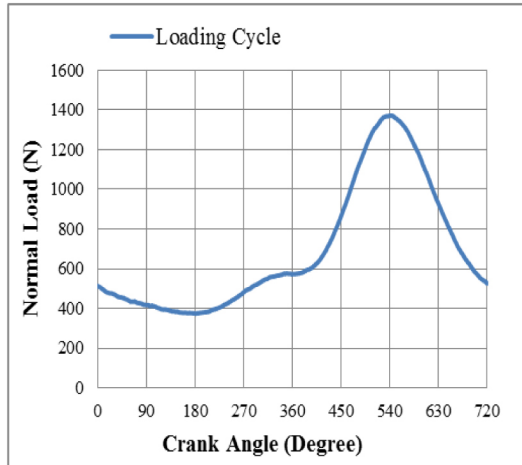


Figure 2. Loading Cycle

Drive system

The connecting rod was connected to the arm driven by a cam follower as shown in [Figure 3](#). The cam follower was fixed to a rail that slid linearly to produce the swinging motion of the connecting rod. The rail was driven by another arm connected to the rotation wheel that transferred the rotation from an AC motor to a linear motion. [Figure 4](#) shows the piston and the connecting rod assembly. The piston was flipped over, so the load could be apply directly to the connecting rod small end. It also increases the stiffness of the entire assembly.

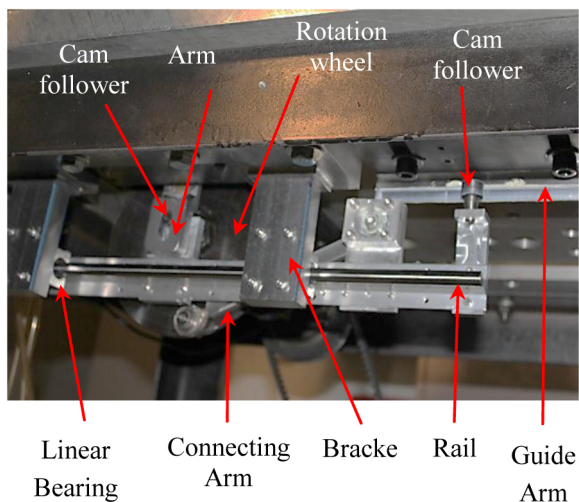


Figure 3. Drive System

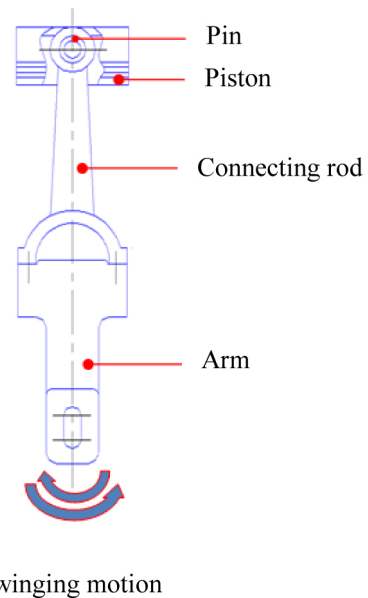


Figure 4. Connecting Rod Assembly

Synchronization system

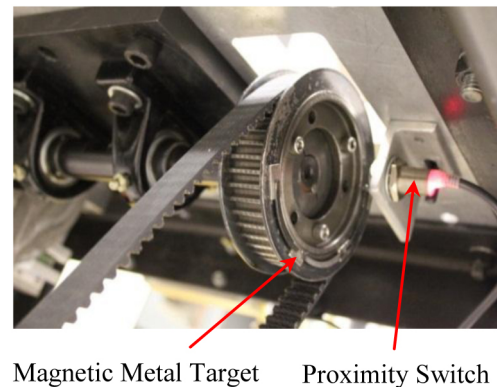


Figure 5. Synchronization System

To ensure that the loading cycle and the connecting rod swing cycle are synchronized, a proximity switch shown in [Figure 5](#) and an electronic circuit consisting of a flip-flop and AND gates were applied to produce a signal with a frequency which is half of the connecting rod swing frequency. The proximity switch can detect magnetic metal objects when they are in very close proximity to the switch and that will trigger a high voltage output to the electronic circuit. When the metal moves away from the proximity switch, the voltage will return to a low value. The electronic circuit ensures a signal with the right frequency to be sent to the PZT to apply the load. The position of the magnetic metal target and its path length were designed to ensure the load from the actuator to the connecting rod small end is applied at the required angle position. The output signal from the load cell