Numerical Analysis of Secondary Motion of Piston Skirt in Engines

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The motion of the piston pin plays an important role in the secondary motion of the skirt, and in the resulting noise and vibration features of combustion engines. In the engine, the small gap between the piston skirt and the cylinder liner allows a small movement of the piston in a lateral direction, in addition to the reciprocating motion of the piston during operation of the engine. Although the piston is held in its cylinder bore by means of piston rings, there is a small gap between the rings and the grooves, and hence it is free to move within this gap. The existence of the piston-liner gap puts a limit on the amplitude of piston motion, but not on the degree of freedom in the lateral, as well as the reciprocating, motion.

This work discusses a numerical model of the lateral motion of the skirt. Dynamic parameters of the skirt were used to analyse this motion. Further, COMSOL-7 Multiphysics was used to simulate the motion of the skirt. Both the simulation and the experiment showed a good correlation.

NOMENCLATURE

\[ F_x \] Piston side-thrust force
\[ \omega \] Angular velocity
\[ M \] Mechanical mobility
\[ m_p \] Dynamic mass of piston assembly
\[ m_b \] Dynamic mass of engine block
\[ I_p \] Moment of inertia piston assembly
\[ \theta'' \] Rotatory acceleration of piston assembly
\[ \theta' \] Rotatory velocity of piston assembly
\[ \theta \] Tilting angle of piston
\[ K_p \] Dynamic stiffness of piston assembly
\[ K_b \] Dynamic stiffness of engine block
\[ C_p \] Dynamic damping coefficient of piston assembly
\[ C_b \] Dynamic damping coefficient of engine block
\[ C_C \] Dynamic contact damping coefficient of assembly
\[ K_C \] Dynamic contact stiffness of assembly
\[ C_{T} \] Dynamic torsional damping coefficient of piston
\[ K_{T} \] Dynamic torsional stiffness of piston
\[ C_{CT} \] Dynamic torsional contact damping coefficient of piston
\[ K_{CT} \] Dynamic torsional contact stiffness of piston
\[ X''_p \] Piston assembly lateral acceleration
\[ X'_p \] Piston assembly lateral velocity
\[ X_p \] Piston assembly lateral displacement
\[ X''_b \] Block assembly lateral acceleration
\[ X'_b \] Block assembly lateral velocity
\[ X_b \] Block lateral displacement
\[ M_z \] Moment about piston pin
\[ X_c \] Piston-liner gap

1. INTRODUCTION

Noise emissions from an internal combustion engine can be classified as combustion-based noise, mechanical noise, aerodynamic flow noise, etc. There is a small lateral gap between the skirt and the liner due to manufacturing tolerances. Hence, the skirt is able to strike the liner in a lateral direction, in addition to its usual reciprocating motion. This lateral motion of the skirt is also known as its slapping motion. Several numerical models have been studied in the past to analyse this secondary motion of the skirt. These models have taken dynamics and tribological analysis into account. However, effects of damping have been neglected in past research works.\(^2\)\(^\text{-}\)\(^5\) During analysis of lateral contact of the liner with the skirt, various dynamic parameters need to be taken into account. Different methods to control the piston slapping motion includes optimization of skirt design parameters like piston pin offset, skirt stiffness, clearance size, and skirt profile. However, there is a trade-off between these parameters. As an example, reduction of the lateral gap between the skirt and the liner reduces the lateral motion of skirt, but at the same time, it increases frictional forces. Other alternative methods have been explored, including the use of dampers to reduce energy in the skirt-liner system.\(^6\)\(^\text{-}\)\(^8\)

The piston secondary motion is crucial to understand the various frictional forces in piston assembly, which contribute to 30–40% of total mechanical losses, and hence are a major cause of inefficiency in an engine.\(^9\)\(^\text{-}\)\(^11\) The piston translates from one side, to the liner, to the other side, due to the change in direction of the side-thrust force and due to the motion of connecting rod.\(^12\)\(^\text{-}\)\(^15\)

The basic motion of the piston’s secondary motion can be seen in Fig. 1. A numerical model shown in Fig. 1 was used to analyse this motion. The dynamic motion of the skirt may be summarized in matrix form as given by Eq. (1).\(^1\)