

Estimation of Piston Assembly Friction by Finite Element Approach

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ABSTRACT

The paper presents the results of finite element study conducted by developing a three dimensional model of single cylinder engine piston assembly. A new method to estimate the piston assembly friction by finite element approach on the bases of IMEP (Indicated Mean Effective Pressure) without using any instrumentation and engine modification has been discussed. The basic CAD model of the engine cylinder required to build finite element model was developed using UG-Nx-3 software. The finite element model of the single cylinder engine cylinder piston assembly was generated by using HYPERMESH 7 preprocessing software. The respective boundary conditions, loads, material properties, contact pairs were defined to mimic the real working conditions of the engine. In order to impose the effect of lubrication one dimensional Reynolds equation was solved to find hydrodynamic pressure acting on the piston skirt. The final model is solved by L.S.Dyna solver. The results of finite element simulation were used to calculate the piston assembly friction force. The forces required to calculate the piston assembly friction force by IMEP method were obtained from finite element simulation. The results obtained are compared with earlier reported experimental studies. It is concluded that the finite element approach can be used as an inexpensive tool to estimate the piston assembly force in the beginning stages of engine design and where the experimentation are difficult.

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INTRODUCTION

The Internal Combustion Engines being major sources of transportation of people and goods contribute significantly to air pollution and require large amount of fossil fuels. The factors concern to environment and the dependency on the foreign oils in the use of Internal Combustion Engines are motivating automotive companies to improve engine design in order to reduce emission and fuel consumption by using different advanced design approaches. It is estimated that 40 to 55 % of the frictional losses are due to engine cylinder system made up of piston (25-47 %), ring pack (28-45 %) and connecting rod bearing (18-33 %). The oil ring in the ring pack contributes more for frictional losses (50 - 75 %) compared to top ring (13-40), & second ring (10 - 22 %) [1, 2].

The amount of frictional losses in power cylinder system represents a significant portion of energy loss in the engine and shows an opportunity for improvement in engine efficiency. Accurate measurement of engine friction losses is not easy due to its smaller magnitude compared with other power losses. The following are the piston friction measurement methods

- Direct motoring test with tear down
- Morse test
- Willans line method
- Measurement of FMEP from IMEP and BMEP
- Floating liner method

- Instantaneous Indicated Mean Effective Pressure method
- P- ω method

Direct motoring of the engine, is used to estimate mechanical frictional losses of internal combustion engines due to its simplicity and capability to measure the friction losses of each engine component via tear down test under same conditions as close to firing. [3,4,5]. Although the motoring condition tries to simulate the firing condition as closely as possible, but the motoring frictional losses are different from those for firing conditions due to the lower cylinder pressure acting on the piston, piston rings and bearings for motoring than for firing conditions.

In the Morse test the power output is recorded by a firing multicylinder engine. Then, power is cut from a single cylinder, the engine is adjusted to previous speed, and power is measured again [6]. The difference in the power is the piston assembly friction for that particular cylinder. The major difficulty for this test is that a multi-cylinder engine is required [5, 6]. The Willans line method is a method that can be used when sophisticated instrumentation is not available. Engine load is measured and plotted at constant speed as a function of engine fueling rate. The curve is then linearly extrapolated to zero fuel flow, which results in negative load. This negative load indicates the losses of the engine power. This method gives not only the mechanical friction but also includes the pumping losses [5, 6].

The engine friction reduces the indicated work of an engine and is the difference between the indicated work and brake work. It is useful to normalize engine friction into a mean effective form as:

$$FMEP = IMEP - BMEP \quad (1)$$

The indicated mean effective pressure is the network per unit displacement volume done by gas during compression and expansion. It is possible to calculate the total work done by the cylinder pressure and combustion by integrating the pressure-volume diagram [1]. This will give net indicated mean effective pressure (NIMEP) [1],

$$NIMEP = \int_0^{360 \cdot nr} \left(\frac{P}{nr \times D} \right) \times dV \quad (2)$$

where, P - Cylinder pressure, V - Cylinder volume, nr - number of revolution per cycle, D - Engine displacement (volume).

The brake mean effective pressure (BMEP) is external shaft work per unit displacement volume done by the engine and is an indicator of how much energy is delivered by the engine, which can be obtained by:

$$BMEP = \left(\frac{BP \times nr}{D \times rpm} \right) \quad (3)$$

where, BMEP = Brake mean effective pressure BP = Brake power, nr = Number of revolution per cycle D = Engine displacement (Volume), rpm = Revolution per minute. The mechanical frictional energy is called Friction Mean Effective Pressure (FMEP). It is related to NIMEP and BMEP by the following [1]:

$$NIMEP = BMEP + FMEP \quad (4a)$$

$$FMEP = NIMEP - BMEP \quad (4b)$$

In order to evaluate cylinder friction by using FMEP, it is necessary to measure the cylinder pressure. This is required for integration of pressure and volume to obtain NIMEP, which requires a good instrumentation.

The floating liner method is widely used for fired engines by many researches to measure piston assembly friction force without much engine modification. The method was developed at Furuham International Combustion Research Laboratory [7]. Figure 1 shows a schematic of friction measurement method using floating liner method.

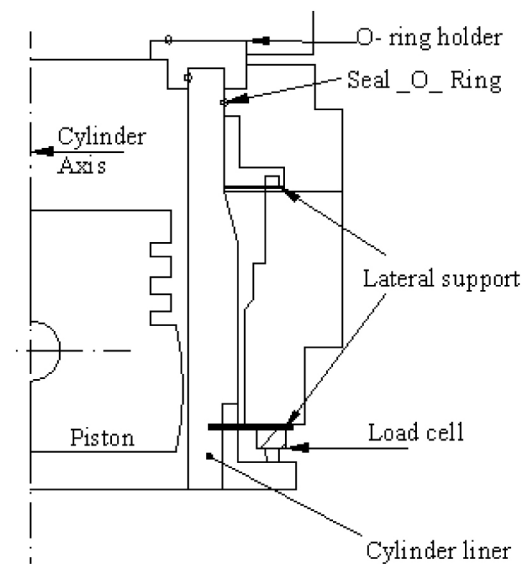


Figure 1. Schematic representation of floating liner method.

The basic idea of this method is to measure the friction force using a load cell installed in the cylinder liner. The liner is separately fabricated from the cylinder block and it is supported by specially designed liner supporting devices. During the motion of the piston the floating liner is displaced in axial direction due to presence of piston assembly friction. The load cell installed between lower part of liner and block senses this friction force. The greatest shortcoming of this method is the need for extensive engine hardware modification.

Urass and Patterson [8] developed a technique called "Instantaneous IMEP Method" to measure the friction force. The main idea of IMEP method is that the forces of the

piston are known at each crank angle, if any three of the total force (gas force, friction force, thrust force, inertia force) in the axial direction are known, then the fourth force can be determined from force balance. In this method the accuracy of the friction force depends on the accuracy of the instruments used. Another short coming of this method is the requirement of linkage mechanism for transmitting the connecting rod force signal to the instrumentation.

A technique to quantify cylinder kit friction is referred as the (p- ω) method. This technique measures the instantaneous changes in angular velocity of the flywheel that are caused by cylinder kit friction variations [1]. This method requires the measurement of cylinder pressure and the instantaneous angular velocity of the flywheel to calculate the instantaneous components of the frictional losses.

The determination of instantaneous piston friction losses of automobile engines through experiments is quite difficult. Hoshi, M [9], conducted a theoretical analysis on piston friction losses by using a model. The results obtained were compared with the experimental values. They stated that theoretical simulations of the piston friction losses are possible and it is also possible to estimate these losses at the design stages.

Takaharu, G. et.al [10] developed a technique to measure friction by adding two extra compression and expansion strokes at the end of the conventional four stroke of an engine. The results of experiments revealed that lubrication state of the piston and piston ring assembly undergoes various changes during the cycle operation and affects the friction force.

Young- Gon Ku.et.al [11] developed a technique termed the 'Fixed Sleeve' method to measure the instantaneous friction of the piston and ring assembly as a function of crank angle. They concluded that the friction is predominately hydrodynamic during mid-strokes and boundary or mixed near the dead centers. The friction is significantly affected by engine operating temperature, but only slightly by engine speed within the ranges investigated. Piston friction was not affected by weight added to the piston pin, piston friction is greatly influenced by the oil supply to the liner surface.

Riaz A.Mufti.et.al [12], proposed a study to measure piston assembly friction on a single cylinder gasoline engine using the IMEP (Indicated Mean Effective Pressure) method. They revealed that, at the start of each stroke, the piston-liner friction is more towards boundary lubrication where as at mid stroke it is generally hydrodynamic because of relatively high entraining velocity

Kurbet and Kumar [13, 14], developed three-dimensional finite element models of single-cylinder and four-cylinder internal combustion engines to analyze the piston and ring motions. The ring motions were studied in detail. They concluded that piston tilt has a profound effect on the end gap variation, the ring twist and the ring lift. The crank and connect rod were modeled with beam elements. The effect of lubrication was neglected.

The literature review study conducted by Kurbet and Malagi [16], indicates that the piston and ring dynamics is a complex phenomenon, which has a serious effect on oil consumption and frictional losses. The piston and piston ring dynamics has to be understood thoroughly to control oil consumption and frictional losses but experimental investigation of these motions is difficult and time consuming in the initial stages of design.

When the engine manufactures are designing and developing a new I.C.Engine to achieve the required goals, it becomes difficult to test experimentally each and every design alternatives, because the development and testing process are time consuming and costly in the beginning stages of the development. In such conditions the finite element modeling and analysis is one of tool which can be used and design engineers can analyze their own designs while they are still in the initial stages. CAD models allow for quick changes and promote implementation of analysis results in the design process.

MODEL DESCRIPTION

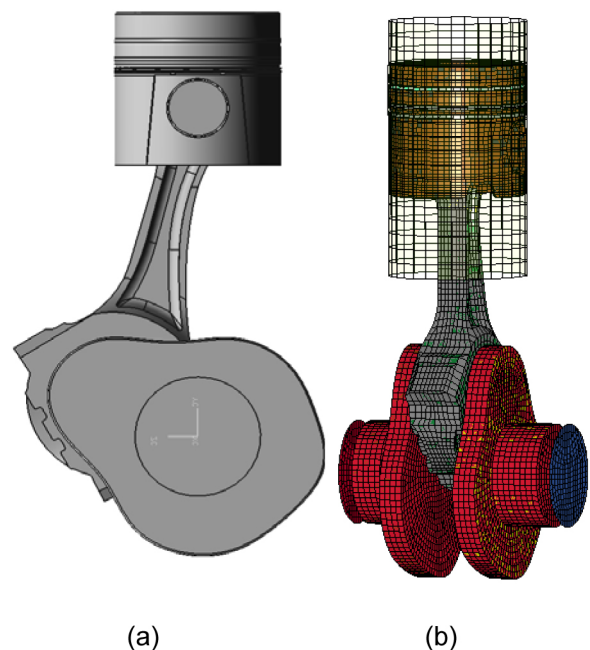


Figure 2. a) Solid model b) F.E. Mesh of single engine piston assembly.

The finite element model comprises of an assembly of piston, piston ring, cylinder liner, connecting rod and crank. Figures 2(a) and 2(b) show the solid and finite element models developed using UG-Nx-3 solid modeler and Hypermesh-7 finite element preprocessing software respectively. The components are meshed in the three dimensional form by using hexahedral elements. All the meshed components are tested for the quality of the mesh. After proving the quality of the mesh, the components are assembled to represent the engine cylinder system.

