Elastodynamics of the compression ring for evaluation of ring-liner conformance

Elastodynamics of the Compression Ring for Evaluation of Ring-Liner Conformance

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Abstract

The piston ring pack accounts for a disproportionate amount of the total engine losses (up to 25% of parasitic, with the compression ring accounting for approximately 5% of engine losses) [1], especially when considering the size of the component. Certain challenges posed by a low carbon future, coupled with the multitude of vehicles currently utilizing the internal combustion engine and the expected global increase in vehicle demand, motivates engineers to improve engine efficiency. The paper aims to investigate the effect of piston ring pack dynamics on the frictional losses. The ring dynamic behaviour determines the contact in terms of ring-liner conformability, applied load and kinematics. These are used as key input parameters in tribological models which predict contact pressure distribution, film thickness and generated friction.

1. Introduction

The compression ring undergoes a multitude of motions during the engine cycle. These motions are as the result of forces applied to the ring from its contact with its retaining grooves, interactions with the liner surface (contact reaction and friction), and gas pressure acting behind the ring. These forces excite a plethora of ring modal responses resulting in a number of undesired phenomena such as ring jump, twist, rotation and in-plane deformation, adversely compromising the functionality of the compression ring as a sealing device.

Finite Element Analysis (FEA) is a well-established numerical technique for dynamic analysis. However, it is both time consuming and difficult to implement within a combined tribo-dynamic analysis. Developing a ring dynamic model, which reduces the computational requirements whilst addresses the ring behaviour accurately is a key focus area in this paper. In order to establish and validate the model, it is initially developed, based on a straight beam representing the un-wrapped geometry of the piston ring.

2. Methodology/Results/Discussion

An Euler's beam method is developed, accounting for bending in the x-z and x-y principal planes, as well as torsional and axial degrees of freedom. The beam is discretised into elements and the solution is found by performing direct numerical integration in time domain. Figure 1 displays a single beam element.

The governing equation for bending in the x-z plane is as follows [2]:

$$EJ_{yy}\frac{\partial^4\Delta_z}{\partial x^4}+\rho A\frac{\partial^2\Delta_z}{\partial t^2}=0 \quad (1)$$

The above equation is also solved for bending in the x-y, with J_{yy} replaced by J_{zz} and Δ_z replaced with Δ_y.

The governing equation for the axial mode becomes [2]:

$$\rho A\frac{\partial^2\Delta_x}{\partial t^2}-EA\frac{\partial^2\Delta_x}{\partial x^2}=0 \quad (2)$$

The governing equation for torsional motion is [2]:

$$\rho J_p\frac{\partial^2\theta_j(x)}{\partial t^2}-GJ_p\frac{\partial^2\theta_j(x)}{\partial x^2}=0 \quad (3)$$

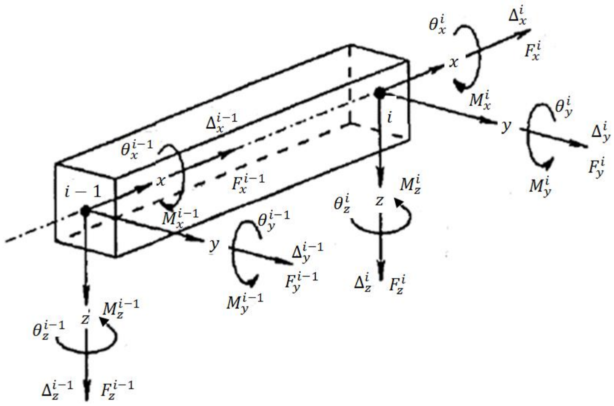

Figure 1: A single beam element

3. Results

Figure 2 is a frequency sweep between 1 Hz and 1 kHz for an unwrapped ring, with some natural frequency contributions validated against FEA free-free modal analysis. The next step is to create a multi-elemental beam representation of an incomplete ring in polar co-ordinate system.

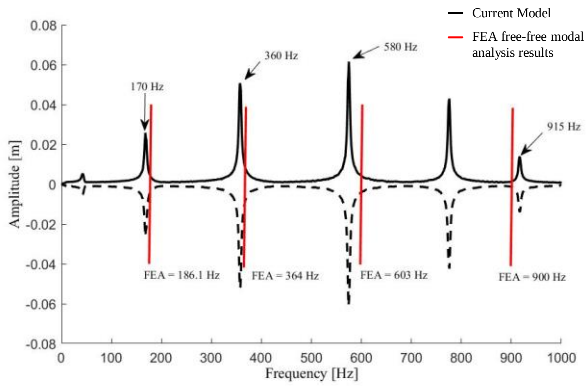

Figure 2: Frequency amplitude sweep for the bending modes in the x-z plane

4. References

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