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Computer Simulation of the Behavior of the Piston Ring Pack of Internal Combustion Engines

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Abstract: Due to stricter pollutant emission regulations for internal combustion engines the increase of the effectiveness of power units got even more into the center of attention in the last few decades. Therefore, the need for the optimization of even smaller engine parts – like piston rings – became more discussed, and their research and development became more important. The main objective of this project was to develop a computational model for the simulation of the behavior of the piston ring pack, capable of supporting the design process of new piston rings with lower friction losses.

Applied theory

For the determination of the instantaneous pressures above, behind and below the rings in the calculation a labyrinth model is used, which divides the volumes created by the rings-piston assembly into chambers. The pressures are determined from the volumetric flow of the gases between the chambers. This model presumes the gas flow through the piston ring gap to be an isentropic orifice flow between two volumes [1].

In case of gas flow through a small clearance between the ring and the piston groove a one-dimensional Reynolds equation is used to calculate the mass flow, assuming flow to be laminar [2].

The determination of the mass flows in and out of each volume is carried out in each time step, while the pressures in the crevices are calculated using the mass conservation equation in combination with the equation of state for ideal gas.

Concerning the lubrication regime – in case enough oil is present between the ring and the liner, hydrodynamic lubrication is considered. The given problem is described by the Reynolds equation which defines the relationship between the lubricant pressure and the lubricant film shape. Since the ring-liner contact pair due to its characteristics can be considered as an infinitely long flat sliding bearing, the 2-dimensional Reynolds equation can be further simplified [3]:

$$\frac{d}{dx}\left(\phi_x \frac{h^3}{12\eta}\frac{dp_A}{dx}\right)=\frac{U}{2}\frac{dh_{TA}}{dx}+\frac{U}{2}\sigma_C\frac{d\phi_s}{dx}+\frac{dh_{TA}}{dt} \qquad (1)$$

In cases where the oil supply is insufficient, and the asperities of surface roughness come to contact, mixed, or boundary lubrication regime is calculated. Pure boundary lubrication is solved according to Greenwood and Tripp, where the nominal pressure due to the elastic deformation of the surface roughness peaks can be calculated as [4]:

$$p_c=\frac{8\pi}{5}(\eta\beta\sigma)KF_{5/2}\left(\frac{h}{\sigma}\right) \qquad (2)$$

Further input variables entering the computation, like the temperature distribution of the piston and its deformations due to operation were calculated using FEM approach on the basis of Ortjohann's proposition [5].

The utilized numerical approach incorporates an iterative solution for the force equilibrium calculation for each crank angle by the use of a modified Newton-Raphson method for better approximations to the roots. The blow-by calculation is speeded up by utilizing the 4th order Runge-Kutta method for the iterative solution. To achieve another significant acceleration in the solution time, variable time step is utilized, although the time step is reduced only in a few places where convergence is more problematic.

Experimental validation

The experimental validation of each numerical method is undoubtedly desired. For the purpose of this project an experimental setup for determining the amount of blow-by gases has been built. The setup involves a commercial three-cylinder spark ignition engine with the blow-by measuring device from AVL. The obtained results show good correlation to the calculated values, as it can be seen in the graph in Fig. 1.

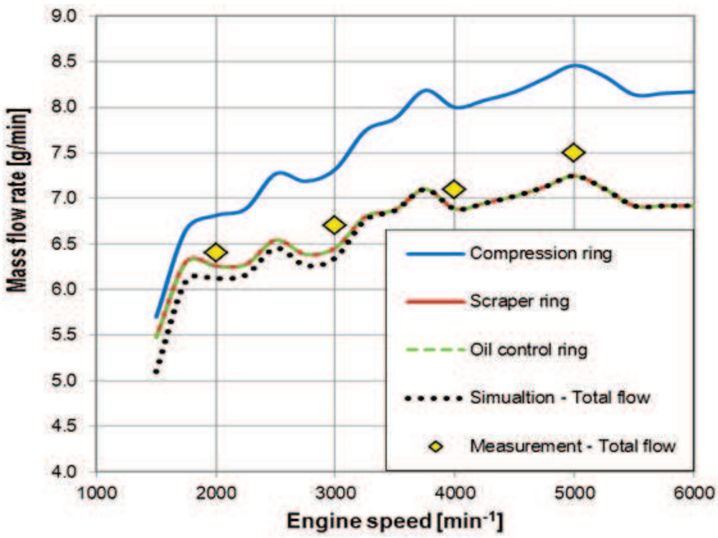

Fig. 1: Gas blow-by through piston ring pack.

Conclusions

By incorporating the above presented theory, besides others, into the numerical scheme, the force balance on each ring is solved at every time step of the calculation. Lastly, the developed computational model is applied to a standard inline three-cylinder passenger car petrol engine to obtain computational results of the identical engine as utilized in the experiment.

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