RESEARCH ENGINE FOR INVESTIGATION OF THE PHENOMENA ACCOMPANYING THE RINGPACK PERFORMANCE IN A DIESEL ENGINE

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Abstract

The paper describes a method of experimental research of ringpack performance, which enables direct measurements of ring axial movements in the groove, pressures in inter-ring lands and temperatures of piston during actual engine operation. The research piston was equipped with a set of sensors and two electronic modules. The set of sensors consists of two piezoelectric pressure transducers, two proximity sensors based on Hall effect, two accelerometers and surface thermocouples. One of the electronic modules incorporates a microcontroller and signal conditioning circuits. The second module contains batteries and optical coupling for communication. Movable data acquisition system enables simultaneous measurement of data from eight channels with high resolution in domain of crankshaft angle. During measurements data is stored in external memory and afterwards can be retrieved and sent to personal computer. Result obtained with the use of developed wireless measurement and data acquisition system will be used in order to validate mathematical model of gas flow and piston rings dynamics.

Keywords: *combustion engine, piston-rings set, wireless measurement, data acquisition, telemetry*

1. Introduction

A piston with rings, which create a movable seal and reciprocating slide bearing should ensure the best tightness of the combustion chamber and smallest mechanical losses and wear of the elements at possibly lowest oil consumption. The degree of fulfilment the above requirements directly influences performance, fuel consumption, durability and environmental impact of an engine. Thus, improving of the ring-pack is very important for development of piston engines. But to be able to effectively improve the design of the piston-rings set the rules of ring-pack working should be know. The prediction of ring-pack behavior in different operation conditions is difficult due to complexity of processes accompanying sealing working of the set. The complexity results from the big number of geometrical and other physical features characterizing the ring-pack and from its transient working conditions (piston velocity and pressure in combustion chamber are changing). Numerical simulations done with the use of mathematical models of the ring-pack are very helpful tools for prediction of the ring-pack behavior. These models describe, among others, ring-liner hydrodynamic lubrication, inter-ring gas flow, motions of the ring in the groove. Models presented in the literature differ with each other in number of parameters taking into account and the way of particular phenomena modeling.

Mathematical models of the ring-pack are more and more complex and allow to precise prediction of influence of design and operation parameters on performance of the ring-pack. However, in spite of the complexity of the models serious simplifications are used. To check if the applied description is proper the results of the calculations should be compared to the results of measurements. That is why the development of the mathematical models is accompanied by the development of measuring techniques.

In the paper a measuring system for investigation of phenomena accompanying the ring-pack working is described. The results of the research conducted with the use of the system are to be utilized to validation of the mathematical model of the ring-pack.

2. Modeling of ring-pack operation

A mathematical model of the gas leak through the crevices of the ring-pack integrated with a model of rings axial dynamics was developed [4, 5]. In the model it is assumed that the gas flows through the labyrinth consisting of several stages linked together by the throttling passages. Inter-ring lands and behind-ring spaces are treated as separate stages of the labyrinth. The throttling passages correspond to ring-end gaps and to crevices between side surfaces of the ring and the groove, which cross-section areas result from instantaneous axial position of the rings in the groove. Thermal deformations and wear of the piston, rings and cylinder are considered in the model. Axial positions of the rings in the grooves are determined taking into account the forces of gas pressure, ring friction against the liner and inertia.

As a result of the calculations, among others, the values of pressure in the inter- and behind-ring spaces, axial positions of the rings in the grooves and flow-rates in particular crevices are obtained (fig. 1). The blowby rate is achieved by integration of instantaneous flow-rates in the crevices, which are connected directly to the crankcase. The results of numerical simulations allow to analyze relations between dimensions and other physical features of the ring-pack, rings motions and gas flow-rates in different engine operation conditions. Considering the above numerical simulations can be very helpful in design of the ring-pack, especially taking into account that prediction of these highly complicated inter-relations in other way than simulations is almost impossible. However, if the simulations are to be useful in the design, the mathematical model must be adequate. It can be checked only by comparison the results of calculations to the results of measurements conducted on the real engine.

Up to now, the elaborated mathematical model was verified with the use of "global" blowby measurements. Blowby measurement is relatively simple technique provided that a proper device is available. Moreover, it does not cause any disturbances in engine operation.

Value of global blowby is a very good measure of quality of piston-rings sealing operation, however it does not allow to verify mathematical model in wide extent. Blowby measurement provides cumulative value of gases flow under some engine operation parameters. In reality, blowby intensity is determined by a set of instantaneously varying factors, i.e. cross-sections of the throttling channels and gas pressures in the inter-ring lands. As a result, the mathematical model can provide accurate result of global blowby, however obtained on a wrong way.

Time and spatially resolved measurement of the key values calculated by the mathematical model would allow to verify used formulas and assumptions with high degree of accuracy. Although direct measurement of flow-rate in ring-pack crevices seems not to be possible with the use of currently available methods, indirect values, like pressures, rings positions and temperatures are measurable.

In most cases for pressure measurement quartz pressure transducers are used [2, 8, 9, 11]. Axial movements of the piston rings were assessed with the use of capacitive [10, 11] or inductive sensors [1, 7, 8]. Unfortunately, in literature mentioned above there is lack of detailed information considering technical solutions.

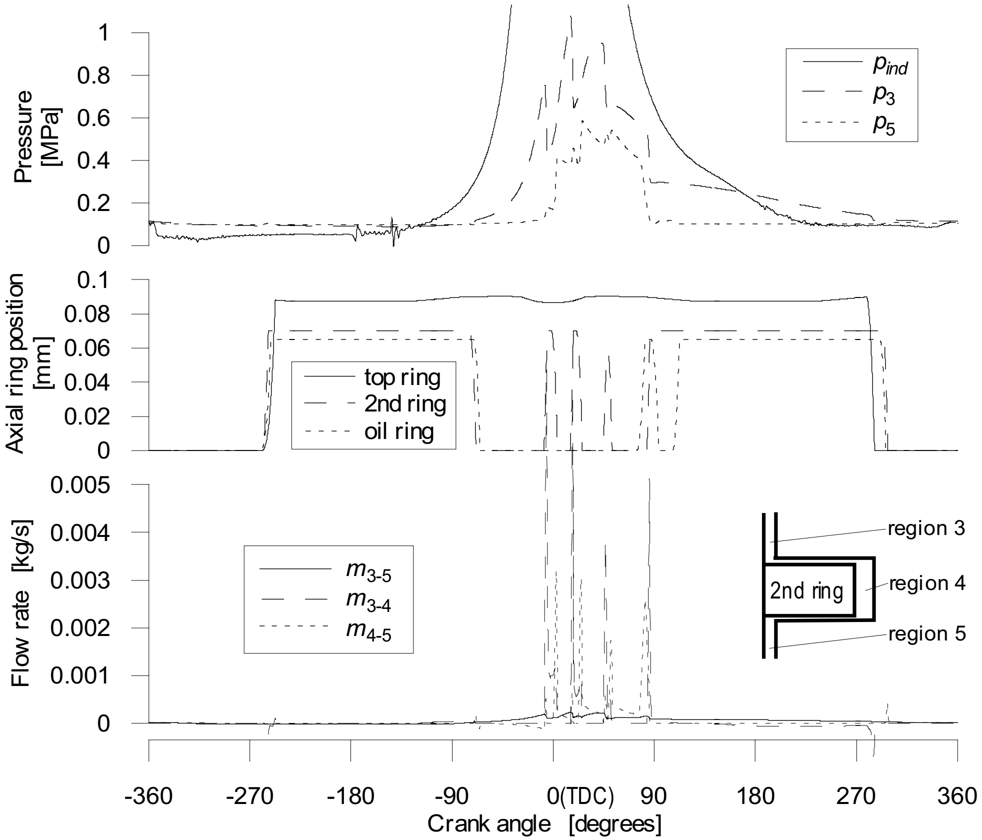

Fig. 1. Pressures (p_{ind} – in the combustion chamber, p_3 – in the land between the top and the second ring and p_5 – in the land between the second and the oil ring), axial positions of rings in their grooves (value zero means, that ring adheres to upper groove flank) and intensities of gas flow through crevices of second compression ring (m_{3-5} – through the ring-end gap, m_{3-4} and m_{4-5} through crevices between the ring and the groove)

3. Wireless measurement and data acquisition system

During the design process of the moving measurement system, some number of problems was to be resolved. The first obstacle was method of electrical excitation. The simplest way appeared to be battery power source. Unfortunately, most of popular batteries can operate under temperatures up to 60…70 °C. Alternative solution was the use of magnetic coupling similar to ones applied in electrical tooth brushes. However, in this case, relatively heavy and big cores and inductors would have to be used. As a result a set of proper batteries was used. Special batteries designed for wheels pressure sensors have maximum operation temperature up to 150 °C and hopefully would withstand high acceleration rates.

In relatively large piston with diameter of 110 mm, finding enough space for transducers and printed circuits did not pose a problem, however some modifications of crankshaft counterweights were needed.

The last challenge was arrangement of communication device. After studies of used solutions from cables to radio connections an intermediate solution was chosen. During the measurement period data is stored in internal memory and afterwards is sent via infrared optical coupling to a personal computer. Although space of used memory limits number of samples and engine has to be stopped for data subtracting, the simplicity of this solution substantially shortened the design and testing process.

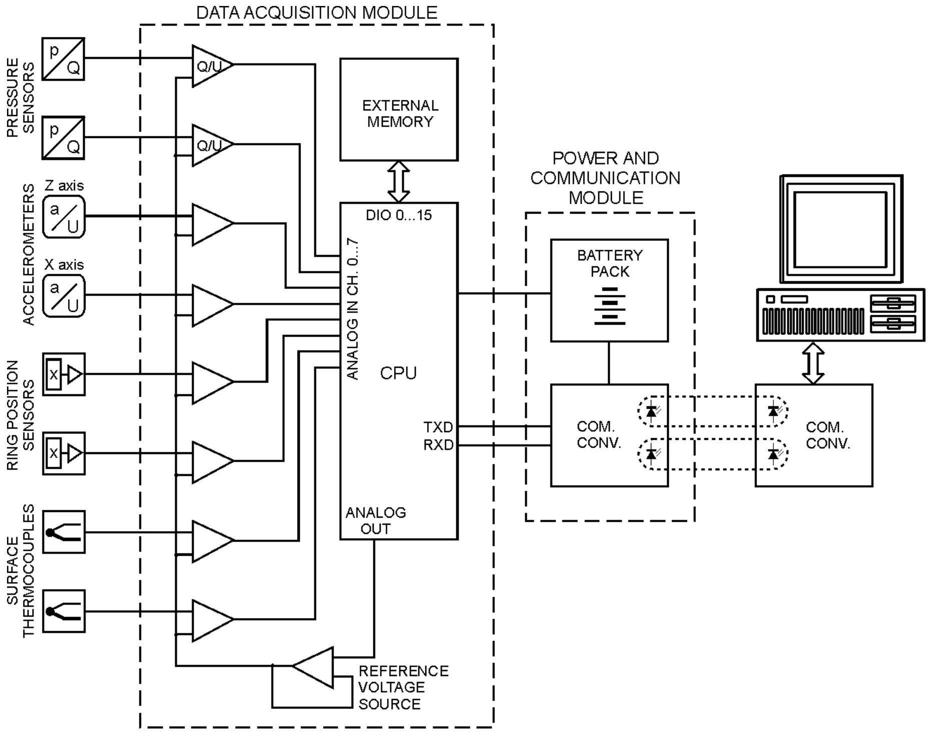

Fig. 2. Block diagram of movable data acquisition system

The measuring and data acquisition system consists of set of sensors, data acquisition module, power and communication module and a personal computer (fig. 2). For pressure measurement in spaces between piston rings typical piezoelectric pressure transducers were used. The critical parameter of chosen pressure transducers was susceptibility their signals to acceleration. Pressure signals are conditioned by two monocircuit charge amplifiers with gain 10 mV/bar and time constant of 0.6 s. Piston acceleration is measured in two axes; parallel to main cylinder axis and perpendicular to piston pin. The first acceleration value is used for synchronization of measured signals' courses with piston position and the second one, for analysis of piston snaking in the cylinder liner. Accelerometers are equipped with buffer stages based on operational amplifiers. Measurement of axial rings positions was resolved with the use of originally designed sensors (fig. 3). Each sensor consists of magnetic bridge placed through the piston skirt, a Hall sensor and a solid magnet. This solution not only allows to recognize limit positions of the rings but also provides linear signal for their intermediate positions assessment. The measurement system is also equipped with two surface thermocouples and signal converters. As one electrode piston material was used, the other one was made of NiCr wire. Surface junction was obtained by gold weld. Thermocouples are placed on the piston walls between piston rings.

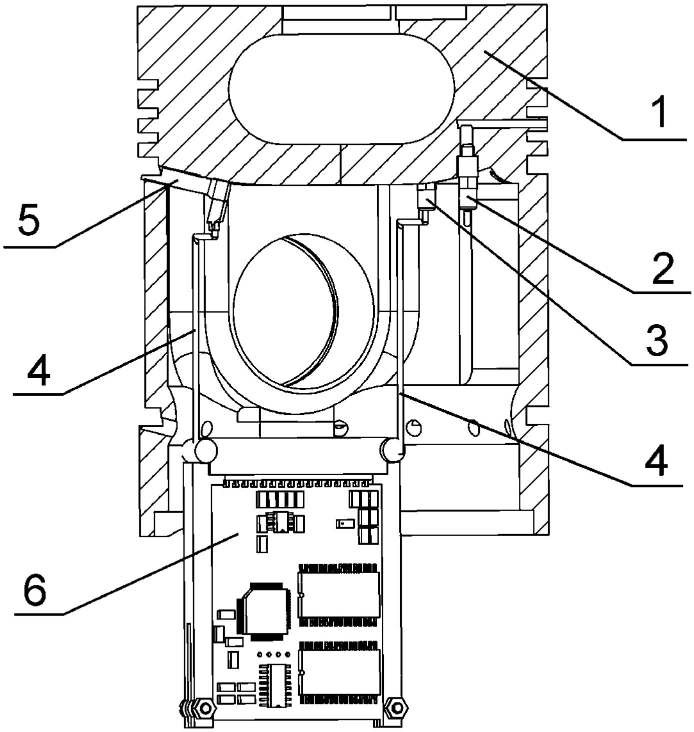

Fig. 3. Arrangement of electronic devices in the research piston
(1-piston crown, 2,3-pressure transducers, 4-connecting wires, 5-proximity sensor, 6-electronic circuit)

Conditioned analog signals are sent to A/D converter with 12 bit resolution and maximum sampling rate of 350 kHz. A/D converter is combined with a microcontroller. Measured data is stored in an external memory with capacity of 300k samples. This number of samples allows for acquisition data from more than 50 cycles of engine operation at resolution of 1 °CA.

The data acquisition module is assembled on four-layer printed circuit 5 cm wide and 6 cm long. In a second module of the same dimensions two batteries and optical communication converter is placed. Electronic printed circuits are mounted at the bottom part of piston skirt on both sides of connecting rod. In order to protect electronic components against high accelerations and possible electric conductivity of metal remnants in the lubricating oil both sides of printed circuits were protected with a resin layer.

Signals from components built in piston are sent to the personal computer via optical coupling using serial communication standard. Communication between personal computer and measurement system is held when engine is stopped and the crankshaft set in position allowing the optical converters to be on one level.

The first step of data acquisition procedure is programming of the measurement module. Programming allows for selection of used channels, setting sampling frequency for each channel, setting number of samples and a delay between START command and beginning of data acquisition. After sending the START command communication is closed and engine can be started. After collection of all defined samples and stopping of the engine crankshaft should be again set in position allowing communication and system is ready for retrieving collected data from measurement system. Afterwards the system is ready for the next measurement cycle.

Summary

A new movable and wireless system to measure time resolved data including pressures in inter-ring lands, rings axial positions, piston's acceleration and surface temperatures in actually operating engine was built.

Particular signal conditioning circuits of the system fulfill all assumed metrological requirements concerning time response, noise level and susceptibility to magnetic interferences. To check if the system is resistant to very harsh operation environment that exists in real engine electronic circuits were tested in high temperatures of 100 °C and under acceleration up to 200 g. Due to technical limits, combination of mechanical and thermal loads was not applied. The applied conditions did not influence both operation and quality of recorded signals. Results of conducted tests allow to assume that designed measurement system will work properly in operating engine and be a useful tool for analysis of ring-pack operation and validation of the mathematical model.

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