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ENGINE RESEARCHES ON THE INFLUENCE OF THE PISTON RING INSERT ON TEMPERATURE DISTRIBUTION IN PISTON

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Abstract

The article presents a method of piston temperature measurement on a running engine using electromagnetic induction for transferring measurement results from a moving measuring system placed in a piston to a stationary system attached to the engine crankcase and to measuring system located outside the engine. Selected test results that were carried out on a single-cylinder Diesel engine are presented. A system consisting of a thermistor and a secondary coil was mounted in the piston. The primary coil was mounted in the crankcase under the cylinder liner of the engine. Engine tests were aimed at determining the influence of the piston ring insert on the temperature distribution in the piston. Temperature measurements in the piston without the ring insert were carried out for comparison. In both cases, the pistons had the same geometrical dimensions. The tests were carried out in conditions of external characteristics (the maximum load as a function of engine speed) and load characteristics (load changes at constant engine speed). The test results in the form of the temperature difference between the temperature of piston top and the temperature under the top compression ring indicate that the ring insert is a barrier to the heat flow from the piston to the engine cooling system. In addition, the results of the piston temperature measurements during the step change of the engine speed and its load to the nominal value are presented.

Keywords: *combustion engine, engine piston, piston ring insert, electromagnetic induction, temperature measurement, thermistor*

1. Introduction

The distribution of temperature in the piston during the operation of the internal combustion engine has a significant impact on the durability, reliability and economy of its operation. The pistons of combustion engines are mostly made of aluminum alloys, whose strength decreases with increasing temperature. It is assumed that the maximum temperature in the piston cannot exceed 623 K. On the other hand, the piston is in contact with the lubricating oil and in the area of this contact; the temperature should not exceed the decomposition temperature of the lubricating oil, which is about 503 K. Under conditions of high engine loads, when the piston temperature is greatest, it may be necessary to use additional cooling of the piston. For this reason, it is necessary precisely to determine the temperature distribution in the piston under different engine operating conditions [2, 3]. Although advanced programs are available to determine the temperature distribution in the piston on a running engine, it is necessary to know the boundary conditions. Therefore, measurements of the piston temperature in the running engine are necessary.

Different methods of measuring the temperature of the piston on the running engine are available. One of them is the contact method in which the temperature measurement result is transferred to the stationary system when the contact elements of both the movable (piston) and stationary systems meet at the TDC or BDC point. Another method is the direct continuous transfer of temperature measurement results using flexible hoses attached to a special lever system. The telemetric method is also known when the transmitter is in the piston and the receiver in the engine crankcase; an electromagnetic method in which the transmission of temperature measurement results from a mobile to a stationary system when coupling two systems when the piston is in the BDC; hot-melt method, which allows to determine only the maximum temperature without the possibility of determining the conditions in which the maximum temperature occurred [6]. Contact methods and flexible cables can be used in slow speed motors. The telemetric method is very sensitive to environmental conditions due to possible interference (high ambient temperature, oil mist). Analysing the methods of measuring the temperature of the piston, electromagnetic induction method has the least limitations, and has been used in engine tests of temperature measurement [1, 4, 5].

2. Method of temperature measurement with electromagnetic induction

The essence of the piston temperature measurements on the running combustion engine is the installation of an induction coil connected to a thermistor placed in a movable measuring point, which is a secondary induction system. The primary coil is located in the fixed engine block. This coil is connected to an external measuring system. During engine operation, the piston reciprocates and the coil of the secondary system moves along the coil of the primary system. During this movement, a measurement temperature signal is generated.

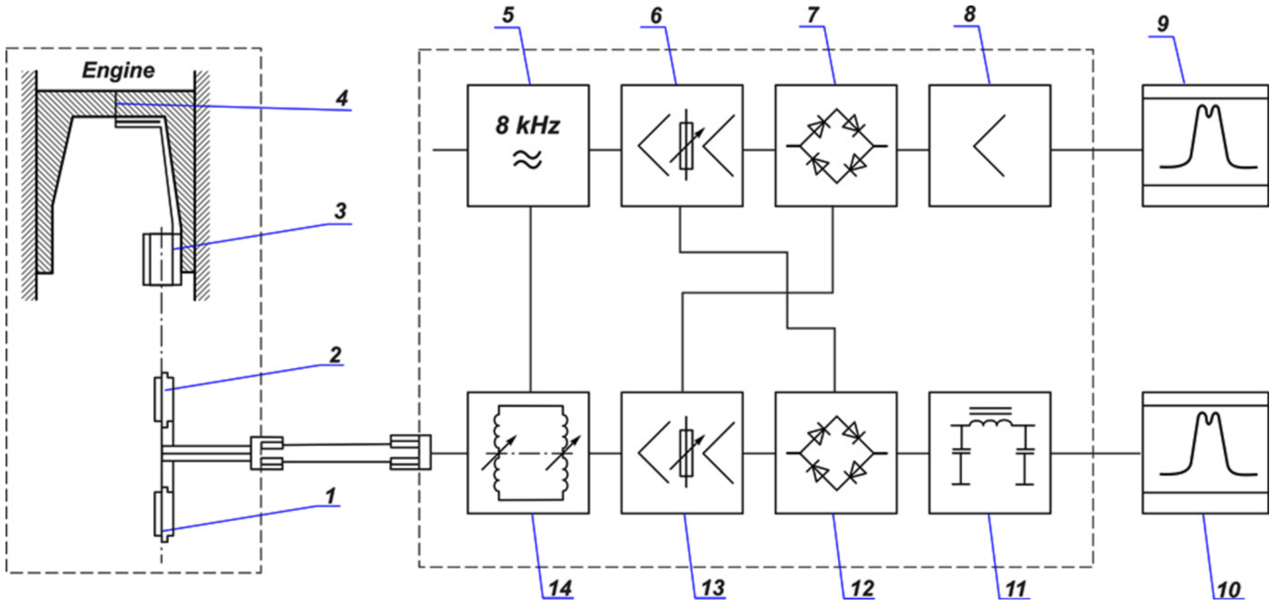

Fig. 1. Functional diagram of the piston temperature measuring system with electromagnetic induction; 1 – primary compensation coil; 2 – primary active coil; 3 – secondary coil; 4 – thermistor; 5 – generator; 6 – gain regulator; 7 – rectifier; 8 – DC amplifier; 9 – oscilloscope; 10 – oscillograph; 11 – filter; 12 – rectifier; 13 – gain regulator; 14 – regulating half-bridge

Fig. 1 shows a functional schematic of the temperature measurement system. The primary system coils: compensation 1 and active 2 are mounted in the engine crankcase. The secondary coil

3 and the thermistor 4 are installed in the piston. The secondary measuring system is supplied with a sinusoidal alternating current of 8 kHz from a generator 5 located outside the engine. The thermistor placed at the measuring point 4 changes its resistance as the temperature changes. During operation of the engine, the secondary coil 3 moves relative to the primary coil 2 and while the secondary coil 3 is near the BDC point, inductive coupling with the primary coil 2 takes place and a measurement signal is generated proportional to the temperature at the measuring point.

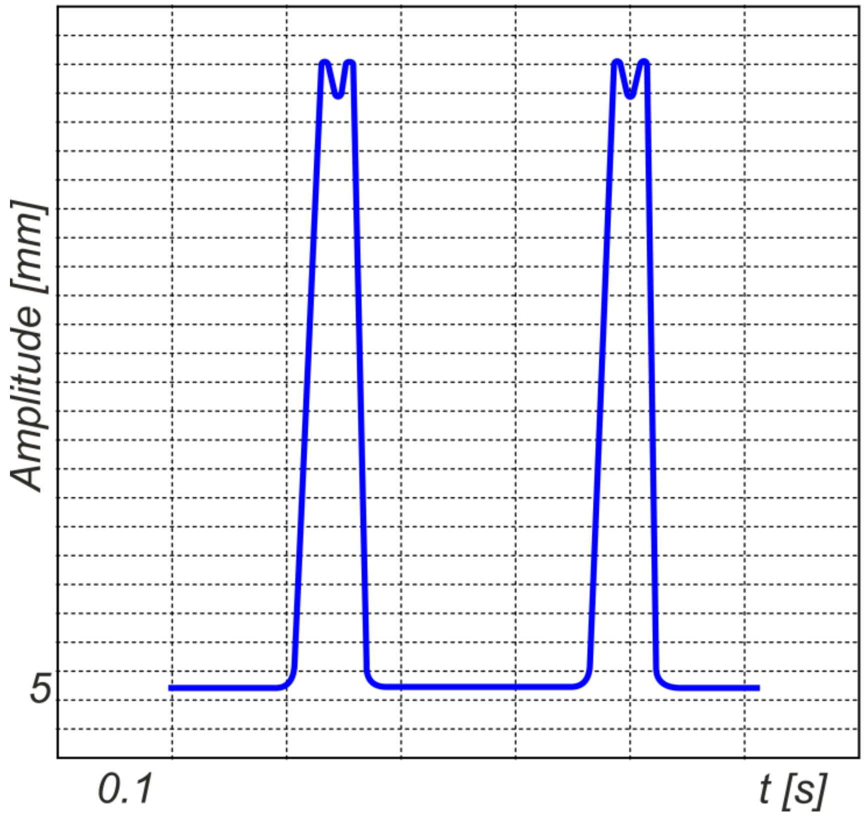

Fig. 2. Diagram of temperature measuring point

Fig. 2 shows a diagram of the piston temperature at the measuring point. The maximum value on the ordinate represents the piston temperature at the measuring point. The presented curve has two humps, which confirms that during the movement of the piston there was a maximum inductive coupling. For this purpose, the primary coil 2 is mounted slightly higher than at point BDC, whereby the maximum inductive coupling is achieved before the BDC and after the BDC. The diagram in Fig. 2 also indicates that in the time before BDC and after BDC, the temperature value is constant under these engine-operating conditions.

3 Results of temperature measurements in the piston on the running engine

The tests were carried out in a single-cylinder diesel engine. The engine parameters were as follows:

bore (cylinder diameter)	107.19 mm;
piston stroke	120.65 mm;
displacement cylinder volume	1.090 dm^3;
nominal rated power	15.8 kW;
rated engine speed	2600 rpm;
engine speed at maximum torque	1600 rpm;
maximum torque	63.8 Nm;
nominal compression ratio	16.5.

The tests were carried out in which the engine characteristics are determined: external (engine speed) characteristics for maximum load and for 1000 rpm, 1,400 rpm; 1600 rpm; 2200 rpm; 2600 rpm; load characteristics at constant engine speeds of 1000 rpm, 1400 rpm; 1600 rpm; 2200 rpm; 2600 rpm and for variable engine loads − up to the maximum for given speeds. The results of piston temperature measurements are presented as a function of the average indicated pressure determined by the dependence (1):

$$p_e = 60 \cdot \frac{P_e \cdot \tau}{V_d \cdot n \cdot i} [MPa], \tag{1}$$

where:

- P_e − effective power [kW];
- V_s − engine displacement [dm^3];
- n − engine speed [rpm];
- τ − number of crank revolutions for power strokes (2 for four-strokes, 1 for two-strokes cycle);
- i − number of engine cylinders.

The introduction of one parameter to assess the engine's load allows comparing the results of piston temperature measurements for different engine operation parameters, but for the same conditions as in the engine's combustion chamber. These conditions should have the same influence on the temperature distribution in the piston.

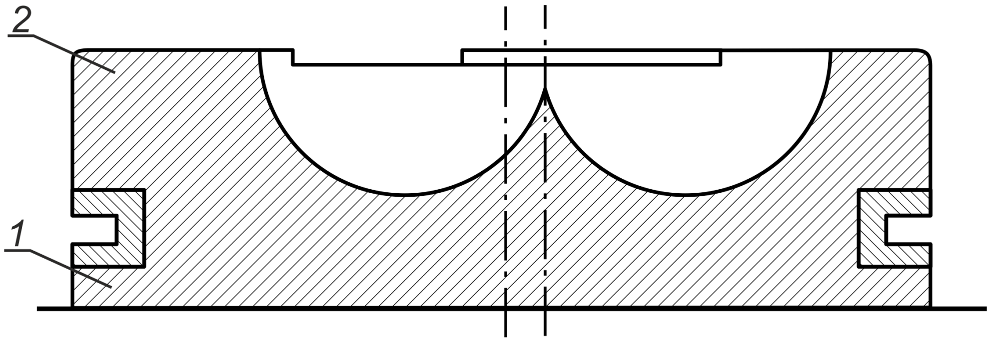

Fig. 3. Measuring points in the piston; 1 – under top compression piston ring; 2 – top piston crown

In order to determine the influence of the insert for the top compression piston ring on the temperature distribution in the piston, comparative tests were carried out using a piston with a sub-ring and a piston without a piston ring insert. Thermistors for measuring temperature in the pistons were placed under the edge of the piston crown and under the top piston ring groove or under the piston ring inset itself, as shown in Fig. 3. The upper part of the thermistor was placed at a distance of 0.1 mm by the piston crown, because at this distance there is a constant temperature in the whole cycle of the engine.

Due to the differences in the material properties of the silumin piston and the piston ring insert, which is made of austenitic cast iron containing Nickel and Chrome, a barrier is formed at boundary between the piston ring insert and the piston material for the heat transfer to the cylinder liner. There is a congestion of isotherms and as a result, the temperature difference between the measuring point at the piston's crown and the measuring point under the top compression piston ring.

Fig. 4 shows the temperature differences in the piston with a piston ring insert and without the piston ring insert at the measuring points under conditions of rapid load change during rapid change in engine speed. The temperature measurement was recorded for 120 s and during this time, a continuous increase in temperature was recorded. After 120 s, the temperature of the piston remained at a fixed level (did not grow).

In the piston without piston ring insert, the temperature at the piston crown was lower than in the piston with piston ring insert, while the temperature under the first compression piston ring was higher during increasing the engine load. It was found that these differences were lower in relation to the temperature at the piston crown. The temperature at the piston crown with piston ring insert was 578 K and without the piston ring insert – 581 K.

The temperature under the top compression piston ring was 488 K for the piston with piston ring insert and 469 K for the piston without piston ring insert. The temperature in this point is very important, because it largely determines the lubricating oil consumption that burns, decomposes and cokes at high temperature.

Fig. 5-9 show changes in the temperature difference at the piston crown and under the top compression piston ring for the piston with piston ring insert and without the insert one. The presented results were obtained in tests under load conditions with reference to engine speed 1000 rpm, 1400 rpm, 1600 rpm, 2400 rpm and 2600 rpm.

From the analysis of the data shown in Fig. 5-9, the increase in load increases the temperature difference at the measuring points on the piston crown and under the top compression piston ring. Higher values of the temperature difference occur for the piston ring insert due to the lower thermal conductivity value of the piston ring insert material than the piston material. Increasing the temperature difference between the measuring points has a beneficial effect on reducing the level of oil consumption. On the other hand, this causes an increase in thermal stresses in the piston, which in extreme conditions can lead to loss of cohesion between the piston ring insert and the piston.

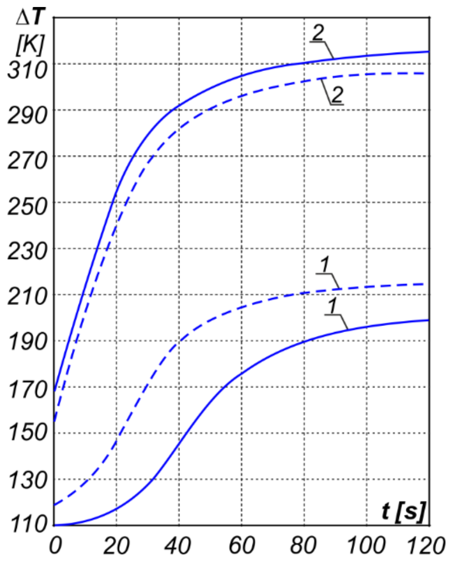

Fig. 4. Difference in piston temperature after rapid increase of engine speed and engine load; solid line – piston with piston ring insert; broken line – piston without piston ring insert; 1 – top piston compression ring; 2 – top piston crown;

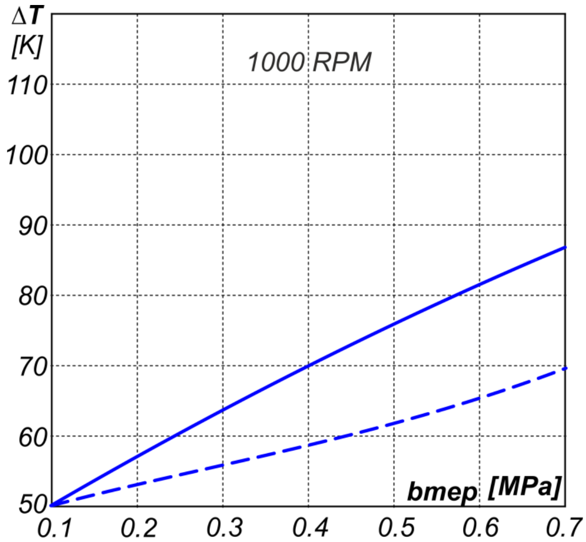

Fig. 5. Difference in piston temperature between the piston crown and top piston compression ring as a function of the brake mean effective pressure (bmep) during tests under load conditions for n = 1000 rpm; solid line – piston with piston ring insert; broken line – piston without piston ring insert

In Fig. 10, the temperature difference between the measuring point at the piston crown and the measuring point under the top compression piston ring during the test conditions of the external (speed) curve is shown. The data from Fig. 10 indicates that temperature differences increase with increasing engine speed up to 2400 rpm. Then, these differences are reduced.

Fig. 11 shows the temperature differences between the piston crown measuring points and the measuring points under the top compression piston ring during the conditions of change in engine speed and load. The data in Fig. 11 shows that a significant increase in differences takes place during 30 seconds. These differences are then reduced and stabilized up to 118 K for the piston with piston ring insert and 89 K for the piston without the piston ring insert. These results indicate slow stabilization of the heat flow from the piston to the cylinder liner and the engine cooling system. With regard to the piston without the piston ring insert, the temperature stabilization process is faster than for the piston with piston ring insert.

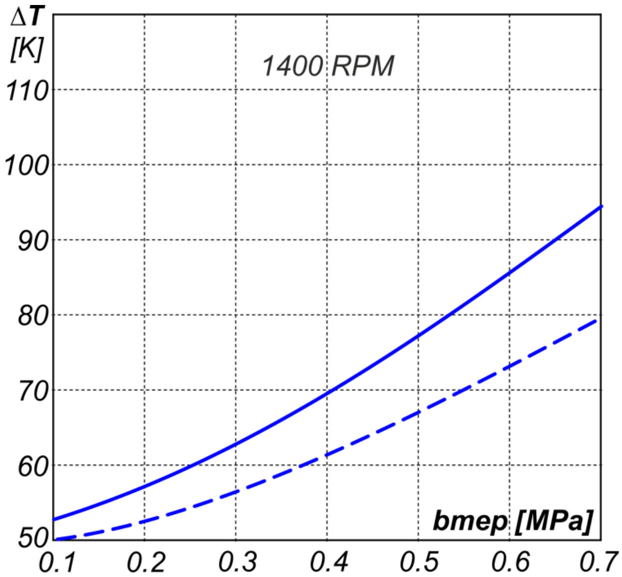

Fig. 6. Difference in piston temperature between the piston crown and top compression piston ring as a function of the brake mean effective pressure (bmep) during tests under load conditions for n = 1400 rpm; solid line – piston with piston ring insert; broken line – piston without piston ring insert

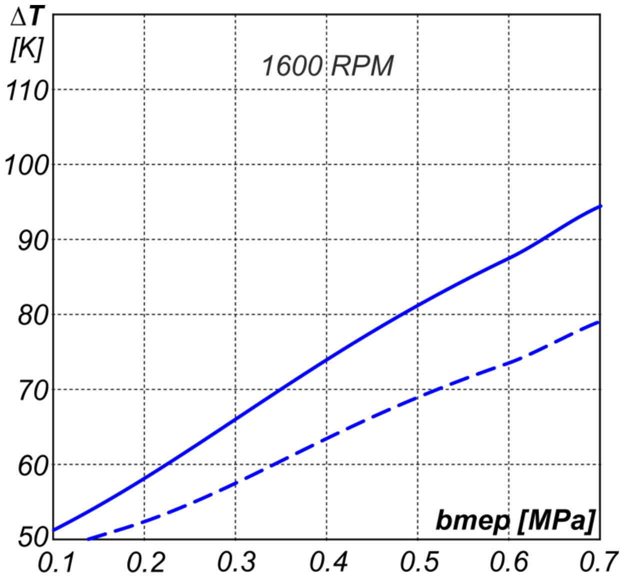

Fig. 7. Difference in piston temperature between the piston crown and top compression piston ring as a function of the brake mean effective pressure (bmep)during tests under load conditions for n = 1600 rpm; solid line – piston with piston ring insert; broken line – piston without piston ring insert

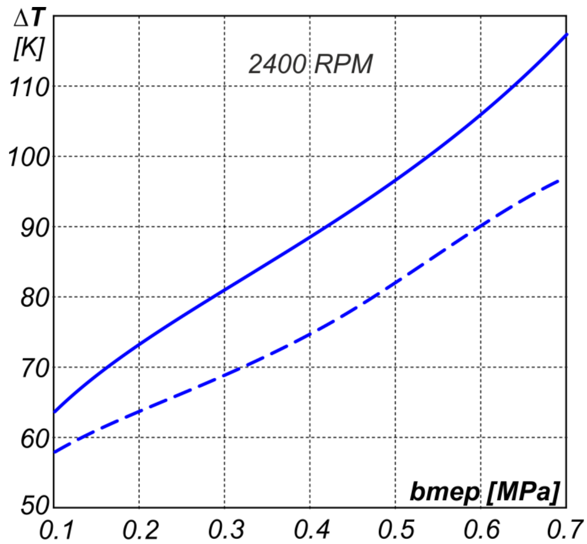

Fig. 8. Difference in piston temperature between the piston crown and top piston compression ring as a function of the brake mean effective pressure (bmep) during tests under load conditions for n = 2400 rpm; solid line – piston with piston ring insert; broken line – piston without piston ring insert

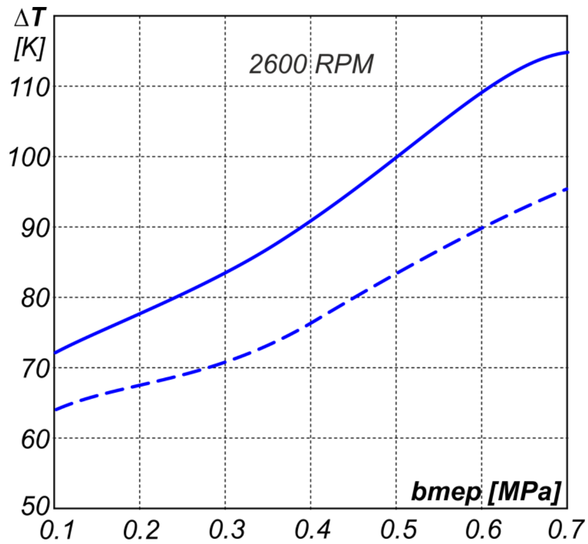

Fig. 9. Difference in piston temperature between the piston crown and top piston compression ring as a function of the brake mean effective pressure (bmep) during tests under load conditions for n = 2600 rpm; solid line – piston with piston ring insert; broken line – piston without piston ring insert

3. Conclusion

1. Measurements of piston temperature on a running engine result from the need to establish boundary conditions necessary for numerical calculations in novel prototype and modernised designs.
2. They also allow optimising the piston geometry to obtain economic effects (fuel and lubricating oil consumption), to achieve ecological effects (noise, hydrocarbons emission) and functional effects (mashing the engine, coking lubricating oil) and durability effects (stress gradients).

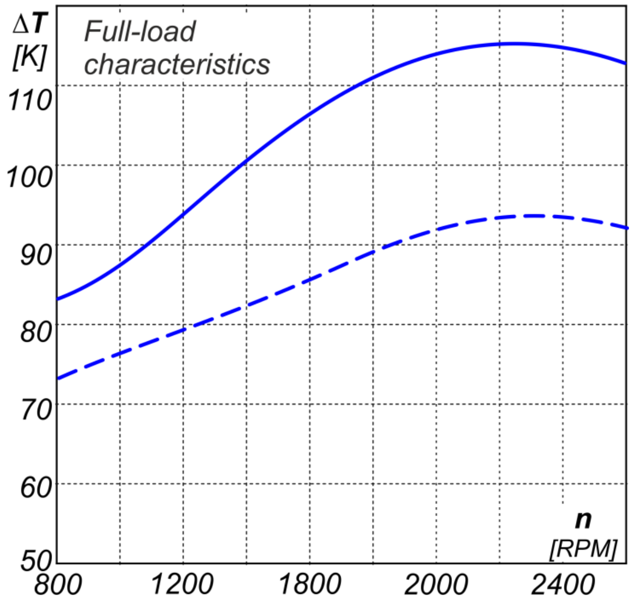

Fig. 10. Difference in piston temperature between piston crown and top piston compression ring as a function of engine speed under full load engine conditions; solid line – piston with piston ring insert; broken line – piston without piston ring insert

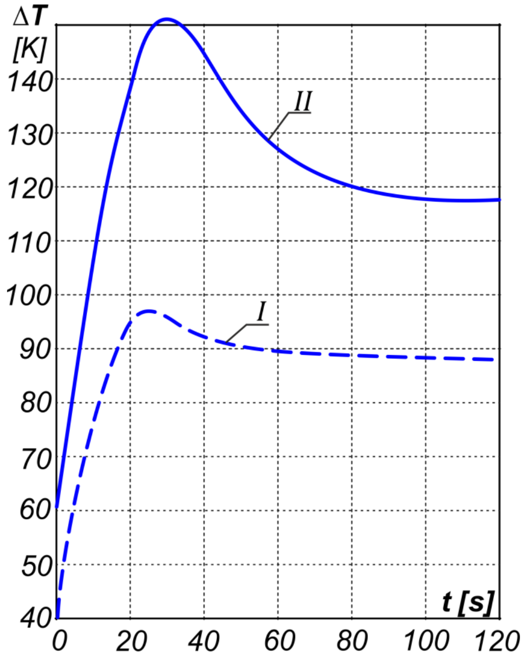

Fig. 11. Difference in piston temperature between piston crown and top piston compression ring after rapid change of engine speed and load; solid line – piston with piston ring insert; broken line – piston without piston ring insert

3. The developed method of inductive coupling gives the possibility of temperature measurements with high accuracy and repeatability in a wide range of engine speed and engine loads.
4. The maximum temperature was obtained under rated conditions of the engine operation:
   − piston crown 587 K for piston with piston ring insert and 581 K for the piston without piston ring insert;
   − under the top compression piston ring – 496 K for piston with piston ring insert and 448 K for the piston without piston ring insert;
5. Austenitic cast iron piston ring insert is a significant barrier to the heat flow from the piston to the cooling system, which is advantageous from the point of view of lubricating oil consumption but unfavourable from the point of view of thermal stresses.
6. With increasing engine speed and load, the difference in temperature between the piston crown and the top compression piston ring increases, except that the piston with piston ring insert is characterized by greater differences.
7. The rapid change of the engine speed and load increases the temperature difference by up to 20% compared to the stabilised temperature.

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