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The resistance to motion of internal combustion engine during the running-in process

Abstract: It is common that service manuals of modern passenger car do not establish any special rules of engine running-in process. It does not mean that the running-in process does not take place in the combustion engine, but the geometrical precision of engine elements is so high that manufacturers permit to operate the engine with full power from the very beginning of passenger car operation. To determine if such approach is correct the investigation of resistance to motion during engine initial operation period was made. The friction losses sum of all kinematic couples is the basic parameter that allows to evaluate the advance of engine running-in process. Many factors have influence on resistance to motion of combustion engine which means that determination of friction forces changes during running-in process is very difficult. The investigations presented in the paper were made on the engine in which most of the friction losses components are eliminated and only crank mechanism is considered. Obtained results allow to state that manufacturers resigned to early from running-in prescription which would guarantee the maximization of service life after running in period. Presented results of resistance to motion torque investigations are also the preliminary attempt to determine in which engine cycle phase the differences during and after running-in period are greatest.

Keywords: *piston-cylinder assembly, running in*

Opory ruchu silnika spalinowego w trakcie procesu docierania

Streszczenie: Obecnie instrukcje użytkowania samochodów osobowych nie przewidują szczególnych zasad docierani silnika w okresie początkowej eksploatacji. Nie oznacza to oczywiście, że proces docierania został wyeliminowany, jednak precyzja wykonania oraz jakość powierzchni współpracujących elementów pozwalają na pełne obciążenie silnika nowego samochodu. W celu określenia zasadności ww. poglądu zostały przeprowadzone badania zmian przebiegu sił tarcia w początkowym okresie eksploatacji silnika. Straty tarcia w parach kinematycznych silnika spalinowego są podstawowym parametrem pozwalającym ocenić zaawansowanie procesu docierania silnika. Niestety na opory ruchu silnika składa się szereg czynników, co powoduje, że określenie zmian sił tarcia w okresie docierania jest bardzo trudne. Zaprezentowane w artykule badania przeprowadzono na silniku spalinowym, w którym wyeliminowano większość składowych momentu oporu ruchu. Uzyskane wyniki pozwalają wyrazić opinię, że w obecnych instrukcjach obsługi silników spalinowych zbyt wcześnie zrezygnowano z zaleceń gwarantujących maksymalne wydłużenie eksploatacji po okresie docierania po okresie docierania. Zaprezentowane wyniki badań momentu oporu ruchu są również wstępną próbą określenia, w jakim momencie cyklu pracy silnika różnice w okresie docierania i po tym okresie są największe.

Słowa kluczowe: *grupa tłokowo-cylindrowa, straty tarcia, proces docierania*

1. Introduction

According to the prescriptions of manufacturers modern passenger cars, and in particular their engines, do not require any special directions for use during so called running in period. The aim of such running in instructions was to ensure the longest possible service time of the engine, maximum operating parameters, minimal fuel and oil consumption. Nowadays it is almost totally forgotten when it was obligatory to follow the instructions of brand new car which determined the special driving style and maintenance. Currently approach of typical passenger car user has change. Car became an ordinary device just like any other household device. Nobody would have thought that for example kitchen mixer will require running-in period. Such device has to be operation ready in all operating conditions from the very beginning. The same ready to use principle is valid for modern passenger car. But consumer expectations are not the only and main factor of engine development. The most important development pulse impact of transport means on natural environment. Modern engines to be able to fulfil the emission standards, for example EURO VI, became not only much more complicated in the aspects of structure, but also geometrical and dimensional tolerances of engine elements are also much more stringent. These stringent tolerances are meaningful to the most phenomena that occur in the combustion engine, for example charge exchange, combustion process, and especially lubrication of all kinematic pairs. On one side the stringent tolerances allows to resign from special running-in period instructions, but on the other hand there is a question if the running-in process indeed does not take place in new engine. The easiest way to find the answer to this question can be found in every brand new car in which fuel consumption is significantly higher at the beginning of operating period than after mileage of few thousand kilometres. As a simple example will serve 2010 VW Passat CC with 2.0 TDI CR 125 kW engine. When the car was brand new with the mileage of 10 km the fuel consumption of idling engine was 1.0 l/h (oil temperature 85 °C). With growing mileage of the car the fuel consumption of idling engine was diminishing until it reached stable level 0.7 l/h (oil temperature 85 °C) after 1000 km. This example clearly shows that some running in processes occur in the engine during early operating phase. Because of complexity of a series car it is hard to distinguish and determine all phenomena so authors decided to establish investigation on selected running-in processes in the combustion engine. As the basic mechanism of combustion engine and in the same time most interesting in the aspects of running in the authors chose to investigate the crank mechanism.

Every machine component is characterised with shape, dimensions, and geometrical and dimensional tolerances. Moreover, in the aspects of elements mating, very important parameter is the surface roughness, for example of the piston ring and cylinder liner sliding surfaces, which are schematically presented on Fig. 1. The surface roughness is connected with after machining because every machining forms particular unevenness in the range of assumed tolerance.

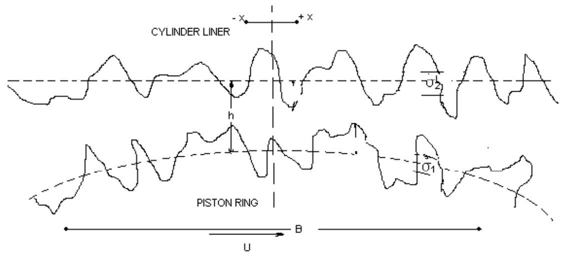

Fig. 1. Surface roughness of piston ring-cylinder liner assembly [3]

The basics of running in processes are directly connected with surface roughness. In the early phase of engine service time, so called running in period, every kinematic pair surfaces are matching each other and mixed friction with metal to metal contact can be observed. This means that in this phase wear process of the surface occurs much more intensively than after running in time. In this period surface shape changes and so are the mating parameters. After specified time combination of geometric parameters and surface roughness allows to generate constant oil film which means that mating surfaces are fully separated by thin layer of lubricating oil. When the fluid friction is permanent not only friction forces are brought to minimum but also wear processes theoretically do not occur, because no metal to metal contact is present. The character of running in wear processes depends not only on engine parts geometrical and surface parameters but also on load conditions. Load conditions in every kinematic pair of the engine results from engine operating conditions, which can be basically described with engine load and engine speed. On Fig. 2 example research results of tribological studies of coated pistons are presented [4].

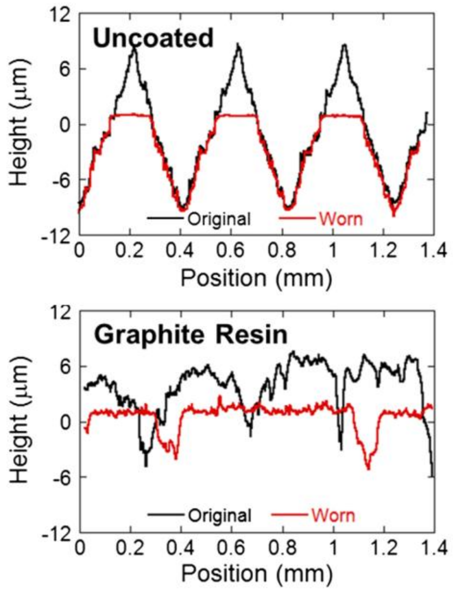

Fig. 2. Graphs showing profilogram of the uncoated and graphite resin piston samples, before and after 20 min of testing [4]

It can be noticed that after just 20 minutes of testing geometrical parameters of piston side surface, both uncoated and graphite resin, changed dramatically. This changes have further influence on oil film formation and is great example of running in occurrence.

Also the thermal state is crucial. The oil viscosity changes with oil temperature, and according to hydrodynamic lubrication theory the oil viscosity is fundamental parameter in the aspect of oil film generation. Moreover clearances of elements mating changes with the thermal state of the engine, and the clearance has to be treat as one of the geometrical factor which has the influence on oil film parameters

2. Test stand structure

The basic conception of the researches and as follows the test stand construction is to measure the friction torque of the crank mechanism. This means that no other sources of friction losses, such like valve train, can have influence on registered signal from the torque meter. The authors decided to drive the crank mechanism by external electric machine and separate all supporting systems from the crank mechanism, so the registered friction torque signal is connected only with the crank mechanism.

The test stand is equipped with the Fiat 170A.046 engine. The engine before researches was brand new which is unequivocal to zero hours of service time. This means that no running in processes could occur before beginning of the researches with use of this particular engine. As said earlier all supporting systems were separated from the crank mechanism. The camshaft chain was demounted so the camshaft is not rotating with the crankshaft revolution. All of the valves stay permanently in closed position, therefore no combustion process is be realised in the cylinders. The fuel and ignition system are dissembled from the engine as well. The coolant and oil pumps are driven independently by electric engines.

The engine is connected with an electric machine by the HBM Drehmomentmesswelle T 5 high resolution torque meter with measuring range of 50 Nm. The maximum sample rate of torque meter allowed authors to set measurements resolution to 1 degree of crankshaft revolution. The overall view of the test stand is presented on Fig. 3. The connection of the combustion engine with the electric engine by torque meter is shown on Fig. 4.

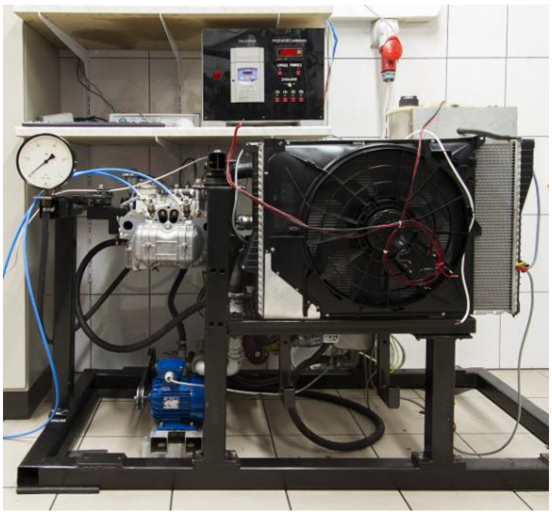

Fig. 3. Overall view of the test stand

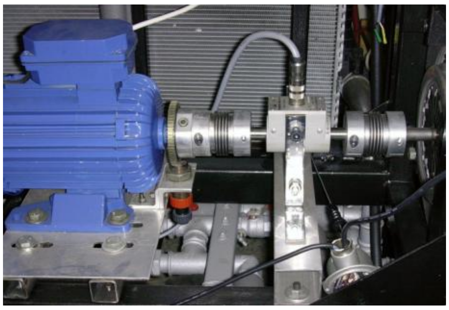

Fig. 4. HBM torque meter

In every combustion engine research very important matter is the control precision of thermal state of the engine. Friction researches require special approach to the oil temperature stability, of course because of the oil viscosity. Authors made special modification to the cooling system, where the oil temperature is regulated through the coolant temperature in heat exchanger. Block diagram of thermal state control system is presented on Fig. 5.

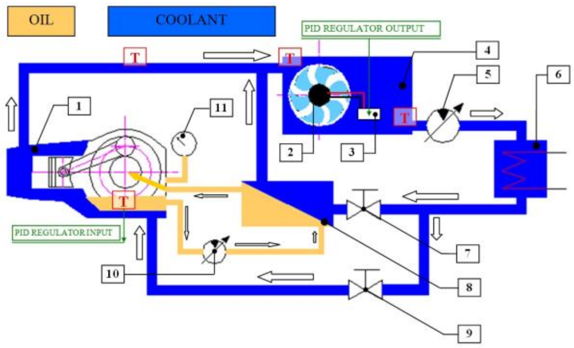

Fig. 5. System of oil temperature control: 1 – engine, 2 – cooling agent cooling fan, 3 – fan rpm controller, 4 – radiator, 5 – electric cooling agent pump, 6 – coolant electric heater, 7 – ball valve of the small coolant circuit, 8 – coolant to oil heat exchanger, 9 – ball valve of the large coolant circuit, 10 – electric oil pump, 11 – oil pressure gauge [1]

3. Research results

This paper concentrates on the very beginning of the running in process of the combustion engine. Authors decided to present first 20 minutes of the engine run. Long term investigations are still in progress and their results will be the subject of future papers.

To achieve comparable conditions for whole time of the investigation authors assumed a stable temperature of 80 Celsius degree of coolant and oil temperatures. The idea of the researches was that valuable measurements should contain also the first few minutes of engine run, so the engine had to be preheated before the research begun. It was possible because of external electric coolant and oil pumps and electric heater. Also the engine speed was assumed to be constant. In this particular case was 1000 rpm engaged. In such researches constant engine speed is necessary to allow to compare measures from different time points. Fig. 6. presents the course of measured friction torque as function of time.

In the first 5 minutes of engine run the friction torque drop under test conditions is most significant. In the first minute the mean value for whole four crankshaft revolution was 4.19 Nm and just after 5 minutes it was 3.90 Nm. It is expected that during this phase the semi dry and mixed friction occurs very intensively in all kinematic pairs of the crank mechanism and piston-cylinder assembly. After this time friction torque value started to oscillate which can be connected to the slight oil temperature fluctuation.

From Fig. 7 and 8 it can be noticed that course of friction torque during one engine cycle also changed, which similarly to the mean value of friction torque is connected with oil film parameters during engine cycle. On both pictures the blue line, which is associated with the scale marked on the left side of the chart, presents the results of a direct measurement. The course of the torque corrected by subtracting these harmonics from the measurement results which are not in the phase with the angular velocity of the engine is represented by the green line, and a summary torque subtracted, as a result of correction from the desired torque, by the red line. The range of courses marked green and red is shown on the right side of the figure.

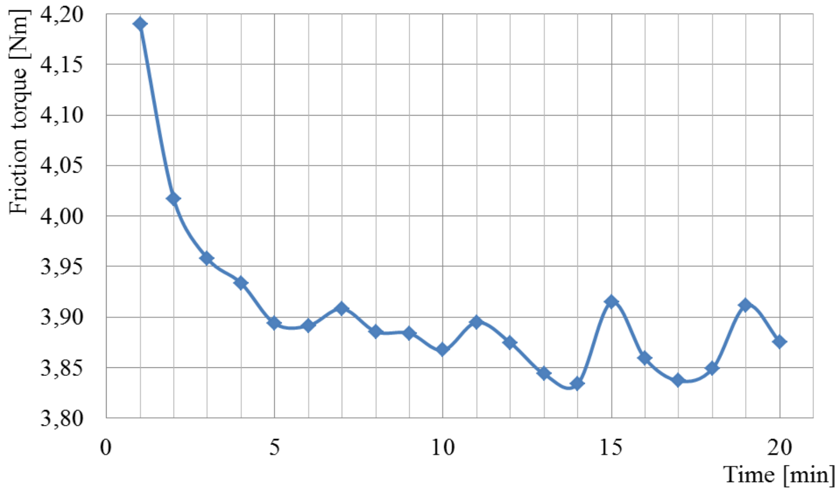

Fig. 6. Friction torque during 20 minutes running in phase

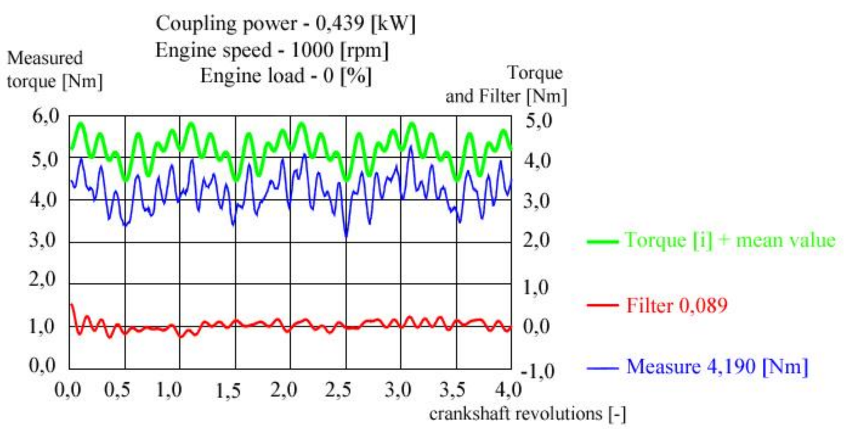

Fig. 7. The course of measured torque (blue line), corrected torque (green line) and difference of these two torque courses (red line) after first minute of engine run

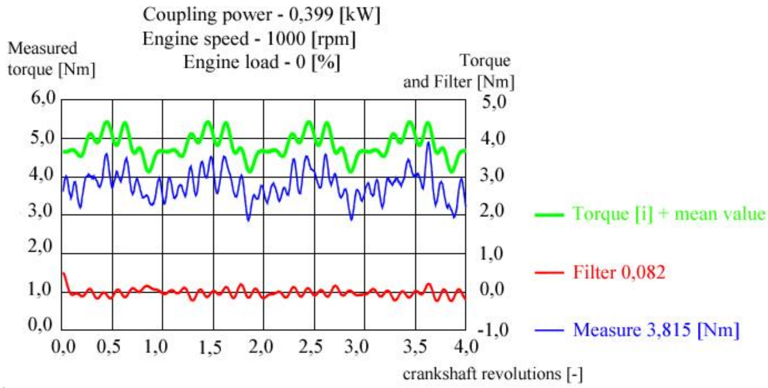

Fig. 8. The course of measured torque (blue line), corrected torque (green line) and difference of these two torque courses (red line) after sixteen minutes of engine run

4. Conclusions

The engine running in is very important phase in aspects of long term proper engine operation. Not only long term oil consumption and engine durability will depend on this early engine run period, but for example also fuel consumption and emissions of toxic exhaust compounds. The researches presented in this paper and also by other authors [4, 5], prove that despite the high manufacture precision the running in still occurs and should not be overlooked. It is worth to mention that presented researches concerned the crank mechanism and piston-cylinder assembly only, but it is expected that the running in will occur in every other mechanism of the internal combustion engine, for example in the valve train.

It is certain that the proper and purposeful engine operating conditions during running in period are still important and even the most sophisticated engine will be influenced by the running in course. The drivers of modern passenger cars do not have to understand all off the phenomena that occur inside the combustion engine, so it is engineers role to determine and suggest the best operating conditions during running in to obtain highest possible engine service life and reliability.

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