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POWER LOSS IN A COMBUSTION ENGINE OF A PROTOTYPE VEHICLE

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Abstract

The paper deals with the analysis of power loss involved in an experimental single-cylinder internal combustion engine during its operation. The experimental engine has been developed and built entirely at the University for the purposes of Shell Eco-marathon. A series of experimental measurements was taken to discover the reasons for the issues we had encountered by obtaining output power characteristics and the value of compression pressure regularly at specific intervals. The data we obtained served to diagnose faults and to propose solutions for their elimination.

Keywords: prototype combustion engine, power–torque measurement, engine diagnostics, compression pressure

INTRODUCTION

Current trends in the automotive industry, as well as the vision for the future, revolve around going green and are closely tied to the reduction of the CO_2 emissions and a shift to alternative energy sources.

In order to optimize the performance and the emissions of an engine, detailed and specific knowledge of the combustion process inside the engine cylinder is required. In that sense, the torque generated by each combustion event in an IC engine is one of the most important variables related to the combustion process and engine performance [1].

Shell organizes a special annual competition for students from around the world, in which the teams present their ultra energy-efficient vehicles.

Our team created a prototype vehicle titled BaS with a prototype single-cylinder 25 cm^3 combustion engine to enter the competition.

During the application and testing of its electrical control system, we discovered persisting technical issues with the drive unit which resulted in an evident drop in torque and engine performance. The paper aims to analyze and uncover the reasons behind these issues. There are many publications dealing with this subject. For example, [2] deals with the processes and characteristics of combustion in the internal combustion engine and the equipment available to a test engineer for its analysis. The paper [3] systematically reviews the engine knock phenomenon, including the mechanisms, influencing factors, consequences, and detection methods etc. Wear is another highly relevant factor. The wear of metals and alloys takes place in many forms, and the type of wear that dominates in each instance is influenced by the mechanics of contact, material properties, the interfacial temperature, and the surrounding environment [4]. Tribology is closely linked to wear; along with using new types of coating and nano coating on the friction areas of the mechanical components which ultimately also affect emissions, fuel consumption, and performance. Such authors as [5],[6],[7],[8] deal with this subject, while the practical applications can be found in [9] and [10].

As far as failure diagnostics is concerned, vibration analysis can help to a large degree. It has been elaborated, for instance, in [11],[12],[13]; along with [14] which provides an interesting perspective as well.

DRIVE UNIT CONSTRUCTION

Our combustion engine was developed specially for the prototype eco vehicle project. The process of determining its construction parameters involved many calculations aimed to achieve greatest possible combustion efficiency and minimization of internal mechanical losses.

An experimental combustion engine is a simple structure with a single 25-cm^3 cylinder, a 34-mm boring, and a 28-mm lift. The operating revolutions range between 2 500 – 8 000 min^{-1} at the 140 °C operating temperature. The crank mechanism came from a 27,2 cm^3 chainsaw engine producing 0,75 kW. To minimize its mechanical losses, all bushings were replaced by needle roller bearings [15], [16], [17].

Specially fitted piston, precision-ground piston rings, and light-weight piston rod, along with the nitride-coated steel cylinder form a reliable basis for an engine. A double overhead camshaft type valve distributors are controlled by a pair of chaindriven adjustable gear wheels. A pair of camshafts that is embedded in the antifriction bearings autonomously controls two suction valves and one exhaust valve. To eliminate the radial forces caused by the rotating cam, it is opened by a solid eccentric stud cam follower without a possibility to set the clearance. The valve and cam follower sliding surfaces form precise holes in the valve head. The suction and exhaust valves are closed by the valve springs designed to achieve the required valve closing characteristics. The valve seats comprise a single cast iron insert in the valve head with the milled valve seats and a service opening for a spark plug. Fig. 1 shows the view of the experimental combustion engine.

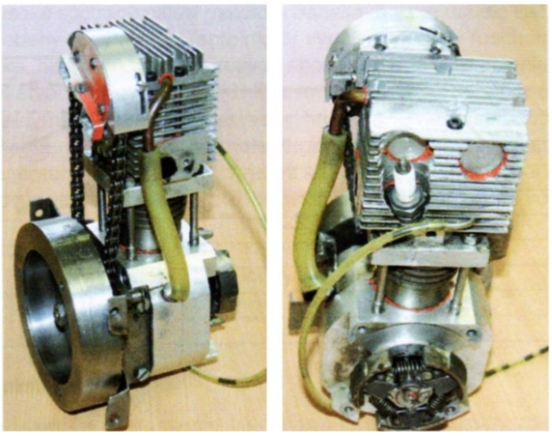

Fig. 1. Experimental combustion engine [15]

DESCRIBED ISSUE AT HAND

During the operational testing done on the experimental combustion engine, technical issues were found that manifested as a reduction in the torque and performance. Since the tuning of the prototype engine focuses primarily on achieving an optimal combustion, stable operating temperatures, and an optimal torque, we have made attempts to eliminate the issues which have been narrowed down to making changes to the mixture richness. Such changes, however, brought about a minimal surge of the output parameter values in the high revolution range. In this regard, the central unit was fitted with adjusted fuel maps (Fig. 2) with an intention to match the maximum output engine values that were measured previously.

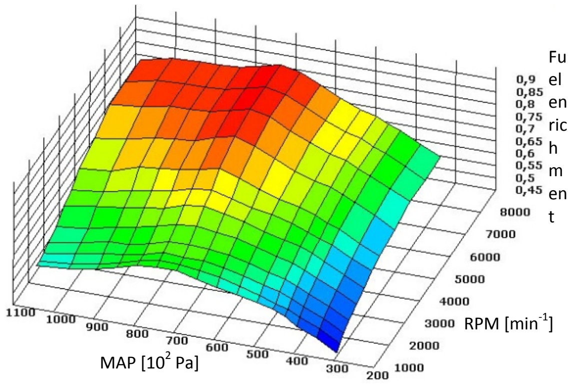

Fig. 2. Power measurement fuel 3D map

Using the fuel maps that were optimized for higher performance, however, was not yielding an adequate increase in values to the required level.

MEASUREMENT

Due to the ongoing issues, it was necessary to take a series of measurements that would help to identify the root causes behind the technical issues with the engine. The measurements focused on finding out the compression pressures in the combustion area (Fig. 3).

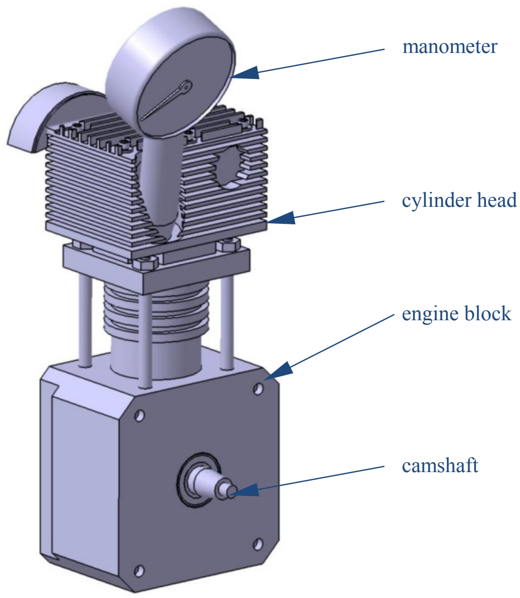

Fig. 3. Compression pressure measuring model

For the sake of this measurement, we installed a pressure sensor in the spark plug and took measurements in regular intervals after continuous operation and loading of the engine. The compression pressure results are presented in Fig. 4.

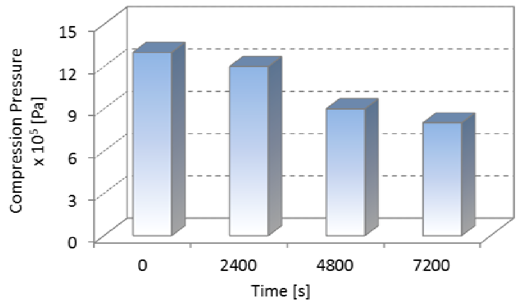

Fig. 4. Engine compression pressure values

Each compression pressure value was matched with the corresponding output parameters.

The measurements were taken by an electrical motor dynamometer (Fig. 5) developed specially for the experimental purposes of developing the prototype ecological combustion engines. The torque measurement stand works on the principle of sensing the incremental input revolutions with an adequately growing excitation of the electrical dynamo to create a loading effect of an engine break. The specially developed measurement stand can also start the engine and thus eliminate the cyclical loading of a highly sensitive starter clutch.

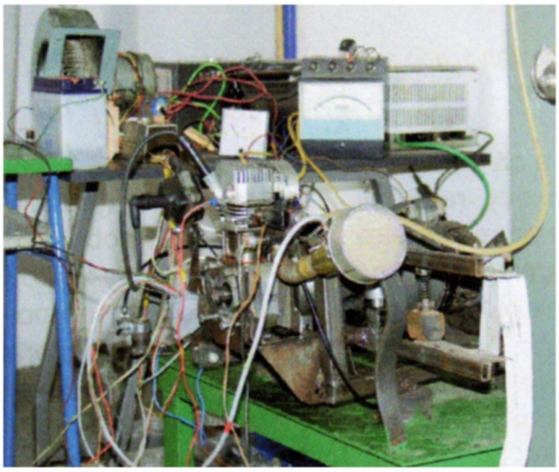

Fig. 5. Dynamometer and the prototype engine [15,18]

Engine power (Fig. 6) and torque (Fig. 7) in relation to the revolutions per minute at various compression pressures indicate the tendency of these parameters to decrease in relation to the engine operating time.

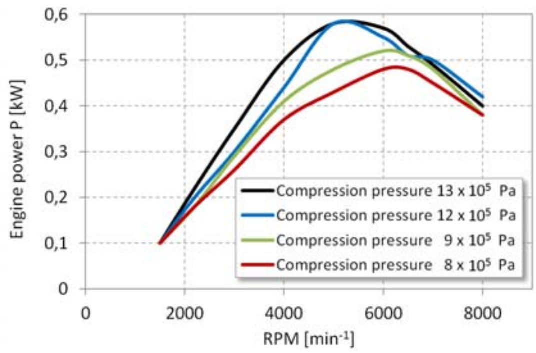

Fig. 6. Engine power in relation to the revolutions measured at various compression pressures

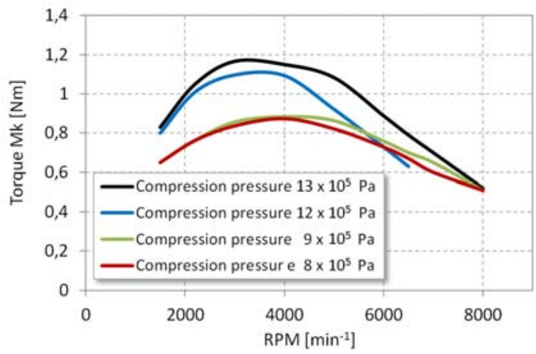

Fig. 7. Torque in relation to revolutions measured at various compression pressures

A significant change in the development of the engine's output parameters can be observed when we compare the data from the diagram in Fig. 8, which presents the engine power and torque at the optimal engine operation, with Fig. 9, which shows the parameters after 120 minutes of operation.

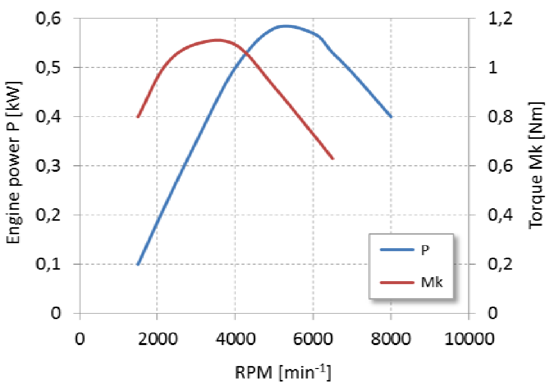

Fig. 8. Measured engine power and torque at optimal engine operation

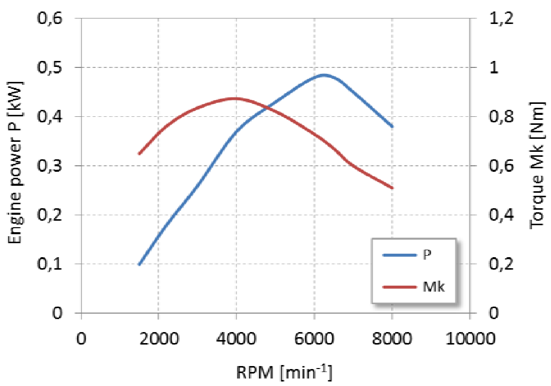

Fig. 9. Measured engine power and torque after 120 minutes of engine operation

A summary diagram showing a decrease of engine performance during its operation is shown in Fig. 10.

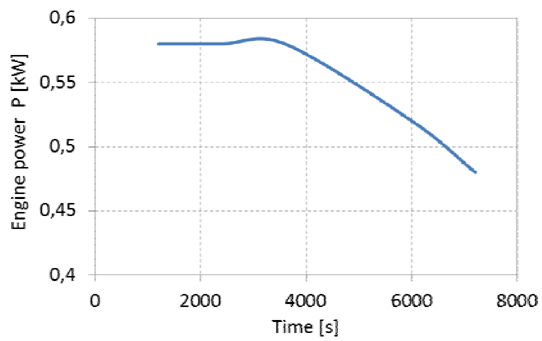

Fig. 10. Maximum performance values during engine operation drop

The tendency of the measurement results to decrease constantly at the identical settings of the control system indicated a failure in the mechanical parts of the experimental engine. The gradual decreasing trend that is evident in the torque curve is consistent with the ongoing engine compression issues. The shift of a maximum number of curves into higher revolutions corresponds with the piston's inadequacy to develop sufficient pressure in the combustion area. Our analysis has identified the following issues:

a) Leakage has been occurring between the cylinder and the piston rings (Fig. 11).

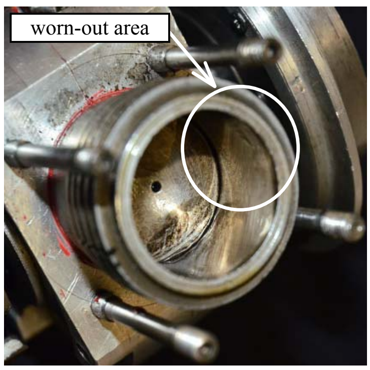

Fig. 11. Cylinder wall wear

This phenomenon causes wear in the moveable parts of the engine. High friction occurs when the piston is in reverse motion and the normal force of the piston rings affects the cylinder wall. The construction designed with double piston rings inhibits the pressure to leak from the combustion chamber into the engine's crankcase to a maximum possible degree. Two jointly turning, precision-ground valve rings, prevent pressure leaks in the piston ring joint or the piston groove. Wiping the grease off the cylinder wall is equally effective. The pressure of the piston ring itself and its edges against the cylinder wall during the swinging motion of the piston can cause the rings as well as the surface of the cylinder to wear out on the side along the direction of the camshaft's rotation.

b) The deformities on the joint between the cylinder and the engine head. These deformities cause the compression pressure to leak while the installation points of the head joints, as illustrated in the simulation model of stress distribution in Fig. 12. To furnish the bearing surface with a greater sealing ability, a pliable 0.3 mm copper washer was inserted between the steel cylinder and the cylinder head.

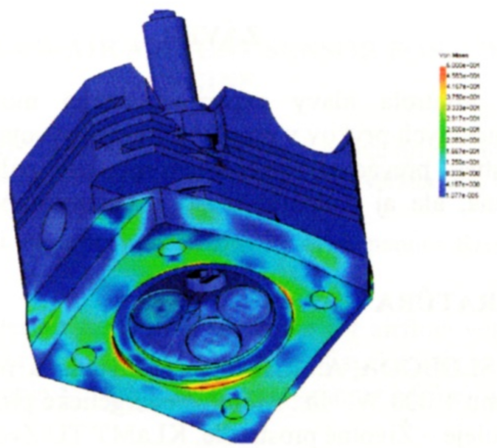

Fig. 12. Bending stresses on the installation surface of the cylinder head [15,18]

c) Mechanical damage on the valve bearing surface (Fig. 13) which creates pressure leaks from the compression area of the combustion engine. The valve spring and the disk make the valve to close at a high speed against the valve seat in the cylinder head. Each valve is opened by a camshaft and a cam follower once every two turns of the crankshaft. The regular impact of the valve against the hard valve seat causes the narrow bearing surface of the bonnet to wear out. The malformed edge of the valve reduces its ability to seal the seat and the suction, or the exhaust channel in the cylinder head. The valve's impact against the seat is caused mostly by the simple structure of the lifting mechanism which makes it impossible to set the clearance for the valves. The clearance could be furnished only by removing material from the valve tip, or alternatively, from the solid cam follower.

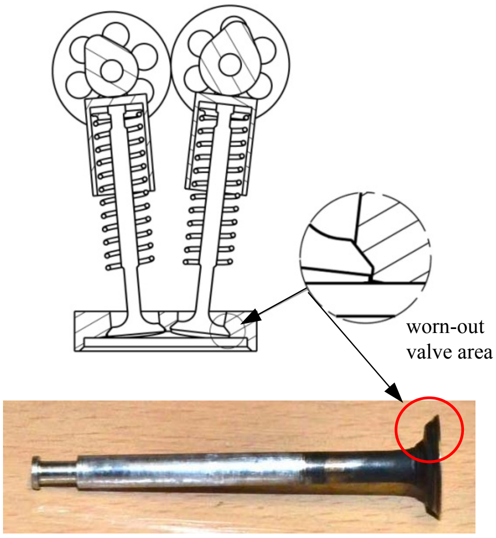

Fig. 13. Internal moving components - engine head

SUMMARY

The prototype experimental combustion engine has been designed to reach maximum effectivity of all phenomena occurring during its operation. Transformation of the energy contained in the fuel into mechanical work and minimization of mechanical and thermal losses are key to reaching low values of the overall specific fuel consumption. The combination of low fuel consumption and maximum torque in a broad revolution spectrum is key to developing an effective drive unit of an eco-car. During the experimental measurements and result analysis, we have found significant deficiencies in the mechanical structure of the engine. A considerable value variability of the compression pressures during operation makes the conditions for operation and the overall setting of the engine unfavorable. To optimize the fuel and spark maps when the combustion engine mechanics show variable values becomes literally impossible. The pressure changes occur right during the engine operation with which the electronic system is not able to contend and adjust for it. The fuel batch correction using an oxygen exhaust sensor is not possible in short intervals, during which the engine runs under maximum loading.

The valve mechanism undergoes considerable material wear although the valve material is also used in the car industry where it has shown high reliability and resistance to wear. Cyclically loaded sealing surfaces of the valve disk get deformed in a very short span of time by the valve seat in the engine head. The sealing surface deformation consequently leads to a reduced ability to maintain compression pressure. The sealing surface expands significantly, which reduces the pressure the valve spring exerts on the valve seat. As the valve sealing surfaces wear out, the valves gradually get depressed into the cylinder head, and the clearance of the cam follower and the camshaft shrinks. Heat expansion can cause the camshaft to keep the valve open the whole time during each stroke of the engine.

Our proposed solutions to eliminate the origins of compression pressure loss in the engine are following:

- change the materials used on valve sealing surfaces,
- change the rigidity of the valve springs,
- change the structure of the valve lifting, mechanism to include the possibility to set their clearance,
- apply advanced coatings on the cylinder wall to reduce friction.

Our vehicle with the experimental engine has entered the competition six times between 2003 and 2015. It managed to travel as far as 783.1 km on a liter of fuel (Fig. 14) weighing 102,6 kg including driver.

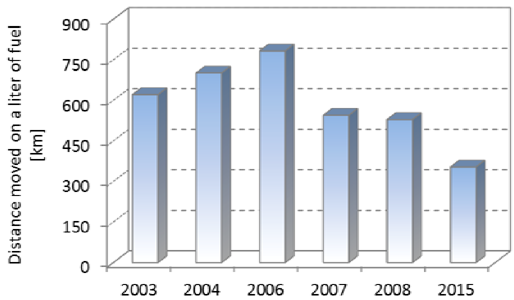

Fig. 14. The vehicle's travel distance review in the history of its participation in Shell Eco-marathon

The vehicle traveled approximately 589 km on a liter of fuel on average during its history of participating in Shell Eco-marathon. Once all the noted issues were eliminated, it was possible to raise the average value. The adjustments, however, push the engine's capacity to the absolute limit. Looking ahead, our team is already working on a new drive aggregate, whose structure considers all noted deficiencies and builds on the experience gained from the previous competitions. The results accomplished thus far are assumed to be surpassed by this unit by far.

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LITERATURE

1. Lee B, Rizzoni G, Guezennec Y, Soliman A, Cavalletti M, Waters J. Engine Control Using Torque Estimation. SAE Tech Pap 2001:SAE 2001-01-0995. doi:10.4271/2001-01-0995.
2. Martyr A. J, Plint M. A. Engine Testing. 2012. doi:10.1016/B978-0-08-096949-7.00012-1.
3. Zhen X, Wang Y, Xu S, Zhu Y, Tao C, Xu T, et al. The engine knock analysis - An overview. Appl Energy 2012;92:628-636. doi:10.1016/j.apenergy.2011.11.079.
4. Blau PJ. Elevated-temperature tribology of metallic materials. Tribol Int 2010;43:1203-1208. doi:10.1016/j.triboint.2010.01.003.
5. Priest M, Taylor CM. Automobile engine tribology-approaching the surface. Wear 2000;241:193–203. doi:http://dx.doi.org/10.1016/S0043-1648(00)00375-6.
6. Adams DR. 8 - Tribological considerations in internal combustion engines. 2010. doi:http://dx.doi.org/10.1533/9781845699932.2.251.
7. Tung SC, McMillan ML. Automotive tribology overview of current advances and challenges for the future. Tribol Int 2004;37:517-536. doi:10.1016/j.triboint.2004.01.013.
8. Wong VW, Tung SC. Overview of automotive engine friction and reduction trends. Effects of surface, material, and lubricant-additive technologies. Friction 2016;4. doi:10.1007/s40544-016-0107-9.
9. Rasheed AK, Khalid M, Javeed A, Rashmi W, Gupta TCSM, Chan A. Heat transfer and tribological performance of graphene nanolubricant in an internal combustion engine. Tribol Int 2016;103:504-15. doi:10.1016/j.triboint.2016.08.007.
10. Lubas J. Practical application of boron-modified sliding pairs in I.C. engine. Tribol Int 2010;43:2046-50. doi:10.1016/j.triboint.2010.05.008.
11. Puchalski A. Application of statistical residuals in vibrodiagnostics of vehicles. J Vibroengineering, 2014;16:3115-3121.
12. Kostyukov VN, Naumenko AP. Standardization in the sphere of vibrodiagnostic monitoring of piston compressors. Procedia Eng., 2015:113:70-80. doi:10.1016/j.proeng.2015.07.290.
13. Grega R. et al. The chances for reduction of vibrations in mechanical system with low-emission ships combustion engines. 2015. In: International Journal of Maritime Engineering. 2015;157:235-240.
14. Czech P. Identification of Leakages in the Inlet System of an Internal Combustion Engine with the Use of Wigner-Ville Transform and RBF Neural Networks. Conference: 12th International Conference on Transport Systems Telematics Location: Katowice Ustron, Poland, 2012.
15. Sloboda A, Bugár T, Sloboda O, Ďurovský F. Experimentálne vozidlá. Vienala 2012.
16. Wierzbicki S, Śmieja M, Grzeszczyk R. Zintegrowane sterowanie stanowiskiem badawczym silników o ZS w środowisku fast prototyping. Combustion engines, 2013;52(3): 536-541.
17. Sloboda A, Bugár T, Tomková M, Sloboda A ml., Piľa J, Tkáč Z. Konštrukcia automobilov I. Piestové spaľovacie motory. TU Košice 2006.
18. Bugár T, Laboš J, Sloboda A. Pevnostná kontrola hlavy valca z pohľadu jej spoľahlivosti a bezpečnosti. 2005. In: Kvalita a spoľahlivosť technických systémov. Nitra, SPU, p. 203-205.

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