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Contribution of developing advanced engineering methods in interdisciplinary studying the piston rings from 1.6 spark ignited Ford engine at Technical University of Cluj-Napoca

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Abstract. Study of construction and wearing process in the case of piston-rings and other significant components from internal combustion engines leads at any time to creative and useful optimizing ideas, both in designing and manufacturing phases. Main objective of the present paper is to realize an interdisciplinary research using advanced methods in piston-rings evaluation of a common vehicle on the streets which is Ford Focus FYDD. Specific objectives are a theoretical study of the idea for advanced analysis method in piston-rings evaluation and an applied research developed in at Technical University from Cluj-Napoca with the motor vehicle caught in the repairing process.

1. Introduction

The expansion of modern engines would have been unfeasible without advanced lubricant chemistry and proper lubricant formulation. Introduction of diamond like carbon (DLC) coatings opens further possibilities in improving performance of engine and transmission components, which cannot longer be achieved only by lubricant design. DLC coatings show extremely good promise for several applications in automotive components as they exhibit excellent tribological properties [1].

Despite extensive research into alternative methods, the internal combustion engine is expected to remain as the primary source of vehicular propulsion for the foreseeable future. There are still significant opportunities for improving fuel efficiency, thus directly reducing the harmful emissions. Consequently, mitigation of thermal and frictional losses has gradually become a priority. The piston-cylinder system accounts for the major share of all the losses as well as the emissions. Therefore, the need for an integrated approach, particularly of a predictive nature is essential. The cylinder liner temperature is critical in mitigating power loss as well as reducing Hydrocarbon (HC) and Nitrogen Oxide (NOx) emissions from the compression ring – cylinder liner conjunction [2].

The past work of the authors on this subject developed experimental testing procedures on the specific task of piston-ring technical state determination in the case of spark ignited engine from Ford Focus 1.6 16v Turnier, code DNW 74 kW. Piston-rings construction and operation, as well as its specific working-surface configuration, materials, dimensions and lubrication procedure, in various thermo-mechanical loading regimes, are essential in influencing the engine's life-expectance. In this paper are presented the piston-rings construction and their measured dimensions at the end of exploitation period of a spark ignited engine from Ford Focus. The importance for monitoring the piston-ring dimensions at different locations and directions consists in the possibility of controlling their wear-ness [3].

The vehicle and main components considered for this study are shown in the Figure 1.

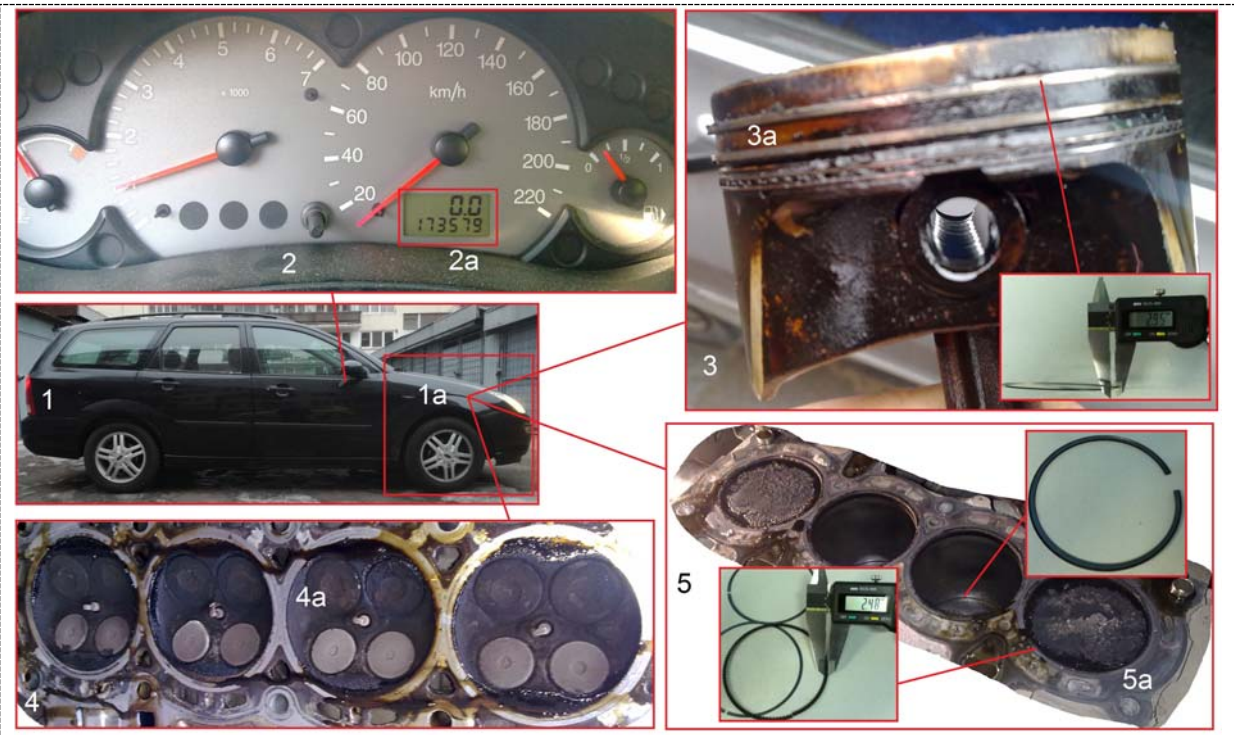

Figure 1. The studied vehicle type model Ford Focus with spark ignited engine 1600 dm^3 FYDD [3]

Figure 2 shows the main features of piston rings which are installed on the piston assembly in order to isolate the combustion chamber from the oil sump.

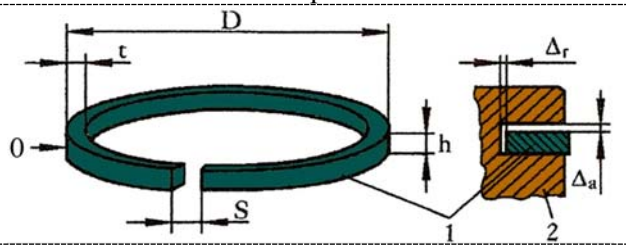

Figure 2. Piston ring significant features [4].
0-operational interface; 1-compression piston ring; 2-piston; D-exterior diameter; S-piston ring clearance; h-piston ring height; t-piston ring thickness; Δa-axial clearance between piston and ring; Δr-radial clearance between piston and ring.

There is an opportunity to develop the studies around piston rings in order to better understand the specific phenomenology of their wear process. This opportunity resides in the common use and availability of selected car in this study, as well as of its common engine. The operation of exchanging the piston rings is often applicable to engines after few hundred thousand kilometers in use or even earlier if the operating regime is higher (in the range of full loads).

By knowing the wear process specific evolution and by understanding the mechanical efforts applied on the surfaces and parts of the piston ring from the analyzed engine of Ford Focus it may be assessed the technical state of the entire engine or even the whole motor-car.

The second compression piston ring was took into detailed consideration in order to highlight the wear process, the critical wear area, to obtain some insight related to the working and wear evolution, as well as digital inspection of the wear parameters.

In figure 3 is shown the simplified model of the second compression piston ring from the analyzed Ford engine.

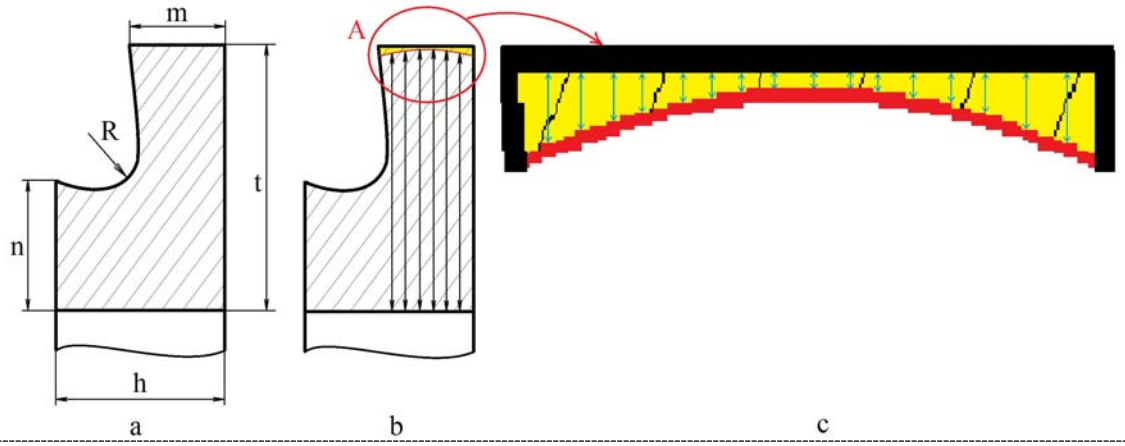

Figure 3. Simplified section cut through second compression piston ring from the Ford Focus FYDD engine.
a-dimensions; b-analyzed wear area; c-main wear zone; A-critical area detail.

The present paper shows the possibility of implementing an advanced method of digital evaluation and inspection of automotive mechanical components in order to improve the data acquisition and development process, as well as design of those parts.

2. Methodology and materials

2.1. Methodology

By analyzing the construction, considering the materials and design which were inspected or determined in the study, respectively by using the computer aided scanning and evaluation, it may be understood and interpreted the wear-ness level, as well as its evolution peculiarities. The present paper points out an engineering method for computer aided piston-ring evaluation and analyze in the field of physical wear-ness concerning the spark ignited engine in service. The researched and evaluated case is a real Ford Focus FYDD spark ignited engine, and was brought to be analyzed with precise methods by use of latest technology. An innovative method of advanced engineering analyze was put at work, using Digimizer application in order to inspect the piston ring surface. The correlation between computer processing power and piston - ring evaluation effort is mentioned.

First, there are some basic measurements of piston rings. Secondly, image capturing on test bed. Thirdly, software analyze of wear zone with Digimizer.

2.2. Materials

The present paper takes into close consideration a motored vehicle available at the Technical University from Cluj-Napoca in order to outline the possibility of digitizing and inspecting very closely the wear area. There were used devices and apparatus such as cameras and graphical processing units in order to improve data analyze from the piston ring cut section.

The graphic and image recording camera was placed close to the piston ring supporting bench. Both the camera and test bench were kept steady still while the proper image was taken and properly transferred to processing unit to further develop the analysis and wear inspection.

Using the Digimizer application (often and commonly used till now in medicine and biology) in automotive field is already an innovation by its own, but the present work takes the analyzing process to a new level by making progressive steps concerning the wear process evaluation and wear area inspection with mechanical, digital and graphic tools.

Figure 4 shows the some of the significant components that are considered in first stage of practical experimentation due to the necessity of starting with measured data.

Figure 4. The first stage of measurement.

2.3. Mathematics and calculus

When the rings are installed on the piston and in operation there are some peculiar efforts and specific forces that applies to them which have to be considered in order to determine the causes of their degradation and lack of performance in operation.

The main effort in a piston ring is bending, when the maximum stresses appear in the external fiber, which determines the maximum bending torque during the operation time through middle fiber radius (r_o) and the surface pressure [5] which influences the dynamic rim wear in engine's operation:

$$M_{max} = 1.742 \cdot p_{em} \cdot r_o^2, \tag{1}$$

where: M_{max} is maximum torque generating the bending effort, in Nm; p_{em} – medium elastic pressure, in bar; r_o – middle fiber radius, in m.

Calculating the elastic pressures (that press the piston ring on the cylinder influencing the wear force and the rim slit) with the following mathematical model [5]:

$$p_{em} = 0.15E \frac{S_o / t}{\left(\frac{D}{t} - 1\right)^3 \frac{D}{t}}, \tag{2}$$

may be determined the basic bending effort in operation as follows:

$$\sigma_{f\,max} = \frac{M_{max}}{W} = 1.242 \frac{E \cdot S_o / t}{\pi D \left(\frac{D}{t} - 1\right)^3}, \tag{3}$$

where: W resistance modulus of the cut section; S_o – clearance between ring ends when free (unrestraint); t – radial thickness of piston ring; D – cylinder diameter.

Shear stress which is generated when installing the piston ring between the piston and the cylinder does not depends on the ring height, but make a significant difference in rim wear evolution.

When installed inside the engine cylinder the piston ring takes a stress given by the following relation [5]:

$$\sigma_{m\,max} = \frac{4 \cdot E \cdot \left[1 - \frac{S_o / t}{2{,}804 \cdot \pi}\right]}{\pi \frac{D}{t} \left(\frac{D}{t} - 1{,}4\right)^3}. \tag{4}$$

3. Experimental setup and protocols

3.1. Experimental setup protocol for testing and measurement

In order to achieve the desired and targeted applied results and to develop some interesting conclusions in relation with the practical measurements and Digimizer mapping of wear area in an effort of implementing the advanced and innovative engineering method in studying piston ring post-operation state and phenomena in a specialized research I.C.E. Laboratory of the Technical University from Cluj-Napoca there was designed and implemented a test bed represented simplified in figure 5 and also was configured a digital processing station for software applied research as in figure 6.

Figure 5 shows the basic model in the image capturing process when implementing the fundamental idea of the present work.

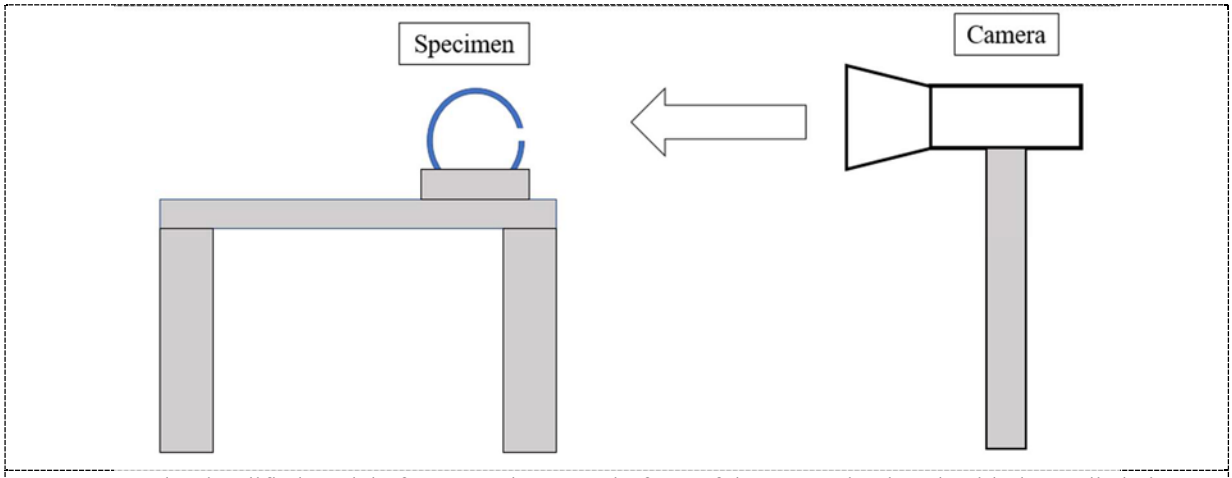

Figure 5. The simplified model of camera placement in front of the supporting bench with the studied piston ring.

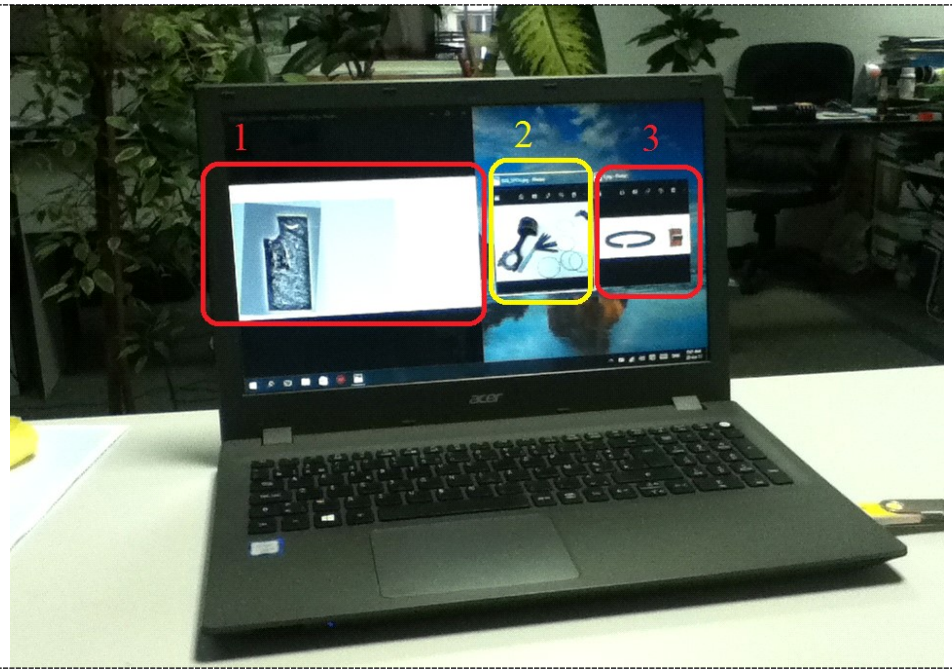

Figure 6. Post-operation processing unit used for data analyze and information storage.
1-Digimizer interface; 2-obtained data through practical measurements; 3-CAD for modeling the piston ring.

3.2. Experimental results and observations

Wear area of piston ring end parts may be determined specifically in each particular case after the engine was dismantled and components were separated and measured in order to get precise measured data necessary for digital processing phase. After measuring the piston rings in the present case and after taking the adequate image capture with the image recording camera (as it is shown in figure 5) a specialized software is used in order to determine the precise wear area according to the figure 7 and figure 8.

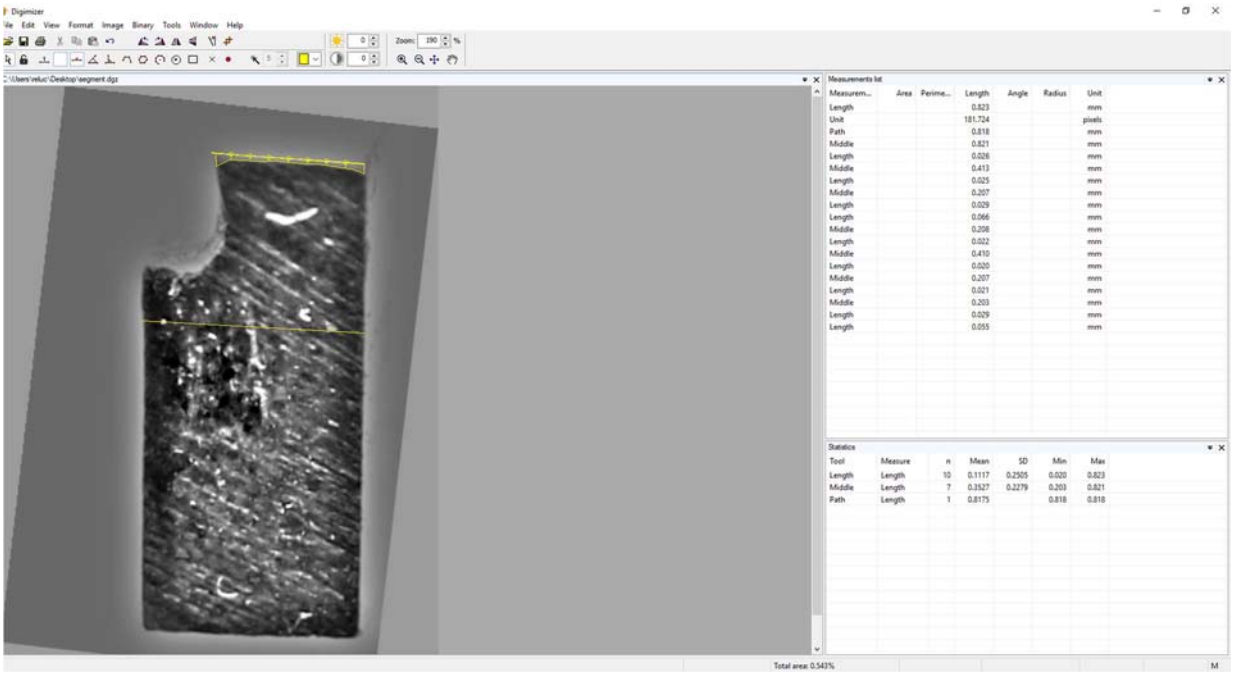

Figure 7. Digimizer interface with measurements and data concerning wear area of piston ring.

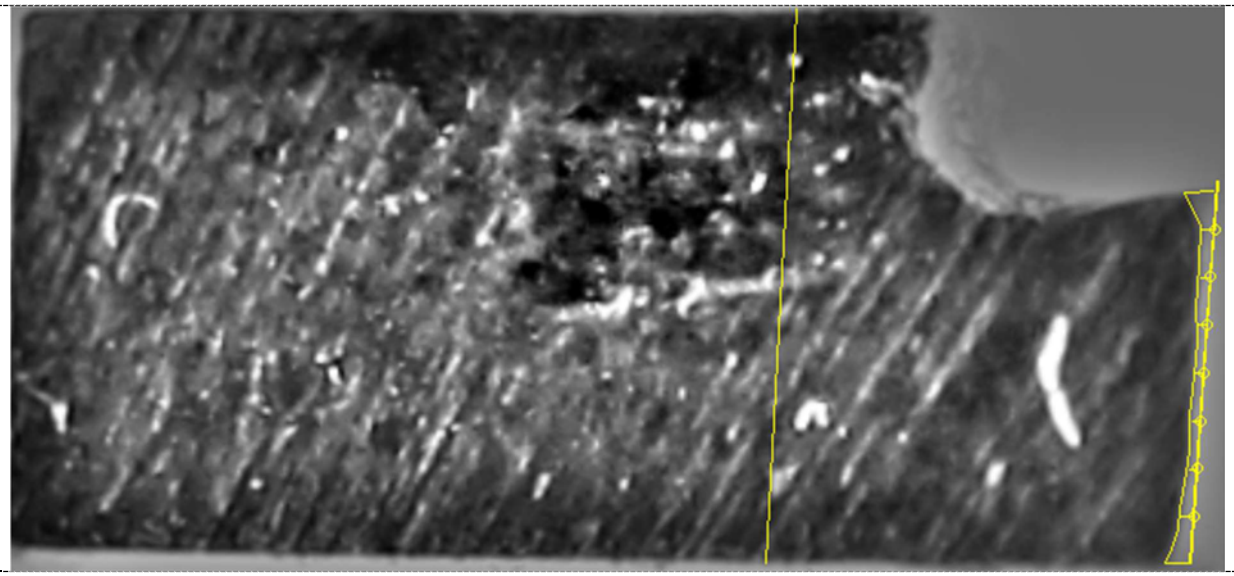

Figure 8. Detailed image capture of piston ring section cut with Digimizer advanced method of critical wear area determination

By defining up a computer assisted graphic content analysis model and determining the primary dimensions of wear area which may give consistent information about the piston ring damage, as well as precise data about the surface deposits and post operation state there were obtained the points and measurements represented schematically in figure 9, being caused by the oscillating movement of the piston ring. The vehicle technical specs are considered in simplified form as presented in table 1.

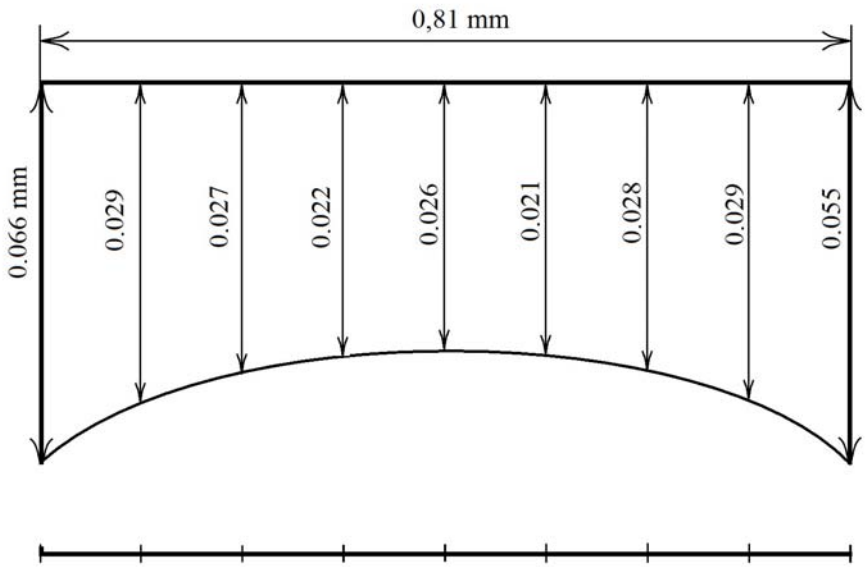

Figure 9. Measuring points and results on the simplified model wear area obtained in Digimizer application through software graphic content advanced analysis.

In a detailed analysis of the wear area of the end part from compression piston ring has a particular shape influenced both by the elastic pressure and the translation, which may be considered in order to formulate a comprehensive theory concerning the wear process in engine operation and to extend the knowledge on the other piston rings.

Table 1. Technical specs of tested motor-car.

Parameter	**Actual Value**
Manufacturer	Ford
Model	Focus
Type	FYDD
Engine displacement	1600 cm^3
Fuel type	Petrol
Number of valves	16
Code	DNW
Nominal power	74 kW
Diagnosis interface	OBD 2

3.3. Limitations of the proposed study

The present study is limited to the implementing of the new engineering interdisciplinary method between computer aided scanning evaluation for piston rings and automotive classic applications, but it may be used in other systems as well, for analyzing the engine components and other systems.

3.4. The novelty of the achievement

The authors are experienced in solid state phenomena, finite element method, manufacturing engineering, rapid prototyping, alternative technologies in manufacturing and computer aided

technologies. The consideration of piston - rings evaluation aspects in real conditions presents a development of research capacities and interdisciplinary study. Even if there were also studied in the previous works some aspects related to Ford Focus FYDD engine, this is the most complete research of many advanced aspects that define piston - ring evaluation and advanced engineering computational methods based on today processing power available at Technical University from Cluj-Napoca.

In figure 10 is presented the virtual model of the piston ring which was considered in the present analyze in order to point out the critical wear location.

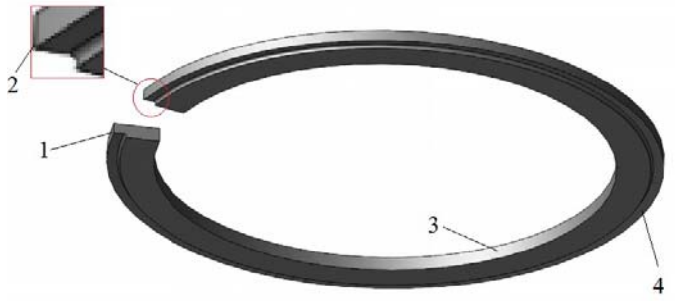

Figure 10. Virtual model of the piston ring that was studied and analyzed with Digimizer and by applying the modern advanced methods.

1-cut section end of piston ring; 2-detail with the critical wear area; 3-interior surface; 4-cut canal for oil scraper.

4. Conclusions

Defining the analysis methods in automotive and internal combustion engines field is close related to the applied science research. Piston - ring parameters are not interacting alone as sole factors in the cylinder and combustion chamber assembly. A piston – ring should be considered in relation with the complex assembly consisting in the cylinder liner, piston itself, con-rod and cylinder-head, which is a thermo-dynamic environment. The causes that determined the rim profile presented in Figure 9 consist in cyclic dynamic stress and high combustion pressures. The wear aspects of the piston-rings have a major influence in the operation or control of the internal combustion engines, but in the same time they lead to a more profound financial impact when it comes to maintenance and repairing processes. In conclusion, the results facilitate the development of an easy-to-use method of wear determination and its causality. Further developments are necessary concerning piston-ring wear and tear-off analysis, rotated with 90°, as well as numerical modeling with finite elements method. Innovative capabilities are very important in order to stimulate and generate other studies of the problem concerning the wear process and critical area in the case of piston rings and engine components.

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