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CAD/CAM/CAE, reverse engineering, the internal combustion engine

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CRANK-PISTON MODEL OF INTERNAL COMBUSTION ENGINE USING CAD/CAM/CAE IN THE MSC ADAMS

Abstract

The article presents the modeling and simulation of the crank-piston model of internal combustion engine. The object of the research was the engine of the vehicle from the B segment. The individual elements of the gasoline engine were digitizing using the process of reverse engineering. After converting the geometry, assembling was imported to MSC Adams software. The crank-piston system was specified by boundary conditions of piston forces applied on the pistons crowns. This force was obtain from the cylinder pressure recorded during the tests, that were carried out on a chassis dynamometer. The simulation studies allowed t determine the load distribution in a dynamic state for the selected kinematic pairs.

1. INTRODUCTION

Nowadays there is growing competition between car and engine manufacturers. This race generates a need to shorten the time needed for the construction and the design phases of the products. In the case of an analytical approach to the design, there is possibility to save time and costs of products production. This way is presented in the article Czyż & Magryta (2016), Wendeker & Czyż (2016)

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where the loads acting on the drive unit of an unmanned helicopter during special maneuvers has been studied. However, there is no way to compare analytical results with the actual behavior of the products. On the second side, the experimental approach involves the development of a prototype or a series of prototypes. For this method, you can record the most accurate results and get the highest costs. Both approaches can be integrated into a hybrid method. This can be achieved through a combination of analytical calculations and simulation research of prototypes. Such actions, limited the duration of the measurements and their costs. In case of an experienced researcher, you can get results at a similar level to real studies. Properly built solid model makes it possible to analyze its mechanical properties in the states of static and dynamic operating conditions, which translates into a large number of design solutions before building the final model (Apanowicz, 2002; Chang, 2014; Ionescu, 2007; Troncossi, Ricci & Rivola, 2011).

2. MSC ADAMS SOFTWARE

To determine the mechanical load response of the crankshaft main bearings of the engine, the MSC Adams simulation software was used. Multibody environment allows for simulation of dynamic phenomena. It allows the determination of the parameters of kinematic mechanisms. It allows to analyze the distribution of forces in the nodes of kinematic pairs, at any time step. The software makes it easier to modify and optimize the performance of the designed products. In addition, MSC Adams allows to perform simulation tests of prototypes and their components. There is a possibility of solving kinematic, dynamic, static and quasi-static equations. (Balyakin & Kosenok, 2015; Hroncová, Binda, Šargaa & Kicák, 2012).

Simulation studies starts by drawing a solid model in a software module or by importing the finished geometry from the CAD (*Computer Aided Design*) environment. Solid models or entire assemblies can be imported from software such as *Catia*, *Inventor*, *Solid-Works*, *ProE* or *Unigraphics*. The *MSC Adams* software can import geometry format like: *STEP*, *IGES*, *DXF*, *Parasolid* and others. The individual elements of the simulated mechanisms may be subjected to static or dynamic loads in the form of a concentrated force or continuous loads. In addition, you can simulate the static and dynamic friction or elements contact properties. While the results of the simulations are stored in a transparent manner in the form of a graphic or numbers. (Biały, Wendeker, Szlachetka & Magryta, 2013; Tomić, Sjerić & Lulić, 2012).

3. OBJECT OF STUDY AND RESEARCH METHODOLOGY

The object of the research was the crank-piston system of internal combustion engine, codenamed *A14XER*. This drive unit is mounted in passenger vehicles of B segment (e.g. *Opel Corsa D*). It is a four-cylinder engine with Otto work cycle. The unit is equipped with a multi-point injection system. In addition, the engine has a variable geometry of intake system and has infinitely variable valve timing. Basic specifications of *A14XER* engine are summarized in table 1.

Tab. 1. Specifications of *A14XER* engine („Opel diagnostyka", 2017)

Parameter	Value	Unit
Name	*A14XER*	[ ]
Displacement	1398	[cc]
Configuration	I4	[–]
Bore / Stroke	73.4 / 82.6	[mm / mm]
Compression Ratio	10.5 : 1	[–]
Power	74 at 6,000 rpm	[kW]
Torque	130 at 4,000 rpm	[Nm]
Number of valves	16	[ ]
Emission	EURO5	[–]

The methodology of digitization of the crank-piston *A14XER* engine is described in the next section. The model was loaded with a piston force. This force was obtained on the basis of the investigations of vehicle equipped with discussed unit. The study was conducted on a *Maha FPS 3000* chassis dynamometer. This device allows to simulate road conditions for a number of urban cycle and measurement of maximum power. In addition, chassis dynamometer allows to determine the flexibility of the engine, checking the speedometer and a number of other parameters. (Bukovan, Jakubovicova, Sapieta & Sapietova, 2017; Kolator & Janulin, 2014). Figure 1 shows the A14XER engine.

Fig. 1. Research *A14XER* engine ("Gmpowertrain", 2017)

The pressure in the combustion chamber was recorded during the test bench tests. It was realized by using individual fiber optic pressure sensors from *OPTRAND* company. The sensors were placed in the spark plug, individually for each cylinder. The in cylinder pressure was recorded at a constant rotation speed of the crankshaft (1,500 rpm) and constant load (constant pressure in the intake manifold 90 kPa). The figure 2 shows the single characteristics of averaged cylinder pressure.

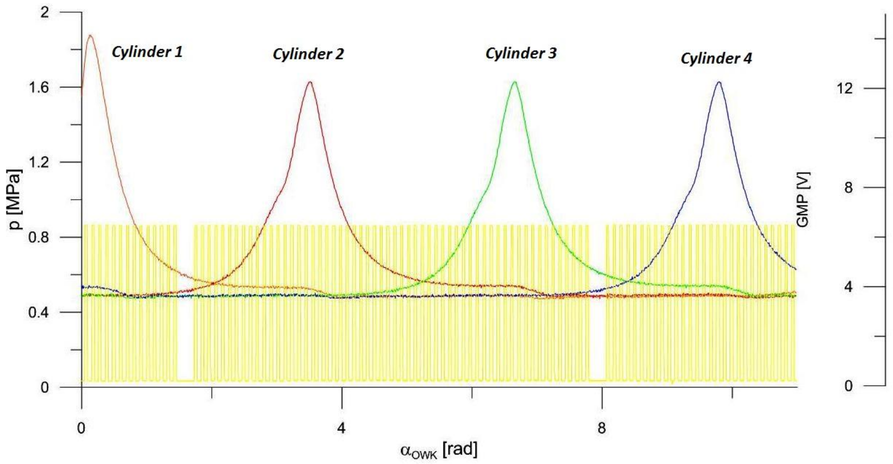

Fig. 2. The characteristic of cylinder pressure and TDC mark

4. DIGITALISATION OF THE CRANK-PISTON SYSTEM

The process of simulation tests of the *A14XER* engine using *MD Adams* software consisted of the following steps:

- surface scanning with the use of three-dimensional scanner,
- model preparation (geometry import, applying of the material characteristics, applying of degrees of freedom),
- applying the load force from the gas to each of the pistons in the form of a concentrated force; course of effective pressure for the full working cycle of the engine (Sun & Zhang, 2017).
- linking of the load value with the angle position of the crankshaft (Zhenga & Zhou, 2014),
- export of research results to a graphical or tabular form.

The virtual model of all components of the crankshaft-piston engine system was developed based on actual parts. In the first stage, using a handheld *ZScanner® 700* scanner (Figure 3), the surface of the points cloud was digitized.

This handheld scanner, due to its ability of movement relative to the object, allows one to scan the interior of an object so that the inner surface is generated. (Czyż, Kayumov & Montusiewicz, 2015).

Fig. 3. Handheld laser scanner *ZScanner® 700*

Then, based on the points cloud, the three-dimensional model of the crankshaft piston engine was created in *Catia v5* software. The components were developed in the form of the solid elements using the Part Design module. While the assembly of a whole unit was made using the Assembly Design module. The model of the crankshaft-piston system in *Catia v5* is shown in figure 4.

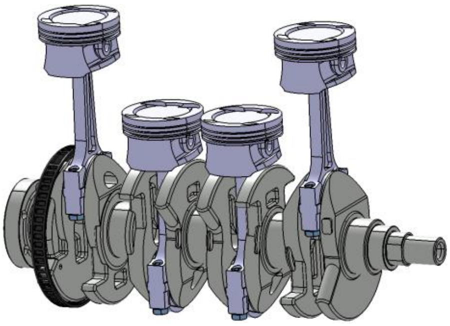

Fig. 4. Model of crankshaft-piston system in *Catia v5*

CAD model of the crank-piston system contained the following elements:
- crankshaft,
- four connecting rods with the bottom parts and screws,
- four piston pins,
- four pistons.

5. MSC ADAMS SIMULATION STUDIES

Developed three-dimensional solid model of the crank-piston system was exported from *CAD* to *MSC Adams* software. Due to the lack of a uniform data format between the two programs, an intermediate geometry translator was used. The exported model in *STEP* format (from *CAD*), was converted and imported in the form of *parasolid* to the *Adams View* module (figure 5).

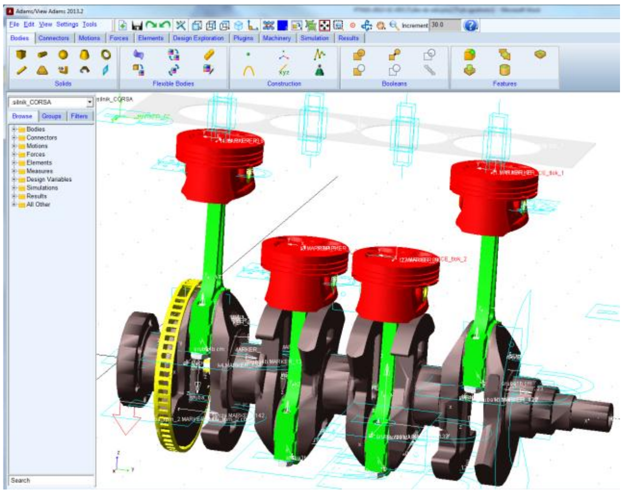

Fig. 5. Windows screenshot of *MSC ADAMS* software from the Adams-View module

Then specific data for all elements of the assembly were set up. Mass and material properties (Stojanovic & Glisovic, 2016) were added (table 2).

After defining characteristic data for the individual components, the process of receive degrees of freedom from kinematic pairs started. In the model we can see such pairs as rotation of: pin main shaft, rod bearing, planar motion of the piston relative to the cylinder and et cetera. For this purpose, the following features were used:

- revolute joint – to simulate the rotation,
- translation joint - to carry out reciprocating motion,
- fixed joint - in order to restrain the elements in relative motion, e.g. to the connecting rod bearings.

Tab. 2. Material properties

Name	Number	Mass	Young's modulus	Poisson's ratio
	[units]	[kg]	[N / mm^2]	[ ]
Crankshaft	1	9.4408	$2.07 \cdot 10^5$	0.29
Connecting rod	4	0.3261		
Cover rod	4	0.0908		
Piston	4	0.3026		
The piston pin	4	0.0695		
Bolt rod	8	0.0166		
Disk	1	0.2725		
Bolt disk	3	0.0034		

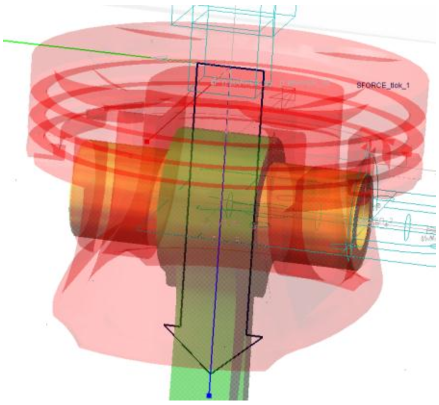

Fig. 6. Added load in the form of a concentrated force resulting from effective pressure

Before the last stage of the model preparation it was necessary to add piston forces. Those forces were calculated on the basis of the pressure measurement and in the combustion chamber. The forces were added for individual pistons, to each piston crowns. Added load in the form of a concentrated force to one of the pistons is shown in figure 6.

At the last stage, the piston forces value were related to the angle of rotation of the crankshaft. For this purpose *Akima function*, type *AKISPL* was used. The *AKISPL function* uses Akima spline interpolation to return the y values for the x variable input through the spline entity. It uses spline curve in x–y direction and linear interpolate in x-z direction. (*Basic ADAMS Full Simulation Training Guide*, 2001; “MSC Software”, 2017; Sun & Zhang, 2017).

6. RESEARCH RESULTS

Simulation tests were carried out for a fixed crankshaft rotational speed and constant load (represented by the constant pressure in the intake manifold). Simulations were realized for several consecutive cycles of the engine work. In figures 7 and 9, the results of research simulation are shown.

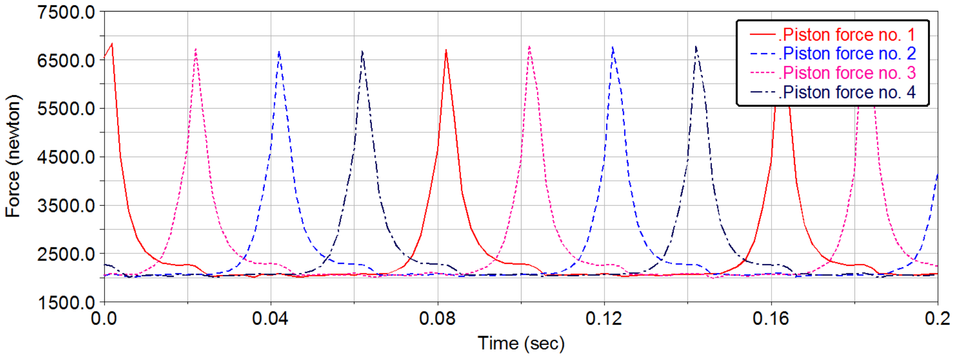

Fig. 7. Load characteristic of the piston force

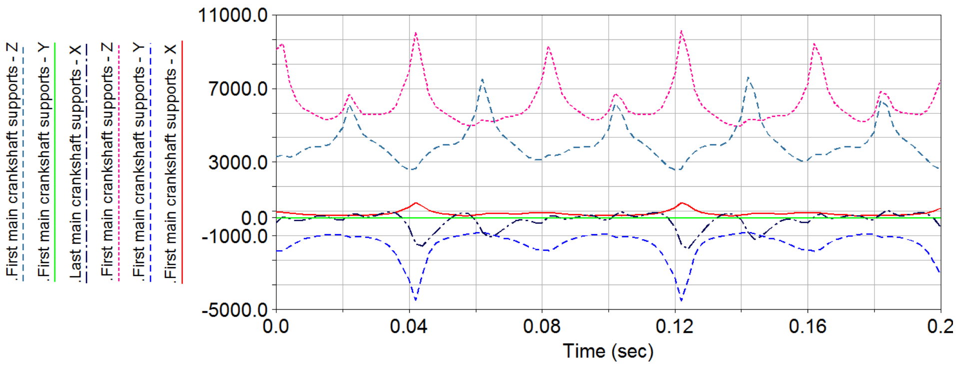

Fig. 8. Load characteristic of the main crankshaft supports (first and last)

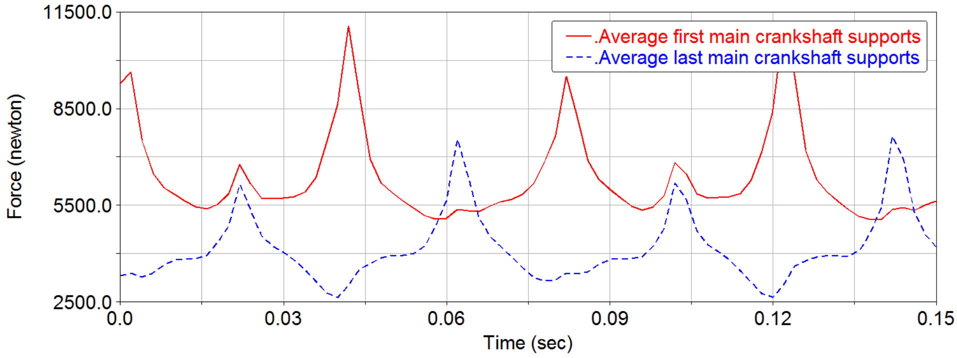

Fig. 9. Average load characteristic of the main crankshaft supports (first and last)

7. CONCLUSIONS

Simulation studies confirm the benefits of hybrid research. The cost of hybrid testing is significantly reduced as compared to the real tests. Besides of the purchase of software, the hybrid tests does not require the construction of a measuring station equipped with measurement and control equipment. There is no need to purchase a number of samples, filling the media (fuel, oil etc.). Furthermore, there is a time shortening. The model construction using scanning process and *CAD* modeling lasts from a few to dozen days (depending on the complexity of the model). The biggest difficulty in modeling, becomes the choice of materials and factors characteristic for solid parts e.g. the selection of the parameters of friction in the kinematic nodes.

On the basis of performed simulation studies, the load of the crankshaft of the internal combustion engine was determined. This load is transmitted further into the engine body, and then, via flexible supports to the bodywork of the vehicle and consequently to the passenger area. Knowledge of the course of load spectrum transferred from the engine to its mounting points allows for the selection or design of the new flexible elements. A further phase of work involves the selection of stiffness and damping parameters of supports for such an internal combustion engine. It should be noted that the simulation studies were carried out only on the basis of several successive cycles of engine operation in a steady state. However, the primary objective of the studies was to present the ideology of the model development of the crank-piston system from the internal combustion engine.

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