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# THE NONUNIFORMITY OF THE PISTON MOTION OF THE RADIAL ENGINE

**Abstract**

*The results of kinematic analysis of the ASz-62IR radial engine crankshaft was presented. In addition, the one-dimensional model of the working cycle of the engine was created in AVL BOOST system. Differences in the waveforms for each pistons causes the differences in the filling process what reflects in the mass of the load supplied to cylinders. Additionally, due to one dimensional model computation. The results show differences in the value of maximum pressure. This causes differences in mean effective pressure of up to 4% and which also affects the vibrations of the whole engine.*

## 1. INTRODUCTION

The radial engines are used in aviation for a long time, mainly due to the simple design, high reliability and low purchase and operation costs. There used to be a source of power system in most aircrafts. Gradually, they has been replaced by gas turbine engines, however, they are still used in certain groups of aircraft, including airplanes used in agriculture and by firefighters and they are still produced. This is mainly due to the relatively low costs of production, operation, reliability and simple surveys of those radial engines. They are still ongoing works to improve their performance. An example is ASz-62IR engine (Fig. 1) produced by the Polish Aviation Company PZL Kalisz and mounted in the M-18 Dromader and An-2 aircrafts, in which the carburetor has been replaced by fuel injection system into inlet pipes. This allows to fuel consumption reduction. The system also enables to supply the engine with an automobile petrol. Comparison of the performance of an engine running on different fuels is presented by Czarnigowski, Jakliński, and Wendeker (2010).

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One of the major disadvantages of radial engines are high value of vibrations. They cause rapid wear of engine parts and load to aircraft design. One of the vibration causes is nonuniformity of individual cylinders of the radial engine, which is due to its specific structure. Works on the diagnostic method of this phenomenon, based on statistical nonlinear analysis of time series in radial engine were conducted by Gęca, Litak, Wendeker, Jakliński, Czarnigowski, and Pietrykowski (2009). This phenomenon, combined with the specific construction of the engine, results in an uneven heat load in the cylinders (Tulwin, 2016), and (Pietrykowski & Tulwin, 2015). However, the literature does not explain the impact of this phenomenon on the engine work process. This was the motivation to explain this phenomenon.

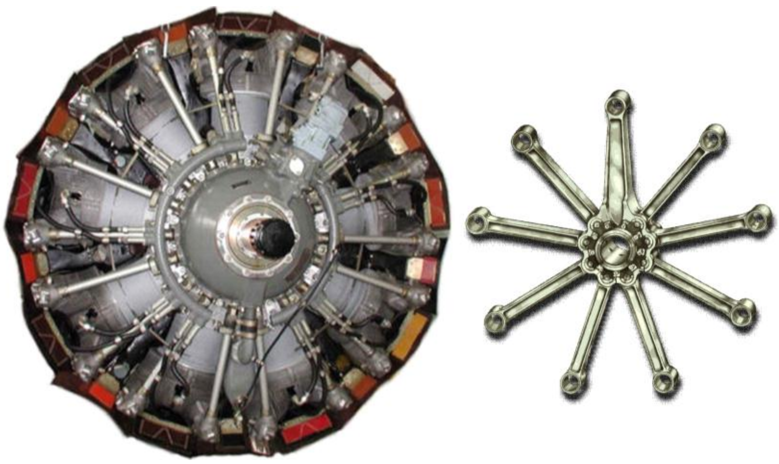

**Fig. 1. AS-62IR engine and assembly of connection rods**

The object of the research is a 9-cylinder aircraft radial engine named ASz-62IR. The engine is air-cooled and supercharged by radial compressor. Engine performance data are shown in Table 1.

**Tab. 1. ASz-62IR engine performance**

| | |
|---|---|
| Power | 746 kW (1000 HP) 2200 RPM |
| Compression ratio | 6.4:1 |
| Fuel consumption | about 200 l/h |
| Specific Fuel Consumption | 469 g/(kWh) |
| Power/Mass | 1.3 kW/kg |

## 2. PISTON MOTION MODELL

### 2.1. Piston motion equation

In radial engine, determination of the piston position is easy for the first piston, since the main connecting rod (master rod) is connected directly to the crankshaft, as in most piston engines. The situation becomes more complicated, when we consider the motion of the other pistons of a radial engine, whose connecting rods (articulated rods) are connected to the master rod.

To mapping of the motion course of the individual pistons with the specific characteristics of the radial engine crank-piston system uses the equation (1) developed by Sibert (1940). It should be noted that the formula provides for simplification of the angle $\alpha = \beta$, and relationship $l + r = L$ does not have to be fulfilled. These assumptions are correct for the ASz-62IR engine.

Figure 2 shows a kinematic diagram of the master rod and one of the articulated rod. Point O is the center of the crankshaft, P and P' are the pivot points of connecting rod little end, C and C' are the pivot points of connecting rod big end. Line OP'= S', is the search position of piston pin of any of the pistons. Then, as shown in Figure 2:

$$S' = R\cos(\theta - \beta) + r\cos\varphi + l\cos\varphi' \tag{1}$$

Equation (1) was used to calculate S' as $\varphi$ and $\varphi'$ can be determined from the relationship:

$$L\sin\varphi = R\sin\theta \tag{2}$$

$$l\sin\varphi' = R\sin(\theta - \beta) + r\sin\varphi \tag{3}$$

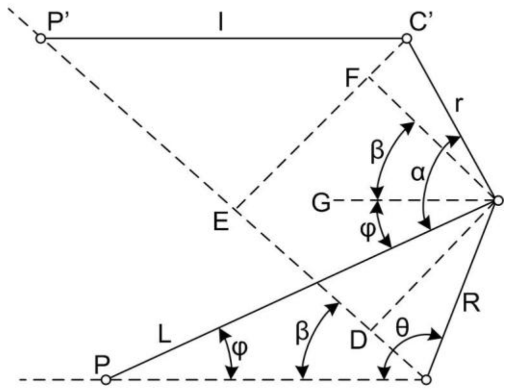


**Fig. 2. Scheme of crank-piston system (Sibert, 1940)**

In order to perform the calculations, it was necessary to add parameters of the model. They result from the dimensions of the crank-piston system of ASz- 62IR engine. They were obtained from the technical drawings of elements of the crank-piston system and shown in Table 2.

**Tab. 2. The dimensions of the ASz-62IR engine crank-piston system**

| Cylinder no | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| R [mm] | 87.25 | 87.25 | 87.25 | 87.25 | 87.25 | 87.25 | 87.25 | 87.25 | 87.25 |
| l | 349.25 | 274.62 | 274.62 | 274.62 | 274.62 | 274.62 | 274.62 | 274.62 | 274.62 |
| r [mm] | 0 | 76.098 | 77.792 | 76.961 | 75.002 | 75.002 | 76.961 | 77.792 | 76.098 |
| β [mm] | 0 | 40 | 80 | 120 | 160 | 200 | 240 | 280 | 320 |

## 2.2. Verification of the model of the piston motion

In order to validate the analytical model of the pistons motion model, a kinematic model in CATIA v5 was built (Fig. 3). CATIA v5 is a program from a group of CAD (Computer Aided Design) software for creating 2D and 3D geometry models. Sketcher module allows to quickly explore dependences of the geometry in complex physical model. It does not allow to find solutions in the form of analytical equations, but allows to verify them in the selected points. The dimensions of the elements in Figure 3 were taken from Table 2.

The results of calculations for different angles for all the cylinders were compared with the values read from the piston positions of the kinematic model, what showed full compliance of both models. The model can be used to calculate the course of motion of the pistons.

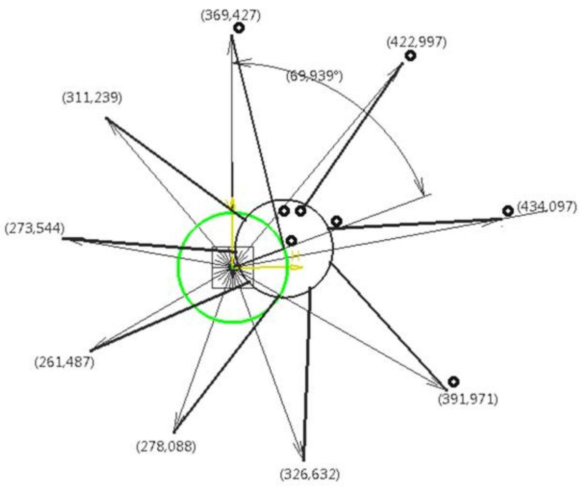


**Fig. 3. The kinematic model of the crank-piston system of ASz-62IR engine**

## 3. 1D ENGINE WORKING CYCLE MODEL

To examine the effect of the crank-piston system geometry on work of radial engine, a 1-dimensional model of the ASz-62IR engine was built in AVL BOOST system. This software is a tool dedicated for 1-dimensional modeling of internal combustion engines. This program uses a zero-dimensional physical modeling, based on the principle of laws of conservation of mass and energy. This approach allows for mapping of the processes in the internal combustion engine and the parameters of the working medium in the cylinder, for the defined conditions, while speeding up the calculations as compared to three-dimensional models. AVL BOOST allows to analyze the impact of design configuration for engine performance (power, torque, fuel consumption, etc.).

AVL Workspace Graphical User Interface is a tool for pre-processing, that includes a model editor and a system for import external data, necessary to simulate and compare results. Model creation is based on choosing the block elements, forming the structure of the engine and connecting them by segments, serving as conductors of circular cross-section. With this approach it is possible to create and modify even the most complex models, consisting of many components.

Engine model (Fig. 4) consists of an intake system, including the compressor, the cylinders and the exhaust gas system. Compressor model includes a map that takes into account the dependence of pressure ratio and efficiency from the mass flow and rotational speed. The dimensions of the flow elements were obtained from the construction drawings of the engine. In order to obtain correct model, the characteristics of valves lift were introduced into the cylinder.

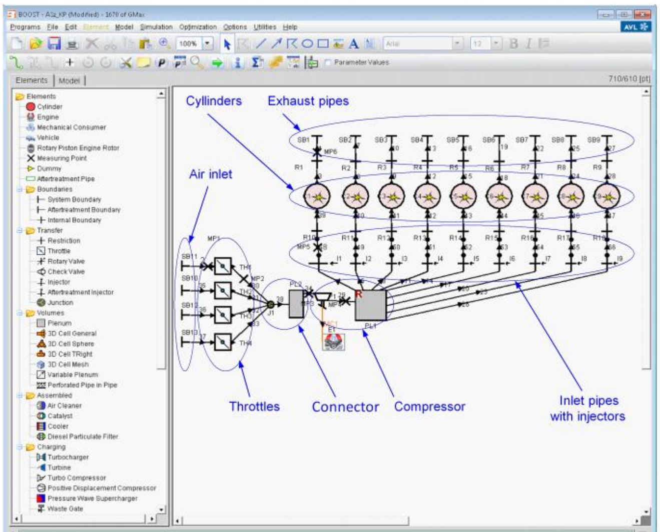


**Fig. 4. 1D model of ASz-62IR engine (Pietrykowski & Gęca, 2014)**

Combustion model was defined using Vibe function (Fig. 5). Model parameters are the same for all cylinders. Detailed description of the engine model is presented in paper of Pietrykowski, and Gęca (2014).

An important function of the AVL BOOST system is the ability to independently define any course of motion of any piston. The motion of the piston of the first cylinder is determined by the software based on the dimensions of the crank-piston system. The other characteristics of cylinders were made using text files containing waveforms calculated by the analytical model.

## 4. RESULTS

### 4.1. Pistons positions

Based on the equations of the piston motion and the dimensions of the ASz-62IR engine crank-piston system (Table 1 and 2), the calculations of ASz-62IR engine pistons motion was made. Figure 5 shows the calculated characteristics of position of the pistons.

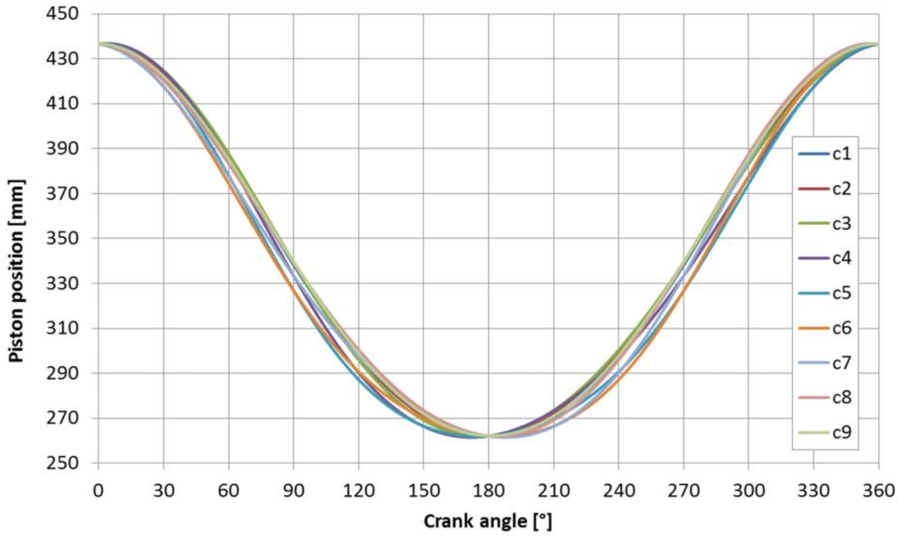


**Fig. 5. Characteristics of position of the piston**

In the drawings 6 and 7 the characteristics of position of the pistons are also shown, however, the scale is adjusted in this way to show the differences in the angles of incidence of the upper and bottom dead center of the piston. The maximum difference between the bottom dead center positions of the pistons is 0.72 mm and between top dead center positions is 0.3 mm. These differences are not large enough to significantly affect the degree of compression or pistons stroke and cause variation of the combustion process in each cylinder. The other situation occurs in the angle value of the top dead center position of the pistons. The maximum difference occurs between the cylinders 4 and 7, and is 7.6 CAD causing a significant shift in ignition timing in most cylinders according to TDC. Moreover, different velocities of the pistons during the filling process can result in different mixture mass provided to the individual cylinders.

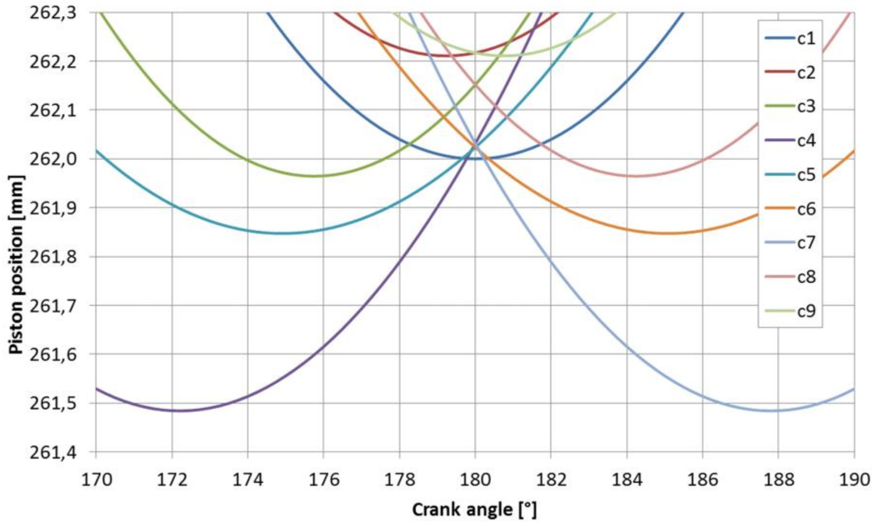


**Fig. 6. Characteristics of position of the pistons (near BDC)**

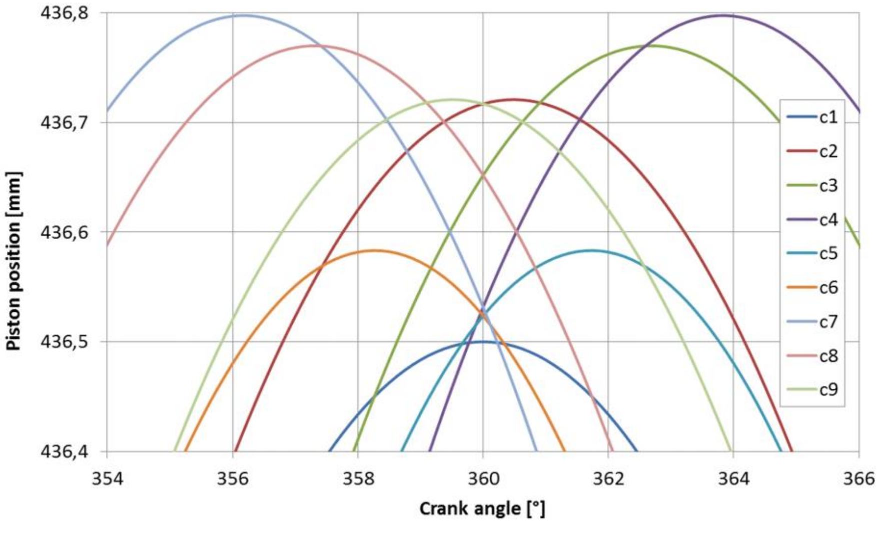


**Fig. 7. Characteristics of position of the pistons (near TDC)**

### 4.2. Engine work process

Figure 8 shows the calculated characteristics of pressure in the cylinders of the radial engine. There were no significant differences in compression pressure, but there are differences in the maximum pressure values. This is a result of different combustion process in each cylinder. This phenomenon can be observe in the radar scheme (Fig. 9) showing the percentage deviation from mean indicated pressure in comparison to the first cylinder. The maximum difference is 4% and occurs between the cylinders 5 and 7.

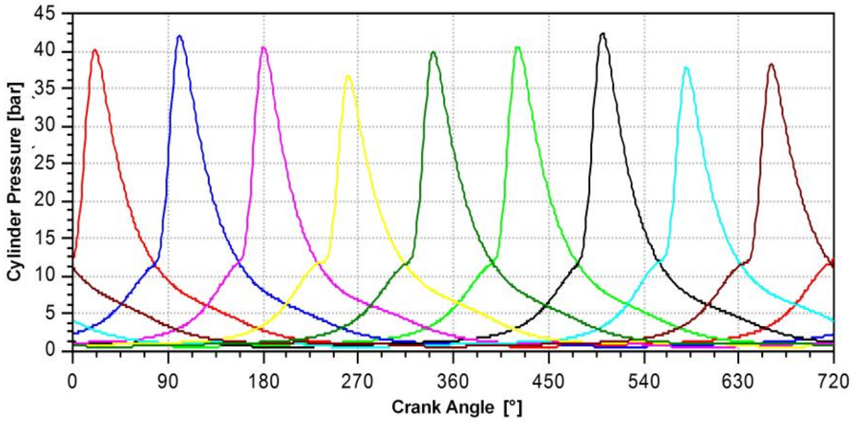


**Fig. 8. Characteristics of pressure in the cylinders**

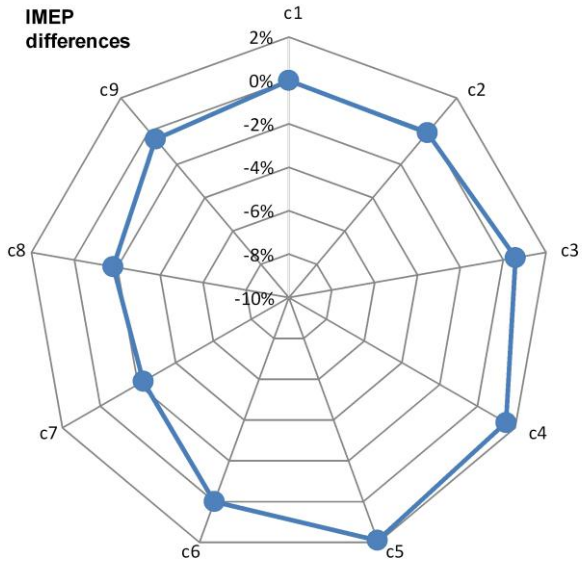


**Fig. 9. Distribution of IMEP for each cylinder**

## 5. CONCLUSIONS

Cylinder-to-cylinder variation in radial engines and resulting vibrations have been known for a long time. Now, advanced software enables us to perform a qualitative evaluation of the impact of rod-crank system's kinematics on engine performance.

The 1D model, built in the AVL BOOST software, allows to quickly perform calculations and prediction of radial engine performance. Software enables to check the influence of the specific crank-piston system on the cylinders pressure. The difference in IMEP are 4%, resulting in variation of power generated by the individual cylinders and contributes to engine vibrations.

This phenomenon can be overcome by individual ignition control in every cylinder. However, this requires a replacement of the ignition system for electronically controlled. Radial engines are fitted with a magneto ignition system which is a simple and reliable solution. Today's electronic solutions also enable the required reliability and regulation of ignition timing for each cylinder and operating conditions to improve engine performance and increase the TBO.

Our further 1D-model research will be for varied ignition timing. There will be also a test bench at a dynamometer.

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