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## ENGINE LOAD IMPACT ON MAXIMUM VALUE OF NORMAL FORCE IN PISTON MECHANISM

Grujić, I.<sup>1</sup>, Stojanović, N.<sup>2</sup>, Dorić, J.<sup>3</sup>, Glišović, J.<sup>4</sup>, Narayan, S.<sup>5</sup>, Davinić, A.<sup>6</sup>

### SUMMARY

*Working machines are an indispensable part of agriculture. Until today, all working machines, as a power engine, use the IC engine. Unlike the engines for the passenger cars, the engines for the working machines are exposed to more extreme working conditions. The normal force is known that have greatest impact on the cylinder wearing, and as such reduces engine life. An experimental determination of the pressure value in the cylinder of the engine was carried out for the cultivator engine. Measurement was performed for three different engine speeds at four different loads. On the basis of the obtained pressure, the values of the maximum normal force that act in the piston mechanism are calculated. As a result it is obtained relation between the maximum value of the normal force and engine load.*

**Key words:** working machines, IC engine, cylinder wearing, cylinder pressure.

### INTRODUCTION

IC engines are most used drive train for agricultural machinery. Agricultural machines are not cheap. It can be safely said that the price of agricultural machines is considerably higher than the prices of some luxury cars. Of course, the reason for this is more than obvious. The specificity of the working conditions of agricultural machinery requires high reliability and an appropriate life cycle duration.

Taking into account that the IC engine is a vital part of agricultural machinery, its reliability greatly affects the life cycle and reliability of the agricultural machinery.

By improvement of IC engines we improve the performance of agricultural machines, which can lead to reduction of impact on environment [1]. So by improvement of IC engines we can also improve their exhaust emission [2].

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In diesel engines, as well as in other piston engines, very high pressures occur in the cylinders during combustion. In the 1970s, peak pressures were in the order of 100 bar, but in modern engines the values have increased to around 180 bar. These high pressures tend to lift the cylinder head. To avoid cylinder leakage, the head is attached to the frame of the engine with tie-rods (see Fig. 1), in which a considerable pre-stress is introduced. The loading of these tie-rods and the required pre-stress are discussed in this example. As the pressure in the cylinder increases during the compression phase of the cycle and reaches a maximum value during combustion, the loading of the tie-rods is a dynamic load (that varies in time) [3].

One of the most common causes of IC engine failure is the wear of the cylinder. Cylinder wear causes that the original cylindrical shape is converted into an ellipse. This is happening because the normal force that occurs in the piston mechanism. The normal force in the piston mechanism, as well as the normal force that acting during the sliding of one part over another, is a component of the friction force [4]. It is generally known that friction is an undesirable phenomenon in any machine assembly, as it directly affects on the life cycle of the assembly in a negative sense. For these reasons, all mechanisms where we have friction must be lubricated in order to reduce friction.

One method of calculating the load of the piston mechanism is the application of mathematical models [5], of course inclusion of friction as a key parameter for the calculation.

The aim of this paper is to determine the impact of the load on the maximum value of the normal force that occurs during the operation of the real engine.

## KINEMATIC AND DYNAMIC ENGINE CALCULATION

In order to calculate the kinematics of the piston mechanism, we will observe the diagram of the non-axial piston mechanism, which is given on Figure 1.

Based on figure 1 we can write next relations:

- Piston displacement  $x_k = \left(\frac{x_A}{r}\right) = \left(\frac{h}{r}\right) - \cos\alpha - \frac{1}{\lambda} \cos\beta$
- Piston speed  $v_k = \left(\frac{v_A}{r\omega}\right) = \sin\alpha + \frac{1}{\lambda} \sin\beta \frac{d\beta}{d\alpha}$
- Piston acceleration  $a_k = \left(\frac{a_A}{r\omega^2}\right) = \cos\alpha + \frac{1}{\lambda} \left[ \cos\beta \left(\frac{d\beta}{d\alpha}\right)^2 + \sin\beta \frac{d^2\beta}{d\alpha^2} \right]$

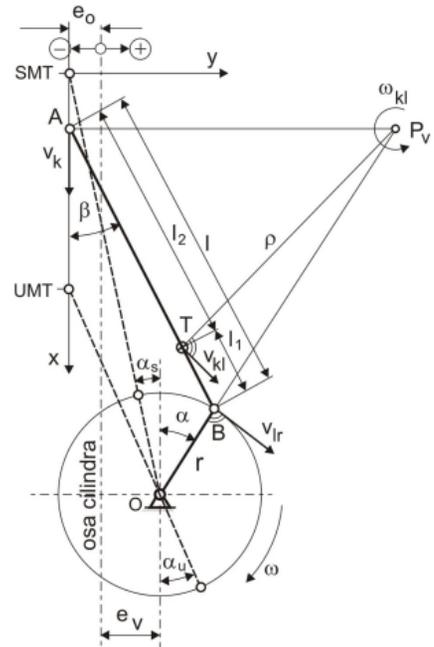


Fig. 1. Non axial piston mechanism

By taking into the account that our engine have axial piston mechanism, relations for piston kinematics now have next form:

- Piston displacement  $x_k = (1 - \cos\alpha) - \frac{\lambda}{4}(1 - \cos 2\alpha)$
- Piston speed  $v_k = \sin\alpha + \frac{\lambda}{2}\sin 2\alpha$
- Piston acceleration  $a_k = \cos\alpha + \lambda\cos 2\alpha$

For calculation of the piston mechanism dynamic's, or more accurate calculation of the forces that are acting in piston mechanism, it necessary to known cylinder pressure. The cylinder pressure is obtained by the experiment that is performed on the real engine. In order to determine the relations for piston mechanism dynamic's, axial piston mechanism (Figure 2) will be observed.

First it is necessary to calculate next forces:

- Gas force  $F_g = (p_g - p_o) \cdot A_k \cdot 10^5$
- Inertial force  
 $F_{io} = -ma = F_{io1} + F_{io2} = -mr\omega^2\cos\alpha - mr\omega^2\lambda\cos 2\alpha$
- Result force  $F_R = +F_g + F_{io}$

It can be noticed that the resulting force is pulled into two forces, connecting rod force and normal force. By using the

trigonometry, we can obtain the equation for the normal force  $N = F_R / \sin\beta$ .

Based on the previous equations, it can be concluded that the most influential parameter for determining the normal force is the cylinder pressure, which will in this case be determined experimentally on a real engine.

### EXPERIMENTAL RESEARCH

Taking into account that the goal of this paper is determination of the load impact on the maximum value of the normal force that occur in piston mechanism, an experiment was first performed. The experiment was performed according to the European stationary cycle shown in Figure 3. The measurements were made for three different engine speeds and four different loads. In this way, the cylinder pressure signal was

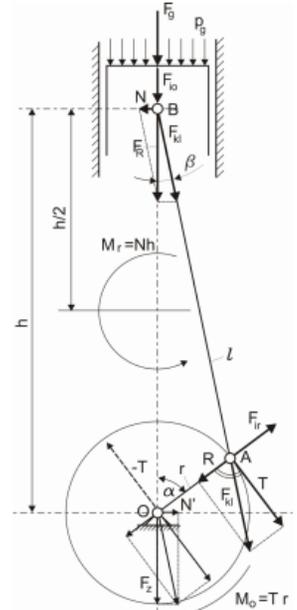


Fig. 2. Axial piston mechanism

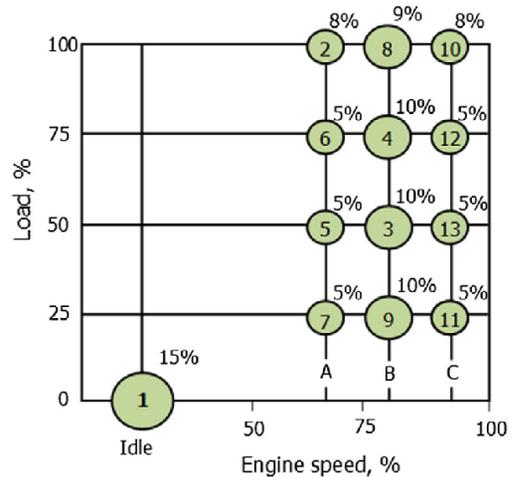


Fig. 3. European stationary cycle

The measurements were made for three different engine speeds and four different loads. In this way, the cylinder pressure signal was

recorded for 12 mode. The thirteenth mode from Figure 3 represents the idle mode which essentially represents the smallest possible mode, and as such it will not be taken into the consideration.

Numbers in circles represent modes, at a certain engine speeds and loads. The engine speeds for points A, B, C are obtained on the basis of the following relations.

$$n_A = n_{N\_30} + 0,25 \cdot (n_{N\_50} - n_{N\_30})$$

$$n_A = 3050 + 0,25 \cdot (1600 - 3050) \tag{1}$$

$$n_A = 1962 \text{ rpm}$$

$$n_B = n_{N\_30} + 0,50 \cdot (n_{N\_50} - n_{N\_30})$$

$$n_B = 3050 + 0,50 \cdot (1600 - 3050) \tag{2}$$

$$n_B = 2325 \text{ rpm}$$

$$n_B = n_{N\_30} + 0,75 \cdot (n_{N\_50} - n_{N\_30})$$

$$n_B = 3050 + 0,75 \cdot (1600 - 3050) \tag{3}$$

$$n_B = 2687 \text{ rpm}$$

Also four load values that are obtained during the experiment are given:

$$w_e = 0.14 \text{ kJ/dm}^3$$

$$w_e = 0.28 \text{ kJ/dm}^3$$

$$w_e = 0.42 \text{ kJ/dm}^3$$

$$w_e = 0.56 \text{ kJ/dm}^3$$

An experimental diesel engine was used for experimental research. It is a monocylidronic engine that is used on a motor cultivator, which belongs to agricultural machines. Engine characteristics are given in Table 1.

The measurements during the experiment are organized, to obtain a sufficient number of parameters for determining the indicating and effective engine parameters. The measurement scheme is shown in Figure 4.

**Tab. 1. Engine characteristics**

<i>Engine displacement</i>	<i>454 cm<sup>3</sup></i>
<i>Number of cylinders</i>	<i>1</i>
<i>Bore/Stroke</i>	<i>85 x 80 mm</i>
<i>Compression ratio</i>	<i>17.5:1</i>
<i>Engine torque</i>	<i>28.5 Nm</i>
<i>Engine power</i>	<i>7.3 kW</i>
<i>Engine speed</i>	<i>3000 min<sup>-1</sup></i>

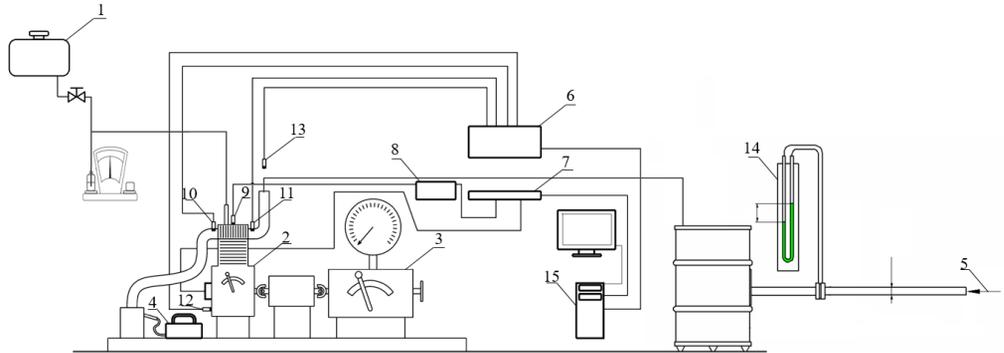


Fig. 4. Measurement scheme

1 – fuel tank, 2 – engine, 3 – dynamometer, 4 – AVL Ditest, 5 – Air flow, 6 – HBM UPM 60, 7 – AVL Indimer 619, 8 – Kistler 5007, 9 – cylinder pressure sensor, 10 – exhaust port temperature sensor, 11 – intake port temperature sensor, 12 – oil temperature sensor, 13 – environment temperature sensor, 14 – U manometer, 15 – PC

By using the experimental installation from Figure 4, the cylinder pressure values are obtained for the 12 required modes. The obtained pressure values were implemented in the previously displayed equations for kinematics and dynamics of the engine and the determination of the maximum normal force for all 12 modes.

## RESULTS AND DISCUSSION

Obtained results for the normal force maximum values in the function of the engine speed, for different loads are given in Table 2.

Tab. 2. Normal force maximum values in the function of the engine speed, for different loads

$w_e/n$	n=1962 rpm	n=2325 rpm	n=2687 rpm
$w_e = 0.14 \text{ kJ/dm}^3$	1.93	1.8	1.79
$w_e = 0.28 \text{ kJ/dm}^3$	2.26	2.14	2.1
$w_e = 0.42 \text{ kJ/dm}^3$	2.58	2.46	2.42
$w_e = 0.56 \text{ kJ/dm}^3$	2.87	2.75	2.74

For easier analysis of the load impact on the normal force maximum value, diagram from Figure 5 will be observed.

By analysing Figure 5, it can be noted that the value of the maximum force increases with load increasing for each of reference engine speeds. It is also obvious that how engine speed increases, the value of the maximum normal force decreases. However, an increase in the speed does not reduce the value of the maximum normal force to the extent that the load increases.

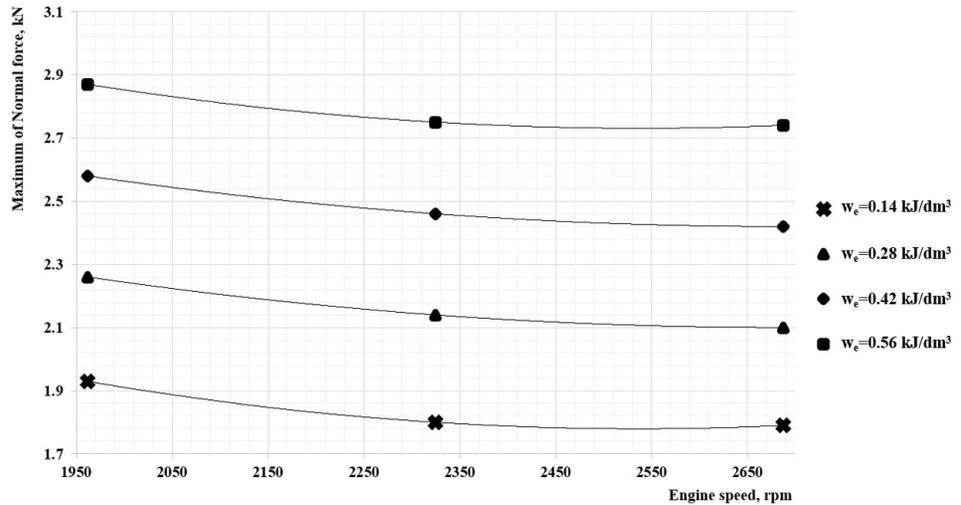


Fig. 5. Normal force maximum values in the function of the engine speed, for different loads

The trend of the change in the maximum value of the normal force can be described by the second-order polynomials that are given in the following relations.

$$N = 5 \cdot 10^{-7} \cdot n^2 - 0.0023 \cdot n + 4.7121 \quad (1)$$

$$N = 3 \cdot 10^{-7} \cdot n^2 - 0.0016 \cdot n + 4.2933 \quad (2)$$

$$N = 3 \cdot 10^{-7} \cdot n^2 - 0.0016 \cdot n + 4.6133 \quad (3)$$

$$N = 4 \cdot 10^{-7} \cdot n^2 - 0.0021 \cdot n + 5.4248 \quad (4)$$

By applying such equations, it is possible to determine on which engine speed will be obtained minimal value of the normal force. Of course, it is generally known that even with the engine it cannot go into infinity, however, we always can tend to some optimal solution. However, by taking into account the obtained values of the normal force in relation to the gas force value, it can be said that normal force is relatively small, and as such a normal force is not dangerous for the engine operation. Of course, it should be taken into account that this force is directly related to the friction in the cylinder, and because of this the wear of the cylinder is unavoidable.

## CONCLUSION

Experimental investigations were carried out in order to determine the load impact on the normal force maximum value. The normal force is an undesirable phenomenon in the piston mechanism that causes the wear of the cylinder, and as such should not be neglected. It was found that how the load increases, there is an increase in the value of the normal force and, consequently, the increasing of the friction force in the cylinder. Of course, the good side is that the engines have lubrication, and in the engine we never have dry friction. In the case of dry friction, the engine failure will happen in incredibly short period, even for very small values of normal force. It was also found that with the increase of the engine speed, the

maximum value of the normal force is reduced. However, of course, the maximum engine speed is limited. For future research it would be interesting to observe the non-axial piston mechanism, since it is known that such mechanisms are designed primarily for the reduction of normal force.

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