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POWER MEASUREMENT OF MECHANICAL LOSSES IN EXPERIMENTAL RECIPROCATING AIR COMPRESSOR IMPACT OF PISTON GROUP

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Abstract: *Power losses in the reciprocating piston air compressors are mainly engaged to overcome friction. Based on the large number of research on internal combustion engines have confirmed that the mechanical losses of piston group parts make up most of the losses related to friction in the engines. Therefore, their reduction has a direct effect on reducing fuel consumption. For research purposes, the sliding surface of the piston and cylinder of aluminium alloy are tribological optimized. In addition to tribological, have carried out and testing of experimental reciprocating compressor on the bench, in the laboratory for engines and compressors in Faculty of Engineering in Kragujevac. Optimization has confirmed by measurement of mechanical losses related to specific effective work with tribological optimized different pairs of piston groups.*
Key words: *Aluminum, friction, mechanical losses, reciprocating compressors.*

1. INTRODUCTION

Starting from the UN Climate Change Conference in Paris 2015 exists a political consensus to start implementing measures for lowering greenhoouse gases (GHG) emissions and against global warming. The European Comission (EC) is working on the measures to reduction of GHG emissions from all sources, too. Specific emission of carbon dioxide (CO_2) from transport sector has limited. The proposed limits are obligatory for new registered passenger cars and light-duty vehicles [1,2,3].

For heavy-duty (HD) vehicles such a regulation exists no in force in the EU. There was not much progress in reduction of fuel consumption and thus exhaust emission starting from vehicle model EURO I (1992-1996) to EURO VI (saince 2013).

Because of the fact that all vehicles must give to reduction of fuel consumption and emission, the EU formed regulation for certification of all new registered HD vehicles. The main idea is to determinate which components of HD vehicles contributing to lowering mechanical efficiency and fuel consumption [4,5].

As a contribution, we researched reduction of power demand of auxiliary devices

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on the engine, specifically in air compressor [6, 7, 8].

The air compressor in brake system of trucks and buses is two-stroke reciprocating machine which delivering air into pressure vessels to feed the consumers as pneumatic brakes, clutch, gearbox and drivetrain, suspension system, actuators at engine, AdBlue injector, if exists inside of the exhaust system etc.

According to above facts, model for the analysis of the compressor power and measurement of the air consumption was given in Fig. 1.

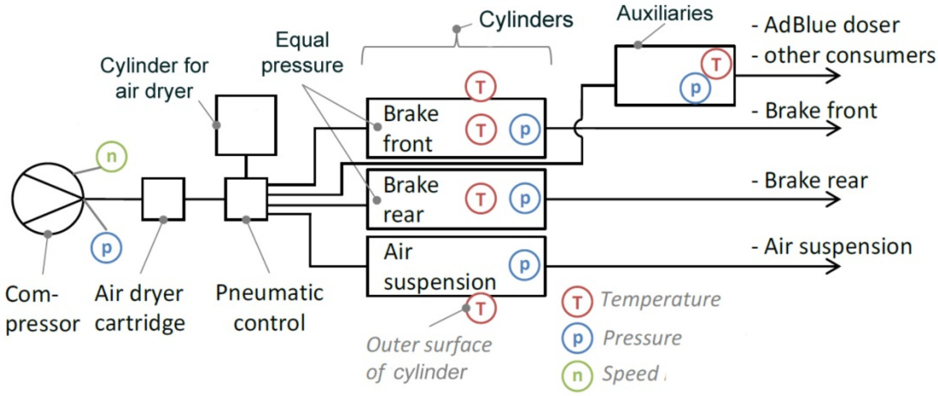


Fig. 1 *Pneumatic system of a delivery truck (category N2)*

In every moment of time, the air mass inside the pneumatic system we will determined by application of the ideal gas law, Eq. 1 and Eq. 2. Air temperature, air pressure and the cylinder volumes were main input values [8].

$$(p \cdot V)_R = R_{s,air} \cdot (m \cdot T_{avr})_{R,air} \quad (1)$$

and,

$$V_{air,tot,std} = \frac{m_{air,tot}}{\rho_{air,tot}} \quad (2)$$

where is:

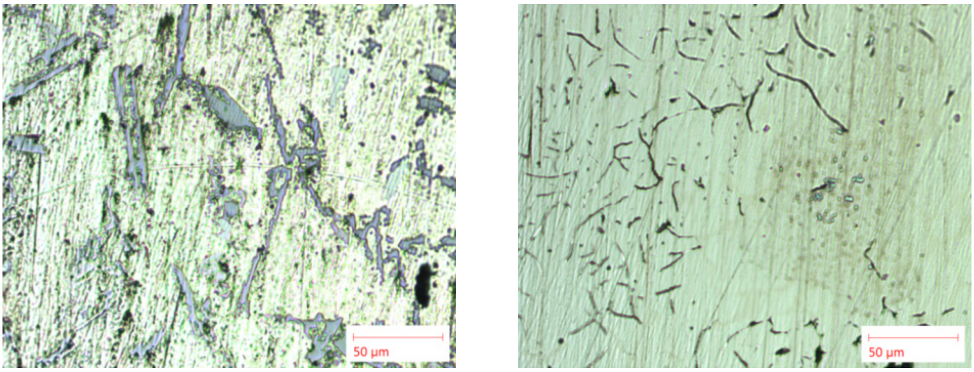
- $(p \cdot V)_R$ - Volume of air cylinder and pressure in cylinder;
- $(m \cdot T_{avr})_{R,air}$ - Air mass and average temperature in cylinder;
- $m_{air,tot}$ - Total air mass, cylinders brake front, brake rear, air suspension system, auxiliaries;
- $R_{s,air}$ - Specific gas constant for dry air, $287.1\, J \cdot (kg \cdot K)^{-1}$;
- $\rho_{air,std}$ - Density of dry air at standard conditions: $(20℃, 1.013\ bar)$: $1.204\ kg \cdot m^{-3}$
- $V_{air,tot,std}$ - Total air content, mass unit of standard litres air; one litre of dry air at $(1\ bar, 20\ ℃)$; $[sl] = 0.001204\ kg$.

The air mass in cylinders need to be calculated in steps of one second with the ideal gas law for dry air. Also being introduced and assumptions that the volume of the cylinders brake front/rear and suspension are equal, and the pressure in the two brake cylinders is equal, too.

2. TRIBOLOGICAL RESEARCHES AND RESULTS

The present work investigate the effect of tribological plugs as reinforcements on tribological behavior of patented aluminum cylinder for use in air compressor [9,10].

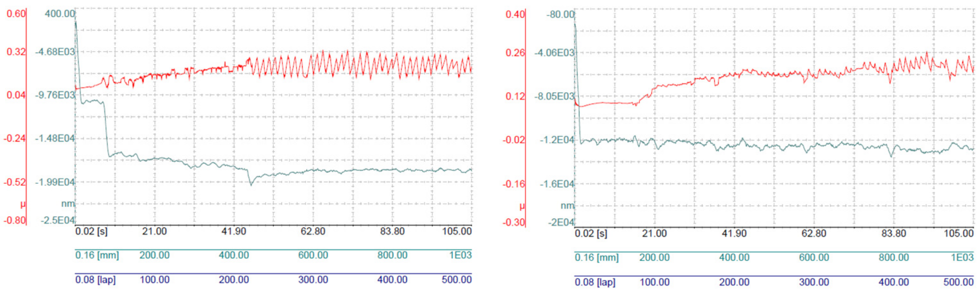
Experiments were carried out with the base material for cylinders (aluminum alloy) and with the material for reinforcements made of cast iron. Fig. 2.a presents optical microscopy of base aluminum alloy surface, where grey phases, which are noted on the surface, presents eutectic silicon. Fig. 2.b presents surface of cast iron nodular discrete pads (reinforcements) [9,11]. Deeper analysis of the presented surface revealed that black lines across the surface are graphite inclusions in cast iron.



a) b)

Fig. 2 *Photography of patented aluminum cylinder with tribological pads (a-continual and b-nodular discrete pads)*

Diagrams of friction coefficient (COF) and penetration depth during reciprocating sliding are shown in (Fig. 3.a) for base material (aluminum) and in (Fig. 3.b) for tribological inserts of cast iron as reinforcements.



a) b)

Fig. 3 *a) COF and PD under* ($F_N = 0{,}9\ N;\ V = 15\ mm \cdot s^{-1}$) *for base material;*
b) COF and PD under ($F_N = 0{,}9\ N;\ V = 15\ mm \cdot s^{-1}$) *for reinforcements; filtered signal*

Under higher load conditions a lower maximum value of COF of the reinforcement was also recorded, too, Fig. 3.a and Fig. 3.b. The obtained COF values range in the range (0.087–0.262) for the reinforcements, and (0.076–0.327) for the base material. The mean value of COF of the reinforcements is lower (0.176) than the value for base material (0.202).

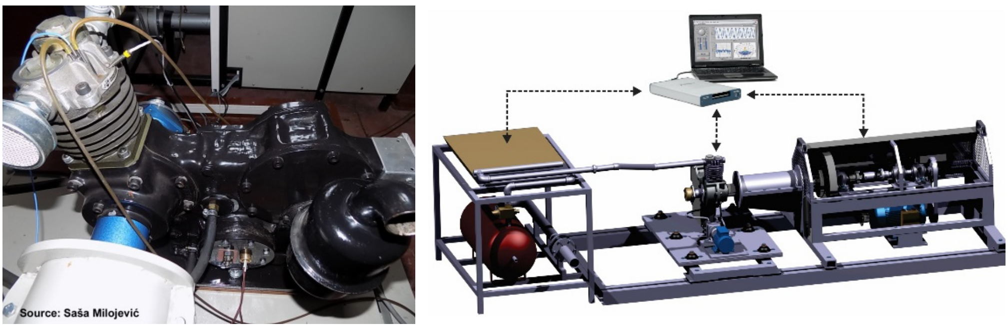
3. TEST RIG FOR MEASUREMENT OF LOSSES RELATED TO FRICTION IN AIR COMPRESSOR

Investigated reciprocating compressor, as an auxiliary device on the vehicle, drive an internal combustion engine, or an electric motor during its laboratory testing. When determining power (kW) of friction losses (P_m) using the indicator method, the indicated mean effective pressure (W_i) is determined with the help of pressure sensor which mounted in cylinder head, Fig. 4.a. The pressure inside the cylinder is captured by piezo-electric pressure transducer and the data is stored using data acquisition system. Effective compressor power (at the flywheel), (P_e) is analogous to it, the driving power, contrary to the IC engines. Indicated power (P_i) is less than the effective power for friction losses, that demanded to overcome mechanical losses in the compressor (friction in the cylinder, bearings, etc.), Eq. 3.

$$P_i = P_e - P_m \tag{3}$$

Mechanical efficiency is the relationship between these two values, Eq. 4.

$$\eta_m = \frac{P_i}{P_e} = \frac{P_e - P_m}{P_e} = 1 - \frac{P_m}{P_e} \tag{4}$$



a) b)

Fig. 4 *a) Photography of the experimental reciprocating air compressor; b) Test rig for small air compressors*

Use of the indicator method requires very high reproduction accuracies of the operating conditions, and thus of the friction conditions. For the most precise control and reproducibility of the boundary conditions, therefore, the oil and coolant pumps are replaced with external cooling system. The compressor is cooled by a fan. The detailed test rig setap for small air compressors is shown in Fig. 4.b. [12]. The compressor is connected with air reservoir and the pressure is maintained by using the automatic servo valve.

Generally, over a period of time, performance of compressor reduce drastically. The causes are mainly such as wear and poor maintenance. Because, a periodic performance assessment is essential to minimize the cost of compressed air. To test performance of the compressor proposed the use of ACACA Protocol™ 2000 of the Australian Commercial Air Compressor Association. Protocol defines standard test procedure for measuring of Free Air Delivery (FAD) of air compressor package.

FAD ($l \cdot min^{-1}$) is the volume flow rate of air (measured at ambient pressure and temperature and humadity) which has been compressed and delivered to the terminal discharge point of the air compressor package. It is a measure of the volume of air available for use at the exit point of the air compressor package.

The air flow is measured by pump up test method. The pump up test consists of operating the compressor at a constant speed and observing the time required to increase the pressure in the air receiver (cylinder of measured volume) from $6-8\ bar$ ie when the compressor is operating under load. The approximate air output of the compressor or FAD can then be calculated with application of the Eq. 3:

$$FAD = \frac{V_R \cdot (p_1 - p_2)}{p_o \cdot t} = \frac{2 \cdot V_R}{t} \tag{3}$$

where is:

- p_1, p_2 - Air cylinder pressure at start and at and of test, respectively;
- t - Pump up time taken to increase the pressure in the air cylinder from $p_1\ to\ p_2$, min; and
- p_o - Atmospheric pressure $p_0 = 100\ kPa\ (1\ bar)$.

Testing must need to be completed within twenty minutes after the compressor has reached normal operating temperature. After the results of 3 tests have been recorded, take the average and calculate FAD of compressor package in accordance with Protocol.

However the pump up test is a useful comparative measure and has been selected as being suitable to rate commercial air compressors for pump displacements, up to $600\ l \cdot min^{-1}$. Large compressors must be rated in accordance with standard ISO 1217.

Pump displacement ($\dot{V}_h, l \cdot min^{-1}$) is the theoretical volume of air that can be pumped by a reciprocating air compressor, if it was 100% efficient, Eq. 4:

$$\dot{V}_h = \frac{\pi d^2}{4} s N \chi n_e 10^{-6} \tag{4}$$

where is:

- d, s - Cylinder diameter and stroke, mm;
- N - Number of cylinders;
- χ - 1 for single acting and 2 for double acting cylinders; and
- n_e - Compressor speed, rpm.

4. CONCLUSION

The European Comission is working on the measures to reduction of greenhoouse gases emissions from all sources. Because of the fact that all vehicles must give to reduction of fuel consumption and emission, the EU formed regulation for certification of all new registered HD vehicles. We researched reduction of power demand in air compressor as auxiliary device on the engine, by tribological optimization of their piston and cylinder.

Presented results obtained during tests of materials from which consisting cylinder, shows that by transferring the contact between the piston rings and cylinder made of aluminum on the reinforcements, it is possible to reduce the friction and wear.

To test performance of the experimental compressor on test rig proposed the use of ACACA Protocol™ 2000. Protocol defines standard test procedure for measuring of free air delivery and pump displacement.

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