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Degree Report: The influence of intake and exhaust configuration on operational characteristics of automotive Otto engine

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Summary
Introduction. Serial engine DMB 128A. This paper analyse the influence of intake and exhaust configuration on performance of an automotive Otto engine. The data necessary for this analysis were obtained by Boost simulation program. Therefore, it was necessary to study the program, equations and physical laws used for calculation of each element. Simulations were conducted on engine DMB 128 A, which is located in Laboratory for Engines and Vehicles at Faculty of Mechanical Engineering and Naval Architecture in Zagreb. This is an old engine, but for this engine all geometrical data that are needed for calculation were available. For calculation of heat release the Vibe model was used because in previous papers at faculty calculation of high pressure cycle in cylinder was done using the Vibe calculation, so the data of Vibe parameters for this engine were available. Flow coefficients at pipe ends, and pipe junctions were taken from tables in Boost User's guide.

Figure 1. Model of serial engine: DMB 128A.

Originally the engine DMB 128A have an intake system with carburettor, and the first model made in Boost was model with that kind of intake system. Figure 1 shows the boost model of engine DMB 128A with intake system with carburettor.
Although the boost offers a series calculation, for this paper a series of single calculations for engine speeds from 1000 rpm to 6000 rpm with steep of 500 rpm were conducted. This is done because transient and crank angle dependent results were analysed, and the second ones are not available with serial calculation. The desired results were extracted from boost post processor and imported in Excel worksheet. This is done because the Excel has more options in editing charts. In this paper the considered results were: air delivery ratio ambient, residual gas, brake torque, brake power and brake specific fuel consumption. Since in single calculations the results of brake torque and brake power are not available they are calculated in excel sheets from the results of BMEP and engine speed. Previously mentioned results are shown in charts in figures 2-4.

![Figure 2. Air delivery ratio ambient and residual gas of engine DMB 128A (calculated results).](image1)

![Figure 3. Brake torque, brake power and brake specific fuel consumption of engine DMB 128A (calculated results).](image2)
**Improved engine DMB 128A - FI.** Analysis of influence of intake and exhaust system configuration on engine behaviour was conducted on the improved engine with intake system with fuel injectors, and therefore new Boost model of engine was made. This model has a new name DMB 128A – FI, and it is shown in figure 4.

**Figure 4.** Model of reconstructed engine with fuel injection intake system: DMB 128A – FI

Regarding the intake system the three different analysis were made. First the influence of the length of intake pipes on engine behaviour. For this purpose three models of engine with three different pipe lengths were made.

**Figure 5.** Influence of intake pipe length on air delivery ratio (calculated results).
The results of air delivery ratio and break specific fuel consumption were analysed together with the results of pressure fluctuations in the intake pipe over the crank angle at some specific points. The pressure fluctuations were analysed with purpose of determining what kind of fluctuations will give maximum air delivery ratio and what kind of fluctuations will cause minimal break specific fuel consumption. The analysis also showed how the length of the intake pipe influences the pressure fluctuations in the pipes. The results of the air delivery ratio and break specific fuel consumption are shown in figures 5 and 6.

![Figure 6. Influence of intake pipe length on brake specific fuel consumption (calculated results).](image-url)

The second analysis was the influence of intake pipe diameter on engine behaviour. For this purpose the models with three different intake pipe diameters were made ($d_1=22$ mm, $d_2=35$ mm and $d_3=50$ mm). The results were analysed in the same way as those for the pipe length. Results showed that the smaller pipe diameter causes greater air delivery ratio at low engine speeds, but at high engine speeds it causes substantial drop of air delivery ratio. On the other hand larger pipe diameter causes a drop of air delivery ratio at low engine speeds, but dropping of air delivery ratio at high engine speeds with larger intake pipe diameter is slighter. The results of fuel consumption showed that reducing of intake pipe diameter leads to increase of brake specific fuel consumption at high engine speeds. At low engine speeds the influence of intake pipe diameter on BSFC is insignificant. Difference between three curves of BSFC starts at 3000 rpm. It is shown that the reason of increase of BSFC at high engine speeds is the increase of gas exchange work due to increase of resistance because of diameter reducing.

The third analysis was the influence of the intake manifold volume on engine behaviour. For this purpose the models with three different intake manifold volumes were made ($V_1=6$ l, $V_2=8.5$ l, $V_3=11$ l). The results of this analysis showed that change of intake manifold volume leads to insignificant changes of air delivery ratio. Since the volumes in considered models were many times greater than the volume of cylinder ($V_1=21.5*V_h$, $V_2=28.7*V_h$, $V_3=39.4*V_h$), three additional models were made. In these models the intake manifold volume was greatly reduced. In these models the volumes are $V_4=1*V_h=0.279$ l, $V_5=0.5*V_h=0.139$ l and $V_6=4*V_h=1.116$ l. Results of air delivery ratio in these additional
model also showed that the influence of intake manifold volume is insignificant. The results of pressure fluctuations over the crank angle showed that changing of intake manifold volume leads to the changes of the pressure fluctuations in the intake manifold. But these changes of pressure fluctuations in the intake manifold did not change the pressure fluctuations in the intake pipes and therefore there have been no changes in other engine characteristics.

For analysis of exhaust systems several models of engine were made with a different types of exhaust systems. Considered exhaust systems are used on Otto engines in practise, and all of them have a same length of exhaust pipes before first plenum. Results of residual gases were analysed because they show how much combustion products remains in the cylinder after the gas exchange process, and they are shown in Figure 7.

![Residual gas graph](image)

**Figure 7.** Influence of exhaust system type on residual gas (calculated results).

If a lot of combustion products stays in the cylinder, less of fresh working fluid will come in the cylinder and the value of air delivery ratio will be smaller. If less of combustion products stay in the cylinder, more of fresh working fluid will come in the cylinder and the value of air delivery ratio will be bigger.

On the right side of the diagram the sketches of considered exhaust system types are shown in colours that matches the colours of respective curves.

Together with the results of residual gases, the results of pressure fluctuations over the crank angle in the exhaust pipes at some specific points were analysed. This is done because with purpose of determining which pressure fluctuations will give smaller residual gas and which bigger one, and to see how configuration of exhaust system affects the pressure fluctuation.

Then the results of BSFC were analysed for the same types of the exhaust systems. It turned out that exhaust systems in which the average pressure in exhaust pipe during the exhaust stroke is bigger causes bigger BSFC, and those in which this pressure is smaller causes smaller BSFC.

After that the same analysis of exhaust systems was repeated but instead of different types of exhaust systems the different length of exhaust pipes before the first plenum were
analysed. For this purpose four engine models with different length of exhaust pipes of the exhaust system type E were made. At the end, on the basis of analysis made before, three configurations of intake and exhaust systems that improve air delivery ratio characteristic were designed. For each variant first the exhaust system was designed, and then for that exhaust system the intake system with changeable length of intake pipes was adopted. Intake pipe lengths are adopted for three different engine speeds (2500 rpm, 4000 rpm, 5500 rpm) and at those engine speeds they cause so called resonance charging. Variant 1 has an original exhaust system, variant 2 has an exhaust system that improves scavenging at low engine speeds, and variant 3 has an exhaust system that improves scavenging throughout all tested engine speeds. With so dimensioned intake and exhaust systems boost models were made and the results of air delivery ratio for these three variants are shown in figure 8. For comparison the results of engine with original intake and exhaust system are added.

![Figure 8](image-url)  
Figure 8. Air delivery ratio comparison of serial engine (DMB 128A) and improved engine (128A – FI) with three different intake and exhaust systems (calculated results).

References:

[10.] Inženjerski pripomoček – Temelji inženjerstva, Šolska knjiga, Zagreb 1996