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The Effects of the Intake Pipe Configuration on Gas Exchange, and Technical and Economic Indicators of Diesel Engine with 21/21 Dimension

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Abstract

The increase of the power density, improvement of fuel efficiency and minimization of the environmental impact of modern internal combustion engines form the main trend of the engine development. Turbocharging is pivotal to ensure the thermodynamical as well as commercial competitiveness of modern large diesel and gas engines. The optimization of the gas-dynamic and heat transfer characteristics of the gas flow in the intake system targeting the optimization of the gas exchange process is an important task in engine building. Numerical simulation of working process of the 8-cylinder 21/21 diesel-motor (Russia, Ekaterinburg) was performed with the ACTUS simulation software (Switzerland, Baden, ABB Turbo Systems Ltd). The numerical study showed that the geometric dimensions of the intake pipe significantly impact the flow dynamics. In particular, it is shown that the use of inlet pipe with a larger diameter (on the 8DM-21 engine) leads to the average 0.5% increase in the filling ratio. This leads to an up to 0.7 % increase in engine power and reduces the effective specific fuel consumption by about 0.50-0.75.

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Keywords: piston engines; gas exchange processes; gas dynamics; numerical simulation; ACTUS; improvement of diesel engines.

1. Introduction

It is known that the geometric characteristics of the elements of the intake system significantly affect the quality of the gas exchange and on technical and economic performance of internal combustion engines (ICE) [1-4]. This is

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especially true for diesel engines with advanced exhaust turbocharging, where a positive pressure drop over the engine is enabled. Because the gas dynamics in the intake and exhaust systems is very complex (significant wave phenomena of gas flows occur in pipelines) [5-7], thoroughly optimization of intake and exhaust systems are required.

Nomenclature

ICE	internal combustion engine
IC	intercooler
φ	crank angle, degrees
n	engine crankshaft rotation frequency, rpm
p_x	pressure in the intake pipe, bar
A_{px}	amplitude of the pressure fluctuations, bar
η_v	filling ratio
N_e	effective power, kW
g_e	effective specific fuel consumption, kg/(kW·h)
D	channel diameter, mm
l_x	linear dimension, mm

2. The software and the object of research

Today numerical simulation of working process in a dedicated software is one of the most effective approaches to improvement of internal combustion engines [8-11]. Numerical simulation of the working process of diesel engine with the 21/21 dimension was performed in ACTUS software (Switzerland, Baden, ABB Turbo Systems Ltd). The object of modeling was the eight-cylinder diesel engine with turbocharger. This engine was made by Ural diesel-motor plant (Russia, Ekaterinburg). Factory designation for this engine is 8DM-21.

ACTUS consists of two parts: A modern user interface with a graphical topology editor for setting up the simulations and a simulation kernel for performing the calculations. ACTUS allows to specify the geometrical characteristics of the intake and exhaust systems, the parameters of the turbocharger and also other essential indicators of the cylinder group and the whole engine. ACTUS is used to investigate new turbocharging concepts and their impact on the combustion engine. A number of these studies were presented at the 27th CIMAC World Congress in 2013 [12-14].

The results of numerical simulation of the influence of the geometric characteristics of the intake pipe on the wave phenomena in the intake system, the quality indicators of gas exchange and techno-economic characteristics of the diesel engine (8DM-21) are presented in this article.

The schema of the intake system of the studied diesel engine (8DM-21) is represented in Fig. 1.

This engine has a single turbocharger. The air is compressed in a centrifugal compressor and further compressed air flows into the intake pipes on the left and right side of the V-shaped diesel. The turbine housing has four inlets (pulse turbocharging). The exhaust pipes from two cylinders are combined into a single pipeline to maximize the energy conversion of the pressure wave, which provides strong improvement of the engine performance especially at part load.

The inner diameter of the original intake pipe for 8DM-21 diesel was 156 mm, the length was 1625 mm. The inner diameters of the new intake pipes were (unchanged pipe length):

1. inner diameter of inlet pipe D_1 = 80 mm (the diameter is 2 times smaller than the original diameter for 8DM-21 diesel);
2. inner diameter D_2 = 250 mm (the diameter is 1,5 times larger than the original diameter);
3. inner diameter D_3 = 330 mm (the diameter is 2 times larger than the original diameter).

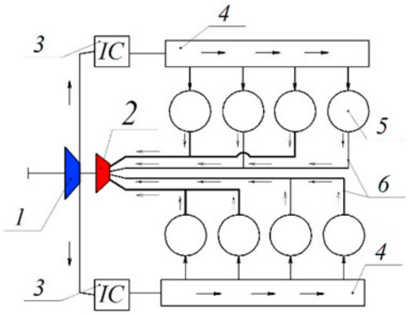

Fig. 1. The schema of the intake system of 8DM-21 diesel: 1 – compressor; 2 – turbine; 3 – the intercooler (IC); 4 – intake pipe; 5 – engine cylinders; 6 – exhaust pipe

3. The results of numerical simulation

The calculated dependences of the pressure in the intake pipe p_x from the crankshaft angle φ for engine nominal regime for different diameters of intake pipe are shown in Fig. 2.

Numerical modeling in ACTUS confirmed the presence of wave phenomena in the intake system. Wave phenomena are initiated with the filling and empting of the cylinder interacting with the resonance of the pipe system between compressor outlet and cylinder inlet, hereby the charge air cooler acting as a damper.

Large pipe do act as damper to the resonance phenomena; with smaller pipes the system needs to be optimized in order to avoid low-pressure peak at the position of the intake valve whenever the valve are open. These phenomena are described in detail in [15,16].

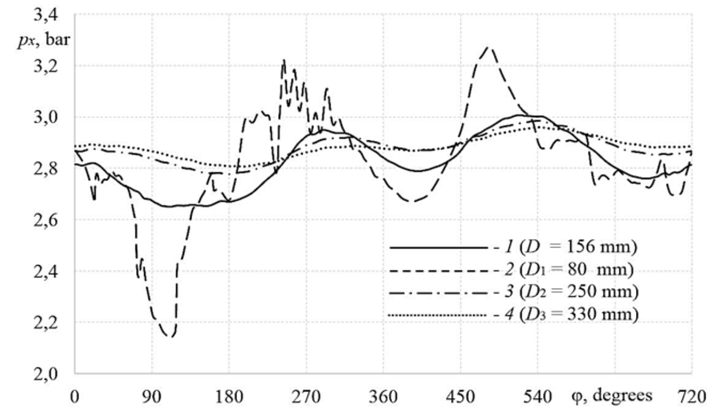

Fig. 2. The calculated dependences of the pressure in the intake pipe p_x (inlet of the third cylinder) from the crankshaft angle φ for engine nominal regime for different diameters of intake pipe: *1* – D = 156 mm; *2* – D_1 = 80 mm; *3* – D_2 = 250 mm; *4* – D_3 = 330 mm

The diameter of the intake pipe has a significant impact on the dynamics of the gas flow (Fig. 2). The reduction of the inner diameter up to 80 mm leads to a significant fluctuations of flow pressure. The increase of the inner diameter up to 250-330 mm leads to a slight smoothing of the pressure amplitudes in the intake pipe.

Smoothing of pressure pulsations in the intake pipe at different diameters of the channel can be seen in Fig. 3 in more detail. Calculated dependences of the amplitudes of the pressure A_{px} along the length of the intake system l_x with different diameters of the intake pipe are shown in Fig. 3. It shall be noted that the amplitude of the pulsation is changing along the axial direction, this is related to resonance phenomena. The piping topology and firing order of the cylinders needs to be optimized in order to enable sufficient quality of the gas exchange for each cylinder. The major challenge hereby, is that the resonance phenomena are dependent on the engine speed. For all applications with varying engine speed (traction, marine main propulsion) the whole engine operating range needs to be covered and optimized.

It was found that the diameter reduction (from 156 to 80 mm) leads to an increase in the amplitudes of the pressure fluctuations in the intake pipe (Fig. 3). The growth of the pressure amplitudes was about 2.0-2.5 times in comparison with the original pipeline. The increase of the intake pipe diameter (from 156 to 330 mm) leads to a smoothing of wave phenomena in the intake system of the 8DM-21 diesel engine. In this case, the reduction of pressure oscillation is about 1.5-2.0 times.

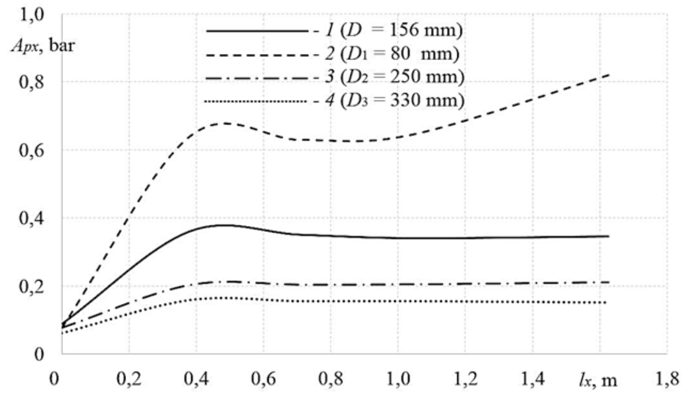

Fig. 3. Calculated dependences of the amplitudes of the pressure A_{px} along the length of the intake system (0 being the compressor outlet and 1.7 being the inlet of the last cylinder) l_x with different diameters of the intake pipe: *1* – D = 156 mm; *2* – D_1 = 80 mm; *3* – D_2 = 250 mm; *4* – D_3 = 330 mm

Smoothing of pressure fluctuations in the intake pipe should have a positive impact on the filling of the cylinders of the diesel engine. Since this should lead to a reduction in the hydraulic resistance of the intake system and accordingly it will improve the quality of gas exchange [17-19].

This hypothesis was tested using numerical simulation in ACTUS. Calculated dependences of the filling ratio from the crankshaft rotation speed for different diameters of intake pipe are shown in Fig. 4.

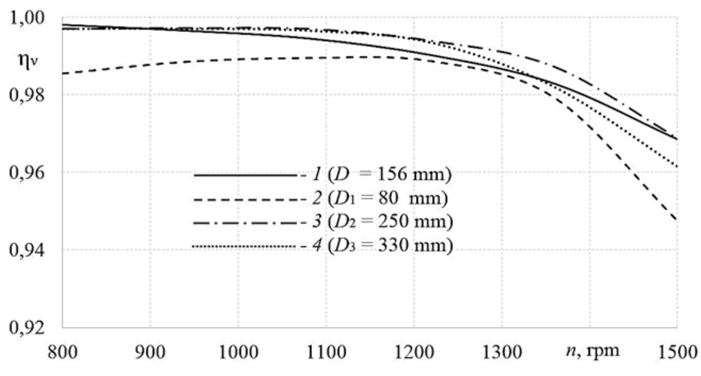

Fig. 4. Calculated dependences of the filling ratio from the crankshaft rotation speed for different diameters of intake pipe:
1 – D = 156 mm; *2* – D_1 = 80 mm; *3* – D_2 = 250 mm; *4* – D_3 = 330 mm

The use of intake pipe with an inner diameter of 80 mm leads to a general decrease in the filling ratio. This is true especially for operation at high engine speed and low engine speed, the impact during operation at moderate engine speed is considerably less extensive on the 8DM-21 diesel (Fig. 4). The use of intake pipes with large diameters

(220 and 330 mm) leads to an increase of the filling ratio on average by 0.5 %. This increase is characteristic for a partial operating modes of the engine.

The values of the filling ratio influence the power characteristics of a diesel engine (Fig. 5).

The use of inlet pipe with a small diameter (80 mm) leads to a decrease in power of diesel by 0.5-2.5 %, while the use of inlet pipe with a large diameter (330 mm) leads to an increase in engine power by up to 0.7 % (Fig. 5).

It should be noted that the increase in the power of a diesel engine is accompanied by a decrease in fuel consumption by 0.75% in the partial operating modes of a diesel engine (Fig. 6).

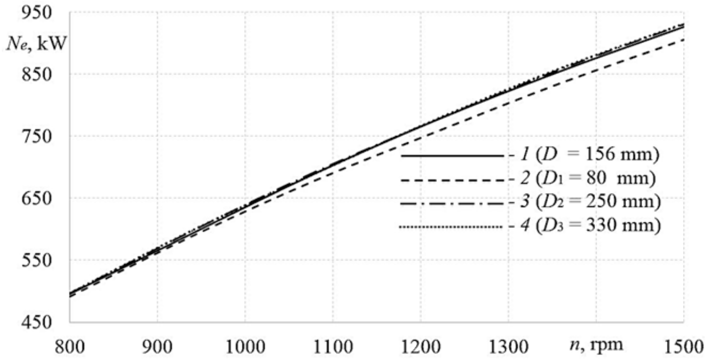

Fig. 5. Calculated dependences of the effective power N_e of the diesel engine from the crankshaft rotation speed *n* for different diameters of intake pipe: *1* – D = 156 mm; *2* – D_1 = 80 mm; *3* – D_2 = 250 mm; *4* – D_3 = 330 mm

The quality of gas exchange has a direct impact on the residual gas in the cylinders, which affects directly the engine thermal load and combustion quality; as well as on the gas exchange work exerted on the cylinder, which affects directly the engine fuel consumption [20, 21].

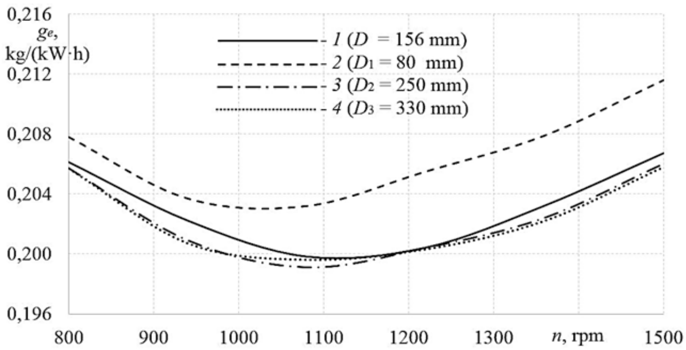

Fig. 6. The calculated dependences of the effective specific fuel consumption g_e from the crankshaft rotation speed *n* for different diameters of intake pipe: *1* – D = 156 mm; *2* – D_1 = 80 mm; *3* – D_2 = 250 mm; *4* – D_3 = 330 mm

Summary

Thus, the numerical study showed that the geometric dimensions of the intake pipe have a significant impact on the flows dynamics. The quality of gas exchange can be improved by choosing the optimum configuration of the intake system. This leads to an increase of technical and economic parameters of diesel engines.

In general, it is shown that the use of inlet pipe with a larger diameter (on the 8DM-21 engine) leads to an increase of the filling ratio on average by 0.5 %. This leads to an increase in engine power by up to 0.7 % and reduce the effective specific fuel consumption by about 0.50-0.75.

This is in direct contract with the costs of the engine as larger pipe diameter directly increase the specific weight and cost of the engine, therefore an optimum needs to be determined. Advanced simulation of turbocharging systems enable to determine this optimum and, by an appropriate deign of the piping system, to optimize the intake system toward more compact piping system with respect to resonance phenomena.

References

[1] M.M. Vihert, Ju.G. Grudskij, Construction of the intake systems of high-speed diesel engines, Mashinostroenie, Moscow, 1982.
[2] B.H. Draganov, M.G. Kruglov, V.S. Obuhova, Construction of intake and you-throughput channels of internal combustion engines, Golovnoe izdatelstvo, Kiev, 1987.
[3] D.N. Vyrubov, N.A. Ivashhenko, V.I. Ivin, Internal combustion engines: the piston - theory and combined engines, Textbook for technical colleges in the specialty of internal combustion engines, Mashinostroenie, Moscow, 1983.
[4] J.B. Heywood, Internal combustion engine fundamentals, McGraw-Hill, New York, 1988.
[5] N. Watson, M.S. Janota, Turbocharging the internal combustion engine, Mechanical Press Ltd, Hong Kong, 1982.
[6] S.L. Dixon, Fluid mechanics and thermodynamics of turbomachinery, 4th edition, Butterworth-Heinemann, Oxford, 1998.
[7] A.E. Simpson et al., Turbocharged high-speed diesel engines, Mashinostroenie, Moscow, 1976.
[8] L. Eriksson, L. Nielsen, J. Brugard, J.M. Bergstrom, F. Pettersson, P. Andersson, Modeling and simulation of a turbo charged SI engine, Ann. Rev. Control. 26(1) (2002) 129–137.
[9] S. Bernasconi et al., Two-stage turbocharging solutions for Tier 4 Rail applications, ASME ICED Fall Division, Huston, 2015, pp. 256–268.
[10] H. Chen, D. Winterbone, A method to predict performance of vaneless radial turbine under steady and unsteady flow conditions, Turbocharging and Turbochargers, Institution of Mechanical Engineers. (1990) 13–22.
[11] A. Bjork, Numerical methods for least squares problems, SIAM, Philadelphia, Pennsylvania, USA, 1996.
[12] P. Schurmann et al., Contribution of turbocharging solutions towards improved fuel efficiency of two-stroke low-speed engines, CIMAC Congress 2013, Shanghai, 2013, pp. 152–160.
[13] C. Christen, D. Brand, IMO Tier 3: Gas & Dual Fuel Engines as Clean & Efficient Solutions, CIMAC Congress 2013, Shanghai, 2013, pp. 178–182.
[14] M. Kahi et al., Second Generation of Two-Stage Turbocharging Power 2 Systems for Medium-Speed Gas & Diesel Engines, CIMAC Congress, Shanghai, 2013, pp. 222– 228.
[15] R. Stone, Introduction to Internal Combustion Engines, 3rd Edition, Macmillan Press Ltd, 1999.
[16] V.N. Lukanin, K.A. Morozov, A.S. Hachijan, Internal combustion engines, The theory of working processes, Textbook, 1995.
[17] L.V. Plotnikov, B.P. Zhilkin, Y.M. Brodov, The influence of cross-profiling of inlet and exhaust pipes on the gas exchange processes in piston engines, Procedia Engineering. 150 (2016) 111–116.
[18] B.P. Zhilkin, Y.M. Brodov, Process Improvement in gas path of reciprocating internal combustion engines, a monograph, Izd-vo Ural, Ekaterinburg, 2015.
[19] D.S. Shestakov, L.V. Plotnikov, B.P. Zhilkin, N.I. Grigor'ev, Mitigation of air flow pulsation in turbocharged engine suction system, Dvigatelestroenie. 1 (2013) 24–27.
[20] R. Chen, N. Milovanovic, A computational study into the effect of exhaust gas recycling on homogeneous charge compression ignition combustion in internal combustion engine fuelled with methane, Int. J. Thermal Sci. 41 (2002) 805–813.
[21] N. Milovanovic, R. Chen, J., TurnerInfluence of variable valve timings on the gas exchange process in a controlled auto-ignition engine, Proceedings of the Institution of Mechanical Engineers, Journal of Automobile Engineering. 218 (2004) 567–583.