

Analysis of Resonator Installation Effect in Intake System of the Diesel Engine on Parameters of Gas Exchange Quality



L. V. Plotnikov, S. Bernasconi and B. P. Zhilkin

Abstract The results of numerical simulation of the resonator installation effect in the intake system of a diesel engine of dimension 21/21 on wave phenomena, technical, and economic indices are presented. The objective of the study is a diesel engine with eight cylinders: the cylinder diameter is 210 mm, the piston stroke is 210 mm. Diesel (factory designation is 8DM-21/21) is produced at the “Ural diesel-motor plant” (Russia, Ekaterinburg). Numerical simulation was performed in the ACTUS software (Switzerland, Baden). The simulation was performed taking into account the geometric parameters of the elements of the inlet system and the gas-dynamic flow nonstationarity. The article briefly describes the functions and designs of resonators used in the field of engine building. It is shown that the resonator installation in the intake system of the 8DM-21/21 diesel engine significantly changes the gas dynamics of the flow. For example, there is a smoothing of wave phenomena. This leads to an improvement in the quality of gas exchange (an increase in the filling ratio up to 0.5%). At the same time, the specific fuel consumption is reduced by an average of 0.3% while maintaining the power of a diesel engine.

Keywords Diesel engine · Intake system · Resonator · Gas exchange processes
Numerical simulation · ACTUS

L. V. Plotnikov (✉) · B. P. Zhilkin

Ural Federal University Named After the First President of Russia B. N. Yeltsin,
19, Mira st., Yekaterinburg 620002, Russia
e-mail: leonplot@mail.ru

S. Bernasconi

ABB Turbo Systems Ltd, Bruggerstrasse 71a, 5401 Baden, Switzerland

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1 Introduction

It is known that the technical and economic characteristics of piston internal combustion engines (ICE) are largely determined by the perfection of processes occurring in gas–air systems [1–5]. Modern requirements for the environmental and economic performance of diesel engines with a turbocharger make high demands on gas dynamics in the intake system when the air moves from the compressor wheel to the engine cylinder. It is necessary to evaluate the gas-dynamic perfection of all elements of the intake system when designing a diesel engine. In particular, it is necessary to design an intake system with the optimal geometric shapes and devices that smooth the flow of gases.

The methods for studying the intake and exhaust processes of piston engines can be divided into two large groups. The first group includes theoretical analysis, as well as numerical modeling of gas dynamics and heat transfer. The second group includes methods for the experimental study of gas exchange processes. To date, one of the most effective approaches to improving the piston engines is the numerical simulation of the working cycle in specialized software [6–8].

This article presents the results of numerical simulation of the influence of the resonator installation in the intake system on wave phenomena, gas exchange quality parameters, and technical characteristics of diesel engines of 21/21 dimension. Numerical modeling of the working cycle of diesel produced by the “Ural diesel-motor plant” (Russia, Yekaterinburg) was carried out in the ACTUS software (Switzerland, Baden, ABB Turbo Systems Ltd.).

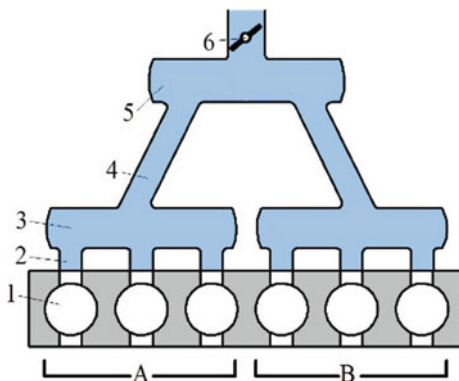
2 Functions and Designs of Resonators

It is known that significant wave phenomena exist in gas–air systems of piston ICEs. They are caused by the cyclic operation of the engines, the action of the turbocharger’s blading apparatus, and the peculiarities of the physical processes occurring in the intake and exhaust systems. Resonators are installed in order to smooth out these wave phenomena, to equalize the flow in the gas–air systems of the engines, and to improve the efficiency of the noise silencers. Examples of resonator designs for the exhaust systems of automobile engines are presented in [9, 10].

Resonators are widely used in intake systems of piston ICEs with supercharging and without it. Resonators are used to create a resonant boost in engines without a turbocharger [11–14]. To obtain a resonant boost (Fig. 1), groups of cylinders 1 (A, B) with identical ignition timing (in terms of the crankshaft rotation angle) are connected through short intake pipes 2 with their resonant chamber 3. In turn, these chambers 3 through the resonant intake pipelines 4 are connected either to the

Fig. 1 Scheme of the intake system with resonators of a piston engine without a supercharging [11, 12]:

- 1—cylinder;
- 2—short intake pipe;
- 3—resonant chamber;
- 4—resonant intake manifold;
- 5—collection chamber;
- 6—throttle valve. A, B—combined cylinder groups



atmosphere or to the collecting chamber 5 and, accordingly, the chambers act as Helmholtz resonators. Separation of the intake system into groups of cylinders with two resonator intakes manifold prevents the overlap of the boost process in neighboring cylinders in the order of ignition.

The crankshaft speed range determines the length of the resonant inlet pipelines and the size of the resonant chambers at which the resonant boost effect should occur. It should be noted that large common chambers can lead to dynamic failures during sudden changes in load due to the accumulation effect. Therefore, the use of resonators in the intake and exhaust systems requires serious research and thorough debugging. Quite often, resonators are also used in the intake systems of piston engine with supercharging (Figs. 2 and 3) [15].

It should be noted that the main purpose of the resonator installation in the intake system of the engine with a supercharger is the damping of the wave phenomena in hydraulic system. Thus, specialists tend to align the flow in the intake system and reduce the hydraulic resistance. This should lead to an increase in the filling ratio (improving the quality of gas exchange), as well as a reduction in the specific fuel consumption.

Fig. 2 Scheme of an intake system with a controlled resonator of a diesel engine with supercharged:

- 1—turbocharger;
- 2—charge air cooler;
- 3—intake pipeline;
- 4—resonator;
- 5—connecting pipelines of adjustable length;
- 6—cylinders

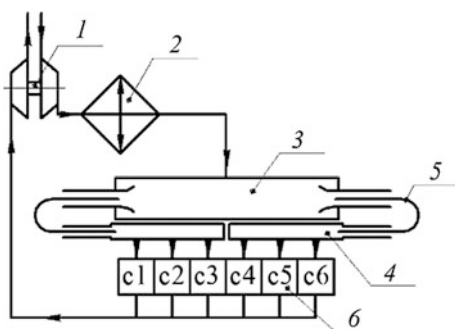
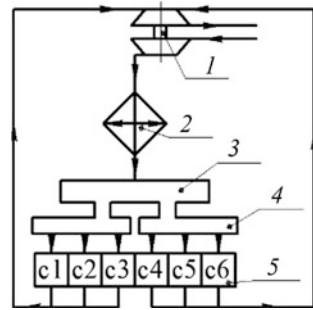


Fig. 3 Scheme of an intake system with a resonator of the diesel engine with supercharged:

1—turbocharger; 2—charge air cooler; 3—intake pipeline; 4—resonator; 5—engine cylinders



3 Statement of the Research Task

Modeling of the working process of the 8DM-21/21 diesel engine was carried out in the ACTUS software, developed by ABB Turbo Systems (Switzerland). The ACTUS allows you to set the geometric characteristics of the intake and exhaust systems, turbocharger parameters, as well as other necessary parameters of the piston-cylinder group and supercharging. ACTUS is used to simulate the workflow of modernized or newly developed piston ICES with supercharging, as well as to assess the effect of turbocharging on the main engine performance. This software is actively used for scientific research in the field of engine [16–18].

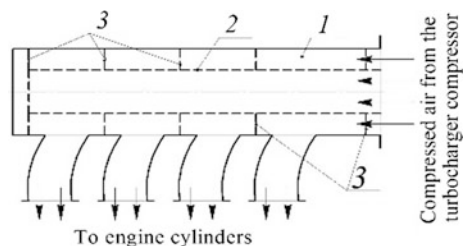
Thus, the modeling of the working process of the 8DM-21/21 diesel engine with an intake system with a resonator was performed in the ACTUS software. The scheme of the investigated intake system is shown in Fig. 4.

The following configurations of the resonators were investigated in the numerical modeling of the working process of the 8DM-21/21 diesel engine:

- (1) intake pipe without a resonator (basic model);
- (2) a resonator having a diameter $D = 0.078$ m and a length $l = 1.2$ m, in this case, its volume was $V_{p1} = 0.0055$ m³;
- (3) a resonator with a diameter $D = 0.10$ m and a length $l = 1.5$ m, with a volume equal to $V_{p2} = 0.0120$ m³;
- (4) resonator with the parameters: $D = 0.05$ m, $l = 0.80$ m and, respectively, $V_{p3} = 0.0015$ m³.

Fig. 4 Scheme of the intake system with a resonator of the 8DM-21/21 diesel engine:

1—intake pipeline; 2—resonator; 3—partitions



4 Simulation Results and Analysis

The calculated dependencies of pressures p_x in the intake system with resonators of different configurations from the crankshaft rotation angle φ for different operating modes of the diesel engine 8DM-21/21 are shown in Fig. 5.

The influence of resonators on the gas dynamics of flows in the inlet system depends on the operating mode of the piston engine (Fig. 5). Some smoothing of the amplitude of pressure pulsations by about 15% is observed when using a resonator with $V_{p2} = 0.0120 \text{ m}^3$ at nominal engine mode (see also Fig. 6). The installation of a resonator with a volume of $V_{p3} = 0.0015 \text{ m}^3$ leads to an increase in

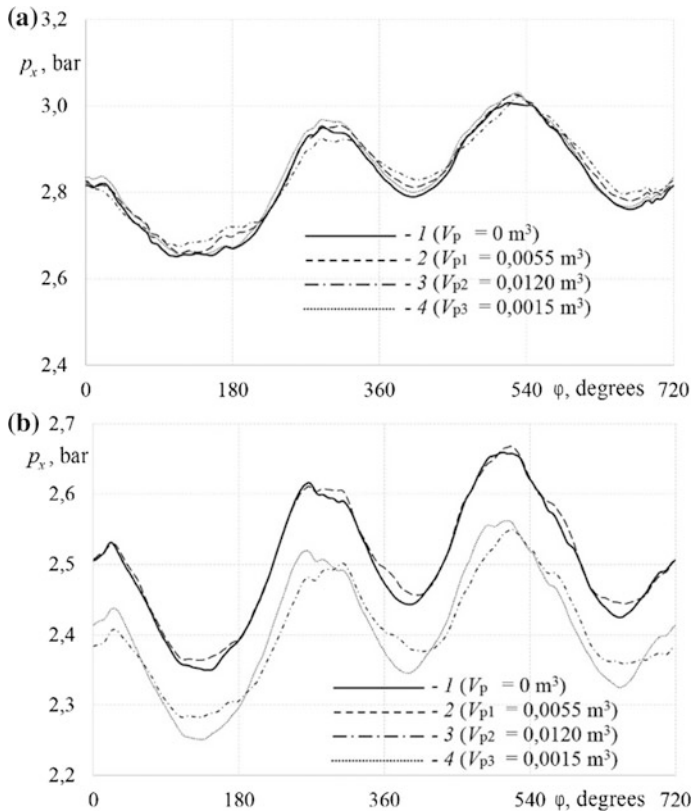


Fig. 5 Calculated dependencies of pressure p_x in the intake system with the resonator from the crankshaft rotation angle φ near the third cylinder for different operating modes for the 8DM-21/21 diesel: **a** nominal mode of engine operation ($N_e = 930 \text{ kW}$, $n = 1500 \text{ rpm}$); **b** partial engine operation ($N_e = 704 \text{ kW}$, $n = 1220 \text{ rpm}$) System configurations: 1—without a resonator; 2— $V_{p1} = 0.0055 \text{ m}^3$ ($D = 0.078 \text{ m}$, $l = 1.2 \text{ m}$); 3— $V_{p2} = 0.0120 \text{ m}^3$ ($D = 0.1 \text{ m}$, $l = 1.5 \text{ m}$); 4— $V_{p3} = 0.0015 \text{ m}^3$ ($D = 0.05 \text{ m}$, $l = 0.8 \text{ m}$)

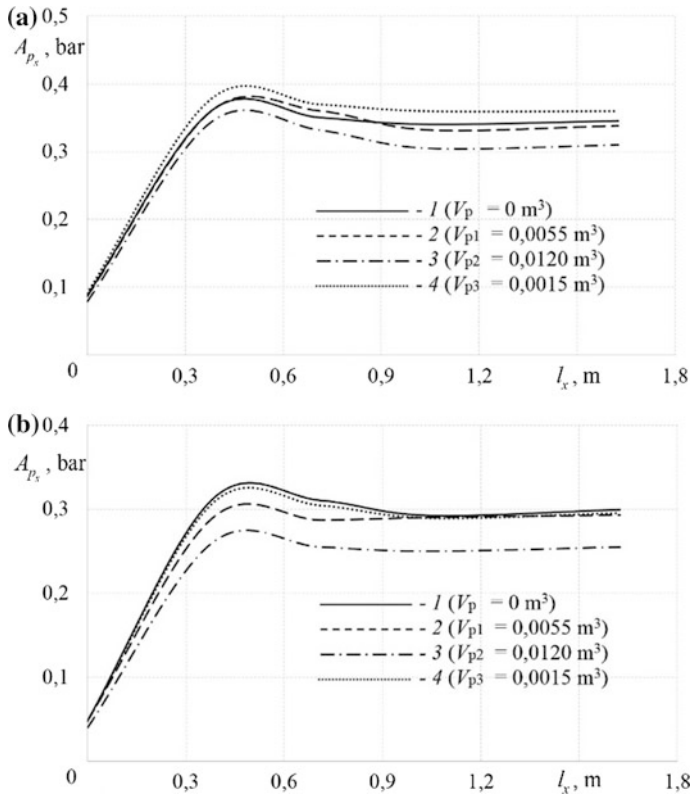


Fig. 6 Calculated dependencies of the magnitude of pressure amplitudes A_{p_x} along the length l_x of the intake system with resonators of different configurations: **a** nominal mode of engine operation ($N_e = 930$ kW, $n = 1500$ rpm); **b** partial engine operation ($N_e = 704$ kW, $n = 1220$ rpm). System configurations: 1—without a resonator; 2— $V_{p1} = 0.0055$ m³ ($D = 0.078$ m, $l = 1.2$ m); 3— $V_{p2} = 0.0120$ m³ ($D = 0.1$ m, $l = 1.5$ m); 4— $V_{p3} = 0.0015$ m³ ($D = 0.05$ m, $l = 0.8$ m)

the pressure pulsations in the intake pipeline (an average of 5.5%). The effect of another resonator configuration ($V_{p1} = 0.0055$ m³) on gas dynamics is negligible.

The physical picture is somewhat changed at the partial operation of the engine. It can be noted that the largest changes in gas dynamics are also caused by the installation of a resonator having a volume of $V_{p2} = 0.0120$ m³. However, in this case, the decrease in the magnitude of the pressure amplitude in the intake pipeline is already about 17–19% (Fig. 6). Other configurations of resonators do not have a significant effect on gas dynamics and wave flow phenomena in the intake system in this mode of operation of the 8DM-21 diesel engine.

As one would expect, a single resonator design can have a positive effect on gas exchange processes in certain modes of operation of a diesel engine, and another resonator configuration can have a positive effect on other modes. The level of the positive effect of the resonator also depends on many factors: the geometric

dimensions of the intake system and the resonator itself, the operating mode of the diesel engine and the turbocharger, the type of boost system, and so on. Thus, the installation of a resonator in the intake system of a piston ICE requires a detailed study of the gas-dynamic and heat exchange characteristics of the flows, as well as the careful refinement of the configuration of the intake system throughout the operating range of the engine.

The effect of the resonators installation of different designs on the filling ratio of the 8DM-21/21 diesel engine is shown in Fig. 7.

Resonator with the volume of $V_{p2} = 0.0120 \text{ m}^3$ has a positive effect on the quality of gas exchange at low speeds of the crankshaft (Fig. 7). The filling ratio η_v has higher values in comparison with the base engine by 0.1–0.3% in the range of n from 800 to 1150 rpm. While the resonator with $V_{p3} = 0.0015 \text{ m}^3$ is most effective at high speeds of the crankshaft (especially, at the nominal operating mode of the diesel engine). In this case, the growth of the coefficient η_v is up to 0.5%.

It should be noted that the change in the power of the 8DM-21/21 diesel engine was in the range of $\pm 0.4\%$ when installing resonators of different configurations in the intake system. A similar dependence is also characteristic for the change of the specific fuel consumption (Fig. 8).

There is a correlation between the change in the filling factor η_v and the specific fuel consumption g_e when using resonators of different designs (see Figs. 7 and 8).

Specific fuel consumption g_e has lower values in comparison with the base engine by 0.1–0.3% when installing a resonator with a $V_{p2} = 0.0120 \text{ m}^3$ volume at low speeds of the crankshaft. While fuel consumption g_e has lower values (up to 0.5%) with a resonator with $V_{p3} = 0.0015 \text{ m}^3$ at high speeds of the crankshaft.

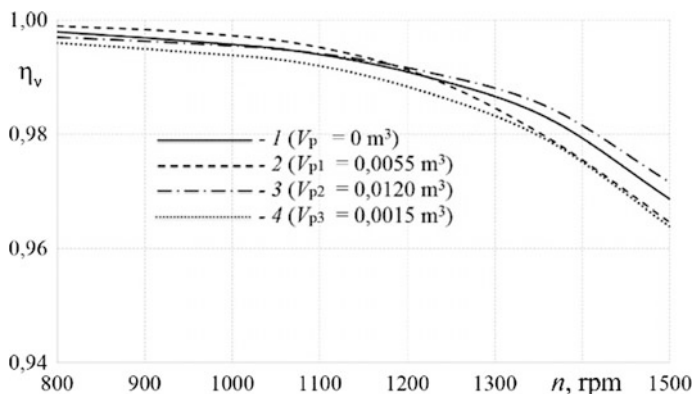


Fig. 7 Calculated dependences of the filling factor η_v from the engine speed n for the 8DM-21/21 diesel engine with an intake system with resonators of different configurations: 1—without a resonator; 2— $V_{p1} = 0.0055 \text{ m}^3$ ($D = 0.078 \text{ m}$, $l = 1.2 \text{ m}$); 3— $V_{p2} = 0.0120 \text{ m}^3$ ($D = 0.1 \text{ m}$, $l = 1.5 \text{ m}$); 4— $V_{p3} = 0.0015 \text{ m}^3$ ($D = 0.05 \text{ m}$, $l = 0.8 \text{ m}$)

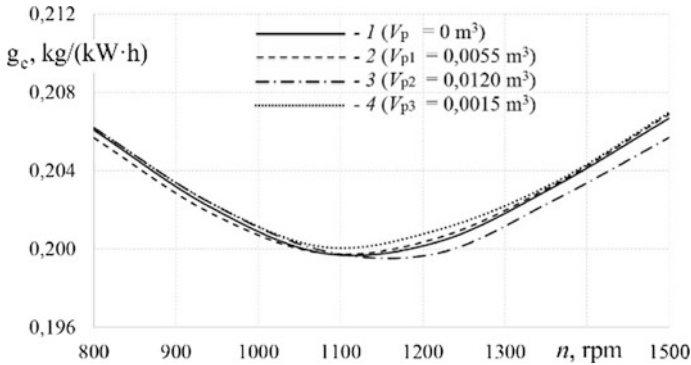


Fig. 8 Calculated dependences of the specific effective fuel consumption g_e on the crankshaft rotational speed n for the 8DM-21/21 diesel engine with an intake system with resonators of different configurations: 1—without a resonator; 2— $V_{p1} = 0,0055 \text{ m}^3$ ($D = 0,078 \text{ m}$, $l = 1,2 \text{ m}$); 3— $V_{p2} = 0,0120 \text{ m}^3$ ($D = 0,1 \text{ m}$, $l = 1,5 \text{ m}$); 4— $V_{p3} = 0,0015 \text{ m}^3$ ($D = 0,05 \text{ m}$, $l = 0,8 \text{ m}$)

5 Conclusion

Thus, the installation of the resonator significantly changes the gas dynamics of the flows in the intake system of the piston engine. It is possible to achieve an improvement in the quality of gas exchange processes by smoothing wave phenomena in the intake system due to the choice of the resonator configuration. Additional studies of gas-dynamic flow characteristics in the intake system are required in case of application of the resonator. It is also necessary to thoroughly refine the diesel engine in all modes of operation in order to find the optimal configuration of the resonator and to obtain the maximum effect from its use.

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