Research of the influence of alternative fuels on diesel engine noise level

A L Iakovenko¹,², A Y Dunin¹, P V Dushkin¹, E A Savastenko¹ and M G Shatrov¹
Moscow Automobile and Road Construction State Technical University (MADI), 64, Leningradski Ave., Moscow 124319, Russia
Email: iakovenko_home@mail.ru

Abstract. One of the advantages of using alternative fuels in internal combustion engines is the possibility of reducing noise. The article presents the methodology and some results of the research of structure-borne noise of internal combustion engines related to the working process. The main characteristics of alternative fuels allowing reduction of the noise level by modifying parameters of the heat release law and reducing the pressure growth rate are analyzed. The results of calculated and experimental research of the diesel engine structure-borne noise during its operation on gas and mixed fuels are presented. The research showed that the greatest effect is achieved when converting diesel engine to spark ignition gas engine. For gas-diesel engines, noise reduction of the working process is much lower because a high compression ratio is preserved. The use of mixed fuel revealed a need to correct the injection advance angle to reduce the noise level.

1. Introduction
The problem of vehicle noise is very important for big cities because the number of vehicles on the roads increases from year to year. Noise has harmful effects on the environment and human health. Therefore, it is necessary to improve vehicles not only in terms of reducing fuel consumption and emissions of harmful substances, but also to reduce its noise level.

2. Internal combustion engine as a source of noise
One of the main sources of vehicle noise is its engine. The internal combustion engine is a complex source of noise, as its individual sources have different nature.

In the overall acoustic balance of the vehicle, aerodynamic noise exceeds the structure-borne noise value, but its level can be reduced by installing silencers in the intake and exhaust systems [1].

It is very difficult to reduce structure-borne noise because its sources have different origins. Working process and piston shift are the most important sources of the structure-borne noise.

There are various ways to decrease the engine structure-borne noise, which include improvement of working process and engine design or implementation of special measures for additional noise insulation of the engine. One of the methods of the working process modification is the use of alternative fuels [1]. Noise reduction occurs as a result of decreasing the combustion process toughness, that is, the pressure growth rate in the cylinder.

To assess the impact of alternative fuels on the engine noise level, computational and experimental studies were performed at the Department of Thermal Science and Automotive Engines of MADI. Some results of these studies are presented in this article.
3. Methods of modeling and experimental research of engine noise

Currently, taking into account the development of information technology, all engine research is carried out within a single information space. This approach allows to reduce research time and to improve the quality of the results. At the same time, different methods and software for noise calculation should be used at different stages of the design. At the initial stage, quite simplified models and empirical formulas are used, and at the stage of detailed design development, three-dimensional models and finite methods, boundary elements, etc. must be used.

Calculations of the sound power of the engine were performed using the method developed at the Department of Thermal Science and Automotive Engines of MADI [2], which includes the following stages: engine layout parameters formation, calculation of its working cycle, noise modeling and calculation.

The sound power of the engine is calculated by the formula:

\[ P_w(kf_0) = z_S(kf_0) \cdot \rho \cdot c \cdot S_{ICE} \cdot \eta(kf_0) \cdot \left( \frac{\sqrt{2}}{2} \cdot S_{ICE} \right) \]

where:
- \( z_S(kf_0) \) – relative coefficient of resistance to radiation normalized by the area of the outer surfaces of the engine;
- \( \rho \) – air density;
- \( c \) – sound speed in the air;
- \( \rho c \) – wave resistance of the air;
- \( S_{ICE} \) – engine outer surfaces area;
- \( \sqrt{2} \cdot S_{ICE} \) – average squared effective vibration velocity on the outer surface.

The engine is modeled by an equivalent cylindric shell on condition of equality of its masses, lengths and surface area. For the shell, the vibration velocity of its outer surface can be calculated by the formula:

\[ \tilde{v}_{e(S)}(kf_0) = \frac{1}{2\pi \cdot M_{ICE} \cdot T_0} \sum_{k=1}^{N} G^2(kf_0) \cdot \frac{1}{z_S(kf_0) \cdot \eta(kf_0) \cdot (kf_0)} \]

where:
- \( k \) – ordinal number of harmonic;
- \( G(kf_0) \) – spectral density of the load factor at the frequency of the \( k \)th harmonic (N·s);
- \( T_0 = \frac{30\tau}{n} \) – working cycles sequence period (s);
- \( \tau \) – engine cycle factor;
- \( f_0 = \frac{60}{n} \) – crankshaft rotation frequency (Hz);
- \( n \) – number of crankshaft revolutions per minute (rpm);
- \( A \) – number of the lower harmonic of the load factor (provided that \( f_0 \) is the first);
- \( N \) – number of the highest harmonic of the load factor (provided that \( f_0 \) is the first).

Experimental noise measurements were carried out using the hardware-software complex LMS Pimento (figure 1) in compliance with the standard methodology (GOST R 53838-2010, GOST R 51401-99).

4. Results of engine structural noise research when it is running on alternative fuels

Currently, the use of natural gas as a motor fuel is a relevant challenge in the engine industry, so the work on conversion of diesel engines to operate on gas fuel has been and continues to be carried out in MADI [3–5].

An 8-cylinder (D = 12 cm, S = 12 cm) diesel engine was converted to spark ignition (SI) natural gas engine. The main results of the noise measurements for the original diesel and converted SI gas engine are shown in figure 2 and figure 3.

Thus, conversion of the diesel engine to SI gas engine enabled to decrease it noise throughout the speed range by 3...6 dBA.

Comparison of spectra of indicator diagrams (figure 3) in the mid- and high-frequency regions showed a significant decrease in the values of spectral components, which led to the decrease in the overall noise level of the engine.

In one more work performed at the Department, a 6-cylinder diesel engine (D = 10.7 cm, S = 12.4 cm) was converted to gas-diesel process, the compression ratio remained unchanged [3, 4]. The results are shown in figures 4–6.
Figure 1. Scheme of the experimental setup:
1 – measuring surface in the shape of a rectangular parallelepiped; 2 – envelope rectangular parallelepiped; 3 – microphone; 4 – engine; 5 – hardware-software complex LMS Pimento; 6 – computer

Figure 2. Overall noise levels of working cycles of diesel and SI gas versions of the 8-cylinder engine
Figure 3. The spectra of indicator diagrams of working cycles of diesel and SI gas versions of the 8-cylinder engine at n = 2200 rpm

Figure 4. Overall noise levels of diesel and gas-diesel versions of the 6-cylinder engine

Figure 5. The sound power spectra of diesel and gas-diesel versions of the 6-cylinder engine at n = 1420 rpm
Figure 6. The sound power spectra of the 6-cylinder engine for working cycles of diesel and gas-diesel at $n = 1625$ rpm

As a result, the noise level of the 6-cylinder engine also decreased by 0.6...2.0 dB, which is significantly less than of the 8-cylinder engine. This is caused by the use of a common-rail fuel system on the original diesel engine, which provides a lower noise level compared to the traditional split-type fuel system, and preservation of the compression ratio, which generally reduces the influence of alternative fuel on the toughness of the working process.

Research carried out at the Department [6–12] showed the possibility of flexible control of fuel injection characteristics when using the CommonRail system. As a result, the harshness of the working process of the diesel can be reduced, which also reduces the diesel noise level.

The Department works on the use of mixed fuels in diesel [13–15], one of which is water-fuel emulsion.

The research of the influence of the water-fuel ratio in the emulsion on engine noise level was performed for a 4-cylinder diesel engine ($D = 11$ cm, $S = 12.5$ cm). The results are shown in figures 7–9.

Figure 7. Overall noise levels of the 4-cylinder engine for mixed fuel having different composition
Figure 8. Overall noise levels of the 4-cylinder engine for mixed fuel having different composition at $n = 1700$ rpm

The overall sound power level for all the emulsion compositions investigated increased when rising of the engine speed. At the same time, the lowest noise corresponds to the pure diesel fuel, and the highest – to the mixture of 70 % of diesel fuel and 30 % of water.

The noise grows when rising the proportion of water in the mixture, which is caused by the increase of the ignition delay period at the same injection advance angle and, as a consequence, by the increase of the combustion process toughness.

Figure 9. The sound power spectra of the 4-cylinder engine for mixed fuel having different composition at $n = 2400$ rpm
5. Conclusion
1. The results of conversion of the diesel engine for operation on gas fuel showed that the use of this fuel can significantly reduce the engine noise level.

   The noise of the 8-cylinder diesel engine after its conversion to spark ignition gas engine decreased by 3...6 dBA. It is caused by decrease in the toughness of its working process.

   After conversion of the 6-cylinder diesel engine to the gas-diesel engine, its noise decreased by 0.6…2 dB. There is little variation in the overall level of noise due to the use of the common-rail fuel system and preservation of the compression ratio of the original diesel engine during conversion.

2. The use of a water-fuel emulsion as a fuel in the 4-cylinder diesel engine maintaining the same value of the injection advance angle, led to the increase in the noise level due to the growth of the ignition delay period. Thus, to reduce the noise when using such a fuel, correction of the injection advance angle is required.

References
[1] Shatrov M G, Yakovenko A L and Krichevskaya T Y 2014 Noise of automobile internal combustion engines (Moscow: MADI) 68 p
[2] Shatrov M G and Yakovenko A L 2009 Vestnik Moskovskogo avtomobil’nogo-dorozhnogo gosudarstvennogo teknicheskogo universiteta (MADI) 1(16) 10–8
[3] Shatrov M G, Sinyavski V V, Dunin A Yu, Shishlov I G, Vakulenko A V and Yakovenko A L 2018 Using simulation for development of the systems of automobile gas diesel engine and its operation control Int. J. of Engineer. and Technol. 7(2.28) 288–95
[4] Shatrov M G, Sinyavski V V, Dunin A Y, Shishlov I G and Vakulenko A V 2017 Method of conversion of high- and middle-speed diesel engines into gas diesel engines. Facta Univer. Ser. Mechan. Engineer. 15(3) 383–95
[5] Shatrov M G, Khachiyan A S, Sinyavskij V V and Shishlov I G 2013 Transp. na al’ternat. toplive 4 29–32
[6] Shatrov M G, Golubkov L N, Dunin A U, Yakovenko A L and Dushkin P V 2015 Influence of high injection pressure on fuel injection performances and diesel engine working process Thermal Sci. 19(6) 2245–53
[7] Shatrov M G, Golubkov L N, Dunin A U, Yakovenko A L and Dushkin P V 2015 Research of the injection pressure 2000 bar and more on diesel engine parameters Int. J. of Appl. Res. 10(20) 41098–102
[8] Shatrov M G, Golubkov L N, Dunin A Yu, Dushkin P V and Yakovenko A L 2017 A method of control of injection rate shape by acting upon electromagnetic control valve of common rail injector Int. J. of Mechan. Engineer. and Technol. 8 issue 11 676–90
[9] Shatrov M G, Golubkov L N, Dunin A U, Dushkin P V and Yakovenko A L 2017 The new generation of common rail fuel injection system for Russian locomotive diesel engines Pollution Res. 36(3) 678–84
[10] Shatrov M G, Malchuk V I, Dunin A U and Yakovenko A L 2016 The influence of location of input edges of injection holes on hydraulic characteristics of injector the diesel fuel system Int. J. of Appl. Engineer. Res. 11(20) 10267–73
[11] Shatrov M G, Malchuk V I, Dunin A Y, Shishlov I G and Sinyavski V V 2018 A control method of fuel distribution by combustion chamber zones and its dependence on injection conditions Thermal Sci. 22(5) 1425–34
[12] Shatrov M G, Golubkov L N, Dunin A U, Yakovenko A L and Dushkin P V 2016 Experimental research of hydrodynamic effects in common rail fuel system in case of multiple injection Int. J. of Appl. Engineer. Res. 11(10) 6949–53
[13] Shatrov M G, Dunin A U, Yakovenko A L and Eziev A A 2013 Avtomobil’ i Elektronika. Sovremennye Tekhnologii 2 123
[14] Shatrov M G, Kudryashov B A, Dunin A U, Eziev A A and Livanskij A N 2013 Izvestiya Volgograd. Gosudarstv. Tekhnich. Univer. Ser. Nazemnye transport. Sist. 7(21) 62–6
[15] Mal’chuk V I, Shatrov M G and Dunin A Yu 2007 Trakt. i sel’skohozyajstv. mashiny 4 34–7