MOBILITY & VEHICLE MECHANICS

DOI: 10.24874/mvm.2018.44.02.03
UDC: 534.836

METHOD AND SOME RESULTS OF INVESTIGATION OF STRUCTURE-BORNE NOISE OF DIESEL ENGINE AT ACCELERATION MODE

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Received in August: 2018 Accepted: September 2018

RESEARCH ARTICLE

ABSTRACT: A vehicle engine operates most time at transient modes. Therefore the problem of engine noise investigation in real-life operation conditions is important. The paper presents a method and results of calculation of the engine structure-borne noise at transient operation mode using the components of the IC Engines Single Informational Environment. Investigation of the noise of the V8 120/120 mm diesel engine at the acceleration mode was carried out. The transient mode was presented as an ensemble of steady modes for which the working cycle was calculated and noise calculation was carried out successively. Finally the engine acceleration performance was formed. Analysis of the investigation results demonstrated that at the acceleration mode, the diesel engine noise was by 1.5-2.0 dBA higher than at the similar engine speeds at stationary conditions. It was determined that the basic factors which cause the difference in the diesel engine acoustic performances at the acceleration mode were the injection start angle, ignition delay period, thermal inertia of engine parts and some others. Consequently the pressure rise rate in the cylinder increases which causes the engine noise growth.

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The approach presented in the paper enables to forecast the engine acoustic performance during its development and perfection.

KEY WORDS: structure-borne noise, diesel engine, transient mode, acceleration mode, sound power

METOD I NEKI REZULTATI ISPITIVANJA STRUKTURNE BUKE DIZEL MOTORA U REŽIMU UBRZAVANJA

REZIME: Motor vozila uglavnom radi u tranzijentnim režimima rada. Stoga je problem istraživanja buke motora u stvarnim uslovima vožnje važan. Ovaj rad prezentuje metod i rezultate izračunavanja strukturne buke motora u tranzijentnim uslovima korišćenjem komponenata jedinstvenog informacionog okruženja IC motora. Izvršeno je proučavanje buke V8 120/120 mm dizel motora u režimu ubrzavanja. Tranzijentni režim je predstavljen kao skup stabilnih modova za koje je radni ciklus sračunat i procena buke je izvršena sukscesivno. Na kraju su formirane performanse ubrzavanja motora. Analiza proučavanih rezultata pokazuje da je u režimu ubrzavanja, buka dizel motora veća za oko 1.5-2.0 dBA nego kod sličnog motora u stacionarnim uslovima. Utvrđeno je da su osnovni faktori koji utiču na razlike u zvučnim performansama dizel motora u režimu ubrzavanja ugao startovanja injektora, period odlaganja paljenja, termička inercija delova motora i drugo. Iz tog razloga se povećava stopa podizanja pritiska u cilindru što uzrokuje rast buke motora. Pristup prikazan u ovom radu omogućava predviđanje akustičkih performansi motora tokom njegovog razvoja i perfekcije.

KLJUČNE REČI: strukturna buka motora, dizel motor, tranzijentni režim, režim ubrzavanja, zvučna snaga

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1. INTRODUCTION

The relevance of reducing the noise of road transport increases with the growth of the engine power augmentation.

Operation mode exerts a great influence on the noise level of the engine. In urban traffic, the vehicle is moving at variable speed a significant part of the time. Therefore, the search for effective solutions to reduce engine noise at a transient mode, especially during acceleration, requires the development of appropriate modelling techniques.

It should be noted that the measurement of the external noise level of the vehicle according to GOST 41.51-2004 is carried out on a section of the road by a special method at the acceleration mode.

2. THE MODEL OF FORMATION OF STRUCTURE-BORNE NOISE OF THE INTERNAL COMBUSTION ENGINE

With appropriate design solutions that provide a specified level of aerodynamic noise, the main noise in the internal combustion engine (ICE) is its structure-borne noise.

Its level is influenced by excitatory factors: the working process, piston tilting, etc., specific freatures of the design, as well as its radiating properties.

In accordance with this, the mathematical model of structure-borne noise of ICE, formed at the Department "Heat Engineering and Automotive Engines" of MADI, proposes the following steps for its implementation.

2.1 Engine working process modelling

The model used to calculate the working cycle of an internal combustion engine takes into account the actual chemical composition of the working fluid, heat exchange processes in the cylinder, dependence of the heat capacity of the working medium on temperature, heat release characteristics, parameters of the timing mechanism (diameter and number of valves, their flow sections, valve timing), calculation of gas exchange processes. Heat release characteristic is calculated according to the method of I. Viebe.

It does not work out in detail oscillatory processes in the manifold and the mixing process. Surface temperatures in the cylinder depend only on the operation mode of the engine, the size and material of the parts. For calculation of heat-transfer processes, the G. Voschni model [1] which has proved many times its efficiency is used.

2.2 Engine structure modelling

When calculating structure-borne noise, a number of mass-geometric parameters of the structure is used: weight, length and area of the external surfaces of the engine. Simplified analytical models, as well as three-dimensional models of the engine structure, can be used to calculate these parameters depending on the design stage [2]. The use of three-dimensional modeling can improve the quality of information about the engine, visualize its design and individual parts. The use of parameterization in the development of models makes it possible to change rapidly the design and evaluate the results of changes.

In the model of structure-borne noise, the engine emission, the properties of its design are integrated into an equivalent cylindrical shell, for which the oscillatory characteristics are known. Equivalence conditions are: equality of mass, length and area of the outer surface of the engine and of such a shell [3].

2.3 Simulation of engine structure-borne noise from individual sources

To simulate the structure-borne noise of the engine, a physical model is proposed, according to which the sound power is emitted by its oscillating outer surfaces under the influence of exciting force factors [3].

Calculation of sound power is carried out by the formula

$$P_w(kf_0) = z_s(kf_0) \cdot \rho c \cdot S_{ICE} \bar{v}^2_{e(S)}(kf_0) \qquad (1)$$

$z_S\,(kf_0)$ - normalized by the area of the outer surfaces of the engine S_{ICE} relative coefficient of resistance to radiation; ρ - air density; c - speed of sound in the air; ρc - wave resistance of the air; S_{ICE} - area of the outer surfaces of the engine; $\bar{v}^2_{e(S)}(kf_0)$- the average squared effective vibration velocity on the outer surface; k - counting number of harmonics; f_0 - crankshaft speed.

The vibration velocity of the outer surface is calculated by the formula

$$\bar{v}^2_{e(S)}(kf_0) = \frac{1}{2\pi \cdot M_{ICE} \cdot T^2} \sum_{K=A}^{N} G^2(kf_0) \frac{1}{z_v(kf_0) \cdot \eta \cdot (kf_0) \cdot (kf_0)} \qquad (2)$$

$G(kf_0)$ - spectral density of the force factor at the frequency of the k^{th} harmonic; T - working cycle follow-up period;

A - number of the lowest harmonic force factor (provided that the first is f_0); N - number of the highest harmonic force factor (provided that the first is f_0); M_{ICE} – mass of the engine; $\eta(kf_0)$ - inelastic loss ratio; $z_V(kf_0)$ - input resistance of engine design.

Equivalent cylindrical shell model is used to calculate the resistance of the engine structure.

It was found that the most active sources of structure-borne noise are the working process and piston tilting. For each of these sources, mathematical model was developed to calculate their force factor and its spectral density.

The presented technique was tested experimentally when assessing the noise level of the V8 120/120 mm diesel by the full-load performance (Figure 1). The discrepancy between the calculated and measured sound power levels was 0.5 ... 2.0 dB, which is sufficient accuracy for vibroacoustic studies.

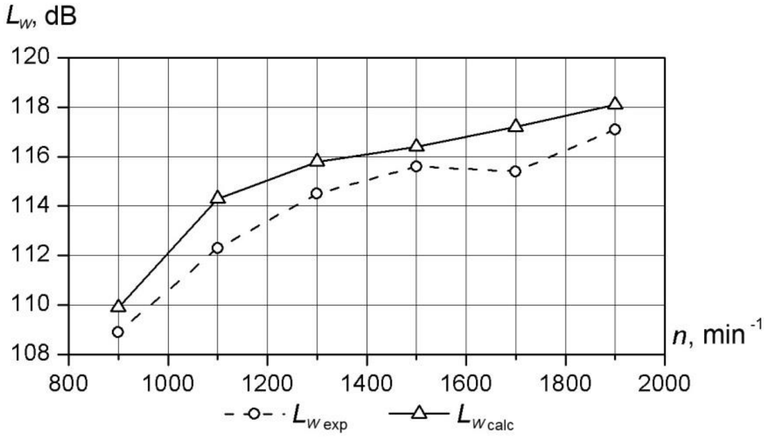

Figure 1. Calculated and experimental structure-borne noise levels of the V8 120/120 mm diesel by the full-load performance

3. ASPECTS OF MODELLING OF WORKING PROCESS AT THE TRANSIENT MODE

In case of unsteady operation of the engine and continuous variation of its speed compared to the stationary mode, the main difference is observed in the organization of the working process. This stipulates the need for changing the method of modelling of structure-borne noise of the internal combustion engine in these conditions. Taking into account a high dynamics of the working process of the diesel engine in comparison with the spark ignition engine, the study of the structure-borne noise of the diesel engine in transient conditions is more relevant.

Analysis of the working process of the diesel engine in transient conditions stipulates the need to take into account the features of the processes occurring in the cylinder: fuel and air supply, mixing, combustion and heat transfer with a continuous variation of speed.

The main factors affecting the working process of the diesel engine at the transient mode are:

- the amount of fuel supplied to the cylinder during the ignition delay period;
- fuel injection characteristics;
- thermal state of the engine parts forming the combustion chamber.

When the engine is running at transient mode (TM), characteristics of fuel injection in comparison with the same speed at the steady-state mode (SSM) change. For different types of fuel systems, this can be caused by different reasons. In traditional fuel equipment, there are oscillations of the fuel pump rack, and in Common Rail fuel systems – wave propagation effects in the rail and fuel lines.

With an increase of the engine speed, the delay period of the ignition increases up to the state when the entire cycle fuel portion is injected during this period, which results in the increase of the rate of pressure growth in the cylinder and the noise level of the ICE, respectively. Also at TM, there are problems with supply of air to the cylinder due to its excessive turbulence in the manifold. This is especially evident in turbocharged diesel engines as the turbocharger has a certain inertia. As a result, composition of the fuel-air mixture at the transient mode differs from the steady state.

The process of heat transfer to the walls of the combustion chamber also affects the character of the change of pressure in the cylinder. It depends on the temperatures of surfaces forming the combustion chamber. It was established in [4] that at the same speeds, the combustion chamber walls temperatures for TM and SSM are different due to thermal inertia of the engine body parts.

4. FEATURES OF THE METHOD OF MODELLING THE STRUCTURE-BORNE NOISE OF INTERNAL COMBUSTION ENGINES AT THE TRANSIENT MODE

At the Department "Heat Engineering and Automotive Engines" of MADI, a method of modelling and calculation of structure-borne noise of the internal combustion engine at the transient mode was developed.

The method includes the following steps (Figure 2):

- Formation of conceptual parameters of the engine. The following input data are used: engine type (diesel or spark ignition engine), cylinder diameter *D*, piston stroke *S*, compression ratio *ε*, etc.
- Modeling of internal combustion engines. It is performed depending on the degree of study of the engine design or using analytical dependencies or three-dimensional models. As a result, the required mass-geometric parameters (mass M_{ICE}, the area of the outer surface S_{ICE} and the length of the engine L_{ICE}, the material parameters of the structure) are determined which are also transmitted to the subsystem for noise calculation.
- Calculation of the working cycle taking into account the transient process. In this case, the transient process itself is quasi-stationary. In this case, the difference between calculation of the cycle from the traditional stationary mode lies in taking into account the changes of individual factors: fuel supply, thermal state of the parts forming the combustion chamber. The following input data are assigned depending on the time of the HP fuel pump rack movement *h*, engine speed *n*, temperature *t*.

For naturally aspirated engines with conventional fuel equipment, appropriate algorithms for calculating the changes in the specified factors were proposed [4].

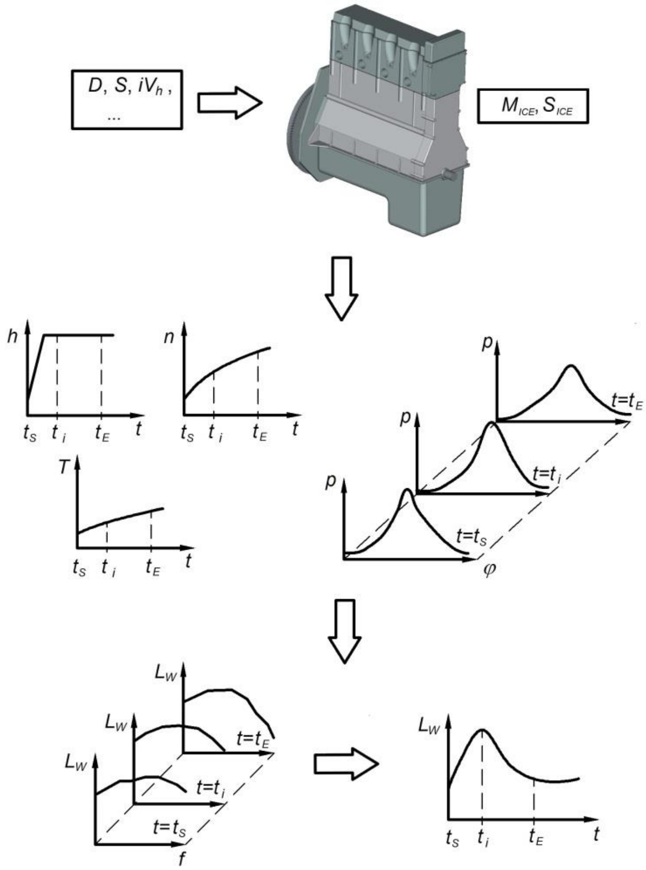

Figure 2. The sequence of calculation of structure-borne noise at the transient mode

However, for modern turbocharged diesel engines with Common Rail fuel systems, the methods of calculating the injection characteristics and the thermal state at the transient mode only have to be formed, they require experimental data on the transient process of the diesel engine. Research in this field is currently performed at the Department.

Therefore, at present, for a given time interval from nS (tS) to nE (tE) for each selected engine speed (timepoint) of a quasi-stationary transient mode, calculation of the working cycle is performed and the indicator diagram is determined. Then the totality of the obtained data is transferred to the ICE CAD subsystem for noise calculation.

- Calculation of spectrum and total sound power levels of the main engine noise sources. At this stage, the existing model of formation of structure-borne noise from the working process and piston tilting for the stationary mode is applied, which is implemented in the corresponding ICE CAD subsystem.

First, calculation of the spectrum and overall sound power level for each engine speed comprising the transient process is carried out. Then, using the dependence of the speed variation on time and the set of spectrum and noise levels obtained for each mode, a graph of the change in the acoustic characteristics of the engine depending on time or engine speed at the transient mode is formed.

5. CALCULATION OF THE STRUCTURAL NOISE OF THE V8 120/120 MM DIESEL ENGINE AT THE ACCELERATION MODE

Using the developed technique, calculation of the noise level of the V8 120/120 mm diesel engine for acceleration mode by the full-load performance was made.

Experimentally determined parameters of the engine [4] describing the transient process were used as input data.

With the use of a set of input data, calculation of the working cycle of the diesel engine for a number of modes of its operation by the full-load preformence was carried out. After that, the noise level of the V8 120/120 mm diesel engine was estimated at the acceleration mode, the spectrum and the overall sound power levels were determined (Figure 3).

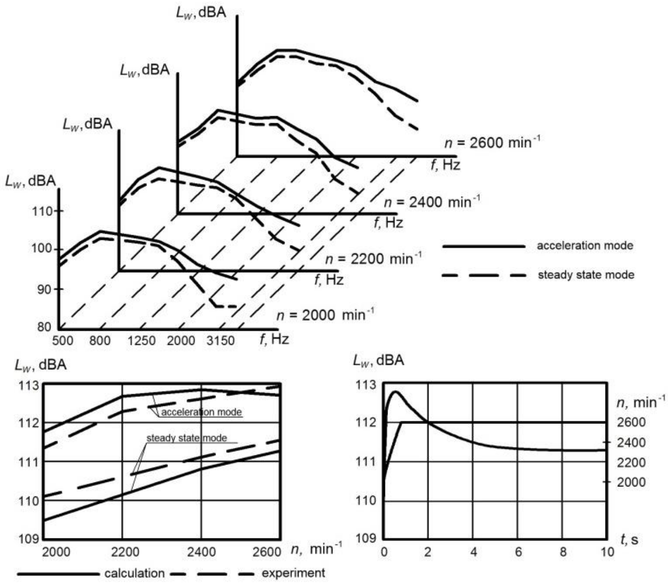

Figure 3 The results of calculation of the noise level of the V8 120/120 mm diesel engine for acceleration mode by the full-load performance

Analysis of the calculation results showed that the noise level during acceleration by the full-load performance is by 1.5 ... 2.5 dBA higher compared to similar speeds at the steady state.

6. CONCLUSIONS

The method of modelling of the structure-borne noise of the engine in the transient mode is described.

Specific features of calculation of structure-borne noise emissions of a diesel engine in the transient mode were worked out in detailes.

Parameters of the transient process of the V8 120/120 mm diesel engine were obtained experimentally and its noise levels were calculated which showed the divergence of the noise levels for steady-state and transient modes by 1.5...2.5 dBA.

REFERENCES

[1] Lukanin, V., Shatrov, M., Krichevskaya T., etc.: "Internal combustion engine. In 3 Books. Book 3. Computer workshop, Modeling of processes in internal combustion engines: Textbook for universities", 3rd ed., 2007, Moscow, 414 p.

[2] Shatrov, M., Yakovenko, A.: "Methods and some results of calculation of the internal combustion engine structural noise for the formation of components of a single information space of the" ice", Vestnik MADI (GTU), Vol. 1, No. 16, 2009, Moscow, pp 10-18.

[3] Shatrov M.: "Formation of components of a single information space to ensure the life cycle of internal combustion engines", dissertation of doctor of technical Sciences, 2007, MADI (GTU), 403 p.

[4] Gadir, N.: "Analysis of the processes of formation of diesel noise on unsteady modes of operation and development of measures to reduce it", dissertation of candidate of technical Sciences, 1991, MADI (GTU), 135 p.

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