MATHEMATICAL DESCRIPTION OF VIBRO-ACOUSTIC PROCESSES OF INTERNAL COMBUSTION ENGINE

МАТЕМАТИЧЕСКОЕ ОПИСАНИЕ ВИБРОАКУСТИЧЕСКИХ ПРОСЕССОВ ДВС

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Abstract:*An internal combustion engine is considered as a material body, which characterized by inertial, elastic and dissipation properties, which are impacted from various forces. Oscillatory motion of a material body occurs in accordance with spectral characteristics of force and frequency responses of the system. The outer surface of the engine generates acoustic energy and causes mechanical noises.*

The paper dwells on determining acoustic energy in accordance with the acoustical radiation rate if the radiation coefficient of the object observed is known. Also, the sound of the engine is presented as a sum of its separate acoustic powers, and there is determined the acoustic radiation coefficient of the engine for the entire surface, by using the acoustic radiation coefficient of each surface. Simultaneously, there is determined the vibro-energy distribution in the engine design, the assessment of which is made by means of the energy-transfer coefficient, which generates the frequency responses of vibro-acoustic parameters.

KEY WORDS: INTERNAL COMBUSTION ENGINE; MATERIAL BODY; VIBRO-ACOUSTICS; OSCILLATORY MOTION; NOISE; SPECTRAL CHARACTERISTIC; ACOUSTIC RADIATION COEFFCICIENT.

1. Introduction

Specific design features and operating modes of mechanisms and details have significant effect on the level of engine noise.

The level of engine noise during operation at nominal mode is quite high and reaches 95-118 dB. Changes of the camshaft rotational frequency from the minimal to maximal value cause a sharp increase of noise level to 12-20 dB, but increasing the load for the engines running on petrol – to 6-8 dB, and for diesels – to 1-2 dB [1].

At the same time, variation or pressure in the cylinders and vibro-energies caused by impact impulses during operation of mechanisms and details are unevenly distributed in the engine design and cause the various-frequency vibrations of the outer surfaces of engine, so the mentioned surfaces radiate the various-frequency acoustic energy. Hence, there takes place formation of the very active elementary surfaces, which represent the main source of structure-borne noises [2].

2. Preconditions and means for resolving the problem

That is why it becomes necessary to determine the impact of structure-borne noise on the value of engine general noise. In this regard, an internal combustion engine is considered as a material body, which characterized by inertial, elastic and dissipation properties, which are impacted from F(t) force. Therefore, spectral characteristics of force and frequency responses of the system cause oscillatory motion of a material body. The oscillation of the studying engine's outer surface radiates acoustic energy. Simultaneously, it is known that acoustic radiation energy is determined by the radiation rate. If the acoustic radiation coefficient studying object is known, then the radiation power during operation of engine is determined by the formula [3]:

$$W_m = \sigma \cdot \rho C \cdot S \cdot V^2$$

where, W_m–radiation acoustic power, W;
σ - radiation coefficient;
ρC- medium acoustic resistivity, kg/(m^{2}sec),ρC = 400;
S - the area of radiation surface, m^2;
V^2–root-mean-square vibration velocity, m/sec.

We shall name the square of root-mean-square area radiation the vibration velocity reduced to the engine surface. Therefore,

$$B = S \cdot \mathrm{V}^2,$$

where, B - is a vibration velocity reduced to the surface.

The engine noise can be represented in the form of the sum of acoustic powers of separate surfaces

$$W_m = \sum_{i=1}^{i_0} W_i ,$$

where,W_m–is the of engine radiation acoustic power, W;
i_0–surface quantity , by which the outer surface of engine is divided;
W_i - acoustic power irradiated by the i-thsurface of engine, W.

We shall represent the second formula in the following form:

$$\sigma_m \cdot \rho \cdot C \cdot S_m \cdot \tilde{V}_m^2 = \sum_{i=1}^{i_0} \sigma_i \cdot \rho \cdot C \cdot S_i \cdot \tilde{V}_i^2 ,$$

where, σ_m–engine radiation coefficient;
S_m–the area of engine's outer surface, m^2;
$\tilde{V}_m^2$ - root-mean-square vibration velocity of the entire surface of engine, m/sec;
σ_i – i-th surface radiation coefficient;
S_i – the area of i -th surface, m^2;
$\tilde{V}_i^2$ – i-th surfaceroot-mean-square vibration velocity, m/sec.

If the engine's acoustic power is known, the area of the entire surface and root-mean-square vibration velocity of this surface, then the engine's radiation coefficient is derived from the equation (1):

$$\sigma_m = \frac{W_m}{(\rho \cdot C \cdot S_m \cdot \tilde{V}_m^2)} ,$$

and

$$S_m = \sum_{i=1}^{i_0} S_i$$

Based on the basic acoustic theory, with high enough accuracy, the engine's radiation coefficient can be considered equal to the vibro-acoustic surface radiation coefficient, which has the maximum acoustic power, that is the engine's radiation coefficient σ_m is equal to radiation coefficient $\sigma_{i\,max,}$, which characterizes the maximum "noisy" acoustic radiation, then

$$W_i = \sigma_m \cdot \rho \cdot C \cdot S_i \cdot \tilde{V}_i^2 ,$$

The maximum "noisy" acoustic radiation is determined by the maximum values of $S_i \cdot \tilde{V}_i^2$.

The root-mean-square vibration velocity of a given surface can be determined by measuring the vibration velocity level on this surface, then

$$\tilde{V}_i^2 = \frac{1}{K_i}\left(V_0^2 \sum_{i=}^{K_i} 10^{0,1L_{ViK}}\right)$$

where, K_i –is the number of points measured by the vibration velocity logarithmic level for this surface;
$V_0 = 5\cdot10^{-8}$–the vibration velocity ultimate value, m/sec;
L_{ViK}– the vibration velocity logarithmic level at K point on the i-th surface, dB.

The equation shown in parentheses of the formula (3) is the sum of the squares of the vibration velocity at all points. We shall designate:

$$C_i = V_0^2 \sum_{i=1}^{K_i} 10^{0,1L_{ViK}} = \tilde{V}_i^2 \cdot K_i$$

where, C_i–is the sum of the squares of the vibration velocity at all points of the i-th surface, m^2/sec^2.

Then, the root-mean-square vibration velocity of the entire surface of engine for the root-mean-square of the vibration velocities of the known separate surfaces will have the following form:

$$\tilde{V}_S^2 = \sum_{i=1}^{i_0} C_i \Big/ \sum_{i=1}^{i_0} K_i = C_m/K_m$$

where, C_m - is the sum of the squares of the vibration velocity at all points, m^2/sec^2;
K_m - the number of the vibration velocity points to be measured on the engine's entire surface.

Assessment of the acoustic radiation is carried out by means of the acoustic power, which represents an absolute integral characteristic of studying object in a special-purpose semispherical chamber. When measuring the engine noise, the level of acoustic power in the free field on its reflecting plane is measured as follows:

$$L_W = L_P - 10\left(\frac{1}{2\pi r^2} + \frac{4}{A}\right),$$

where,L_W–is a level of acoustic power, dB;
L_P–average level of measuring surface at all points, dB;
r–the radius of measuring semi-sphere, m;
A–the area equivalent to acoustic absorber, m^2.

Average level of the engine's acoustic pressure at the values of the corrected braking is determined by the equation:

$$L'_P = 10lg\left(10^{0,1L_P} - 10^{0,1L''_P}\right),$$

where, L'_P - is an average level of the engine's acoustic pressure at the values of the corrected braking, dB;
L''_P - an average level of the acoustic pressure at braking, dB.

Finally, taking into account the noise braking, the level of the engine's acoustic pressure and the acoustic pressure in the frequency band are determined as follows:

$$L_W = L''_P - 10lg\left(\frac{1}{2\pi r^2} + \frac{4}{A}\right)$$

and

$$W = 10^{0,1L_W} \cdot W_0,$$

where, W_0=10^{-12}–acoustic power ultimate value, W.

The impact variable forces arisen during operation of engine cause the engine vibration due to the existence of gaps in different mechanisms and varied direction. As a whole, the engine can be represented as a body oscillating toward the basis (mountings), and transfers vibration energy to the frame of the vehicle, which causes oscillation and vibration of a certain mass of the vehicle. In order to assess efficiency of the engine mounting pillows or vibration energy transferred to the frame, which is a source of noise, it is necessary to consider the notion of the energy transfer coefficient, which is determined as follows

$$W_W = \frac{F_x(t)}{F_y(t)} = \frac{F_x(j\omega)}{F_y(j\omega)} = W_W(j\omega),$$

where, $F_x(t)$–is a total force on the engine design, and characterized by complex-nature variability. Its determining is impossible analytically. Thus, to determine a total force it is necessary to determine the force of each excitation source during operation of engine.

$F_y(t)$–is a force, which is excited by oscillation arisen on the frame of the vehicle. Therefore, the motion of oscillation system depends on the acting force properties, which is excited by the action of various sources, and on the engine design features and geometric geometrical sizes.

3. Conclusion

Thus and so, the system's transfer coefficient can be determined not only under the action of outer harmonic inputs, but by the action of complex spectrums of the acyclic processes on the input and output of the system. So, in order to analyze the vibration energy output impulses in the studying system, it is necessary to know the value of the system's transfer coefficient $W_W(j\omega)$, which can be determined during the outer harmonic inputs, when determining the value $W_W(j\omega)$for some given conditions, and when we know the variability regularities of the acting force impulse dependent on the time, then we can determine its complex spectrum $F_y(j\omega)$, and then the reaction of complex spectrum

$$F_x(j\omega) = W_W(j\omega) \cdot F_y(j\omega)$$

Thus and so, in order to determine the transfer coefficient of vibration energy radiated by the separate surfaces of engine, it is necessary:

1. To determine the engine's radiation coefficient and vibro-frequency responses of energy;
2. To identify the surface of the maximal value $S_i\tilde{V}_i^2$, which among all surfaces is characterized by generation of a high acoustic power;
3. The radiation coefficient of the given surface equals the engine's radiation coefficient, and the engine noise power is determined by the formula (1);
4. To determine the vibro-frequency responses of vibration energy on the frame of the vehicle.

4. Literature

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