DETERMINING THE INFLUENCE OF VIBRO-ENERGY OF INTERNAL COMBUSTION ENGINE ON CAR SUPPORTS AND FRAME

ОПРЕДЕЛЕНИЕ ВЛИЯНИЯ ВИБРОЭНЕРГИИ ДВС НА ОПОРЫ И РАМУ АВТОМОБИЛЯ

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Abstract: *When the internal combustion engine operates there are arising forces acting on the supporting elements, and by both value and sign they represent variable forces. They vary depending on time, depend significantly on load conditions of engine and are characterized by different vibro-frequency energies. These energies are unevenly distributed due to fact that the engine design comprises the elements having inertial, flexural and dissipative properties, frequency characteristics of which often vary within a wide range.. The paper describes the method for determining frequency characteristic of vibro-energy transferred to the frame by introducing the vibro-energy transfer coefficient, which allows for determining frequency characteristics of vibro-energy transferred to the frame, on the basis of which, in turn, it becomes possible to determine efficiency of bearing shoes.*

KEY WORDS: *INTERNAL COMBUSTION ENGINE, VIBRO-ENERGY, FREQUENSY CHARACTERISTIC, NOISE LEVEL, VIBRO-ENERGY TRANSFER COEFFICIENT*

The vehicle's reciprocating internal combustion engines, their details and mounts are of complex design, thus the engine weight distribution law in horizontal, vertical and any other direction is of a very complex nature. The flexural properties and energy dissipation are also unevenly distributed. Such design properties lead to considerable propagation of vibro-pulses caused by impact and operation processes during the motion of the engine details and mounts. The mentioned forces act on the supporting elements, and by both value and sign they represent variable forces. The value of their variation depends on both the engine rotational frequency and load conditions, the frequency characteristics of which often vary within a wide range. On the basis of oscillatory motion caused by forces arisen in a system, there are determined frequency characteristics of vibro-energy of the engine external surface influencing on a car frame by passing through the bearing shoes that in turn causes vibration of frame and increases the noise level as well as puts the engine bearing shoes and car frame out of order.

For describing and studying the frequency characteristics of the engine bearing shoes, it is possible to use the vibro-energy transfer function, which represents the ratio between the car frame vibro-energy and the engine vibro-energy. In this case, there is examined the influence of one system on another one by means of intermediate member (bearing shoes). If we name the pulse and energy of force acting on a system an external or entry action, which we denote by y(t) function, then the pattern of a system's studying parameters variation is considered with its output reaction, which we denote by x(t) function. So, the action of a system's input parameter y(t) and output reaction will be functionally linked by means of the appropriate operator Wφ. The mentioned operator determines the nature of transformation of input reaction action when moving through the system, and simultaneously, this operator can be both linear and nonlnear. The operative form of vibro-energy transformation in a system can be displayed as shown below:

(1) $$x(t) \to W_\varphi y(t)$$

In order to better analyze the vibration transfer coefficient, there has been examined a linear system, in other words, the system, which is described by the linear differential equations with constant coefficients and linear homogeneous operators, which has the following properties:

(2) $$\left.\begin{array}{l} W_\varphi[\sum_{i=1}^{n} y_i(t)]=\sum_{i=1}^{n} W_\varphi[y_i(t)] \\ W_\varphi[C\,y(t)]=CW_\varphi[y(t)] \end{array}\right\}$$

First of all, such a linear system is characterized by the impact of the external forces on the object under study. In general, the linear system can be described by differential indices of the *n*-th degree and constant coefficients

(3) $$\sum_{k=0}^{n} A_k \frac{d^k x}{dt^k} = \sum_{e=0}^{m} B_e \frac{d^e y}{dt^e} ,$$

where, n>m and it is assumed that $\frac{d^0}{dt^0} = 1$. When studying the linear system, the initial conditions are studied in the usual way, and the rest state is taken as an initial state of system, but the external impact is represented by a unit function or unit impulse. In this case, the system's output reaction takes the form of a unit function or a unit impulse function, accordingly. Let us consider passing of a simple harmonic motion through the linear system

(4) $$y(t) = Be^{j(\omega t+\varphi_1)} = Be^{j\omega t} \cdot e^{j\varphi_1} = \dot{B}e^{j\omega t}$$

where, complex amplitude $\dot{B} = Be^{j\varphi_1}$.

During steady-state operating conditions, the system's output reaction is of a harmonic nature as well

(5) $$x(t) = Ae^{j(\omega t+\varphi_2)} = Ae^{j\omega t} \cdot e^{j\varphi_2} = \dot{A}e^{j\omega t}$$

This equation represents a particular solution of the 3rd equation, and by inserting (3) and (5) equations, we obtain in the 3rd equation

(6) $$\dot{A}\sum_{k=0}^{n} A_k (j\omega)^k = \dot{B}\sum_{e=0}^{m} B_e (j\omega)^e$$

In the conditions of a simple harmonic motion of system, the ratio of the system's output and input complex amplitudes represents complex transfer coefficient of a linear system

(7) $$W_\varphi(j\omega) = \frac{\dot{A}}{\dot{B}} = \frac{A}{B} e^{j(\varphi_1+\varphi_2)} = \frac{\sum_{e=0}^{m} B_e (j\omega)^e}{\sum_{k=0}^{n} A_k (j\omega)^k} = \frac{Q(j\omega)}{P(j\omega)}$$

If $(\varphi_2 - \varphi_1) = \varphi$, then finally we obtain

(8) $$W_\varphi(j\omega) = \frac{A}{B} e^{j\varphi}$$

By (7) and (8) equations, we obtain

$$(9)\quad \left.\begin{aligned} \frac{A}{B} &= W_\varphi(j\omega) = \left|\frac{Q(j\omega)}{P(j\omega)}\right| \\ \varphi &= \arg W_\varphi(j\omega) = arg\frac{Q(j\omega)}{P(j\omega)} \end{aligned}\right\}$$

Consequently, it should be noted that the transfer coefficient module represents the ratio of harmonic amplitude of the system's output reaction (A) and input reaction of harmonic amplitude (B). This ratio depends on the frequency (ω) and is a system's amplitude characteristic $k(\omega)$. φ is a phase change of input and output harmonic process, thus the dependence $\varphi(\omega)$ represents a phase-frequency characteristic. Therefore, the linear system's complex transfer coefficient can written down in the following form

$$W_\varphi(j\omega) = k(\omega)e^{j\varphi(\omega)}$$

As could be seen from these equations, coefficient $W_\varphi(j\omega)$ represents sufficient characteristic of linear system.

If during the study of system, the external perturbation action is nonperiodic, then the output reaction will have several forms of nonperiodic process. But if both parts of motion equation takes integral transformation of one-sided basis for the initial zero conditions, then the complex spectrum is easily obtained for the appropriate processes like in case with the equation (9), and we obtain

$$\frac{F_x(j\omega)}{F_y(j\omega)} = \frac{Q(j\omega)}{P(j\omega)} = W_\varphi(j\omega)$$

Consequently, the energy transfer coefficient can be determined not only by the external harmonic impact, but as a ratio of complex spectra of nonperiodic processes between the input and ouput parameters. On that basis, we can conclude that in order to determine the energy transfer coefficient, it is necessary to determine first the frequency characteristic of interacted bodies, in this case - of the engine and car frame vibroenergy that, according to above stated yields a function characteristic of intermediate member (the engine's supporting shoe), in other words, in such case it is described by a transfer function.

When the engine operates, the oscillatory energy of the external surface for this case is written down in the following form

$$(10)\qquad y(t) = \frac{M_g}{2}\tilde{V}_{gj}^2$$

The oscillatory energy transferred to a car frame is determined as follows

$$(11)\qquad x(t) = \frac{M_e}{2}\tilde{V}_{ej}^2$$

where, M_g – engine gross weight, kg; $\tilde{V}_{gj}^2$ – vibro-speed of the engine's external surface, m.sec^{-1}; M_e – car frame weight, kg, which is subjected to the action of engine; $\tilde{V}_{ej}^2$ - vibro-speed of a car frame surface, m.sec^{-1}. Based on the acoustics theory, and with high enough accuracy, we may assume that the engine's sound radiation coefficient is equal to the surface radiation coefficient, which comprises the maximum sound power, in other words, radiation coefficient σ_g and the surface's maximum sound radiation energy σ_{max} are equal to each other, and then the engine's sound power is

$$(12)\qquad W_{gj} = \sigma_g \cdot \rho c S_g \cdot \tilde{V}_{gj}^2,$$

Also, if we assume that radiation coefficient of a car frame is equal to σ_c, then sound power of car is

$$(13)\qquad W_{cj} = \sigma_c \cdot \rho c S_c \cdot \tilde{V}_{cj}^2,$$

where, $\rho c = 400$ kg/m^{2}sec – is a specific acoustic impedance of the environment;

S – (m^2) – is a radiation surface area.

If by using the 12th and 13th formulas, we determine the effective speed of the engine and car frame and insert in the 10th and 11th equations, we obtain

$$y(t) = \frac{W_{gj}}{\sigma_g \cdot \rho c \cdot S_g}, \qquad x(t) = \frac{W_{cj}}{\sigma_c \cdot \rho c \cdot S_c}$$

but

$$(14)\qquad W_{\varphi(t)} = \frac{x(t)}{y(t)} = \frac{M_e}{M_g}\cdot\frac{\sigma_g}{\sigma_c}\cdot\frac{S_g}{S_c}\cdot\frac{W_{cj}}{W_{gj}}$$

If we denote that $m_e = \frac{M_e}{S_e}$ kg/m^2 and $m_g = \frac{M_g}{S_g}$ kg/m^2, then

$$W_{\varphi j} = \frac{m_e}{m_g}\cdot\frac{\sigma_g}{\sigma_c}\cdot\frac{W_{cj}}{W_{gj}}$$

Consequently, the transfer function of vibro-energy $W_{\varphi j}$ represents a frequency characteristic expressed in accordance with a sound power.

On the other hand, the surface's vibro-speed is expressed in the following form

$$V_j^2 = V_0^2 10^{0,1L_{Vj}}$$

where, $V_0^2 = 5 \cdot 10^{-8}$ m·sec^{-1} – vibro-speed limit value;

$W_{Vj}(db)$– vibro-speed logarithmic level.

With regard for the 15th formula $V_{gj}^2 = V_0^2 10^{0,1L_{goj}}$ and $V_{cj}^2 = V_0^2 10^{0,1L_{cvj}}$

With provision for the latter one, the 14th formula has the following form

$$W_{\varphi j} = \frac{M_e}{M_g}\cdot 10^{0,1(L_{c0j} - L_{goj})}$$

The obtained expression represents a frequency characteristic of vibro-energy transfer coefficient, and it predetermines the values of logarithmic level of the engine and car frame vibro-energy at the mounting locations of supporting shoes. The latter formula also allows for describing the efficiency of supporting shoes in various frequency ranges.

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