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Method of calculation of vibrating characteristics technical system

Introduction

When the movement of vessels of mixed navigation (river-sea), there are situations associated with a sharp change in the depth of the channel in which the impact effect on the propulsion system leads to a change in the state of the control object.

On the river shoals and shallows of the water jet impact effect on the screw creates an effect that leads to the longitudinal and transverse vibrations of ship structures and elements**.**

Sometimes the external pressures on the propulsion system may lead to partial or complete failure of the system, that is to bring the ship in an emergency condition.

An analysis of statistical data on the failure of the main elements of the Courts, shows that a large number of failures have diesel engines.In use of ship systems, operating at the different environmental conditions (temperature, moisture, pressure), are exposed to a variable mechanical(vibration, impacts, acceleration) and electrical (voltage, current) loads. Influence of the specified operational factors is exhibited in a deviation of the current values parameters from design values.

The refusals of elements of ship mechanisms can be shared on sudden and step-by-step. The sudden refusal happens at a jump modification of parameters, reasons which one can be mechanical and electrical loads superior acceptable values, availability of open manufacturing defects, mechanical damages of an element, maintenance error staff. Phasing refusal is the result of long-term operation and modification of parameters of an element up to values superior to values exceeding the permissible limits Phasing refusal is stipulated by two main factors: wear and aging. Mechanical wear and tear leads to a change of shape and surface details. Electric wear leads to a change in the parameters of the element of physical and chemical nature depending on the time and conditions of use.

The raise of component reliability is linked to a requirement specification on projection and service conditions. When designing reliability of elements is ensured with development of the simple schemes of elements with the least amount of details, selection of operating modes with low load factor, ensuring appropriate conditions for repair and replacement of details.

The mechanical factors can act both separately, and in aggregate. Let's remark, that the ship vibrations caused by like not only the work of ship machinery but also the action of hydrodynamic forces acting on the hull and superstructure.

In the operation of the ship accumulate irreversible changes in the elements and structures of power plant (metal fatigue, gap in clutches, wear and warping of shafts, violation of serrated joints in reductors and so on) are accumulated.

The method of recovery of the generating function allows to estimate an exposure on a mechanical system and to construct scaled model her of conduct in extreme conditions. The analysis of parameters model will define a choice of control preventing origin of an emergency situation. The given problem till now is not resolved at simulation of conduct of vessels of a type the river - sea.

For vibrational diagnosis of any mechanism it is necessary to define dependences (direct and return) between a set of diagnostic attributes of a technical condition of investigated object and diagnosed parameters of its technical condition.

Diagnostic attributes, as a rule, are chosen or from physical reasons, or on the basis of mathematical modelling.

The physical model of object and its mathematical description adequately reflecting investigated vibrating processes is necessary for mathematical modelling. For example, there is a plenty of the dynamic models of diesel engine applied to its calculation of vibrational description. But the most rational dynamic models of a diesel engine are models in the form of oscillatory system with discrete parameters [6, 7], offered by the professor L.V.Tuzov which can differ greater or smaller detailed elaboration. In them equivalent weights of details which are connected by elastic damping communications [2, 7] are accepted to the concentrated weights. The mathematical description of such structural model is the system of a kind:

$$\left.\begin{array}{l} m_1\ddot{U}_1+\eta_1\dot{U}_1+c_1U_1-\eta_2\left(\dot{U}_2-\dot{U}_1\right)- \\ \quad -c_2\left(U_2-U_1\right)=\eta_1\dot{W}+c_1W, \\ m_2\ddot{U}_2+\eta_2\left(\dot{U}_2-\dot{U}_1\right)+c_2\left(U_2-U_1\right)- \\ \quad -\eta_3\left(\dot{U}_3-\dot{U}_2\right)-c_3\left(U_3-U_2\right)=0, \\ m_i\ddot{U}_i+\eta_i\left(\dot{U}_i-\dot{U}_{i-1}\right)+c_i\left(U_i-U_{i-1}\right)- \\ \quad -\eta_{i+1}\left(\dot{U}_{i+1}-\dot{U}_i\right)-c_{i+1}\left(U_{i+1}-U_i\right)=0, \\ m_{n-1}\ddot{U}_{n-1}+\eta_{n-1}\left(\dot{U}_{n-1}-\dot{U}_{n-2}\right)+c_{n-1}\left(U_{n-1}-\right. \\ \left.-U_{n-2}\right)-\eta_n\left(\dot{U}_n-\dot{U}_{n-1}\right)-c_n\left(U_n-U_{n-1}\right)=0, \\ m_n\ddot{U}_n+\eta_n\left(\dot{U}_n-\dot{U}_{n-1}\right)+c_n\left(U_n-U_{n-1}\right)=0, \\ \qquad\qquad i=3,4,\ldots,n-2 \end{array}\right\} \quad (1)$$

Where parameters m_i, k_i, c_i are elements of crank gear models: m_i - weight of i-th element, η_i - damping factor of oil film in i-th elastic-communications, c_i - rigidity of i-th elastic communication, W - absolute moving of an installation site, U_j - absolute moving of j-th element $(j=1,2,\ldots,n)$.

At use of above-mentioned models the analysis of a vibrating condition is usually spent by splitting of a diesel engine into a number of subsystems with communications of type of dynamic rigidity, an impedance, a pliability.

Solving system eq. (1) relatively, as a result we receive the equation describing behaviour of last element in multimass system [1]:

$$\begin{gathered} a_{2n}U_n^{(2n)}+a_{2n-1}U_n^{(2n-1)}+a_{2n-2}U_n^{(2n-2)}+\ldots \\ \ldots+a_1U_n^{(1)}+a_0U_n=b_{n+1}W^{(n+1)}+ \\ +b_nW^{(n)}+\ldots+b_1W^{(1)}+b_0W \end{gathered}$$

where $a_{2n},\ a_{2n-1},\ ,\ldots,a_1,\ a_0,\ b_{n+1},\ b_n,\ldots,b_1,\ b_0$ – are calculating through m_i, k_i, c_i.

Method of calculation of condition of technical system

Vibration of the mechanism is consequence of action of various forces. In a general view, they can be presented in the form of the sum of periodic, casual and percussive components.

To distinguish and identify these forces in practice it is so problematic, and in some cases in general it is impossible, that’s why it is necessary to consider only special cases of the decision of a problem of vibrational diagnosis

In work [2] the method is presented, allowing to restore revolting influence using oscillatory characteristics of the mechanism considered as infinite sequence of multimass systems. But in this case, the real engine should be presented as oscillatory system with infinite greater number of degrees of freedom. However, in this case, exhaustive research of its fluctuations is impossible neither analytical, nor experimental by (it would be required to establish the same quantity of the gauges equal to number of its degrees of freedom on the engine)

In practice traditionally aspire to receive and use the simplified model of a diesel engine which allows to provide necessary accuracy in vibrational diagnosis at its smaller labour input.

The majority of the approached methods of research of fluctuations lead to replacement of a real design with some idealize oscillatory system with the minimal number of degrees of freedom, but with the greatest possible preservation of the main oscillatory properties of the real engine [3, 5]. Thus, one units of the engine are represented in the form of weights, (in this case neglecting their elastic properties), in others - consider only elasticity, neglecting weights [6]

Let's show opportunities of a method of restoration of revolting influence [1, 2], on an example of sequence of two one-mass systems.

It is known, that the behaviour of each weight can be described by equations

$$\begin{aligned} &\ddot{U}_1(t)+2\Delta f_1\dot{U}_1(t)+f_1^2(4\pi^2+\Delta^2)U_1(t)=-a(t), \\ &\ddot{U}_2(t)+2\Delta f_2\dot{U}_2(t)+f_2^2(4\pi^2+\Delta^2)U_2(t)=-a(t), \end{aligned} \quad (2)$$

where $a(t)$ - differentiated function of time t on an interval $[0,+\infty)$; $U_1(t),\ U_2(t)$ - the functions of time t describing behavior of weights accordingly to $m_1,\ m_2$; Δ - the logarithmic decrement of fluctuations defined as the natural logarithm of the attitude of two subsequent maximal values of a deviation колеблющейся of weight in same party; f_1, f_2 - own frequencies of fluctuations for weights m_1 and m_2 accordingly, such, that characteristic numbers of each of the equations represent themselves complex numbers with negative material parts, written down in the form of:

$$-\Delta f_1 \pm 2\pi f_1,\ \ -\Delta f_2 \pm 2\pi f_2 \quad (3)$$

including that $f_1 < f_2$.

Let's choose some pair own frequencies:

$$f_1, f_2 \quad (4)$$

also we shall write out the appropriate pair decisions of the eq. (2):

$$U_1(t),\ U_2(t), \quad (5)$$

satisfying to zero entry conditions

$$U_1(0)=0, \dot{U}_1(0)=0, U_2(0)=0, \dot{U}_2(0)=0 \quad (6)$$

Let's enter into consideration the pair of generated functions

$$W_1(t)=a(t)+\ddot{U}_1(t),\quad W_2(t)=a(t)+\ddot{U}_2(t) \quad (7)$$

and also

Values of the least moments of time

$$t_1 \text{ and } t_2, \quad (8)$$

at which absolute values accordingly $W_1(t)$ and $W_2(t)$ functions also reach the greatest values.

Values of generated functions

$$W_1(t_1)=W_1 \text{ and } W_2(t_2)=W_2 \quad (9)$$

Let's consider a way restoration of function $a(t)$ by known sizes $W_1(t_1), W_2(t_2), f_1, f_2, \Delta$.

Let's write out the decision of the each equation from eq. (2) in the form of Duhamel's integral (convolution) at zero entry conditions

$$U_1(t)=\frac{-1}{2\pi f_1}\int_0^t e^{-\Delta f_1(t-x)}\sin 2\pi f_1(t-x)a(x)dx,$$
$$U_2(t)=\frac{-1}{2\pi f_2}\int_0^t e^{-\Delta f_2(t-x)}\sin 2\pi f_2(t-x)a(x)dx \quad (10)$$

Differentiating on t twice each of decisions eq. (10), we shall receive

$$\dot{U}_1(t)=-\frac{1}{2\pi}\int_0^t[2\pi\cos 2\pi f_1(t-x)-$$
$$-\Delta\sin 2\pi f_1(t-x)]e^{-\Delta f_1(t-x)}a(x)dx$$
$$\dot{U}_2(t)=-\frac{1}{2\pi}\int_0^t[2\pi\cos 2\pi f_2(t-x)-$$
$$-\Delta\sin 2\pi f_2(t-x)]e^{-\Delta f_2(t-x)}a(x)dx \quad (11)$$

$$\ddot{U}(t)=-a(t)+\frac{f_1}{2\pi}\int_0^t e^{-\Delta f_1(t-x)}[(4\pi^2-\Delta^2)\sin 2\pi f_1(t-x)+$$
$$+4\pi\Delta\cos 2\pi f_1(t-x)]a(x)dx$$
$$\ddot{U}(t)=-a(t)+\frac{f_2}{2\pi}\int_0^t e^{-\Delta f_2(t-x)}[(4\pi^2-\Delta^2)\sin 2\pi f_2(t-x)+$$
$$+4\pi\Delta\cos 2\pi f_2(t-x)]a(x)dx \quad (12)$$

Using equality (7) and (12), we can write

$$W_1(t)=f_1\int_0^t e^{-\Delta f_1(t-x)}[2\Delta\cos 2\pi f_1(t-x)+$$
$$+\frac{4\pi^2-\Delta^2}{2\pi}\sin 2\pi f_1(t-x)]a(x)dx,$$
$$W_2(t)=f_2\int_0^t e^{-\Delta f_2(t-x)}[2\Delta\cos 2\pi f_2(t-x)+$$
$$+\frac{4\pi^2-\Delta^2}{2\pi}\sin 2\pi f_2(t-x)]a(x)dx, \quad (13)$$

generated functions eq. (7) defining sequence.

According to [1, 2, 4] it is possible to approve, that to each generated function $W_1(t)$ and $W_2(t)$ continuous on an interval $[0,+\infty)$, there corresponds unique continuous on $[0,+\infty)$ generating function $a(t)$, satisfying to each equation in eq. (13) everywhere on this interval.

For definition of an obvious kind of generating function $a(t)$ it is possible to present it, for example, in the form of Maclairen's varieties

$$a(t)=\sum_{k=0}^{\infty}a_k t^k \quad (14)$$

Having substituted decomposition eq. (14) in the right parts of equality (13) and to believe to consistently t equal members of sequence eq. (8) we shall receive expressions for factors a_k in decomposition eq. (14) [3]. We shall notice, that decomposition eq. (14) is not a unique opportunity for definition of function $a(t)$. For example, we shall search for generator function $a(t)$ in a following form

$$a(t)=A\sin\beta t, \quad (15)$$

where the amplitude A and frequency ω are a subject to definition provided that numbers $f_1, f_2, \Delta, W_1, W_2$ are known, under conditions $\beta\neq 2\pi f_1, \beta\neq 2\pi f_2$.

If to substitute expression eq. (15) in the right parts of equality (11) and (13), then to put in $t=t_1$ in the first equality (11) and (13), and $t=t_2$ in the second equality (11), (13), and to take advantage of that $\dot{U}_1(t_1)=\dot{U}_2(t_2)=0$ we shall receive system of four equations for definition of sizes t_1, t_2, A and β.

$$\begin{cases} \dfrac{[\Delta^2 f_k - 2\pi(\beta - 2\pi f_k)]\cos\beta t_k + \Delta\beta\sin\beta t_k}{\Delta^2 f_k^2 + (\beta - 2\pi f_k)^2} - \\ \quad - \dfrac{[\Delta^2 f_k + 2\pi(\beta + 2\pi f_k)]\cos\beta t_k + \Delta\beta\sin\beta t_k}{\Delta^2 f_k^2 + (\beta + 2\pi f_k)^2} - \\ e^{-\Delta f_k t}\left[\dfrac{\Delta\beta\sin 2\pi f_k t_k + [\Delta^2 f_k - 2\pi(\beta - 2\pi f_k)]\cos 2\pi f_k t_k}{\Delta^2 f_k^2 + (\beta - 2\pi f_k)^2} + \right. \\ \left. + \dfrac{\Delta\beta\sin 2\pi f_k t_k - [\Delta^2 f_k - 2\pi(\beta - 2\pi f_k)]\cos 2\pi f_k t_k}{\Delta^2 f_k^2 + (\beta + 2\pi f_k)^2}\right] = 0, \\ \dfrac{A f_k}{2}\cdot\left[\dfrac{[2\Delta^2 f_k - (\beta - 2\pi f_k)\cdot\dfrac{4\pi^2 - \Delta^2}{2\pi}]\sin\beta t_k -_k}{\Delta^2 f_k^2 + (\beta - 2\pi f_k)^2} + \right. \\ \quad \left. + \dfrac{\Delta[2(\beta - 2\pi f_k) + f_k\dfrac{4\pi^2 - \Delta^2}{2\pi}]\cos\beta t}{\Delta^2 f_k^2 + (\beta - 2\pi f_k)^2}\right] + \\ + \dfrac{A f_k}{2}\cdot\left[\dfrac{[2\Delta^2 f_k^2 + (\beta + 2\pi f_k)\cdot\dfrac{4\pi^2 - \Delta^2}{2\pi}]\sin\beta t_k}{\Delta^2 f_k^2 + (\beta + 2\pi f_k)^2} - \right. \\ \quad \left. - \dfrac{\Delta[2(\beta + 2\pi f_k) - f_k\dfrac{4\pi^2 - \Delta^2}{2\pi}]\cos\beta t_k}{\Delta^2 f_k^2 + (\beta + 2\pi f_k)^2}\right] - \\ - \dfrac{A e^{-\Delta f_k t} f_k}{2}\left[\dfrac{[2\Delta^2 f_k - (\beta - 2\pi f_k)\cdot\dfrac{4\pi^2 - \Delta^2}{2\pi}]\sin 2\pi f_k t_k}{\Delta^2 f_k^2 + (\beta - 2\pi f_k)^2} - \right. \\ - \dfrac{\Delta[2(\beta + 2\pi f_k) + f_k\cdot\dfrac{4\pi^2 - \Delta^2}{2\pi}]\cos 2\pi f_k t_k}{\Delta^2 f_k^2 + (\beta - 2\pi f_k)^2} - \\ - \dfrac{[2\Delta^2 f_k + (\beta + 2\pi f_k)\cdot\dfrac{4\pi^2 - \Delta^2}{2\pi}]\sin 2\pi f_k t_k}{\Delta^2 f_k^2 + (\beta + 2\pi f_k)^2} + \\ \left. \dfrac{\Delta[2(\beta - 2\pi f_k) - f_k\cdot\dfrac{4\pi^2 - \Delta^2}{2\pi}]\cos 2\pi f_k t_k}{\Delta^2 f_k^2 + (\beta + 2\pi f_k)^2}\right] = W_k(t_k), \end{cases} \tag{16}$$

for $k = 1{,}2$.

For simplicity we shall consider a special case, we shall put in the equations of system (16) $\Delta = 0$, then the system (16) will become

$$\begin{cases} \cos 2\pi f_1 t_1 - \cos\beta t_1 = 0, \\ \cos 2\pi f_2 t_2 - \cos\beta t_2 = 0, \\ \dfrac{2\pi f_1 A}{\beta^2 - 4\pi^2 f_1^2}(\beta\sin 2\pi f_1 t_1 - 2\pi f_1\sin\beta t_1) = W_1(t_1), \\ \dfrac{2\pi f_2 A}{\beta^2 - 4\pi^2 f_2^2}(\beta\sin 2\pi f_2 t_2 - 2\pi f_2\sin\beta t_2) = W_2(t_2). \end{cases} \tag{17}$$

Having written down first two equations of system (17) in the form of

$$\sin\frac{2\pi f_k + \beta}{2}t_k \cdot \sin\frac{2\pi f_k - \beta}{2}t_k = 0, \qquad (k = 1{,}2)$$

receive on two sequences of positive decisions for each of these equations

$$t_{kp}^{(1)} = \frac{2p\pi}{2\pi f_k + \beta},\ t_{kp}^{(2)} = \frac{2p\pi}{2\pi f_k - \beta},\ k = 1{,}2;\ p = 1{,}2{,}3{,}\ldots,$$

least roots of these equations will be accordingly numbers

$$\frac{2\pi}{2\pi f_1 + \beta} \text{ and } \frac{2\pi}{2\pi f_2 + \beta}.$$

Considering that t_1 and t_2 as mean the least moments of time at which absolute values of functions $W_1(t)$ and $W_2(t)$ accept the greatest values, we shall consider for definiteness, that

$$t_1 = \frac{2\pi}{2\pi f_1 + \beta} \text{ and } t_2 = \frac{2\pi}{2\pi f_2 + \beta} \tag{18}$$

If from equality (18) to find βt_1 and βt_2, and then to substitute accordingly in the third and fourth equation of system (17) after identical transformations they will become

$$\frac{2\pi f_k A}{\beta - 2\pi f_k}\sin 2\pi f_k t_k = W_k \qquad (k = 1{,}2) \tag{19}$$

Having divided on their these equations on another, and, having replaced t_1 and t_2 to corresponding expressions, we shall receive the equation for definition β

$$\frac{f_1\sin\dfrac{4\pi^2 f_1}{2\pi f_1 + \beta}}{W_1(\beta - 2\pi f_1)} = \frac{f_2\sin\dfrac{4\pi^2 f_2}{2\pi f_2 + \beta}}{W_2(\beta - 2\pi f_2)} \tag{20}$$

After a finding β by means of equality (18) and (19), we can find sizes of t_1, t_2 A.

Thus reduced model of an estimation of performance parameters of ship systems (automation, ship propulsive plant and power engineering) allows drawing a conclusion that generally conduct of these systems and their elements can be shown to definition of estimations of indexes of the generating function of vibration and impacts. This is specially is characteristic for vessels the river - sea of float, when the accidental shock loads on a propulsion system are practically stationary values.

The comparative analysis about shock action aimed on recovery of the generating function with the design data of the hydrodynamic model, allows giving a comparative estimation of a design data and operation. Such estimation allows already at early phases of operation to make the prognosis and diagnose malfunctions in a system with the purpose of a choice mode of the current monitoring and scheduled-preventive maintenance.

These are:

1.Identifying the optimal time to stop the engine for maintenance and repair work, lengthening the period between repairs, and reducing the consumption of spare parts.

2.Preventing failures and breakdowns of units and parts in order to prevent accidents and reduce the number of forced stops, as well as determine the extent of repair work.

3.Reduction of time troubleshooting and reasons for rejection.

4.Improving the efficiency of engines by providing optimum conditions, by maintaining the required level of technical condition.

5.Reduced labor costs for maintenance and the time of the prevention and repair.

Thus, the offered method allows to establish communication between revolting influence and own fluctuations of the mechanism. And also the given method can be used for the analysis of changes of the internal processes which are passing in the mechanism under various external influence.

Abstract

The method, allowing to restore revolting influence is offered in the paper, being based on target data and on elastic damping properties of the investigated object considered as multielement system. The example, illustrating applications of the offered method for sequence of two one-mass systems is resulted.

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