Protection methods for ship crew and passengers against the vibration of power plants

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Abstract. This article considers the problem of protecting crew and passengers against noise and vibration emitted by marine engines. The authors present their method of how to evaluate the engine's vibration activity caused by gas-dynamic and mechanic factors. This vibration diagnostic method can be effectively used to solve the problem of negative impact of marine machinery on people.

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Introduction

The protection of crew and passengers against noise and vibration emitted by machines, auxiliaries and propeller, and also the reduction of sound emission into the ambient space are the primary tasks in solving the problem of noise and vibration in shipbuilding [1]. The high level of noise and vibration affects the efficiency, well-being and health of people, the work of equipment and so on [2]. The influence of vibration on people depends on its spectral composition [3], direction, application point, duration and individual human peculiarities [2]. Besides, vibration plays a big role in erosion and corrosion of transportation system elements. To prevent them, one should use cooling liquid without toxic components [4]. It is noteworthy that vibration itself not only has a negative physiological impact on human body but also is a source of airborne noise. Noise level is mainly determined by the acoustic and vibration power generated by the source [3].

There are a number of opportunities for the solution of the foregoing problem [2, 5, 6], for example – to use low-noise machines, auxiliaries and propellers; to choose the general layout of rooms so that the distance between the sources of noise and vibration and the places where vibration and noise should be reduced is as big as possible; to install the sources of noise and vibration so that the hull receives less acoustic and vibration energy; to use noise absorbers in rooms, etc. [1, 7].

The analysis of diesel engine stock [8] showed that diesel engines produced in Russia and the CIS mainly include high-speed motors (52%) [9].

The forecast of foreign diesel industry for the period until 2016 indicate that the main trend of its development is still to increase mean effective pressure, fuel efficiency and reliability together with the reduction of weight-size parameters [9].

That is why the diesel engine stock for mixed vessels will be renewed simultaneously with the increase of high-speed motors percentage. At the same time, the maximum carrying capacity of motor-driven ships and, consequently, the power of marine propulsion plants are practically fixed while the mean effective pressure of internal-combustion engines grows.

The foregoing leads to the conclusion that in close prospect it is necessary to improve methods and means of diagnostics and to broaden their usage in the fleet in order to raise the level of protection against machinery noise and vibration [10].

Fault detection by vibration parameters is one of the most intellect-consumptive parts of the diagnostics of reciprocating machinery including marine engines. There are many unsolved scientific and practical problems concerning this aspect [9].

The goal of the research presented in this article is to eliminate these gaps, first of all on the basis of the full description for vibration processes by means of similarity theory and dimensional analysis.

Main part

The level and characteristics of changes in vibration parameters are very important indicators for the technical condition of diesel engines. These parameters are the most sensitive ones to various deviations of technical condition.

The level and character of vibration depend both on the number, magnitude, character, place, application method of disturbing forces and the features of reciprocator as a vibrating system.

It is well-known [9] that the main sources of vibrations in diesel engines are: cylinder-piston group; fuel burning; joints and connections of actuated parts; fuel facilities; timing gear; gearbox; air supply system; gas outlet system; imbalance of actuated parts; torsional vibration.

Such methods as the similarity theory and the dimensional analysis can be effectively used to research vibrations [10, 11]. The empirical regularities found with the help of these methods make it possible to abstract from too detailed information but at the same time they can be reproduced in course of experiments with high precision [12, 13].

The analysis of differential equation system and boundary conditions which describe the phenomenon shows the links between groups of values. Then they unite in complexes of a certain kind. These complexes are the combinations of values which are significant for the processes under study. In other words, these complexes are generic variables (similarity criteria and simplexes).

The concrete expressions for similarity criteria are based on the following rules [9]:

1. One should transform all variables to dimensionless form choosing appropriate scale (conversion multiplier), or divide each variable by preset representative value.

2. One should divide all equations by the value of one equation coefficient so that each term becomes dimensionless (secondary reduction).

The dimensional theory is used in case when it is impossible to derive equations that could reflect the studied phenomenon with enough completeness [9]. In this case, one has to conduct the research on the basis of less concrete relations using the results of experiments. These experiments help us to find values which are significant for the process under study.

The method of dimensional analysis (dimensional theory) is a mathematical method for the determination of formulae to express the dependence between physical quantities in studied phenomena. This method is based on studying the dimensions of these quantities [9].

A. The assessment criterion for the level of cylinder sleeves and blocks vibrations generated by fuel burning.

The theoretical analysis of equations which describe the forced vibrations of casings and the methods of similarity theory allowed us to find a criterion which makes it possible to assess how the gas-dynamic processes of fuel burning influence the vibration of cylinder sleeves and blocks [9].

$$\bar{s} = C_2 \cdot \frac{S_n \cdot D_{\mathrm{c}}^2 \cdot P_z}{D_{czvt} + k \cdot D_{czb}},$$

where $\bar{s}$ is the relative movement of cylinder sleeve's center line under the influence of operation; k is the empirical coefficient which depends on the design features of the internal-combustion engine and the damping properties of its materials.

This criterion includes such characteristics as the rigidity of the blocks (D_{czb}) and sleeves (D_{czvt}) of cylinder; maximum pressure of the cycle (P_z); piston travel (S_n); cylinder diameter (D_{c}).

B. The criterion which allows to take into account the dependence of vibration velocity on the density of material and to measure the vibration velocity on the surface of cylinder block.

Using the methods of similarity theory and dimensional analysis, we obtained a criterion which allows taking into account the dependence of vibration velocity on the density of material and measuring vibration velocity on the surface of cylinder block.

$$\pi_1 = \frac{\rho \cdot h \cdot w \cdot n^2}{P_z},$$

where P_z is the maximum pressure of cycle; w is the vibration movement; h is the thickness of sleeve; ρ is the density of material; n is the rotation frequency of crankshaft.

C. The criterion which takes into account the influence of piston reversal on the vibration activity of marine diesel engine.

As the vibration condition of marine diesel engines depends also on blows in tribocoupling gaps [9], we conducted the analysis of physical processes taking place in course of piston reversal in marine diesel engines. We obtained a criterion which allows taking into account the influence of piston reversal on the vibration activity of marine diesel engine [14]:

$$\pi_2 = \frac{N_{\max}\delta}{D_{czvt} + c \cdot D_{czb}},$$

This criterion includes such characteristics as the rigidity of cylinder block (D_{czb}), the rigidity of sleeve (D_{czvt}), the maximum value of side force ($N_{\max}$) and the size of spacing between piston trunk and sleeve bearing surface (δ); c is the empirical coefficient which depends on the design features of internal-combustion engines and the damping properties of its materials.

D. The criterion equation for the calculation of vibration velocity

In order to analyze the dependence of vibration level on the above listed characteristics, we derived the equation of vibration velocity which depends on the intensity of both mechanical and gas-dynamic effect on framework parts [10].

$$\overline{V} = C_4 \cdot \omega \cdot S_n \cdot \left[\frac{P_z}{\rho \cdot h \cdot n^2}\right]^r \cdot \left[\frac{N_{max}\delta}{D_{czvt} + c \cdot D_{czb}}\right]^t \cdot \left[\frac{S_n \cdot D_c^2 \cdot P_z}{D_{czvt} + k \cdot D_{czb}}\right]^m .$$

This equation takes into account such important design and operation factors as piston travel (S_n); cylinder diameter (D_c); block rigidity (D_{czb}) and sleeve rigidity (D_{czvt}); the size of spacing between piston trunk and sleeve bearing surface (δ); the maximum pressure of cycle (P_z); the maximum value of side force (N_{max}) and angle frequency (ω), and also unknown coefficients C_4, m, c, k, t and r which depend on the design features of internal-combustion engine and the damping properties of its materials.

It should be noted that the method of least squares is reasonable to be used for the calculation of unknown coefficients.

Findings

The analysis of diesel engine stock for river vessels showed that it is necessary to improve the methods and means of vibration diagnostics and to broaden their application field in river craft in order to protect passengers and crew against vibration and noise emitted by marine engines – both low-accelerated but rundown ones and new high-accelerated ones.

The dimensional analysis helped to obtain the criterion which allows assessing the influence of piston reversal in expansion gap on the vibration level of cylinder sleeves and block. Besides, it allows assessing the dependence of vibration velocity on the density of material.

The theoretical analysis of equations describing the forced vibration of casings and the methods of similarity theory helped to obtain the criterion which allows assessing the influence of gas-dynamic processes taking place in course of fuel burning on the vibration level of cylinder sleeves and block.

The authors present the criterion equation obtained by the combination of similarity criterion described before. This criterion equation can form a base for a method which could be useful in the identifying the value of diameter clearance between cylinder sleeve and piston trunk, calculating the current wear rate of cylinder-piston group and make a well-grounded choice of the maintenance periodicity.

The direct measure of vibrations on the external surface of sleeve will make it possible to simplify the criterion equation and extend the precision of forecast concerning the wear process of cylinder-piston group.

It follows from the above stated that the methods of similarity theory and dimensional analysis are powerful tools for the diagnostics of marine diesel engines, and first of all for the research of vibrations generated by blows in tribocouplings.

The authors consider reasonable further research aimed at the development of methods for gap detection between the parts of piston group and in crankshaft bearings on the basis of diesel vibration measuring with a glance to elasto-hydrodynamic processes in these tribocouplings.

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