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UNSTEADY VIBRATION OF SHIP STRUCTURE-BORNE SOUND SOURCES

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The main source of structure-borne sound at sea ships is machinery. Ship equipment vibration levels have a noticeable dispersion even in case of unchanged technical state. This vibration variation makes difficult the acoustic diagnosis of engine technical condition.
The paper presents some recommendations on procedure of vibration level measurement which permit to exclude dispersion effect and detect unreversible changes of vibration due to engine wear and different defects.

The main source of structure-borne sound at sea ships is machinery. The results of research works show that vibration characteristic has a complicated time-space structure.
The vibration levels at selected points (for example over the perimeter of mounting plate) have a definite deviation caused by non-equal distancies from points to working device, which are the vibration sources, and by anisotropy of inertia-rigid features of structure.
Vibration levels fluctuation in similar points of machinery of the same type is explained by accidental technological error during their manufacture and mounting.
Nevertheless vibration levels at monitoring at fixed control points with stationary installed accelerometers at invariable working conditions are not constant.
Examples of ship engine vibration fluctuation during comparatively short time-period are shown at Figs.1, 2, 3.

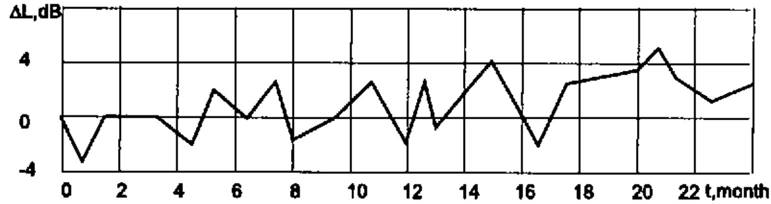

Fig.1. The results of measurements of ship machine vibration levels in operating condition (the measurements were made one or two times in a month)

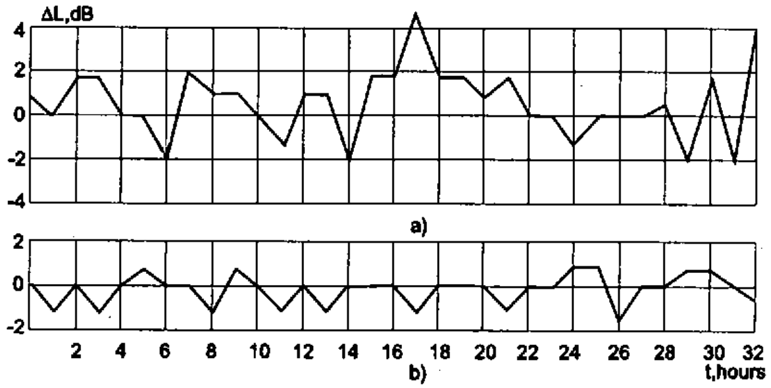

Fig.2. The results of measurements of ship pump vibration levels in operating condition (at every hour measurements): a) at rotation frequency; b) at blade frequency

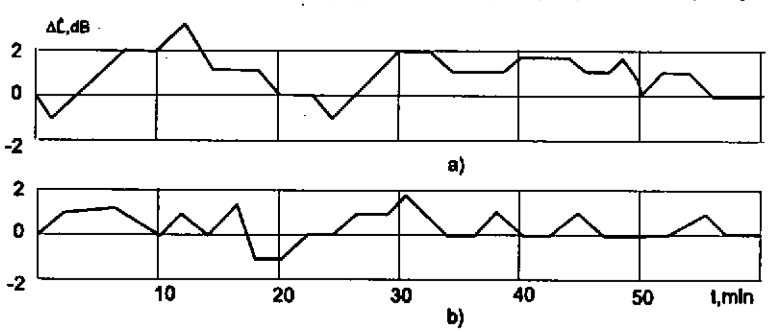

Fig.3. Fluctuation of ship turbomachine vibration levels in operating condition (meter's reading was made every 2 min): a) at rotation frequency; b) at second harmonic of rotation frequency

Figure 1 shows results of periodic measuring of ship pump vibration levels during two years. As one can see these levels differ by a value of 3-8 dB.

Some results of measuring of ship pump vibration levels during 32 hours are shown at Fig.2. Fluctuation of results of measuring every 0.5 hours is characterized by a value of 3-5 dB.
Vibration instability one way or another shows itself at operation of ship machinery of all types and practically in full frequency range. Results of uncorrect vibration measurement often is explained by metrological errors only. Really using of different measuring channels, transducer transpositions when portable instruments are used, to significant error evaluated as 3-4 dB.
Systematic measurements of vibration level fluctuation show that these fluctuations are random and are defined in great degree by specific features of ship power plant. Even at constant ship speed the power plant operation mode particularly of ship electric power station and auxiliary systems can't be considered immutable. At connection of periodically acting machinery for, example separators of fuel and oil, the valves of pipeline systems are commutated and the head of working medium (water, oil, ets) in system change and so pump operation mode changes. Besides the connection of additional pipeline sections changes natural frequencies of system. Displacement of resonance characteristics of pipeline leads to change of pump vibration levels in frequency bandwidths.
Current quality affect the vibration of driving electric motor.Among current parameters affecting ship electric machine vibration the most important are: fluctuations of voltage and current frequency, asymmetry of supply voltage, low-frequency of high orders.
The affect of current quality on vibration of induction motors can be significant, so the experiments allow to make clear that at up to 3% changing off voltage factor for 3-phase network

$$k = \frac{U_{max} - U_{min}}{U_{nom}},$$

where $U_{max}, U_{min}, U_{nom}$ are maximum, minimum and nominal phase voltage correspondently; the vibration of electromotor at frequency of 100 Hz can grow by 25-30 dB (Fig.4).
Machinery vibration levels fluctuation is revealed to changing of mode of itself (even in case of single mode mechanism). So heat condition depending on period of operating in this mode and on mode which was before this one can influence in high degree on vibration level variation as to each heat condition (temperature field) the proper clearances and specific value of distributed rotor unbalance caused

by uneven proper clearances and specific value of distributed rotor unbalance caused by uneven heating corresponds. Change of load, voltage or current frequency leads to changing of rotation frequency (for single mode machine the frequency change within static characteristic is usually equal to 1-3%).

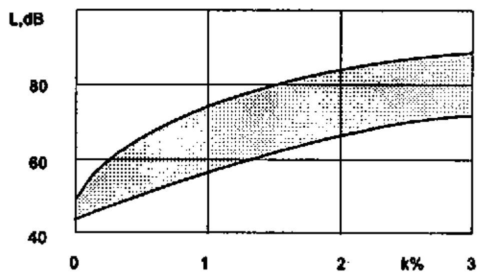

Fig.4. Electromotor vibration level at frequency 100 Hz due to asymmetry of supply voltage

Rotation speed fluctuations change the operating frequency deviation from balance frequency and change by this means rotor unbalance and vibration at rotation frequency accordingly. The higher initial rotor unbalance and residual unbalance relation the greater is vibration change at rotation frequency with speed different from nominal one.

Thus a desire to improve vibration characteristics of ship machinery only by its final balancing without improvement of rotor manufacturing technique can lead vibration increasing at operating process when rotation speed is carried with proper tolerances. In order to avoid this situation it is necessary to decrease the initial distributed rotor unbalance.

Fluctuation of vibration levels at steady operating condition can be defined by region of ship sailing and atmospheric conditions. So at sailing at tropical regions with higher water temperature the outboard water flow rate through heat exchangers for ship power plant needs should be increased in comparison with consumption at sailing with the same speed in temperate latitudes. The loading mode of outboard water pump is changed respectively besides that the increase in water temperature can tell on change of pumps cavity reserve (margin) particularly if they are installed without enough head of water at suction.

All of these facts will lead to change of pump vibration levels in wide frequency range.
At high seaway because of ship list and trim the conditions of suction of outboard water pumps and some other pumps (for example, condensate removal pump) can change. Pressure change at suction affects cavitation reserve (margin) of pumps and can cause increase in vibration at high frequency band.
Thus in operating process even at steady-state conditions and at fixed operation mode of power plant (within accuracy carried by crew and control system of rotation speed and medium operation parameters) the machinery vibration has some fluctuations because of many factors. Consideration of known factors doesn't lead to disappearing of vibration levels fluctuations what shows that all factors influenced this phenomenon are not yet known.
In conditions one can keep up sufficient accuracy of operating mode and vibration fluctuation is characterized by RMS deviation equal approximately 1 dB at wide frequency band.
In ship condition natural fluctuation increases to mean RMS equalled 1.5-2 dB. Machinery vibration is one of the most parameters for diagnostics of technical state of mechanism.
The reliability of diagnosis of any system including vibration diagnostic system is mainly defined by accuracy of measurement of diagnostic parameter (for our case by accuracy of vibration measurement) at given mode.
The higher dispersion of parameter measurements the less diagnostic value it represents as random deviations unconnected. Therefore the fluctuation of vibration measurement results can cause trouble to detect the change of technical condition of mechanism in good time.
Regular measurements of ship machinery vibration allows to reveal two types of vibration variation:

1. monotonous (trend) because of variation of structure parameters in a process of wearing and ageing and
2. discrete (uneven) because of breakages or maintenance of machines.

Monotonous vibration variation revealing on base of a large number of measurements is explained by mechanical wearing of friction pair, corrosion and erosion wearing of details being in liquid, deterioration of lubricating oil quality and ageing of rubber used for damping.

Sum total of all enumerated factors causes a gradual change (as usual an increase) of vibration level, about 1 dB per 1000 hours of operation.

All aforesaid permits to give concrete expression to procedure of ship machinery vibration monitoring. A variation of machinery vibration can be regarded as random process for relatively short time intervals (hours, days). Consequent measurements will be independent in that case, if a measurement period exceeds the correlation period. Taking into account a real speed of parameter vibration, it is reasonably to make measurements not more often then in hour for normal operation and, in practice, in 2-4 hours.

A number of consequent measurements which are necessary for calculation of averaged vibration value characterizing machinery condition depends on the results scattering of single measurements and required accuracy of determination

$$n > \left[\frac{t(p)}{\varepsilon}\right]^2 \sigma^2,$$

where ε - estimation accuracy, σ - RMS deviation, $t(p)$ - assigned reliability.

For appropriate values of ship machinery $\sigma = 1 \div 1.5$ dB vibration estimation accuracy $\varepsilon = 1$ dB and reliability $p = 0.95$, the measurement number is $n = 4 \div 10$, hence, 4-6 measurements can be assumed as sufficient. In case of intense increasing of vibration, measurement periodicity should be reduced respectively.

CONCLUSION

1. A number operating factors, influencing on working conditions of ship machines (which are main sources of structure-borne sound), leads to continuous change of its vibration and noise.

2. Fluctuation of ship machine vibration levels at factory facilities during operating at steady-state condition is characterized by mean RMS equalled 0.5-1.0 dB. In ship condition fluctuation increases to mean RMS 1.5-2 dB.

3. An irreversible change of ship machine vibration level equals 0.5 - 1.5 dB (on average 1 dB) per 1000 hours of operation.