Study of sensitivity and interference protection of various bearing diagnostics methods

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Abstract. Due to the widespread use of bearing units with rolling bearings in ship equipment, the question of using diagnostics-in-place methods to determine their technical condition is relevant. For diagnostics, various methods of different sensitivity and interference protection can be applied. These qualities are of particular importance for diagnosing the bearing units of ship’s gearboxes access to which can be difficult, and the units themselves include several different types of bearings. The article provides materials on comparing the sensitivity and reliability of two methods for diagnosing rolling bearings: the diagnostic method based on the analysis of the envelope spectrum and diagnostic method based on shock pulses. Measurements were taken by these methods at different points of the bearing unit on the special bench, equipped with two different bearings. Previously, defects on the ring were artificially created on one of the bearings of the unit. Measurements have shown that the shock pulse method provides acceptable results only when a sensor is located directly at the point adjacent to the outer ring of the bearing. At the control points distant from the bearing location, the defect was diagnosed with an error, but the presence of a defect, nevertheless, could be determined by applying monitoring at a specific point of control. The method of analyzing the envelope allows secure detecting and identifying the defect even when a sensor is installed at a considerable distance from the bearing. The influence of the interference generated by the mounted lubrication pump is considered. The envelope spectra and the nature of their changes are provided.

1. Materials and methods
Rolling bearings are one of the most common structural elements of marine facilities. Bearing units with rolling bearings can have both a simple design used in electric motors and generators of low and medium power, and a complex one including several bearings of different types in one bearing unit. As a rule, bearing units of gearboxes of diesel-gear assemblies have such a complex design. Thus, the TKG2-03 gearbox of the "Atlantic-333" project ship has a bearing unit with three different bearings. [1] An example of the bearing units of the HSU-135 ship’s gearbox is shown in Fig. 1.
The consequence of the wide distribution of bearing units with rolling bearings is that they largely determine the reliability of marine equipment, which leads to the need for applying the diagnostics to determine their technical condition. Units with rolling bearings have high reliability but the failure of the bearing unit when a ship is at sea can result in serious consequences, and unjustified replacements lead to excessive financial expenses increasing the cost of operating marine equipment.

It should be noted that during repairs with disassembly of the bearing unit, the bearing condition is determined either purely visually or by rolling the measuring probe, which does not give reliable results for determining its technical condition. Most often, the bearing is simply replaced without any attempts to detect its technical condition. [2].

Unreasonable disassembly of bearing units on ship’s gearboxes or electric machines reduces the resource of the unit due to the necessity to align parts after assembly.

The optimal way to maximize the use of bearing life and possibility of avoiding accidents can be the use of methods of diagnostics-in-place of bearing units, for example, the use of vibration diagnostics methods. The use of diagnostic methods allows transferring all ship equipment to repairs according to the condition and significantly reduces the cost of its operation. [3] [4]

Currently, four methods for assessing the technical condition of rolling bearings can be used in vibration diagnostics [4] [5]

- PEAK factor method;
- direct spectrum method;
- envelope spectrum method;
- shock pulse method.

But diagnostics based on the envelope spectrum and diagnostics based on shock pulses have become the most widespread. The essence of the methods is widely covered in the literature and is not presented here.[5][6][7][8] The peculiarities of the work on the diagnostics of bearings of ship’s
gearboxes include difficult access to bearing units due to the presence of closely located rotating parts and induced vibration from adjacent bearing units, which can distort the diagnostic results. [9] [10]. The envelope spectrum diagnostics can detect the following rolling bearing defects: wear of the outer ring, cavities, cracks of the outer ring, wear of the inner ring, cavities, cracks of the inner ring, wear of the rolling bodies, chips on the rolling bodies, skew of the outer ring, separator defect, lubrication defect.

As a rule, not all of these defects occur simultaneously and are determined during diagnostics. Most often, defects related to with the outer ring are manifested, and the most dangerous defects of the rolling bearing - the separator defects - are rarely diagnosed.[11]

2. Research objects and methods
The object of the study is sensitivity and interference protection of the above mentioned diagnostic methods - by the envelope spectrum and by the shock pulses of the bearings. To determine the sensitivity, a special bench was developed with a bearing unit that includes two different rolling bearings installed in one housing. Based on the frequency of defects of real equipment, an artificial defect – a cavity – was created on the outer ring of one of the bearings on the bearing unit of the bench, and to approximate the real conditions, a violation of the bench shafts alignment and drive mechanism was introduced. To measure the vibration, a CON.TEST C9000 collector – analyzer with the ConSpekt software was used. The device has channels, both for carrying out bearings diagnostics by the envelope spectrum, and by the method of shock pulses. Measurements on both diagnostic channels were carried out at five points of the bench in the vertical direction at a bench rotation speed of 1000 rpm. During the measurements, the bandpass filter frequencies of 8 and 16 kHz were used, with the results averaged over eight measurements.

Figure 2. Laboratory installation scheme

1 - rolling bearing; 2 - race; 3 - frame; 4- measurement point 1; 5 - measurement point 3; 6 - measurement point - 4; 7- point of measurement 5, 8- point of measurement 6.

Point 1 was located on the housing of the unit, directly above the bearing, point 2 - on the housing of the bearing unit in the area of the second bearing, point 3 - on the bolt securing the housing of the bearing unit to the frame of the installation, point 4 - at the top, and point 5 at the bottom of the frame, point 6 - on the frame of the drive unit.
The initial measurement for obtaining the envelope spectrum was performed on a defect-free bearing, the initial vibration level being determined from it, and subsequent measurements were carried out after the creation of defects: a defect on the outer ring and a violation of the drive shaft alignment. Taking into account the bearing design, the characteristic bearing frequencies were calculated [4] [12]. The characteristic bearing frequencies are shown in Fig. 3

![Figure 3. Characteristic frequencies of bearing defects. Frequency band 0-500 Hz.](image)

**Results**

The envelope spectra obtained for measurements at various points of the bench with an 8 kHz bandpass filter are shown in Fig. 4 – Fig. 9. The envelope spectra obtained at a 16 kHz bandpass filter frequency do not have significant differences from the spectra with an 8 kHz bandpass filter and are not presented here.

In the initial envelope spectrum in Fig. 4, several discrete components are visible, the first of which corresponds to the outer ring frequency. The discrete component has an insignificant value and has no higher harmonics. The presence of such components in the spectrum of a serviceable bearing is not uncommon. [10] [11]

A completely different picture is observed on the envelope spectrum of the defective bearing, point 1. There, the harmonic corresponding to the defect on the outer ring has a greater intensity and ten higher harmonics, which emphasizes the severity of the defect. At point 2 located closer to the coupling, in addition to the discrete components of the outer ring, the frequencies generated by the violation of the drive alignment are also added.

At points 3,4,5, the picture changes significantly: there is a decrease in the amplitudes of the main and higher harmonics of vibration generated by the defect, up to their complete disappearance. The amplitudes corresponding to the rotation frequencies also decrease. But even at point 6, which is a considerable distance away from the bearing unit, the first harmonic of the outer ring is visible.
**Figure 4.** Envelope spectrum for point 1. Defect-free bearing.
Frequency range 0 – 500 Hz

**Figure 5.** Envelope spectrum for point 1. Defective bearing.
Frequency range 0 – 1000 Hz
Figure 6. Envelope spectrum for point 2. Defective bearing.
Frequency range 0 – 1000 Hz

Figure 7. Envelope spectrum for point 3. Defective bearing.
Frequency range 0 – 1000 Hz
A completely different picture is observed when measuring shock pulses. At the first point, the diagnostic program made the correct diagnosis corresponding to the defect. At the second point (at a distance of about 10 cm), the diagnosis was already erroneous, but the defect was identified to some extent. At subsequent control points, it no longer corresponded to reality. However, the detection of a defect at some distance from the bearing allows determining the presence of a defect, although it does not allow determining its severity.
Table 1. Control results on shock pulses

| Control point | dBi | dBm | dBc | Program diagnosis               |
|---------------|-----|-----|-----|---------------------------------|
| 1             | 0   | 30  | 30  | Major defects                   |
| 2             | 0   | 19  | 15  | Appearance of defects           |
| 3             | 0   | 10  | 10  | Good bearing condition          |
| 4             | 0   | 11  | 7   | Good bearing condition          |

There is another factor that can distort or significantly complicate the determination of a bearing malfunction during the vibration diagnostics procedure on bearings of main ship’s gearboxes. This is a presence of a mounted lubrication system pump on the ship's gearbox.

When working on insufficiently heated oil, the pump creates vibration on all bearing units to which the oil is supplied, including due to pressure pulsation in the system.

The envelope spectrum with vibration generated by the pump of the lubrication system is shown in Fig. 10. [13]. This mode (in case of interference from the pump) was not modeled when measuring vibration on the bench.

![Vibration envelope spectrum of the gear pump of the lubrication system.](image)

**Figure 10.** Vibration envelope spectrum of the gear pump of the lubrication system.

As can be seen from the presented envelope spectrum, the pump generates tooth frequencies and frequencies corresponding to the rotation frequency with higher harmonics. Similar spectra are detected on all bearing units of the gearbox, but the harmonics have different intensities. The discrete components generated by the pump teeth have frequencies much higher than the discrete components of the bearing frequencies. They rarely create interference to determine the presence of a defect. Their value is easily calculated when the pump speed and the number of teeth on the rotor are known by multiplying the speed in hertz by the number of teeth on the pump rotor (gear). [13] [15]. Rotary frequencies (rotation speeds) are also easily detected on the spectrum, their danger lies in the fact that they can "mask" the frequencies corresponding to the frequencies of the defective bearing, which is especially unpleasant if there are frequencies corresponding to the defect of the separator. It is
extremely difficult to reject such interference, but on all bearing units they, as a rule, differ in frequencies from the rotation frequency of a particular shaft, which helps to identify defects correctly. In the absence of pump data, a direct spectrum can be used to determine pump frequencies, as direct spectrum always contain pump frequencies, and frequencies corresponding to bearing defects are only apparent if the bearing has an extremely developed defect and in practice almost do not occur. [11]. [14].

A slightly different picture is formed when using the shock pulse diagnostic method. In this case, the vibration generated by the pump can distort the test results to a large extent, especially on the bearing unit to which the pump is attached. It does not seem possible to verify the correctness of the diagnosis in this case. [5].

Conclusion
The following conclusions can be drawn from the above materials:

The diagnostic method based on the analysis of the envelope spectrum is more sensitive and allows avoiding an erroneous diagnosis if it is not possible to install the device sensor directly on the bearing. This circumstance greatly facilitates measurements on shipboard equipment, especially on the gearboxes of the main transmission, where access to bearing units is often difficult.

When making measurements on units with bearing units located at a small distance, especially if they have the same speed and similar bearings, it is necessary to take into account the possibility of interference from a neighboring bearing. In this case, to reduce the probability of making an erroneous diagnosis, it is necessary to take into account that the first harmonics corresponding to the defect will be induced. Higher harmonics, even with a developed defect, will fade. The harmonics determined by the rotation frequencies and the defects generated by the separator will also attenuate.

When taking measurements at a considerable distance from the bearing location in the bearing unit, the risk of getting an incorrect diagnosis increases precisely because of the attenuation of higher harmonics (the criticality of the defect decreases) and the frequencies of a very dangerous defect – the separator defect - attenuate. These circumstances must also be taken into account.

Despite the lower reliability of the shock pulse diagnostics when it is not possible to install a sensor directly on the bearing, the method can be used in a monitoring mode, given that the appearance of a message from the measuring device concerning an incipient defect may indicate a serious bearing defect.

When diagnosing the bearing units of a ship’s gearbox with a mounted pump, it is necessary to take into account the vibration created by the pump, both due to the housing vibration and the oil flow pulsation. Therefore, it is recommended to take vibration measurements on a well-warmed unit and record the vibration of the pump itself to minimize errors from this vibration. It is better not to use the shock pulse method of diagnostics on bearing units if the lubrication system pump is attached to their shaft.

References
[1] Antsevich A V, Egorov P K, and Zuev A V 1983 Diesel-g geared Units of Fishing Vessels (Murmansk Publishing House) p 160.
[2] Zhukov A S, Sergeev K O 2012 Problems of transferring gearboxes of diesel-g geared units for repair according to the condition Ekspluatatsiya morskogo transporta. No 4 (7) 45–50.
[3] Sergeev K O 2019 Technical diagnostics as a means of reducing the cost of operating marine power plants. - International scientific and practical conference “Science and education in the Arctic region” [Electronic resource] Proceedings of International scientific and practical conference, Murmansk, Federal state budget educational institution of higher education “Murmansk State Technical University” State registration № 033000109.
[4] Rosenberg G Sh, Madorsky E Z and Golub E S 2003 Vibrodiagnostics ( SPb. PEIPK ) p 284.
[5] Golub E S, Madorsky E Z and Rosenberg G Sh 1993 Ship Technical Equipment Diagnostics (Moscow, Transport) p 150.
[6] Mattew D, Alfredson R 1984. Application of vibration analysis for monitoring the technical condition of rolling bearings Konstruirovanie i technologiya mashinostroeniya Mir, Vol. 106 No 3 100-108.

[7] Barkov A V 2013 Monitoring and Diagnostics of Rotary Machines by Vibration (Saint Petersburg Sevzapuchcentr) p 158.

[8] Scheffer C, Girdhar P 2004. Practical Machinery Vibration Analysis and Predictive (Maintenance. Oxford: IDC Technologies, Newnes) ISBN 0 7506 6275.

[9] Sergeev K O 2011 Experience of using diagnostics in-place to determine the technical condition of TKG2-03 STM gearboxes of the “Atlantic – 333” type Vestnik of MSTU Vol. 14 No 4.

[10] Sergeev K O, Pankratov A A 2018. Results of diagnostics of rolling bearings of gearboxes of diesel-gear units of fishing vessels Vestnik of MSTU Vol. 21 No 4.

[11] Sergeev K O 2019 The results of bearings diagnostics of ship electric motors and generators IOP Conference Series: Materials Science and Engineering Vol. 560 No 1.

[12] Barkova N A, Borisov A A 2009 Vibration Diagnostics of Machines and Equipment Calculation of the Main Vibration Frequencies of Machine Components, Parameters of Measuring Uipment and Practical Expertise (Publishing Centre of SPbSMTU, SPb) p 111.

[13] Sergeev K O 2017 Features of diagnostics in-place of marine rotary pumps Vestnik of MSTU Vol. 20 No 4 121-129.

[14] Lukyanov A V, Lebedeva N Yu 2011. Improving the accuracy of vibration analysis on the spectrum Sovremenny Technologiy. Sistemny analiz. Modelirovanie No 2 32-37.

[15] Hasanli Sh M, Mehdizadeh R N, Huseynov E K and Seyedzadeh S A 2004 Vibro-acoustic diagnostics of rotary type machines and mechanisms Second international conference on technical and physical problems in power engineering Tabriz-Iran p 509.