12th INTERNATIONAL SCIENTIFIC CONFERENCE ON DEFENSIVE TECHNOLOGIES
OTEH 2026
Serbia, Tara, 21 - 24 October 2026

INSPECTION OF THE PROPULSION SYSTEM OF THEAUXILIARY SHIP PBR-36 "ŠABAC"

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Abstract: *The subject of this paper is the assessment of the condition of the existing propulsion system of the auxiliary ship PBR-36 "Šabac" from the aspect of the occurrence of increased vibrations on the shaft lines for power transmission to the propeller. The paper presents a detailed and comprehensive approach aimed at detecting the source of increased vibration levels in the propulsion system, which consequently led to the failure of the ship and its decommissioning, which is part of the River Flotilla of the Land Forces. By implementing control vibration measurements, using measuring instruments and diagnostic equipment, the main source of increased vibrations was determined, based on which a recommendation was given for further measures to eliminate malfunctions in the propulsion system. After examining the condition and analyzing the measurement results, the ship PBR-36 "Šabac" was sent to docking, with a focus on repairing the propulsion system. After lifting the ship to the river dock and inspecting it in a disassembled state, the assumptions obtained by the diagnostic equipment were confirmed and the source of increased vibrations in the power transmission system from the engine to the propellers was determined (defective release bearing and misalignment of the propeller shaft). After the work on replacing the defective parts and assemblies of the propulsion system, as well as bringing the eccentricity of the propeller shafts to the permissible deviation limits, the ship was launched into the water, after which control measurements were performed again. A condition assessment was performed and a comparative analysis of the deviations of the measured vibration values after docking was given in relation to the previous report and the reference values defined by the standard. Finally, a conclusion was given with a condition assessment and a proposal for further work.*

Keywords: *propulsion system, vibrations, shaft line, docking, measurement.*

1.INTRODUCTION

The auxiliary river ship PRB-36 "Šabac" is in operational use as part of the 1st River Detachment, River Flotilla, Army.

A ship of this type is designed for demagnetizing ships, forming and maintaining a command post of the river detachment rank, patrolling and controlling river routes.



Figure 1. The auxiliary river ship PRB-36 "Šabac"

The ship is powered by two four-stroke diesel engines,

both with a power of 192kW, which provide the ship with a displacement of 115.8t with a maximum speed of 22 km/h.

The ship's propulsion system consists of two parallel diesel engines, which drive one bronze propeller with fixed blades each via a coupling, cardan shaft, and propeller shaft.

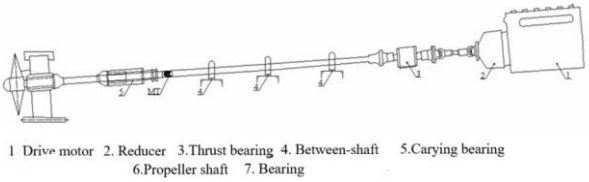


Figure 2. Sheme of propulsion

In this case, the drive motor (1), through a reducer with a coupling (2), drives a propeller with fixed blades. Between the reducer and the propeller is a thrust bearing (3), which receives the axial force from the propeller and transfers it to the ship. The propeller shaft consists of an

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DOI: 10.5937/OTEH26142D

intermediate shaft supported on three roller-type support bearings (4), and a propeller shaft supported in sliding rubber bearings in the mast tube and the rudder (5).

Taking into account empirical indicators in operation, characteristic examples of failures of ship subsystems occur precisely in the system for transferring power from the engine to the propellers, which was the case here. After the malfunction of the ship's propulsion complex, as a consequence, operating parameter values outside the permissible range appeared in operation, which led to the occurrence of failures. Taking into account the experience of the crew, signs of failure in operation were identified in time, thus preventing major damage to vital ship sites.

2.FAILURE OF THE SHIP'S PROPULSION SYSTEM

During the regular operation of the ship, changes in the state of the ship's propulsion system were observed, in the form of increased vibrations transmitted to the ship's shell, a specific sound of a failed bearing, and an increased temperature of the thrust bearing housing. Based on empirical indicators of non-specific operation and characteristic deviation parameters, the ship's crew took measures to prevent further failure of vital ship systems by operating the ship within the empirically acceptable load range.

Based on the above, it was necessary to detect the degree of malfunction of the propulsion system of the auxiliary ship "Šabac", define the cause and consequences of the failure, and propose further measures that need to be taken to restore the ship to proper condition.

Detection of ship propulsion malfunctions included diagnostic measurements carried out by the Technical Testing Center, with the assistance of the ship's crew. For this purpose, and in order to obtain as realistic a picture of the problem as possible, a test run was carried out on the Danube River, in different sailing modes, which ensured a simulation of the propulsion system load in real conditions.

3.DIAGNOSTIC MEASUREMENTS

The content of the diagnostic measurements was determined by the symptomatic occurrences of failures as well as previous experience in detecting the cause of malfunctions of the ship's propulsion system on other ships of the River Flotilla. Based on the above, the diagnostic measurements included the determination of the following parameters, as a function of assessing the state of the propulsion system: torque and power measurements, linear vibration measurements and bearing temperature measurements on the ship's propeller shaft of the auxiliary ship PRB-36 "Šabac".

3.1 Measurement conditions

The measurement was carried out in upstream travel at approximately normal ship displacement (D= 110 t), on the left and right propellers. The measurement was carried out in three sailing modes, and with the restriction that the maximum mode of the propulsion engines was at 1400 rpm. The specified mode was empirically estimated as the maximum safe mode (according to the ship's commander's assessment), in which vibrations of the propulsion complex cannot cause damage to the propulsion elements and for which there is a very low risk of failure.

3.2 Measuring equipment

To measure the shaft deformation, on the basis of which the power delivered to the propeller was calculated, measuring tapes of the type XY21 6/120 (tape factor K=2.09), manufactured by Hottinger Baldwin Messtechnik, connected in a full Wheatstone bridge, were used.

To measure the number of revolutions of the propeller shafts, a tachometer TAC-10, manufactured by SPM, was used, while measurements of linear vibrations of the propulsion complex elements were performed using a portable vibrodiagnostic device Falcon and a three-axis accelerometer 0.1dB-Metravib SAS.

Measurements of the bearing housing temperature were carried out using a non-contact thermometer VOLCRAFT, IR-1000L.

4.RESULTS OF MEASUREMENT

4.1 Power measurement results on the left and right return lines

The results of the power measurements on the left and right propeller shafts were obtained based on the read values of the changes in the resistance of the tape, which is proportional to the deformation. Using the Spider 8 measurement acquisition device and the transmitted signal from the measuring tape, with prior calibration, the tangential and normal stresses were determined, and therefore the torque and transmitted power on both shaft lines.

Table 1. Result of power measurement

Nv (o/min)	Nmot (o/min)	M_v (Nm)	Pv (kW)	Nv (o/min)	Nmot (o/min)	M_v (Nm)	Pv (kW)
507	1014	668,21	35,46	509	1018	713,85	38,03
670	1240	1146,85	80,42	647	1294	1228	86,11
705	1410	1417,8	104,62	695	1390	1391,04	101,19

Nv – shaft speed, Nmot – drive motor speed, Mv – torque measured on the shaft, P v – power measured on the shaft (power delivered to the propeller).

Comparing the measured power values on the left and right shafts, it can be concluded that at lower driving modes the right engine is more loaded than the left. This is also supported by an insight into the measured values of the exhaust gas temperature of the left and right engines, where a constantly higher exhaust gas temperature of the right engine is observed compared to the left engine (the difference is up to 100 °C).

4.2 Linear vibration measurement

By analyzing the measured values given in Table 1, it is observed that the vibration level is above the values recommended by the American Bureau of Shipping (ABS) standard for vibration on marine propulsion devices, on the following elements of the return line: 1) right reducer, longitudinal and vertical, at 585 rpm; 2) left thrust bearing, longitudinal, at 605 rpm and 705 rpm; 3) right thrust bearing, vertical and longitudinal, at 500 rpm and 650 rpm.

Table 2. Result of vibration measurement

DEVICE NAME: Ship's shaft line (left/right)				MEASUREMENT POINT LOCATION: Reducer
rpm of the shaft (o/min)	Effective speed of vibration Vef (mm/s)			Note
	Vertical	Horizontal	Longitudinal	According to the ABS standard, the recommended permissible value is 13mm/s.
507/500	4,12/4,07	5,68/7,94	4,92/5,39	
655/650	/14,82	/6,79	/18,38	
705/690	6,13/10,15	4,79/9,11	9/8,08	
DEVICE NAME: Ship's shaft line (left/right)				MEASUREMENT POINT LOCATION: Thrust bearing
rpm of the shaft (o/min)	Effective speed of vibration Vef (mm/s)			Note
	Vertical	Horizontal	Longitudinal	According to the ABS standard, the recommended permissible value is 5mm/s
507/501	1,84/1,03	2,77/1,59	4,8/5,17	
655/651	2,1/1,69	3,99/2,29	6,25/8,2	
705/691	3,06/8,27	4,04/2,04	10,22/3,25	
DEVICE NAME: Ship's shaft line (left/right)				MEASUREMENT POINT LOCATION: Bearing
rpm of the shaft (o/min)	Effective speed of vibration Vef (mm/s)			Note
	Vertical	Horizontal	Longitudinal	According to the ABS standard, the recommended permissible value is 7 mm/s up to 13 mm/s
507/502	1,24/1,19	2,11/1,76	1,85/1,3	
655/652	1,81/2,18	3,98/2,65	3,39/1,78	
705/692	4,19/3,23	5,25/3,05	4,13/4,88	
НАЗИВ УРЕЂАЈА: Бродски вратилни вод (лево/десно)				MEASUREMENT POINT LOCATION: Carying bearing
rpm of the shaft (o/min)	Effective speed of vibration Vef (mm/s)			Note
	Vertical	Horizontal	Longitudinal	According to the ABS standard, the recommended permissible value is 7 mm/s up to 13 mm/s
507/503	1,95/0,91	1,24/2,08	0,73/1,18	
655/653	1,08/1,35	1,53/0,95	1,08/0,8	
705/693	3,96/2,26	1,92/1,58	1,23/1,26	
DEVICE NAME: Ship's shaft line (left/right)				MEASUREMENT POINT LOCATION: Ship's plating
rpm of the shaft (o/min)	Effective speed of vibration Vef (mm/s)			Note
	Vertical	Horizontal	Longitudinal	According to the ABS standard, the recommended permissible value is 7 mm/s up to 13 mm/s
705/694	4,08	2,49	3,06	

4.3 Measuring temperature on bearings

Given the inaccessibility of the measurement site, the temperature was measured contactlessly on the bearing housing itself.

Table 3. The measured temperature values

rpm	Legft/Right thrust bearing	Legft/Right bearing between shaft	Legft/Right bearing shaft
500	33.3/42	21.3/18.1	27.3/24.4
600	34.9/43	22.6/19.5	28.7/27
700	36.6/47.2	24/19.7	34.1/29.8

4.4 Analysis of measurement results

After conducting diagnostic tests and performing measurements, and analyzing the measured operating parameters of the left and right return lines, the following conclusions were reached:

On the left shaft, values of impermissible vibration levels were observed at the thrust bearing, as well as the existence of angular misalignment in the axle assembly. The recommended permissible vibration speed value according to the ABS standard is 5 mm/s, while the measured values are up to 10.22 mm/s, at 705 rpm.

An irregularity was observed on the right shaft in the form of impermissible vibration levels on the gearbox and thrust bearing, which indicates the existence of angular misalignment of the shaft. The recommended permissible vibration speed value according to the ABS standard is 13mm/s, while the measured vibration speed values are 18.38 mm/s at 650 rpm. In addition, a malfunction of the left cardan shaft and the engine foot was detected. Taking into account the increased temperature value of the thrust bearing, the malfunction will also affect the service life, since thermal overload will occur in operating conditions over a longer period of time.

By comparing the condition values of the left and right thrust bearings, based on the frequency spectrum of axial vibration accelerations, a worse condition of the left thrust bearing is observed, which is in the zone of limited service life, i.e. there is the appearance of dominant frequencies in the zone of characteristic bearing frequencies, and the appearance of the so-called "carpet".

Taking into account that the measurements were carried out at modes lower than nominal, it is assumed that at higher modes, the values of the measured vibrations would be significantly higher.

Based on the conducted testing, docking of the ship and elimination of the malfunction were proposed.

5. DOCKING THE SHIP

Docking the ship and eliminating the malfunction, as shown in the previous chapter, was preceded by dismantling the malfunction, identifying the cause, and proposing defined works to be carried out in order to eliminate the causes and consequences of the malfunctions, identified during control measurements.



Figure 3. Docked ship

The observed defects during diagnostic testing and measurements carried out during the docking preparation process confirmed the assumptions regarding bearing defects, as well as return line misalignment.



Figure 4. Defective thrust bearing built

After troubleshooting in a disassembled state, it was determined that the thrust bearings had suffered serious mechanical damage, and that they had been exposed to operating conditions with improper cooling, and a similar condition was observed on the rolling support bearings of the return line after construction. Due to the general poor condition and worn out bearings, they were replaced with new ones. The condition of the propeller required machining, edge sharpening and balancing to bring the eccentricity within permissible limits.



Figure 5. Machined propeller bearings

As part of the final work on the docking of the ship, the painting of the ship's hull and plating was carried out.

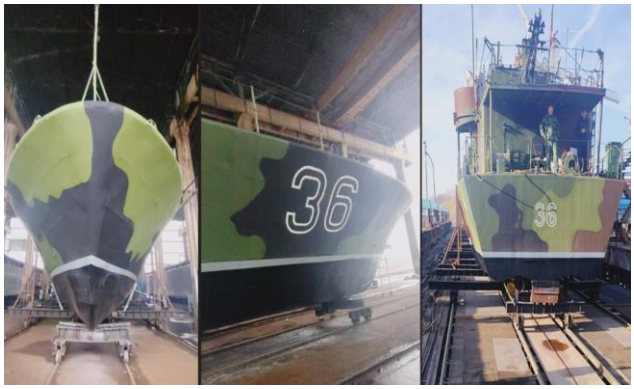


Figure 6. Appearance of the ship after docking

6. CONTROL MEASUREMENTS AFTER DOCKING

After the completion of docking and the elimination of malfunctions in the propulsion system, a test run was carried out as part of the handover works, during which control measurements were also performed to assess the condition of the ship's propulsion system.

The measurement was performed while sailing upstream at approximately normal ship displacement, on the left and right axle rows.

The measurement was performed in four sailing modes, with the note that the maximum mode was at 1590 rpm for the left main engine, and 1500 rpm for the right main engine. The specified mode was assessed as the maximum safe mode, according to the ship's commander, in which vibrations of the propulsion complex cannot cause damage to the propulsion elements.

Diagnostic measurements on the return lines included the determination of the following parameters:

– Measurement of linear vibrations on the supporting elements of the return lines;
– Measurement of temperatures on the supporting elements of the return lines.

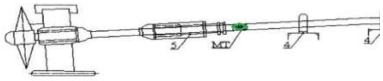


Figure 7. Position of measuring tapes on the return line

6.1 Linear vibration measurement

Linear vibration measurements were performed with the aim of establishing the vibration level, as well as comparing the measured values with the permissible values according to the American Bureau of Shipping standard.

Linear vibration measurements of the propulsion complex elements were performed using the Falcon portable vibration diagnostic device (сер.бр.10909) and the 0.1dB-Metravib SAS triaxial accelerometer, while the TAC-10 tachometer, manufactured by SPM, was used to measure the rotational speeds of the drive shafts.

Table 4. Result of vibration measurement

DEVICE NAME: Ship's shaft line (left/right)				MEASUREMENT POINT LOCATION: Reducer
rpm of the shaft (o/min)	Effective speed of vibration Vef (mm/s)			Note
	Вертикално	Хоризонтално	Уздужно	
495/480	4,47 / 3,06	15,99 /9,91	4,22 / 3,97	According to the ABS standard, the recommended permissible value is 13mm/s.
630/600	6,48 / 5,88	6,24 / 5,08	6,66 / 9,50	
720/75	5,95 / 9,93	5,51 / 8,47	7.29 9,37	
795/750	8,35 / 8,74	6,98 /9,2	8,35 / 8,73	
DEVICE NAME: Ship's shaft line (left/right)				MEASUREMENT POINT LOCATION: Thrust bearing
rpm of the shaft (o/min)	Effective speed of vibration Vef (mm/s)			Note
	Вертикално	Хоризонтално	Уздужно	
495/480	1,55/ 1,62	2,74 / 4,32	3,96 / 3,74	According to the ABS standard, the recommended permissible value is 5mm/s
630/600	1,92 / 1,96	4,03 / 4,01	4,00 / 3,95	
720/75	4,03 / 2,08	4,55 / 4,1	4,53 / 4,05	
795/750	3,90 / 1,97	4,95 / 3,43	7,75 / 7,69	
DEVICE NAME: Ship's shaft line (left/right)				MEASUREMENT POINT LOCATION: Carying bearing 1
rpm of the shaft (o/min)	Effective speed of vibration Vef (mm/s)			Note
	Вертикално	Хоризонтално	Уздужно	
495/480	2,55 / 1,76	5,3 1 / 4,29	5,14 / 4,03	According to the ABS standard, the recommended permissible value is 7 mm/s up to 13 mm/s
630/600	4,99 / 2,59	**8,86** / 6,00	6,30 / 5,93	
720/75	5,98 / 2,49	**16,45** / 4,01	**15,35** / 6,04	
795/750	5,30 / 2,40	**10,52** / 4,30	11,10 / 7,09	
DEVICE NAME: Ship's shaft line (left/right)				MEASUREMENT POINT LOCATION: Carying bearing 2
rpm of the shaft (o/min)	Effective speed of vibration Vef (mm/s)			Note
	Вертикално	Хоризонтално	Уздужно	
495/480	1,49 / 3,14	1,64/2,38	4,70/ 5,54	According to the ABS standard, the recommended permissible value is 7 mm/s up to 13 mm/s
630/600	2,03/4,29	2.94/ 2,58	5,54 /4,98	
720/75	3,95 / 5,75	6,97/ 3,63	6,89 / 7,86	
795/750	4,22 / 6,58	6,35 /4,88	6,86 / 9,56	
DEVICE NAME: Ship's shaft line (left/right)				MEASUREMENT POINT LOCATION: Carying bearing 2
rpm of the shaft (o/min)	Effective speed of vibration Vef (mm/s)			Note
	Вертикално	Хоризонтално	Уздужно	
495/480	1,93/ 1,23	3,90 / 1,86	4,49 / 1,05	According to the ABS standard, the recommended permissible value is 7 mm/s up to 13 mm/s
630/600	4.33/ 1,56	3,82 / 2,27	4,33 / 1,24	
720/75	4,77/ 2,61	6,72 / 2,93	6,97 / 2,43	
795/750	5,17 /4,37	4,95 / 5,13	7,44 / 3,63	

By analyzing the measured values given in Table 4, it is observed that the vibration level is for the most part (in terms of measurement points and modes) within the limits recommended by the American Bureau of Shipping (ABS) standard for vibrations on marine propulsion devices.

Based on the measured results, it can be concluded that the extent of the work carried out on the docking of the ship was entirely aimed at eliminating the consequences and causes of the malfunction of the ship's propulsion system.

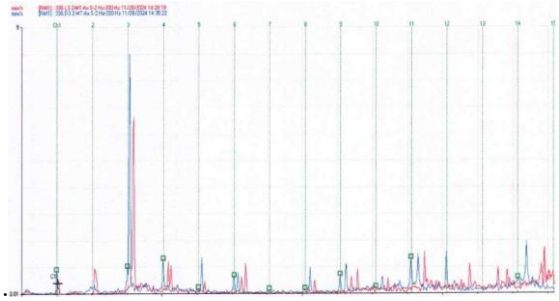


Figure 8. Frequency spectrum of the vibration on the thrust bearings

Figure 8 shows the frequency spectrum of vibration speeds, a comparison of axial vibrations on thrust bearings, for the case of the right engine 750 rpm, the left engine 795 rpm.

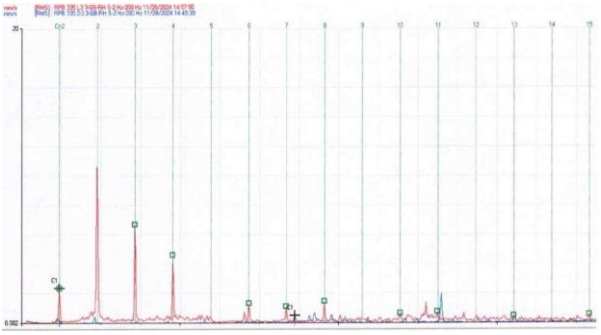


Figure 9. Frequency spectrum of the vibration on the on the first support bearing

Figure 9 shows the frequency spectrum of vibration speeds, a comparison of horizontal vibrations on the first support bearing, for the case of the right engine 675 rpm, the left engine 720 rpm.

6.2 Measuring temperature on bearings

Temperature measurement was carried out contactlessly, on the bearing housings, in four operating modes, and the VOLCRAFT IR-1000L instrument was used for this purpose.

Table 5. The measured temperature value

rpm	Left/right thrust bearning (t °C)	Left/right carying bearing 1 (t °C)	Left/right carying bearing 2 (t °C)	Left/right carying bearing 3 (t °C)
500	39,8 / 35,5	30,9 / 31,8	36,3 / 31,9	45 / 40. 1
600	37 / 31,6	29,4 ' 3 I,8	36,1 / 31,6	46,4 / 41,6
700	39,9 / 34	33,7 34,5	33,4 / 30,7	46,4 / 42.5
775	42,2 / 36,6	34,9 37,4	34,3 / 30,5	45,2 / 4 1,8

Comparing the measured temperature values, a slightly higher temperature of the last support bearings in the series is observed, but there are no results that significantly deviate from the measured temperature intervals. By reviewing the measurement results and comparing the bearing temperature values of the left and right return lines, it can be concluded that the values at different modes are approximately negligible differences for the left and right return lines, and that small differences in deviation can be attributed to the sensitivity of the measuring device.

7. EVALUATION OF MEASUREMENT RESULTS

By analyzing the measured operating parameters of the left and right shaft lines, the following conclusion is drawn:

The thrust bearing (behind the thrust bearing) of the left shaft line at driving modes above 1300 rpm had a horizontal vibration value exceeding the values recommended by the standard. The irregularity in the form of an impermissible vibration level, considering the order (second) and the direction of vibration (horizontal), indicates the probable existence of a parallel misalignment of the shaft line.

The thrust bearings on both shaft lines at maximum speed during operation had axial vibration values above the values recommended by the standard. The measured values, in accordance with previous experience and diagnostic measurements on Russian ships, are not unusual for the propulsion complex. By analyzing the frequency spectrum, it can be concluded that the higher level of vibration is caused by minor misalignments of the shaft line or unbalance of the propeller blades.

The measured bearing temperature values are within the permitted range and there are no values that significantly deviate from other measured temperatures on the return line bearings.

Empirically, from the perspective of the crew and experts from the River Flotilla who attended the test run, which lasted more than four hours at different operating modes, in upstream and downstream navigation conditions, the docking and repair work on the ship's propulsion complex met expectations and completely eliminated the consequences and causes of the failures.

It is particularly important to emphasize that early detection of failures in the operation of all subsystems is very important, because in this way the chain of failures of other subsystems and assemblies, causally and consequentially related to them, is prevented. Also, empirical understanding, understanding and "feeling" can often be crucial in cases of observing the state of health of ship subsystems, given that the assets under consideration (ships) represent complex technical systems, for which previously defined limitations and parameters do not coincide with actual operating conditions.

8. CONCLUSION

Warships are complex technical systems, which as such represent factors of a large number of subsystems.

The most important among them is the ship's propulsion system, which represents the "heart of the ship".

Ensuring the health of a ship's propulsion system involves a complex technical process of observing a number of parameters, as well as monitoring the health of components and return line elements. For this purpose, diagnostic tests are often carried out, in which measurements are carried out to determine quantitative indicators and assess the condition of the tested system, which was the case here.

The role of the crew was very important in the early detection of the failure of ship systems, so thanks to the timely reaction and diagnostic measurements, the malfunction of the ship's propulsion system of the auxiliary river vessel "Šabac" was confirmed, while maintaining the functional integrity of the ship by applying a limited mode of use (load).

After determining the malfunction of the ship's propulsion system of the auxiliary river vessel "Šabac" and analyzing the results of diagnostic measurements, the ship was docked and comprehensive work was carried out to eliminate the causes and consequences of the failure.

During the docking process, the ship's propulsion system components were disassembled and inspected, which allowed for a clear understanding of the causes and consequences of the malfunction. After the malfunction was identified, all defective components and assemblies of the ship's propulsion system were replaced, the return lines were processed to bring the eccentricity within the limits of permissible deviations, and the propellers were balanced.

After eliminating the observed malfunctions in the ship's propulsion system and the works envisaged by the scope of docking, a test run was carried out as part of the handover works, during which control measurements were carried out on the ship's propulsion system.

By analyzing and comparing the results of control measurements before and after docking, we conclude that the values of the measurement parameters after docking are within the limits of permissible deviations. Also, the empirical observation of the state of the ship's propulsion system by the ship's crew fully confirmed the drastic difference in ensuring the ship's maneuvering and propulsion characteristics after docking, which is in the function of ensuring the expected values.

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