Determination of stiffness coefficient of stern shaft bearing

Aleksey Halyavkin[1], Igor Razov[2], Victor Mamontov[3], and Guriy Kushner[3]

[1]OOO «Gazprom dobycha Astrakhan», 414000, Lenina str. 30, Astrahan', Russia.
[2]Industrial University of Tyumen, Volodarskogo 38, Tyumen, 625001, Russia.
[3]Astrahan' State Technical University, Tatishheva, 16, Astrahan', 414056, Russia.

E-mail: Razovio@mail.ru

Abstract. In this article the authors solve the problem of determining a stiffness coefficient of stern shaft bearing with mechanical and geometrical parameters of the ship shafting and stern bearings. The influence of the stiffness coefficient on transverse and parametric vibrations is investigated. The dependence of the Ship's Shafting of tension state and deformation of stern bearing is shown. The equation for determining the stiffness coefficient is obtained. The numerical value of the stiffness coefficient of feed bearings of some types of vessels is presented.

1. Introduction
The ship shaft is a system of connected shafts in a single line for the transferring the torque from the engine to the propeller and sensing the axial force from the propeller to the hull of the ship.

Reliable and long-term operation of shafting is one of the actual problems at the moment. There are a lot of published domestic and foreign scientific works [1-14].

The determination of the frequencies of free transverse vibrations as well as of torsional vibrations is one of the main tasks in the design of the stern shaft. The purpose of this calculation is to prevent the resonance phenomenon in the operation of stern shaft.

Calculations of ship shaft lines are regulated by the Rules of the Russian Maritime Register of Ships and the Rules of the Russian River Register for Inland Navigation Vessels. In accordance with these Rules, the design and dimensions of the shafts, the structural dimensions of the shaft connection parts, the number of shaft supports and the spacing between them.

The calculation of all parameters of the ship's stern shaft is preliminary, because they must be refined based on the calculation of the torsional and transverse vibrations of the ship's stern shaft.

In the operation of the ship's stern shaft may occur parametric vibrations [15]. Parametric vibrations are characterized by tearing off the stern shaft from the bearing. The height of the lift depends on the shape and size of the bearing wear.

Therefore, when calculating the parametric vibrations of ship's stern shaft, it is necessary to take into account the elastic and mechanical characteristics of the stern bearing. According to [15], such bearing characteristics can significantly affect the value of the own frequency of the stern shaft. The elastic characteristics of the stern bearing are characterized by a stiffness coefficient k.

In many works, there are only the numerical value of the stiffness coefficient k of the bearing material is given in calculating the shafting without reference to the sources.

In general, the purpose of the stern bearing is to provide the necessary waterproofness of the hull of the ship, and the propeller shaft - one or two supports, to perceive static loads from the weight of the stern shaft and the screw and dynamic from the propeller in conditions of various immersion.

2. Materials and methods

The ship's stern shaft carries the torque of the engine to the propeller, and the propeller-driven ship's hull (figure 1). During operation, the stern shaft is under the influence of a whole series of loads, which can be divided into two groups: stationary and variable loads. The stationary loads include the own weight of the propeller shaft, the weight of the screw, the weight of the auxiliary parts and etc.
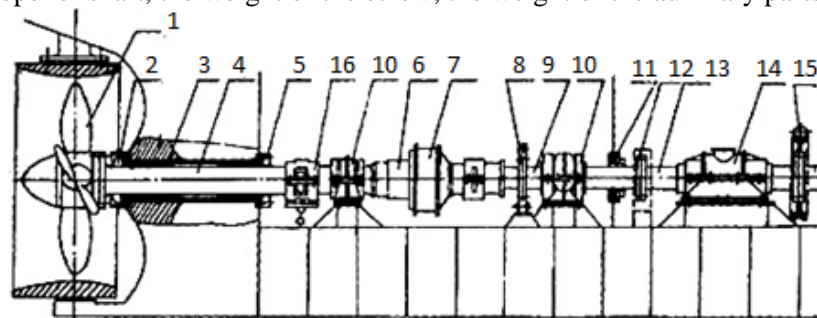

Figure 1. The stern shaft of the vessel [18]: 1- ship propeller; 2 - sternward; 3 - stern tube assembly; 4 - screw shaft; 5 - bow stern tube seals; 6 - half coupling screw shaft; 7 - pitch actuating mechanism; 8 - buffer; 9 - line shaft; 10 - entre bearing; 11 - bulkhead seal; 12 - current collection equipment; 13 - thrust block shaft; 14 - compressive bearing; 15 - rotating device; 16 - center plate oil tank.

The vibration of the stern shaft is caused by a number of factors, including the effect of torsional, longitudinal and transverse vibrations, which arise in turn under the action of varying loads. In work [16] is described that the hull of the vessel introduces an inhomogeneity in the field of water flow rates, which rides on the propeller. That is, the action of this type of loading generates a total hydrodynamic moment, which consists of the sum of the constant and periodic components. The frequency of the periodic component is equal to the product of the rotational speed of the screw by the number of its blades. The periodic component of the hydrodynamic moment is the cause of the excitation of bending vibrations of the stern shaft. The forces of inertia of the propeller during these vibrations are taken into account by dynamic amplification of the variable component of the hydrodynamic moment.

The most dangerous variable loads can also be attributed to ice loads, which are manifested in the form of random torsional, axial and flexural vibrations of the stern shaft. This kind of load arises from occasional interactions of the propeller with ice, which considerably exceed the hydrodynamic forces on the screw in pure water: by a torque of 6-10 times, by a bending moment of 8-15 times, by a 1.5-2.5 times [17].

Each time, depending on the operational conditions of the vessel, the operating conditions of the stern shaft change: the influence of some types of loads is increased; the influence of others is weakened or completely disappears [16]. So, the ship shaft works in difficult conditions and is a complex dynamic system (Table 1)

Table 1. Some characteristics of stern bearings.

Material of stern bearing	Circuit speed, m/s	Limiting diameter, m	Moisture absorption for 24 h, %	Ultimate swelling,%	Wear for 1000 h of work, mm
Bakout	10	0.8	15	16.5	0.1 – 0.3
Textolite	10	0.4	0.45	-	0.1 – 0.3
WLP	10	0.4	20	-	0.15 – 0.40
Caprolon	15	0.5	8	6.8	0.10 – 0.25
Rubber	10	0.45	-	-	0.10 – 0.25

In order to eliminate of the resonance state of the stern shaft, under the action of periodically varying loads during its operation, calculations are necessarily made for torsional and transverse vibrations. The stern shaft is designed so that its own frequency of 20-30% does not exceed the blade frequency. Stern bearing of sea vessels is divided into two groups: with nonmetallic and metallic liners.

As the antifriction material of the bearing, in the first case it is used bakout, textolite, wood-laminated plastic, rubber-metal and thermoplastic materials (caprolon), etc. In table 1 presents some characteristics of the materials. In the case of a metal bearing with oil lubrication, the bearing shells are filled with Babbitt. In this paper, a methods for determining the stiffness coefficient of a stern bearing was obtained. In the design scheme stern bearing use like an elastic foundation. The methods is also applicable to the calculation of shafts with a propeller shaft.

The mathematical model of a sliding bearing presented in the form of two elements: the stern shaft stern bearing has the form (figure 2).
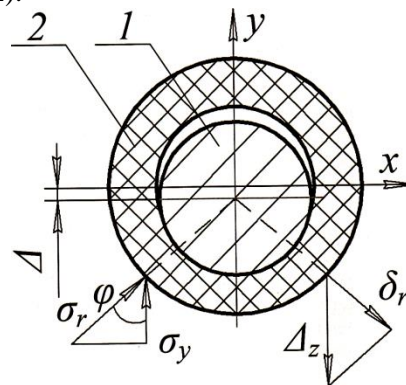

Figure 2. Scheme of interaction of a propeller shaft with a stern bearing:
1 – shaft, 2– bearing body.

3. Results

Because the modulus of elasticity of steel is more than twice that of the elasticity modulus of the bearing material [2,3], we suppose that the shaft and the housing are absolutely rigid.

The origin is placed in the center of the bearing. Suppose that the shaft has received a vertical displacement relative to the origin Δ_0 and angle of rotation θ along the length of the bearing. Then, at a distance z from the origin of coordinates along its length, the displacement will be:

$$\Delta_z = \Delta_0 + \theta z. \tag{1}$$

We suppose that the angle Θ is small, and at a short length dz, the vertical displacement Δy is the same. When an absolutely rigid shaft is introduced into the bearing body, this movement will cause a radial displacement of the inside surface of the bearing body δr.

It can be seen from figure 2 that

$$\delta_r = \Delta_z \cos\varphi. \tag{2}$$

The normal tension occurring in the body of the stern bearing will take the form:

$$\sigma_r = E\varepsilon_r , \tag{3}$$

where: ε_r - relative compression of the stern bearing:

$$\varepsilon_r = \frac{\delta_r}{h} , \tag{4}$$

where: h- thickness of stern bearing.

It can be seen from figure 2 that the vertical component of the normal tension will take the form:

$$\sigma_y = \sigma_r \cos\varphi \tag{5}$$

From equations (2), (3), (4), equation (6) takes the form:

$$\sigma_y = \frac{E}{h}(\Delta_0 + \theta z)\cos^2 \varphi. \tag{6}$$

Summing σ_y along the circumference, we obtain a distributed load along the length of the shaft:

$$q = \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \sigma_y r d\varphi = \frac{E}{h}(\Delta_0 + \theta z)r \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \cos^2 \varphi d\varphi, \tag{7}$$

where:

$$q = \left(\frac{E}{h}(\Delta_0 + \theta z)r\right) \cdot \left(\frac{\varphi}{2} + \frac{1}{4}\sin 2\varphi\right)\Big|_{-\frac{\pi}{2}}^{\frac{\pi}{2}}. \tag{8}$$

Then equation (8) takes the form:

$$q = \beta(\Delta_z + \theta z); \quad \beta = \frac{\pi E d}{4h}. \tag{9}$$

Therefore, the bearing stiffness k (N/m) in the vertical (or in any other radial direction) will have the form:

$$k = \frac{Q}{\Delta_z} = \frac{\pi E d^2}{4h} \tag{10}$$

Table 2 presents the stiffness coefficients k of the stern bearing for some types of vessels.

Table 2. - Value of vertical stiffness coefficients k for some types of vessels.

№	Type of vessels	Material of stern bearing and modulus of elasticity		D, mm	d, mm	h, mm	L, mm	k, N/m
		Material	E, Pa					
1	RDOS type «MORYANA»	Caprolon	$2.1 \cdot 10^9$	300	245	27.5	840	$4 \cdot 10^9$
2	HAZAR-1	Caprolon	$2.1 \cdot 10^9$	170	131	29.5	520	$1 \cdot 10^9$
3	TSJ-300	Caprolon	$2.1 \cdot 10^9$	190	150	0.2	560	$2 \cdot 10^9$

4. Conclusion

A mathematical model of the interaction of a propeller shaft with a feed bearing is developed. Dependences for calculation of the sliding bearing on strength and rigidity are obtained. A brief analysis of the stiffness of the caprolon bearing and some of its test results is obtained. Stiffness coefficient values of the stern bearing material for full-scale vessels are calculated. According to the obtained results, it follows that the numerical value of the stiffness coefficient is significantly affected by the geometric and elastic characteristics of the bearing. The effect of the rigidity of the stern bearing on the value of the natural frequency was evaluated for transverse vibrations of the shaft of the ship shafting. The obtained results can be used in the design and calculation of the ship shafting.

Reference
[1]   Ashurov A E and Gorin S V 1997 *Sudostroenie* **2** pp 32-33
[2]   Babaev N N and *Lentjakov* V G 1961 *Nekotorye voprosy obshhej vibracii sudov* (Leningrad, Sudpromgiz) 308 pp
[3]   Babakov I M 2004 *Teorija kolebanij* (Moscow: Drofa) 592 pp
[4]   Climont W and Kinbay D 1979 *Transactions of the Institute of Marine Engineers* **4** pp 35-46
[5]   Kozousek V M and Davies P G 2000 *LR Technical Assosiation* **5** pp 37-40
[6]   Latron Y and Nielsen A 1979 Transactions of the Institute of Marine Engineers **4** pp 3-11
[7]   Larsen O C 1979 *Transactions of the Institute of Marine Engineers* **4** pp 12-23
[8]   Bakšys B and Mikolainis J 2011 *Mechanics* **5** pp 492-497
[9]   Šestan A 2012 *Transactions of FAMENA* **1** pp 35-44

[10]   Han Q and Chu F 2012 *Archive of Applied Mechanics* **5** pp 709-722
[11]   Babilio E 2014 *Intern. J. of Structural Stability and Dynamics* **8** 1440014
[12]   Carta G 2012 *Archive of Applied Mechanics* **9** pp 1219-1232
[13]   Ma J 2015 *Archive of Applied Mechanics* **2** pp 125-129
[14]   Mironov A I and Haljavkin A A 2010 *Vestnik AGTU* **1** pp 131-135
[15]   Bolotin V V 1961 *Nekonservativnye zadachi teorii uprugoj ustojchivosti*. (Moscow, Fizmatgiz)
            341 pp
[16]   Jacenko V S 1968 *Jekspluatacija sudovyh valoprovodov* (Moscow,Transport) 171 pp
[17]   Merkulov V A and Timofeev V I 1981 *Sudostroenie* **3** pp 22-25
[18]   Rumb V K 1996 *Osnovy proektirovanija i rascheta sudovogo valoprovoda* (St. Petersburg
            Izd.centr SPbGMTU) 106 pp