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ANALYSIS OF GREASING AND WEAR PROCESSES ON THE SLIDING BEARINGS OF A NAVAL PROPULSION ENGINE

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Abstract: In recent years maritime and inland waterway transport have developed unprecedentedly in close agreement with the rapid pace of industrialization and the increase in domestic and foreign freight traffic. This led to the development and upgrading of naval equipment. Thus, a series of programs have also been developed in the field of operation and maintenance of naval equipment. This also involved certain upgrades in the field of equipment maintenance and implicitly in terms of lubrication and increasing the service life to their nominal parameters. This development of shipping also included the development of engine oils. an important part of the safe operation of naval propulsion engines. Nothing is more important for the life of an internal combustion engine than proper lubrication and oil filtration for the engine and other moving parts. This paper aims to analyze the lubrication systems and the wear processes at the sliding bearings of the engine assembly for a marine propulsion engine. The last part of the paper presents the thermal calculation of the sliding bearings both due to the fluid friction and the heat release from the engine. The reference engine considered in the calculation of the lubrication system was a naval engine type ROLLS-ROYCE-B32: 40L8P with a rated power of 4000 kW. Starting from the oil flow required for lubrication, the oil flow required to dissipate the heat from the bed bearing was determined.

Key words: wear process, sliding, bearing, naval, propulsion

1. INTRODUCTION

The main aggregate in the composition of any water transport vessel on which its performance depends to a considerable extent, is the engine. During operation, important changes are made to the mechanisms, systems and parts of the internal combustion marine propulsion engines which lead to worsening of the propulsion performance. The main cause of the worsening of the technical condition of the engine mechanisms and systems is the wear of the parts in the operation process. This wear and tear is largely influenced by external factors characteristic of the specific operating conditions of the vessels.

The operating conditions of ship engines are complex and often change. To these operating conditions are added the influences of oil, coolant and fuel used in the engine, as well as the action of mechanical impurities entering the cylinders with the combustion air in oil and fuel. Also to these operating conditions is added the influence of high temperature and pressure, operating so that the oil is subjected to the aging process. requiring its periodic replacement, [1].

1.1 Tribosystem – Friction. Wear and Lubrification

The science that deals with the study of friction, wear and lubrication is called tribology (tribos - friction). Tribology deals with surfaces that exert reciprocal actions on each other and at the same time are animated by a relative motion (figure 1.). The nature and consequences of these interactions reflect the laws of nature, with a multidisciplinary focus, their understanding requiring knowledge of physics, chemistry, materials and machine construction, [2].

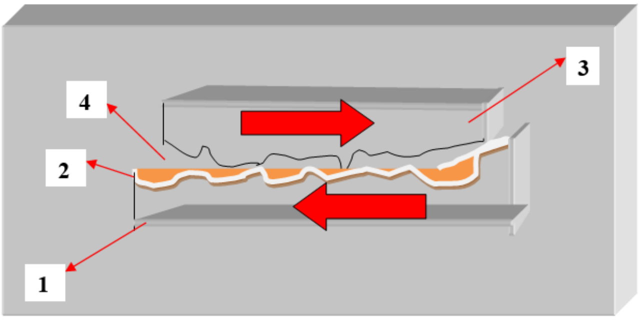

Fig. 1. Tribosystem structure:
1-piece; 2-lubrificant; 3-counterpart; 4-the environment

1.2 Friction

Friction can be defined as the molecular, mechanical, energetic process that takes place between two surfaces in contact, in relative motion, subjected to a normal pressing force.

In the case of the internal combustion engine, the friction is manifested at the level of some kinematic

friction torques (bearings. piston-cylinder, skate-slide, etc.). being a physical-mechanical phenomenon, which determines mechano-thermal wear.
The following types of frictions are distinguished:
•*Dry friction:* the contact between the two surfaces of the coupling is direct, without lubricant film or a layer to be interposed between the two surfaces;
•*Boundary friction (unctuous):* thin (molecular) layers of lubricant are interposed between surfaces;
•*Semi-fluid friction (mixed):* the surfaces have a certain degree of roughness, so that. although the lubricant film has the appropriate thickness, it breaks and recovers (ex: piston-cylinder);
•*Fluid friction (hydrodynamics):* ensures theoretically perfect separation of surfaces (ex: bearings);
•*Elastohydrodynamic friction:* occurs in case of deformation of the contact area. as a result of pressures and loads, and the viscosity increases up to 15 times (ex: gears. bearings).

1.3. Wear types

One of the most important effects of friction is wear. This can be defined as the progressive loss of material due to mechanical interactions between the contact surfaces.
The types of wear and tear encountered in heat engines are:
•*Adhesive wear,* due to the intermolecular forces of the surfaces that come into contact, is accentuated by the thinner the film or the protective layer of lubricant is thinner;
•*Abrasive wear* occurs due to the action of solid particles existing between surfaces, from material tears or carbon deposits;
•*Corrosive wear,* due to chemical processes in the lubricant that act on the material of the coupling surfaces;
•*Fatigue from contact materials,* characteristic of loaded contacts.
If the contact surfaces are subjected to the action of vibration, a specific wear called pitting occurs (pinching, for example on the sides of the gear teeth or on the ball-bearing contact on the bearings), [2].

1.4. Lubrification

Another important process, of a tribological nature, is lubrication, which consists in ensuring the presence between the moving surfaces of the tribosystem of an environment with a lubricating effect.
Lubricants according to their state of aggregation can be:
•*Gaseous lubricants* (have limited applications in the case of heat engines);
•*Liquid lubricants* (the most common in the field of heat engines);
•*Solid lubricants* (in the case of marine engines, it ensures the lubrication of coupling joints, such as rotary dampers, or torques in the distribution system, such as exhaust valves for two-stroke engines).
As an element of the tribosystem that interposes between the two metal surfaces in relative motion, the main functions of lubricants are:
•*Lubrication function.* It aims to reduce the friction between the surfaces of the coupling. which are in relative motion, to avoid the grip and to keep the wear as low as possible.
•*Cooling function.* The lubricant is the main means of evacuating the heat produced in the friction process, and at the level of the torques in the internal combustion engine it also takes over a fraction of the thermal energy released in the combustion process.
•*Chemical protection function*. Oxidation of an oil and contamination by condensation and impurities due to combustion are causes that lead to the production of acids in the engine oil. Motor oils also aim to combat these acids.
•*Sealing function.* It is made by the very presence of lubricant between the surfaces of the coupling, which helps to prevent the access of foreign particles, which would cause abrasive wear, [2].

2. MATERIALS AND METHODS FOR MAIN ENGINE PROPULSION

The lubrication system of the slow main motors is particularly complex and is characterized by the existence of all types of lubrication [3, 4].
The most important components are:
•low and medium pressure lubrication subsystem, made in a closed circuit, which serves all the engine mechanisms and even realizes the cooling of the piston in some engines;
•lubrication subsystem of the supercharger;
•high pressure, open circuit lubrication subsystem.
Lubrication systems are particularly complex installations and have a considerable number of components.
The most representative are as follows: circulation pumps; cylinder lubrication pumps; filters; oil coolers;
•circulation tanks; oil separators

2.1. Circulation pumps

Circulating pumps are used for closed-loop lubrication systems and the most commonly used types are gear pumps, especially for low-power motors, when driven directly by the motor.
These pumps can be geared:
•exterior, most common;
•interior have higher flow rates, but are more complicated to build, so they are rarely used.
Circulation pumps are used in lubrication systems and have efficiencies of (60÷75) %, discharge pressures up to 25 barr and flow rates between (0.1÷350) m^3/h,

which vary slightly when changing the discharge resistances, but are very sensitive to increased suction height.
However, their main disadvantage is the very high noise level, but they are very widespread due to their simplicity of construction and very low cost price, [3, 4].

2.2. Cylinder lubrication pumps

Cylinder lubrication pumps are used in open circuit, the pistons are driven by cams, several pistons are grouped in a single pump and serve one or more cylinders. The rotational movement of the cams is obtained depending on the load on the drive shaft.

2.3. Filters

Filters, like fuel filters, can be:
• coarse, which are mounted at the oil inlet sockets before the transfer pump and are usually manually cleaned;
• fine, which is mounted in the lubrication circuit after the oil coolers; due to the high flow rates that need to be conveyed, so as not to exaggerate the dimensions; fine oil filters have a thickness of only 0.01mm; they are usual with metal blades and self-cleaning.
For the cleaning of impurities smaller than 0.01mm. volumetric magnetic filters and centrifugal filters are used that retain impurities with dimensions larger than (0.003 ÷ 0.005) mm, but are covered by only (5÷15) % of the amount of oil circulated. The cleaning of a filter battery is done by reversing the flow in the element to be cleaned, [3, 4].

2.4. Oil coolers

Oil coolers are surface heat exchangers that ensure the temperature of the oil within the limits of ensuring good lubrication. These can be of the type:
•With pipes - in which water passes through pipes, and oil through pipes; to increase the cooling efficiency, the oil spaces are provided with baffles that contribute to the intensification of heat exchange.
Pipe oil coolers can be:
- with straight pipes, preferred because they are easy to clean, but with sealing problems due to expansion;
- with U-shaped pipes, which eliminates the disadvantage of sealing due to expansion
•With plates - they are more and more used lately.
The biggest problem with their operation is the danger of water contamination of the oil, therefore the oil pressure must be higher than the cooling water, and when the water comes out of the cooler there is an indicator that can signal the presence of oil in the water. To maintain high cooling efficiency, relatively easily clogged oil spaces are connected to chemical cleaning systems, [3,4].

2.5. Circulation tanks

There are two types of oil tanks:
•For circulation:
- structural, under the engine most commonly encountered in large engines;
- above the straw, very rare;
- oil bath. for auxiliary, semi-fast engines; and fast;
- buffer tanks, when lubricating the turbocharger unit.
•For storage.
Oil tanks are similar to fuel tanks and are equipped with:
- vent pipe removed on deck, provided with vents protected from water and flame;
- overflow pipe with visor;
- structures for limiting free surfaces;
- autoclaves for cleaning and inspection;
- drain valves;
- level bottles;
- remote level measurement and signalling systems.
Of these, a special construction is the structural circulation tanks, located under the main engine. They are built in double bottom, are insulated from the rest of the tanks with cofferdams, to avoid contamination with sea or bilge water and have a slight stern inclination towards the area where the oil suction of the lubrication pump is found. The crankcase drains must be long enough to remain immersed in oil under any conditions, thus isolating the crankcase from the tank gases.

2.6. Oil separators

Oil separators are only used for medium and high power propulsion systems; they are also of the centrifugal type, as are those used for fuel separation. Separation removes water and impurities exceeding (0.003 ÷ 0.005) mm.
The oil separators are therefore the same as the fuel separators operating in the clarifier mode; however, the working temperature is lower, being in the range of (60 ÷ 87) ºC.
Centrifugal separation ensures the removal of water and solid particles larger than 0.02 mm.
The separator flow rate is such that it can separate the entire amount of oil from the lubrication circuit in (2 ÷ 4) hours of continuous operation, [3, 4].

3. RESULTS AND DISCUSSIONS FOR WEAR OF THE MAIN ENGINE PARTS

Among the moving parts of the engine, wear of the cylinder-piston-segment tribosystem worsens the operation of the engine, while wear of the sliding bearings, valves and timing system makes it impossible.
The wear of the cylinder liners takes place as a result of the working conditions determined by the variable mechanical stresses and the difficult thermal regime of operation, which determines thermal stresses, [5].
The process of wearing cylinder liners knows the three

main forms of wear, namely:
•Adhesion (dry or semi-liquid rubbing);
•Abrasion (mechanical impurities in oil and flue gases);
•Chemical (chemical flue gas attack and complex chemical corrosion).

The area of adhesion wear (contact occurs) at the end of the piston stroke (PMS and PMI) where the piston speed is very low and hydrodynamic lubrication cannot occur.

Abrasion wear can occur anywhere along the length of the cylinder liner, but preferably in the PMS area, where coal deposits are collected.

The surface of the cylinder wears out due to corrosion caused by sulfuric and nitric acids, formed during combustion.

For each engine, the friction force as well as the wear produced by the cylinder generators vary according to the evolution of the pressure on its walls (figure 2 and figure 3).

At the top of the cylinder the wear is higher due to the unfavourable temperature, pressure and lubrication conditions. Wear decreases, almost in proportion to the length of the cylinder to the bottom. Cylinder wear it is, in most cases, abrasive, corrosive or both.

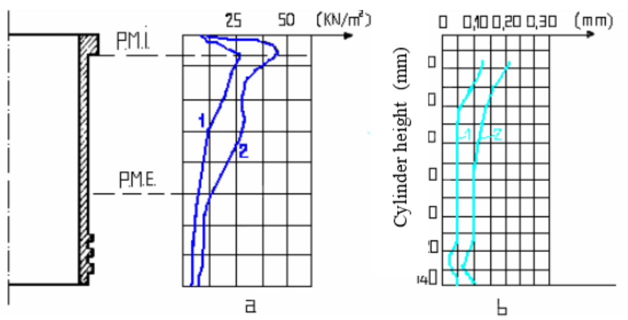

Fig. 2. Wear of the cylinder liners.
a-specific force of friction during compression (1) and during combustion and expansion (2);
b-wear in the longitudinal (1) and transverse (2) plane of the engine;

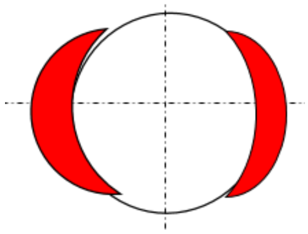

Fig. 3. Wear perpendicular to the plane of movement of the connecting rod.

Wear differing in the plane of movement of the connecting rod from the plane perpendicular to the plane of movement of the connecting rod gives rise to an oval of the cylinder liner.

Fuel can have a significant influence on the failure and wear of the piston-segment assembly. It is thus known that non-compliant petrol causes clogging of the windows of the lubrication segments and the formation of resinous deposits on the piston skirt. The use of diesel with a long distillation end, low cetane content and high sulfur content is the cause of the stiffening of the segments and deposits on the piston skirt.

Wear of bearing and shaft spindles - Most of the defects that occur in the bearing torque are due to mounting and lubrication.

Faults may occur at:
•due to corrosion;
•due to insufficient lubrication;
•to mechanical degradation when the mounting clearances are not observed;
•Improper assembly or incorrect machining.

Corrosion - Anti-friction alloys made of copper-lead and cadmium are most easily corroded by acidic oil products. Other anti-friction alloys are rarely exposed to corrosion. However, their faults are often mistakenly attributed to corrosion. Figure 4 shows two of the most common forms of corrosion found in copper-lead bearings.

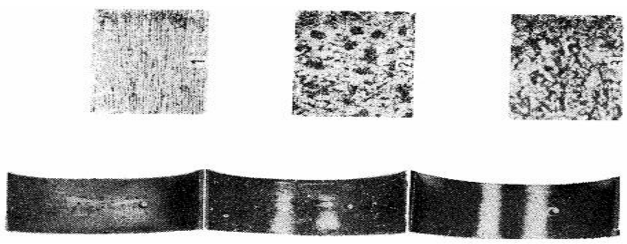

Fig. 4. Forms of corrosion of copper-lead bearings.

Bearing 1 - no signs of corrosion, either visually or after metallographic examination.

Bearing 2 - has pinch-shaped material detachments. The metallographic examination shows that the corrosion process due to the thermal instability of the oil consisted in removing the lead from the alloy. without affecting the copper.

Bearing 3 - has a more superficial form of corrosion (cold corrosion), due to the acidic products in the oil, coming from the condensation of the flue gases of the sulfur fuels escaped in the crankcase. This type of corrosion is highlighted by the attack of copper on sulfuric acid.

Insufficient lubrication – dust, impurities and abrasive materials accumulated in the oil are the main cause of bearing damage. These materials are usually inserted into the bearing material and then work as micro lathes on the shaft spindles. On the surface of such a bearing are observed small gaps and elevations, as a result of the penetration of hard impurities, or parallel circular grooves on both surfaces of the bearing, caused by larger hard impurities, [6.7].

3.1. Calculation of the greasing system

3.1.1Calculation of the forces acting in a bearing

The reference engine considered in the calculation of the lubrication system was a naval engine type ROLLS-ROYCE-B32: 40L8P, with the following characteristics, [8]:
-Rated power- 4000 kW;
-Number of cylinders - 8 in line;
-Stroke- 400 mm;
-Bore - 320 mm.
-Average effective pressure - 23.35 Bars;
-Speed - 750 rpm
-Average piston speed- 10 m / s
The forces acting on the bearings of the engine mechanism (figure 5) are due to the forces of gas pressure in the cylinder and those of inertia of the masses in linear-alternating motion and rotation. Thus, the figure below shows the forces acting on the crankshaft bearings of the engine.

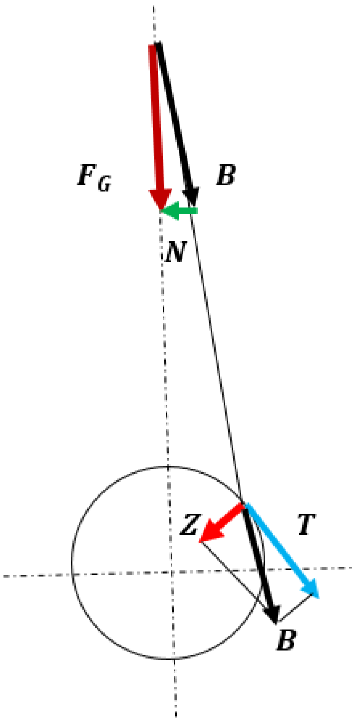

Fig. 5. Forces acting in a bearing.

The following notations from figure 5 are as follows: F_G– Gas pressure force [N]; B – Connecting rod force [N]; *N* – Normal force [N]; Z – Bearing force [N] and T – Tangential force [N].
For large internal combustion engines (airplanes, locomotive, ships) the bearings are mounted in the lower crankcase. [9]
The connecting rod is the connecting piece between the piston pin and the crankshaft. The connecting rod transmits the reciprocating reciprocating motion of the piston to the crankshaft, which it converts into a rotational motion
Using the values of the forces Z and T. the resulting force acting in the crankshaft bearing is determined with relations (1) and (2).

$$R_M = \sqrt{Z^2 + T^2} \qquad [kN] \qquad (1)$$

$$\psi_M = arctg\frac{-Z}{T} \qquad [deg] \qquad (2)$$

The value and direction of the force required on the crankshaft are given in Table 1.

Table 1. Value and direction of the force for the crankshaft

$\Delta\alpha$ $[deg]$	R_M $[KN]$	ψ_M $[deg]$	$\Delta\alpha$ $[deg]$	R_M $[KN]$	ψ_M $[deg]$
0	309.4	270.0000000	378	3434.0	112.9686204
18	253.5	104.4496964	396	2045.0	136.2571991
36	180.2	113.5729328	414	1100.0	160.0457263
54	96.9	95.55204065	432	746.3	182.8188414
72	125.8	223.0430089	450	622.0	202.6826077
90	224.4	217.9553321	468	583.0	219.4759002
108	306.2	226.5664588	486	542.0	234.2416764
126	316.2	238.9923047	504	495.0	247.4109239
144	324.4	249.9366272	522	420.0	259.3889574
162	325.2	260.2048385	540	340.0	270.0000000
180	325.2	270.0000000	558	309.2	99.67834064
198	325.2	99.79516153	576	291.0	109.2575663
216	324.4	110.0633728	594	220.0	119.1151839
234	316.2	121.0076953	612	102.0	127.5467857
252	289.0	132.4882963	630	91.8	128.0028902
270	246.5	144.3870280	648	165.0	91.68809130
288	214.2	158.9220489	666	256.7	235.9353739
306	249.4	184.6400169	684	302.4	240.1033280
324	510.0	218.2858004	702	312.0	254.2260135
342	1265.0	245.9779821	720	309.4	270.0000000
360	3379.6	270.0000000			

The forces required by the connecting rod bearing depend on α and β.
α - crankshaft rotation angle [deg];
β - the angle of obliquity of the connecting rod. [deg].
The value and direction of the force required by the connecting rod bearing are given in Table 2.
These are determined by the relations:

$$R_M = \sqrt{R_X^2 + R_Y^2} \qquad [kN] \qquad (3)$$

$$\psi_M = arctg\frac{R_Y}{R_X} \qquad [deg] \qquad (4)$$

$$R_X = Bsin(\alpha + \beta);\ R_Y = B - Bcos(\alpha + \beta) \quad [kN] \qquad (5)$$

Table 2. Value and direction of the road bearing

α $[deg]$	β $[deg]$	$\alpha+\beta$ $[deg]$	R_X $[kN]$	B $[kN]$	R_Y $[kN]$	R_M $[kN]$	ψ_M $[deg]$
0	0	0	0	-128.15539	182.3321333	182	90
18	4.4286	22.4	20.66	-97.36500	147.4476891	149	262.02
36	8.4463	44.4	37.92	-60.79779	99.48988817	106	249.14
54	11.6647	65.7	49.35	-6.04537	28.39896286	57	209.92
72	13.7590	85.8	54.02	53.88656	-49.83222005	74	137.31
90	14.4775	104.5	52.47	107.22511	-120.7207963	132	113.49
108	13.7590	121.8	46.10	145.69857	-174.1646879	180	104.82
126	11.6784	137.7	36.53	142.14198	-182.1545606	186	101.34
144	8.4649	152.5	25.11	142.64454	-190.6507437	192	97.50
162	4.4503	166.5	12.77	140.02635	-192.6764539	193	93.79
180	0.0228	180.0	0.06	138.95555	-193.1322558	193	90.02
198	-4.4068	193.6	-12.64	140.02635	-192.7072806	193	266.25
216	-8.4276	207.6	-24.99	142.14198	-190.7142233	192	262.54
234	-11.6510	222.3	-36.42	142.14198	-182.2532992	186	258.70
252	-13.7444	238.3	-46.01	134.75173	-163.3528611	170	254.27
270	-14.4775	255.5	-52.43	122.14966	-135.8123721	145	248.89
288	-13.7662	274.2	-54.04	118.18753	-114.3189380	126	244.70
306	-11.6920	294.3	-49.43	160.25866	-138.0859480	147	250.30
324	-8.4836	315.5	-38.07	336.31241	-297.7660515	300	262.71
342	-4.4721	337.5	-20.86	794.21476	-744.2139465	744	268.39
360	-0.0456	360.0	-0.22	2041.96096	-1987.784649	1988	269.99
378	4.3850	382.4	20.46	2252.09771	-2201.933905	2323	90.53
396	8.4089	404.4	37.77	1241.11017	-1202.272850	1203	91.80
414	11.6372	425.6	49.27	667.27032	-644.7360342	647	94.37
432	13.7371	445.7	54.01	439.99320	-433.7530275	439	97.07
450	14.4774	464.5	52.51	350.24886	-363.5772429	368	98.22
468	13.7734	481.8	46.18	311.25605	-339.5868.16	343	97.74
486	11.7057	497.7	36.63	276.57948	-316.4929514	319	96.60
504	8.5022	512.5	25.23	240.64788	-288.5902583	290	95.00
522	4.4938	526.5	12.90	193.30848	-245.9274350	246	93.00
540	0.0684	540.1	0.19	143.41439	-200.5907812	201	90.06
558	-4.3632	553.6	-12.51	134.22395	-186.9353873	187	266.17
576	-8.3902	567.6	-24.87	123.89155	-172.0243649	174	261.77
594	-11.6235	582.4	-36.31	115.30176	-155.5114473	160	256.86
612	-13.7297	598.3	-45.93	93.40957	-122.1453502	130	249.39
630	-14.4773	615.5	-52.38	54.76994	-68.59939821	86	232.63
648	-13.7805	634.2	-54.05	1.59756	2.085370276	54	177.79
666	-11.7193	654.3	-49.51	-57.90669	79.89831916	94	121.79
684	-8.5208	675.5	-38.22	-107.46419	145.8642938	151	104.68
702	-4.5155	697.5	-21.05	-127.04808	176.9662536	178	96.78
720	-0.0913	719.9	-0.43	-128.14635	182.3213752	182	90.14

The mean value of the force acting on the crankshaft bearing is calculated from relations (3), (4) and (5) using the values of the angles α and β in Table 2:

$$\overline{R_M} = \frac{1}{60}\sum_{j=1}^{60} R_{Mj} = 327.51\ kN \tag{6}$$

and the extreme values are

$$R_{M\,max} = 2323\ [kN];\ R_{M\,min} = 54\ kN \tag{7}$$

3.1.2. Calculation of the forces acting in a bearing

The complexity of the lubrication process and the conditions in which it takes place lead to the adoption of simplifying hypotheses, leading to acceptable solutions in terms of calculation volume. The accuracy of the results increases if any experiments obtained in similar constructions are available.
Depending on the flow rate required for lubrication, the oil circulation pump is dimensioned or adopted. A calculation of the lubrication of the crankshaft bearings is then performed to achieve a smooth lubrication of the crankshaft bearings, [10]
The oil flow required to lubricate a naval engine can be calculated using the amount of heat dissipated with the lubricating oil. Thus, for the calculation of the heat dissipated by the oil, the relation (8) is use:

$$\overline{Q_{ulei}} = 10^{-3}\cdot f_u \cdot P_{ef}\cdot c_e \cdot H_i = \\ = 10^{-3}\cdot 0.02\cdot 4000\cdot 185\cdot 42500 = 629000\ kJ/h \approx 174.72\ kJ/s \tag{8}$$

where:
f_U=0.02 - the fraction of heat used by the engine that is found in the lubricating oil. recommended at nominal engine loads between 0.015 and 0.025;
P_{ef} = 4000 kW - effective motor power at rated load;
c_e = 185 g / kWh - specific fuel consumption.
Hi = 42500 kJ / kg - specific energy
The oil flow required to lubricate the engine will be:

$$V_u = \frac{\overline{Q_{ulei}}}{c_{vu}\cdot\Delta T_u} = \frac{629000}{2.2\cdot 12} = 23825.75\ \ l/h \tag{9}$$

where:
c_{vu} = 2.2 kJ / l - specific volume heat of the oil;
ΔT_u = 12° - the temperature difference of the oil at the inlet / outlet of the cooler;
Based on V_U values obtained with relation (9), determine with (10) the actual oil flow required for lubrication, which is:

3.1.3. Heat discharge from bed bearings

One of the functions of the oil is to dissipate some of the heat from the engine and the heat from the friction tribosystem so that the operation of the tribosystem does not produce major thermal stresses or lead to

changes in the surface structure of the metal surfaces in contact.
The lubrication system is estimated to dissipate about 4 ÷ 6% of the actual engine power by heat. The heat dissipated by the lubrication system is calculated with the relation (11):

(Qulei)̅=0.06·P_ef=0.06·4000=240 kJ/s (11)

The heat from the lubrication system is removed from the engine by the oil cooler. The purpose of the oil cooler is to bring the oil temperature to the temperature of the inlet to the lubrication system from the temperature of its discharge from the lubrication system, [10].
From the calculation of the heat taken up by the oil lubrication system and the temperatures mentioned below, the oil flow required to dissipate the heat from an engine plain bearing can be calculated. So, the relationship is:

$$\overline{Q_u} = D_r \cdot c_p \cdot (t_{eo} - t_{io}) = 1.19 \cdot 2.2 \cdot (60 - 40) = 52.36\ kJ/s \quad (12)$$

where:
(Qu)̅ - heat dissipated through a bed bearing [kJ/s]
Dr - lubricant flow per bearing - is the ratio of the oil flow required for lubrication to the number of bed bearings [l/s]
t_{eo} - engine oil exhaust temperature [°C]
t_{io} - oil inlet temperature in the bearings [°C]
In the case of the engine under study these temperatures are:
t_{eo}=60 ℃
t_{io}=40 ℃
D_u=10.7 kg/s=>D_r=10.7/9=1.19 kg/s.
c_p=2.2 kJ/kg·°C - specific heat of the lubrificant, value recommended by the engine manufacturer.

3.1.4 Thermal balance of the bed bearing

The equation of the thermal equilibrium of a sliding bearing is:

P_f=W_1+W_2, [kW] (13)

where:
P_f - power lost by friction [kW];
W_1 - heat flux removed from the bearing by lubricant [kW];
W_2 - heat dissipation from the bearing into the environment through the spindle, bearing and bearing body.
For the calculation of the heat flow that is removed from the bearing through the lubricating oil we use the following relation:

$$W_1 = c_p \cdot \rho \cdot D_r \cdot (t_{eo} - t_{io}) = 2.2 \cdot 0.898 \cdot 1.19 \cdot 20 = 47.02\ kW \quad (14)$$

where: ρ=0.898 kg/dm³ - density of lubricant.

The heat flow transmitted through the housing and shaft is:

$$W_2 = \gamma \cdot A \cdot (t - t_0) \quad [kW] \quad (15)$$

where:
γ - bearing thermal convection coefficient
A - outer surface of the bearing [m2]
t=60℃ - temperature of the lubricant film
t_0=28℃ - ambient temperature

$$A = \pi \cdot H \cdot \left(L + \frac{H}{2}\right) = 3.14 \cdot 0.7 \cdot (0.994 + 0.35) = 2.95\ m^2 \quad (16)$$

where:
$H = 700\ mm$ - bearing housing height;
$L = 994\ mm$ - total lenght of the bearing.

$$\gamma = 0.07 + 0.12 \cdot \sqrt{v'} = 0.07 + 0.12 \cdot \sqrt{1.25} = 0.20416\ kW/m^2 \cdot ℃$$

Considering the construction of the engine and the manufacturer's recommendations - the speed of air circulation in the dry crankcase of the engine is 1.25 m/s.
After determining the surface area and the convection coefficient with relations (16) and (17), we introduce these values in relation (15).

$$W_2 = \gamma \cdot A \cdot (t - t_0) = 0.20416 \cdot 2.95 \cdot (60 - 28) = 19.27\ kW \quad (18)$$

Using relations (14) and (18), the two heat fluxes were calculated. The value of the power lost by friction is found by replacing these values in relation (13).

$$P_f = W_1 + W_2 = 47.02 + 19.27 = 66.29\ kW \quad (19)$$

4. CONCLUSIONS

This paper analyzes a major problem of the operation of naval propulsion engines, their lubrication.
The calculation elements of the lubrication systems are included in Chapter 3. The thermal calculation of the sliding bearings, respectively the heat dissipation function of the oil that develops in the sliding bearing, both as a result of the fluid friction and and engine heat release.
This function has been found to be essential for the proper operation of the internal combustion engine plain bearings and may be the basis for determining

the oil flow required for lubrication. For the calculations, the most requested motor bearing, the bed bearing, was taken into account.

The oil flow required to lubricate a marine engine can be calculated using the amount of heat dissipated with the lubricating oil.

The value of the actual oil flow required for lubrication was determined based on the value of the oil flow rate required for engine lubrication, taking into account the recommended flow coefficient for the engine type, rated power and wear.

Taking into account the heat flow that is removed from the bearing through the lubricating oil and the heat flow transmitted through the housing and shaft, the power lost by friction was determined, thus achieving the thermal balance of the bearing.

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