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PROPULSION SYSTEMS OF MOTOR-SAIL YACHTS — PROBLEMS OF DIAGNOSING

ABSTRACT

The paper presents operational problems in diagnosing the propulsion system of motor-sail yachts. The advantages and operational problems are presented in the paper and the specificity of use of the propulsion systems. It is shown here solutions to meet the requirements of the marine environment. There are shown exemplary damages resulting from operational errors of crew use. It is proposed program of sea trials, which further operation would be an indispensable diagnostic tool supporting the reliability and safety of the yacht at sea.

Key words:
motor-sail yachts, propulsion system, vibration, diagnostics.

INTRODUCTION

The last 30 years have proved that the decision to leisure on the sea often asked question, to motor or to sail. Evidently there are differences in the design, construction and operation of each type of vessels. All the time arisen questions which factors should be considered when making the final decision of type of propulsion. Both types of propulsions have its supporters and opportunists. The result of such competition was the creation a new type of leisure yachts motor-sail type — figure 1.

The new technological solution allows the use of all the advantages of both types of yachts such as:

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– large deck area dedicated to recreational use during the motor mode;
– the excitement of the sail race and the eco-friendly nature of the vessel in sail mode;
– motor mode has possibility to explore almost 360° view of the sky for satellites communication and navigation (much less reductions than on sailing yachts), due to the hidden sail;
– the use of high mast on the vessel enables to mount antennas much higher than on typical motor yachts, which results in communications and radar systems work a greater distance;
– the simultaneous use on the a yacht the efficient propulsion systems motor and sailing, significantly increases the level of maritime safety and reliability.

Fig. 1. Leisure yachts motor-sail [author's photo]

The basic problem of motor sail type yachts is the hardness of recruiting of the crew. The challenge is finding engineers for motor sailing yachts as the pool of candidates with passion and competence. Moreover, candidates have to meet professional requirements of the STCW Convention.

SPECIFIC FEATURES OF WORKING CONDITIONS OF THE PROPULSION PLANT

While mechanical propulsion system of the sailboat is almost completely independent of the sail drive, however, the principles of cooperation of both the drives are the specifics of this type of crafts. Design intent usually takes the form of hybrid drive that is the capability to drive mechanical and sail together and/or separately. This is a great similarity in the concept of the combined drive systems of warships. The main difference lies on the passive use of the sail drive — making the common operation of both drives fairly complicated. Sailing drive uses usually hydraulic or electrical energy from mechanical drive to operate the drive sail. Regardless of the type currently used sail propulsion, mechanical or hybrid the role of engineer on board is essential.

The pleasure yachts have the propulsion system includes engines, transmissions, propeller or propellers, integrated control systems, thrusters, auxiliary hydraulic systems and GenSets — figure 2. During normal hydro meteorological conditions the boat's crew may freely determine the choice of mode: sailing or mechanical drive. It is the decision of the Captain, who adjusts the plan to cruise and maneuvering requirements to the existing conditions and needs of the owner.

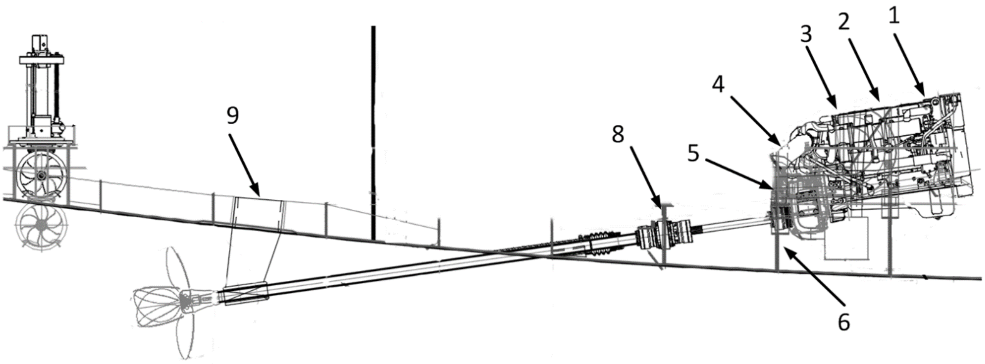

Fig. 2. An example diagram of the propulsion system yacht of motor sail type, where: 1 — front part of the main engine (cylinder head cover), 2 — middle part of the main engine (cylinder head cover), 3 — aft part of the main engine (cylinder head cover), 4 — the input of reduction gear bearing, 5 — the output of reduction gear bearing, 6 — the foundation of the engine, 8 — the place of assembly thrust bearing to the hull unit, 9 — strut (below strut bearing) [own work]

The situation is quite different in the case of stormy weather conditions [1]. Using the hybrid drive requires knowledge of both sailing and motor drive operation. Captain's errors in the choice of the drive mode can cause damage to the masts, booms and sails and even serious damage to the propulsion system — see figure 3.

Fig. 3. Example the fracture in stormy conditions boom vang (kicking strap) [author's photo]

For safety reasons during storm conditions it must be very carefully use all the variants of the drive of the craft. Sail to use as the only drive that makes it necessary to check the position of propeller's blades and ensure the inhibition of the shaftline, which has no lubrication from the oil pump. Other solutions shaft-lines ensure declutch shafts from the motor/reduction gear and provides lubrication sea water [8].

Another problem is the operation of twin shaft propulsion system on yachts. There have been many cases of operation by heavy seas with simultaneous use of sails and mechanical drive. This variant of the operation is safe under one important condition, Mandatory have to work two shaft lines in stormy weather. Working of one shaftline may cause a dangerous occasion ascent propeller above the water surface and then it sudden immersion. Due to the 800 fold difference in medium density of sea water from the air it will occur proportionally change the value of the thrust. The result can be damage to the thrust bearing and even flexural buckling of the propeller shaft.

PROPULSION POWER PACK OR THE ORIGINAL PROJECT OF POWER TRANSMISSION

For many years, the shipyards have introduced significant changes in the design process of the vessel's propulsion system. Currently, the popularity gained the power packs, which dramatically reduces design and purchasing costs of the propulsion systems. The power packs are flexible in the selection of power, rotational speed of engines/shaftlines and selection of the propeller's diameter. Such a solution is of great benefit in the design process of the merchant vessels. But what about the selection of propulsion systems for the leisure crafts? The next question is whether the adoption solutions such power pack for the leisure crafts is possible and reasonable?

Producers of the power packs for leisure yachts highlight the following advantages of such structural solutions [ZF]:

- integration of the complete propulsion system and its installation;
- exact definition of all interfaces in the drive system, monitoring and control subsystems;
- reduced maintenance costs due of one producer;
- low probability of occurrence of resonance of the drive components;
- wide spectrum of integration of the control systems.

The application of the power pack in the propulsion system of leisure yachts also brings the harmful effects such as:

- the need to adjust the aft section of the hull to the requirements of the producer of the power pack;
- lack of full freedom of the designer in developing the interior of the hull;
- customization and integration requirements of the propulsion control system with other systems.

Advantages and disadvantages of the power pack led that shaftlines are subject of individually design for the expensive, luxury yachts. The requirements of comfort and luxury inside the hull of the craft causes application of commercial engines and reduction gears while the shaft lines and propellers are the most original project design of the office yard.

Presented solutions of the design task is expensive and can cause errors in the calculation of the shaftlines dynamics thereby lowering the efficiency of the drive and the harmful emission of vibrations.

DESIGN AND OPERATIONAL PROBLEMS OF SHAFTLINES

One of the principal problems of the designer of the shaftlines is to perform the strength calculations and the calculations of machine dynamics. The main challenge is quite different impacts on the marine environment for the rotating components in the form of stochastic forces and torques as well as problems with the definition of stiffness and damping of the foundation while working at sea. Moreover, these calculations must take into account the whole range of engine and shaft's speeds and value changes of thrust and the feedback resulting from harmonic loads.

The problem of resonance are common and it is not an easy task to be solved. Main engine or reduction gear is sited on a foundation spilled on coasters of different materials. The errors in the assumed values of stiffness and damping in the procedure of dynamic calculation of supercritical machinery like the shaftline can cause the work in the area close to resonance.

The vibration theory clearly indicates that the system is having a dampening, has natural vibration frequency less than similar system with only stiffness, without damping [3]. The emergence the difference frequency of free vibrations of lower values is highly probable without taking into account the effect of damping what is shown below [5, 9]:

$$f_k = \frac{\sqrt{\frac{k}{m}}}{2\pi}; \tag{1}$$

$$f_{kc} = \frac{\omega_n \sqrt{1 - \frac{c^2}{4m^2\omega_n^2}}}{2\pi}, \tag{2}$$

then

$$\Delta f = f_k - f_{kc} = \frac{\sqrt{\frac{k}{m}}}{2\pi} - \frac{\omega_n \sqrt{1 - \frac{c^2}{4m^2\omega_n^2}}}{2\pi} = \sqrt{\frac{k}{m}} - \omega_n \sqrt{1 - \frac{c^2}{4m^2\omega_n^2}} = \sqrt{\frac{k}{m}} - \sqrt{\omega_n^2 - \frac{c^2}{4m^2}}, \tag{3}$$

where:

Δf — the frequency difference;
f_k — the resonant frequency of the stiffness, without damping;
f_{kc} — the resonant frequency of the stiffness and damping;
ω_n — natural frequency;
c — damping;

k — stiffness;

m — mass.

Considering the fact that the vibration frequency of the compression shaft is reduced proportionally with the value of thrust, than the natural frequency of the propeller shaft can be changed by up to –20% of the value of such a system which only been mounted rigidly. Analysis of the structure of the shaftlines of the leisure crafts shows that their stern seals are mainly made as resin inner tube what clearly confirms the necessity to take into account the effect of damping in the procedure of line shafts calculation (fig. 4).

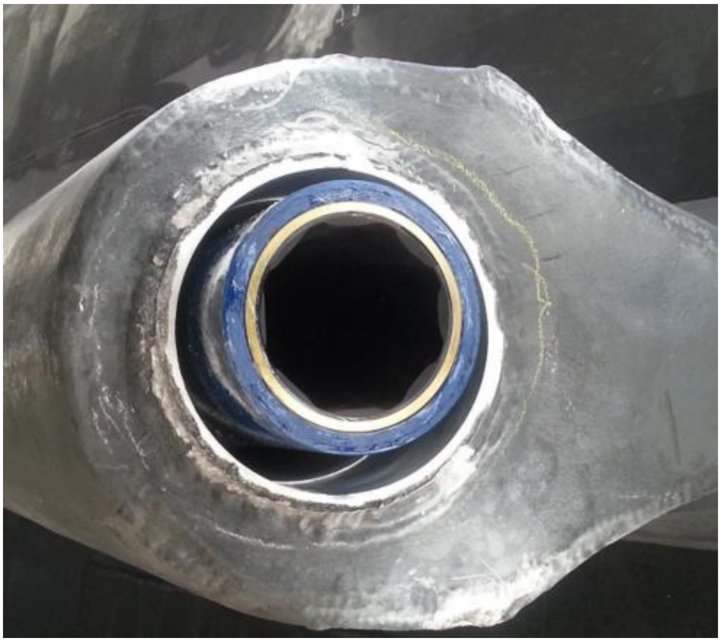

Fig. 4. The resin inner tube mounted into aluminum outer tub
of shaftlines strut [author's photo]

Errors in the calculation of the dynamics of shafting may result in increased emissions of vibration, increased clearance in the packing of the shaft lines, bleed and even the radial run-out of the shaft. The consequences of such events are flexural buckling of the shaft, increased wear seals and uprising of longitudinal and radial clearance of the bearing system — figure 5.

Fig. 5. Comparison of wear and tear shaftlines; visible signs of abrasion over the entire length of the spiral-rubber bearing resulting from the flexural buckling of the shaft shown at the top, the shaft shown in the bottom has the visible signs of proper lubrication contoured thread [author's photo]

DIAGNOSTICS METHODOLOGY USING THE VIBRATION METHODS

Diagnosis of marine propulsion systems are widely used in the operation of all types of vessels. It has its acknowledgment also in the operation of the propulsion systems of motor sail yachts as well. The specifics of hybrid drive dictates a different approach to the problem of diagnosing propulsion system of the motor sail yachts. The main issue is to prepare a methodology for measuring the operating parameters in the testing phase of vessel delivery from the shipyard as well as analytical methods and diagnostic inference [5]. The measurements of operating parameters are intended to prepare the *fingerprints* interpreted as parameters model of the excellent, technical condition [6, 7]. Regardless of the control system used in the marine propulsion system studies should consider the following demands:

- measurement of the engine/engines parameters for determining the power curve;
- measurements of operating parameters of the shaftline, including the determination of the advance coefficient of propeller for various speed of movement;
- measurements of parameters of vibration components of the propulsion system.

The use of vibration method enables quick evaluation of the level of degradation of the propulsion system [2, 4]. The first test should be carried out by the shipyards and the obtained values of vibration parameters can be related to many of standards such as ISO 10816 — table 1. The study of vibration parameters allow detection of many of a currently occurring defects in marine propulsion systems, such as:

– propeller or shaft unbalance;
– misalignment of shaftlines elements;
– cracks or damage of the foundation machines;
– bearing damage;
– damage teethes in the reduction gear;
– the clutch wear or damage;
– excessive radial or longitudinal clearances of the shaftlines;
– local resonances or rumbling effects.

Tab. 1. The values of the parameters of vibration on the basis of ISO 10816-6 [own work]

<table>
<tr><th rowspan="3">Degree of vibration</th><th colspan="3">Maximum value</th><th colspan="7">Group of machines</th></tr>
<tr><th rowspan="2">Displacement μm</th><th rowspan="2">Velocity mm/s</th><th rowspan="2">Acceleration mm/s²</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th></tr>
<tr><th colspan="7">Zones</th></tr>
<tr><td>1,1</td><td>17,8</td><td>1,12</td><td>1,76</td><td rowspan="4">A/B</td><td rowspan="5">A/B</td><td rowspan="6">A/B</td><td rowspan="7">A/B</td><td rowspan="8">A/B</td><td rowspan="9">A/B</td><td rowspan="10">A/B</td></tr>
<tr><td>1,8</td><td>28,3</td><td>1,78</td><td>2,79</td></tr>
<tr><td>2,8</td><td>44,8</td><td>2,82</td><td>4,42</td></tr>
<tr><td>4,5</td><td>71,0</td><td>4,46</td><td>7,01</td></tr>
<tr><td>7,1</td><td>113</td><td>7,07</td><td>11,1</td><td>C</td></tr>
<tr><td>11</td><td>176</td><td>11,2</td><td>17,6</td><td rowspan="7">D</td><td>C</td></tr>
<tr><td>18</td><td>283</td><td>17,8</td><td>27,9</td><td rowspan="6">D</td><td>C</td></tr>
<tr><td>28</td><td>448</td><td>28,2</td><td>44,2</td><td rowspan="5">D</td><td>C</td></tr>
<tr><td>45</td><td>710</td><td>44,6</td><td>70,1</td><td rowspan="4">D</td><td>C</td></tr>
<tr><td>71</td><td>1125</td><td>70,7</td><td>111</td><td rowspan="3">D</td><td>C</td></tr>
<tr><td>112</td><td>1784</td><td>112</td><td>176</td><td rowspan="2">D</td><td>C</td></tr>
<tr><td>180</td><td></td><td></td><td></td><td>D</td></tr>
</table>

A — new machines,
B — vibration is not interfering in long-term machinery operation,
C — machines where the vibration level exceeds the limit, but they can be conditionally operated until the time of repair,
D — machines which are so intense vibration that their continued operation would lead to their destruction.

The fundamental rule is to carry out measurements of vibration parameters in the three axes on all operational loads, including astern drive. In some cases, the procedure reduces the number of measuring directions to such a number that represents all the directions of the forces and moments. Example of assembly of accelerometers on the reduction gear in the propulsion system is shown in figure 6.

Fig. 6. Example of assembly of accelerometers on the reduction gear [author's photo]

Research results should represent the characteristics of the main engine speed what allows to compare the exemplary results with the one carried in the sea. An example of the characteristics of vibration parameters of the propulsion system is presented in the figure 7.

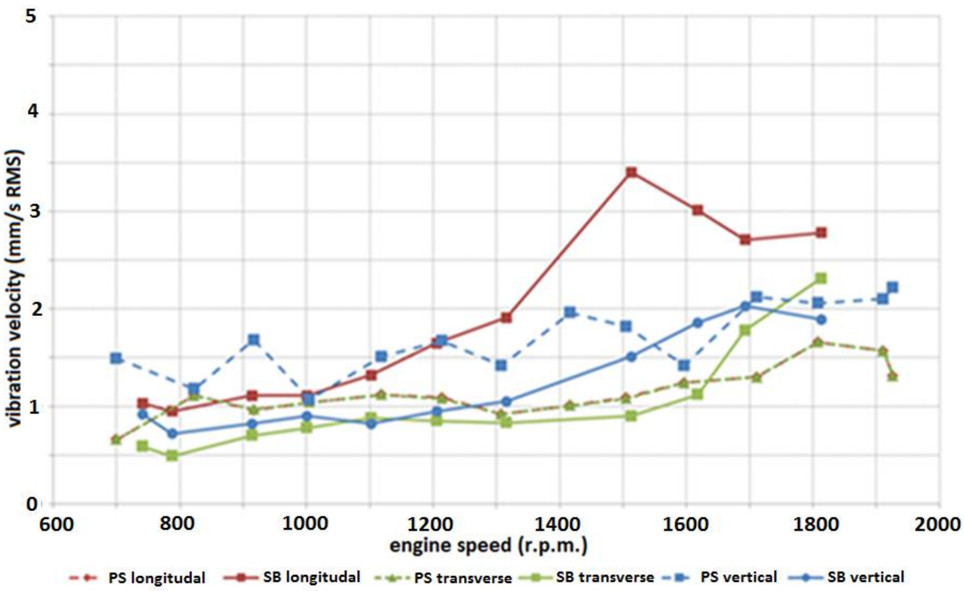

Fig. 7. Example of vibration parameters characteristic of the yachts propulsion system [own work]

CONCLUSIONS

The presented results of the study indicate that the human factor can bring rapid risk in operation. The main conclusions of the study are:
- design and calculations of thrust bearings should take into account the possibility of ascent rotating propellers;
- leisure yachts crew training should emphasize the safety of maneuvering by heavy seas;
- execution of vibration performance curves by yacht producer allows to create faster diagnosis and determine the causes of the accidents.

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PROBLEMY DIAGNOZOWANIA NAPĘDU JACHTÓW MOTOROWO-ŻAGLOWYCH

STRESZCZENIE

Artykuł przedstawia problem dotyczący diagnozowania napędu jachtów motorowo-żaglowych. Zalety wykorzystania diagnostyki w procesie eksploatacji zostały odniesione do specyfiki użytkowania jachtów. Przedstawione rozwiązania są ściśle związane z wymaganiami morskimi, a jako przykład przedstawiono awarię spowodowaną przez błąd ludzki. Proponowany program prób oraz zalecenia mogą być narzędziem diagnostycznym wspierającym bezpieczeństwo eksploatacji na morzu.

Słowa kluczowe:

jachty żaglowo-motorowe, układ napędowy, drgania, diagnostyka.