Simulation research on operation scheme of
dissymmetrical main engine of CODOG propulsion system

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Abstract: [Objectives] How to maintain propulsion capability in a CODOG propulsion system damage situation has important significance. [Methods] A ‘Hull–Engine–CPP–Rudder’ simulation model of a CODOG marine power plant is established on Simulink using the modularized method, and a dissymmetrical main engine urgent working mode is proposed and simulated. [Results] The results show that in the dissymmetrical working mode, two different engines cannot work simultaneously at designed capacity. However, by adjusting the pitch of the CPP, one engine can work at designed capacity and the other can work at partial load capacity; under this working mode, if high speed is demanded, the gas turbine should work at designed capacity. The CPP pitch driven by diesel should be maintained at a high value near the maximum. The maximum speed of this working mode is 84.4% of the designed speed, which is higher than the speed of the single shaft working mode driven by a gas turbine. [Conclusions] The research results of this paper can provide useful references for the design of ship propulsion systems.

Key words: ship; CODOG power plant; dissymmetrical operation scheme; mathematical model

CLC number: U664.1

0 Introduction

Combined Diesel Engines or Gas Turbines (CODOG) propulsion system for naval ship has two operating modes: one is normal mode, namely the twin shaft diesel engine is used for propulsion when cruising and the twin shaft gas turbine is used for propulsion in the case of high speed; the other is abnormal mode, that the ship is driven by one diesel engine on single shaft and one gas turbine on single shaft, or using dissymmetrical main engine propulsion mode which works under one diesel engine and one gas turbine on twin shaft (hereinafter referred to as "one diesel one gas"). In view of the characteristics of naval ship’s mission, constant and intensive operation of the power plant in routine training may lead to a high failure rate or has malfunction due to combat damage. Therefore, abnormal operating mode is used quite often, which is one of the most significant differences between naval ship and merchant ship.

In the case of combat damage or breakdown, an integrated control curve for the abnormal mode that matches the CPP pitch and main engine speed must be developed. This curve cannot be acquired from the design sector but by the Navy itself through the research. Reference [1] investigated the operating mode of a combined diesel marine propulsion system (CODAD) that works under one engine and three engines on twin shaft, proposed an integrated control curve of the engine speed vs. the CPP pitch (hereinafter referred to as "engine–CPP") for these two operating modes and achieved good results. However, for the CODOG propulsion system, due to both of the diesel engine and gas turbine are adopted in main engine, the following approaches are usually taken under abnormal mode: single shaft diesel engine propulsion is used in low speed, and single shaft gas tur-
bine propulsion is adopted in moderate speed, while in high speed, dissymmetrical main engine propulsion that works under one diesel engine and one gas turbine on twin shaft is used. In case malfunctions or failure take place in a gas turbine, meanwhile high speed is also required, then dissymmetrical main engine propulsion mode must be adopted.

Although adopting gas turbine propulsion on single shaft can ensure the ship runs in higher speed, yet it will encounter additional drag produced by another propeller at that moment and resistance by rudder steering for course correction. As whole, ship sailing in moderate or high speed may experience greater resistance produced by propeller and rudder. When ship operates in "one diesel one gas" mode, it not merely can eliminate additional drag of another propeller shaft, but can also reduce additional resistance of the rudder. A particular advantage of this propulsion mode is that it can obtain additional power output from another diesel engine, so it can be ensured that one diesel one gas propulsion mode will gain a higher speed than single shaft gas turbine propulsion does in the mentioned cases. It is the first time to study "one diesel one gas" dissymmetrical main engine propulsion mode in China.

This paper is to study the operation scheme of dissymmetrical main engine propulsion of CODOG power plant. Through the establishment of CODOG propulsion system simulation model, an optimal matching performance of "engine-CPP" for diesel and gas dissymmetrical main engine propulsion mode is calculated, whose result can provide CODOG power plant in this mode with a theoretical basis for formulating emergent operation scheme.

1 Mathematic model

Fig. 1 shows the four main engines propulsion system with twin screws studied in this paper, including two sets of symmetrical CODOG power plant structure (arranged in port and starboard). Based on the modular modeling theory \(^2^\)\(^-^\)\(^3\), a mathematic model of the CODOG propulsion system components is built at first, then Simulink software is used to establish the models for each component, and encapsulating them. Finally, in line with the relevance of operation parameters and force parameters between each component module, integrating them into the whole simulation model of CODOG propulsion system.

1.1 Diesel engine simulation model

Diesel engine simulation model consists of three parts \(^4^\)\(^-^\)\(^5\): diesel engine governor model, diesel engine power-torque calculation model and the load limit model of diesel engine. Diesel engine power-torque calculation model is obtained from test rig based on the several external characteristic curves corresponding to different fuel control rack positions. The interpolation enlargement of this set of curves is achieved through BP artificial neural network \(^2\), so as to realize stepless speed regulating. The external characteristic curves of diesel engine gained by the test rig and the results of BP artificial neural network interpolation extension are shown in Fig. 2. In Fig. 2, " \(\Delta\) " means experimental data, "full line" is the outspread of existing fuel control rack position external characteristic curve, and "dotted line" is the prediction of unknown fuel control rack position external characteristic curve. It can be seen from the Fig. 2 that utilizing BP neural network to establish diesel engine external characteristic simulation model not only can accurately extend the original external characteristic curve, but also can well predict the external characteristic curve corresponding to unknown control rack position \(^6\). The calculation model of the diesel engine power established through this method is expressed as:

\[
P_D = f(n_D, L_D)
\]

where \(P_D\) is diesel engine power, kW; \(n_D\) is die-

![Fig.1 Sketch of CODOG propulsion system](image)

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where \(P_D\) is diesel engine power, kW; \(n_D\) is die-
el engine speed, r/min; $L_D$ is position of fuel rods, mm. Based on the relationship among diesel engine torque, power and speed, the output torque of diesel engine can be deduced.

When diesel engine is working, the location of the fuel control rack is adjusted by the governor, so as to keep the actual rotating speed of diesel engine and setting speed stay the same. When excess load causes diesel engine power output exceeds the maximum, overload phenomenon in a diesel engine arise. To avoid this scenario, the maximum Load Limit Line (LLL) is used to limit diesel engine external characteristic curve. Diesel engine governor model is realized by using PI controller \(^{[3–4]}\), governor mathematical model is expressed as:

$$\begin{align*}
U(t) &= K_p \left[ e(t) + \frac{1}{T_i} \int_0^t e(\tau) d\tau \right] \quad (2)
\end{align*}$$

where $U(t)$ is governor output, namely the fuel control rack position of diesel engine; $e(t)$ is the difference value between diesel engine setting speed and actual speed; $K_p$ is the coefficient of proportionality; $T_i$ is integration time constant. Among them, $K_p$ and $T_i$ can be deduced by classic method ZN.

### 1.2 Gas turbine simulation model

Gas turbine simulation model consists of three parts: gas turbine fuel flow controller model, gas turbine power−torque calculation model and gas turbine load limit model. In accordance with average external characteristic curve of the gas turbine, the relation among output power $P_G$, power turbine speed $n_G$, and the amount of fuel $G_t$ can be obtained as $P_G=f(n_G, G_t)$, from which the relation between output torque $M_G$ and output power $P_G$ can be drawn as $M_G=f(n_G, P_G)$. External characteristic curve not only can fully represent the gas turbine variable working condition performance but also can analyze adaptability of gas turbine for various loads and forecast all kinds of variable working condition performance. The result by using BP artificial neural network to deal with interpolation of gas turbine average external characteristic expansion is shown in Fig. 3. In the figure, "full line" is the external characteristic curve of the experiment, "dotted line" is the forecast result of the external characteristic curve of unknown fuel flow.

Gas turbine load limit model and fuel flow controller model are similar to diesel engine. It should be noted that the speed of power turbine in gas turbine fluctuates around a particular average value in the actual operation, and this paper takes its average value during the simulation calculation.

### 1.3 CPP simulation model

CPP simulation model includes two parts: the calculation model of CPP thrust and torque, and the influence model of hull wake on the CPP. Because the data of this CPP in open water experiment are less, it is difficult to meet the requirements of the simulation calculation, hence this paper adopts the open water experiments combined with the numerical prediction method to obtain the complete open water characteristics of the CPP. Reynolds–averaged Navier–Stokes (RANS) method is used for the numerical prediction of open water characteristics of the CPP. Based on the steps of geometric modeling, computing grid division, RANS discrete equation and iterative solution, a numerical prediction of the open water performance of CPP is made. When designing pitch, numerical prediction results of the thrust coefficient of CPP $K_T$ and torque coefficient $K_Q$ are compared with those of the open water experimental data, as
shown in Fig. 4. In this figure, $J$ is the advance coefficient of CPP. It can be seen from the figure that numerical predictions are in good agreement with experimental results of open water.

RANS method is used to calculate the open water performance of the CPP when changing the pitch from zero to the maximum. In calculation, a pitch change interval is 0.2, $J$ changes from -1.1 to 1.3, and the numerical prediction results are shown in Fig. 5. Fig. 5 represents ten characteristic curves of thrust and torque under ten different pitch ratios of CPP, and the arrow points to the torque characteristics in zero pitch. This paper will simplify the effect of non-uniform inflow of CPP formed by ship wake on its hydrodynamic performance as thrust deduction and wake fraction, both of which are obtained by the experiment.

1.4 Transmission system simulation model

Transmission system simulation model mainly includes three parts: shafting model, the reduction gear box model and hydraulic coupling model. The shafting model mainly consists of the shafting friction loss and rotation dynamics model, which is used to calculate the stern shaft speed (CPP speed). The reduction gear box model contains reduction ratio and gear box friction loss in connection with the input power and speed of gear box. The modeling method about shafting and the friction power loss of reduction gear can be found in reference [5]. Based on part of the general external characteristic curve data provided by manufacturers, the hydraulic coupling model is obtained by using BP artificial neural network combined with the mechanism modeling method [5].

1.5 Hull and rudder hydrodynamic model

Relations of hull resistance changes with speed and that the rudder lift performance and resistance change with angle and speed are both provided by the design sector of this naval ship. The reason for setting up the rudder hydrodynamic model is that the thrust of two propellers are generally not equal in "one diesel one gas" dissymmetrical propulsion mode. At this point, rudders are needed to be turned to keep the course. In this paper, PI controller is used for calculating rudder angle to gain additional resistance of rudders.

1.6 Integration of CODOG simulation model

After establishing the simulation model of various components mentioned above, according to the relationship between the operation parameters and mechanical parameters in the components, the simulation model of CODOG [7-8] power device can be gained, as shown in Fig. 6. The figure only shows one side of the arrangement, and the other side is the same. The input of this simulation model is the main engine speed and pitch of the CPP.
2 Verification and analysis of simulation model

In this paper, the variable steps, fourth order Runge–Kutta method is used to solve the simulation model. In order to check on the precision of simulation model, the speed, power of main engine and shaft power are mainly chosen as verification data. The verification data in this paper mainly come from the related speed trail test results provided by design sector.

2.1 Navigational speed

Without considering the effects of storm and biofouling, the speed of this ship under gas turbine operating condition and that under diesel engine operating condition are verified respectively, and the results are shown as Table 1 and Table 2. It can be found in this paper that gas turbine speed, diesel speed and pitch of CPP are expressed by percentage of relative rated speed pitch. Table 1 is the verification result of the speed under two sets gas turbine working condition. Under the working condition of gas turbine, the relative error of speed is less than 1%, the absolute error of speed is no more than 0.1 kn. Table 2 is the verification result of the speed under two sets diesel engine operating condition. Under the operation condition of diesel engine, the relative error of speed is less than 1%, the absolute error of speed is no more than 0.1 kn. Thus, the prediction precision of simulation model for this type of CODOG propulsion system speed is higher.

The design sector also predicts the increase of resistance under typical sea states (4, 5 and 6) provided by a certain institute and the speed under 5% and 10% biofouling resistance increasing. Because there is no suitable calculation method for biofouling resistance of the ship in service, in this paper, according to the usage of actual ship, biofouling resistance will be taken as the corresponding percentage of the total resistance. Therefore, for 5% of biofouling resistance increasing, it is equivalent to 5% increase of the naked hull resistance; and for 10% of biofouling resistance increasing, it is equivalent to 10% increase of the naked hull resistance.

In this paper, simulation calculation is conducted on the speed under the above-mentioned three sea states and two kinds of biofouling, and the results are compared to the prediction values from design sector and shown in Table 3. The table shows that the simulation results in this paper are quite close to the speed forecast values provided by the design sector.

![Simulation model of CODOG propulsion system](image)

Table 1 Comparison of ship speed between simulation results and the data from design sector for two gas turbine operating condition

<table>
<thead>
<tr>
<th>Sequence number</th>
<th>Percentage of turbine speed of gas turbine/%</th>
<th>Percentage of pitch/%</th>
<th>Relative error of speed/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>44</td>
<td>100</td>
<td>-0.27</td>
</tr>
<tr>
<td>2</td>
<td>48</td>
<td>100</td>
<td>-0.31</td>
</tr>
<tr>
<td>3</td>
<td>57</td>
<td>100</td>
<td>-0.26</td>
</tr>
<tr>
<td>4</td>
<td>78</td>
<td>100</td>
<td>-0.04</td>
</tr>
<tr>
<td>5</td>
<td>92</td>
<td>100</td>
<td>0.14</td>
</tr>
<tr>
<td>6</td>
<td>98</td>
<td>100</td>
<td>0.19</td>
</tr>
<tr>
<td>7</td>
<td>100</td>
<td>100</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Table 2 Comparison of ship speed between simulation results and the data from design sector for two diesel operating condition

<table>
<thead>
<tr>
<th>Sequence number</th>
<th>Percentage of diesel engine speed/%</th>
<th>Percentage of pitch/%</th>
<th>Relative error of speed/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>85</td>
<td>100</td>
<td>-0.63</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>100</td>
<td>-0.22</td>
</tr>
</tbody>
</table>
Table 3 Verification results of ship speed under different sea states and biofouling

<table>
<thead>
<tr>
<th>Sea states</th>
<th>5% of biofouling</th>
<th>10% of biofouling</th>
<th>Diesel engine operating condition</th>
<th>5% of biofouling</th>
<th>10% of biofouling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of propeller shaft speed%</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Percentage of pitch%</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Error%</td>
<td>-0.10</td>
<td>0.10</td>
<td>0.20</td>
<td>0.13</td>
<td>0.36</td>
</tr>
</tbody>
</table>

Table 4 Verification results of shaft power and gas turbine power for two gas turbine operating condition

<table>
<thead>
<tr>
<th>Sequence number</th>
<th>Percentage of shaft speed%</th>
<th>Percentage of pitch%</th>
<th>Relative error of shaft power%</th>
<th>Relative error of main engine power%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>44</td>
<td>100</td>
<td>0.66</td>
<td>-3.13</td>
</tr>
<tr>
<td>2</td>
<td>48</td>
<td>100</td>
<td>0.74</td>
<td>-2.24</td>
</tr>
<tr>
<td>3</td>
<td>57</td>
<td>100</td>
<td>0.67</td>
<td>-0.94</td>
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<tr>
<td>4</td>
<td>78</td>
<td>100</td>
<td>1.19</td>
<td>-3.28</td>
</tr>
<tr>
<td>5</td>
<td>92</td>
<td>100</td>
<td>1.90</td>
<td>-0.40</td>
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<td>6</td>
<td>98</td>
<td>100</td>
<td>2.13</td>
<td>-0.23</td>
</tr>
</tbody>
</table>

Table 5 Verification results of shaft power and diesel power for two diesel operating condition

<table>
<thead>
<tr>
<th>Sequence number</th>
<th>Percentage of shaft speed%</th>
<th>Percentage of pitch%</th>
<th>Relative error of shaft power%</th>
<th>Relative error of main engine power%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>55</td>
<td>100</td>
<td>2.74</td>
<td>-4.45</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>100</td>
<td>2.60</td>
<td>-4.49</td>
</tr>
</tbody>
</table>

2.2 Shaft power and main engine power

Relevant data of shaft and main engine power will be adopted from the rapidity test result provided by design sector, the simulation model of gas turbine and diesel engine operating condition are verified respectively, and the results are shown in Table 4 and Table 5.

3 Match analysis of "engine–CPP" in dissymmetrical operating condition

Normal operation scheme of CODOG power plant proposed by this paper is as follows: two gas turbines are used in moderate or high speed, and two diesel engines are used during cruise. After comparison, gas turbine power under the rated operating conditions is about seven times the value of diesel engine power. However, from comparing the power in steady operation scheme, the power of gas turbine is far greater than that of diesel engine. As a result, in dissymmetrical operating conditions that gas turbine on one shaft along with diesel propulsion on the other shaft, if operation scheme under normal condition is still be required (rotation speed and pitch value of design point), the excessive gas turbine load may happen, and the CPP of diesel engine's shaft turn into the condition of water turbine, resulting in that the turbine speed of hydraulic coupling is greater than that of pump wheel. To avoid this kind of situation, the power allocation of two shafts can be adjusted by changing the pitch of the CPP, making the two main engines provide propulsion power.

The "engine–CPP" matching performance of the propulsion system under normal conditions is shown in Fig. 7(a). In the figure, the abscissa axis denotes rotational speed \( n \), and coordinate axis denotes power \( N \). Curve 1 represents gas turbine load limit line, Curve 2 represents the diesel engine load limit line, and Curve 3 represents the propeller characteristic curve under the designed condition; Point A is the steady state matching point of the diesel engine and the CPP in cruise speed, point B is the steady state matching point of gas turbine and CPP in the rated
speed; \( N_{\text{GH}} \) is rated power of gas turbine, \( N_{\text{DH}} \) is rated power of diesel engine; \( n_{\text{DH}} \) is rated speed of diesel engines, \( n_{\text{GH}} \) is rated speed of gas turbine.

When adopting diesel engine on one shaft, and gas turbine on the other shaft propulsion mode, if the pitch remains unchanged, then the "engine-CPP" match performance in the Fig. 7(a) will change. At this moment, compared to the diesel engine in cruise condition, increasingly speed will cause an increase in advance coefficient \( J_\text{D} \) of CPP driven by diesel engine, and propulsion characteristic curve of CPP will go downward, so that diesel engine will stay in partial load condition, namely light load condition. However, compared to the high speed working condition of gas turbine, decreasing speed will cause a decrease in advance coefficient \( J_\text{G} \) of CPP driven by gas turbine. At this time propulsion characteristic curve of CPP will go upward, and the gas turbine will stay in overload condition. It can be noted from the figure that the new steady-state matching points of diesel engines and gas turbine are \( A_1 \) and \( B_1 \) respectively. Obviously, neither the diesel engine nor the gas turbine produces rated power, but the reasons are different. The diesel engine fails to produce rated power since in light load condition, while gas turbine fails since in a state of overload. Furthermore, the original power turbine speed dropped from the rated speed \( n_{\text{GH}} \) to speed \( n_{\text{G1}} \) that always in "one diesel one gas" propulsion operating condition. Other parameters and symbols in the figure: \( N_{\text{D1}} \) is diesel engine power in "one diesel one gas" propulsion working condition; \( N_{\text{G1}} \) is gas turbine power in "one diesel one gas" propulsion working condition; \( n_{\text{D1}} \) is diesel engine rotational speed in "one diesel one gas" propulsion working condition.

In "one diesel one gas" propulsion mode, if diesel engine and gas turbine produce rated power at the same time, two pitches of CPP must be changed. The analysis shows that when changing a pitch of CPP, the propulsion characteristic curves of the two propellers will change. Therefore, the priority is to keep the pitch of CPP driven by gas turbine the same as that of the designed pitch, and gradually increase the pitch of CPP driven by diesel engine. At this time, the two propeller propulsion characteristic curves will move toward the design point location. Through calculation, when pitch of CPP driven by diesel engine becomes the maximum, the diesel engine is still in the partial load working state, but gas turbine is in a state of overload. Meanwhile, the maximum pitch is unchanged, and the pitch of the CPP driven by the gas turbine is gradually reduced. The results after calculating show: when pitch of the CPP driven by the gas turbine reduces to 88% of the designed pitch, gas turbine is right in the rated condition, while diesel engine is still in the partial load performance. If continuing to reduce the pitch of the controllable pitch propeller driven by gas turbine to 62% of the designed pitch, the gas turbine will stay in partial load performance, while diesel engine is just in the rated condition. Thus it can be inferred that in "one diesel one gas" propulsion mode, diesel engine and gas turbine cannot work in rated condition at the same time.

4 Study on the operation scheme of biaxial dissymmetrical main engine

When CODOG power plant is in the condition of battle damage or malfunction and a gas turbine fails, "one diesel one gas" dissymmetrical main engine propulsion mode is required if a high speed is still required. The analysis shows that in the propulsion mode, two main engines cannot run under the rated
conditions at the same time. Therefore, there are two solutions: first is that a gas turbine works in rated conditions, and the diesel engine in partial load performance; second is that a diesel engine works in rated conditions, gas turbine in partial load performance. Because under rated condition, the power of gas turbine is about 7 times that of diesel engine. If high speed is kept in the dissymmetrical propulsion mode, the first scheme is the best choice. The specific measures are: in the beginning, the pitch of the CPP driven by diesel engine should be set in the maximum, through changing the pitch of CPP driven by gas turbine to make it run in rated conditions (in accordance with the relevant specification, leaving 10% of the power reserve). Table 6 shows the simulation results of the gas turbine working under rated conditions in 10% reserve power. In the table, data of rotating speed, power and speed are taken as the percentage relative to the rated value.

<table>
<thead>
<tr>
<th>Table 6 Simulation results when gas turbine operates at design condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of main engine speed/%</td>
</tr>
<tr>
<td>----------------------------------</td>
</tr>
<tr>
<td>Diesel engine</td>
</tr>
<tr>
<td>Gas turbine</td>
</tr>
</tbody>
</table>

The two thrust values of the CPP obtained from simulation show that, the most power for sailing is provided by CPP driven by gas turbine, and speed meets the 84.4% of the designed speed. It can be noted from calculation result that when the gas turbine runs under rated conditions and has 10% power reserve, the highest speed can reach 84.4% of the designed speed. In a single gas turbine operating conditions, adjusting the pitch of the gas turbine under rated conditions, the maximum speed is 82.4% of the designed speed. However, under the same circumstances of diesel engine, the maximum speed is only 47% of the designed speed. Thus, the "one diesel one gas" dissymmetrical emergent propulsion mode has more advantages than single shaft mode when the main engine failure occurs and a high speed is required keeping at the same time.

5 Conclusions

For the performance of CODOG power plant that single gas turbine may fail to operate due to malfunction, this paper proposes that adopting twin shaft dissymmetrical main engine propulsion scheme as an emergency measure, so as to solve the security problem that when a gas turbine failure occurs but high speed still needs keeping. First of all, according to the modular concept, CODOG power plant mathematical model of four engines with twin screws propulsion is built. And simulation model should be integrated in Simulink environment, and then the speed, main engine power and shaft power are chosen to verify the precision of simulation model.

Then, under dissymmetrical operating conditions, the feasibility of diesel engines and gas turbine working in the rated state is analyzed. It is found that diesel engine and gas turbine cannot work in the rated state at the same time by the match performance analysis and simulation of the "ship–engine–propeller–rudder".

Finally, "one diesel one gas" dissymmetrical propulsion scheme is studied. The results show that the maximum speed under the conditions can reach the 84.4% of designed speed. Compared with the single shaft propulsion mode, this mode has certain advantages.

There are few literatures about the abnormal operating mode of CODOG power plant in China, and most of them focus on the normal mode. From the analysis of this paper, the application of abnormal operation scheme still has great potential under special circumstances.

References

柴燃联合动力装置非对称主机推进工作制的仿真研究

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摘 要: 当舰船柴燃联合动力装置 (CODOG) 因作战而导致某台主机发生故障时, 如何使其保持较好的推进性能, 对于该推进系统的应急使用具有重要意义。方法: 在 Simulink 环境下采用模块化建模思想构建“船—机—桨—舵”系统的仿真模型, 提出 CODOG 双轴非对称主机推进的应急运行模式, 并对该运行模式进行仿真。结果: 仿真结果表明: 若额定工况下 2 台主机无法同时工作, 可通过调整 2 部调距桨的螺距使其中一台主机在额定工况运行, 另一台主机则采取部分负荷运行; 若要保证高航速, 应使燃气轮机产生额定功率, 此时柴油机对应的调距桨的螺距应保持在最大值附近; 在最高航速下可达到设计航速的 84.4%, 舰船的快速性要优于采用燃气轮机单轴推进模式。结论: 研究结果对 CODOG 动力装置的设计具有一定的参考价值。

关键词: 舰船; 柴燃联合动力装置; 非对称工作制; 数学模型

结构噪声核心价值与理论逻辑解读
第一部分: 释义、价值及认知颠覆

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摘 要: 安静化进程中, 潜艇将再次面临辐射噪声能量新级差。必须应用结构噪声理论进行深度解读, 它已成为工程跨越不可或缺的重要理论拼图。寄希望于浮筏隔振改良、更大结构刚度、阻尼或建造精进, 中国潜艇完成超越的可能性几近为零。科研工作者要用结构噪声新思维, 破解结构背后的声学密码, 将互补特性、叠加特性与潜艇复杂巨系统的功能设计巧妙重构, 才能达成控制能量注入、内波传导和声辐射的目标。这是结构噪声理论的核心价值, 是解决潜艇安静化“最后一公里”的理论工具, 逻辑上具备颠覆意义。

关键词: 结构噪声; 波; 减振降噪; 潜艇