The Fuel Saving Effect of Motor Generator's Running State in Hybrid Propulsion System

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This paper calculated SFC (Specific Fuel oil Consumption) in the hybrid propulsion system. This system may select three operation modes because the system equips propulsion motors and a shaft generator. The SFC of each operation mode is different. Therefore, authors compared the SFC of three operation modes by simulation. From that result, this paper clarified how running state of propulsion motors and a shaft generator provide the impact on the saving fuel oil effect.

Keywords: Electric motor, Shaft generator, Diesel generator, Hybrid propulsion system, SFC, Thermal efficiency

1. Introduction

This paper clarified frequent distribution of SHP (Shaft Horse Power) to discuss a new propulsion system of training and marine science investigation ship. Figure 1 shows the trend of the SHP on Shioji-Maru and Seiyo-Maru which are belonged to Tokyo University of Marine Science and Technology as the training and investigation ship.

The SHP is mainly output in the middle load range while she goes on navigation because FOC (Fuel Oil Consumption) can be saved by decreasing ship speed. On the other hand, the SHP is mainly output in low load range while she is in operation of marine investigation because ship speed is controlled to dead slow for dynamic positioning in order to implement precise investigation [1].
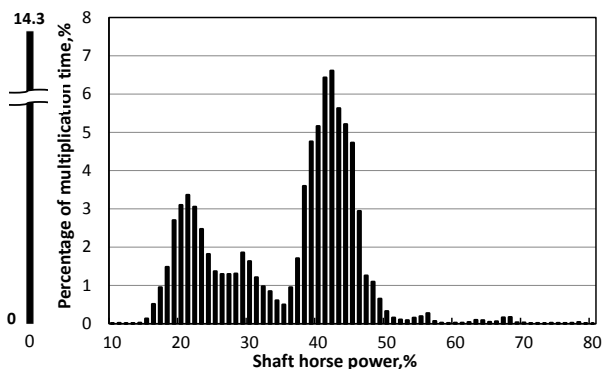
As well known, thermal efficiency of M/E (Main Engine) tends to be lower at the low load condition. Therefore, DR (Diesel engine with Reduction gear) propulsion system is not necessarily appropriate in the training and investigation ship. Figure 2 shows an example of the general DR system. The DR system is quite simple because its main engines drive propellers. In the case of the DR system, the main engines may be run at low thermal efficiency for a long time in the training and investigation ship. Due to these factors, if the training and investigation ship navigates with the DR system, it is difficult to improve the SFC of this ship.

To solve these problems, this study pays attention to the HD (Hybrid Drive) system that can select the DR operation mode and the EP (Electric Propulsion) operation mode. In addition, if the HD system equips S/G (Shaft

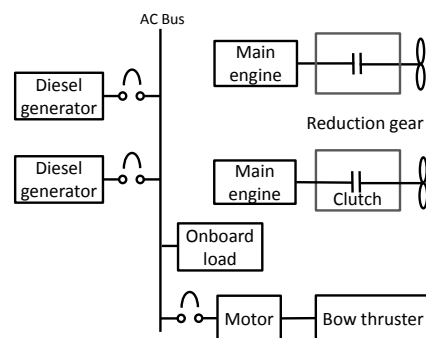Fig.1 Histogram of shaft horse power in Shioji-Maru and Seiyo-Maru

Fig.2 Line diagram of propulsion system in DR system

Generator), the D/G (Diesel Generator) may be stopped by using this S/G. As a result, the HD system will have various characteristics of the SFC depending on the running states of the main engines, the propulsion motors and the S/G.

Authors have developed a simulation program to estimate the FOC of the propulsion system and the onboard electric system [2]. The SFC is also calculated to achieve the FOC in the program.

This paper specially paid attention to the SFC. In the HD system, the SFC was calculated by using the developed tool. Then, authors clarified how running state of the propulsion motors and the S/G provides the impact on the SFC.

2. Propulsion system

2.1 Required specifications for the propulsion system

This paper assumes that the propulsion system has 2 shafts to realize high maneuverability. Additionally, it is necessity to quickly control propulsion power from ahead to astern because delicate control is required for operating the marine investigation. It is thought that CPP is appropriate to fill those requirements.

Propulsion power which ship goes on the maximum speed is assumed to be 1600kW. As a result, rated of main engine is set to 800kW per shaft.

2. 2 HD (Hybrid Drive) system
(1) Operation mode

Figure 3 shows the line diagrams of the HD system which is discussed in this paper. This system can select three operation modes as shown in figure 3. The DR operation mode shown in figure 3-a is the same line diagram of propulsion system as shown in figure 2. Thus, if it is assumed that the rating of M/E and D/G are the same in both figure 2 and 3-a, these SFC are the same characteristic.

In addition, the propulsion system and the electric system are connected two types of electric apparatuses in the HD system. One is induction motors as the propulsion motor and another is a synchronous generator as the S/G. As a result, the HD system can select the DR operation mode (figure 3-a), the EP operation mode (figure 3-b) and the DR + S/G operation mode (figure 3-c).

a) DR operation mode

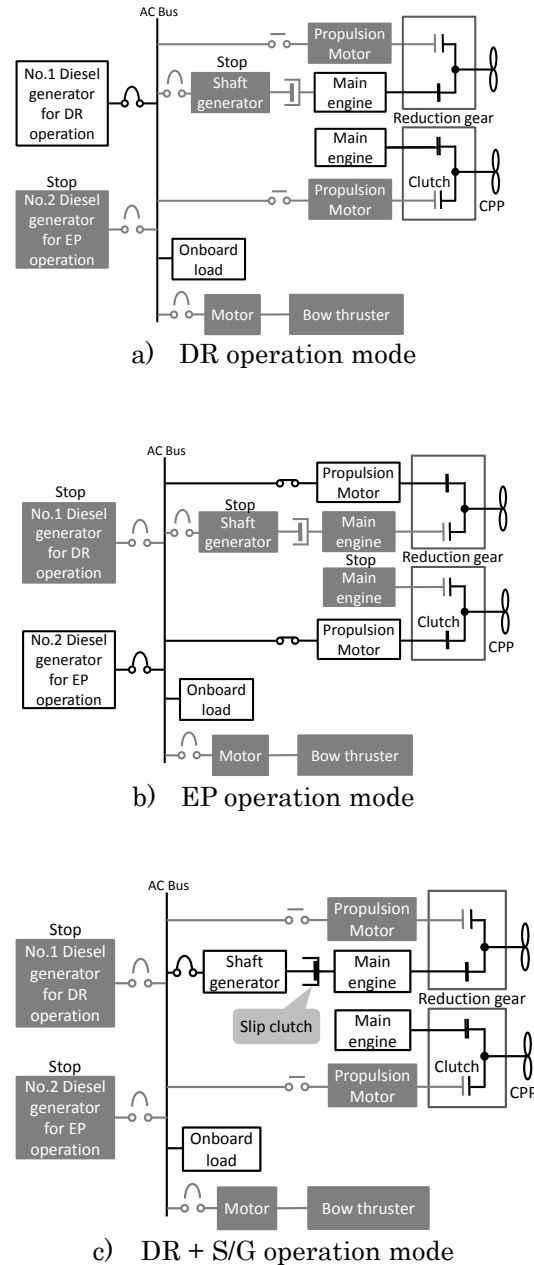b) EP operation mode

c) DR + S/G operation mode

Fig.3 Line diagram of propulsion system in HD system

(2) Relation between operation mode and D/G rating

Authors pay attention to the load of generator in these operation modes. The load of D/G in the DR operation mode is onboard electric load only. While, the load of D/G in the EP operation mode is total of the onboard electric load and the propulsion motors. That is to say, the load of generator is different in the DR operation mode and the EP operation mode. Thus, the rating power of each D/G should be properly designed

from viewpoint of the FOC. In this study, the rating of D/G for the EP operation mode is set to be larger than the rating of D/G for the DR operation mode. Additionally, D/G for the DR operation mode is named as No.1 D/G, and D/G for the EP operation mode is named as No.2 D/G in this paper.

In the DR + S/G operation mode, the load of S/G is onboard electric load only as same as No.1 D/G. Rated power of NO.1 D/G and S/G are set the same because the generator load is comparable in the DR operation mode and the DR + S/G operation mode.

When S/G is input synchronously to the electric system which is maintained by D/G, it is necessary to adjust the frequency and the phase of S/G. Slip clutch is equipped to realize synchronous input of S/G.

3. Condition for FOC simulation

3. 1 Rating of No.1 D/G and S/G, onboard load

In general, rating of generator is specified based on the electric power consumption table. However, instrument to be equipped in the ship is not identified in this study. Thus, authors paid attention to relation between gross tonnage of the investigation ship and the rating of D/G.

The gross tonnage of the ship is assumed to be 600ton in this study. Based on above relation, rated of No.1 D/G and S/G is set to 530kW.

Authors had already reported frequency analysis of the generator load factor in training and investigation ship [1]. The investigation ship may add new electric equipment and investigative instrument after enter into service. As a result, electric demand may significantly increase. Then, the rating of generator on the investigation ship needs to be set enough margin. Therefore, average demanded electric power of navigation for the training and investigation ship belonging to our university is low, which value is approximately 28%.

Value of onboard electric load is specified based on these characteristics. In this study, the average onboard electric load is set to 530kW × 0.28 ≈ 150kW to simplify calculation.

3. 2 Rating of propulsion motor and No.2 D/G

As is well known, advantages of the EP operation are low vibration and low acoustic noise. In marine investigation, these advantages are important characteristics to realize precise acoustic research. Therefore, the EP operation is appropriate when the ship is used for the marine investigation. From the results of our previous survey, the marine research is mainly implemented less than 8kt [3]. Then, the maximum ship speed is set to 8kt in the EP operation.

The total propulsion motor power needs 410kW to cover up to 8kt by the EP operation. Therefore, the rating of propulsion motor set to 205kW per shaft.

Load of No.2 D/G is total of the onboard electric load and the propulsion motors. Then, the rating of No.2 D/G is specified based on the maximum output of the average onboard electric load and the propulsion motors. Although the average onboard electric load is set to 150kW, the estimated load electric power is 265kW if the demanded ratio is 50%. The maximum onboard electric power in the EP operation is total of the estimated load electric power and the propulsion motors. The rating of No.2 D/G is set so that the No.2 D/G load factor does not exceed over 85% when the maximum onboard electric power is output by the No.2 D/G. As a result, the rating of No.2 D/G is set to 800kW in this paper.

3. 3 Condition of calculating SFC

Table 1 shows running state of apparatuses for the propulsion system. The SFC was calculated based on this condition. In addition to this condition, the SHP of both board are assumed as equal in the calculation.

Table 1 Running state of apparatuses

Operationg Mode	DR operation	EP operation	DR + S/G operation
Main Engine 800[kW]×2sets	◯		◯
No.1 Diesel Generator 530[kW]	◯		
No.2 Diesel Generator 800[kW]		◯	
Shaft Generator 530[kW]			◯
Propulsion Motor 205[kW]×2sets		◯	
Onboard Load 150[kW]	◯	◯	◯

4. Calculation result of SFC and consideration

Figure 4 shows the SFC of the HD system. The vertical axis shows the SFC, and the horizontal axis shows total SHP of both boards. In general, the SFC shows the fuel economy performance of M/E. However, the SFC in this study is defined as the fuel economy performance of the whole

system including the M/E and the generators to discuss the fuel saving effect of the HD system. When the CPP blade angle is the neutral state, the propeller outputs forward thrust and backward one simultaneously. Therefore, required SHP become a certain level about 18% which is based on author's other research.

The SHP is suppressed in the EP operation mode and the DR + S/G operation mode in comparison with the DR operation mode. However, the SFC of both operation modes were improved in comparison with the DR operation mode.

Main reason for improving the SFC of the EP operation mode and the DR + S/G operation mode can be concluded that the thermal efficiency of each prime mover is improved. Figure 5 shows the thermal efficiency of each prime mover. The thermal efficiency of No.2 D/E (Diesel Engine of No.2 D/G) and starboard M/E in the DR + S/G operation mode are higher than the thermal efficiency of M/E for the DR operation mode.
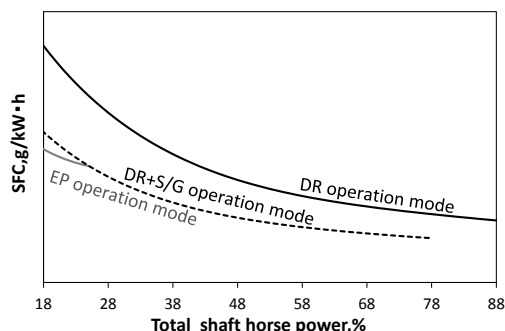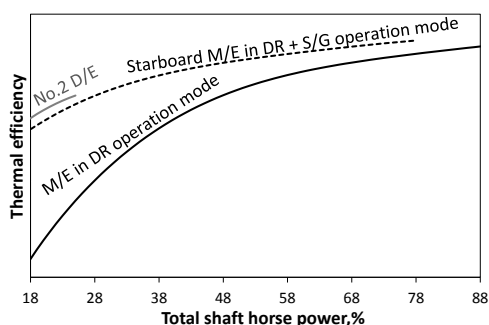

Fig.4 SFC in HD system

Fig.5 Thermal efficiency of each prime mover

In the EP operation mode, the M/E can be stopped because the propulsion power can be delivered by the propulsion motors. As a result, the propulsion power and the electric power become the load of No.2 D/G. Then, the thermal

efficiency of No.2 D/E is improved since the load factor of No.2 D/G is increased.

On the other hand, D/G can be stopped in the DR + S/G operation mode because the electric power can be supplied by the S/G. This S/G is driven by the starboard M/E. For this time, the load of this M/E is not only the propulsion power but also the electric power. As a result, the load factor and the thermal efficiency of the starboard M/E were improved.

As mentioned above, the running number of prime movers can be decreased when the propulsion motors and the S/G are driven. In addition, the thermal efficiency of prime movers under operation is improved. Therefore, it is expected that the SFC of the EP operation mode and the DR + S/G operation mode are improved.

5. Conclusion

This paper shows the SFC of the HD system. It is clarified how the running state of the propulsion motors and the S/G provide the impact on the SFC. Although the SHP is suppressed, high effect for saving fuel may be expected when the propulsion motors and the S/G are driven.

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