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<th>Changes of Output Performances of Main Dynamo System on T/V Kakuyo-Maru during 13 Years</th>
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<td>Author(s)</td>
<td>Nishiya, Toyonari; Kiri, Hiroaki; Kozuma, Masaru</td>
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<td><a href="http://hdl.handle.net/10069/30129">http://hdl.handle.net/10069/30129</a></td>
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NAOSITE: Nagasaki University’s Academic Output SITE
http://naosite.lb.nagasaki-u.ac.jp
Changes of Output Performances of Main Dynamo System on T/V Kakuyo-Maru during 13 Years

Toyonari NISHIYA, Hiroaki KIRI and Masaru KOZUMA

A ship borne system for electric supply coupled with an electric generator and a drive engine gradually decreases its performance year by year even on continuous careful maintenance and arrangements by marine engineers. While a trouble ratio of the total dynamo system in all ship borne machinery generally increases with running duration. The mean trouble ratio is around 10%. Accordingly, marine engineers should regularly check the system to hold their current states to maintain constant performance.

According to Yoshimura et al., the limited load ratio of diesel generators varied with their running duration and are generally given at a range of 60—70% for their constant output. For the T/V Kakuyo-Maru, the electric generator system consists of two main generators of 450 kVA (No 1, No 2) and an auxiliary generator of 100 kVA. The main generators are used alternatively at a suitable interval. The working hours of No.1 and No.2 is around 41,000 h since 1975 when T/V Kakuyo-Maru was built.

Official inspections based on Maritime Safety Law were made by using load tests on the main dynamo systems to check their various performances on May 1987. This report deals on some technical considerations on changes of performances of the systems: output power, various gas pressures, etc, in a test tank of a land factory. The results were compares in the official inspection reports.

Key word: dynamo engine 鉄道用発電機，Specific fuel consumption 燃料消費率
Running title: T. Nishiya, H. Kiri, and M. Kozuma: Output Performance of dynamo engine

1. Methods of tests and measurements

Principal components of the system are given in Table 1.

A series of following measurements on various loads are made in a test tank for the dynamo systems:

i) Electric output of the generator is read as a main distributing board.

ii) Revolution per min of exhaust gas of super charger is determined as mean of three readings on a high speed electrotacometer (HSEC type) arranged on to a blower axle end of the exhaust turbine.

iii) Gas pressures at various parts are measured with Bourdon’s tube pressure-guage, indicator (M type) and pressure transmitter. The pressure readings are given as the mean readings for six cylinders.

The whole temperatures at several sections of the dynamo system are taken with cylindrical thermometer and CA-type electro-thermometer. The temperature readings are also given as the mean readings for six cylinders.

iv) Conditions of fuel injection pumps are given using three mean readings on rack scale of cylinder. The rack is coupled with a common rod of
Table 1. Principal particulars of dynamos of Kakuyo-Maru

<table>
<thead>
<tr>
<th>Generator</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Self-excited Alternator</td>
</tr>
<tr>
<td>Model</td>
<td>GFU 2456B-8</td>
</tr>
<tr>
<td>Voltage</td>
<td>AC 450 V, 60Hz, 3φ</td>
</tr>
<tr>
<td>Capacity</td>
<td>450 KVA</td>
</tr>
<tr>
<td>Current</td>
<td>577 A</td>
</tr>
<tr>
<td>Load factor</td>
<td>80 %</td>
</tr>
<tr>
<td>Number of pole</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Diesel engine</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Single action 4 cycle Diesel</td>
</tr>
<tr>
<td>Model</td>
<td>6MAL-HT</td>
</tr>
<tr>
<td>Number of cyliniders</td>
<td>6</td>
</tr>
<tr>
<td>Maximum continuous horse power</td>
<td>530 ps at 900 rpm</td>
</tr>
<tr>
<td>Cylinder bore</td>
<td>200 mm</td>
</tr>
<tr>
<td>Stroke</td>
<td>240 mm</td>
</tr>
<tr>
<td>Type of fuel injection pump</td>
<td>Bosch</td>
</tr>
<tr>
<td>Type of super charger</td>
<td>VTR-160</td>
</tr>
</tbody>
</table>

| Fuel oil                                                                 |          |
| Grade                                                                    | # 2 first (Rank A) |
| Specific gravity                                                        | 0.8483 at 15/4°C |
| Calorific value                                                         | 10220 Kcal/kg at Lower |

Table 2. Measured and calculated parameters of No.1 and No.2 dynamo engines of Kakuyo-Maru in various load at May 1987

<table>
<thead>
<tr>
<th>L</th>
<th>No.1</th>
<th>No.2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>Pe</td>
<td>76.3</td>
<td>148.9</td>
</tr>
<tr>
<td>T₀</td>
<td>263.2</td>
<td>360.1</td>
</tr>
<tr>
<td>Tₑ</td>
<td>263.3</td>
<td>328.3</td>
</tr>
<tr>
<td>t₀</td>
<td>42.3</td>
<td>43.7</td>
</tr>
<tr>
<td>n</td>
<td>14070</td>
<td>16820</td>
</tr>
<tr>
<td>Pₘₐₓ</td>
<td>62.2</td>
<td>69.2</td>
</tr>
<tr>
<td>Pₑ</td>
<td>0.16</td>
<td>0.29</td>
</tr>
<tr>
<td>R</td>
<td>16.5</td>
<td>14.9</td>
</tr>
<tr>
<td>G</td>
<td>25.3</td>
<td>40.3</td>
</tr>
<tr>
<td>bₑ</td>
<td>331.2</td>
<td>207.7</td>
</tr>
</tbody>
</table>

Remarks
L: Load factor of generator (%); Pe: Output of generator (kW); T₀: Inlet gas temperature of turbo charger (°C); Tₑ: Exhaust gas temperature of dynamo engine (°C); t₀: Cooling water temperature of cylinder (°C); n: Revolution of turbo charger (rpm); Pₘₐₓ: Maximum pressure (kg/cm²); Pₑ: Suction air pressure (kg/cm²); R: Rack length graduated of fuel injection pump; G: Fuel consumption (kg/h); bₑ: Specific fuel consumption (g/kW-h)
the fuel injection pump system.

v) Fuel consumptions are given as certain amount of fuel (5—10 litter) consumed at an elapsed time passed by means of oval-type flowmeter inserted into fuel supply line between the fuel tank and the injection pump. At the same instant, fuel temperature and specific gravity are also measured for calculating the fuel weight.

2. Results and considerations

Measurement results on No.1 and No.2 dynamo engines (D-1 and D-2) are shown in Table 2 at load factor of 20—75%. In this table, various values except the rack length of injection pump and specific consumption of fuel, varied with the loads and the other two, the rack length and consumption are inversely varied.

Comparison on changes of output performances by load during 13 years are presented in Figs 1-A and -B. In figures, the abscissa is output power in kW and the ordinate, various items as mentioned in the above section.

The broken line is the official results (table

![Fig. 1](image_url)

**Fig. 1.** Interrelations between output of No.1 and No.2 dynamos and their various characters. In this figure, the solid lines is given for measured values in the experimental measurements and the dotted lines is referred from official results of the factory test of the dynamo engines in February 1975. In this figure, Fig. 1-A shows No.1 dynamo engine and Fig. 1-B, No.2.

**Remarks**

Pe: Out put of generator (kW); T_in: Inlet gas temperature of turbo charger (°C); T_e: Exhaust gas temperature of dynamo engine (°C); n: Revolution of turbo charger (rpm); P_max: Maximum pressure (kg/cm²); P_b: Suction air pressure (kg/cm²); G: Fuel consumption (kg/h); b_e: Specific fuel consumption (g/kW-h)
Table 3. Official results at the factory test of dynamo engines in February 1975

<table>
<thead>
<tr>
<th>L</th>
<th>No. 1</th>
<th>No. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td>Pe</td>
<td>90</td>
<td>180</td>
</tr>
<tr>
<td>Ti</td>
<td>262.5</td>
<td>345.0</td>
</tr>
<tr>
<td>Te</td>
<td>250.8</td>
<td>325.0</td>
</tr>
<tr>
<td>n</td>
<td>15410</td>
<td>20500</td>
</tr>
<tr>
<td>Pmax</td>
<td>72.3</td>
<td>74.7</td>
</tr>
<tr>
<td>Pb</td>
<td>0.15</td>
<td>0.28</td>
</tr>
<tr>
<td>G</td>
<td>30.0</td>
<td>44.7</td>
</tr>
<tr>
<td>be</td>
<td>333.0</td>
<td>248.5</td>
</tr>
</tbody>
</table>

Remarks
Symbolic terms in this table are all same in Table 2.

3) in test tank and the solid line represents value measured in 1987.

Otherwise, Fig. 2 is shown to compare these two dynamo engines each other in same manner.

2.1 Machinery temperatures

2.1.1 Temperature of exhaust gas at outlet of cylinder, Te

As reported by Higasa and Nishiya, the exhaust temperatures, Te, at the outlets of cylinders of the dynamo engines varied with various conditions of parts concerned with fuel combustion.

The Te generally rises due to wear of parts of air suction system and inversely goes down with wear of an exhaust turbine of super charger during long running time.

According to Yoshimura et al., Te for 10,000 - 20,000 working hours at 60% load condition generally rises to 50 - 60°C more than Te-test of the official results. Accordingly, Te will rise about 18% more than that of the official results.

Te-exp on this experiment shown by a solid line in Fig. 1, are generally higher than Te of the official results which are shown by a broken lines for both D-1 and D-2, respectively.

The rise in Te-exp on the both engines are 5 - 9% for Te-test at a load of 60 - 70%. This result is considerably small as compared to the results of Yoshimura et al.

The Te of the engines are also varied with the temperature of air supplied. The air temperature is 18°C at the factory test and is 26 - 30°C at this experiment on D-1 and D-2.
The air temperature is automatically controlled as to keep a constant condition of about 40°C at the outlet of an inter cooler or at the inlet of a manifold at normal working condition on various load conditions. As reported before\(^9\), the \(T_e\) rises with load conditions when the amount of fuel injection is increased and then an mean indicator pressure of effective gas in a combustion chamber is rose.

From the experimental results, interrelations between \(T_e\) and output powers of the generators in kW, \(P_e\) can be approximated:

For D-1,
\[
T_e = 0.6851 \cdot Pe + 218.02 \quad (°C)
\]

For D-2,
\[
T_e = 0.7561 \cdot Pe + 195.85 \quad (°C)
\]

From these equations, \(T_e\) calculated on D-1 is higher by 6.5% at 80 kW load with that of D-2.

As shown in Fig. 2, \(T_e\) from these equations are well agreed with \(T_e\) observed at any load conditions in kW at the significant level of 95%.

However, there is only small difference between \(T_e\)-exp of D-1 and D-2.

The respective parts consisting the dynamo system have individually different "Mean time between failure" (MTBF), and the reliability in the total system is reduced with increasing working years, since performance of the party fail with increasing time and respective MTBFs are shorten.

A certain upper limit of load is generally set by engine since troubles of diesel engine often happens at high rate in its combustion system. According to Yoshimura et al\(^9\), \(T_e\) is controlled as to keep 400°C or less in general ships, when working time reaches at certain years or more.

The \(T_e\) calculated from the above equations is about 470°C at full load of 100% in both engines. While the safety range of \(T_e\) is 370°-470°C, based on the Handling text book.

This is a commonly accepted fact even without testing the operator or any engine for that matter.

2.1.2 Temperature of supply gas at inlet of super charger, \(T_i\)

A temperature of supply gas into the inlet of super charger, \(T_i\), is relatively higher than \(T_o\), because of friction and wake losses produced in the exhaust manifold by exhaust gas from each cylinder, according to Higasa and Nishiyaa\(^9\).

In this experiment, \(T_i\) of 0°-66°C or 27°-78°C is always higher than \(T_o\) in D-1 or D-2 respectively, and the difference between them is varied with \(P_e\). As shown in Fig. 1, the solid line of \(T_e\)-exp is lower at higher location than that of the broken line of \(T_e\)-test in all load conditions.

According to maker's guide, \(T_i\) is 420°-550°C at regular load while the \(T_e\)-exp at full load is around 520°C in both engines. The \(T_e\)-exp at full load is very near the upper limit of safety working level. Thus the engines should not be worked at full load, as possible.

2.2 Revolution per min of exhaust gas of super charger, \(n\)

Assuming a loss of supplied calories of fuel, \(Q_f\) (kcal/h) is consumed as heat in process as \(\phi\) in % for the total and the heat loss of exhaust gas in \(\phi \cdot Q_f\):

\[
N_e = C_1 \cdot \phi \cdot Q_f = C_2 N_e = C_3 n
\]

where, \(N_e\) is specific horse power of an engine in kcal/h, and \(N_e\), output of the super charger and \(C_1\), \(C_2\) and \(C_3\) are constant numbers. Assuming the conventional efficiency\(^4\) is constant on the both dynamo engines in this experiment, \(N_e\) may be changed linearly with \(P_e\). From the above assumption, a relation of \(N_e = C_4\) \(P_e\) is also introduced. Where, \(C_4\) is constant number.

Then, it is considered that \(n\) is relatively varied with the \(P_e\).

The \(n\) of the both engines for various \(P_e\) are well agreed each other as shown in Fig. 1 and also hardly changed from them in the factory test. Thus it is considered that the super chargers in the both engines are now working in enough performances. Interrelations of \(n\) and \(P_e\) is:

For D-1,
\[
n = 67.71 \cdot P_e + 8.682 \cdot 10^3 \quad (rpm)
\]

For D-2,
\[
n = 69.89 \cdot P_e + 8.406 \cdot 10^3 \quad (rpm)
\]

A shown in Fig. 1, the solid and broken lines
for the experiments and factory test are well agreed each other on both engines. Thus, it is consider that the total efficiencies of both super chargers equal each other.

The responsibility of n is generally decrease to the relatively high range of Pe, as shown Fig. 1. It is one of the remaining problems to solve the n –response in the higher range of Pe.

2.3 Suction air pressure, Ps

Suction air pressure, Ps of a diesel engine is varied with Ne or Pe, as reported by Higasa and Nishiya. The solid line through the data of this experiment is located higher than the broken line from the factory test in both of D-1 and D-2 in Figs 1-A and 1-B.

From these figures, the measured values are higher by 5–35% or 12–23% as compared to the factory test.

Generally, n arises and Ps increase, when combustion gas leaks from small damages of exhaust valves, valve sheets, etc. consisting the combustion system. However, such a gas leak is hardly found on this experiment because of perfect maintenance just after a require inspection. The above rising Ps may be caused by general fous throughout exhaust passage or system failures. Interrelations between Ps and Pe are:

For D-1,
\[ \ln P_s = 0.9977 \ln Pe + \ln 2.0704 \] (kg/cm²)

For D-2,
\[ \ln P_s = 1.2888 \ln Pe + \ln 4.1326 \] (kg/cm²)

2.4 Maximum pressure in cylinder, Pmax

Generally, cylinder pressure in maximum of diesel engine with super charger, Pmax is:
\[ P_{max} = e P_c = \epsilon P_s^{\gamma} \] (kg/cm²)

where, \( \epsilon \) is explosion rate, \( \gamma \), compression ratio, \( P_c \), compression pressure, \( P_s \), air pressure supplied and \( m \), polytropic index.

Pmax is varied with amount of fuel injection because inflammable mix gas constituted in combustion chamber just before ignition increases with amount of fuel injection. On the other hand, P_s and P_c increase with load power. In same manner, Pmax rises with them as shown in the above equation.

Pmax measured on D-1 and D-2 are lower (4–9 kg/cm²), as given by solid lines in Fig. 1-A and -B, than them as given by broken lines from factory test throughout Pe.

There are many factors which affect Pmax of diesel engines. Among them, major affections is give by amount of flammable mix gas in delay timing of ignition as mentioned above and length of the delay timing.

A standard timing of fuel injection on the dynamo engine is 12–13° BTDC in crank angle. The timing is somewhat delayed because timing adjusting parts wear by years of use.

Whereas it is considered that the delay time affect on declare of the measure amount and also Pmax. Ps in this experiment is rather high on both of D-1 and D-2 than that of the factory test as shown in Fig. 1.

This fact on this experiment may show that Pmax becomes to be low down since self flammable temperature of the mix gas drops and the delay time of ignition is shortened.

On diesel engine at the same power, the delay time of after burning is to be longer with going down of Pmax. On this result, \( T_e \) is expected to be higher. This fact is one of the reasonable factors on the rise of \( T_e \). Adjustment of the injection timing should be done careful, because the timing considerably affects thermal efficiency of the diesel engine.

Some interrelations of Pmax and Pe on this experiment is approximated as follows:

For D-1,
\[ \ln P_{max} = 0.1475 \ln Pe + \ln 32.8441 \] (kg/cm²)

For D-2,
\[ \ln P_{max} = 0.1361 \ln Pe + \ln 34.4632 \] (kg/cm²)

As shown in these above equations and Fig. 2, Pmax is high by 0.1–1.2 (kg/cm²) for D-1 than that of D-2.

The Pmax of D-1 is higher by 1.6% than that of D-2 at 75% load and the rising rate for the load rate is however very small on D-1. Therefore it is considered that D-1 and D-2 hardly differ from
each other on their output performance in spite of their long working durations.

2.5 Fuel consumption, G

Mechanical loss on a dynamo engine is hardly varied with load rate because of constant revolution throughout running at any load.

When good combustion is done, \( N_e \propto G \)
where, \( N_e \) is net horse power. From \( N_e \propto Pe \) mentioned in section 2.2, interrelations of \( G \) and \( Pe \) is approximated:

For D-1,
\[
G = 0.1933 \cdot Pe + 11.0030 \quad \text{(kg/h)}
\]

For D-2,
\[
G = 0.1892 \cdot Pe + 11.6097 \quad \text{(kg/h)}
\]

While, \( G \) in this experiment is hardly changed from \( G \) on factory test and even decreases in upper range of \( Pe \) beyond 0.2 (or 85.4) kW on D-1 (D-2). This fact shows that D-1 and D-2 are keeping their good economic performance on the fuel consumption and difference of \( G \) between D-1 and D-2 is very small throughout their output power, as shown in Fig. 2.

The total lost in horse power of the dynamo engine decreases with its output power since mechanical losses of D-1 and D-2 are constant for the output power as mentioned before. Therefore, their mechanical efficiencies rise with their output power and so that their specific fuel consumption rate also goes down.

2.6 Specific fuel consumption, \( b_e \)

Generally, net effective pressure in mean \( P_m \), \( b_e \), or excess rate of air supply, \( \lambda \) is:

\[
P_m b_e = K_o / \lambda \]

where, \( K_o \) is a constant given for engine type, working condition, fuel condition, pressure and temperature of inlet air, etc. \( \lambda \) is a ratio of theoretical and actual amounts of air supply at full combustion of fuel. Interrelations of \( Pe \) and \( b_e \) is introduced from the above equation from this experiment:

For D-1,
\[
\ln b_e = \ln 1111.85 - 0.2804 \ln Pe \quad \text{(g/kW\cdot h)}
\]

For D-2,
\[
\ln b_e = \ln 1209.57 - 0.2971 \ln Pe \quad \text{(g/kW\cdot h)}
\]

These equations also agree with results on main engine as reported by Nishiya et al.

Two regression lines for D-1 and D-2 from these equations crossed at about 160 kW load after which the value be of D-1 becomes larger than that of D-2. However the relationship is reversed at 160 kW load or less.

Estimating from the above \( b_e \), the economic performance of the main dynamo engines on fuel consumption are better at D-1 around 50% load or less than at D-2 while D-2 is better at 50% load or more than D-1.

Conclusions

A series of load test in comparing with the load tests done 13 years ago was made to check annual changes of various conditions concerned with output and economical performances of main dynamo engines of T/V Kakuyo-Maru. Several wearing trends were found as follows:

i) The output performances are hardly changed during the 13 years of use. It is considered that this fact is a result of continuous reasonable maintenance.

ii) Air temperature in the engine room (temperature of supply air), greatly affected the \( T_e \) and \( T_o \) of the dynamo engines.

iii) Marine engineers should take special attention in keeping suitable temperatures of cooling water and supply air since machinery temperatures, such as \( T_e \) and \( T_o \), greatly go up at load condition of 75% or more.

We would like to express our sincere thanks to Dr. Keishi Shibata, Professor of our school, for his critical reading of this report and also thank to Cap. Yuushou Akishige and his officers of T/V Kakuyo-Maru for their useful collaborations.

References

鶴洋丸ディーゼル発電原動機の経年変化

西矢豊就, 桐博昭, 小妻勝

一般に船内装備の主・補機関は、その稼働時間の増加と共に、初期の諸性能が劣化する。これら主・補機関を効率的により安全に運転するには、それらの経時劣化に基づいた、許容荷負の範囲を再調整すべきである。また、これらの諸性能が劣化する経時的原因を究明、適切に計画保全し、信頼性を回復することが安全運転上最も重要である。

そこで、一つの方法として、鶴洋丸主発電原動機の経時変化した現状を確認するため、出力性能実験をした。その結果を考察したところ、次のことが判明した。

1) 出力性能に関与する諸項目の経時劣化は少ない。

2) 発電機負荷、Pe(kW)と燃料消費率、be(g/kW・h)との関係は、1号（D-1）および2号（D-2）主発電原動機で、それぞれ、近似的に次式のようになる。

D-1,

\[ \ln b_e = \ln 1111.85 - 0.2804 \ln Pe \quad (g/kW \cdot h) \]

D-2,

\[ \ln b_e = \ln 1209.57 - 0.2971 \ln Pe \quad (g/kW \cdot h) \]