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MARINE USE ENERGY SAVING EQUIPMENT

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I. FOREWORD

According to the energy saving report of the Ship Transporting Department of the Transportation Economic Research Center, the items shown in *Fig. 1* are future topics of study. As can be seen from this figure, naturally, energy saving measures are efficiency improvement measures and can be said to be:

(1) Improved efficiency through improvement of individual facilities.

(2) Improvement of overall efficiency by effective use of the overall system.

Since the use of energy at shore plants is diverse, after being converted to electric energy, it is often used for various power or heating, according to the purpose. On the other hand, most marine energy is "propulsion" and its

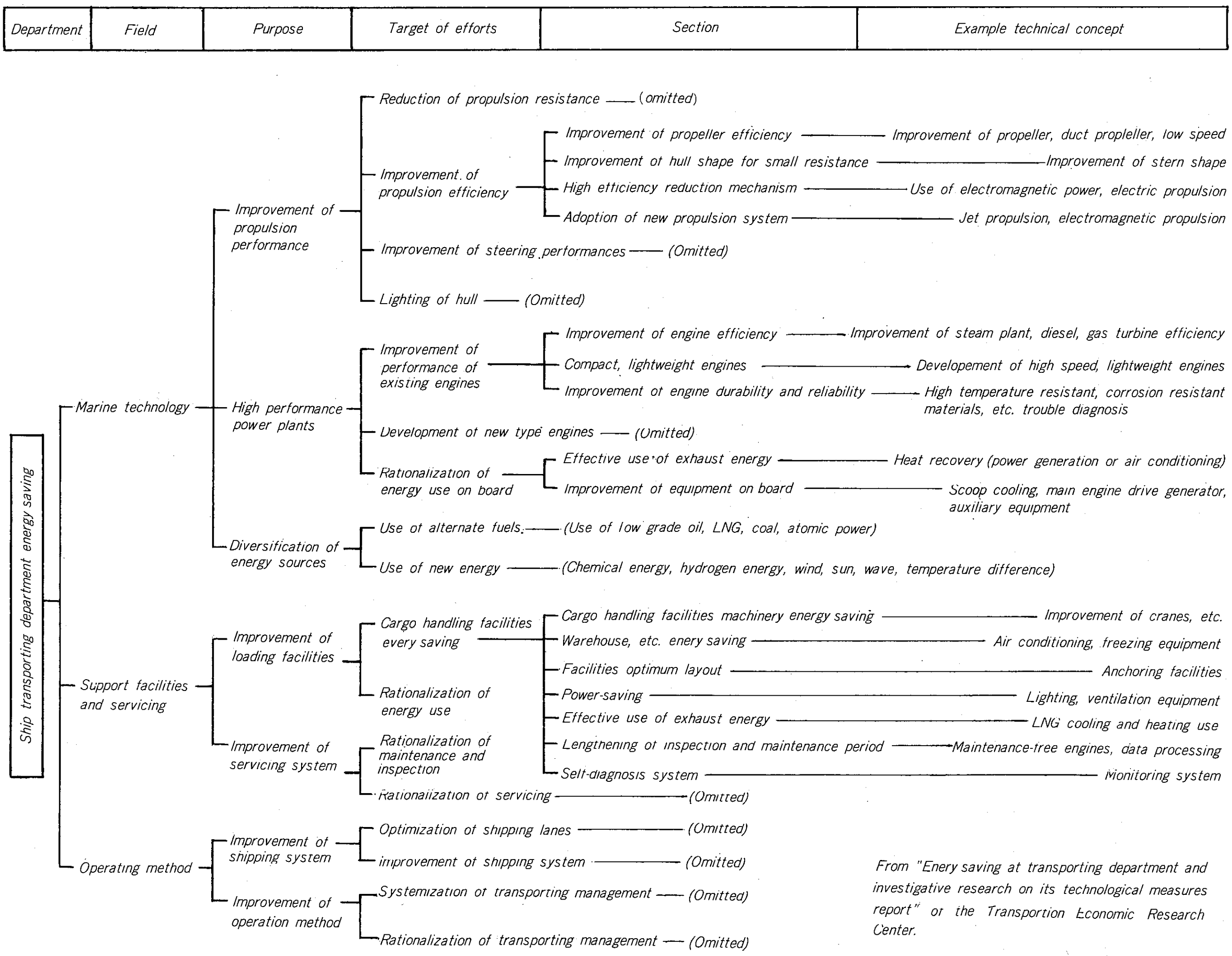

Fig. 1 Energy saving in ship transporting department

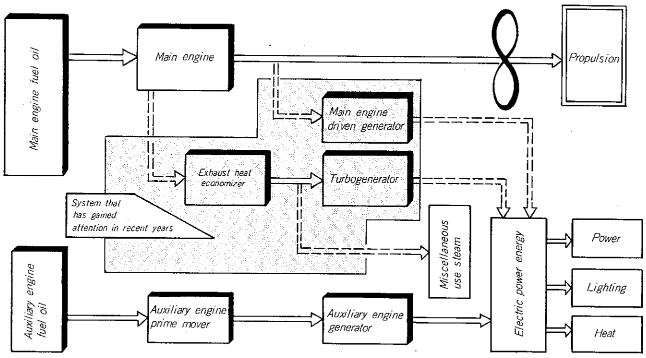

Fig. 2 Energy-flow in ship

proportion is high and use after power conversion depends on the type of ship, but is 10% or less of the whole. Therefore, the effect of power system energy saving is considered to be small, but detailed efforts in rationalization of use of the power generation system and power machinery centered about "Rationalization of energy use on board" of *Fig. 1* is extremely important.

Fig. 2 outlines the energy flow of a ship. Of these, recently, waste heat generation system or main engine driven generation system are energy saving measures that have gained attention.

Table 1 outlines the effect of the items associated with these power saving systems. In addition, more detailed control and monitoring are performed by using data processing equipment operation as a system and if increasing the energy saving effect or increasing efficiency by lowering the propeller speed and increasing operation at the optimum speed, the electric propulsion system is considered. The four points of *Table 1* are summarized here.

Table 1 Energy saving of electric-power system

Waste heat economizer Turbo-generation system	Use of waste heat	300~ 1,000 kVA generation possible
Main engine driven generation system	C heavy oil used	Energy cost reduction Reduction of 15,000,000~ 30,000,000 yen/year
Efficient shipboard electrical parts	Use of high efficiency machines	5~10% rise of efficiency
Drive motor variable speed control	Use of power electronics	

II. POWER GENERATION SYSTEM ENERGY SAVING

Attention has been focussed on the following as marine equipment energy saving measures:

(1) Main engine driven generator

(2) Waste gas turbo-generator

Auxiliary Diesel driven marine generators were frequently used in the past and turbine generators were steadily adopted as the main engine driven by turbine. However, in recent years, the rise in oil costs has been accompanied by focusing of attention on the main engine Diesel driven shaft generator that used cheap C heavy oil and its use to replace the auxiliary Diesel generator that used expensive A heavy oil as fuel is being studied. On the hand, the adoption of a system that recovers the exhaust gas energy generated by the main Diesel is recovered by an economizer and used to driven an exhaust gas turbo-generator is progressing quickly.

1. Shaft generator

There are two different systems; generator coupled to a variable pitch propeller and a generator coupled to a fixed pitch propeller. The former has the following two shortcomings as compared to the latter.

(1) High propeller cost

(2) Normal parallel operation with other generators on the ship is impossible.

Therefore, the adoption and operation of the latter has been higher in recent years, and we have received orders for and are manufacturing a latter system of 700 kW & 720 kW.

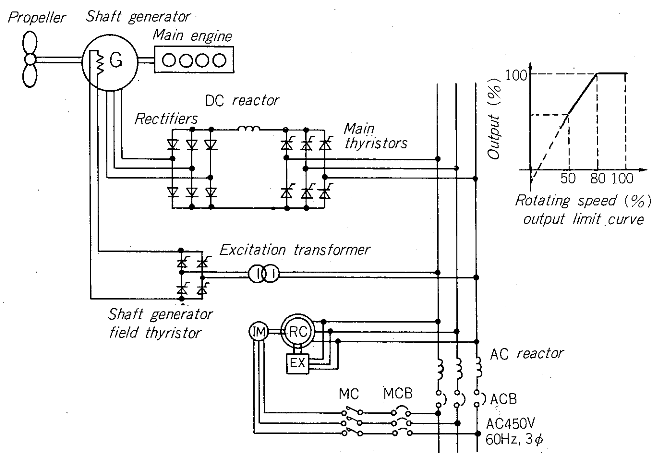

Fig. 3 Main circuit diagram of shaft generator

1) Composition and functions

The main circuit composition is shown in *Fig. 3*. This system is equipment that converts the output of an AC generator direct coupled or overdrive coupled by a variable speed propeller and then converted to AC energy having a fixed frequency and voltage through a separately excited inverter. The main functions are grouped into the following five items.

(1) Constant voltage holding function

This is achieved by means of an AVR installed to a synchronous phase modifier and the separately excited inverter and reactive power required by shipboard load is supplied from the phase modifier.

(2) Constant frequency maintenance function

This is achieved by controlling the increase/decrease of the DC intermediate circuit voltage and its accompanying DC current by means of shaft generator excitation current by means of shaft generator excitation current control.

(3) Load sharing function

Auxiliary generator capacity proportion distribution or shaft generator output limit operation is achieved by frequency drooping control matched to the detected output.

(4) Switching function with auxiliary generator

From auxiliary generator to shaft generator . . . Parallel operation switching is performed after starting of the synchronous phase modifier by the auxiliary generator is complate.

From shaft generator to auxiliary generator . . . When the shaft speed setting has dropped abnormally because of crash astern operation, etc. priority tripping of non-essential loads is performed, the auxiliary generator is simultaneously started, and parallel operation switching is performed.

(5) Short circuit accident processing function

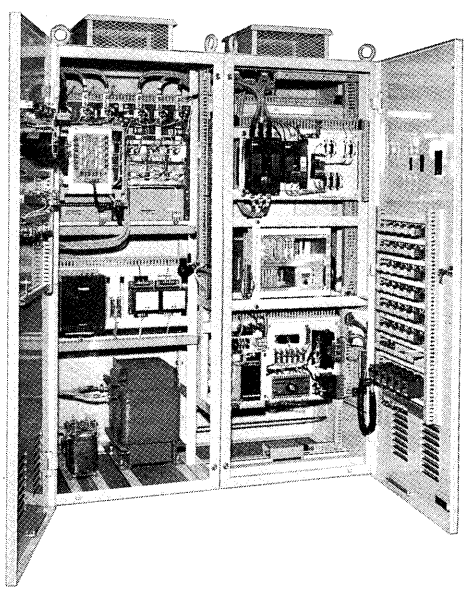

Fig. 4 Shaft generator central panel

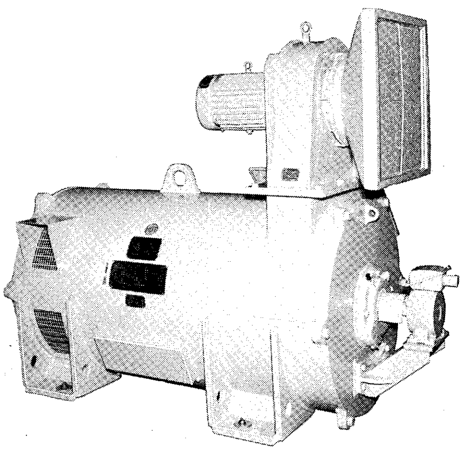

Fig. 5 Shaft generator

The selective tripping continuous short circuit current when a short circuit accident occurs is supplied from the synchronous phase modifier. If the short circuit point is opened by the load side circuit breaker, resupply of power is quickly started automatically. Both direction energy conversion is performed by constructing the rectifier section of *Fig. 3* so that inverter operation is possible. A system with special features can be constructed by combining this equipment with an exhaust gas turbo-generator. Joint development with Kawasaki Heavy Industries, Ltd. is complete and the system is operating in an actual ship. *Fig. 4* and *Fig. 5* shows the central panel and shaft generator.

2) Features

(1) By replacing the auxiliary Diesel generator,

1) A substantial reduction of fuel costs is forecast by changing from expensive A heavy oil to cheap C heavy oil as the drive fuel oil.
2) The auxiliary Diesel maintenance costs and lubrication oil costs are reduced.
3) Auxiliary diesel ancillary equipment, piping, installation, and fitting out are unnecessary and work costs and space are reduced.
4) Auxiliary Diesel cooling water, lubrication oil, fuel, compressed air, and other temperature, pressure, quantity monitoring, inspection and maintenance are unnecessary.
5) Since the drive source is concentrated at the main engine, engine room noise and heat are reduced.
6) The drop in efficiency accompanying changes in the generator load is small and there is no danger of the malfunctions accompanying low load, low term operation that is a problem with an auxiliary Diesel.

(2) By combining a both way energy conversion shaft generator and exhaust gas turbo-generator

1) A system that is very economical when the exhaust gas energy is surplus or lack when the main engine speed changes, the ambient temperature changes with the season, and at load changes are happened.
When exhaust gas energy surplus . . . The shaft is operated as a motor and the surplus exhaust gas is used to drive the propeller shaft.
When exhaust gas energy lack . . . The features of the above shaft generator are displayed.
2) Use as take home (emergency return to port) is possible (limited by the shaft generator capacity).
Since main shaft drived by the shipboard auxiliary generator is possible when main engine trouble occurs, operation reliability is improved.

3) Economical advantages

The advantages accompanying replacement of the auxiliary generator described above is calculated by summarizing them into features 1) and 2) of item (1).

(1) Comparison study base

1) Generator capacity . . . 1,000 kVA
2) Number of sailing days . . . 300 days/year
3) Fuel oil consumption
Main Diesel (C heavyoil) . . . 135 g/PS · h
Auxiliary Diesel (A heavyoil) . . . 167.5 g/PS · h

4) Fuel cost
C heavy oil . . . $150/t
A, B heavy oil . . . $225 ~ 300/t, $1 = 220 yen

5) Auxiliary Diesel overhaul cost
If the auxiliary Diesel is considered to require an overhaul once every 7,000 hours (about 1 year) and the labor is assumed to be 25 man days and labor cost is assumed to be ¥40,000/man day, ¥40,000/ man day x 25 man days = ¥1,000,000/year

(2) Comparison study by overall required cost per year

The facility cost per year is calculated by making the interest rate 8% and the depreciation period 8 years and multiplying the initial investment by 0.174.

Table 2 shows the facility cost, operating cost and total cost for two generator systems. The total cost difference per year by heavy oil cost difference is ¥15,000,000 ~ 30,000,000. If future escallation of heavy oil costs is considered, this difference will steadily increase.

3) Depreciation complete year when the increase of facility investment is compensated by the opeating cost difference

If the difference ¥28,000,000 ~ 43,000,000 of the operating costs of *Table 2* at 8% interest is compensated by the difference of the initial facility investment, *Fig. 6* is obtained. If the facility investment difference is within the realizable ¥72,000,000 ~ 92,000,000 range, repayment will be completed in 2 ~ 4 years.

Table 2 Annual cost comparison

	Facility cost* (thousand yen)	Operating cost (thousand yen)	Total cost (thousand yen)
Auxiliary diesel generator	6,256	80,500 ~95,000	86,756 ~101,256
Main shaft generator	19,532	52,166	71,698

* Facility investment and interest correspond to depreciation/year when depreciated in 8 years.

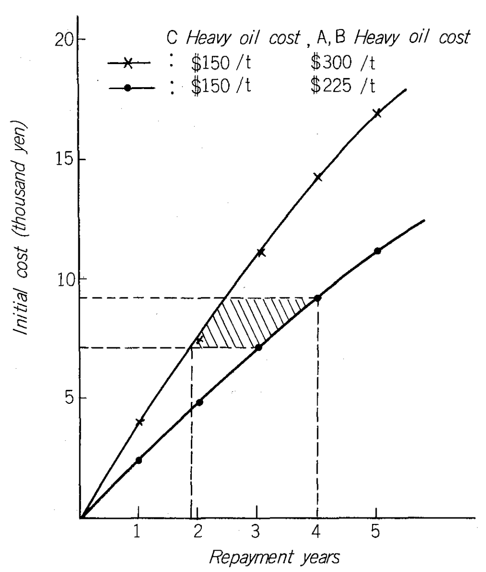

Fig. 6 Difference of initial cost and repayment years

2. Exhaust gas turbine generator

Shipyard and turbine manufacturer is forcefully propelling energy saving by means of the waste heat turbine that uses a heat medium the Freon gas. However, Fuji Electric completed development of 2 pole generator from the standpoint of improving efficiency accompanying the elimination of the generating unit and reduction gear, and is making a series of 5 models having outputs of from 375 ~ 1,875 kVA. One the other hand, progress is also being made in reducing the number of parts and the size and weight of the exciter equipment, and an AVR (HIREX-80C) using power transistors has been developed and put into actual use. *Fig. 7* shows the 2 pole generator and *Fig. 8* shows the transistor AVR.

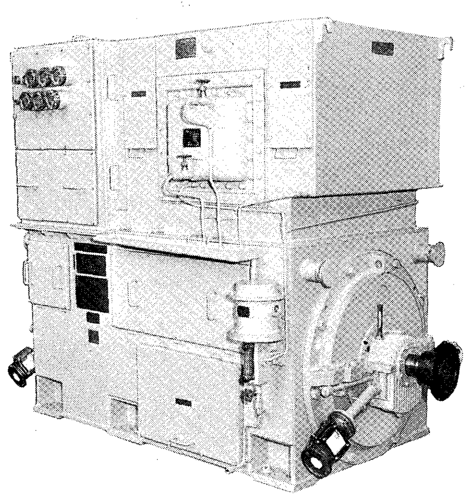

Fig. 7 2 pole generator

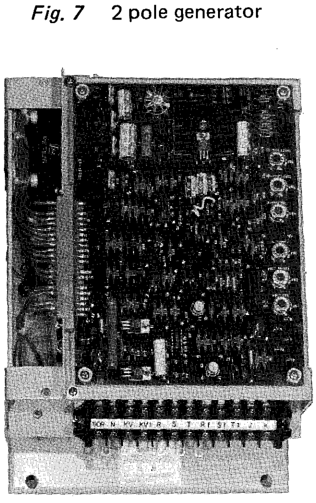

Fig. 8 Transistor AVR

III. ENERGY SAVING AT MOTOR OPERATION

Generally, motor operation energy saving measures are:

(1) Making the motor more efficient
(2) Optimizing the shaft output
(3) Establishment of an appropriate operating schedule

Most motors used in ships operate under continuous operation conditions and are only deck machinery are controlled. However, if detailed operation is studied, there are also motors at which power saving is possible. Since the development of power electronics application technology is recent years has made various operation possible, a restudy of the machinery operating method is also considered to be linked to energy saving.

1. Selection of motors at which efficiency was considered

1) Use of high efficiency motors

Power saving of continuous operation motors are done largely with improvement of the efficiency of motors. Rotary machine technology pursued smaller size with the advances made in insulation technology. At the begining of the 1960s, Class E insulation motors were introduced and at the beginning of the 1970s, motor insulation was changed to Class F insulation and the body was made even smaller. In recent years, the concern for greater efficiency has increased and studies on how the internal losses of a motor can be minimized have progressed.

To reduce the internally generated losses, we stressed the specifications of the electric materials and studied the amount and quality of the core material and improved efficiency by pursuing ideal design and completed a series of efficient, low noise motors (*Fig. 9*).

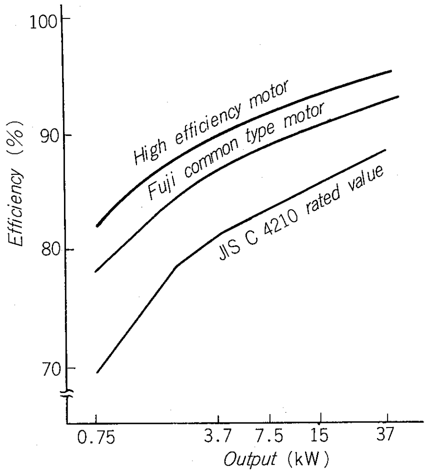

Fig. 9 **Efficiency curves of motor**

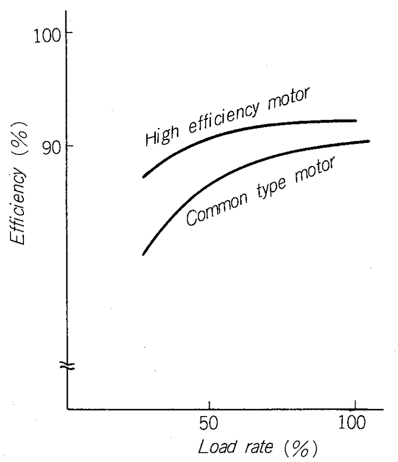

Fig. 10 **Load efficiency curves**

2) Optimization of shaft output

One problem with continuous operation motors is how to select the optimum rating motor for the load.

Generally, the efficiency of a motor is maximum when the motor is operated at 75 ~ 100% load for the rated output. If the motor is operated at a low load rate, efficiency deteriorates and at long-term operation, the loss becomes large (*Fig. 10*).

An advantage of the previously mentioned high efficiency motor is that high efficiency can be maintained even at light loads. Regarding selector of a motor, an optimum motor from the standpoints of load capacity, starting torque, maximum torque, etc. is necessary in power saving.

2. Motor variable speed operation

Shipboard motors have the following three applications:

(1) Periodic operation such as pumps, blowers, etc.

(2) Applications that do not require fine variable speed such as deck windlass, mooring, etc., but use multi-pole conversion motors to provide high torque at low speed.

(3) Applications requiring speed control, such as deck cranes.

The following are considered as motor variable speed operating methods by type of motor:

1) Two step speed control by AC induction motor poles changing.

2) DC motor variable speed operation

i) Method that produces a variable voltage power supply by means of an M-G set.

ii) Thyristor Leonard system

3) AC induction motor inverter operation

4) Synchronous motor cycloconverter operation

5) AC induction motor eddy current joint control

1) Power saving by pump, blower variable speed operation

Many facilities use pumps and blowers and AC induction motors are used to operate these facilities. However, in this case, the motor operates continuously at a constant speed and when the load changes between light load and heavy load, operation is matched to the load by adjusting dampers and valves. In this system, the dampers and valves generate a control loss. Energy saving can be realized by operating the drive motor at low speed to prevent this loss.

If the load equipment having a square reduction torque load characteristics, such as a pump or blower, is adjusted by a damper or valve, even though the *Q-H* curve in *Fig. 11* changes, the operating point will move from point B to point B_1 and the shaft output will remain unchanged. It is well known that if the *Q-H* curve is changed with the damper full open, the shaft driving power will drop by the cube and a substantial reduction will be realized. In *Fig. 11*, the area of A_1-A_2-B_2-B_1 is the power saving.

Power saving: Roughly $\Delta P = P(0.4 + 0.6X - X^3)$

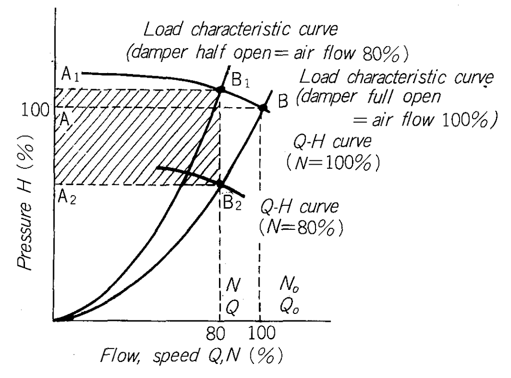

Fig. 11 Characteristic curves of pump and blower

$X = Q/Q_0 = N/N_0$ P: Driving power at full load (kW)

The three kinds of systems, damper control, eddy current joint control, and speed control by inverter, will be compared.

Fig. 12 is the motor shaft output characteristics when the speed of a blower was changed. In order to obtain the same speed, inverter control has the lowest output, followed by eddy current control, then damper control. Since the effciency, including the motor and control equipment, is different for these three systems, the input power for the output of *Fig. 12* becomes as shown in *Fig. 13*. As can be seen from this figure, when the 100% rated load is operated at the rated speed, independent operation of an induction motor requires the lowest input power, but when the speed is controlled, inverter operation is best. Although it also depends on the control range, there are cases when eddy current control is superior to damper control.

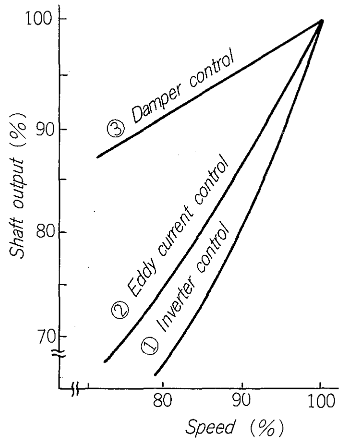

Fig. 12 Characteristic curves of pump and blower motor

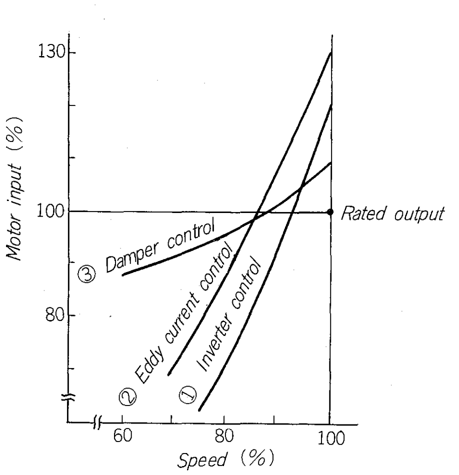

Fig. 13 Input characteristic curves of pump and blower motor

The method of changing the speed should be selected according to the operating mode required by the machine and the facility cost. However, the use of a pole changing switching motor is advantageous at two step control when the flow and pressure when the ship is sailing and when handling cargo, such as an auxiliary boiler force blower.

On the other hand, machines that maintain a constant outlet temperature, such as main engine cooling seawater pump, can provide a power saving if the outlet temperature is monitored and the speed of the motor is controlled accordingly.

That is, planning a facility at which the maximum temperature is not reached because the pump or motor at which the outlet temperature changes with the load and input temperature is run constantly and operating the motor at a constant speed has a large loss. Energy-saving can be achieved by optimum operation by monitoring the conditions that change. A system using an eddy current joint has been practicalized for this purpose. However, recent development in power electronics has brought out the advantages of efficient inverter operation (See *Fig. 14*.). High capacity inverter control uses thyristors, but the development of power transistors in recent years has led to the use of transistor inverters up to 20 kVA. In the future, smaller, low cost equipment will be developed and the use of variable speed control of low capacity machines will spread.

2) Deck machinery thyristor Leonard system

In the past, the following systems have been used to control the speed of deck machinery drive motors:

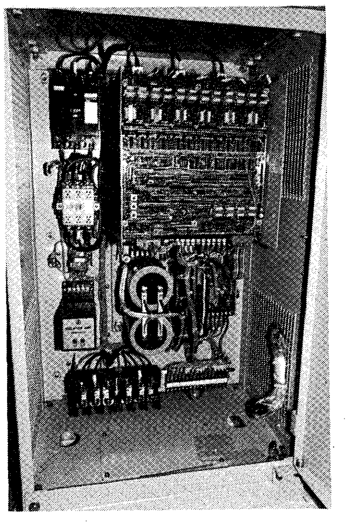

Fig. 14 Transistor inverter

Table 3 Supply list of thyristor Leonard winch

Type	Rating	Motor	Number	Delivery data
Heavy derrick	600t −1.4m/min	2x110kW (hoisting) 2x110kW (luffing)	1 set	1978
Heavy derrick	2,500t −1.5m/min	2x500kW (hoisting) 1x750kW (luffing) 4x10kW (slewing)	1 set	1980
Trawl winch	Various	150~ 750kW	13 sets	From 1971

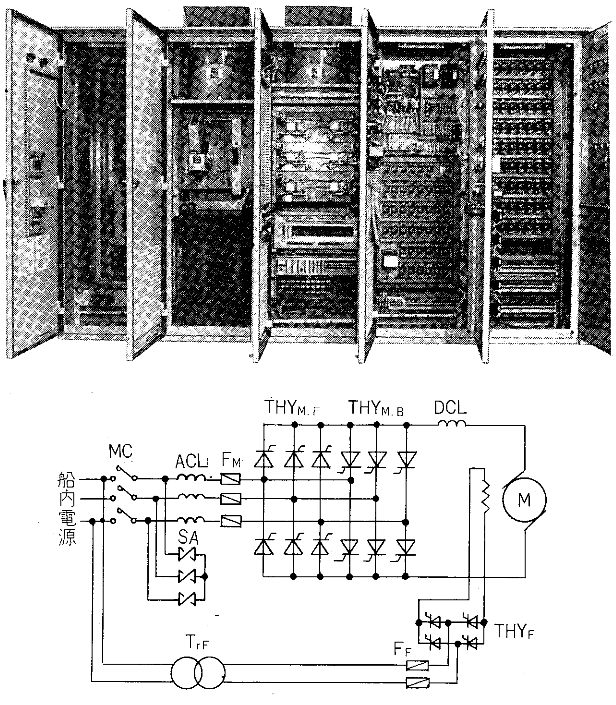

Fig. 15 Cubicle and main circuit of thyristor Leonard system

(1) Pole change motor system
(2) M-G Ward-Leonard system

The pole change motor system is cheap, but it is not for large capacities, it control capacities are poor, and fine control using a DC motor may be necessary, depending upon the hoisting and slewing equipment. In the case of such DC motor operation, a DC variable voltage must be produced by the power supply and an M-G is installed.

The development of power electronics has make it possible to easily produce a DC variable voltage from an AC power source. Fuji Electric has supplied a number of thyristor Leonard equipment (*Table 3*).

When energy saving is considered, the efficiency of the thyristor Leonard system is superior to that of the M-G system, being 80 ~ 85% as compared to the 60 ~ 70% of the M-G system. Considered from this standpoint, the range of use of the thyristor Leonard system is expected to expand (*Fig. 15*).

Table 4 Supply list of thyristor motor

Application	Motor	Control system
Electric propulsion	2 x 200 kW 210 rpm	AC Permotron
Bow thrystor	100 kW 1,170 rpm	Same as above
Trawl winch 22t−80 m/min	380 kW 700~ 1,350 rpm	Same as above

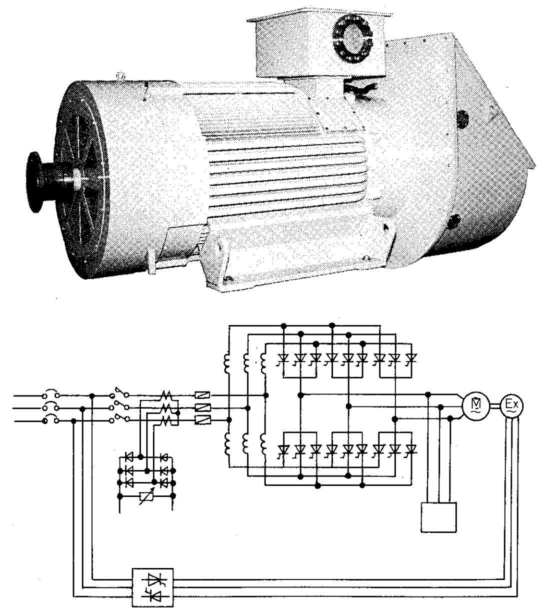

Fig. 16 Thyristor-motor and system for 380 kW trawl winch

3) Other variable speed operation

DC motors contain a commutator and have the disadvantage of degradation of the winding insulation due to the brushes. We also have a record of achievements in special applications of synchronous motor thyristor operation that eliminates this disadvantage and has the same control performances as the DC motor as one field of variable speed control. *Table 4* lists the thyristor motors that we have manufactured (*Fig.16*).

IV. CONCLUSION

Marine technology is emphasized as a topic of future automation and the main object has been the development of monitoring and alarm equipment with M0 classification of the engine room as the target and sophisticated navigation. Energy-saving is expected to be added to this and more research on improving the efficiency of the entire system is expected in the future.

Efficiency improvement is taking up the individual problems of each equipment and control and management so that overall operation is optimized and construction a highly reliable system. For this purpose, power control equipment using power electronics, data processing systems using microcomputers, and sensor technology for monitoring and grasping each state are being adopted by the ship transporting department and are expected to contribute to automation and energy-saving.