UDC 621. 313. 077. 3 : 621. 314. 63. 07 : 621. 864 : 621. 124. 72

MARINE USE THYRISTOR LEONARD EQUIPMENT FOR LARGE STERN-TRAWLER

Koichi Niwa
Transportation Equipment Div.

Takeo Urushibata

Hisao Ohno
Control Technique Center

I. INTRODUCTION

From the standpoint of maritime application, the thyristor is a standout, especially in reliability, service life, handling, maintenance, and installation reckoned as in size and weight. In additions, the advent of labor-saving, automated vessels has long been awaited and higher performance ancillary equipment been hoped for. Reflecting the trend of the times, experts associated with maritime world have entered upon the full scale application of thyristor techniques to various power machines and appliances to be used for maritime services. However, they are facing the many problems—both technical and economical—inherent in the maritime application of thyristor techniques.

Since the first example of power thyristor employed in the exciter for use with a marine use generator in 1966, we have delivered some 300 units of this kind of equipment, and have excerted ourselves to look into the facts for the purpose of solving various problems and developing ultimate equipment.

Fuji Electric has just completed a utility type large-capacity thyristor Leonard equipment for the control of main switching facilities of "Ohtori-Maru", a large stern-trawler owned by Kyokuyo Co., Ltd. This equipment is a control system with an abundance of technical refinements behind which our many years of experience and research efforts.

"Ohtori-Maru" was launched early March last year, and her thyristor Leonard equipment has since been in business without any troubles.

II. TRAWLING EQUIPMENT AND ITS TECHNICAL REQUIREMENTS

1. Operating Methods of Trawling Equipments

The trawl fishery today has extended its activities far ahead of Northern Pacific or even to the Western Coasts of Africa. To cover such long-range activities, the hull size is tending toward becoming larger and larger; as a consequence, the demand for higher performance rigging equipment is strong. For example, it is often that such a high performance trawl winch as is given a rope pay-out capacity of as long as 3,000 m is ordered from a fishing company. *Fig. 1* shows an external view of "Ohtori-Maru". The trawl winch operation consists of three fundamental jobs; paying out, trawling and hauling (*Fig. 2*).

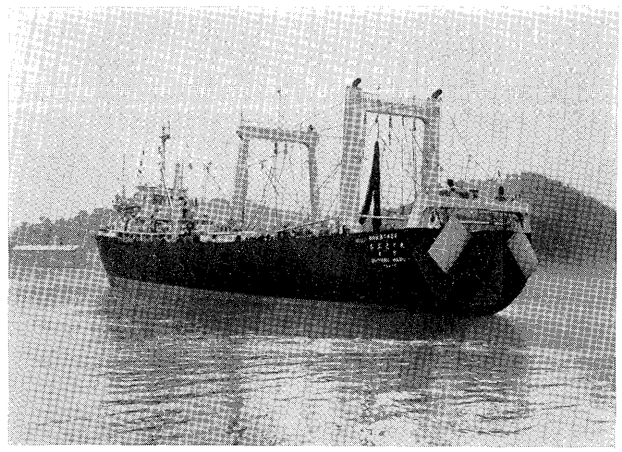

Fig. 1 Stern-trawler "Ohtori Maru"

1) Paying out

(1) Cot end slips on the slipway into the sea. (The trawl winch is stopped, and this operation is carried out by another fishery winch.)

(2) The trawl net is dragging in the water astern owing to the functions of weights attached to the grand rope below the mouth of cot, waves generated by propeller and the retarded forward motion of the ship herself. (From around the time when the grand rope begins dropping into the sea, the winch is to be reversed for the purpose of paying the rope out. Since, however, the friction losses due to gears and metals overcome the tension of cot, the winch motor is in the motoring running.)

(3) At the time when the end of the arm rope clears over the gear loss, the otter board is attached to the joint at which the arm rope and the warp rope are connected together. (The winch gets stopped by means of a mechanical brake on the motor side.)

(4) Immediately when the otter board is slipped into the sea, the vessel begins trawling at a full speed. Simultaneously with this, the winch pays out the

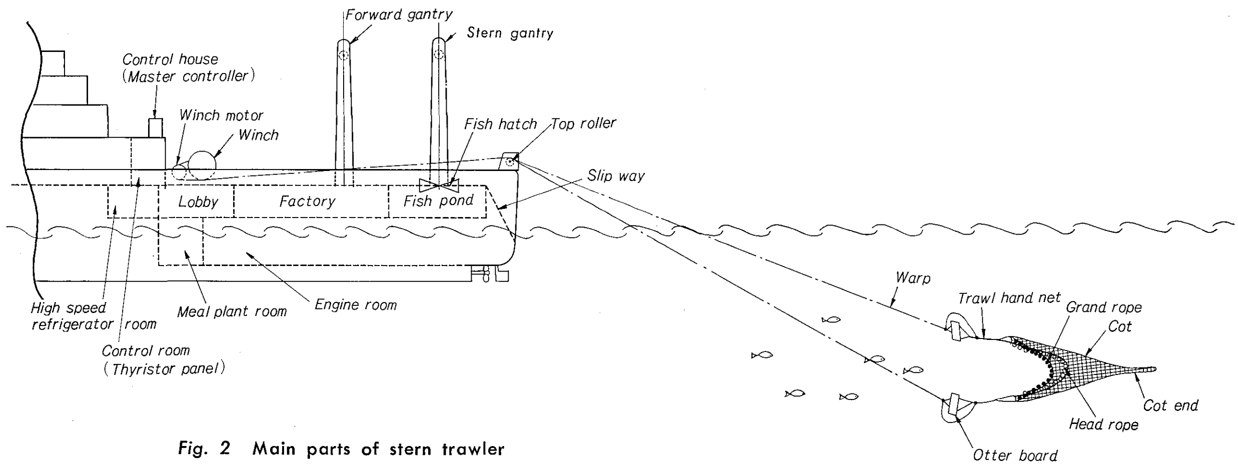

Fig. 2 Main parts of stern trawler

warp. In these courses, the otter board is given an impingement of seawater which is to be determined by vessel speed, warp paying-out speed and tidal flow (undersea current), determining the opening and the floating level of the cot.
The reaction of otter board to the warp will increase with increase in vessel speed if the winch paying-out speed is held constant.
In the vessel accelerating stages, it happens that the warp tension goes over the mechanical loss of the winch and acts to accelerate the motor operation. As a result, the motor operation is shifted from motoring to regenerative running.

2) Trawling

When the cot has been sunk to a required depth by the paying-out operation explained under par. (4), the winch is then stopped, and the main drum is fixed with a band brake. In succession, the gear and drum are disconnected from each other.

Since the warp is secured to the main drum, the trawl net runs at the same speed as the vessel does.

In the event that the cot is caught at obstacles on the bottom, the band brake whose torque can be set adjustably works to minimize net damage.

3) Hauling

(1) After trawling operation, the gear and drum are engaged to each other, and the band brake is released. The warp is wound up on the main drum. When the otter board bracket draws near the top roller, the drum is stopped. Thus, the otter board is untied from the trawl net, and then is set aside on the stern. When winding up the warp, the winch is forced by the resultant force of vessel speed and winding speed ; if therefore the vessel speed is increased, the winch will be overloaded, automatically retarding the winding speed.
For this reason, it is made practice to retard the vessel speed and increase the winding speed for the purpose of enhancing the working efficiency as a whole.

(2) The frontal end of the trawl net (cot) comprising arm net, pen net, sleeve net and grand rope is loaded on the shelter deck through the slip way. This hauling operation is continued until the pen net attains the main drum.

(3) The cot end which fishes are impounded is lifted from the sea onto the slip way. In this case, the cot end is raised by means of the center drum which has a large tracting force, and through a broad block attached to the front gantry in order to adjust the lifting angle, because the raising load is increased excessively by dragging force caused otherwise on the slip way and catch as well as the reduction in the buoyancy of the cot.

(4) Then, the cot end is slinged right above the fish hatch by means of fishery winch through the cot winding block on the stern gantry. Then, the cot end knot is released to complete the entire trawling operation.

2. Required Characteristics of Trawl winch

1) The rope paying-out length is so long, and the winch drum diameter changes to a ratio of one to three or more. The trawl winch is required to give a constant output characteristic in order to keep the rope speed constant all the time even when winch drum diameter shows a wide variation.

2) During paying-out operation, power is fed back to the winch from the rope and otter board. Namely, the winch is required to be able to absorb this return power effectively.

3) The winch is also required fine control of hauling speed to perform easily disengagement of drum clutch ; attaching, detaching and hanging up the otter board.

On the other hand, from the viewpoint of working efficiency, the winch is required to provide as high a speed as some 200% of the normal running speed.

4) When the cot end loaded with catches is laden along the slip way or when the net or rope is caught at obstacles on the bottoms, the winch should generate about 150% to 180% of rated torque to overcome such hitches.

3. Selection of Driving System

Hitherto the electric motor and hydraulic motor have been widely used for trawl winch. However, the hydraulic motor is restricted in its working range, and cannot catch up with the recent tendency for the winch to increase in output at a rapid pace; especially, it is difficult to meet the requirements given under items 1) and 4) above. For this reason, the electric motor, especially that combined with DC Ward Leonard system which is able to fully realizing the winch working conditions comes into highlight. In fact, it is no exaggeration that the Ward Leonard type winch motor holds the majority over others. Nevertheless, this system has the following two demerits.

1) The overall system efficiency is poor, because the DC power required for the DC winch motor is supplied from the motor-generator to be driven by the AC generator inside the vessel.

2) Much time is required for the daily inspection and maintenance, because the DC generator and winch motor use commutators and brushes.

In order to cope with these problems, the inland equipments have employed a static converter using mercury rectifier in place of motor-generator from many years ago. But, the mercury rectifier has now been replaced with thyristor totally. In recent years, the working reliability of thyristor has been increased noticeably, and its cost is also cut down sharply owing to the materialization of mass production. Its excellent performance cannot be affected by circumstances. As a consequence, the thyristor system is beginning to be increasingly used for the vessels.

As a result of comprehensive study, we reached a conclusion to adapt the thyristor Leonard system to the "Ohtori-Maru," and its soundness has been evidenced by unbelievably large improvement in trawl winch characteristics, especially in the accelerating and decelerating performance and stalling characteristics.

III. OUTLINE OF THE EQUIPMENT

1. Specifications

1) Main particulars of trawl winch

Rated tension of main drum: 30,000 kg
Maximum tension of main drum: 1.8 × rated tension
Rated warp winding speed: 90 m/min.
Maximum warp winding speed: approx. 2 × rated speed
Rated motor output: 550 kW
Rated motor speed: 630 rpm

2) Main AC generator

Drip-proof 3ϕ self-excited compound AC generator

Number of units: 4 (including 2 or 3 for normal service and 2 or 1 for standby use)
Model: CVF386/21–10
Voltage: AC 450 V, 60 Hz, 3ϕ
Exciting system: TR system
Accessories: Self-exciting voltage regulator cross current compensator

3) DC motor for winch drive

Water-proof, forced air cooled (tube draft), separately excited DC motor

Number of units: 1
Model: ahVG334/40–6
Output: 550 kW
Running speed: 0~630 rpm (Leonard control range)
630 rpm~1,330 rpm (constantoutput, field-weakening control range)
Voltage: 440 V (Armature circuit)
40 V (Field circuit)
Accessories: DC electromagnetic brake
DC pilot generator

4) Thyristor board

Drip-proof protected forced air cooled self-supporting board

Number of units: 2 panels

Main particulars of major circuits:—

Connection system: Three-phase full-wave Greatz connection; 1S6P6A
Input voltage: AC 440 V (line voltage), 3ϕ
Output voltage: DC 440 V
Type of element used: BAS-GNO216AB
Type of protective fuse: RFA1244–3–350

Main particulars of field circuit:—

Connection system: Three-phase half-wave inverse parallel connection; 2 sets × 1S1P3A
Input voltage: AC 490 V (line voltage), 3ϕ
Output voltage: DC 280/40 V
Current capacity: 1,200 A
Accessories: Fan and motor; flow relay (wind

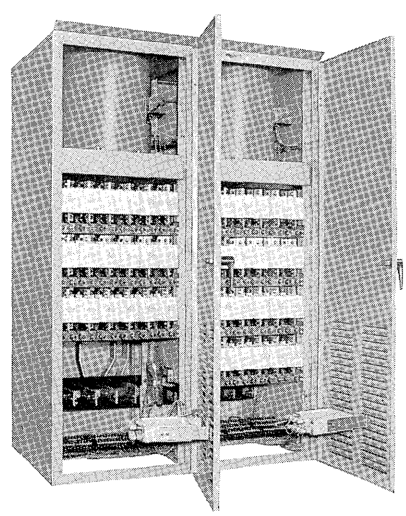

Fig. 3 General front view of thyristor panel

pressure relay)

Fig. 3 shows an external view of the thyristor board with its door opened.

5) TRANSIDYNE board

Drip-proof protected forced air cooled self-supporting type

Number of panels: 2

Control unit: TRANSIDYNE control unit which is compacted by IC system as well as through the organization of the TRANSIDYNE control theory

System configuration:—

(1) Armature circuit

Speed controller, armature current controller, firing angle controller, current limiting operator

(2) Field circuit

Field controller, field selecting changeover operator, counter emf operator, counter emf polarity changeover operator, firing angle controller

(3) Armature circuit/field circuit

Running control operator

(4) Special equipment

F/V converter, filter

Accessories: Fan and motor

Fig. 4 shows an external view of the TRANSIDYNE board with its front door opened.

6) AC board

Drip-proof protected self-supporting type

Number of panels: 1

Principal fitting: Disconnecting switch, AC reactor, transformer, contact relay, surge absorber for thyristor protection, indicator

7) DC reactor board

Drip-proof protected self-supporting type

Number of panels: 1

Main fittings: Chopping preventive reactor, cross current blocking reactor, protective relay

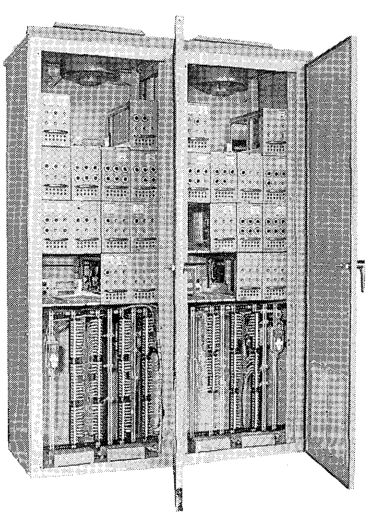

Fig. 4 General front view of TRANSIDYNE panel

8) Control console

Totally closed water-proof self-supporting type

Number of units: 1

Main fittings: Motor speed setting handle, running preparation pushbutton switch, emergency stop switch, indicator

Almost every winch operation can be accomplished on the control console on the master controller accommodated in the control house. The operation is carried out by one man.

2. Outline of the Main Circuit Arrangement and Control

1) Main circuit arrangement

With consideration given to an extraordinarily large load time constant, economics and space limitation, the control system was made of the field inversion type.

Fig. 5 shows the main circuit. The trawl winch is served from two to three of four 925 kVA self-excited compound three-phase AC generators through an air circuit breaker exclusive to it. The main circuit is not passed through the transformer, but directly connected to the AC reactor, rectified through three-phase full-wave Graetz type thyristor bridge, and is then applied to the armature winding of the DC motor through the DC smoothing reactor. On the other hand, the field circuit is fed from a three-phase offset leg transformer through a three-phase half-wave inversed parallel thyristor bridge for rectification and through the cross current limiting reactor.

2) Outline of the control

(1) Feedback control

Both the armature and the field circuit use an ACR minor loop for the current system.

On the other hand, the speed system employs an ASR feedback control system using a tachometer generator.

For this reason, the system response and stability are excellent, and the rush current incidental to acceleration and deceleration can be reduced to a minimum necessary value.

(2) Constant output characteristics for the moderated field operation

From 630 rpm to 1,330 rpm, the system provides moderated field operation.

With the adoption of high response current limiting characteristics, the system is able to put out the rated critical output within this control range.

(3) Field inversion control

The thyristor Leonard control system requires a forward converter which provides a path for the accelerating current and load current to flow from the power supply to the rectifier and a reverse converter which provides a path for the decelerating

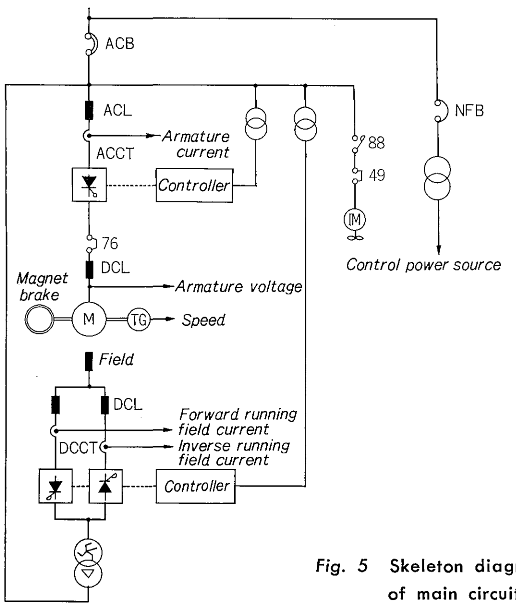

Fig. 5 Skeleton diagram of main circuit

current to flow from the motor to the power supply, because the thyristor element is conductive only in the direction from anode toward cathode. For this reason, such a wiring system as has a forward converter of the cross connection or inverted parallel connection is most commonly practised (*Fig. 6* (a), (b)). But, it requires a large space and costs much since two sets of main circuit converters are necessary. To solve these problems, the so-called field inversion control system (*Fig. 6* (c)) is employed, which inverts the polarity of the counter electromotive force of the motor under deceleration as against the acceleration or under reverse operation as against the forward running in order to make the polarity of the current to pass bring in coincidence with that of the current permitted by the converter. In this system, only a single set of main circuit converters is used.

(4) Efficiency and space

As compared to the ordinary Ward Leonard system, the present one is greatly improved in efficiency, both electrically and spacially, since the motor-generator is dispensed with and since the machine installation becomes easy.

(5) Maintenance and inspection

The present system has no DC generator, and gets rid of the maintenance time otherwise required for the commutator brushes. In addition, the thyristor elements and TRANSIDYNE units are arranged to be accessible from the panel front for easy inspection.

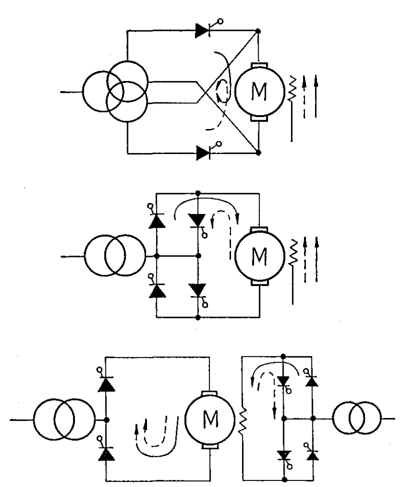

Fig. 6 Principle of thyristor Leonard control system

3. Characteristic Curves

Fig. 7 shows the torque characteristics of load and winch. The load curve is given with the vessel speed taken as a parameter. The speed of the submerged otter board is expressed by "vessel speed + warp winding speed," and the load torque increases with increase in the warp winding speed or vessel speed, if hauling operation is conducted. On the other hand, in case of the paying-out operation, "vessel speed − warp paying-out speed" assumes the speed of otter speed, and the load torque increases with decrease in winding speed or increase in the vessel speed.

In the meantime, the winch is given such a torque limiting characteristic that shows the same pattern for both the first and the third quadrant or for the second and the fourth quadrant. In all quadrants, the Leonard control using armature voltage and armature current is applied for 0 to 630 rpm, and the constant output control using armature current for 630 to 1,330 rpm.

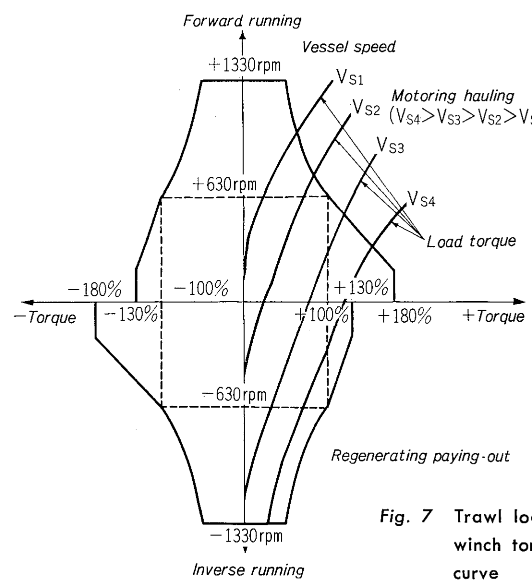

Fig. 7 Trawl load and winch torque curve

IV. FIELD INVERSION CONTROL

The field inversion control system employed in the present system is one that has already been qualified with a rewarding result, and is equipped with an additional circuit to fulfil specific requirements inherent in marine services.

Fig. 8 shows the control system block diagram.

The following lists some of important items of the field inversion control system.

1) The speed control system is by an ASR feedback control system using a tachometer generator directly coupled with the motor, whereby its response and stability against the load variation and disturbance are improved.

By the limiting of output of the speed controller which is one of the most important parts of the system, the current limiting characteristics are obtained.

2) In the field inversion control system, the change-over of forward operation, reverse operation, motoring operation and regenerative operation can be accomplished by inverting the polarity of the field cuiient. For example, if the polarity signal for a given torque to be developed by the motor is inverted, a signal to invert the field current polarity is issued without delay ; if however the armature current is passed immediately before the actual field current has completed polarity inversion, acceleration will be brought about, counteracting the torque signal.

For this reason, as soon as the torque signal is given, the armature current is reduced to zero, and only when the actual field current has been inverted, the said current limiting is put into effect.

3) As will be clear from the above explanation, the field inversion control system has a demerit in that the motor unavoidably causes a blank time as it becomes dead when the armature current is reduced to zero for the purpose of field inversion. During this blank time, the motor loses the controlling power over the load.

In order to settle as far as possible this problem, a circulating current is forced constantly through the forward and reverse thyristors for the field, and in order to reduce the field constant an exciting voltage seven times as large as the rated value and a field current minor loop are used.

V. PROBLEMS OF THE SYSTEM FOR MARINE APPLICATION

In adopting the thyristor equipment to the ship, the following three should be solved with utmost consideration.

1. Considerations and Measures to be Taken for the Vessel Power Supply Capacity

Because of space limitation and economics, the power supply system of the vessel is generally far less in capacity than that of the inland equipment. This is more striking in the trawl boat in which the trawl winch is the largest load among others ; namely, the ratio of the power supply capacity to the trawl winch load (hereinafter called " thyristor load ") is very small. Other ship loads are large starting capacity induction squirrel cage motors of the direct line starting or the reduced voltage starting type,

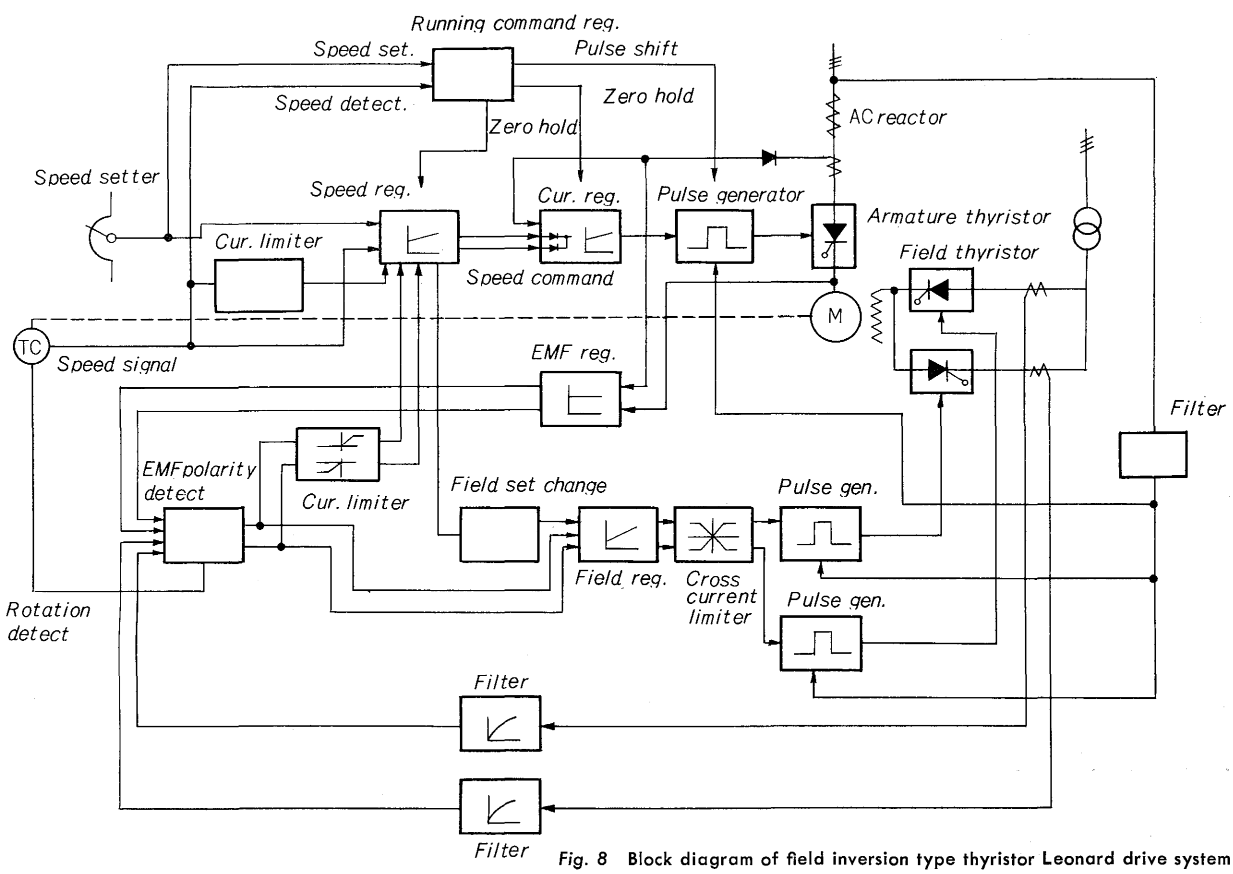

Fig. 8 Block diagram of field inversion type thyristor Leonard drive system

which unavoidably causes a considerably large variation in voltage and frequency. Moreover, the commutation phenomenon inherent to the thyristor equipment (See V. 2) adds to these two demerits, giving rise to the following the problems.

1) Considerations and measures for the determination of $\gamma_{\min}$

In order to make run in an orderly way a thyristor equipment having a regenerative working range, the supply voltage should be lower than that given by the following equation (1) which marks off the commutation critical range at the time of regenerative operation.

$$\gamma_{\min}=\cos^{-1}\left(\cos\delta-e_{XN}\cdot\frac{I_d}{I_{dN}}\cdot\frac{1}{\frac{E_{ac}}{E_{acN}}}\cdot\frac{f}{f_N}\right)+\beta\cdots\cdots(1)$$

Where,

δ: on/off time of thyristor element, electrical angle

e_{XN}: % reactance of line (reduced to the load side)

I_d: maximum regenerative DC current

I_{dN}: rated DC current

E_{ac}: instantaneous source voltage variation

E_{acN}: rated source voltage

f: instantaneous frequency variation

f_N: rated frequency

β: thyristor firing angle deviation due to higher harmonics to be created by frequency variation and commutation plus overlap angle of other thyristor units connected to the same power system

On the other hand, the armature voltage of the motor should be made smaller than that specified by Eq. (2), because the normal driving is required at the time of regenerative operation. Considering that the thyristor load capacity is given by Eq. (3), $\gamma_{\min}$ should be reduced to as small a value as possible in order to reduce the load capacity, i.e., to improve the capacity ratio with ship power supply capacity reduced (for the purpose of improving power factor as a whole).

$$E_d=E_{d0}\times\cos\gamma_{\min}\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(2)$$

$$E_{d0}=K\cdot E_{ac}$$

Where, K: Constant to be determined by the rectifier wiring system

$$P_{AC}\propto E_{acN}\cdot\frac{P_{DC}}{E_d}\propto\frac{1}{\cos\gamma_{\min}}\cdots\cdots\cdots\cdots(3)$$

Where, P_{AC}: Thyristor load capacity

P_{DC}: Motor output

With reference to Eq. (1), in order to reduce $\gamma_{\min}$, it is required to reduce δ, e_{NX}, $\frac{I_d}{I_{dN}}$, $\frac{1}{\frac{E_{ac}}{E_{acN}}}$, $\frac{f}{f_N}$ and β. We consider e_{XN}, $\frac{1}{\frac{E_{ac}}{E_{acN}}}$ and β only here.

e_{XN} is given by Eq. (4)

$$e_{XN}=X_{AC}+X_d''\times\frac{\text{Thyristor load capacity}}{\text{Power supply capacity}}\cdots\cdots(4)$$

Where, X_{AC}: AC reactance

X_d'': Generator secondary transient reactance

Namely, it is required to reduce X_{AC} or $X_d''\times\frac{\text{Thyristor load capacity}}{\text{Power supply capacity}}=X_G$ for the purpose of reducing e_{XN}.

The size of X_{AC} is to be determined in relation of the effect of the voltage drop due to commutation on the other equipment connected to the same power supply as well as of the waveform distortion of the synchronous power supply to X_G. For this reason, X_G, viz., X_d'' and $\frac{\text{Thyristor load capacity}}{\text{Power supply capacity}}$ should be reduced. Namely, the reduction in e_{XN} (X_d'' in consideration of influence over other loads) will greatly improve the system reliability since $\frac{1}{\frac{E_{ac}}{E_{acN}}}$ is directly related to the instantaneous source voltage drop.

On the other hand, β is closely related to three factors. With reference to the variation of the electrical angle of the firing pulse due to frequency variation, the sawtooth wave generator for the thyristor pulse generation is compensated by means of an F/V converter which performs automatic regulation in correspondence to frequency variation.

With reference to the effects of waveform distortion of synchronous signal source to be developed at the time of commutation, the waveform can be ameliorated by the reduction in e_{XN} and $\frac{X_G}{X_G+X_{AC}}$ as well as by making use of a special filter as the overlap angle and drop representing the magnitude of the waveform distortion is given by Eq. (5).

$$\left.\begin{aligned}u&=-\alpha+\cos^{-1}(\cos\alpha-e^{NX})\\ d&=\frac{X_G}{X_G+X_{AC}}(\%)\end{aligned}\right\}\cdots\cdots\cdots\cdots(5)$$

Where, u: Overlap angle

α: Control angle

d: Initial inverse voltage (waveform plunging) (line voltage reduced to zero at 100%)

With reference to the effects of the overlap angle due to other thyristor equipment connected to the same power supply, the same method as explained above is directly applicable to these equipment.

2) Heating-up of generator damper winding due to higher harmonic current

The waveform distortion at the time of commutation results in forcing higher harmonic currents expressed by Eq. (6) into the generator.

$$\nu=nP\pm1\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(6)$$

ν: Order of higher harmonic component

P: Number of phases

n: 1...........n (integer)

Namely, the size of the higher harmonic currents is determined by multiplying the fundamental motor load current by the higher harmonic component factors to be determined by the load angle and overlap angle. Accordingly, if a given generator has a small capacity as compaıed to its load, the feasibility of the power system operation should be examined by converting higher harmonic components into equivalent negative phase currents using Eq. (7).

$$I=\sqrt{\Sigma\left(\sqrt{\frac{\nu}{Z}}\cdot I\nu^{2}\right)} \quad \cdots\cdots\cdots\cdots\cdots\cdots(7)$$

ν : Order of higher harmonic component
$I\nu$: νth higher harmonic current (%)
(ratio to fundamental wave)

3) Effects on marine telecommunication equipment

As detailed in V. 2, such a ship as this trawler which is required to operate fish detector, sonar, loran and other transmitters and receivers during winch motor running, should be carefully designed and provided against radio noises from thyristor equipment and higher harmonics emanating directly from power cables in the early stage of design and engineering.

2. Measure for Marine Use Telecommunication Equipment against Noises

In the thyristor converter, the thyristor elements used transact current (commutation) every cycle as the source voltage changes in accordance with its phase sequence. This is shown in *Fig. 9*. Here, the element that has just begun conduction will increase its current from zero up to a specified DC level through an overlap period, whereas another element which is going about to complete the conduction will reduce its current from the specified DC level to zero. During this overlap period, the line voltage e_{UV} is shortcircuited with elements 1 and 2 which are concerned with commutation, and the full voltage will be applied to the AC circuit reactance. Accordingly, the line voltage e_{12} at point A appearing in *Fig. 9* will be distorted, deforming the source voltage as well.

Also the live voltage snaps up during this period as shown in *Fig. 9*, and parallel RC elements connected to the thyristor elements, stray capacitance in the circuit (especially in the thyristor equipment, gate control circuit, AC reactor and to-the-ground capacitance circuit of the generator) will release charges and cause parasitic oscillation.

AC current of the thsristor circuit itself assumes nearly a square waveform comprising higher harmonic components.

Namely, these higher harmonics due to voltage and current will partly radiated to the open air through the power circuit, and will jam marine telecommunication equipment and fish detector.

For this reason, the thyristor equipment is usually set apart from these telecommunication equipment or isolated with iron enclosure to increase attenuation of radio waves to a practical extent.

On the other hand, the power circuit is comparatively small with reference to the thyristor load, and the voltage in the ship source system is liable to be distorted largely by reactance. The telecommunication equipment connected to this power supply cannot be immune from such system fluctuation. To cope with this problem, a special filter shown in *Fig. 10* is provided in the primary side of vulnerable equipment.

Fig. 11 shows the frequency characteristics of this filter with which all the equipment inside the vessel can be protected from the obnoxious influence of the thyristor converter.

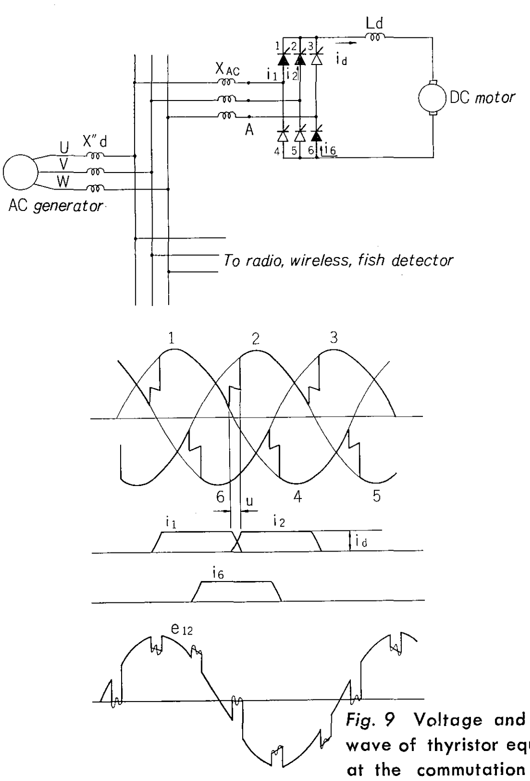

Fig. 9 Voltage and current wave of thyristor equipment at the commutation time

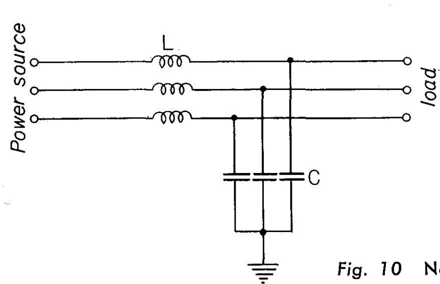

Fig. 10 Noise filter

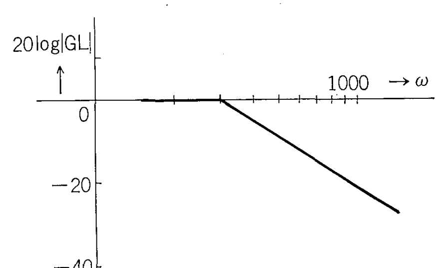

Fig. 11 Frequency characteristic of noise filter

3. Measures from the Viewpoint of Special Circumstances-Inherent in Vessel

In the vessel, the working circumstances of electrical equipment are unusually severe because of confined space, high humidity, high salinity, violent pitching and rolling and excessive engine vibration. Accordingly, extreme prudence is required in the designing of vessel appliances.

In connection with the location, the feasibility of maintenance and inspection is also an important factor. Fuji thyristor equipment and TRANSIDYNE equipment are of the tray type allowing front access for ease of maintenance and inspection as well as replacement work required at the time of troubles.

The conductors for the thyristor equipment which are to convey a large current in the back of the panel are secured by silver soldering because otherwise method such as screw setting requires occasional tightening.

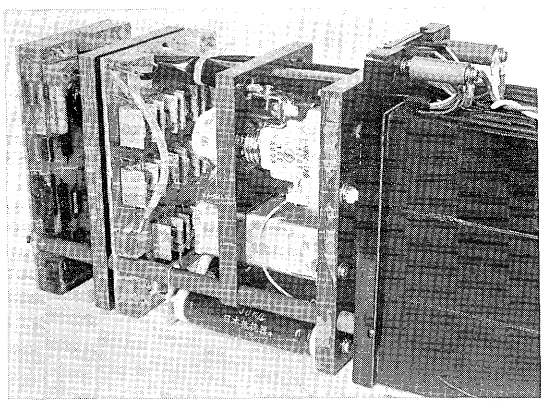

Fig. 12 General view of print board of thyristor unit

The printed circuit boards for the thyristor unit are molded and those for the TRANSIDYNE equipment are coated for moisture proofing and corrosion prevention. Also the gold-plated connectors are used. (*Fig. 12*)

As regards the rocking of vessel and vibration caused by engine, both the thyristor panel and the TRANSIDYNE panel are fixed with resilient rubber under the panel frame and on the back frame in order to nullify vibrating movements, especially those created by engine operation.

VI. TEST RESULTS

All the settings of the regulators have been determined both at the factory and at the time of trial running, along with the verification of operating

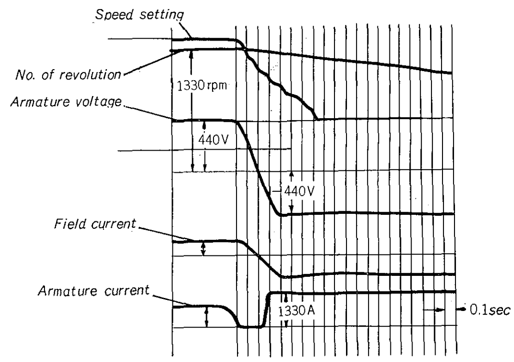

Fig. 13 Maximum to zero notching oscillogram

performance. All was qualified. It should be added by the way that the hindrance which at first was expected to be developed by the dead time required for changing the motoring to the regenerative operation was not caused at all, standing for the soundness of the selection of the field inversion control system for this kind of equip- ment.

Fig. 13 is an oscillogram showing the operations from forward top notch position to the stop position.

VII. CONCLUSION

When applying a large capacity thyristor equipment to the vessel, the limitation of power supply capacity, measures for telecommunication equipment against interference and severe working conditions should be fully taken into account.

Fortunately, our shipowner has been generous in giving advice and assisting us in dwelling on various new phases of matter and taking full measures. The equipment is in business as designed, and it is truly a milestone marked in the advancement of thyristorization of marine use heavy electric machinery.

Finally we wish to express our profound gratitude to Mr. Kishino, Section Chief, Kyokuyo Co. with whom we have argued over various knotty problems, to other Kyokuyo staff who have extended services freely, and those from Maizuru Shipbuilding Yards of Hitachi Shipbuilding Co. with whom we have collaborated in rigging this new equipment.