MAIN AC ELECTRIC MACHINES FOR SHIPS

By

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I. INTRODUCTION

During the past several years, thoroughgoing discussions have been made in various countries concerning the problem of replacing the electric sources of ships from direct current to alternating current. On land, the change to alternating current is required to transmit electric power over long distances. The adoption of alternating current cage motors for main electric machines of ships has been promoted by the high reliability, durability, compact size, light weight, low price and low maintenance cost etc. The merits of this system were fully realized when used on oil tankers and passenger vessels in which AC cage motors are not frequently started and stopped. However, there were several troubles concerning the adoption of AC electric sources for merchant ships which have many electric cargo winches. Namely, when AC generator is installed there is no troubles to use AC cage motors for driving the simple load as pumps and fans, but it brings in such a difficult problem as to determine most suitable type of winches. In this connection the idea of using steam-powered winches was considered; however, it was realized that running cost would be high though relatively low initial cost. On the other hand, when the Ward-Leonard system was used, the cargo handling characteristics would be much improved but the initial cost would be high so that it could be used on special ships only. Also, results of the pole change type cage motor revealed that it was not satisfactory to use this type for all winches on board due to its prominent fluctuation of source voltage at time of cargo handling.

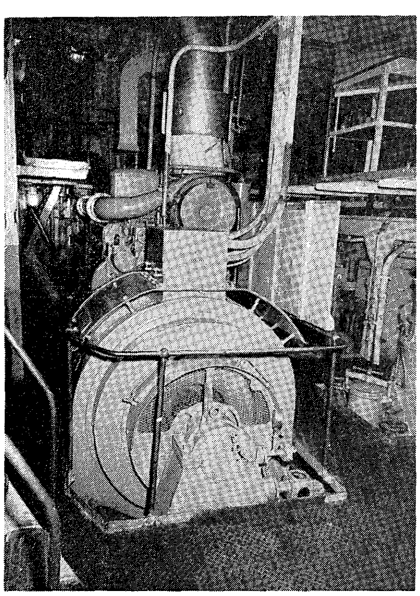

Fig. 1. 300 kVA self-excited alternator on Saitama-maru

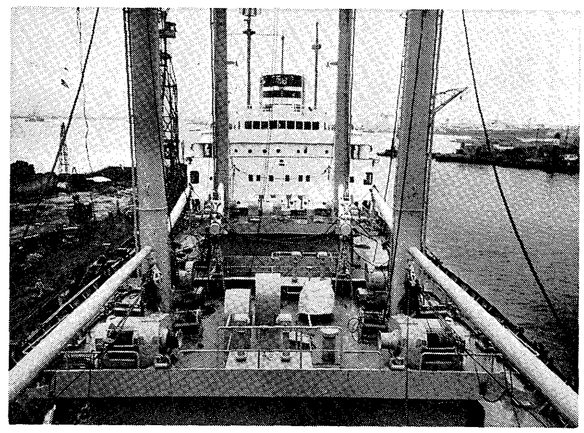

Fig. 2. AC cargo winches and master controllers on deck of Saitama-maru

Recently we succeded in the practical use of unique self excited compound alternators and cage motors for operating winches. And we have delivered our self excited compound alternators and cage motors for deck machines of the NYK's "Saitama Maru" and other merchant vessels and wish to take this opportunity to introduce the outline of these machines.

II. ALTERNATOR

1. General description

When using the cage motor as the drive of winches, there are two major reasons that make the usual alternator with a rotary exciter and a automatic voltage regulator unsatisfactory—due to large rush current of cage motors at time of starting and frequent repitition of start and stop. For example, when the load is suddenly applied on a usual alternator, the variation of terminal voltage is as

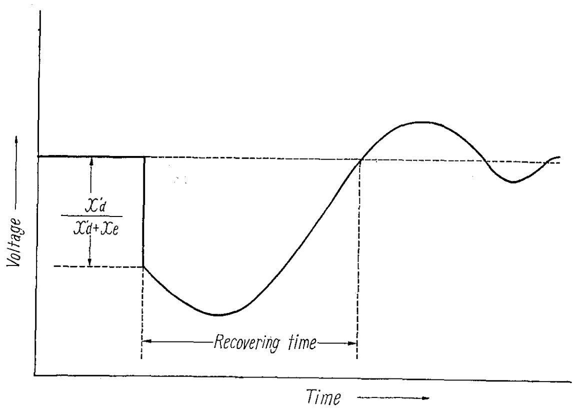

Fig. 3. Instantaneous voltage drop of usual type alternator

shown in Fig. 3. This instantaneous voltage drop shown by the unit method is as follows:

$$\frac{x'd}{x'd+x_e}$$

The $x'd$ is the transient reactance (unsaturated) of the generator while x_e is the connected external reactance. The maximum value of voltage drop is determined by time constant of the generator field circuit, nominal exciter response and capability of the automatic voltage regulator. The maximum value and recovery time of the instantaneous voltage variation varies greatly according to the design of the equipment; however, past experiments have shown that the usual alternator designed for merchant vessels such as the 300 kVA, 514 rpm type show the instantaneous voltage variation shown in Table 1.

Table 1. Instantaneous voltage variation

	Maximum voltage variation	Time
When suddenly removed full load of rated power factor	Appr. 25% (up ward)	Appr. 5 sec (settling time)
When suddenly applied 60% of rated current (power factor less than 0.4) from no load	Appr. 20% (down ward)	Appr. 3 sec (recovering time)

Remark)
It is on supposition that prime mover speed regulation is instantaneous value 7%, settled value 3.5%, and time for settling is 5 sec.

The self excited compound alternator herein introduced does not use the aforementioned rotary exciter and automatic voltage regulator. The maximum voltage drop is checked by the stationary exciting apparatus. Also, measures have been taken to remarkably shorten recovery time. Another outstanding advantage is the great ease and economy of maintenance realized by using static apparatus such as the reactor and selenium rectifier in place of a usual rotary exciter and an automatic voltage regulator. By limiting the character of attached static apparatus to the grade of necessary and sufficient enough, and by adopting same insulation class as that for the alternator, the cost can be cut down to equal or lower than that of the usual type.

As these merits gradually become known, the self-excited alternator is being installed even on ships that are not equipped with alternating current winches. It can be said that the alternrtor with rotary exciter is no longer used in shipbuilding.

2. Settled characteristics

Fig. 4 shows the typical total connection diagram of the self-excited compound alternator and accessary static apparatus. First, the exciting current of this self-excited compound alternator is the vector sum (I_T) composed of two components as shown in Fig. 5. Namely, the I_D element which has no relation with the load current and the ($I_{E1}+I_{E2}$) element which varies according to the load current. The I_D is the current required to give rated voltage when the alternator is at no-load. The ($I_{E1}+I_{E2}$) is the current that counteracts the armature reaction and reactance drop when the current flows into the armature. In order to build up the initial voltage when starting the prime mover, the series reactor and condensor are made to resonate at about 70% frequency during the start of the prime mover and to amplify generated voltage due to residual magnetism so that the generator voltage is rapidly built up.

As can be seen from Figs. 4 and 5, the no-load voltage can be adjusted by selecting the suitable taps of the series reactor. Further minute adjustments can be made by changing the tap position of the primary winding of the three winding transformer. The compounding characteristics can be adjusted by changing the tap position of the primary winding of the theree winding transformer which is connected to the secondary terminals of the current transformer. Fig. 6 shows one example of the external characteristics of a self-excited compound alternator. As long as there is no marked change in the power factor, the influences from ambient temperature, variation in temperature of generator field winding and accessary apparatus are negligible.

3. Instantaneous characteristics

Let us study the variation of voltage when large current is suddenly flown into the main circuit of the alternator. In the usual type alternator, the

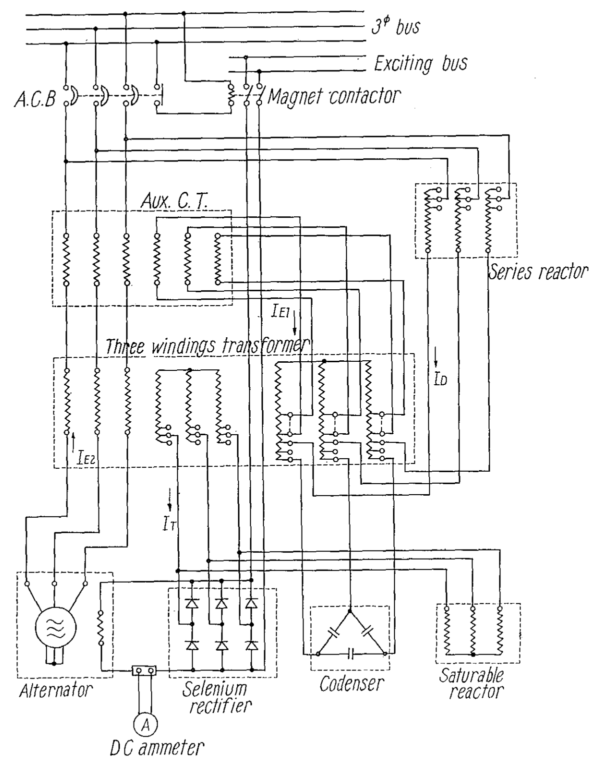

Fig. 4. Total connection diagram of self-excited compound alternator

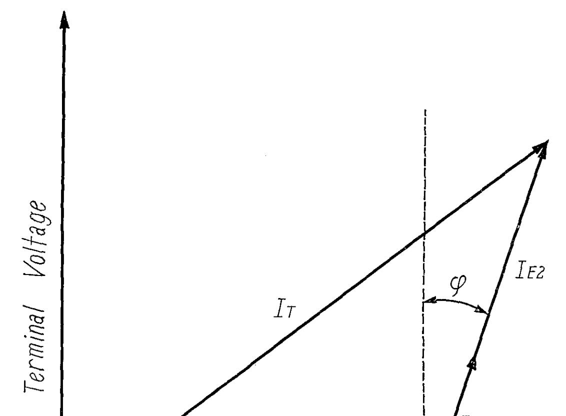

Fig. 5. Vector diagram of stator circuit of self-excited compound alternator

reactance drop resulting from the flow of large current is caught by the automatic voltage regulator and the field of the rotary exciter is excited which in turn raises the terminal voltage of the exciter and excites the alternator field. Since this action requires some time to complete, time is required for voltage recovery; also, it is the cause of hunting such as shown in Fig. 3. In the instance of the self excited compound type, when large current

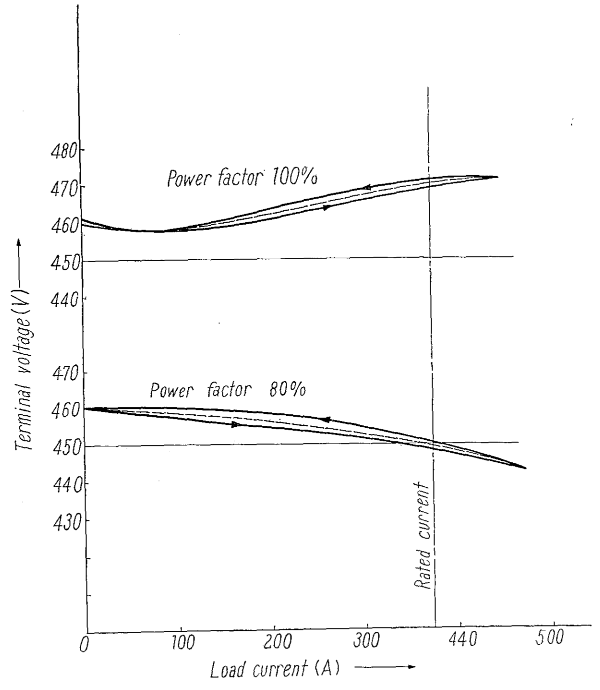

Fig. 6. Load characteristic curve of self-excited compound alternator

flows into the main circuit, the same amount of current flows into the tertiary winding of the three winding transformer and primary winding of the current transformer; consequently, the state of recovery is as shown in Fig. 7. That is, the recovery time is approximately 0.2 second and no useless hunting is produced.

4. Parallel running

For the parallel running of the three phase alternators, it is essential to equalize both effective and reactive currents under all load conditions; particularly at time of heavy load. In order to do this, the speed characteristics of prime movers must be same; however, this is actually difficult to achieve.

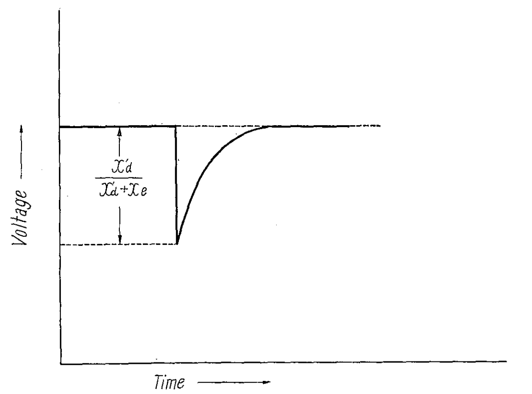

Fig. 7. Instantaneous voltage drop of self-excited compound alternator

Consequently, a drooping characteristic is given to the usual type alternator, but for the self excited compound alternator, parallel operation is made possible by connecting the field circuits with a equalizer as shown in Fig. 4.

Fig. 4 is the connection diagram for the parallel operation of the alternators of the same specifications. The parallel operation of alternators of different specifications is possible by using a similar method. We conducted at our factory experiments of parallel operation of alternators of the same specifications as well as alternators of different specifications such as with the 375 kVA, 514 rpm and 90 kVA, 600 rpm and the results were satisfactory. Since it is usual not to equip this type alternator with on-load voltage regulator, when an alternator is switched in parallel to other running alternators there is usually some voltage difference between the former and latter. In actual cases, however, even when there is a voltage difference of 20 V with a 450 V alternator, when the phase and frequency are same, the cross current at time of switch-in is about 150% and parallel operation can be able to start after about half cycle.

5. Short circuit current

When short circuit occurs in the self excited compound alternator, the maximnm instantaneous short circuit current does not differ from the usual type alternator; however, subsequent change of the current is prominent. In other words, in the usual type alternator, the trend is as shown in Fig. 3. Voltage drop due to armature reaction starts after the reactance drop and a considerable drop develops after 2–3 cycles at which time the circuit breaker starts working. Thus, there is a big decrease in the short circuit current. The change illustrated in Fig. 7 is taken by the self excited compound alternator. The short circuit current is large compared to that of the usual type alternator. In order to obtain the generator's constant voltage characteristics, when current transformer is designed for small flux density at normal condition the short circuit current becomes larger. The short circuit current can be decreased by utilizing the characteristics of the saturable reactor illustrated in Fig. 4 which was designed for this purpose.

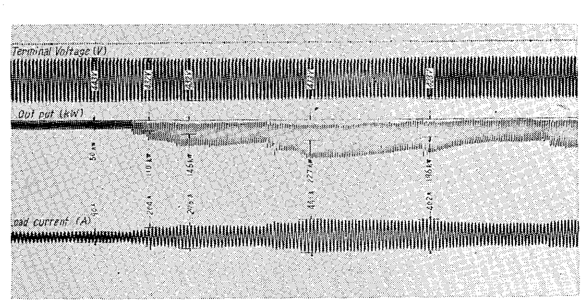

Fig. 8. Oscillogram of No. 1 generator at simultaneous start of winch on Saitama-maru

Winches used in test:

8 units of 3 t 39 m/min AC winch

2 units of 5 t 40 m/min Ward-Leonard winch

Generator:

300 kVA self excited compound alternator

2 units connected in parallel

III. ALTERNATING CURRENT DECK MACHINERY

1. Requisite conditions of alternating current motors for winches

Motors of AC ships that are used for continuous running at constant speed as for regular pumps must be designed with emphasis on efficiency and power factor; consequently, characteristics are normally as shown by the dotted line in Fig. 9.

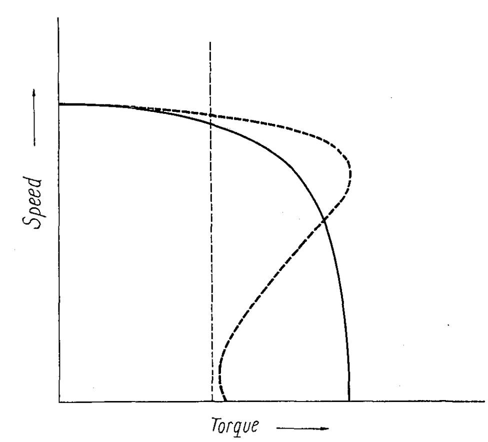

Fig. 9. Speed-torque curve of AC squirrel cage motor

If this motor is used for a winch, we can easily understand that from its characteristics, considerable time will be required to start the motor.

Motors to run machinery that are operated intermittently like winches are required to have superior accelerating and decelerating characteristics. For this, the motor must possess speed torque characteristic shown by the solid line in Fig. 9. This characteristic will not only shorten the accelerating time but will decrease the starting current since conductors of high specific resistance will be used as rotor windings.

In order to improve the accelerating and decelerating characteristics, it is essential to diminish the moment of inertia of the rotor besides taking the abovementioned positive measures. For this purpose, a highly heat resistant insulation class must

Table 2. Supply list of self-excited compound alternator (at Sept., 1959)

Output (kVA)	Voltage (V)	Frequency (c/s)	Speed (rpm)	Power factor (%)	Insulation class	Classification standard	Units	Name or number of ship	Ship builder	Ship owner
240	450	60	450	80	A	N K	2	Nagara-maru	Namura Shipyard Co., Ltd.	Nippon Yusen K. K.
300	445	60	514	75	A	LR. NK	3	Saitama-maru	Mitsubishi Nippon Heavey-Industries, Ltd.	〃
300	445	60	514	75	A	LR. NK	3	S 836	〃	〃
375	450	60	514	80	B	N K	2	Tamba-maru	Ishikawajima Heavey Industries, Ltd.	〃
290	445	60	514	80	A	L R	2	PIPAN	Hakodate Dock Co., Ltd.	(Jugoslavia)
350	445	60	514	80	A	L R	2	KOSOVO	〃	(〃)
210	450	60	600	80	A	N K	2	S 251	〃	Nipponkai Kisen Kaisha
375	445	60	514	80	B	LR. NK	2	Kōwa-maru	Nippon Kōkan K. K. (Tsurumi)	
87.5	445	60	600	80	B	LR. NK	1	〃	〃	Pacific Ocean Transportation Co., Ltd.
175	450	60	600	80	B	N K	2	Nittei-maru	Nippon Kōkan K. K. (Shimizu)	Nissan Kisen K. K.
350	385	50	500	80	B	L R	3	KLADNO	Hitachi Shipbuilding & Engineering Co., Ltd.	(Czechoslovakia)
262.5	450	60	600	80	B	N K	2	Nikko-maru	Uraga Dock Co., Ltd.	Nittetsu Steamship Co., Ltd.
212.5	450	60	600	80	B	N K	2	Unyo-maru	〃	Onoda Cement Co., Ltd.
212.5	450	60	600	80	B	N K	2	S 756	〃	〃
215	450	60	600	80	A	N K	2	Howa-maru	Mitsubishi Shipbuilding & Engineering Co., Ltd.	Nippō Kisen Co., Ltd.
280	450	60	514	80	A	LR. NK	2	S 51	Iino Shipbuilding & Engineering Co., Ltd.	Iino Kaiun K. K.
310	450	60	720	80	B	A B	1	Oriental	Sasebo Ship Industry Co., Ltd.	(Hongkong)
810	450	60	514	80	B	N K	4	Giant	〃	Taiyo Fishery K.K.
280	450	60	514	80	A	LR. NK	3	S 1532	Mitsubishi Shipbuilding & Engineering Co., Ltd.	Daido Kaiun Kaisha, Ltd.
687.5	450	60	600	80	B	N K	3	Otsu-maru	Nippon Kōkan K. K. (Shimizu)	Hōkō Fishing Co., Ltd.
75	450	60	600	80	B	N K	1	〃	〃	〃
60	205	50	750	80	A	N K	2	S 151	Nagoya Shipbuilding Co., Ltd.	Nissan Kisen K. K.
350	450	50	500	88	B	L R	2	S 908	Mitsubishi Heavy-Industries, Reorganized, Ltd.	(India)
300	450	50	500	80	B	L R	1	S 908	〃	(〃)

be adopted and both size and weight must be minimized.

Heretofore, the direct current motor was mainly used as a electric winch motor, the mechanical brake (magnet brake) and electric brake (dynamic brake) could be used together to stop the motor. However, when using an AC motor, some changes must be made in the electric brake. Windings for ultra low speed which has large regenerative braking effect is essential.

Special discussions are being held concerning the time rating and duty factor of the cage motor for winch and considerably severe conditions are desired. However, it can be said that those produced by Siemens who has led the field in developing this motor and who has already manufactured several thousand units are satisfactory. If over-emphasis is placed on the time rating, the size of the motor will naturally increase and the size and weight of the winch must be increased. This will increase the GD^2 of rotor and lower efficiency since long time will be required for acceleration and deceleration. Furthermore, the motor will be operated in a state that rush current is flowing and it will bring in excessive rise in termperature and then the time rating will be reduced on the contrary.

2. Ratings and structures of various winches using AC cage motors

The ratings of the various winches using our AC motor are as shown in Table 3. The main part is composed of a main drum, a warping drum, a gears, a gear case, a winch motor and a magnet brake. The drum and the gear case are of welded steel plate structures and the motor is overhung in the gear case. Ribs that act as cooling air ducts are placed on the frame and this is covered with a thin steel plate jacket. A fan box holding a miniature fan to cool the winch motor and a fan motor is suspended under the winch motor. The motor rib is designed to pass in cooling air. The 3/5 t winch is operated by a gear change-over clutch encased in the gear case. In the 5/10 t winch, the 10 t 12.5 m/min drum is separated from a 5 t. 30 m/min winch and can be used by gearing with the clutch. When

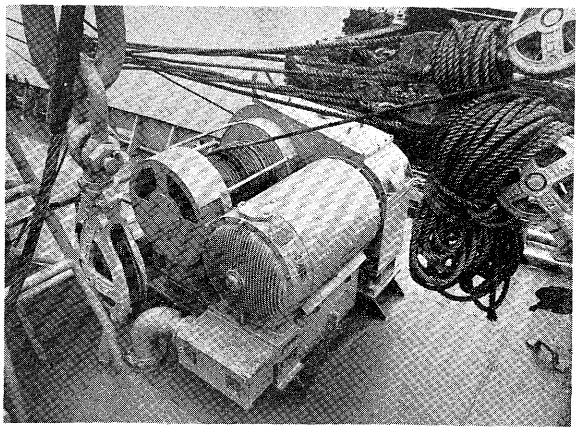

Fig. 10. 3 t 39 m/min AC winch

necessary, an automatic spinning device is installed on the 10 t drum.

3. Cargo handling characteristics of 3 t AC winch

Our cage motor for a winch posesses the requisite conditions mentioned above. First, the speed torque characteristics are as shown in Fig. 11. Particular consideration has been given to improve accelerating characteristics and electric braking effect which is essential to speedy deceleration. Also, the three windings of the motor have been effectively distributed and a new type magnet brake has been adopted. We have succeeded in greatly decreasing the moment of inertia of the rotating parts. Fig. 12 shows the oscillogram of the winch characteristics. The braking effect is so excellent that the oscillogram can not indicate the effect. When the winch is lowering a 3 ton load at the high speed of approximately 84 m/min, the slip is a mere 50 cm when the master controller is switched back to the stop notch. Fig. 13 (solid line) shows the rope speed and load curve of the characteristics shown in Fig. 11. As can be seen from this figure, the lowering speed is slightly faster than the hoisting speed. This is because the same connection is used for both hoisting and lowering and because regenerative brake lowering is used for simplification of design. The characteristics of notch 3 is cut at approximately half load, in order to restrict the motor output at

Table 3. Ratings of AC winch

Kind of winch			3 t Winch	3/5 Winch	5/10 Winch
Mechanical part		Pull and speed	3 t 39 m/min	3 t 39 m/min 5 t 22 m/min	5 t 30 m/min 10 t 12.5 m/min
		Main drum diameter	3 8 0	4 5 0	for 5 t {450 640
		Main drum length	5 6 0	6 4 0	for 10 t {600 750
		Reducation method	Spur gear		
Electric parts		Supply voltage (V)	4 4 0		
	Motor	Manufacture's type	ah ORK 165/11-84 +ah ORK 165/12-32		ah ORK 165/14-84 +ah ORK 165/15-32
		Rotor construction	Double cage type		
		Enclosure	Water-proof forced air cooled		
		Number of poles	4/ 8 /32		4/ 8 /32
		Output (kW)	22/22/4.2		28/28/5.3
		Current (A)	52/43/28		68/51/40
		Insulation class	B class		
		Time rating (min)	30/30/15		
	Accessories	Inside of motor	Magnet brake (B class insulation)		
			Cooling fan		
			Fan motor (A class insulation)		
		Outside of motor	Drip-proof type contactor box		
			Water-proof type master controller		
Total weight (kg)			3,090	3,690	7,400

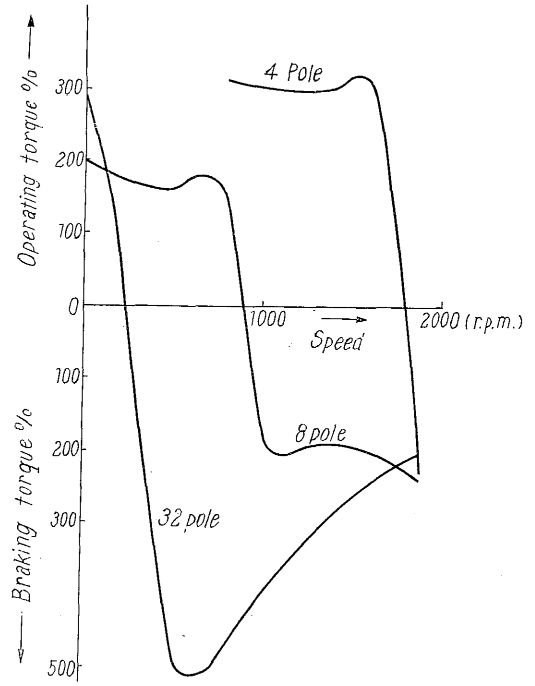

Fig. 11. Motor torque characteristics

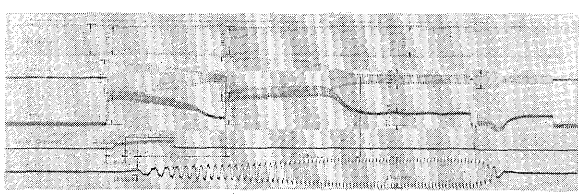

Fig. 12. Oscillogram of 3 t 39 m/min winch at quick operation

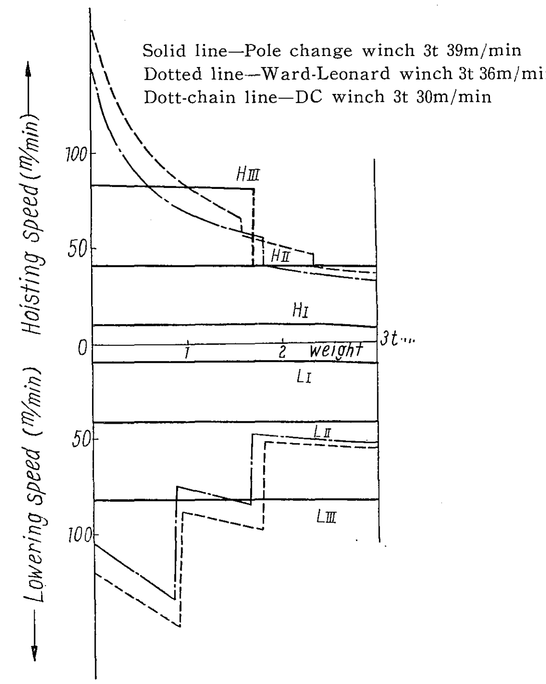

Fig. 13. Characteristic curve of cargo winch

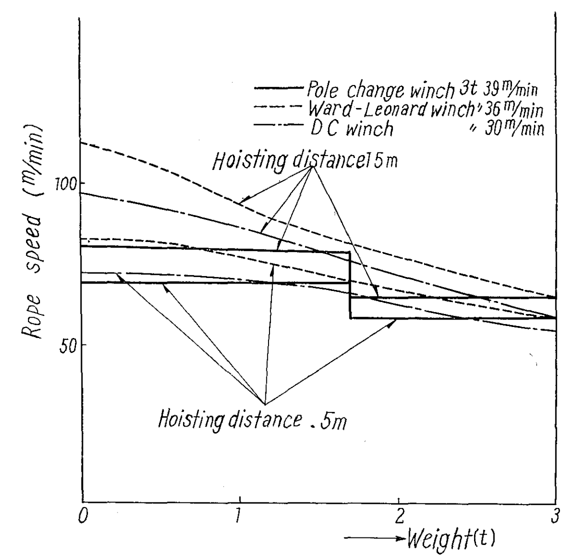

Fig. 14. Average cargo handling speed of cargo winch

notch 3 and thus restrict the rush current and make the electric source capacity the same as when other system winches are used. The results of the comparison between this winch and other system winches manufactured by our company is shown in Fig. 13. The dotted line shows the characteristics of the 3 t 36 m/min Ward-Leonard system winch. The dot-chain line shows the characteristics of the 3 t 30 m/min DC winch. As can be seen from this figure, the AC pole-change winch has marked constant speed characteristics as compared with other system winches. This is proof of its superior accelerating characteristics.

Fig. 14 shows the average cargo handling speed at 5 m and 15 m hoisting distance on the basis of time required for :

load hoisting
load lowering
empty hook hoisting
and empty hook lowering

At full load, the AC winch has better cargo handling characteristics than the 3 t 30 m/min DC winch, and is equal to the 3 t 36 m/min Ward-Leonard winch. At light load, the characteristics are the same as that of the DC winch and somewhat inferior to the Ward-Leonard winch. However, when the load waiting time is taken into consideration, the difference will be remarkably decreased. Furthermore, the AC winch requires less input at load hoisting time than the 3 t 36 m/min Ward Leonard winch while the loading back power at time of lowering is larger than the Ward-Leonard system winch. Consequently, the winch has the advantage of permitting to select a smaller output of electric source than Ward-Leonard winch.

4. Control method of AC winches

Since a winch is usually handled by unexperienced stevedores, the most essential quality is that it be "Fools proof". Consequently, special consideration is given to protective devices. Fig. 15 illustrates the simplified connection diagram. The following distinctive features can be listed:

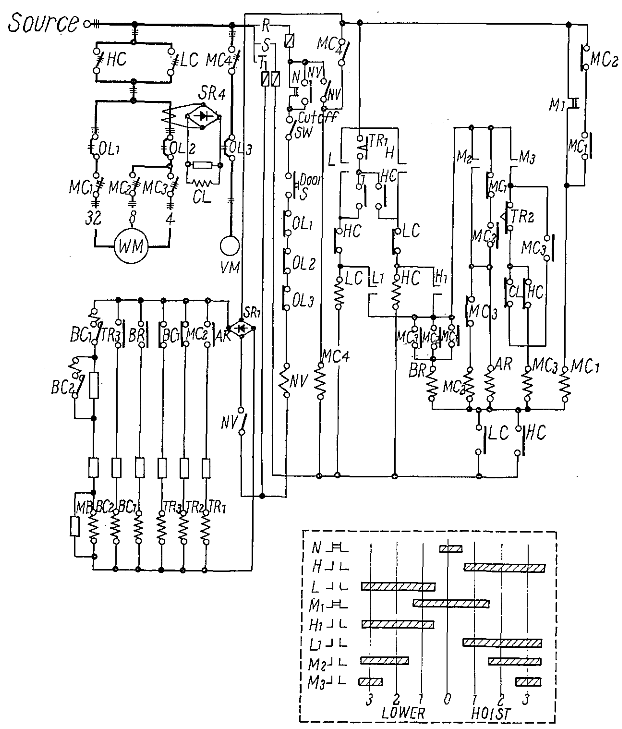

Fig. 15. Simplified connection diagram

1) The one-man control system has been adopted. That is, since a master controller is installed, two winches can be operated by one man.

2) An interlock device is used so that the winch motor will not start operation before the cooling fan starts operation.

3) The excessive overheating of the magnet coil can be prevented by switching in the economic resistor to the circuit by the action of the time limiting relay after the release of the magnet brake. At the same time, the selenium rectifier has been decreased in size and weight.

4) When the master controller is advanced to notch 2 and when there is some trouble with the magnet contactor, the hoisting is operated at notch 1. The same condition applies when the handle is advanced to notch 3.

5) When the master controller is suddenly advanced to notch 3, the winding of a motor is changed to 4 pole connection only after the motor is accelerated at 32 pole and 8 pole connection which have large accelerating torque and small rush current by means of a time limiting relay and a current limiting relay.

6) When the master controller is suddenly turned to stop position during lowering or hoisting, regenerative braking will act for some time by the action of the time limiting relay and the magnet brake will increase the stop effect so that slip is restricted. Also, this prevents damage to the brake lining.

5. AC windlass and mooring winch

When AC cage motor is used for the winch, it is natural to desire the cage motor for the windlass and the mooring winch, and we have equipped a few ships with these motors. Compared to existing motors, the capability is the same and it has the added merits of low price and small maintenance expenses, the same as in the case of AC winch motor.

Table 4. Ratings of windlass and mooring motor

Kind of motor	Windlass motor	Mooring motor
Enclosure	Water proof	
Output (kW)	67/67/18	37/37/16
Voltage (V)	440	
Frequency (c/s)	60	
Pole	4/8/24	4/8/16
Time rating (min)	30/30/10	10/30/10
Accessories	Water-proof type magnet brake	
	Drip-proof type control box	
	Water-proof type control stand	Water-proof type master controller
	Drip-proof type master controller	—

Table 4 shows the ratings of windlass and mooring motors while Fig. 16 illustrates the characteristic curve of the AC windlass motor. It will be noted that notch 2 is the rated notch using the 8 pole winding. In view of the purpose of the windlass, the starting torque has been especially increased. Notch 1 also acts as the dead slow notch which is used when the anchor chain is stopping at the end of the hoisting operation. The 24 pole winding of notch 1 and 8 pole winding of notch 2 make stalling possible for 10 or more seconds; however, in order to prevent over heating of the motor, protecting device have been equiped to release the motor from the power source by using the time limiting relay. A current limiting relay is installed at notch 3 so that when the 4 pole winding at notch 3 is overloaded, the notch will automatically be stepped down to 8 pole winding at notch 2.

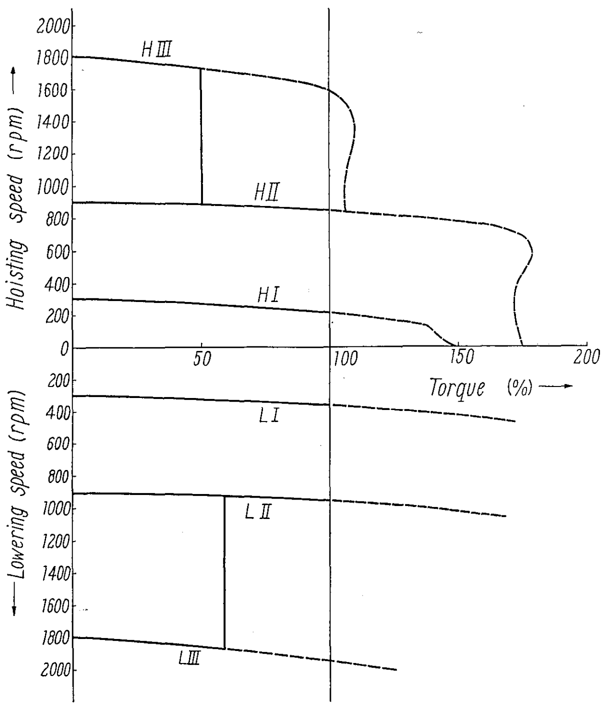

Fig. 16. Characteristic curve of AC windlass motor

IV. CONCLUSION

The alternating current system is widely used as ship electric source in our country except in special cases such as electric propulsion of ships. Further developments are expected with the use of the self excited compound alternator and AC cage motors for deck machinery. As can be seen from the foregoing, our company has succeeded in applying this AC motor to various types of machinery. However, due to objective circumstances, the control method is considerably complex which makes the domestic motors higher in price as compared with the foreign products. Now we have experiences and we are confident of realizing many improvements toward simplification through the kind advice of our many customers. It is our aim to make further efforts toward lowering the price of our products.

Table 5. Supply list of deck machines using AC pole change squirrel cage motor

Kind of deck machine	Units	Voltage (V)	Frequency (c/s)	Classification standard	Name or number of ship	Ship builder	Ship owner
3 t 39 m/min winch	16	440	60	LR, NK	Saitama-maru	Mitsubishi Nippon Heavy-Industries, Ltd.	Nippon Yusen K.K.
3 t 39 m/min winch	14	440	60	N K	Shigaha-ru-maru	Hitachi Shipbuilding & Engneering Co., Ltd.	Shinnihon Steamship Co., Ltd.
3/5 t 39/32 m/min winch	4						
7 t 25 m/min mooring winch	1						
21 t 9 m/min windlass	1						
3 t 39 m/min winch	14	440	60	A B	Corinthic	Iino Shipbuilding & Engineering Co., Ltd.	Portland Shipping Co.
5/10 t 30/12.5 m/min winch	2						
7 t 24 m/min mooring winch	1						
3 t 39 m/min winch	16	440	60	LR, NK	S 1532	Mitsubishi Shipbuilding & Engineernig Co., Ltd.	Daido Kaiun Kaisha Ltd,