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ELECTRICAL EQUIPMENT FOR SLABBING AND BLOOMING MILL DELIVERED TO FUKUYAMA WORKS OF NIPPON KOKAN K.K.

Hiroyoshi Yamamoto,
Toshihiko Hoshi,
Kawasaki Factory
Kazuo Nakamura
Central Technique Center

I. INTRODUCTION

Fuji Electric has delivered the largest and most modern electrical equipment for slabbing and blooming mill drive to the Fukuyama Works of Nippon Kokan K.K. This plant has been operating satisfactorily since March 1969. All the d-c motors in this plant employ thyristor converter power sources.

The use of thyristors in the metal rolling industry has increased tremendously in the 10 years which has elapsed since their development. This has been due to such advantages of thyristors as excellent control characteristics, high reliability and efficiency, maintenance-free features, and the advance of thyristor element having capacities of up to 2500 v 400 amp.

II. OUTLINE OF EQUIPMENT

This ingot sent from the soaking pit is carried on an ingot buggy which moves automatically in a direction perpendicular to the pass line. The cover of the soaking pit and the ingot buggy are remotely controlled by one man. The ingot leaves the buggy and is sent to the 2×5600 kw $\pm35/70$ rpm horizontal roll through the ingot scales. Individually driven rolls are used from the ingot receiving table to the mill back table. The slab or bloom rolled by the mill passes to the 2×1850 kw slab shear via the hot scarfer. It is then sent to the transfer table via the slab scales and carried out by the transfer cars. One of the transfer cars is connected with the heavy-section mill to increase bloom transport efficiency.

III. HORIZONTAL ROLL DRIVE EQUIPMENT

1. D-c Motors

As shown in *Table 1,* the main motors for horizontal roll drive are the largest and most modern blooming mill d-c motors supplied by thyristor power sources in Japan. The power sources for previous blooming mill motors employed the Ilgner generator set or the static Krämer-Ilgner in which slip power was recovered through a silicon rectifier and the rear motor in order to smooth the frequently repeated peak loads. However, the thyristor-Leonard system based on the development of highly reliable high-capacity thyristor elements, advances in application techniques, and strengthening of power supply systems was first employed in this country for reversing mill motors of up to 11,200 kw to improve control performance. An external view of this system is shown in *Fig. 1.* The output voltage of thyristors contains a-c harmonic components unlike that of d-c generators and therefore, d-c motors are designed with special consideration given to commutation, insulation, shaft potential, cooling, and mechanical strength. Regarding commutation, the commutating flux response in respect to changes in the current has been improved through the use of a laminated construction for all magnetic circuits. Efforts have also been

Table 1 **Specifications of horizontal roll drive motors**

Output	2×2 800 kw	No. of unit	2
Voltage	2×750 v	Drive system	Top-forward type twin drive
Rotational speed	±35/70 rpm		
Ratings	Continuous	Armature construction	Double armature
Frequently applied torque	364 t-m (225%)	Insulation	F class
		Temperature rise limit	50 deg
Occationally applied torque	445 t-m (275%)	Power source	Thyristor

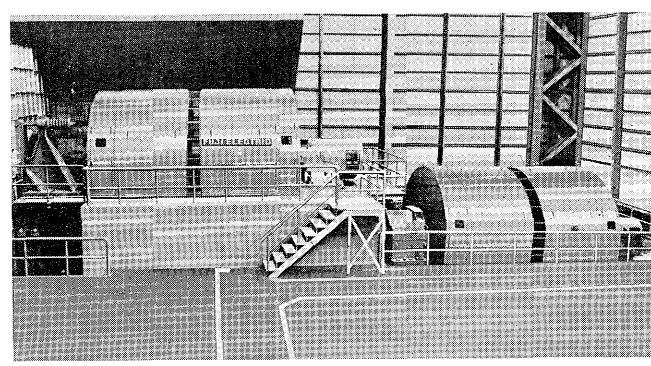


Fig. 1 Horizontal roll drive motors

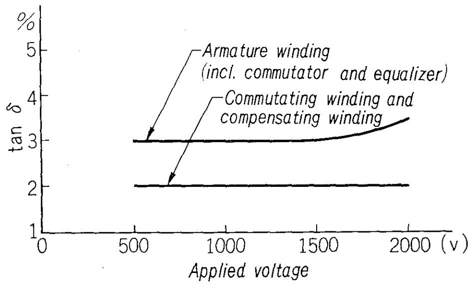


Fig. 2 Tan δ characteristics of main motor

made to reduce the reactance voltage as much as possible by employing armature conductors having a special shape. The brushes are of the tandem split type which prevent short-circuit currents and improve the sliding contact characteristics with the commutator. As a result of these considerations, an excellent black band which compares favorably with rolling mill main motors supplied by pure d-c current source can be obtained. In addition, smoothing reators are provided in the main circuit to reduce the current ripple.

The insulation is class F and consists of polyamide film (NOMEX) and epoxy resin. In recent years, insulation materials with remarkable thermal resistance have been developed. Class F insulation is now widely used in rolling mill motor to improve reliability, make the motors more compact and lightweight, and minimize the flywheel effect. These trends have been followed in this equipment. After the temperature tests were completed, the insulation resistance, corona characteristics, tanδ characteristics, and a-c current/voltage characteristics were measured. These measurements were used to evaluate the new insulation system. The tanδ-voltage characteristics are shown in *Fig. 2* as example of results of the measurements. The value of tanδ is small and almost constant in respect to voltage increases. This confirms that the insulation in both the armature and stator winding is good. Sufficient consideration has also been given to winding insulation protection against voltage surges caused by the switching phenomena and commutation of the thyristors. Therefore, the insulation at the tapping parts of main pole windings have been strengthened and a capacitor connected between the terminals to by-pass the surge voltages. A by-pass capacitor has also been connected in the main circuit and the commutating pole windings and compensating windings placed at each side of the armature in order to prevent increases in the segment voltage.

The shaft potential which produces the shaft current consist of (1) the transformer e.m.f. which is induced in the shaft by the magnetic unbalance of the rotor (2) the voltage induced by homopolar effect due to the residual ampere-turns around the shaft and (3) shaft potential in respect to ground which is

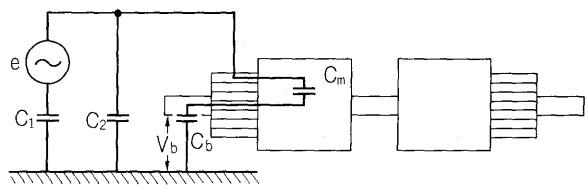


Fig. 3 Equivalent circuit of shaft potential

caused by discharge of high frequency a-c currents through the stray capacitance between the armature coils and core. Of these voltages, (1) and (2) must also be considered in the case of conventional d-c power sources and greater care has already been taken in the design and manufacture stage. However, voltage (3) presents a special problem in the case of rectified power sources such as thyristors. However, the pedestal can be protected from this voltage by taking the following measures. In order to make the investigation simpler, the shaft potential is given from equation (1) for an equivalent circuit composed of only the capacitances of each part as shown in *Fig. 3*.

$$V_b = \frac{C_m \cdot C_1}{(C_m + C_b)\,(C_1 + C_2) + C_m \cdot C_b} \cdot e \quad \cdots\cdots\cdots\cdots (1)$$

Where :

V_b : shaft potential

e : a-c voltage component contained in d-c power source

C_m : stray capacitance between armature coil and core

C_b : capacitance of pedestal oil film

C_1 : stray capacitance of power source in respect to ground

C_2 : capacitance of by-pass capacitor

As can be seen from equation (1), the shaft potential can be made smaller according to the value of capacitance C_2. Therefore, C_2 has been made sufficiently large and the shaft itself has been grounded with metallic brushes. In this way, the value of the shaft potential can be reduced to 1 volt less and therefore presents no trouble.

Since the driven system from the motor to the roll is a complex spring/mass system, tortional vibrations are produced when the ingot enters the roll and alternating stresses higher than the electrical torque are imposed on the rotor. Therefore, the mechanical components of the motor have been designed to withstand this tortional stress and to avoid resonance by considering also the frequency of the ripple current.

Motor arrangement is a twin drive with top-forward system which excellent in respect to maintenance and inspection. In order to reduce the flywheel effect, two double-armature motors with hollow shaft are used. The shaft is lifted by high pressure oil. The oil circulating pumps are located in place where vibration and shock from the mill are small.

Ventilation system is the so-called downdraft system, but the windings and commutator are cooled separately. Armature conductors are all connected with silver solder having a melting temperature of 650° or above.

2. Thyristor Converter Equipment

Of all the mill equipment in a steel works, the blooming mill equipment is the most important and requires very high reliability. The repeated load duty required of the motor is extremely rigorous. These requirements must also apply to the thyristor converter equipment. This converter equipment was manufactured after a wide range of investigations. An outline will be given below.

The ratings of the thyristor converter used for the main motor are ±750 v and ±4150 amp with an overload of 225% per motor armature. The 3-phase bridge crossconnection type are employed. Considering the influence of harmonics to the a-c line, 12-phase connection is employed.

The thyristor elements are type KCP0225 (2500 v, 400 amp) high voltage large capacity disk type elements. These elements employ reliable pressure contacts in respected to the heat cycle produced by the repeated peak load, and are manufactured by means of the alloy-diffusion method. The *dv/dt* has been kept high and there is also sufficient withstand in respect to the *dv/dt* duty, which arises due to the turn-on and turn-off of other phases in the 3-phase bridge connection.

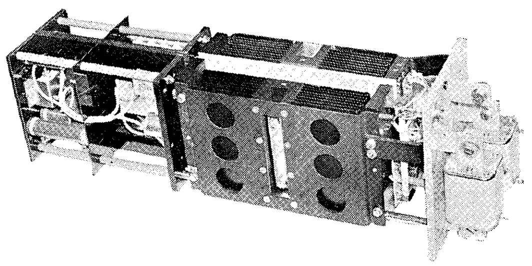


Fig. 4 2500 v 400 amp thyristor unit

The components required for the thyristor were formed in single units including the cooling fin fuse, fuse melting alarm contact, circuit to eliminate overvoltages resulting from carrier storage and insulation transformer for the gate pulse. *Fig. 4* shows an externnal view of the 2500 v 400 amp thyristor unit used with the main motor. A suitable number of these units in accordance with the voltage and current which the load requires are placed in a cubicle, a view of which is shown in *Fig. 5*.

This cubicle is ventilated by cooling air brought in through holes on the front and back of the lower part of the cubicle. The cooling air is exhausted to the exterior via noise-proof ducts on the upper part of the cubicle. There is an a-c lead-in panel in the center of the cubicles which contains current transformers for current detection. In cubicles on the left side are the thyristor units of the common cathode and on the right are the units of the common anode. The cubicles contain six levels of units; the upper three levels consist of forward-drive converter units while the lower three are backward-drive-converter unit. Since a current flows alternately in the two converter units, the temperature of the cooling air inside the cubicle rises very little and good cooling results can be obtained. In such large capacity epuipment, there is considerable influence on the current balance between the parallel connected thyristor elements in the electromagnetic field. In this equipment, the influence of these electromagnetic fields has been investigated and specific measures taken to insure good current distribution.

The air cooling system is very easy to operate, highly reliable and also very economical. However, since the current capacity of semiconductor element is related somewhat to the cooling of the elements, in the future oil and water systems which provide good cooling results as well as a new system utilizing boiling heat transfer will be used.

In general, semiconductor element are very weak in respect to withstand against overvoltages and overcurrents, and suitable protection systems are required.

Overcurrent protection in this equipment includes current limiting by the control equipment, gate inter-

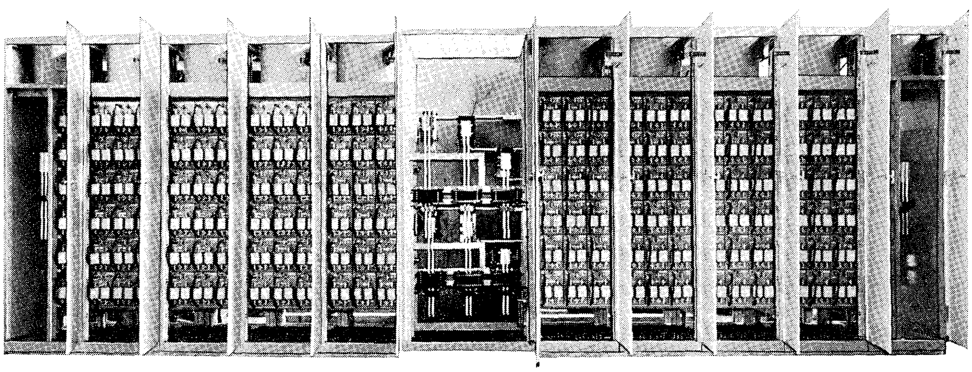
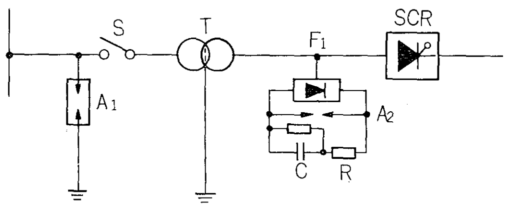


Fig. 5 Thyristor converter for blooming mill drive



A_1, A_2: Arrestors SCR: Thyristor
T: Transformer C: Capacitor
F_1: A-c side surge absorber R: Resistor

Fig. 6 Overvoltage protecting system for thyristor converter

ruption and a super fast fuse connected in series with each thyristor element to provide interruption when such things as element breakdown or erroneous ignition occur. There is also a high-speed dc circuit breaker in the dc circuit. There is also the problem of maintenance if may fuses are blown at one time due to motor flashover, commutation failures or overcurrent during short circuit outside the dc parts. In this equipment, such fault currents are interrupted by the high-speed d-c breaker and the fuses are not blown. Therefore d-c reactors suitable for the fuses are employed. These d-c reactors are ventilated by air and are very compact.

There are several types of overvoltages which can be introduced by the power system, and BIL is well known as standard for insulation against these. However, when thyristors are used in the converter, BIL is uneconomical, so that we select 2.0 to 2.5 as a voltage safety factor. Therefore, overvoltage protection is provided by means of overvoltage absorption equipment. In this equipment, the input voltage is very high (22 kv) and sufficienct surge voltage protection is required. *Fig. 6* showns the overvoltage protection system used in this equipment. An electrostatic shield plate is provided in the voltage transformer to prevent electrostatic shift due to sudden peak surges. A surge absorption circuit made up of a d-c arrestor, resistor and capacitor is provided to protect the thyristors against lightning surges, switching surges etc. The arrestor used for the element in this protection system deserves special attention. No matter what type of surge occurs, it can be kept below the withstand voltage value of the thyristors. However, since discharge of the arrestor in respect to the comparatively frequent surges arising when the transformer exciting current is interrupted are not desirable because of wear in the discharge gap of the arrestor, and therefore a resistor and capacitor are provided to absorb the electromagnetic energy of the voltage transformer.

When planning a thyristor converter with such a large capacity, it was necessary to consider the influence on the a-c system of the converter. Since there is no energy accumulation element in thyristor converter like there are in M-G equipment, the current which flows in the a-c system has a 1 : 1 relation to the load current and the power factor is almost equal to $\cos\alpha$ of the convertor. Therefore, in cases of equipment which is operated with rapid acceleration and deceleration due to the large load changes in blooming mills and also in cases where the reactance of the power supply system is high, power source voltage changes can not be avoided unless the power factor is continuously regulated by a rotary condenser etc. In this equipment, the system capacity is very high and there is no special problem in this respect.

The a-c side currents in thyristor converters contain harmonics. These harmonic components causes distortion in the system voltage, heat the coils in the rotary devices, transformers etc. which are connected to the system and give rise to resonance with leading phase capacitors which can cause burning losses. In this equipment, sufficient investigations were carried out beforehand and 12-phase connection was employed by making a 30-degree difference between the transformer secondary voltages phases of the upper and lower rolls. A filter is also provided for 11th and 13th order harmonics. When 12-phase connection is used, the 5th and 7th order harmonics can not be completely reduced to zero because of the phase fluctuation between the converter pulses and other reasons. Also, since all of the auxiliary devices do not have 12-phase connections, there are also 5th and 7th order harmonic components in the a-c circuits but since there are 5th and 7th order filters in other equipment connected to the same a-c line, there are no special precautions necessary in this equipment.

3. Control Equipment

1) Control regulators

The control regulators are all of the new TRANSIDYN type. The characteristics of this series are as follows.

(1) Only silicon transistor are used and the reliability in respect to temperature changes is higher.
(2) Printed circuit boards are used throughout and each controller and processer is made up of a

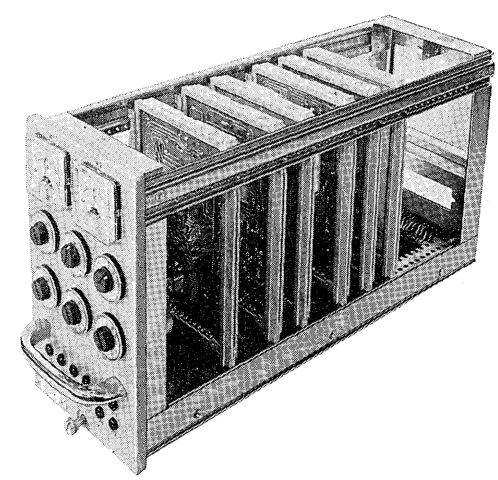


Fig. 7 Control unit of TRANSIDYN

combinations of input, amplifier, feedback and other units.
(3) Logic elements (F-MATIC) and analog elements (TRANSIDYN) are used in the same unit to increase both reliability and response.
(4) Because of the use of printed circuit boards, the space factor is good and the unit is very compact.

Due to the combination of the digital and analog elements in one unit as mentioned in point (3) even complex control equipment can be assembled using standardized units. Therefore the reliability of the equipment is improved and maintenance is easier. *Fig. 7* is a photograph of the TRANSIDYN unit.

2) Main roll control circuits

The main roll control system is as shown in *Fig. 8*. This figure shows the top roll drive motor circuit. The bottom roll circuit is exactly the same.

The control loop contains separate speed cnotrollers for the top and bottom rolls. In the speed controller loop there is a minor armature current loop for each armature. There is an automatic field weakening control system for the motor field which is operated by a single command.

The speed signal from the main controller is fed into the ramp function generator. In this generator, the step signal is converted into an appropriate speed signal. The output becomes the input of the automatic speed controller.

The set input of the speed controller has the top/bottom roll load balance signal added to it. The output of the speed controller becomes the input for the automatic current controller. In other words, it becomes the current setting signal for the main roll motor. Naturally it is limited to a value corresponding to the overload withstand capacity of the motor. This limiting value is processed by the current limitive deving as a function of the motor speed.

In the automatic current controller a circulating current signal is added by the operating signal processer to the current signal. The circulating current is planned so that it decreases in respect to the load current. In other words, when the load current is increased, the circulating current is gradually decreased by the diode and resistors in the current signal circuit, and when the load current increases over some set level, the circulating current becomes zero.

The operating signal processor is made up entirely of logic elements and it monitors the set and actual speed values. The processor operates by a timing

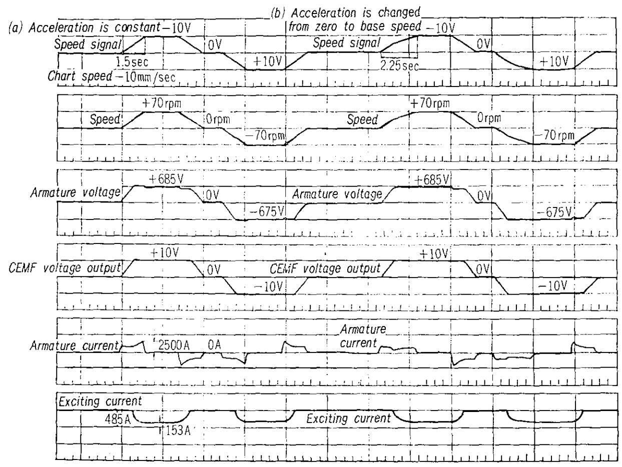


Fig. 9 Oscillogram of acceleration and deceleration of mill motor

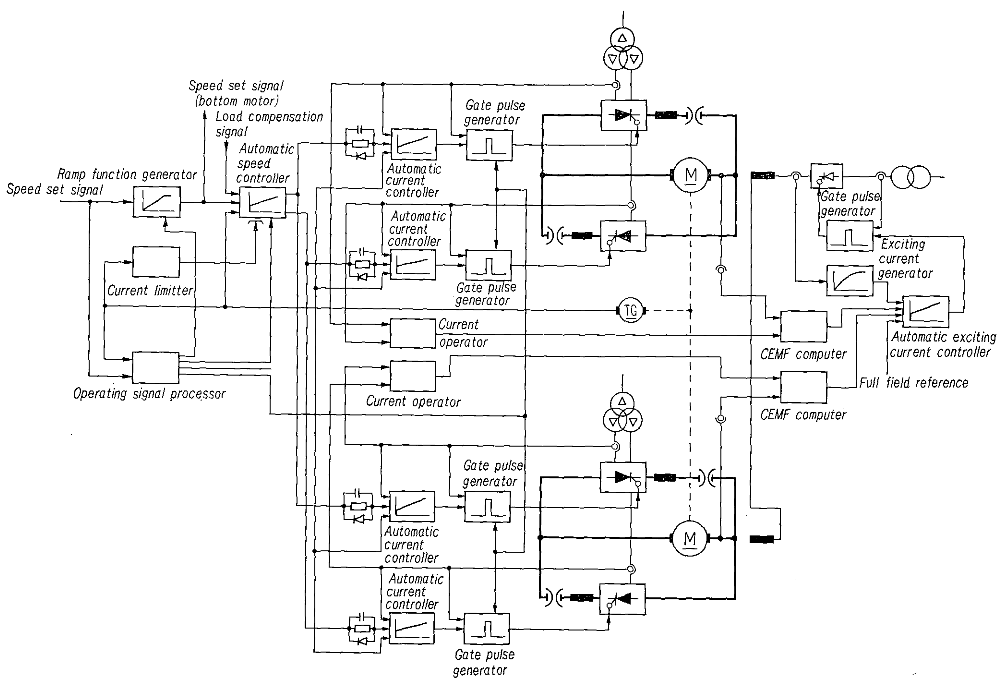


Fig. 8 Main motor control block diagram

which fixes operation and holds each controller at zero. Previously, the controllers were operated the relay sequences. There were discrepancies in the operation of these relays but response and reliability have been improved considerably by the operating signal processor. The operating signal processor has the following functions.

(1) Zero hold and operating signals for the controllers.
(2) Signal for mechanical brake.
(3) Immediate shift signal when fault occurs.
(4) After fault occurs, there is no restarting until the set value and actual value are zero.
(5) It judges that there is an abnormality when the actual value is not fedback within a specified time after the operating signal is sent out.

Fig. 9 shows oscillograms of the main roll during acceleration and deceleration.

IV. SLAB SHEAR AND AUXILIARY ELECTRICAL EQUIPMENT

1. Slab Shear Motor

The specifications of the slab shear drive motors are shows in *Table 2*. The two 1850 kw double-armature d-c motors for a total of 3700 kw operate a crank shaft via a reduction gear and have a record capacity for a slab shear motor. An outerview is shown in *Fig. 10*.

Table 2 **Specifications of slab shear drive motors**

Output	2×925 kw	No. of Unit	2
Rotational speed	450 rpm	Armature construction	Double armature
Ratings	Continuous	Insulation	F class
Frequently applied torque	12 t-m (300%)	Temperature rise limit	50 deg
Occationally applied torque	14 t-m (350%)	Power source	Thyristor

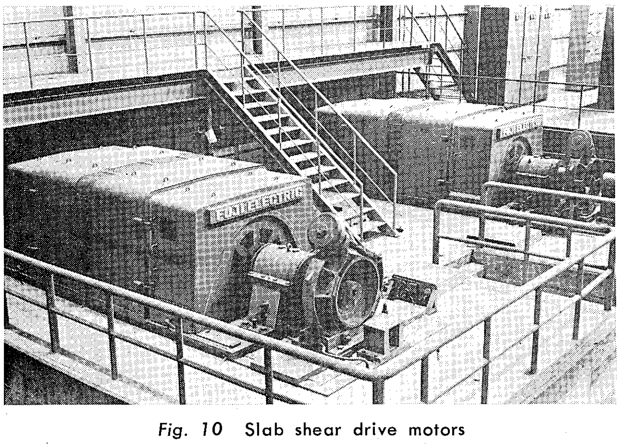


Fig. 10 Slab shear drive motors

Since the maximum torque is 350%, measures have been taken in respect to commutation. Prevention of shaft current, class F insulation, parallel ventilation system, silver soldering, and high pressure oil lifted shaft are exactly the same as those provided with the main motor for horizontal roll drive. The commutator cover is mounted on a rail and can be easily removed to facilitate inspection and maintenance of the brushes and commutator.

2. Auxiliary Motors

All auxiliary motors have 800 line d-c motors instead of the 600 line which feature high reliability and rapid response. All of these motors have thyristor power sources and include 79 variable voltage motors and 34 constant votage motors.

3. Thyristor Converters for Auxiliary Motors

The power sources for all of the auxiliary motors contain thyristor converters. The overall capacity is 16 Mw. The thyristor converters for the auxiliary motors employ cross-connection and anti-parallel connection respect to use. The cross connections with cross current were employed for shear, screwdown and manipulater motors as they require quick response. Cross-current-free anti-parallel connections were employed for the table motors. These anti-parallel-connection reversible converters without cross current are of the so-called no change-over preparation circuit system and they have been planned to include differentiators so that the time taken for

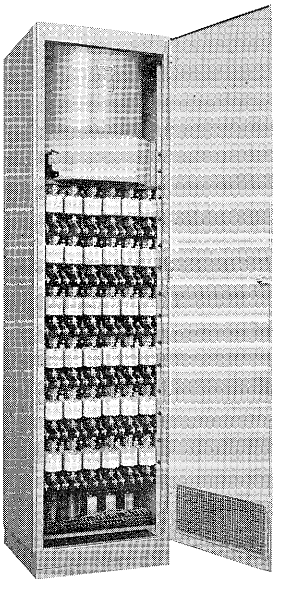
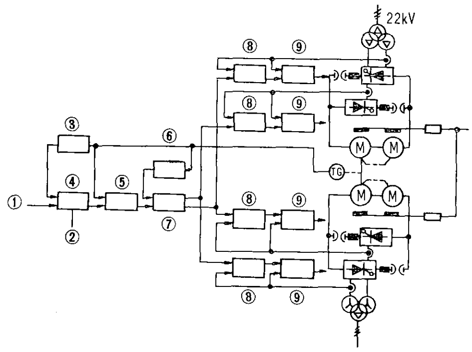


Fig. 11 Standard cubicle for N-unit

change-over is extremely short (patent applied for). The thyristor element used for the auxiliary motors are the disk-type KGP 0225 thyristors with ratings of 2500 v and 400 amp for motor voltages of 750 v, 1600 v 200 amp stud-tyep GTN 0216 thyristors for motor voltages of 440 v and 800 v 200 amp stud-type



① Starting signal
② Speed limit reference
③ Integrator
④ Shear position computer
⑤ Automatic speed controller
⑥ Differentiator
⑦ Ramp function generator
⑧ Automatic current controller
⑨ Gate pulse generator

Fig. 12 Shear motor system block diagram

GTN 0108 thyristors for motor voltages of 220 v. These elements all employ a pressure contact type construction.

These element are assembled in compact units along with their cooling devices and other required accessories. The unit are inserted in standard cubicles. *Fig. 11* shows a standard cubicle for use with GTN type thyristors.

4. Shear Control System

The shear control system is as shown in *Fig. 12*. The shear operation must be automatically stopped at the starting point after the material is sheared. In order to make this operation more efficient, a shear position computer have been provided. This computer calculates the rotational speed which should be employed at the time in accordance with an actual angle of rotation obtained by integrating the rotational angle signal by means of a speed detector. This signal is then sent to an automatic speed controller.

The shearing speed is set at the output limit value of the shear position computer. The automatic speed controller then sends a setting signal to the ramp function generator and therefore speed controller output is limited to provide sufficient acceleration and deceleration in accordance with the required operating cycle. In other words, there are no unnecessary increases in the RMS value of the armature current which would lead to unwanted rapid acceleration and deceleration. In addition to limiting the acceleration and deceleration, the ramp function generator also suppresses overshoot of the motor speed after shearing has been completed.

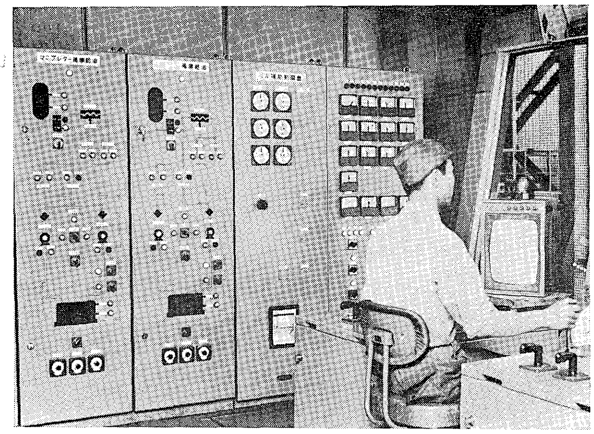


Fig. 13 Oil celler control panel in main roll operation pulpit

5. Oil Celler System

The operation of the previous oil celler was rather complex, and in many cases specialized personnel were required for maintenance of the oil celler. In this equipment, the oil celler itself contains only a switch on the motor side. Control panel are all arranged in the operation pulpit and the celler can be operated easily by the mill operator. In this way personnel can be reduced. *Fig. 13* shows the oil celler control panel in the main roll operating pulpit.

V. CONCLUSION

This article has introduced a thyristor-Leonard system for use in a blooming mill. The authors wish to thank the personnel of the Fukuyama Works of Nippon Kokan K.K. for their invaluable guidance and cooperation.