UDC 621. 771. 1 : 621. 313. /. 314

ELECTRICAL EQUIPMENT FOR SLABBING AND BLOOMING MILL DELIVERED TO MIZUSHIMA STEEL WORKS, KAWASAKI STEEL CORP.

By Michio Hase
Hirohisa Isogai
Takayoshi Nakano
Technical Dept.

Atsushi Ishikawa
Kawasaki Factory

I. OUTLINE

Fuji Electric recently manufactured a complete set of electrical equipment for a slabbing and blooming mill, and made delivery to the Mizushima Steel Works of the Kawasaki Steel Corp. This equipment has been operating satisfactorily since August, 1966. Two sets of 4000 kw ±30/60 rpm top-forward system motors are used as the main motors. A Kraemer-system Ilgner converter was adopted for the first time in Japan. In recent years, tandem rolling has become popular, and the load factor of the converter increased accordingly. This also necessitated an increase in the capacity of the motor to drive the converter as well as the flywheel. However, it is possible to reduce the drive motor capacity and flywheel GD^2 by using a Kraemer system in the converter. The induction motor slip voltage can be controlled entirely by electrical means, so that superior performance is obtained and primary current can be precisely controlled. Since the slip power of the induction motor is not dissipated in a cooler, power consumption can be lowered, and the cooler and cooling water can be eliminated. The above points are main features of this system. The main motors, main generators, and Ward Leonard generators for auxiliary motors are all excited by thyristors, and the automatic control equipment is provided with transistorized regulators. The slab shear are driven by two 1000 kw dc motors. A static Leonard system using mercury arc rectifiers is employed as the dc motor power supply, and high precision programmed operation is possible. Cover cranes for the soaking pit and ingot buggy are remote controlled from pit cranes. The electric room can be seen in *Fig. 1*, and the arrangement of the equipment in the mill yard is outlined in *Fig. 2*.

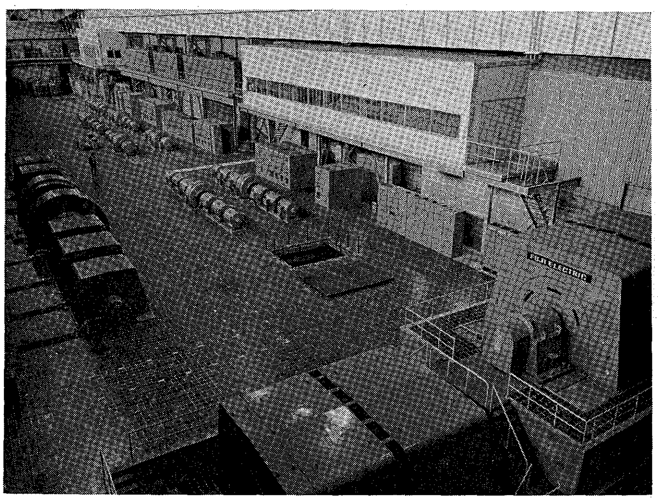
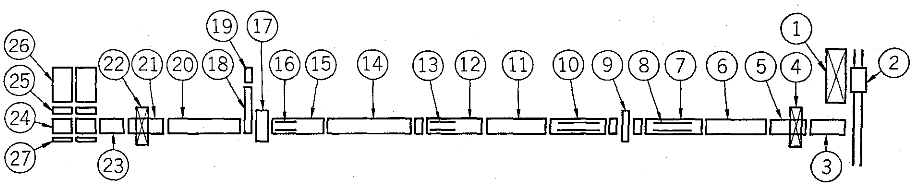


Fig. 1 Electric room



1. Reheating furnace
2. Ingot buggy
3. Ingot receiving table
4. Ingot scaler
5. Ingot scale table
6. Mill approach table
7. Mill front table
8. Manipulator
9. Mill
10. Mill back table
11. Mill run-out table
12. Scarfer entry table
13. Side guide
14. Scarfer delivery table
15. Shear entry table
16. Side guide
17. Shear
18. Crop hoist
19. Dump car
20. Shear delivery table
21. Slab scale table
22. Slab scaler
23. Stamper table
24. Piler table
25. Piler
26. Transfer
27. Pusher

Fig. 2 Arrangement of the equipment

II. ELECTRICAL EQUIPMENT FOR THE MAIN DRIVE

1. Main Motors

Specifications for the main motors are given in *Table 1*. Twin drive motors with top-forward system are shown in *Fig. 3*. This system has proven highly satisfactory in comparison with the bottom forward system, even since it was first employed in Japan by Fuji Electric in 1961.

The yoke is laminated and provides good commutation against impact load change. The double armature has skin-stress construction so as to reduce GD^2 and weight. Because of this, a small capacity crane can be used in the electric room, thus facilitating assembly and disassembly. A down-draft ventilating system is utilized with the provision that the armature and field winding ventilation path is isolated from the commutator ventilation path to provide more effective cooling. This improved cooling effect also allowed for the prevention of carbon-particle adhesion on the windings, which is a frequently encountered problem. As a result, maintenance is simplified and effective cooling of the windings is achieved. Hard brazing is used on the armature instead of soldering. With this new method, the weak points in the rotary machines are strengthened, and the reliability, together with the cooling effect as described above, is enhanced. High pressure lubrication for the bearings is provided in a centralized lubricating system which includes lubrication of the Ilgner converter. Lubricant under high pressure is fed from the low pressure lubrication system of the Ilgner converter via a high pressure booster pump.

This top-forward system with the various features has been employed in a number of drive systems. The main problem points which will be discussed first are the assembly and disassembly of the extension shaft, and maintenance and inspection of bearing. Special consideration has been given to these points as follows. *Fig. 4* is an outline of the main motors. Inspection of the bearing and drive side commutator is facilitated by the extension of the bell crank support pedestal in the mill so as to increase the space around the drive side bearing pedestal, as shown in the figure. The bearing pedestal which supports the extension shaft is installed on the main bed, using a spacer, so that it can be drawn out easily when disassembling the extension shaft. A truck for drawing out the extension shaft is provided beneath the upper motor, so that the extension shaft can be easily drawn using the crane in the mill yard. Special disassembly tools are included and this system allows for much greater convenience than conventional systems. In conventional systems, no space is provided for maintenance and inspection of the bearing of the extension shaft since it is located immediately below the upper motor bearing. In this system, however, the bearing of the extension shaft is positioned on the mill side of the upper motor drive side bearing as described above. This facilitates inspection as well as making the upper motor bed construction more practical. The bearing bed has been designed so that it can be separated during disassembly and maintenance. In this way, disassembly, maintenance, and reassembly time can be cut down to three or four hours.

Table 1 **Specifications of Main Roll Mill Motors**

Number of Units	2	Emergency Max. Torque	357 t-m (275%)
Output	2×2000kw		
Voltage	±(750+750) v	Excitation System	Separate excitation 100/600 v
Current	2990 amp	Rating	Continuous
Speed	±30/60 rpm	Insulation	Class B
Working Max. Torque	292 t-m (225%)	Temperature Rise	50 deg
		Center Distance of Motors	2450 mm

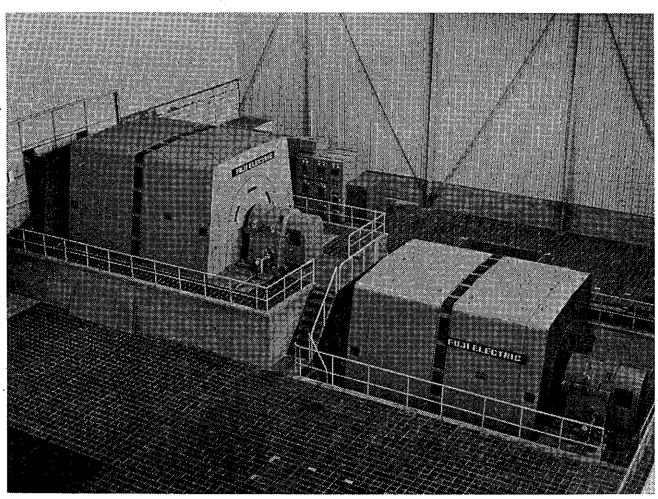


Fig. 3 Main motors

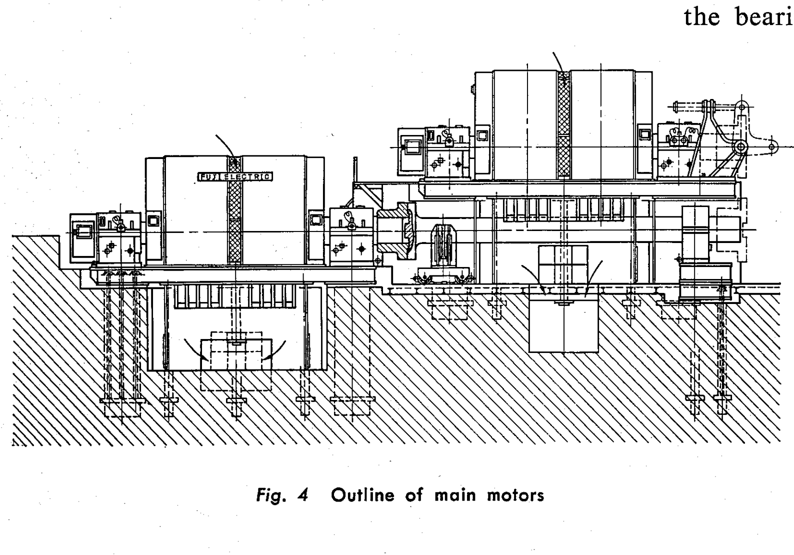


Fig. 4 Outline of main motors

2. Ilgner Converter

Specifications for the Ilgner converter are given in *Table 2*, and machine layout is given in *Fig. 1.* The induction motor and flywheel are positioned centrally while the four generators are arranged on both sides in groups of two. The converter is provided with rear motor. Total length is approximately 27 meters.

***Table 2* Specifications of Ilgner Converter**

	D-c Generator	3-phase Ind. Motor	Flywheel	D-c Motor
Number of Units	4	1	1	1
Output	2250 kw	8000 kw	236500 kw sec	1500 kw
Voltage	750 v	11000 v	—	607 v
Current	3000 amp	—	—	2635 amp
Speed	480−585/600 rpm			
Rating	Continuous			
Max. Output	275%	—	—	200%

This Ilgner converter does not differ from a conventional converter as far as capacity is concerned, but it has unique significance in this equipment from a technical standpoint. This special technical significance can be divided into two features as follows:

(1) A synchronous speed of 600 rpm is used, contrary to all previous practice.

(2) The Kraemer system is emplyed.

The speed of a 2000 to 3000 kw main generator in steel plants is usually 500 or 428 rpm in 50 cps areas and 514 or 450 rpm in 60 cps areas. However, Fuji Electric carefully examined performance and reliability based on a wide range of practical experience, and, as a result, a speed of 600 rpm can now be applied. As a recent practical example, 2420 kw 850 v 600 rpm generators for electric propulsion were installed on the Japanese icebreaker "FUJI". Although operating conditions were severe in that the generators operate in the hold of the ship and are directly connected to the diesel engines, anticipated performance was achieved, and the equipment is still functioning satisfactorily. With such practical experience as a guide, superior characteristics in respect to both performance and reliability have been obtained.

The greatest problem concerning reliability is generator commutation. Due consideration has been given to the shape of the slot, and the dimensions of the core and winding conductor, and every effort has been made to reduce the reactance voltage as much as possible. The most suitable type and quality of carbon brushes have been selected on the basis of past experience. The popular constant pressure type tandem brush holders were selected. Satisfactory commutation is achieved by laminating the entire magnetic circuit so that the inter-pole magnetic flux is not delayed from armature current, even when the impact load is applied. As a result, no spark commutation occurs even under a working maximum load of 225%. The same method as in the main motors is used to provide heat resistance against temperature rise when overloaded.

As a result of the static Kraemer system used in the slip control, current, including many higher hermonic components, flows through the secondary winding of the induction motor, and a pulsating torque is generated in the induction motor in addition to the ordinary torque. This imparts a twisting torque to the converter shaft which directly connects the flywheel, generators, and induction motor. A thorough investigation was conducted into this matter, and a suitable design was drawn up after examining the vibration characteristics. Severe operating conditions are applied to the bearings when the machines are speeded up. The shaft diameter has been selected, and the bearing designed in accordance with the actual load applied to each machine. A centralized lubrication system has been employed for the bearings. This consists of a high pressure lubrication system used during starting, a motor-driven feed pump used temporarily during starting, and a low pressure lubrication system which includes a feed pump directly connected to the Ilgner converter shaft for use during operation.

3. Control Equipment

The main motor control system is shown in *Fig. 5.* It is composed of transistor regulators.

The speed controller operates two synchros without steps, one for forward rotation and the other for reverse rotation. The outputs of these two synchros are differentially added after being converted into dc signals by means of a position-electric changer (PEC), and applied to the unit integrator. This integrator converts stepped input to output signals with a constant gradient in respect to time. The output of the unit integrator is then applied to a speed controller as the speed reference signal. The speed controller is a PI controller whose output is applied to an armature current compensating controller. The armature current compensating controller is a P controller with low gain and serves to keep the motor armature circuit stability.

The output from the armature current compensating controller is sent to a voltage-current controller as the armature voltage reference signal. This controller has a special design. Ordinarily, it operates as a voltage controller. However, when the armature current reaches the specified limit value, it functions as a current controller. The armature voltage control loop is adopted, so that generator voltage can be positively limited even when the circuit breaker is cut-off and the speed control circuit is opened, and so that armature current can be quickly increased to the limit value and impact speed drop can be minimized. The voltage-current controller functions as a PI controller

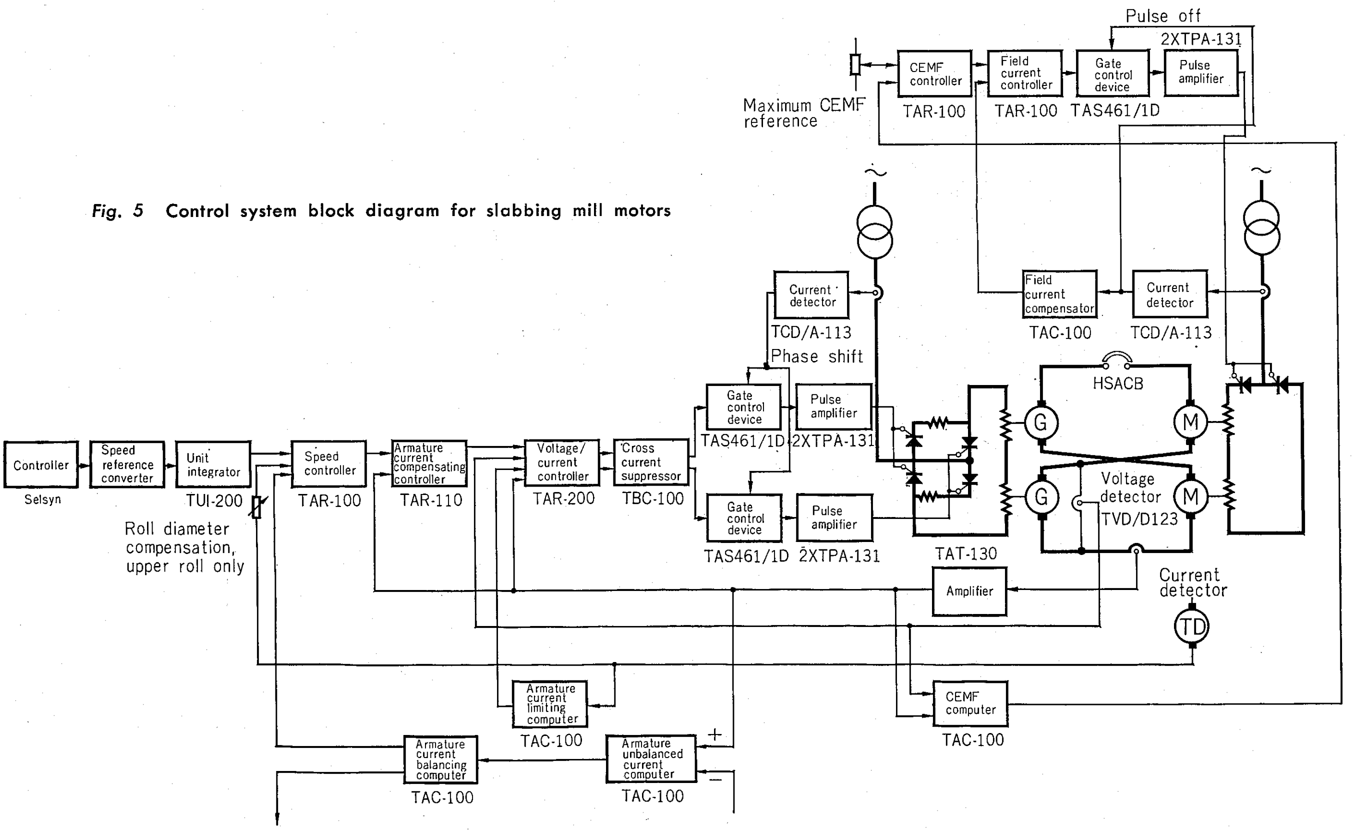


Fig. 5 **Control system block diagram for slabbing mill motors**

when used to control voltage, and as a PID controller when used to control current.

The voltage-current controller output is applied to a cross current limiter to control generator field thyristors connected in a back-to-back arrangement. The cross current limiter provides a constant difference between the firing angle α and γ of the converter and inverter under a static condition, and limits cross current between converter and inverter to a predetermined value by making signal speed difference under a dynamic condition.

The cross current limiter output is converted to the thyristor gate pulse by the gate control unit. The generator field thyristors are arranged in a back-to-back connection with a maximum output voltage of approximately ± 600 v. Gate signals to the thyristors accomplish simultaneous firing by superimposing a wide pulse signal and pulse signal with a short rise time.

Motor field current is automatically weakened when the speed control signal is increased above base speed. A predetermined value corresponding to the rated counter electromotive force of the motor is applied continuously to the counter electromotive force controller. When the actual counter electromotive force is lower than the predetermined value, the output of this controller is saturated since it is a PI controller. This saturated signal corresponds to the full field current reference signal for the field current controller. If the counter electromotive force attempts to increase over the predetermined value, this regulator is no longer saturated and the field current reference value is reduced so that the counter electromotive force is maintained at a predetermined value. The features of this system are that when motor current is excessive, the field current is automatically increased and the torque increases, since control operation takes place to limit this overcurrent by lowering the armature voltage and the counter electromotive force then decreased. The counter electromotive force is determined by a CEMF-computer on the basis of the armature voltage and current. The field current controller is a P controller with comparatively high gain. The feedback signal is obtained from the motor field current through a field current compensator with a first order time delay. The gate control units are the same types as those in the generator field circuit, and the thyristors are connected in a bridge connection.

The armature current limiting computer determines the armature current limiting value on the basis of the motor speed and provides the current limit signal for the voltage-current controller, since the permissible value of the motor armature current changes depending on the speed.

The main purpose of this control system is to match the speeds of the upper and lower rolls. When the motor armature currents of the upper and lower rolls are unbalanced in excess of a certain predetermined level, control is applied to maintain this unbalance level within a specified limit. In other words, the armature unbalanced current computer determines the level of current unbalance between the upper and lower roll motors, and the armature current balance computer provides a signal for the speed controller when this value exceeds the established value, so as

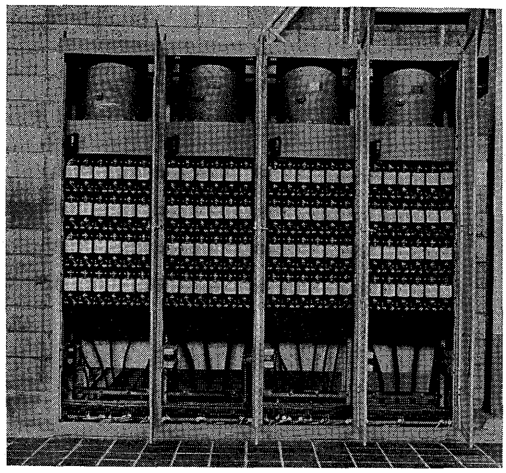
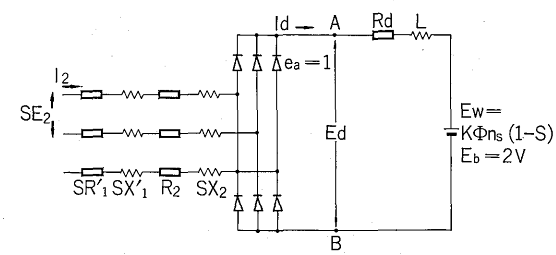


Fig. 6 Exciting thyristor cubicle



SR_1': Induction motor primary resistance
SX_1': Induction motor primary reactance
R_2: Induction motor secondary resistance
SX_2: Induction motor secondary reactance
E_2: Induction motor secondary voltage at S=1
$K\Phi ns$: Rear motor CEMF at synchronous speed

Fig. 7 Equivalent circuit of Kraemer control

to limit the degree of unbalance within a specified level.

Fig. 6 shows the field thyristor converter.

An equivalent circuit for the main Kraemer control circuit in the induction motor is shown in *Fig. 7.* The voltage on the ac side as observed from the rear motor terminals $A-B$ is expressed by the following equation:

$$E_d = 1.35SE_2 - 0.955(SX_1' + SX_2)I_d - \frac{2\sqrt{2}}{\sqrt{3}}(SR_1' + R_2)I_d\sqrt{1-3\phi(u)} - 2 \quad \text{...(1)}$$

In the above equation, the second term on the right indicates the commutation reactance drop, the third term indicates the ac-side resistance component drop, and the fourth term indicates the rectifier drop.

When observing the motor side from points A and B, the equation becomes as follows:

$$E_d = K\Phi n_s(1-S) + I_d R_d + L\frac{dI_d}{dt} + 2 \quad \text{......(2)}$$

The relation between the slip "S" and dc current "I_d" can be derived from equations (1) and (2) as follows:

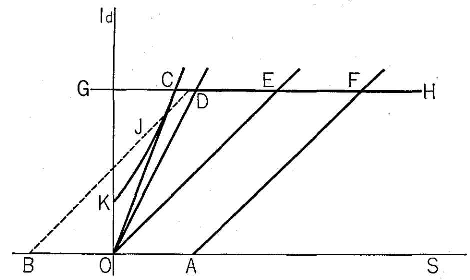


Fig. 8 Current-slip characteristics of rear motor

$$I_d = \frac{1.35SE_2 - K\Phi n_s(1-S) - 4}{R_d + 0.955(X_1' + X_2)S + 2\sqrt{\frac{2}{3}}(SR_1' + R_2) \cdot \sqrt{1-3\phi(u)} + Lp} \quad \text{......(3)}$$

The induction motor secondary current is obtained as follows:

$$I_2 = \sqrt{\frac{2}{3}} \cdot \sqrt{1-3\phi(u)} \cdot I_d \quad \text{......(4)}$$

The denominator of equation (3) above corresponds to the impedance drop, and equation (3) can be modified to equation (3′) below if the denominator is expressed in terms of $R(s)$.

$$I_d = \frac{1.35SE_2 - K\Phi n_s(1-S)}{R(s)} \quad \text{......(3')}$$

This equation can be represented by the graph in *Fig. 8* in which the current vs. slip curve shifts in a parallel manner to the right when the rear motor field "Φ" is increased. In other words, if the rear motor field is zero, the current vs. slip curve is on the *O–E* line. However, if the field is increased, the curves moves to *A–F*. If the field is excited in reverse, the curve moves in the reverse direction to *B–J*. In practice, however, a short-circuit current flows through the bridge connected rectifier. The current vs. slip curve is to the right of the $O-E$ lines as long as the rear motor counter electromotive force is applied in the reverse direction to the rectifier direction. Thus, the Kraemer motor maximum speed is limited to approximately 5% of maximum slip, even if no load is applied.

However, if the rear motor field is reversed and short-circuit current flows through the rectifier, the current of the Kraemer system shifts above the *O—D* line in *Fig. 8* since the "$R_d + Lp$" term in equation (3) can be cancelled out. The Kraemer motor maximum speed can be increased to the degree indicated in the figure.

As can be seen from *Fig. 9*, the condition indicated in the following equation (5) is necessary to short-circuit ac sine-wave current "I_2" completely.

$$\sqrt{2}\, I_2 < I_d = \frac{E_w - e_r}{R_d} \quad \text{......(5)}$$

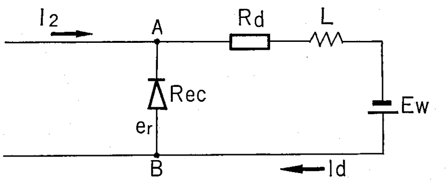


Fig. 9 **Short-circuit by rectifier**

Therefore, the rear motor current must correspond to *O–C* so as to obtain torque vs. slip characteristics which correspond to the *O–D* line in *Fig. 8*.

Fig. 10 is a block diargam of the Ilgner converter control system.

The speed of the Ilgner converter must be maintained nearly at synchronous speed, and disturbances on the power supply caused by load current must be avoided. For this reason, the rear motor current should be mainteined within the *O–C–H* range of values as shown in *Fig. 8*. The line *O–C* indicates the range within which the rectifier is short-circuited to increase the speed and the line *C–H* indicates the current which receives rolling load. This same current accelerates the flywheel after rolling.

The reference signal computer determines an armature current reference value which corresponds to the *O–C–H* range of *Fig.* 8, using the induction motor primary current. The line *O–C* actually becomes curve *K–C* due to the excitation current component of the induction motor. However, this is favorable since there is a margin for short-circuiting of the rectifier. The reference signal computer output is applied to the armature current controller as the current reference signal. The armature current controller functions as a PI controller in order to cancel delay in the armature circuit and to absorb power supply disturbances. The equipment has been designed so that a large bias input is supplied to the armature current controller when the Ilgner converter is started. Consequently, constant input is supplied to the field current controller.

The field current controller controls the field current. The feedback signal passes through the field current compensating computer to compensate for delay caused by eddy current and discharge resistance. The field current controller output controls the back-to-back signal phase bridge-connection exciter after passing through the cross current limiter, and gate control units.

III. ELECTRICAL EQUIPMENT FOR SLAB SHEAR

1. Motor for Slab Shear

Specifications of the motors are given in *Table 3*. These motors are unique in their application to electrically driven slab shear. Load conditions are so severe that the motor must be able to withstand

Table 3 **Specifications of Slab Shear Drive Motors**

Number of Units	2	Max. Working Torque	7.41 t-m (350%)
Output	1000 kw	Max. Emergency Torque	8.05 t-m (380%)
Voltage	500 v	Excitatoin System	Separate excitation 220/2 v
Current	2130 amp	Rating	Continuous
Speed	460 rpm	Insulation	Class B

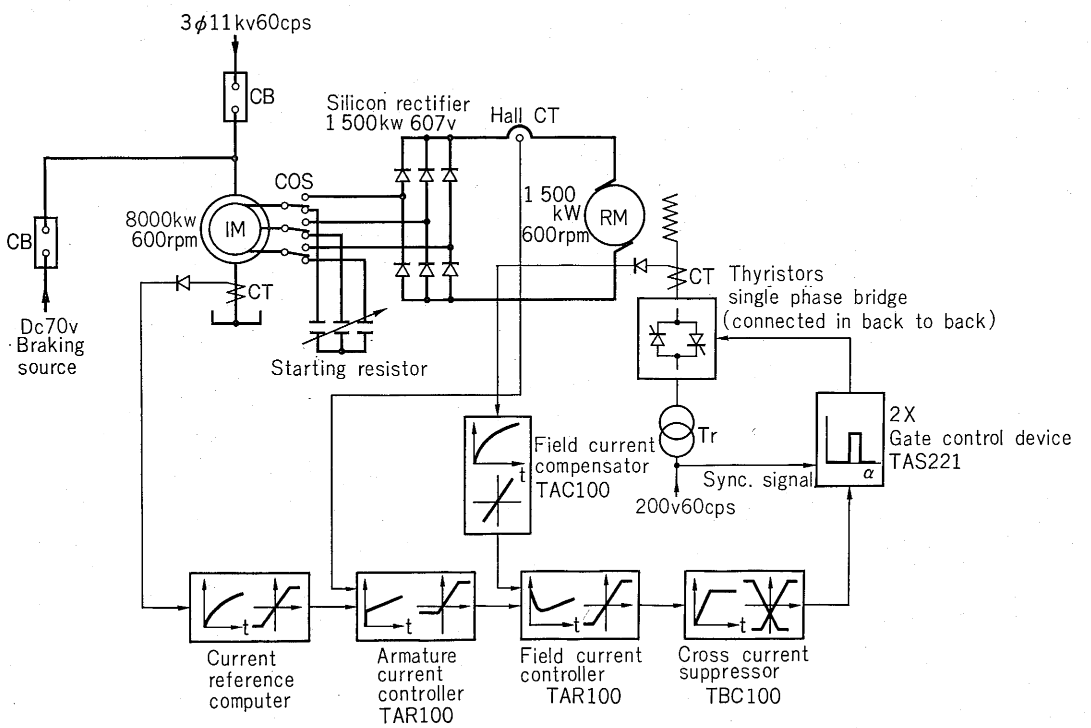


Fig. 10 **Control system block diagram for Ilgner converter**

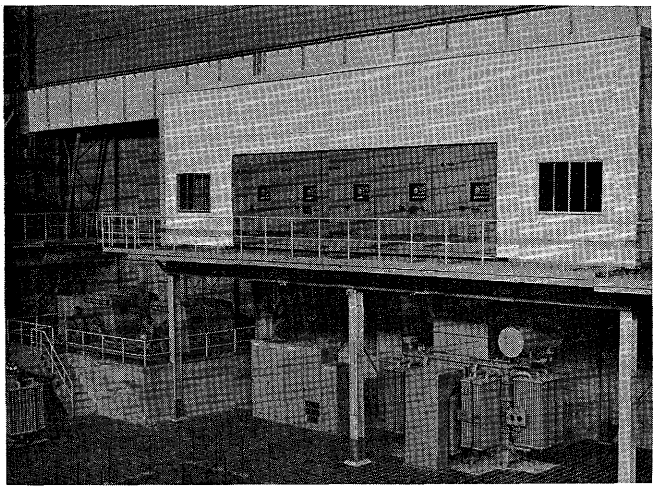


Fig. 11 Slab shear drive equipment

a load of 350% for 30 seconds. It has been designed so that the flywheel effect is limited to the minimum extent. Two motors are mechanically connected by reduction gears to drive the shearing machine crank shaft.

A centralized lubricating system is used for the bearing and the system is located in the basement beneath the motor pit.

Fig. 11 shows the motors and static Leonard power supply equipment. The mercury arc rectifiers are located on the mezzanine, and the rectifier transformer and control equipment are located in the 1st floor.

2. Static Leonard Power Supply and Control

The shear carries out repetitive starting, accelerating, shearing, braking, and stopping whenever a shearing signal is received. For this reason, emphasis is placed on rapid acceleration with current limiting, shearing current limiting, and scheduled braking. A static Leonard power system with its high control performance is most suitable to achieve these goals. A cross-connection reversible Leonard system using mercury arc rectifiers as shown in *Fig. 12* is therefore employed. The Leonard power supply specifications are as follows:

(1) Mercury arc rectifiers: Multi-anode air cooled sealed type
- Converter side: 3 rectifiers-PSL2011
700 kw 1000 v
Overload capacity: 360% load
- Inverter side: 2 rectifiers-PSL 2011
900 kw 1000 v
Overload capacity: 200% load

(2) Rectifier transformer
Nitrogen sealed oil filled self-cooling system for indoor use
- Ac side: 3400 kva 3-phase 60 cps
11.5–11–10.5–10 kv
- Converter side: 2 × 1900 kva, 1040 v double star
- Inverter side: 2 × 1910 kva, 1220 v double star

During determination of the above capacities, various shearing cycles at which the motors RMS value reaches 100% were considered, and capacities were selected in accordance with the individual maximum RMS values of both the converter and inverter sides. The shear has been designed on the assumption that the shearing torque is generated entirely by the motors.

The shear is constructed so that motor power is transmitted to the blade via the crank mechanism, and rotation through 360° provides one stroke. The program is indicated in *Fig. 13*.

When an operation signal is forwarded to the speed reference computer, the motor speed-reference signal is computed from the momentary crank position obtained by integrating the pilot generator output. This computer consists primarily of an adder and square root computer. A limit circuit is attached to the computer. This computer generates output which

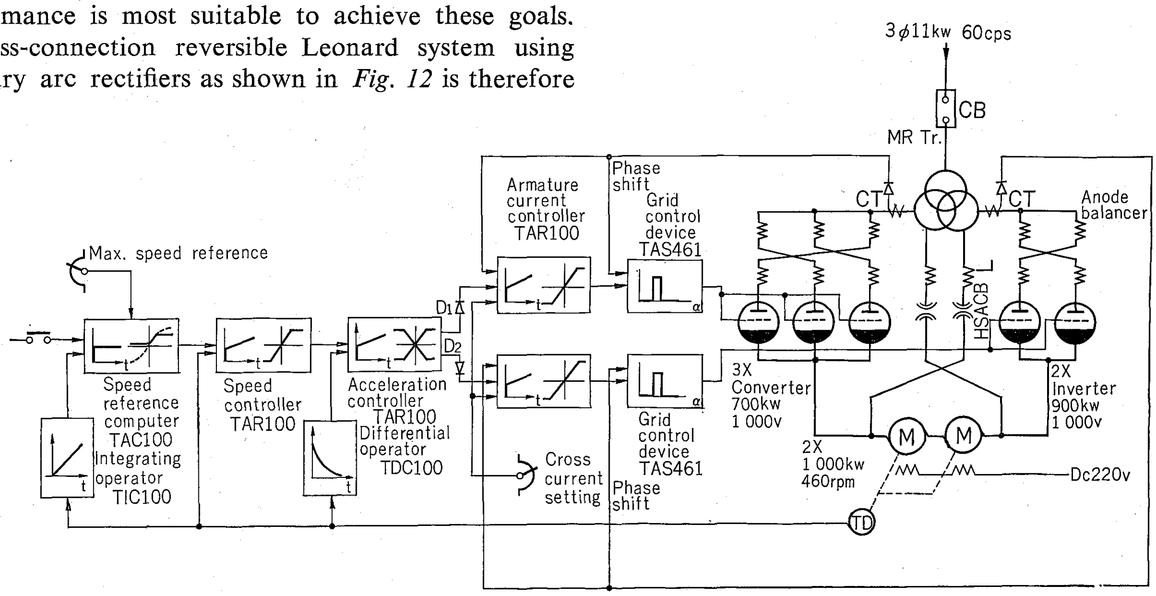


Fig. 12 Control system block diagram for slab shear

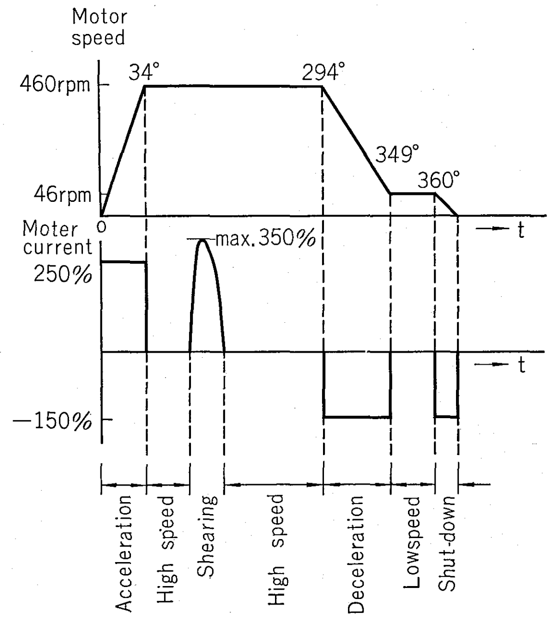


Fig. 13 **Running program of shear motors**

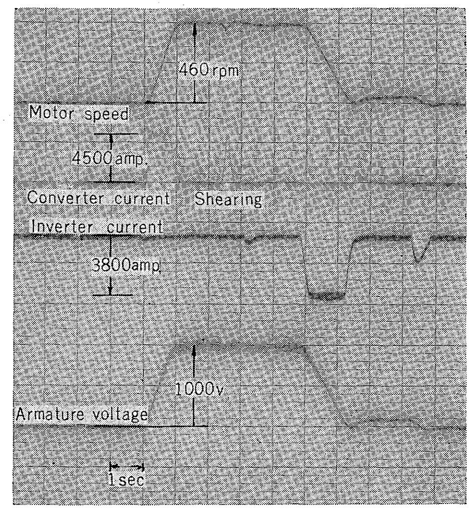


Fig. 14 **Oscillogram of slab shear motors**

corresponds to the speed program in *Fig.* 13.

Speed reference computer output is applied to the speed controller in order to establish the motor speed. The speed controller output serves as the reference of the acceleration controller. The speed controller output is limited within permissible acceleration value and both acceleration and deceleration can be limited satisfactorily. Feedback signal to acceleration controller is obtained by differentiating the pilot generator output in the differential operator. The accerala tion controller output is used as reference input of the armature current controller for both the converter and inverter. This signal is limited by matching with the permissible motor current, so that the armature current is closely limited. The armature current controller prevents power supply disturbances and cuts out the armature circuit delay. The output is used as input for the gate control units.

Fig. 14 shows the oscillogram of one stroke of shearing.

IV. ELECTRICAL EQUIPMENT FOR AUXILIARY DRIVES

This equipment consists of 43 variable-voltage control dc motors and 25 constant-voltage control dc motors. Their specifications are given in *Tables 4* and *5*. Variable voltage auxiliary drive control can be roughly classified into two types: one which controls speed and the other which controls armature

Table. 4 **D-c Variable Voltage Auxiliary Motors**

Machinery	D-c Motor						
	Output (kw)	Time rating	Speed (rpm)	Voltage (v)	Frame no.	Brake	No. of motors
Ingot Buggy	110/220	Continuous	460/920	220/440	616	Shunt	2
Buggy Roller	55/110	One hour	515/1030	220/440	612	Shunt	1
Mill Approach Table	55/110	Continuous	515/1030	220/440	612	—	4
Mill Front and Back Table	150/300	Continuous	420/840	220/440	618	—	4
Individual Roller (Mill Front and Back Table)	27.5/55	Continuous	77/154	220/440	618	—	12
Feed Roller	30/60	Continuous	84/168	220/440	618	—	4
Manipulator Rack	150	Continuous	420	220	618	Shunt	4
Manipulator Finger	150	One hour	420	220	618	Shunt	2
Screw Down	150/300	Continuous	420/840-1260	220/440	618	Shunt	2
Mill Runout Table	55/110	Continuous	515/1030	220/440	612	—	4
Scarfer Entry Table	75/150	Continuous	485/970	220/440	614	—	1
Scarfer Delivery Table	55/110	Continuous	515/1030	220/440	612	—	3

Table. 5 **D-c Constant Potential Auxiliary Motors**

Machinery	D-c Motor						
	Output (kw)	Time rating	Speed (rpm)	Field	Frame no.	Brake	No. of motors
Ingot Receiving Table	55	One hour	515	Compound	612	—	1
Ingot Scale Table	55	One hour	515	Compound	612	Shunt	1
Scarfer Entry Side Guide	19	One hour	650	Compound	606	Shunt	1
Shear Entry Table	55	One hour	515	Compound	612	Shunt	2
Shear Entry Side Guide	19	One hour	650	Compound	606	Shunt	2
Crop Pusher	7.5	One hour	800	Compound	603	Shunt	1
Crop Hoist	75	One hour	485	Compound	614	Shunt	1
Shear Gauge Lifting	26	One hour	575	Compound	608	Shunt	1
Shear Gauge Traversing	55	Continuous	515	Compound	612	Shunt	1
No. 1 Shear Delivery Table	55	Continuous	515	Compound	612	Shunt	1
Shear Swing Roller	4.85	One hour	140	Compound	606	—	1
Shear Pull-back	55	One hour	515	Compound	612	Shunt	1
No. 2 Shear Delivery Table	37	One hour	550	Compound	610	Shunt	1
Slab Scale Table	55	One hour	515	Compound	612	Shunt	1
Stamper Table	37	One hour	550	Compound	610	Shunt	1
No. 1 Piler Table	37	One hour	550	Compound	610	Shunt	1
No. 2 Piler Table	55	One hour	515	Compound	612	Shunt	1
Piler	37	One hour	550	Compound	610	Shunt	2
Transfer	110	One hour	460	Compound	616	Shunt	2
Pusher	75	One hour	485	Compound	614	Shunt	2

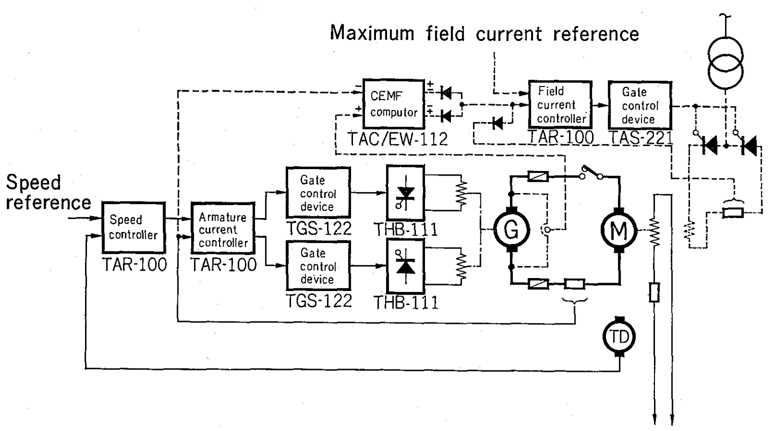


Fig. 15 **Control system for adjustable voltage aux. motor with speed reference (dotted lines only for screw down drive)**

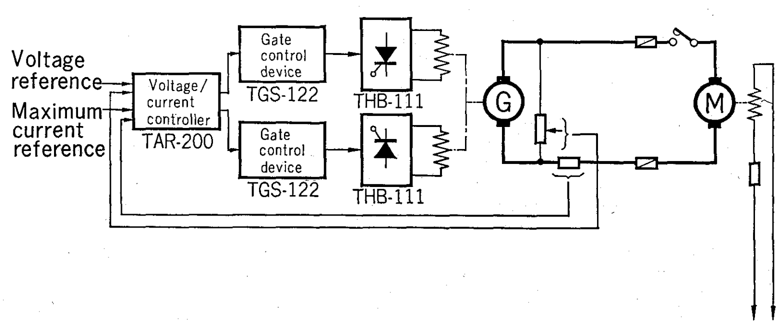


Fig. 16 **Control system for adjustable voltage aux. motor with armature voltage reference**

voltage. The auxiliary drives of which speed is controled are the tables around the scarfing unit which require accurate speeds over a wide range and machines such as the screw-down, manipulator, etc. which carry out precision positioning. The auxiliary drives of which armature voltage are controled are the tables around the mill which do not require such accurate speeds.

Both systems obtain variable voltages by thyristor excitation of the generator field.

For speed control systems with an armature current control loop which has been effectively applied in many systems are employed. This control system is illustrated in *Fig. 15*. The screw-down motor has a field range of 840 rpm∼1260 rpm. Thus, an automatic field weakening system is employed.

For armature voltage control, a voltage-current controller with a system identical to that in the main mill control is used. This control system is shown in *Fig. 16*. The conventional system in which the voltage control signal is controlled to the armature current reducing direction when the current exceeds the limited value has a disadvantage, in that operation is delayed one step since the current control loop is located in the first position from the outside. In this system, ideal control can be achieved over the motor operation since the necessary individual adjustments can be carried out in respect to the armature voltage and armature current.

One 750 kw 230 v silicon rectifier with automatic constant voltage control is used as the power supply for the constant voltage dc motors.

V. REMOTE CONTROL EQUIPMENT

The ingot buggy and cover cranes are provided with remote control equipment so that they can be operated from the pit cranes. A multi-frequency system is employed for signal transmission. The transmitters and receivers consist of stable tuning fork signal generators and mechanical filters. A special cable for signal transmission is provided between the pit cranes and surface level. *Fig. 17* shows the block diagram. The signals used between the pit cranes and the control room at surface level are as follows:

(1) Command signal from the cover crane control room to one pit crane:
One pit selection, two pits selection, response indication (open, close, stop), reset of pit selection, spare (4 positions)
Total: 10 positions

(2) Control signal from one pit crane to cover crane control room:
Open, close, stop, east, west, completion of work, spare (4 positions)
Total: 10 positions

(3) Command signal from buggy control room to one pit crane:
Buggy operation command Total: 1 position

(4) Control signal from one pit crane to buggy control room:
Start, stop Total: 2 positions

There are 10 positions each of command signals and control signals between the cover crane control room and one pit crane. Those 10 signals are transmitted using combinations ${}_5C_2$ from five frequencies and ${}_5C_2$ code is checked in order to avoid erroneous control. The number of command signals and control signals between the buggy control room and one pit crane is 1 position and 2 positions respectively. In this case, one frequency is assigned to one position for transmission, and the ${}_2C_1$ code is checked for the control signal. For cover crane tele-control, 10 waves (5 each for control and command) are required per pit crane, and 3 waves (one for command and two for control) are required for buggy tele-control. A total of 13 waves are therefore required. In this case, two pit cranes are installed so that a total of 26 waves are used. The frequency range is between 1107 cps and 2635 cps.

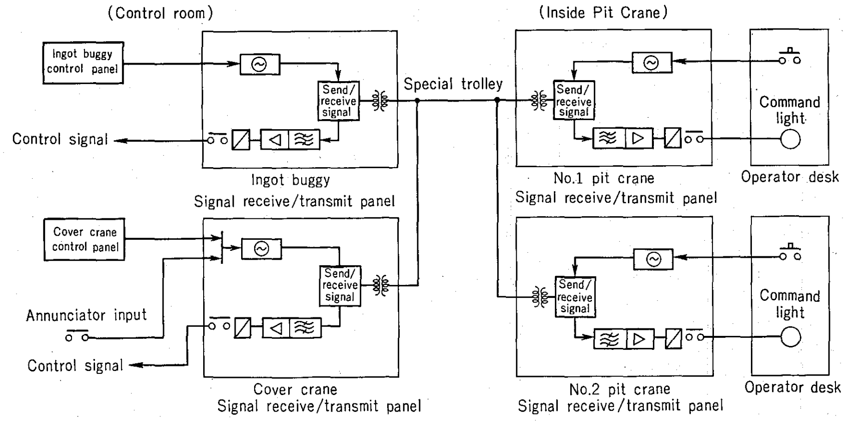


Fig. 17 **Block diagram of tele-control system**