ELECTRIC EQUIPMENT FOR ROUGHING MILL OF THE 80″ SEMI-CONTINUOUS HOT STRIP MILL IN TOBATA PLANT OF YAWATA WORKS, YAWATA IRON AND STEEL CORP.

By

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I. INTRODUCTION

With the enforcement of the second rationalization of iron and steel industry in Japan, new and powerful rolling mills have been installed newly or have increased in many plants. In 1957, we have supplied Chiba Iron and Steel Works, Kawasaki Steel Corp., with all the electric equipments for the finishing mill of the hot strip mill. Furthermore, we completed manufacturing last July the electric equipment for the roughing mill of the 80″ hot strip mill newly installed in Tobata Plant of Yawata Works, Yawata Iron and Steel Corp. and it is being operated since last September.

The equipment is one of the epoch-making works that our latest technique has produced. The main motor of this equipment can reverse its base speed within 0.8 seconds from +40 rpm to −40 rpm. And also the new controlling system or the new rotating amplifier, "Rapidyne" etc. are used in it. As the equipment showed excellent results in its operation, we should like to describe some of the general outline and the features.

II. OUTLINE OF EQUIPMENT

The equipment consists of a 7,000 HP twin drive Ward-Leonard system which drives the quardruple reverse roughing mill including the work roll 36″×80″ and the back-up roll 52″×80″ produced by the co-operation of U.E. Co., U.S.A. with Shibaura Kyodo Kogyo K.K., Japan, and the electric equipment for the auxiliary drives. This equipment can roll a slab of 20″∼68″ in width×100∼190 mm in thickness×7,000 mm in lengh to 19∼25 mm in thickness in 5∼7 passes and then the slab is sent to the finishing mill. Most of the electric equipment for this entire equipment has been manufactured by us.

The arrangement of the equipment is shown in Fig. 1. Each machine is operated in the order arranged at the control desks A, B and C as shown in Fig. 1. The equipment is divided as follows;

A. Furnace

B. Roughing mill scale breaker

C. Roughing mill

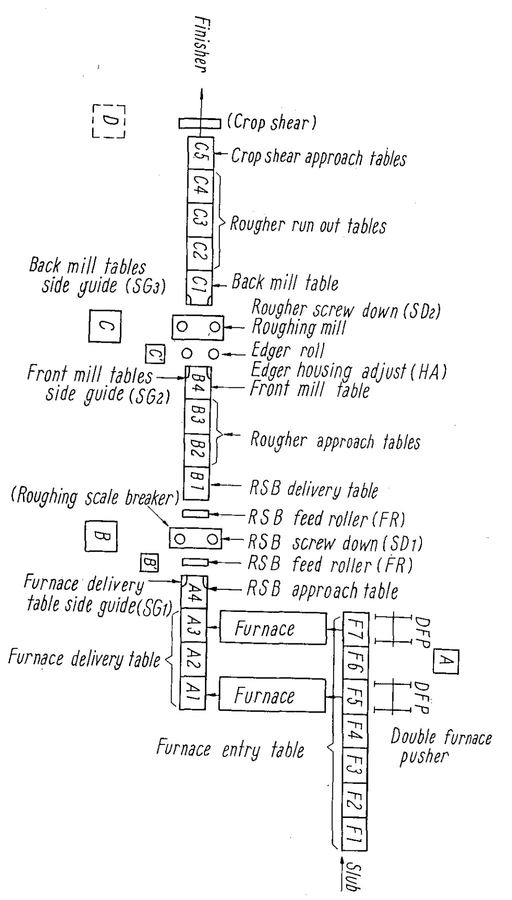

Fig. 1. Total arrangement of roughing mill equipment

The roughing mill and the edger roll are operated at the control desk C of the roughing mill, and the auxiliary motors operated at each control desk are explained in Table 1, list of auxiliary d-c motors.

The crop shear approach table C5 is operated at the control desk D of the crop shear placed at the finishing mill side, and the rougher run out tables C3 and C4 are operated together with C5 at the control desk D if the change-over switch of the control desk C or the photo-cell limit switch installed 50 feet before the crop shear is operated when sending the materials. The control desk of the roughing mill is shown in Fig 2.

Fig. 2. Roughing mill control desk (C desk)

III. SPECIFICATION OF THE ROUGHING MILL DRIVE

1. Main Motor (MM_1, MM_2) 2 units
   3,500 HP ±750 V, 3,780 A, ±40/100 rpm (Twin drive)
   Normal operating torque: 127 TM
   Max. operating torque: 287 TM (225%) 1 min.
   Max. emergency torque: 351 TM (275%) 1 min.
   B class insulation, temperature rise 50°C
2. Edger motor (EM) 1 unit
   2×600 HP ±250/585 V, 2×1,000 A, 150/375 rpm (Double armature)
   Normal operating torque: 2.91 TM
   Max. operating torque: 6.53 TM (225%) 1 min.
   Max. emergency torque: 7.99 TM (275%) 1 min.
   B class insulation, temperature rise 50°C
3. Ward-Leonard motor-generator set
   Consists of the followings:
   1) Ward-Leonard generators for main motor (MG_1, MG_2, MG_3) 3 units
      2,000 kW, ±750 V, 2,670 A, 600 rpm
      Maximum output: 275% 1 minute
      B class insulation, temperature rise 50°C
   2) Ward-Leonard generator for edger motor (EG) 1 unit
      550 kW, ±275/650 V, 2,000 A, 600 rpm
      Maximum output: 275% 1 minute
      B class insulation, temperature rise 50°C
   3) Driving synchronous motor 1 unit
      9,000 HP 11,000 V, 458 A, 60 c/s, 600 rpm
      Overload capacity: 125% 2 hours
      200% 1 minute
      Pull-out torque: 300%
      B class insulation, temperature rise 50°C
4. Exciting motor-generator set
   Consists of the followings:
   1) Exciters for main motor (MME_1, MME_2) 2 units
      85 kW, 220/440 V, 386 A, 1,180 rpm
   2) Exciter for main generator (MGE) 1 unit
      40 kW, 220/440 V, 182 A, 1,180 rpm
   3) Exciter for edger generator (EGE) 1 unit
      12 kW, 100/200 V, 120 A, 1,180 rpm
   4) Constant voltage generator (CP) 1 unit
      20 kW, 230 V, 87 A, 1,180 rpm
   5) Exciter for synchronous motor 1 unit
      75 kW, 110 V, 682 A, 1,180 rpm
   6) Driving induction motor 1 unit
      450 HP 3,300 V, 72.5 A, 60 c/s, 1,180 rpm
5. Controlling motor-generator set
   Consists of the followings:
   1) Rapidyne for main motor field control (MMC) 1 unit
      6 kW, 200 V, 30 A, 1,750 rpm
   2) Field pilot generator for main motor (MFP) 1 nuit
      0.2 kW, 200 V, 1 A, 1,750 rpm
   3) Rapidyne for main motor load balance (MLB) 1 unit
      1 kW, 100 V, 10 A, 1,750 rpm
   4) Rapidyne for main generator voltage control (MGC) 1 unit
      1 kW, 200 V, 5 A, 1,750 rpm
   5) Voltage pilot generator for main generator (MVP) 1 unit
      0.2 kW, 250 V, 0.8 A, 1,750 rpm
   6) Rapidyne for edger generator voltage control
      1 kW, 200 V, 5 A, 1,750 rpm
   7) Speed pilot generator for table motor (SP) 1 unit
      1 kW, 220 V, 4.55 A, 1,750 rpm
   8) Driving induction motor
      20 HP, 200 V, 60 c/s, 1,750 rpm

IV. SPECIAL FEATURES OF MAIN DRIVES

1. Main motors of the roughing mill

It is common now that twin motors are used for a reversing mill equipment in order to save time for acceleration and retardation. The twin motors were adopted by us in 1954 to the 7,000 H P Ilgner set for the slabbing mill installed in Chiba Iron and Steel Works, Kawasaki Steel Corp. Using the same specification as in the above Chiba Iron and Steel Works, we have succeeded to decrease GD^2 to 77%, which indicates our rapid progress of the technique in this field.

As the center distance of upper and lower motors is one of the factors deciding the distance between the main motor and the mill, and also it will have relation with the dimensions of the building, a great effort has been made to make the center distance between the motors as short as possible and we have made it 2,260 mm.

For the yoke, it is ideal to use a laminated yoke which is effective for sudden flux change at rapid acceleration and retardation. However, when the laminated yoke is used, the center distance of motors would become longer than in the case of the cast steel or mild steel yoke.

On the other hand, since the reactance voltage of the twin motors is much lower and the magnetic circuit of the yoke is short comparing with the commutating pole length because the numbers of pole are more than those of the main generator, from the standpoint of commutation, to apply the laminated yoke to the main motor would not be necessary, by the sacrifice of the center distance of twin motors.

With the above reasons, we have successfully manufactured the ring of the yoke with cast steel and welded the split parts and the legs with steel solving the difficult problems in bending the yoke of the welded, thick steel structure and in finishing the surface of the whole cast steel yoke.

The thrust bearing is installed in the bearing stand at the commutator side and is shown in Fig. 3, where (1) represents bearing stand, (2) thrust metal serving also as oil ring and (3) backward thrust bearing, which is able to adjust freely the slop and gap due to the bending of the main shaft and to the error from the finishing. (4) is the back metal of bearing having the spherical seat which receives the forward thrust at its side.

Concerning this kind of motors, the gap of the thrust bearing is especially important to absorb the shocks caused from the vibration thrust of the main shaft by utilizing the buffer action of oil film, and also to adjust the gap at a given time. Therefore, our thrust bearings have been so manufactured that they can easily adjust the thrust surface and we can observe, at any time, the thrust bearings from the outside.

The oil pressure 20～30 kg/cm^2 supplied from the bottom of the bearing metal in order to keep the shaft up so that the friction loss of the bearing may be reduced as much as possible and also the oil film may be prevented from disappearing. The system of oil supply for cooling is epoch-making; the oil for cooling is supplied not from the outside but from its own oil pan, and circulated by the pressure pump. Furthermore, the oil rings are provided for the trouble of oil pump.

Another point to be added is that the bearing stand is completely separated from the inside of the main motor. As the inside of the bearing stand is always breathing with the outside air, the breathing may not be shut out entirely however completely the bearing is covered. It is, therefore, more important to separate the bearing stand from the motor in order to keep out the air including the carbon brush dust which muddles the lubricating oil. This is especially necessary for motors of self lubricating oil.

Using the tandem brush, we have been able to develop the commutation further. Our tandem brush holder can press the brush at any time with the same even pressure regardless of the brush length and without adjusting the spring pressure.

Consequently our brush holder can easily be handled and the unbalance of current or the uneven wear of brush due to the pressure of brush will never occur.

The quality of brushes is "Morganite EG16", which has been proved from the actual test to be sparkless even at a sudden acceleration and retardation.

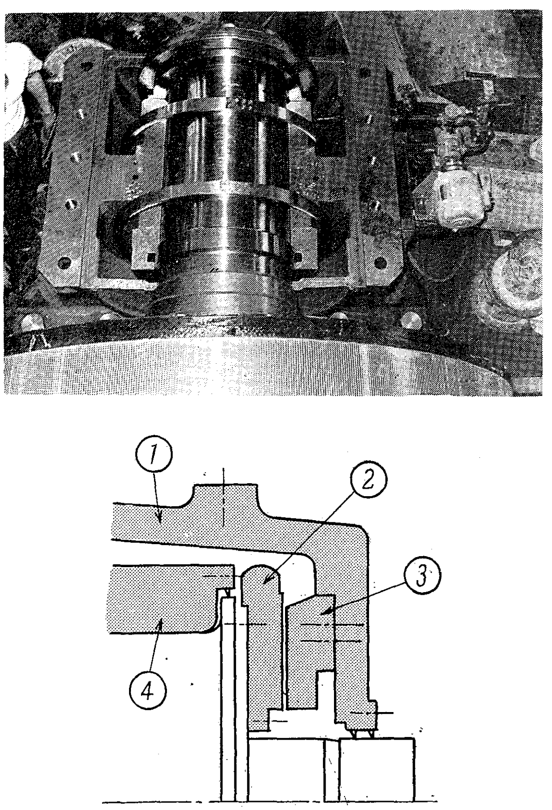

Fig. 3. Bearing and construction of thrust bearing of main motor

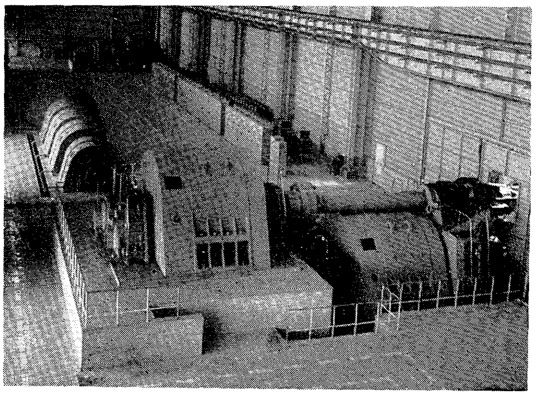

Fig. 4. Roughing mill drive, 7,000 HP twin drive main motors

The arrangement of the main motors is shown in Fig. 4.

2. Edger motor

About edger motor, for decreasing GD^2 of rotor as possible, the arms of armature spider have welded hollow construction and are welded directly to the shaft, and commutator spider is also a welded construction as same as main motors. We have applied to edger motor a double armature construction. By this disposal, if we control edger motor from base speed 150 rpm to top speed 375 rpm by voltage control only, there is no danger of flash over and we have made an advance for the simplification of control circuit and the control characteristics. We have shown the out-look of edger motor in Fig. 5.

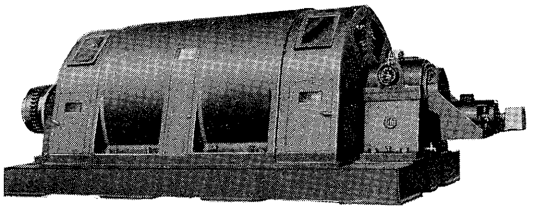

Fig. 5. Edger roll driving motor

3. Ward Leonard motor-generator set

We have applied laminated magnetic yoke to main generators and edger generator for sudden flux change at main poles and good commutation at transient. As to main generators, regarding as the pitches of armature slots and compensated winding's slots, we have skewed the slots of amature for supression of slot ripple and magnetic noise. To apply skewed slots of armature to so large d-c machine is difficult in construction, so there is a few similiar example.

Each of three main generators has cumulative and differential series windings and by cross connection of each other they are projected to balance the loads. As to brushes, we have used tandem brushes as same as main motors. Quality of brushes is Morganite EG16 and from results of actual test all of them are sparkless, so although the speed of rotation is so high as 600 rpm it is evident that there is no anxiety.

9,000 HP synchronous motor is our remarkable article in it's output and is high speed machine which has 63 m/sec peripheral speed of rotor, so we have taken into several considerations for this construction. That is to say, as to damper bars we have used special material which is superior electrically and mechanically, and between damper bar and slot inserted liners, and we have fixed damper bars to segments by pins which are free as to the direction of shaft and radius and fixed as to the direction of circumference. By these consideration, we have prepared for the vibration at sudden load change and the thermal expansion. Otherwise, of course about armature winding, field winding and details as lead wires etc. we have considered for anti-vibration. Ventilation systems for every machine are down draft, and to this synchronous motor we have applied air guide plates, combined with silencer at intake of air for decrease of noise. The result was almost perfect.

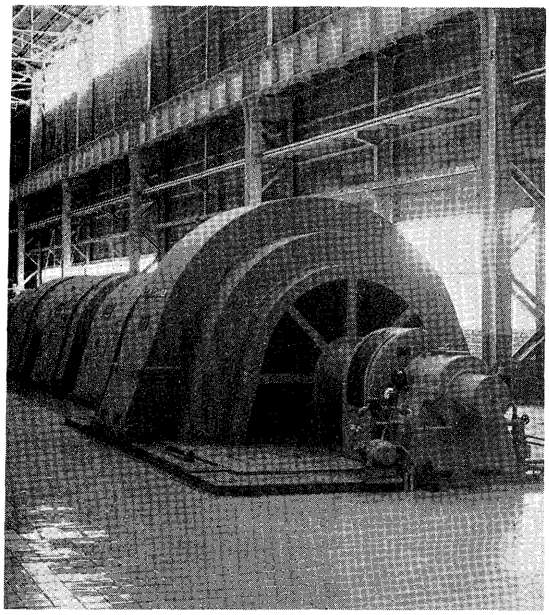

Fig. 6. Ward Leonard motor-generator set

In Fig. 6, we have shown the complete view of Ward-Leonard motor-generator set.

4. Exciting motor-generator set

Exciters for main motors, main generators and edger generator are required quick transient voltage change, so the magnet frames have laminated construction. To overcome the inductance of fields of main machines, the exciters should have sufficient overshoot capacities of voltage, so these exciters have double voltage ratings and are not effected by saturation at several times of steady state voltage.

5. Controlling motor-generator set

We have used Rapidynes, developed recently, as rotating amplifiers so to speak the hearts of control. Rapidyne involves double armature in one frame and the two generators are connected in cascade. One of armature is input stage, and the other is output stage. So the several control signals are supplied to the fields of input stage, and the output of input stage armature excites directly the field of output stage, and in the output stage armature the input signals change to the required output, voltage and current. Comparing with electronic amplifiers, the input stage corresponds to a voltage amplifier and the output stage to a power amplifier. The input stage armature and the field of output stage are standardized, and according to the usage the output stage armature and the fields of input stage are changed optionally.

Ability of an amplifier is shown by figure of merit which is the ratio of power amplitude and response time. At one stage rotating amplifier as old Rototrol upper limit of this value is 400∼500, but at two stages amplifier as Rapidyne power amplitude is the product of those of two stages and response time is the sum of those of two stages, so its figure of merit becomes degree of 20,000.

By using this rotating amplifiers which have so high figure of merits, only a few power of control signal is required. Besides, feed back circuit which is a way of stabilization of control circuit is realized by condenser and resistor in place of damping transformer, so it becomes cheaper and can be adjusted more easily.

V. CONTROL SYSTEM

After 1945, the end of war, we have accomplished several sets of electrical equipment of reversible metal rolling mill, and had many experiences for control circuit of quick reversing mill using rotating amplifier. To this equipment we applied these experiences, and furthermore used new type rotating amplifier Rapidyne, then we have been able to obtain excellent characteristics of control. The control circuit of main motors is shown in Fig. 7, and the control circuit of edger motor is in Fig. 14. We shall describe the outline of control system as follows.

1. Control circuit of main motors

Main motors are controlled in their speed up to 40 rpm by voltage control and from 40 rpm to 100 rpm by field control, then speed control system has two circuits, voltage control circuit and field control circuit. Master controller for speed control is a hand operated cam type, and has 2 notches for voltage control range and 5 notches for field control range ; total 7 notches. In the center of Fig. 2. " C " control desk this master controller is installed and operated by an operator.

In the case of jointly using of voltage control and field control, the curve of ideal acceleration and retardation of motor, i.e. constant current acceleration and retardation, should be the speed changing as shown in Fig. 8. This curve is drawn, considering the decrease of main pole flux in the field control range. τ is the accelerating time to the base speed or the retarding time from base speed. This curve is a straight line up to 40 rpm, and a quadratic curve above 40 rpm. Then in

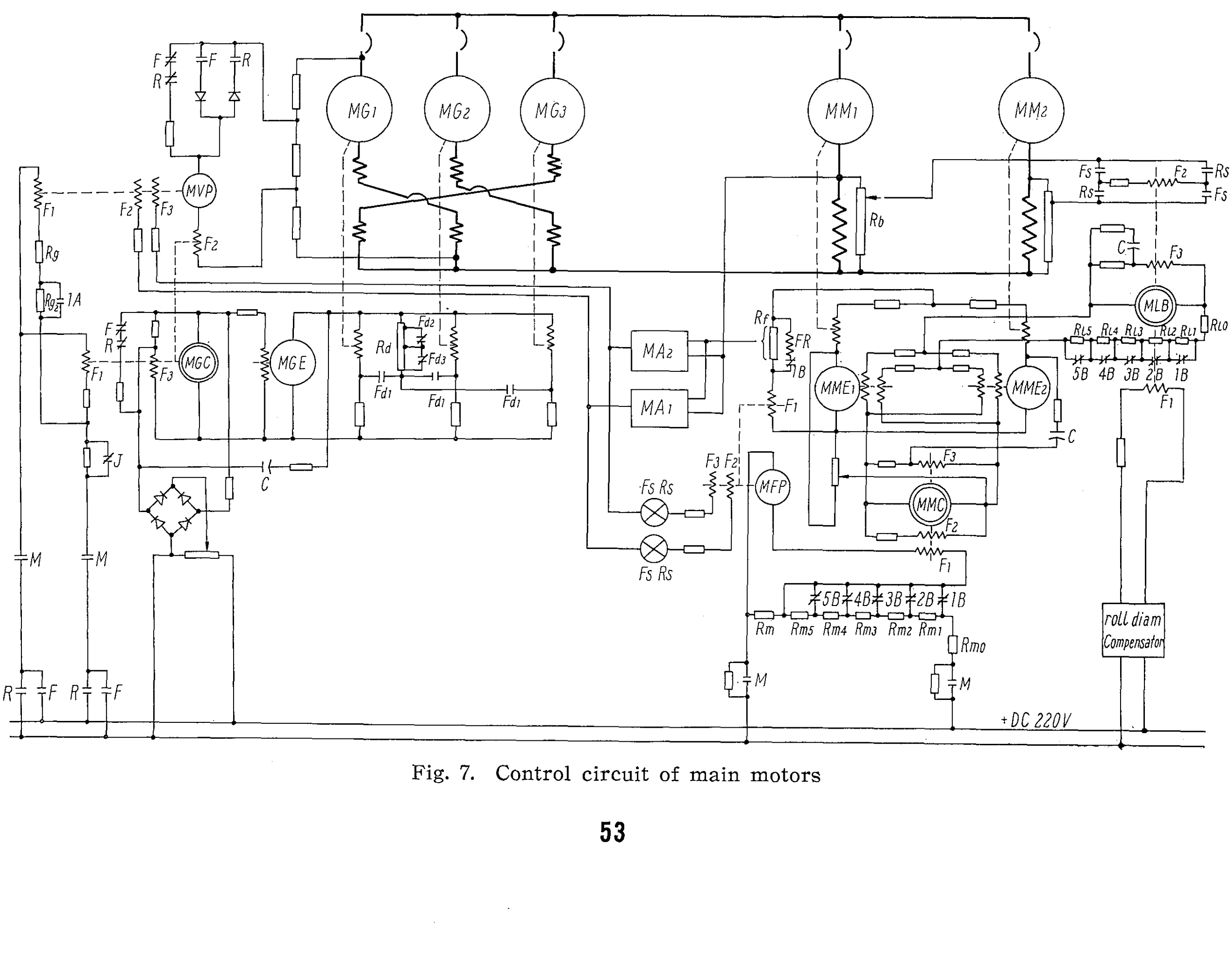

Fig. 7. Control circuit of main motors

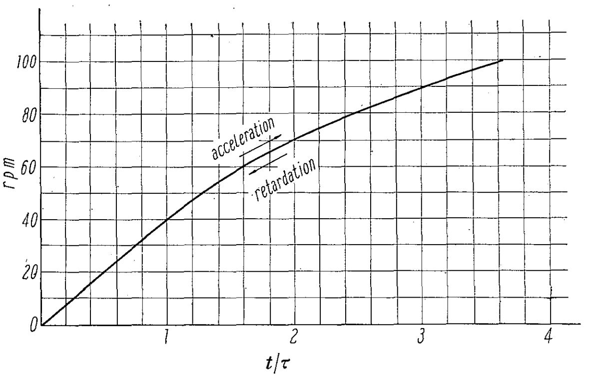

Fig. 8. Ideal acceleration and retardation curve of main motor

voltage control range, the voltage of main generators must build up as linearly as possible, and in field control range the field flux of motors should be changed as to change the speed as nearly as possible to this curve of speed change. Otherwise the relation between voltage control and field control should have also the near behavier to the curve in Fig. 8.

Another for these circuits, this equipment has load balancing circuit of upper and lower motors, compensating circuit for roller diameters, load limitting circuit and demagnetizing circuit. Now we describe the details of these circuits as follows.

1) Voltage control circuit

If we atempt to make the voltage of main generators build up linearly, we must pay attention to the field currents of main generators, which have the nearly propotional relation with voltage. In a field circuit with resistance and inductance, to make the current build up linearly, the exciting voltage must have the linearly changing voltage for resistance part, and furthermore the voltage equal to $L\frac{di}{dt}$ for inductance part. As the $\frac{di}{dt}$ is constant, the inductance voltage is constant. Then the exciting voltage requires this inductance voltage other than the steady voltage, so the exciter for main generators should have the capacity which can cover this overshoot voltage. Rapidyne, which excites field, must have the voltage capacity, which covers the overshoot voltage of the exciter and further the inductance voltage of the field circuit of the exciter, and should be excited forcedly to this maximum voltage.

The F_1 field of Rapidyne for voltage control MGC in Fig. 7 has the action of forcing excitation. In the range of voltage control a certain forcing excitation is supplied to the Rapidyne MGC. So that, when master controller is operated from 0 notch to 1st or 2nd notch, a certain excitation is given to the MGC F_1 field, and the voltages of MGC, MGE and MG build up rapidly. If the 1/3 of the voltage of MG exceeds the voltage of voltage pilot generator MVP, a current flows for the first time through the selenium rectifier to MGC F_2 field. This MGC F2 field has inverse polarity to F_1 field, then finally the excitation of F_2 field balances with that of F_1 field. In the case of notching up from 1st notch to 2nd notch, the current of MGC F_2 field is blocked by selenium rectifier with the rapidly rising of voltage of MVP, and forcing excitation has the same value as the above. Inversely, at the notch down from 2nd notch to 1st notch, the voltage of MVP downs, and the current of MGC F_2 field rapidly increases, then the forcing excitation for voltage down is given. When master controller is returned to 0 notch, the excitation of MGC F_1 field is lossed, and at the same time the MGC F_2 field is excited through the by-pass circuit of selenium rectifier and contactor. This excitation is adjusted to the same forcing excitation as in other cases.

Thus we could make the voltage of MG steeply change. But we must settle this voltage to the final value with perfect stability. As the method of stabilizing, the output voltage of MGC is fed differentially to the MGC F_3 field and the amplitude of MGC is adjusted. Otherwise the output voltage of MGE is fed differentially to the F_3 field of MGC through a condenser and a resistor. We could easily determine the best values of these stabilizing elements by using an analogue computer.

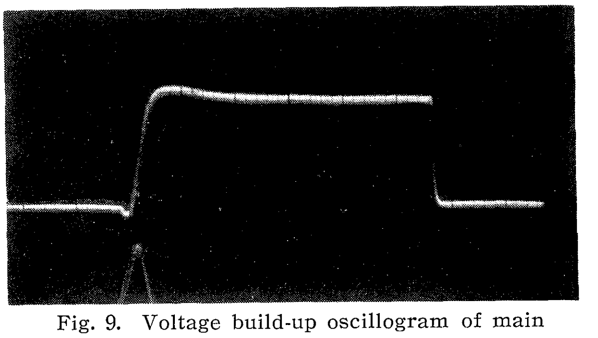

Fig. 9. Voltage build-up oscillogram of main generator by analogue computer
Total time: Equivalent to 5 sec.

In Fig. 9 the voltage build-up oscillogram of MG by analogue computer is shown. We have almost needed no change of the values of resistors etc. in this circuit, determined by analogue computer, at the test both in our factory and in customer's works.

The characteristics of main motors at the case of rapid acceleration and retardation are shown at the oscillogram in Fig. 10. This shows that the accelerating time from 0 to 40 rpm is 0.65 sec. and the reversal time from +40 rpm to −40 rpm is only 0.783 sec., and the behavier of the control circuit is very rapid and stable.

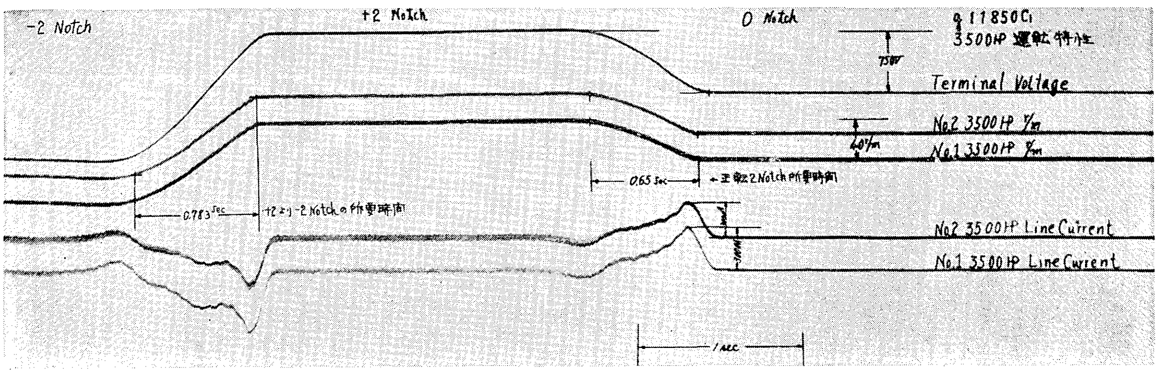

Fig. 10. Rapid acceleration and retardation oscillogram of main motors in voltage control range

2) Field control circuit

The fields of two main motors MM_1 and MM_2 are excited by each exciter, MME_1 and MME_2. Each exciter has two separated fields, which construct a bridge circuit. The Rapidyne for field control MMC so excites this bridge circuit that each field of MME_1 and MME_2 has cumulative polarity. As the total field current of MM_1 and MM_2 is introduced to F_1 field of field pilot generator MFP, the induced voltage of MFP is proportional to the total field current. This induced voltage is compared with the crossing voltage of resistor R_m, which is given potentiometric by the notches of master controller. The difference of these two voltages excites the F_1 field of MMC, then the field currents of MM_1 and MM_2 are established. Of course, MME and MMC have thorough overshoot capacities by which the speed of main motors can change along the curve of Fig. 8. For stabilizing of the field control circuit, the F_3 field of MMC is used as well as in the voltage control circuit.

If the notching contactors 1B···5B are directly operated at the rapid operation of master controller, the speed of main motors changes too rapidly, compared with the ideal curve of Fig. 8, and the accelerating or retarding current of main motors becomes too large. Then the operation of notching contactors has adequate time delays. Moreover, at the operation from weak field to full field the braking current of main motors is apt to become too large. To keep off this phenomenon we have compared the voltages of MME_1 and MMC, and if the voltage of MMC becomes over the anticipated voltage of MME_1, a current flows through the F_2 field of MMC, then automatically the voltage of MMC downs.

If the master controller is rapidly operated from the voltage control range to the field control range or reverse, and a change begins before another change has not finished, the accelerating or retarding current of main motors of course becomes too large. Ordinally the current at acceleration is not so large, because the response time of voltage control is shorter than the response time of field control. But at retardation from top speed to stopping or reversing, the current becomes considerably large. For these phenomena, we have held the notching contactor 1A closed if the field current of main motors has not increased to a sufficient value. The relay FR in Fig. 7, which is inserted to the both end of resistor R_f in the field circuit of main motors, is an over-voltage relay for this purpose. The back contact of contactor 1B, which is inserted in series to FR relay's coil is to reset the FR relay.

The oscillogram in Fig. 11 shows the behavier of the main motors at rapid operation of master controller up to the field control range. The interlocking by FR relay is clearly shown, but this is too effective, then the curve of speed has a step.

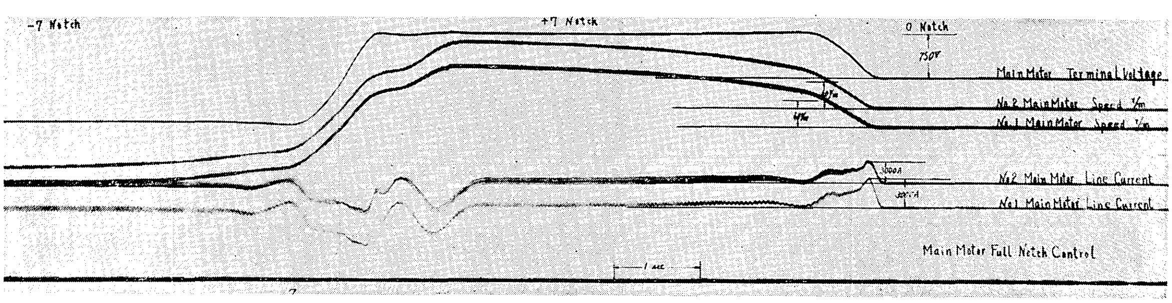

Fig. 11. Rapid acceleration and retardation oscillogram of main motors in full control range.

This curve is easily adjustable by adjusting the operational voltage of FR relay.

3) Control circuit of roller diameters and load balancing

As one significance of twin drive system, if the diameters of upper and lower rollers are different, these are easily compensated by electrical circuit. For this, the speed settings of two motors should be different according to the ratio of diameters of upper and lower rollers. Hence, to make the field current of motors different, we have supplied a voltage to the opposite point of the bridge circuit of the fields of MME, and made the voltages of MME_1 and MME_2 different. To this point the load balancing Rapidyne MLB is connected, and the F_1 field of MLB is excited by roll diameter compensator, which is adjusted according to the ratio of diameters of main rollers. The output current of MLB is readjusted to the adequate values by series resistors $Rl_0 \cdots Rl_5$, which are selected by the notches of master controller. The excitation of the MLB F_1 field is finely controlled by roller diameter compensator from -10% to $+10\%$ of speed ratio. Then operator can continue the rolling without difficulty if the ratio of diameters of upper and lower rollers is within 1.1 : 1.

In the case of separate drive of upper and lower rollers, a slub under rolling warps if the characteristics of two motors are different even a little. This means the difference of works done by each motor. This defect can be eliminated by using an automatic load balancing equipment. As the two main motors are connected in parallel to one bus, the field currents of main motors are so adjusted that the load current of main motors become equal. That is to say, the field of over-loaded main motor is strengthened, then its induced voltage becomes larger, and the field of under loaded motor is weakend, then its induced voltage becomes smaller. Thus the difference of load currents can be minimized. As shown in Fig. 7, the differential voltage of IR drops at commutating windings of main motors excites the F_2 field of MLB, then the induced voltage of MLB is proportional to the difference of load currents. In the case of these system of load balancing, ordinally the gain of load balancing circuit increases extremely at weak field. Because at weak field, if the current, fed from MLB to the field circuit of MME, is constant for a certain difference of load current, the ratio of this current to the setting current of field increases extremely, and the flux change of main motors to the change of field current becomes large by the effect of saturation of flux. In these cases it is difficult to establish a load balancing circuit with sufficient stability and gain for all field control range. But at the circuit of Fig. 7 resistor $Rl_0 \cdots Rl_5$ are inserted to the output circuit of MLB by the field control notches of master controller, so that the change of speed of main motors, that is, the change of flux ratio is constant for a certain constant voltage of MLB. This means that the gain of load balancing circuit is held constant at every notch in field control range. Generally, a control system detecting load current is apt to become unstabilizing if man wants to make the gain of the circuit and the accuracy of control higher, because there exists a time delaying system of moment of inertia in addition to the time delays of field circuit of machines. But we have been able to obtain without difficulties a very stabilized system of control for this constant gain of circuit, and as a stabilizing we have used only a negative feed back to MLB F_3 field with a resistor and a condenser as shown in Fig. 7. In Fig. 12 a response oscillogram of this circuit by analogue computor is shown.

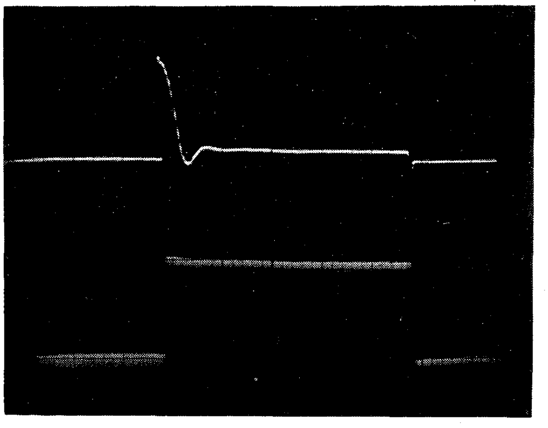

Fig. 12. Load balance response oscillogram of main motors by analogue computer
upper: load current difference
lower: load unbalance signal
total time: equivalent to 10 sec.

Because the direction of current balancing in this circuit should be changed over according to the direction of rotation of main motors, directional relays F_S and R_S change the polarity of F_2 field of MLB. This directional relays are operated by the polarity of voltage of main circuit through selenium rectifiers and over-voltage relays. We could not use the contactors F and R of master controller for this purpose, which have a time difference to the direction of rotation of main motors. The difference of time between the polarity of voltage and direction of rotation is negligibly small.

If man wants to change intentionally the portion of loads for two motors according to the situation of rolling, he can adjust the ratio of detecting currents by the potentiometric regulator R_b connected to the commutating winding. Fig. 13 shows the oscillogram of the currents of upper and lower

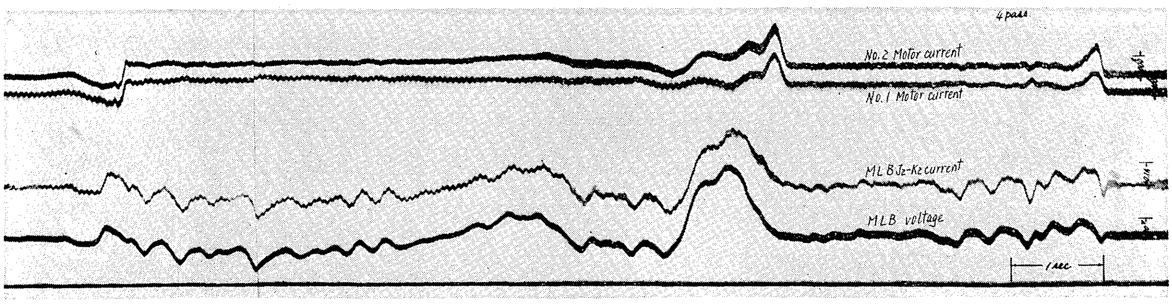

Fig. 13. Oscillogram of load balancing circuit at actual rolling

motors and the operation of MLB at actual rolling.

4) Load limiting circuit

When a over-load causes in main motors, it is needed that the rolling can be continued by drooping the speeds automatically before trip of main circuit breakers. For this, we used magnetic amplifiers MA_1 and MA_2 which have back-rush characteristic, so if load current becomes over a certain value, voltage of main generators is droped by supplying the output of magnetic amplifiers to F_2 or F_3 field of MVP and at the same time fields of main motors are strengthened by supplying to F_2 or F_3 field of MFP. Conversely, for the excess of braking currents, the currents are suppressed by rising voltage of main generators and weakening the field of main motors. MA_1 and MA_2 are used as a push-pull amplifier and adjust their starting points of operation by giving biases to their control windings. Regarding to character of main motor, at weak field the magnetic amplifiers should begin their operation at smaller value of load currents than at full field. For this purpose, the biases of magnetic amplifier are given from the voltage drop at resistance R_f, which is proportional to the field current of main motors, and from the constant potential source. Then the starting point of magnetic amplifiers is 200% load current at full field and 160% at weakest field. For the direction of rotation of main motors, as to voltage side the polarity of limitting action is not necessary to be changed but as to field side it must be changed, so it is changed over by the directional contactors F_S and R_S which are used in load balancing circuit.

5) Demagnetizing circuit

If any accident occurs at rolling, it is ordinary practise that circuit breakers at main circuit are tripped together, but it takes more time to restart. Especially at high speed rolling if a slub runs out and circuit breakers are tripped, it needs pretty time to stop, because main motors have no braking action. In the case of over-current in voltage control range and over-wattage in field control range, we do not trip the circuit breakers of main circuit but use demagnetizing circuit, which acts to stop main motors quickly without excess of braking current, and we intend to shorten the restarting time at an accident. When over-current or over-wattage relay operates, main contactors of control M shown in Fig 7, are released, and these make signal for voltage control circuit to zero, and at the same time insert resistors into the signal circuit of field control to make the excitation of main motors nearly minimum. At that time, decrease of voltage of main generators is very rapid and more speedy than that of field excitation of main motors, so there is a fear that the braking current becomes very large and trips main circuit breakers automatically. Then to the fields of main generators a discharging resistor R_d is inserted by contactors F_{d1} to suppress sudden change of field currents, and after certain period contactors F_{d2} and F_{d3} are released one after another to make the braking currents equalize at the all time. By this device the operation of relays under any condition does not trip circuit breakers and stop the main motors quickly and safely. It is possible to reclose M immediately and restart rolling. Closing of M contactors needs the condition that the master controller is at 0 notch.

Otherwise, as protecting devices we prepared over-voltage relay, over-speed relay, under-field current relay etc. and established perfect protection system.

2. Control circuit of edger motor

At this roughing mill a slub is rolled by edger rollers and main rollers at the same time, so between the speeds of edger motor and main motors there is required synchronous relation and a ratio to correspond to draft, which is concerned to the reduction of slub thickness at main rollers. At this roughing mill, a preset control system is applied to the screw down of main rollers, so quantity of draft is decided beforehand about every pass. For synchronous operation to main motors and getting a speed ratio to correspond to preset draft at the same time, we covered the all speed range of edger motor only by voltage control. Therefore edger generator becomes large size naturally, but it is more useful to compare with simplicity of control circuit. Edger motor has double armature construction and these armatures are parallelly connected to the edger generator, and the fields are also parallelly excited from constant potential source. Besides, by inserting economize resistor to the field circuit, power consumption at rest time is curtailed. By inserting series dead resistors R_a to each armature, the motor has drooping character of speed and at the same time they are used for detecting current to load limitting circuit.

1) Voltage control circuit

As shown in Fig. 14, voltage of edger generator EG is controlled by an exclusive exciter EGE and a Rapidyne EGC. Refference value of speed is supplied to F_1 field of EGC, and in the case of cooperation with main motors it is supplied from the voltage of tachometer-dynamo T attached to main motor. For the preset of draft aforesaid, one of the contactors 1D···5D is opened and by inserting resistor in series to F_1 field of EGC 20∼45% draft is established. In the case of jogging by changing over the contactor SE and operation of contactors F or R, hand operated controller gives a signal to EGC F_1 field from constant potential source. The voltage of edger generator EG is fed back to F_2 field of EGC and compared with refference excitation of F_1 field. As same as main generators the stabilization of this circuit is made by giving negative feed back to F_3 field of EGC with combination of resistors and a condenser. In Fig. 15, there is shown the voltage response of edger generator to a step input by analogue computer, and Fig. 16, shows the voltage response to the linearly changing signal which in shown at lower part. About actual circuit, build up time of voltage is nearly 0.4 sec. to a step input.

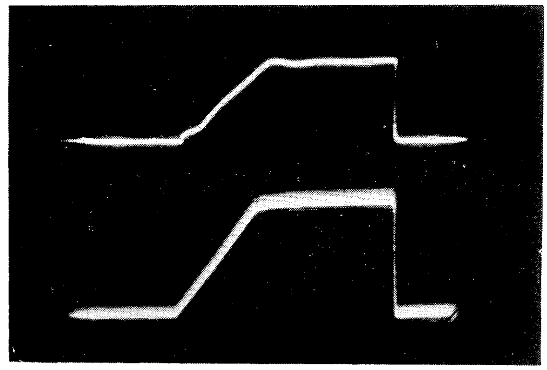

Fig. 16. Voltage response oscillogram of edger generator to linearly changing signal by analogue computer
upper: Voltage
lower: signal
total time: equivalent to 10 sec.

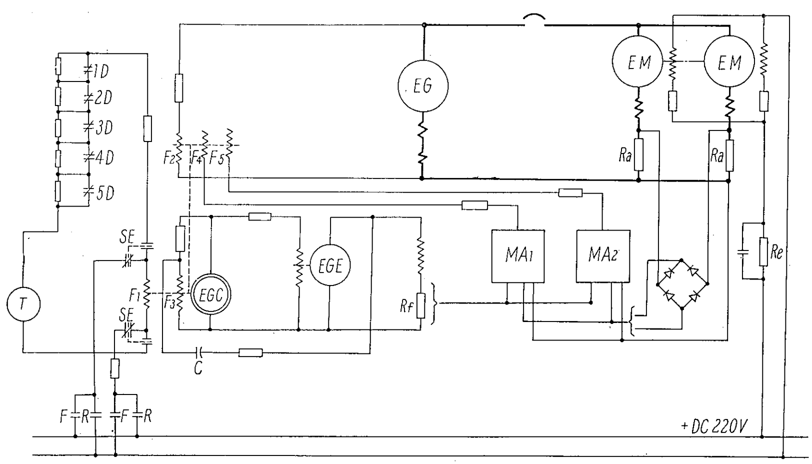

Fig. 14. Control circuit of edger motor

Fig. 15. Voltage build-up oscillogram of edger genetator by analogue computer
total time: equivalent to 5 sec.

2) Load limiting circuit

As a slub is rolled by edger roller at the same time as rolled by main roller, if we missed the setting of draft, there causes a fear of over-load or over-braking in edger motor. Then, when the armature current of edger motor becomes over a certain positive or negative value, it must be limited by reducing or rising the speed of edger motor. Of course, this limiting value of current must be reduced at high speed, so the limiting action should be operated not by current but by power.

In this equipment, as same as main motors, we have used push-pull magnetic amplifiers MA_1 and MA_2 of back-rush characteristic and these output have excited F_4 or F_5 fields of EGC. As a signal input to MA_1 and MA_2, voltage drop at resistor R_f inserted to the field of edger generator is taken for a voltage element and voltage drops of resistors R_a inserted in series to the armatures of edger motor are used for current elements. These R_a are inserted to each armature, combined with selenium rectifiers and one larger current signal of them is fed to MA_1 and MA_2 in preference to other. The voltage element and the current element are summed up in magnetic amplifier, and when this value becomes over a certain value, MA_1 or MA_2 begins to operate.

VI. D-C MOTORS FOR MILL AUXILIARIES

1. Motors

As shown in Table 1, amount to 179 d-c motors are used for mill auxiliaries as to only roughing mill, and all of them are the standard motors for mill auxiliaries by JEM 1109 (Standard of Japan Electrical Manufacturer Association). But in U.S.A., as the motors of variable voltage control for table rollers the standard motors of rated voltage 550 V are used by changing their armature voltage, and in Japan the standard rated voltages are 220 V and 440 V, so these motors are off-standard. Therefore, we have developed the standard motors of rated voltage 550 V by AISE standards, and applied them

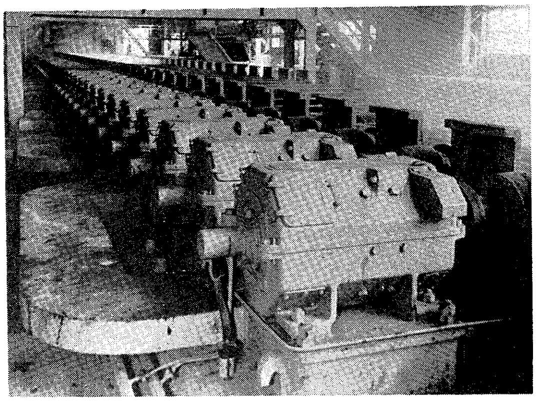

Fig. 17. Motors for rougher run out table roller

Table 1. Table of auxiliary d-c motors

Service	Motor							Control	Control desk
	Units	Frame	Output (HP)	rpm	Volt.	Field	Rating		
Furnace entry tables ($F_{1\sim7}$)	7	610	50	550	220	comp.	1 hr.	Rev., Dynamic brake, Plugging	A
Double furnace pusher (DFP)	4	616	150	460	220	comp.	1 hr.	Rev., Dynamic brake, Plugging	A
Furnace delivery tables ($A_{1\sim4}$)	4	610	50	550	220	comp.	1 hr.	Rev., Dynamic brake, Plugging	B
Furnace delivery table side guide (SG 1)	1	604	15	725	220	comp.	1 hr.	Rev., Dynamic brake, Slow down	B
RSB screw down (SD 1)	1	610	50	550/1650	220	special comp.	1 hr.	Rev., Dynamic brake, Slow down	B
RSB feed rollers (FR)	2	602	7.5	900	220	comp.	1 hr.	Rev., Dynamic brake, Plugging	B
RSB delivery table (B_1)	16	606	10	280	220	shunt	cont.	Rev., Leonard control	B or C
Rougher approach table (B_2)	17	606	10	280	220	shunt	cont.	Rev., Leonard control	B or C
Rougher approach table (B_3)	17	606	10	280	220	shunt	cont.	Rev., Leonard control	C
Front mill table (B_4)	17	608	14	250	220	shunt	cont.	Rev., Leonard control	C
Back mill table (C_1)	17	608	14	250	220	shunt	cont.	Rev., Leonard control	C
Front & back mill table side guide ($SG_{2,3}$)	2	604	15	725	220	comp.	1 hr.	Rev., Dynamic brake, Slow down	C
Edge housing adjust (HA)	1	610	50	550	220	comp.	1 hr.	Rev., Dynamic brake, Slow down	C
Rougher screw down (SD_2)	2	614	100	485/970	220/440	shunt	cont.	Rev., Leonard double voltage control	C
Rougher run out table-1 (C_2)	17	606	10	280	220	shunt	cont.	Rev., Leonard control	C
Rougher run out table-2 (C_3)	18	606	10	280	220	shunt	cont.	Rev., Leonard control	C or D
Rougher run out table-3 (C_4)	18	606	10	280	220	shunt	cont.	Rev., Leonard control	C or D
Crop shear approach table (C_5)	18	606	7.5	280	220	shunt	cont.	Rev., Leonard control	D

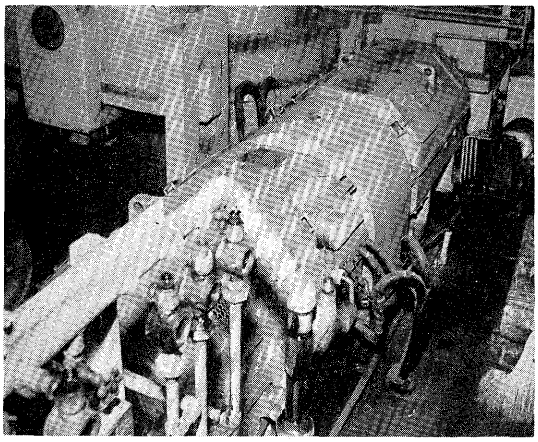

Fig. 18. Motors for rougher screw down

at voltage 220 V. Every table roller is directly coupled to each motor, and 16～18 motors are controlled by one Leonard generator. In Fig. 17, the group of table motors for rougher run-out table rollers is shown. The motors for roughing mill screw down, shown in Fig. 18., are controlled by double voltage Leonard generators, and in the case of connected operation with magnet coupling the load balancing circuit for two motors is constructed.

2. Control system for variable voltage auxiliary motors

Variable voltage motor is rapidly acceleralated or retarded by Leonard generator and Rapidyne shown in Table 2. In Fig. 19, two motor-generator sets, shown at backward of the photograph, are the Leonard generators and two small set at center of the photograph are the Rapidynes.

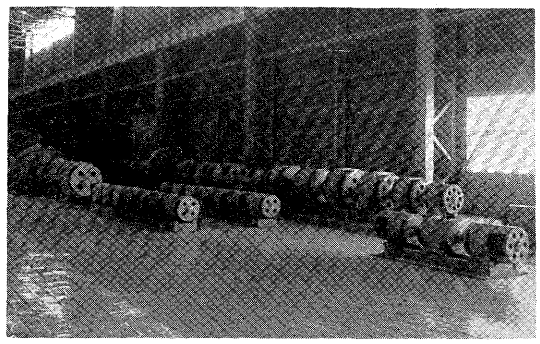

Fig. 19. Motor-generator sets in electrical room

Table 2. Table of Leonard generators for variable voltage auxiliary motors and Rapidynes

Service	D-c Generator						Rapidyne				Control
	Units	Frame	Output (kW)	Volt.	rpm	Rating	Units	Output (kW)	Volt.	rpm	
Rougher screw down (SD_2)	2	GM312	100	240/480	1200	cont.	2	2	200	1750	Curr. limit, Load balance
Tables (B_4, C_1)	2	GM312	250	240	1200	cont.	2	2	200	1750	Curr. limit
Tables (B_{1-3} C_2-C_5)	8	GM302	180	240	1200	cont.	8	2	200	1750	Curr. limit (1 set spare)
C.P. exciting source	2	GM265	120	230	1200	cont.	—	—	—	—	—
Driving motor	2	PF 405/21-6 1300 HP 3,300 V 3ϕ 60c/s p.f. 0.8 lead (Synchronous motor)					2	40 HP 200V 3ϕ 60c/s (Induction motor)			

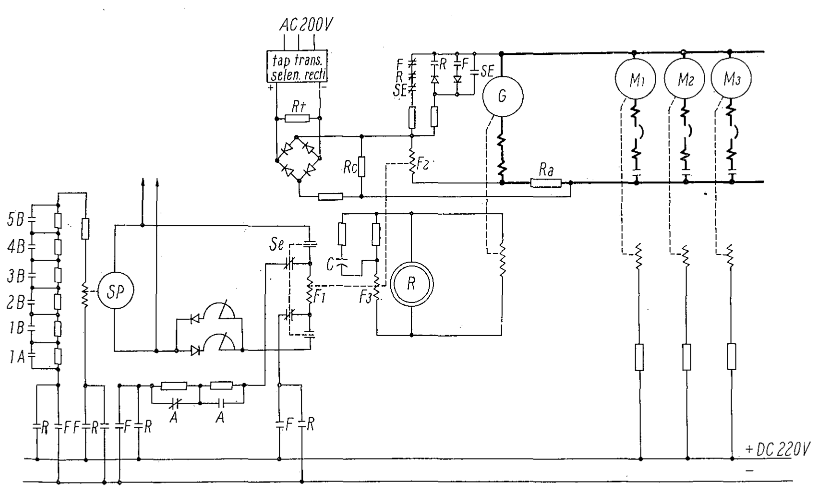

Fig. 20. Control circuit of table motors

As an example of control system for variable voltage auxiliary motors, we have shown control circuit of table motors in Fig. 20. Rapidyne *R* directly excites the field of generator *G* and the signal of speed standard is supplied to the F_1 field of *R*. In the case of cooperation with main roller of roughing mill, this standard signal is supplied from the voltage of speed pilot generator SP, which is controlled by the notches of master controller for roughing mill, and for forward and reverse rotation 2 sets of selenium rectifier and rheostat are inserted into this circuit to adjust the speed ratio separately. This voltage of SP is used further for the speed signal to another groups of table motors. In the case of individual operation we change over a contactor SE and give a signal from constant potential source which is manually controlled by contactors F, R and A etc. The F_2 field of R is excited by the voltage of generator G and further has a action of limiting over-current. That is to say, if voltage drop at resistor R_a inserted to main circuit becomes over the voltage at both end of resistor R_l, which is fed from a-c source through a tapped transformer and selenium rectifier, then a current flows into the F_2 field of R through bridge connected selenium rectifiers and the voltage of G downs and the load current is suppressed. Rheostat R_c controls drooping character of generator G. F_3 field of R is used for stabilizing of circuit. In Fig. 21, an oscillogram of table motors and its generator is shown, where the table motors are rapidly accelerated by manual controller.

Screw down motors for roughing mill are accelerated, retarded or slow down by manual controller or signals from preset control panel. The system of control circuit is nearly same as that of table motors, except that the F_3 field of R has still more a load balancing action of two screw down motors. The situation of rapid acceleration of these motors is shown in the oscillogram of Fig. 22.

3. Control system for constant potential auxiliary motors

The constant potential auxiliary motors start, stop and reverse their rotation individually. Motors which are required quick stopping have circuits of plugging together with dynamic braking.

Motors, machines of which are required precise stopping position, are retarded to slow speed automatically by the signal from limit switches and stopped using magnet brakes. As these magnet brakes we have used standard magnetic brakes for mill auxiliaries by JEM 1120.

VII. CONCLUSIONS

We have introduced about 7,000 HP Ward-Leonard electric equipment for roughing stand of the hot strip mill. By accomplishment of this set with an electric equipment for finishing stands of hot strip mill which we had supplied to Chiba Works of Kawasaki Steel Corp. last spring, we have been able to complete all electric equipment for hot strip mill. To our great delight, all of them have been operated with good results.

Basing on valuable experiences by accomplishing this equipment, we will make up our mind to effort for continuous study and advance for electric equipments of steel mills.

Finally we want to express our heartfull gratitude to stuffs of Yawata Iron and Steel Corp. who instruct us at the stages of planning, manufacturing and testing of this set.

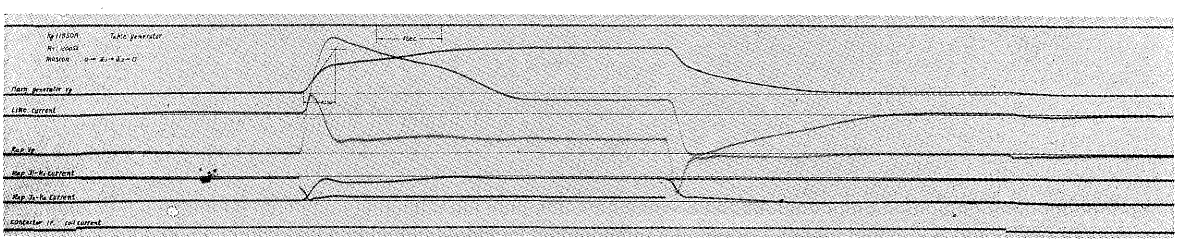

Fig. 21. Rapid acceleration oscillogram of table motors

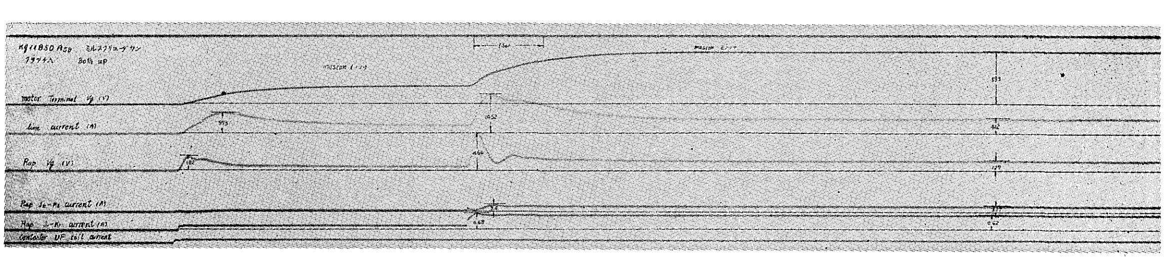

Fig. 22. Rapid acceleration oscillogram of rougher screw down motor