ELECTRIC EQUIPMENT FOR SECTIONAL DRIVEN PAPER MACHINE

By

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I. FOREWORD :

Stationary Leonard equipment for common-shaft-driven paper mills which Fuji Denki supplied to Niigata Plant of the Hokuetsu Paper Mfg. Co., and Jujo Plant of the Jujo Paper Mfg. Co. are now enjoying a high reputation among the users. Recently, moreover, the company has been successful in completing a Sectional Drive System in which it adopted, for the first time, in Japan the stationary Leonard equipment, although technically such equipment requires high precision for electric power application and there is a difficulty in the power control. Fortunately it has achieved an excellent result as well as other new devices adopted together. The author will attempt to explain briefly the outline of their mechanism and functions in this Article.

II. PAPER MILL AND ITS DRIVING SYSTEM

The paper mill consists of a couch, press, dryer, calender and reel sections all related continuously in this order. Paper is produced through the following process : in the couch section the white water (liquidated paper) pushed out of flow box and after being sliced is carried on the wire meshes, losing water content to become a wet paper ; then at the press section it is strongly pressed and as it passed through many steam-heated dryer cylinders and cloths, the moisture is gradually removed ; the calender section give the dried paper the beautiful and even luster by the friction and pressure of the rollers ; finally the reels of the reel section wind up the paper. The speed of paper making varies acording to the quality of paper. That is, generally slow speed for good paper and faster for cheaper paper. Especially for news paper use, high speed of paper production is required ; for instance maximum 1,300–1,500 ft/min in Japan while 2,000–2,400 ft/min in Europe and America.

The speed of paper mill must be kept exactly constant to limit the thickness of paper in a permissible limit.

Also the paper obtains elongation (or shrinkage for some kinds) as it passes the process of pressing and drying. Therefore, it is necessary to provide some difference of speed between the sections, which is called " draw ". The draw must be adjustable in an easy way because its proper degree differs according to the quality, moisture contents and production speed and other compricated conditions of the paper. On the other hand, however, if the proper degree is once set up it must be kept constant being free from any disturbace such as change of voltage, cycles and load, for if the draw fluctuates there would be tearing-off or wrinkle of the paper. It is an important technical problem that every section of paper making machine can be precisely controlled for its relative and absolute speed of the operation.

There are two ways of driving a paper mill : one is "Common shaft drive" system in which one motor drives all the sections, while the other " Sectional drive " system employing different driving motors, one each on every composing section. The machines of high speed and large capacity which require precise control are generally of the sectional drive system. The ways of motor control for each section can be classified roughly into two ways : the position control system and the speed control system. Fig. 1 shows the theory taking up a very simple example. The speed control system is of an elect-

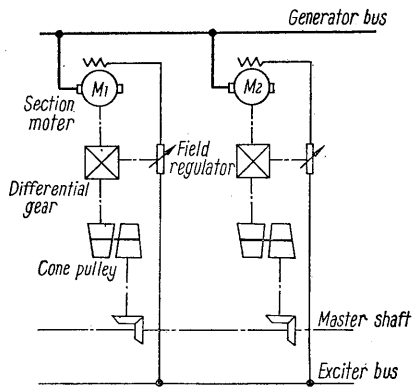

Fig. 1 (a) Position control system for section motors

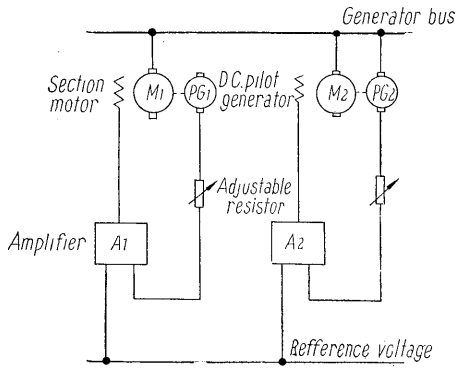

Fig. 1 (b) Speed control system for section motors

rical control and relatively simple but there is a difficulty in keeping accuracy of d–c pilot generators and industrial voltage standard and tension or slack among sections caused by the accumulation of minute errors. The position control system is a kind of mechanical control employing cone pulleys, differential gears and others. Its mechanism is rather complicated. It is inferior in its swiftness of response, but because of adopting the revolving speed (or cycles) as the operation standard, it guarantees high precision for industrial purpose. Moreover, the position controll system overcomes the excessive tension or slack among the sections. Also some devices to increase speed response have been made on the mechanism. Such are the reasons why the improved type of position control system is employed in this requisition.

Table 1. Section motor HP and standard draw

Section	Motor HP (at 1,800 ft/min)	Standard draw (%)
Couch	180	7
No. 1 press	60	2
No. 2 press	60	2
No. 1 drier	180	0
No. 2 drier	150	0
Calender	180	
Reel		

III. OUTLINE OF EQUIPMENT AND CONTROL SYSTEM

1. Specification of Paper Machine

The paper machine described here is a fourdrinior type for newsprint manufacture having a width of 142 inches. Driving motor horsepower and standard draw of each section are shown in Table 1. The draw is indicated by the percentage of the value obtained by subtracting the peripheral circumferential speed of the preceding roll from that of the roll following it against that of the No. 2 drier. Although the rated paper making speed is 1,800 ft/min., speed can be varied over the range from 800 to 2,000 ft/min. However, with the present equipment, the actual paper making speed is up to approximately 1,500 ft/min. and for speeds above this, auxiliary equipment (helpers) is required.

2. Section Motor and Its Reduction Gear Set

Each section of the paper machine is driven by

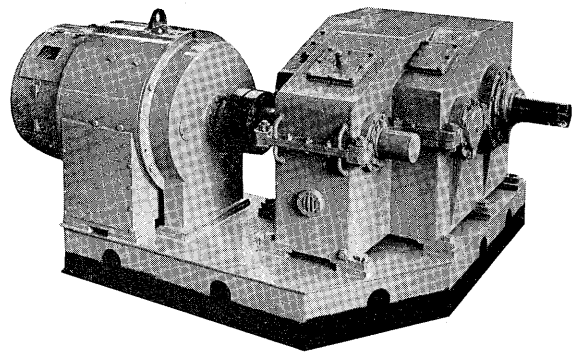

Fig. 2. 180 HP d–c motor and reduction gear set (gear ratio 5.24) for couch section drive

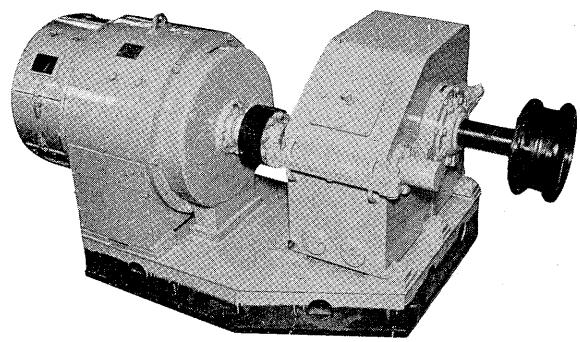

Fig. 3. 60 HP d–c motor and reduction gear set (gear ratio 5.40) for No. 1 press section drive

three 180 HP motors (Fig. 2), one 150 HP motor, and two 60 HP motors (Fig. 3), a total of six d–c motors. The rated speed and voltage selected are 1,200 rpm and 600 volts respectively. The motors are enclosed forced-ventilated type and are made

Table 2. Specification of reduction gear set

Section	Motor HP	Motor speed (rpm)	Gear ratio	Gear stage	No.
Couch, Calender, Reel	180	1,200	5.24	2	2
No. 1 Press, No. 2 Press	60	1,200	5.40	1	2
No. 1 Drier	180	1,200	10.26	2	1
No. 2 Drier	150	1,200	10.26	2	1

moisture-proof. The field consists of a stationary winding and two control windings for back and boost actions. Since it is desirous to maintain the speed fluctuation rate of the motors themselves as small as possible in order to increase the accuracy in their speed control, a special consideration has been given to this problem. The speed control (co-operative running) of the section motors is made by a draw regulator as explained later. The three phase synchronous generator used for detecting the rotational speed is contained in the section motors. This a-c generator winding is common to the motor winding, and three phase alternating current is drawn through the slip rings. The frequency of this current is 40 cycles/sec. at 1,200 rpm.

The reduction gear set is as specified in Table 2. The material used is carefully selected so as to withstand the speed of 2,000 ft/min. (motor speed 1,333 rpm). The material for the pinion is Ni-Cr steel and the gears are double helical gears made of cast steel. In order to withstand long use, the gears are at first high frequency hardened and then ground to increase the surface hardness of the gear teeth. Spherical roller bearings are used.

3. Mercury Rectifier

A pumpless air-cooled multi-anode mercury rectifier having a special rating of 984 kW., 667 volts and 1,475 amperes was selected as a power source for the above-mentioned six d-c motors and a 180 HP driving motor for the white water pump

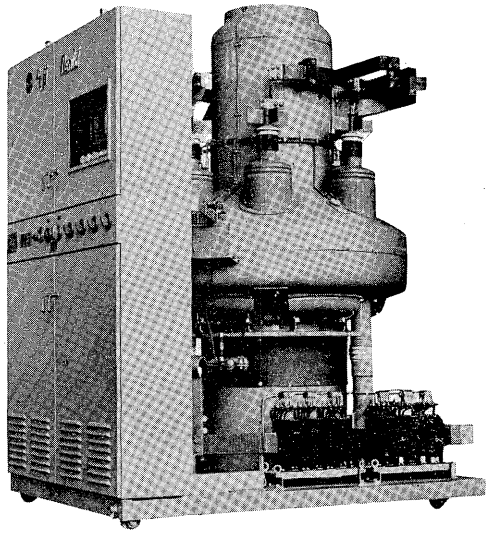

Fig. 4. 984 kW Pump less air-cooled multi-anode mercury rectifier and auxiliary runing cubicle

(Fig. 4). The specification of the transformer used for the rectifier is 1,250 kVA, 3/6 phase, 3,150/693 volts, 60 cycles/sec. and has a self contained inter-phase reactor. This rectifier for use with the sectional drive of the paper machine is the first one made in our country and its performance is being watched with interest. The rectifier has high efficiency, excellent voltage control and simplicity in installation and maintenance, etc. Recognized of these merits they are in a tendency to be widely used in this industry.

In response to the paper making speed of 800–2,000 ft/min., the capacities of the phase shifting reactor and the interphase reactor are selected so that the output voltage can be controlled at will by a grid control between approximately 267 and 667 volts. However, to depend on grid control only for the control of the voltage over a wide range will result in an undesirable fact that power factor will become low in proportion to the grid factor. Therefore, a N.V. tap changing device is installed on the primary side of the transformer of the rectifier so that against primary voltage of 3,150, secondary voltage can be changed in 9 steps between 693 and 414 volts. By selecting a tap suited to the paper speed, voltage can be controlled over a wide range with a comparatively small grid control range and a high power factor operation can be obtained.

4. Outline of the Control System

The control diagram of the equipment is illustrated in Fig. 5. Each section motor is equipped with a common mercury rectifier as its power sourse and its speed control for co-operative running is made by the field control. To prevent the occurrence of any disturbance in the speed of the section motors due to fluctuations in the voltage of the power source, an automatic voltage regulator is equipped on the mercury rectifier to correct immediately any voltage fluctuations in the power source. The field of the section motor is controlled by the speed control magnetic amplifier. This is accomplished by detecting the speed difference between the d-c motor for producing standard rotational speed (master motor) and each of the section motors. This detection is made by the use of differential gears and it is so controlled that the rotational difference becomes zero. The adjustment of draw is made by the cone pulley located between the master motor and the differential gear.

No. 1 drier is coupled to No. 2 drier by means of gears. The driving motors for each of the driers are controlled in such a way that the load is always divided in proportion to their rated outputs. In order to do this, the difference in the load currents of both motors is detected and fed differentially into the speed control magnetic amplifier to obtain balanced control of the load current.

The master motor which produces the standard rotational speed, is controlled by a generator using

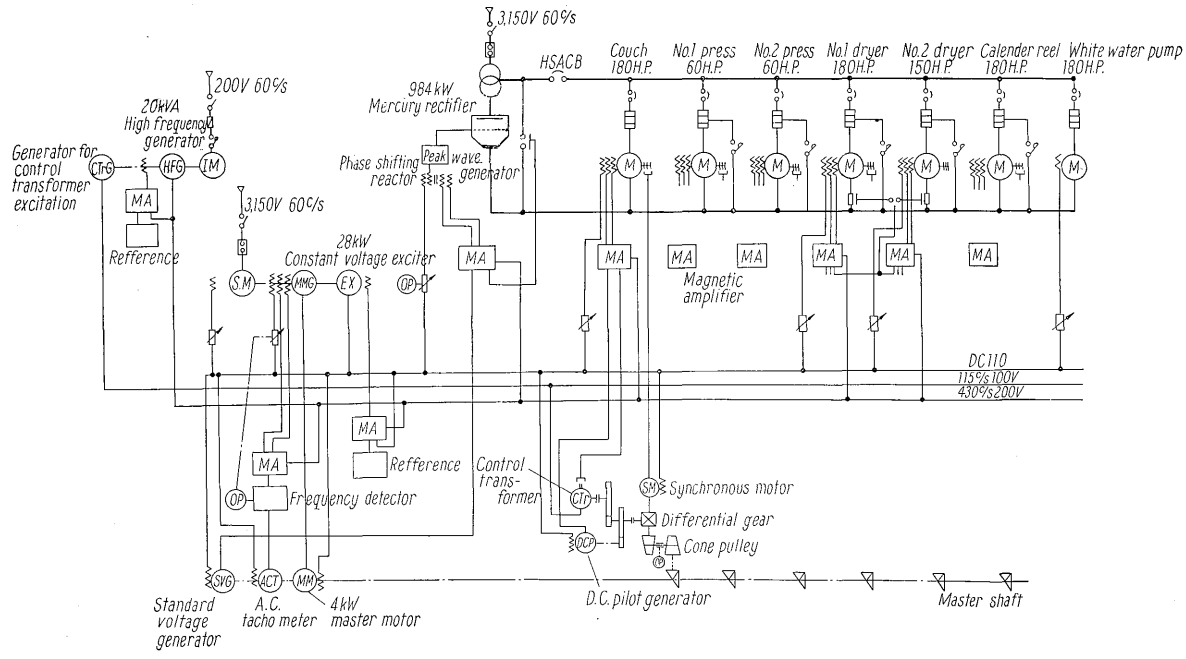

Fig. 5. Control diagram for paper machine sectional drive

the Leonard method, and this speed is accurately maintained to a constant value by a speed regulator which controls with precision the frequency of an a–c tachometer dynamo directly attached to the master motor. Moreover, a standard voltage generator is directly coupled to the master shaft (standard rotational shaft driven by the master motor) to generate a constant d–c voltage proportional to the rotational speed of the master motor. This generated voltage is used as the standard voltage for the automatic voltage regulation of the mercury rectifier. In this way, the output voltage of the mercury rectifier becomes proportional to the rotational speed of the master motor, and each section motor is operated with almost the same rotational speed as that of the master motor without changing the field ampere turns. Therefore, whenever it is required to change the paper speed, a large control action is not necessary for the speed control of the section motor.

Also since the voltage of the exciter must be maintained accurately to a constant value, an automatic voltage regulator is attached. Each automatic regulator is a magnetic amplifier type and a 20 kVA, 430 cycle/sec. high frequency generator is used as power source. In order to maintain the output of this power source always at a fixed value, a magnetic amplifier type automatic voltage regulator operating at 430 cycle/sec. is attached. Therefore, practically no error is produced by the regulators on account of voltage fluctuations in the power source. Although the construction of the entire equipment is as described above, a more detailed explanation concerning the specially important co-operative running of the master motor and the section motors is given below.

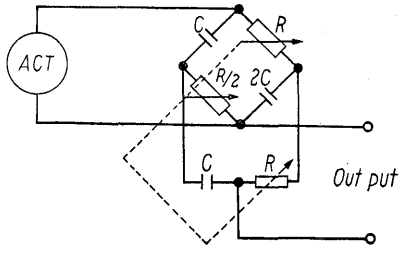

Fig. 6. Double T type bridge for frequency detection

5. Precision Control of Rotational Speed of Master Motor

The most important part of the speed control of this paper making machine is the rotational speed control device of the master shaft which produces the standard speed of the paper. Therefore, a detector of extremely high sensitivity is attached to control the speed of the master motor. For the detection of rotational speed, an a–c tachometer dynamo is used. The generated frequency from this dynamo is fed into an extremely high sensitive frequency detector consisting of a combination of a double T-type frequency bridge as shown in Fig. 6 made up of resistors and condensers and a special magnetic amplifier having a synchronous rectifying action. The characteristics of this detector is shown in Fig. 7. With this special type of detector, the error produced is approximately 0.03～0.04% for

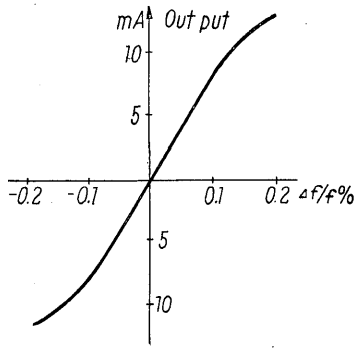

Fig 7. Characteristics of frequency detector

temperature variation of ±10°C. Hence, a very high accuracy can be obtained. There are the usual two stages of push-pull amplifiers following this detector unit and the output from this amplifier is used to control the field of d–c generator which is the power sourse of the master motor. 4–ganged resistors are used as variable resistance elements of the double T–type bridge as shown in Fig. 8. Three of the

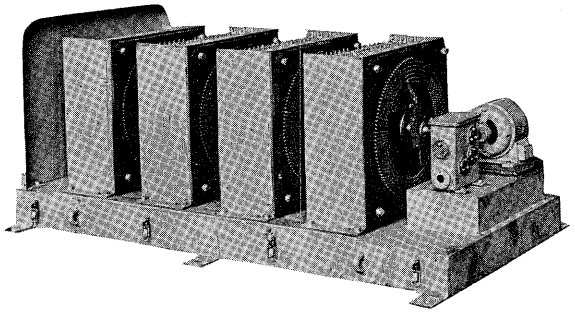

Fig. 8. 4-ganged resistor for machine speed setting

4–ganged resistors are the variable resistance elements of the double T–type bridge and the remaining one-gang controls the fixed magnetic field of the generator for master motor by changing the field excitation so that the master motor will maintain the standard rotational speed. The 4–ganged resistors for establishing the paper speed between 800～2,000 ft/min. have 720 notches including dummy notches to change the paper speed at the rate of 2 ft/min. during the paper making operations. Since there are a large number of notches, the fixed contact buttons are arranged spirally on an insulation board. The moving brush is fixed at the end of a sliding arm which is mounted in such a way that it slides inside the support mounted on the driving shaft.

6. Co-operative Running of Section Motors

The co-operative running of section motors is accomplished by the draw regulator and the magnetic amplifier, that is, the three-phase alternating current of frequency proportional to the rotational speed of the section motor is taken out of the slip ring of the section motor and used to rotate the synchronous motor of the draw regulator located in the electric machine room. The difference in the rpm of this synchronous motor and that of the master motor which has been corrected by the cone pulley for regulating the draw, is detected by the differential gear. A d–c pilot generator and control transformer are connected to the differential shaft of this differential gear. These devices induce voltages which are proportional to the rotation angle. When the differential shaft rotates, d–c voltage is generated by the d–c pilot generator and the control transformer rotates to produce voltage. These two voltages are amplified by the magnetic amplifier and negatively fed back to the field of the section motor. Since the signal from the control transformer is an integration of rotational speed error, it is used to adjust the sag or the tension in the paper to the correct amount. The output of the pilot generator has a function of rapid controlling the error resulting from disturbances which have entered ahead of the control action of the control transformer. The output voltage of the

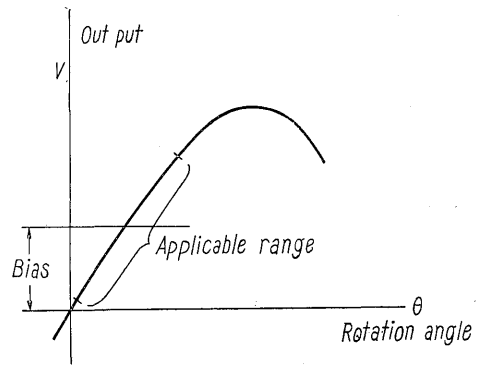

Fig. 9. Output voltage of control transformer

control transformer is, as shown in Fig. 9, an a–c voltage. This a–c voltage is rectified and the bias obtained from rectifying the voltage of exciting (primary winding) power source of control transformer is added to this rectified voltage, thereby the control transformer being so adjusted that when rotated at a certain angle (approx. 25°) the output becomes zero ; at any angle less than this, the output is becomes positive and above this angle, the output become negative. Thus, though the voltage of the power source may vary, zero point will not change. Also, since the power source of the control transformer is 115 cycle/sec. a–c generator use only for this purpose, any sudden change in the voltage is unlikely to occur. The draw regulator is illustrated in Figs. 10 and 11. The draw regulation of each section is made by pressing a button mounted on a control pillar in the paper making

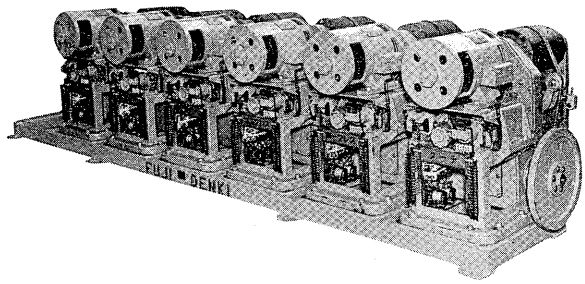

Fig. 10. Draw regulator (front side)

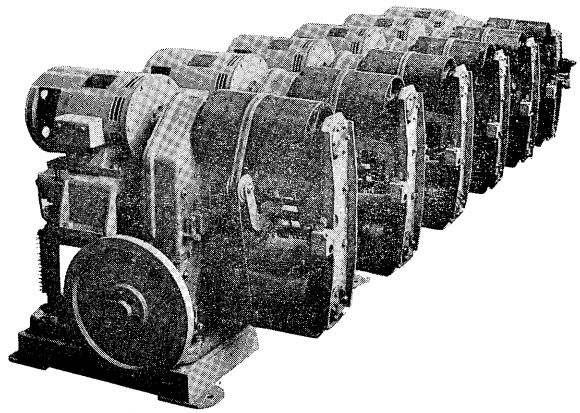

Fig. 11. Draw regulator (back side)

room to rotate the draw regulator motor, which causes a lead screw feed mechanism to operate and shift the cone pulley belt. By shifting the cone pulley through its entire range, draw regulation of $\pm 7.5\%$ from standard draw taken as a center, can be obtained. A slack taking-up device is attached to the calender section. By this device, the entire belt feed system is attracted to a certain distance by the slack taking-up magnet and as long as the push button is being pressed, the speed of the section motor is raised to take up the slack. The master motor which drives the master shaft has 4 kW output. An a–c tachometer dynamo and a standard voltage generator are directly coupled to to its shaft. Moreover, a fair sized fly whell is attached to the master motor in order to obtain the same degree of transient characteristic as that of the drier system.

7. Starting and Slow Speed Running

Each section motor is equipped with a starting rheostat and is made starting automatically with a current-limiting relay. Also, since slow speed running is necessary for the couch, No. 1 press and No. 2 press in order to replace or inspect wire meshes felt, the starting rheostat is designed to be of continuous rating and applicable for slow speed operation.

A separate starting generator may be used for starting method, but by this method the motors must be started one by one and starting the entire sections need considerable time. Also the circuits become complicated and the cost will be very high. For the above reasons, this method was not adopted. No. 1 and No. 2 driers, are mostly consist of drying rollers, and there two sections are connected by gears, which makes their GD^2 very large. Therefore, the gears attached to the No. 2 drier speed reduction driving mechanism is started by barring gear driven by a 50 HP wound induction motor (max. torque—400%). The peripheral speed of the roller is now approximately 100 ft/min. Since the drier requires at least 30 minutes of low speed running for replacing or inspection of canvas, ropes, etc., this starting motor is made a one hour rating.

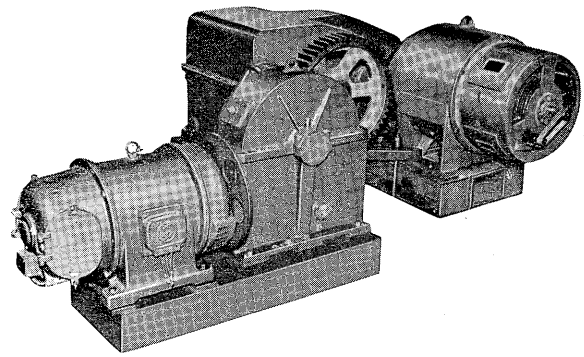

Fig. 12. 150 HP d–c motor reduction gear set (gear ratio 10.26) and 50HP barring gear set for No. 2 drier section drive

8. Synchro-Tie

Since the differential shaft of the differential gear rotates at high speed when the section motor is stopped or started a d–c pilot generator and the control transformer are cut-off by a magnetic clutch to protect them both mechanically and electrically. When the section motor has gained sufficient speed and rotational speed of the differential shaft has reached below a certain value, the fact is sensed by a cam switch and a time-limit relay, and they are made to tie-in. The above action is called the synchro-tie.

9. Stop

All section motors except that of couch are equipped with dynamic brakes so that they can be stopped instantly. This is especially necessary for drier sections which have large GD^2. Quick stops are not made for couch section since wire meshes might break. In case quick stop is necessary, for the sake of trouble all section motors except those of couch section are stopped by pushing an emergency stop button. If the couch section is stopped at the same time, the white water from the sluice will overflow above the wire mesh.

10. Switch Gear and Switchboard

Most part of the switch gears and switchboards are installed within the electrical room together with the mercury rectifier and its transformer, draw regulator, 4-ganged resistors, constant voltage exciter, high frequency generator, etc. The main switchboard (Fig. 13) is a self supporting open type having various types of control switches, meters, relays, electro-magnetic contactors and resistors mounted on it. The sectional drive is a combination of many pieces of equipment and also there are a number of protective devices. Therefore, fault indicators are mounted collectively on a control alarm panel so that any faults can be watched at one place. Also, in each magnetic amplifier circuit, a double coil balancing voltmeter is connected to observe the operating condition at all times. The magnetic amplifier for the field control of section motor is mounted on a frame attached to the wall near the draw regulator. (Fig. 14) The auxiliary running cubicle for ignition and excitation and automatic temperature control devices for the mercury rectifier are mounted on the same bed with the mercury rectifier. The grid control circuit is arranged within the automatic grid control cubicle. D–c high voltage bus bars for the mercury rectifier, air circuit breaker for section motor connected to the bus bars, d–c electro-magnetic contactor, etc. are arranged together in a H.T. frame. High voltage a–c equipment such as HSACB for reverse current protection of mercury rectifier, transformer for mercury rectifier, synchronous motor for driving exciter, three 3.4 kV oil circuit breakers for induction motors used in starting the driers, etc. are installed in a separate location. Running or stopping of auxiliary equipment and mercury rectifiers are entirely controlled from the main switchboard in the electrical room. In the paper making room, there is a control pillar for each section and push buttons for running and stopping of section motors and regulating the draw, load current ammeters, speedmeter, synchronous lamp, etc. are mounted on this pillar. (Fig. 15) On the control pillar for the couch section, there are, in addition, push buttons for regulating the paper speed (both rough and fine adjustments), emergency stop buttons, voltmeter for mercury rectifier, speedmeter for the master motor and drawmeter for indicating the draw between the couch and the No. 1 press. Speed adjustments for the entire paper machine can be made at will between 800 and 2,000 ft/min. There is a push button for low speed on each control pillar for couch, No. 1 and No. 2 presses, No. 1 and No. 2 driers, and a push button for compensating any slack in the paper on the control pillar for calender section.

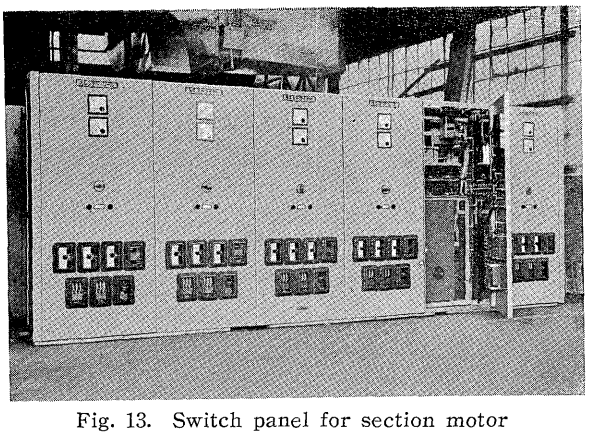

Fig. 13. Switch panel for section motor

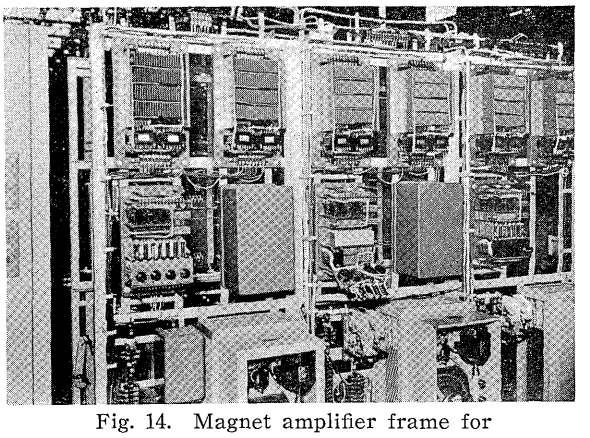

Fig. 14. Magnet amplifier frame for section motor

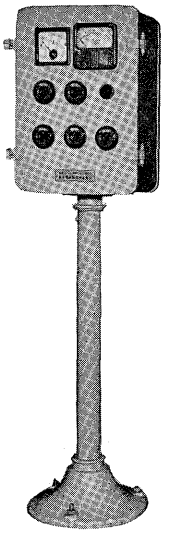

Fig. 15. Control pillar for No. 1 press section

IV. TESTS AND OPERATIONAL RESULTS

Special care being taken in the design and manufacture of this equipment, combined tests were conducted smoothly without any trouble satisfactory results were obtained in about two weeks. The

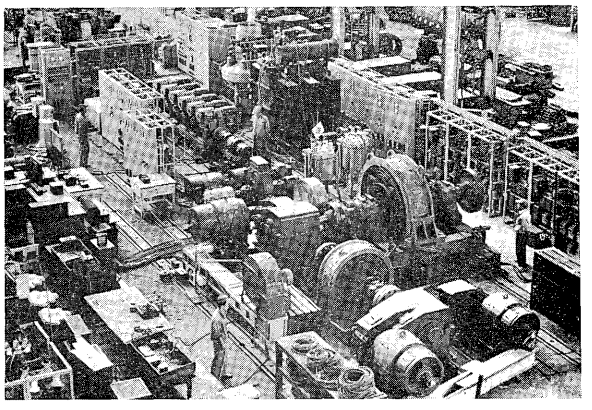

Fig. 16. Combination test in the factory

state of the combined test is illustrated in Fig. 16. At first, in the partial combined test, the accuracy obtained in the voltage control was as high as 1% for high frequency generator, 0.3% for low voltage exciter and 0.2% for the mercury rectifier under the following test condition: variation in receiving voltage ±10% and variation in frequency 56~61 cycles/sec. Though special attention had been focussed on the adjustment of speed control of the master motor, it was possible to raise the accuracy to 0.05% and excellent results were obtained as excepted. Moreover, the slip of the cone pulley belt was carefully measured and it was found that this slip did not affect the accuracy of the master motor to any extent. Co-operative running test was conducted by the use of three section motors; one for driving the No. 1 drier having the largest GD^2 against HP, one for the couch having the lowest ratio and the third for the No. 1 press having the ratio in between these two. The test was conducted by connecting a load generator to the couch and No. 1 drier together with a flywheel having equivalent value of GD^2 connected to the high speed side of speed reduction gear of No. 1 drier to simulate the actual condition. With the equipment arranged in this condition and after having confirmed the smoothness in starting and synchro-tie actions, the test was conducted for speed variations of the section motors and their mutual rotational displacement when input voltage, frequency, load, and other conditions were varied. The result was that the error in the adjustment was found to be within 0.1% and at 100% load variation, maximum displacement at the motor shaft between the two section motors to be between 10 and 40°. Since the maximum load variation of paper making machine is 20%, this value is sufficient against paper tearing, slack, etc. Also, at the rate of 2 ft/min. the maximum relative variation during speed adjustment was 0.2%. Draw adjustment, slack taking-up actions were also found to operate in a satisfactory manner. Adjustments after the installation of the paper machine at the actual operating site, have been carried on successfully and although the time for electrical adjustments was limited due to time needed far adjusting the paper machine itself, the test were completed after two weeks from the start of the individual running of section motors. A satisfactory operation was obtained in the test without the paper in the machine for speeds between 800 and 1,800 ft/min. and from Dec. 1956 paper making was started. Since then, the paper machine has been operating with excellent results.

V. CONCLUSION

As described above, the section drive equipment for the high speed paper machine has achieved a success as was expected; a joy which cannot easily be hidden.

The accomplishment of this equipment was a result of demonstration on the overall technique of our Company with co-operated effort on the part of Design & Research, Manufacturing, and Testing Division personnel. Finally, the writer wishes to express his thanks to Mr. Sakurai of Jujo Paper Mfg. Co. and others for instructions, technical assistance, etc. so generously offered.