UDC 676. 2. 052: 621. 313/314

PAPER MACHINE SECTIONAL DRIVE ELECTRICAL EQUIPMENT

Teruaki Iijima
Tokyo Factory

Hajime Kohno
First Industrial Application Engineering Dept.

Takayoshi Nakano
Technical Planning Dept.

I. INTRODUCTION

The two most important points concerning paper machine sectional drive equipment are as follows.
1) In order to coordinate precisely the speeds of each part, it is necessary to achieve a high level of static and dynamic speed control, and to facilitate paper machine operation.
2) Operation must be stable over long periods and maintenance must be easy.

In order to achieve these two conditions, Fuji Electric recently completed sectional drive equipment for use with high speed paper machinery which is based on the latest technology and the company's wide experience in this field.

The first condition is satisfied in this equipment as follows:
(1) Analog speed control using Fuji's TRANSIDYN system is employed.
(2) Digital-type draw control (a scanning system) is used.
(3) An individual power supply is provided for each part using thyristors.

The second condition is met as follows:
(1) Thyristor elements with pressurized, semi-permanent contacts are used.
(2) Speed control stability is insured by a permanent magnet-type pilot generator.
(3) Easy maintenance is achieved with draw-out type control equipment and thyristor units.

An outline of the equipment delivered to the Tonami Paper Mfg. Co., Ltd. will be given here.

II. PAPER MACHINE

This machine is of the Fortlinear type and is used for making newsprint. A general view is shown in *Fig. 1* and the specifications of each part are given in *Table 1*.

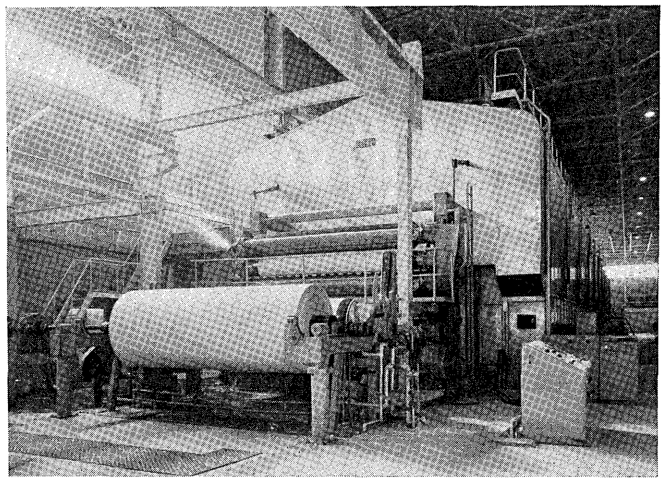


Fig. 1 General view of paper machine

Table 1 Specifications of Each Part

Part Name	Driven Part Section Name	Rated Motor Output (kw)
Wire	Wire turning roll (D)	150
	Suction couch roll (H)	150
No. 1 and No. 2 Press	No. 1 press buttom roll (D)	100
	Pick-up roll (H)	30
	Wringer roll (H)	50
	No. 2 press bottom roll (H)	100
No. 3 Press	No. 3 press bottom roll (D)	125
No. 1 Dryer	Main drive pinion (D)	100
No. 2 Dryer	Main drive pinion (D)	150
No. 3 Dryer	Main drive pinion (D)	150
Breaker Stack	Bottom roll (D)	30
	Top roll (D)	15
No. 4 Dryer	Main drive pinion (D)	100
Calender	Bottom roll (D)	125
Reel	Reel drum (D)	50

III. ELECTRICAL EQUIPMENT

1. Electrical Equipment Construction

Power is obtained from a 3.3 kv source. From a

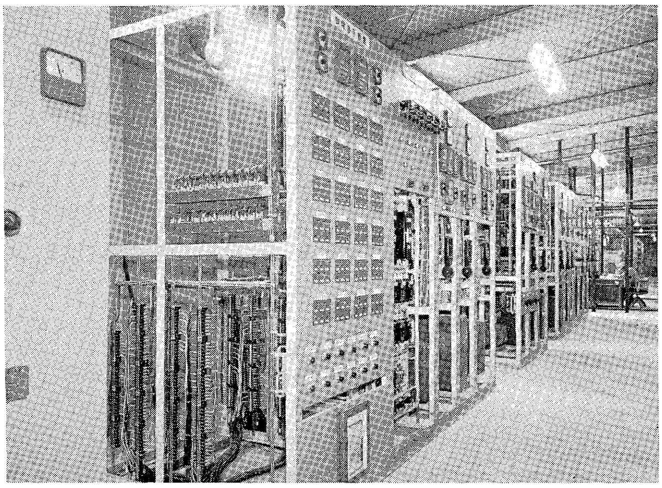


Fig. 2 Dc switchgear

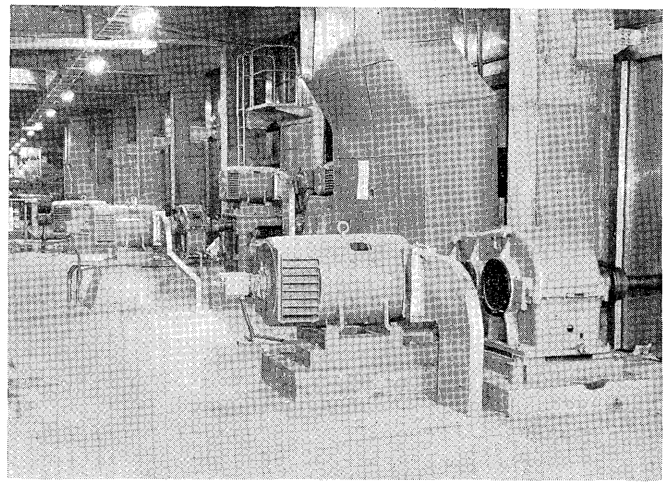


Fig. 3 Dc section motors

common transformer for rectifiers; it is fed to the thyristor cubicle of each part by way of secondary branch panels. Reactors to prevent mutual interference are provided on the ac sides of the thyristors for each part. The thyristor dc output is supplied to dc motors via dc switchgear. This dc switchgear consists of the main dc circuit equipment, meters and relays (See *Fig. 2*).

The thyristors of each part are controlled from TRANSIDYN cubicles used for analog-type speed control. In order to improve the accuracy, a digital draw control system is provided which serves to compensate the analog system. The TRANSIDYN cubicle includes load control equipment for the motor used to drive the couch rolls of the wire parts. The dc motor field is excited by means of a thyristor type dc power source with 3-phase hybrid bridge type connection. The operation of all parts can be performed from the control desk by the paper machine.

Since scanning type digital draw measuring equipment is used, the draw (speed ratio) between each part is displayed on a digital display tube on each control desk. With an analog recorder arranged on the measuring frame units, the draw of the section selected by the multi-switch can be recorded as a d/a converted value.

2. Dc Motors and Reduction Gears

The motor is dc 440 v and all except for the 3 kw models are standardized at 1200 rpm. Since the paper machine rooms are at a high temperature and humidity, the motor has the open tube type ventillation system and there are two cooling blowers for branch ventillation to all motors. All the insulation is specially processed to resist humidity and the brushes are especially selected for use in paper mills.

The reduction gears are of the splash lubrication type and contain cooling water tubes. The analog speed control pilot generators for the required sections (directly connected to the motor bearing side shaft end) and the pulse transmitters for digital draw control (directly connected to the non-motor side of the reduction gear high speed shaft) are connected to the dc motors.

The pilot generator which possesses especially high accuracy as highly stable characteristic is used. In this totally enclosed permanent magnet type 3-phase ac generator, compensation is made for flux changes in the permanent magnet due to variation in the ambient temperature and in order to increase the accuracy, specially oriented steels are used.

Fig. 3 shows dc motors connected to the paper machine.

3. Thyristor Source Equipment

This equipment is of the individual source type and there is a 3-phase pure-bridge connected thyristor source in each part. The helper motors are connected in parallel to the sources of their parts. Each thyris-

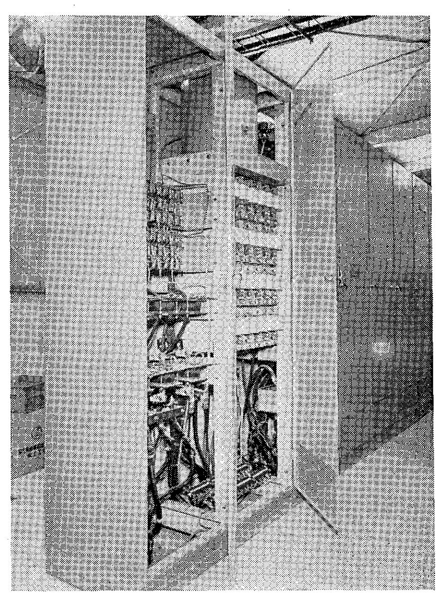


Fig. 4 Thyristor cubicle

tor makes a unit which contains a cooler, protective fuse, parallel CR, protective resistor, lead relay for fuse blowout detection and gate pulse transmission equipment. The units can be easily inserted or removed and the number of spares is small (See *Fig. 4*). *Table 2* gives the specifications of the thyristor power source.

Table 2 **Specifications of Thyristor Power Source**

Part Name	Thyristor Power Source Specifications
Wire	326 kw dc 440 v, 742 amp continuous, connection : 2S3P6A, 150% load, 1 min
No. 1 and No. 2 Press	313 kw dc 440 v, 712 amp continuous, connection : 2S3P6A, 150% load 1 min
No. 3 Press	137 kw dc 440 v, 311 amp continuous, connection : 2S1P6A, 150% load 1 min
No. 1 Dryer	110 kw dc 440 v, 250 amp continuous, connection : 2S1P6A, 150% load 1 min
No. 2 Dryer	163 kw dc 440 v, 371 am continnous, connection : 2S1P6A, 150% load 1 min
Breaker Stack	59 kw dc 440 v, 134 amp continuous, connection : 2S1P6A, 150% load 1 min
No. 4 Dryer	110 kw dc 440 v, 250 amp continuous, connection : 2S1P6A, 150% load 1 min
Calender	137 kw dc 440 v, 311 amp continuous, connection : 2S1P6A, 150% load 1 min
Reel	56 kw dc 440 v, 127 amp continuous, connection : 2S1P6A, 150% 1 min

4. Automatic Control Cubicle

The TRANSIDYN cubicle (See *Fig. 5*) is completely transistorized and constructed of standardized draw-out type units. The amplifier elements used in these units are all standardized, i.e. there are only two types and therefore few spares are needed. Since each unit contains an input/output indicator and test jack terminals, adjustment, checking and maintenance are easy.

The digital cubicle is also transistorized and employs the printed circuit board system.

5. Control Desk

The wire part control desk contains general operation devices and indicators which serve to colligate all the parts. These include a sheet speed indicator, a sheet speed set value indicator, a push button switch for changing the sheet speed, a push button switch for emergency stopping of all parts, etc. The operating desks for each part contain dc voltmeters, ammeters, push button switches (stop, slow, start, draw increase/decrease) and signal lamps. The draw measurement system consists of digital indicator tube selection push button switches and reset push buttons. The draw measurement system can normally be used for scanning. This result appears on the display tube, but if the selection button is pushed, scanning stops and the draw of that particular section is displayed continuously. If the reset button is pushed after this, scanning is resumed.

In the wire parts, there is a wire turning, a suction couch, and a ratio setting resistor used for automatic load balance control. The calender and reel parts contain push buttons for increasing or decreasing the sheet slack. If these buttons are pushed, the speed can be made slightly above or below the value at which the speeds are synchronized.

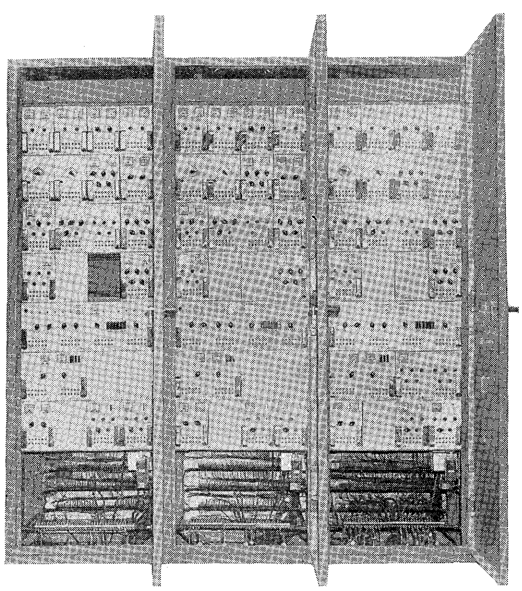


Fig. 5 TRANSIDYN cubicle

IV. CONTROL

When deciding on the method for connecting the main circuit, it was necessary to consider such points as economy, installation, noise and maintenance as well as control. Three popular main circuit connection methods are shown in *Fig. 6*, but in this equipment the individual thyristor power source system was used as described in the "Introduction". With this method, starting can be carried out smoothly

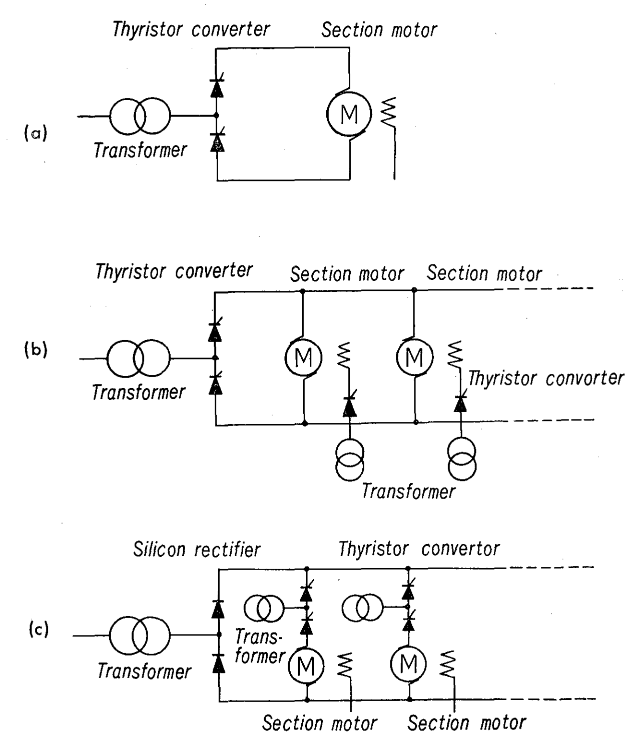


Fig. 6 Connection diagram of control circuit

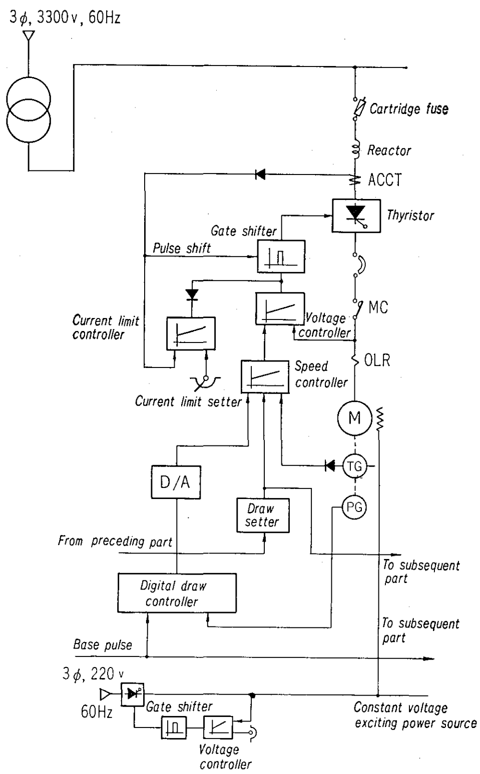


Fig. 7 **Block diagram of control circuit**

therefore, there is no adverse influence from the wires and felt; there is absolutely no interference between the motors as often occurs in common bus systems; and response is excellent since there is no field current delay which can not be completely extinguished through field control. Both (b) and (c) common bus systems are suitable in respect to sheet speed range, capacity etc., and a more detailed investigation is necessary at each condition.

Fig. 7 shows a block diagram of the main circuit and the control circuit. The speed of each section motor is controlled by an analog system and there is a digital control loop in addition to the analog loop. The main control unit is an analog system, and a digital system is used as compensation to provide highly synchronized speed control accuracy. Inside loop is for voltage control which is used mainly to absorb power source external disturbances quickly. The outside loop is the speed control loop and the output of the speed controller serves as the command for the voltage regulator.

In many cases, speed control by means of any ordinary rheostat contains a minor loop for armature current but in paper machines, there is no rapid starting and stopping and loads are not reversed; such machines are started slowly and the load inertia is generally high. Therefore, since it is difficuit to obtain optimum speed control with an armature minor loop attached, this equipment is provided with a voltage minor loop and with a current limiting loop for limiting the armature current. When the armature current is below the limit value, the voltage loop is activated but when the limit value is surpassed, the voltage loop is separated from the control system and the circuit switches over to the current limiting loop so that the thyristor converter output current is maintained at the limit value. In addition, an overcurrent arc suppressor is provided—when the armature current becomes excessive, the thyristor gate pulse instantaneously shifts to the maximum control angle, and cut out the current.

When only the analog speed control system is used, the main causes for speed variations are changes in the set voltage, drift due to power source variations or temperature changes in the first stage amplifier, output voltage variations due to temperature changes in the pilot generator. Among these, however, the latter is the most common. For this reason, this equipment contains the previously mentioned permanent magnet type ac generator which is made from specially treated steel and contains temperature compensation equipment. Since high frequencies (600 Hz at 1200 rpm) are employed, there is no problem concerning rectifier ripple and the brushes cause no trouble. Since the ac output is rectified and used as dc, the speed and output voltage characteristics contain a non-linear portion of the rectifier diode but this is compensated for by a special circuit so that linear characteristics are obtained and the draw can be maintained in its former position by the analog system even if there are variations in the sheet speed.

Since the inertia in the sheet speed specifications is high, a No. 2 dryer with a small load variation was chosen by considering the neighbouring parts as well. The draw setting among the sections is done with the No. 2 dryer draw as standard (See *Fig 8.*)

The specified source for the sheet speed is constructed of constant voltage diodes and the set voltage is obtained by voltage division with an electrical setting resistance which changes at maximum sliding time of 600 sec. The speed setting of the preceding section is fed to the draw setting resistor and draw setting computer, and the speed setting value for the particular section is determined by adding the difference

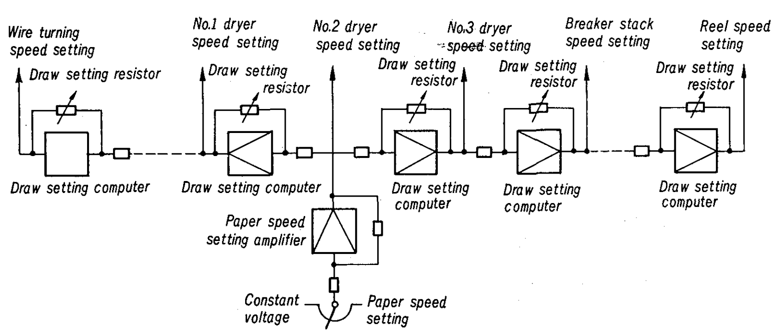


Fig. 8 **Connection diagram of paper speed and draw setting**

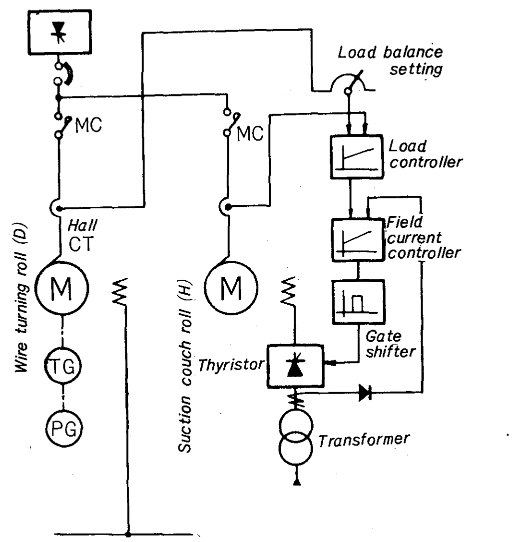


Fig. 9 Skeleton diagram of automatic load balance

between the output and input of the draw setting computer which represents the draw. The draw setting resistor can vary a draw ±5% at a maximum sliding time of 300 sec.

When compared with the conventional system in which the draw of each section is taken in respect to a specified section, it is not necessary to correct the draw setting of other sections when there is a draw setting change in one position in this system. Therefore, since there is no change in other sections when the draw changes in one position, draw changes are easy to make. The helper motor possesses drop characteristics due to a series field or a series resistance and connected to the same thyristor power source of the main motor in that section. Load balancing is carried out with the field regulation resistor. Load balancing of the turning of the wire part and the couch is performed automatically, i.e. load balancing control is carried out using the thyristor in the couch motor field. At that time, the field current delay is eliminated by means of the field current control loop within the load balance control loop. Since the field current set value serves as the output of the load balance regulator, emergency speed increases due to insufficient field and counter electromotive force can be eliminated by chosing appropriate upper and lower limits for this output.

V. DIGITAL DRAW CONTROL AND METERING EQUIPMENT

1. Digital Draw Control Equipment

The digital draw control equipment is used in combination with the TRANSIDYN system speed control equipment. Compensation is made for variations over long periods, due to temperature drift, drift during equipment operation etc. This digital draw control equipment features:

1) The suppression of control operation when there is a rapid external disturbance.

2) Sufficient resolving power in respect to slow external disturbances.

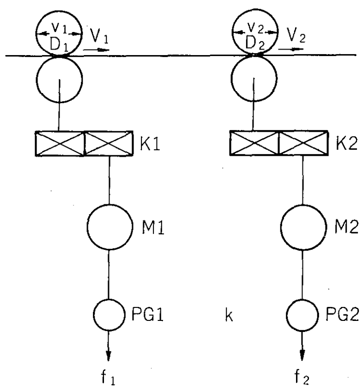
3) Operation of the digital type draw control equipment has been simplified and more accurate control can be achieved automatically with the TRANSIDYN control equipment.

4) Highly accurate computing is possible since the draw computing circuits are used in common by the employment of a scanning system. This also saves on cost.

5) If some kind of adverse condition arises, the digital equipment can be cut out and operation continued by means of the analog system alone.

Designed with the above 5 points in mind, the Fuji Electric digital draw control system described hereafter was used. The scanning speed of the digidraw control system was taken as 5.5 seconds for 1 section at the highest sheet speeds. By one scanning with the digital draw control equipment, the operating capacity is saturated at a maximum of 0.15%. For this reason, the TRANSIDYN control equipment performs control in respect to large, sudden external disturbances, while the digital draw control equipment performs control only in respect to external disturbances over a long period. The saturation points of the operating capacity of the digital type draw control equipment lie between 0.01% and 0.15% and settings can be made anywhere in that range at 0.01% intervals. The resolving power of the equipment is 00.1% and the circuit elements of each circuit are all chosen to have sufficient stability. The set draw value and the roll diameter correction constant of each roller are computed automatically by the draw computing circuit inside the control equipment so that no manual setting is required. By operation of the TRANSIDYN control equipment, the most appropriate paper conditions are achieved and when the digital draw control equipment is operated at this time, the draw value and roll diameter correction values of each section are calculated and stored in the memory circuit at the first scanning for each section. After the second scanning, control is performed according to the memorized constants as set values. Within the memory circuit there will be no change even the power is cut as long as manual resetting does not take place. When draw changes are made with the TRANSIDYN control equipment, the constant of only the section concerned or related sections is caluculated and the memory circuit contents are altered. The memory circuit contents can also be set manually.

The digital type draw control equipment for this paper machine controls 9 sections, but in order to make the scanning period short, the sections are divided into those previous (wet-side) to the No. 2



D_1 D_2: Roll diameters
K_1, K_2: Gear ratios between motor and roll
M_1, M_2: Drive motors
PG_1, PG_2: High frequency generators connected to motor shafts
f_1, f_2: Output frequency of PG_1 and PG_2
k: High frequency generator constant (number of pulses obtained from the high frequency generators when the motor makes one revolution)

Fig. 10 Relation between pulse generator and roll peripheral speed

dryer which contains the standard roller and those after it (dry-side). There is one computing circuit for the 4 wet-side sections and one for the 5 dry-side sections. Each of these carries out scanning independently. The scanning periods are 22 seconds respectively at maximum sheet speeds.

1) Draw computing circuit

When the paper passes between two rolls as shown in *Fig. 10*, and the paper speed when passing through the roll is V_1 and V_2, then the draw D can be expressed as follows:

$$D=\frac{V_2-V_1}{V_1} \quad \cdots\cdots (1)$$

However, to measure the paper speed is very difficult and so the roll peripheral speeds v_1 and v_2 are usually used instead. When each constant is set as shown in *Fig. 10*, the following relations are formed between v_1, f_1 and v_2, f_2.

$$v_1=\pi D_1\times\frac{1}{K_1}\times f_1\times 60\times\frac{1}{k} \quad \cdots\cdots (2)$$

$$v_2=\pi D_2\times\frac{1}{K_2}\times f_2\times 60\times\frac{1}{k} \quad \cdots\cdots (3)$$

A and B are considered as positive whole numbers and the times which PG_1 output pulse reaches account of A and PG_2 output pulse reaches B are T_1 and T_2 respectively. If the number of output pulses from PG_2 in the time (T_1-T_2) is expressed as P, then

$$P=(T_1-T_2)\times f_2=\left(\frac{A}{f_1}-\frac{B}{f_2}\right)\times f_2 \quad \cdots\cdots (4)$$

When f_1 and f_2 are eliminated by substituting equations (2) and (3) in equation (4), then

$$P=(T_1-T_2)\times f_2=\frac{A\times\frac{K_2\cdot D_1}{K_1\cdot D_2}\times v_2-B\times v_1}{v_1} \quad \cdots (5)$$

Here A and B are determined as follows:

$$A\times\frac{K_2\cdot D_1}{K_1 D_2}=B=10^n \quad \cdots\cdots (6)$$

Then equation (5) becomes

$$P=\frac{v_2-v_1}{v_1}\times 10^n \quad \cdots\cdots (7)$$

This means that P is equivalent to the draw D. As in equation (6) the reduction ratio for each section and the roll diameter change can be compensated by changing A.

A block diagram of the draw computing circuit is shown in *Fig. 11*. The control circuit controls three gates —1, 2 and 3 with the contents of the two preset counters 1 and 2. The draw signal is determined depending on which of the preset counter values is achieved first. The number of pulses P which make up the output of gate 3 shows the draw and therefore, if it is counted by a separate counter, the draw at that time can be obtained. If this is integrated by considering the signal, the integrated value of draw deviation can be obtained.

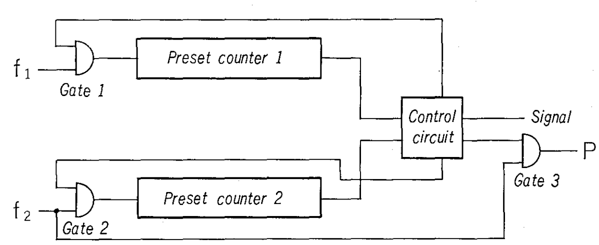


Fig. 11 Block diagram of draw computing circuit

2) Constant computing circuit

At the most appropriate paper conditions, the draw becomes D_0 and the outputs of PG_1 and PG_2 becomes f_{01} and f_{02} respectively. When the draw changes to D, the two outputs change to f_1 and f_2, the digital type draw control equipment must have a control output of $D-D_0=\Delta D$.

ΔP which is equivalent to ΔD can be expressed as follows:

$$\Delta P=P-P_0=\left(\frac{A}{f_1}-\frac{B}{f_2}\right)\times f_2-\left(\frac{A}{f_{01}}-\frac{B}{f_{02}}\right)\times f_{02} \cdots (8)$$

Since A and B are arbitrarily determined integers as was mentioned previously, then A and B can be chosen so that $\left(\frac{A}{f_{01}}-\frac{B}{f_{02}}\right)\times f_{02}$ becomes equal to zero. Therefore ΔP correspond to ΔD can be shown as in equation (8).

Therefore,

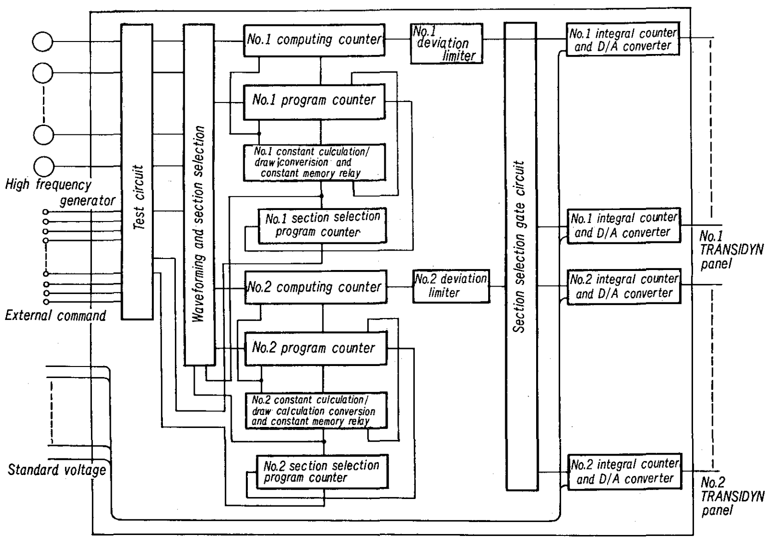


Fig. 12 **Block diagram of digital draw controller**

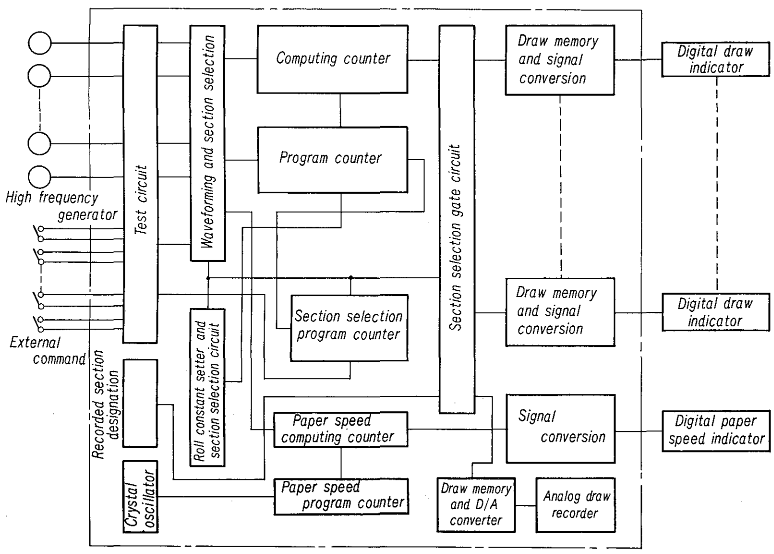


Fig. 13 **Block diagram of digital draw meter**

$$A=\frac{B}{f_{02}}\times f_{01} \quad \cdots\cdots\cdots\cdots\cdots\cdots (9)$$

In equation (9), if the number of pulses from PG_1 becomes A in the time taken for B pulses to be obtained from PG_2, equation (8) indicated that $\varDelta P$ proportional to $\varDelta D$ can be computed. In other words, the optimum paper condition is achieved by the old method using the TRANSIDYN control equipment and at this time the digital type draw control equipment operates. In the initial sampling period for each section, the number of pulses from PG_1 in the time which is required for B pulses to be obtained from PG_2 is counted and if this becomes the set value for the digital type draw control equipment, this equipment output will be such that it can generally maintain the most optimum paper conditions.

3) Test circuit

Fuji Electric digital draw control contains a test circuit to facilitate maintenance. The test circuit consists of a neon indicator lamp, a control/test conversion switch, various command push button switches and a test oscillator. Characteristics are as follows:

(1) The neon lamp indicates the computing counter and the contents of especially the important register. Therefore, by looking at this indication during operation, the operation of the digital type draw control equipment can be checked.

(2) The control/test conversion switch converts the digital draw control equipment pulse input and the external command from the high frequency generator to the test oscillator and from the command switch on the external operation desk to the various push button command switches for testing. In this way, operation can be checked whether the paper machine is actually operating or not.

(3) The various push button command switches have the same functions as the command switches on the external operation desk and therefore they can be used for imitating all types of actions during machine operation.

A block diagram of the digital draw control equipment is shown in *Fig. 12*. For the voltages specified in the figure, there are means to obtain them from an external voltage supply proportional to the sheet speed since the control output of the digital draw control equipment is proportional to the sheet speed. The voltage is supplied from the TRANSIDYN cubicle.

2. Digital Draw Measuring Equipment

The computing circuit of the digital draw metering equipment can be considered in exactly the same way as that of the draw control equipment. However, the following characteristics are required with the draw metering equipment.

1) The measuring time for each section should be as short as possible.

2) Continuous measuring and memory must be possible in a specified section.

In order to fulfill these conditions, the Fuji Electric draw measuring equipment was designed as follows.

The measuring time per section is 1.9 seconds at maximum sheet speed. The resolving power is 0.01% and indication is given digitally as a percentage. The reduction ratio and roll diameter correction for each section are performed manually.

Since a circuit can be formed for scanning all sections by switching to one of the draw computing circuits the sampling period becomes 1.9 seconds times the number of sections.

A signal from the site operation desk is sufficient for continuous measuring in a specified section.

A block diagram of the digital draw measuring equipment is shown in *Fig. 13*. *Fig. 14* shows the digital draw control cubicle.

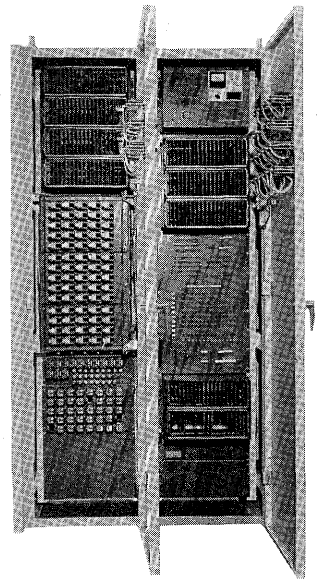


Fig. 14 Digital draw control cubicle

V. CONCLUSION

This equipment is now operating satisfactorily and it is considered that the conditions mentioned previously have been fulfilled.

At present, the Japanese paper industry is investigating the use of computer control and introduction of computer are being made with paper machine process control. It is anticipated that paper machine draw measurement can also be computerized. With this equipment, set values from a computer can easily be fed to the digital draw control equipment and the digital draw measuring equipment is very useful in collecting data for this.

In conclusion, the authors wish to express their thanks to all the personnel of the Tonami Paper Mfg. Co. Ltd. for their kind cooperation.