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SYNTHETIC FIBER HEATER AND APPLICABLE TEMPERATURE CONTROL

By Yuki Ito
Technical Dept.

I. INTRODUCTION

Ten years have elapsed since Fuji Electric began manufacturing equipment for heat processing of synthetic fibers, such as nylon, polyester.

Over the past decade, Fuji Electric has supplied literally thousands of such heaters of nearly a hundred different types, while the number of items of multipoint temperature control equipment delivered during this same time runs past the 100 mark.

Remarkable progress has also been made in synthetic fibers during this period, resulting in successive introduction of such new fibers such as nylon, polyester, and polypropylen. Each time a new fiber has been introduced, a new method of heat processing has usually evolved.

Fortunately, Fuji Electric had the advantage of being able to design, produce, and supply heaters, temperature control equipment, and heat power units as complete sets of equipment. The following presentation provides a general description, development, and present status of this equipment.

II. PRODUCTION PROCESS

Synthetic fibers are produced as polymers from monomers and spun into filaments (threads) by extrusion through porous nozzles at a temperature near their yield point.

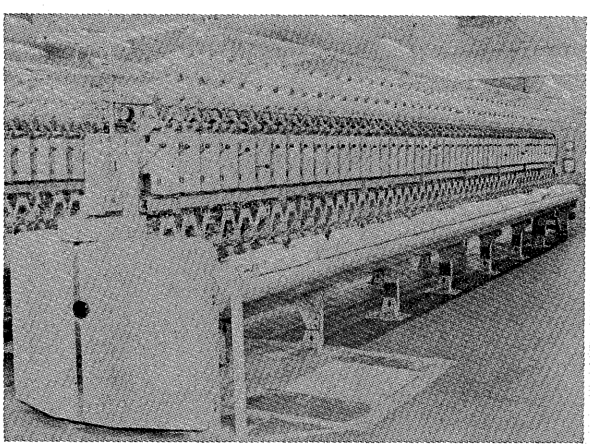

Fig. 1 Twister

Most synthetic fibers require heat processing while in filament (thread) form. This heat processing is applied for drawing (denier reduction), relaxation (stress relief), and twisting, while the use of heat speeds up the processing rate.

Drawing refers to the process in which the filaments are heated, finely drawn out, and twisted by a twister.

Drawing provides such fiber characteristics as tensile strength, elasticity, and shape.

The layout for drawing is as shown in *Fig. 2*.

The fiber is fed by feed roller *2* from bobbin *1* through pin *3*, plate heater *4*, and roller *6* to winding bobbin *7*, where it is wound. During this process, it is heated by plate heater *4* and travels several times around roller *6* and pin *5*.

The feed and winding rollers used are designed so that the winding roller rotates faster than the feed roller at a specified speed ratio, so as to draw the filament into drafted thread.

While a plate heater is used in the example, in some cases both roller and pin heaters are used.

Drawing is generally performed under the following conditions:

Thread denier ....50 to 1000
Feeding speed ....50 to 500 m/min
Temperature (applied heat) ...100 to 250°C

Twisting refers to the second processing step applied to the filaments after they are drawn.

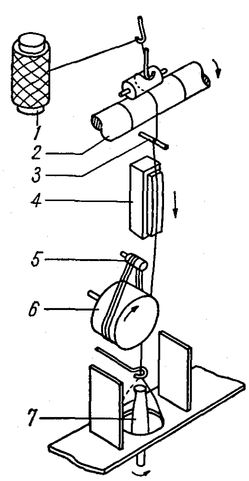

Fig. 2 Drawing heater

In practice, it is performed by twisting the filament while heating them. This corresponds to the so called wooly or bulky process.

A thread twisted, drawn, and relaxed at extreme high number of revolution while heating becomes frizzled and bulky due to loose slubbing, and becomes soft and pliant as well as loose so that air passes freely through the filaments.

The twisting is performed after the drawing, so as to produce thread having a low denier. General conditions for twisting are as follows:

Thread denier ....50 to 100 deniers
Feeding speed ....50 to 200 m/min
Twisting speed ....5 to 200,000 rpm
Temperature (applied heat)......50 to 250°C

The twister is shown in *Fig. 1,* and heaters and temperature control panels are shown in the photograph in *Fig. 1.*

Heat processing of the filaments is not intended solely for the purpose described above, but also to accelerate processing. Moreover, it determines the quality of the thread produced.

In other words, tensile strength, elongation, elasticity, feel, dyeability, etc., of thread depends upon the heat processing applied.

Accordingly, effective heat processing is vital to the processing of synthetic fibers. Moreover, it should be performed within a very narrow temperature range approximating the yield point of the filament so as to produce uniform threads on the numerous spindles. For this reason, a heat processing system must be provided that is easy to control and is at the same time extremely accurate and stable over a prolonged period of time, such as a system employing heaters and temperature controls.

III. HEATERS

The heaters used for heat processing of the thread are usually installed in the manner illustrated in the layout shown in *Fig. 2.* They are used for drawing as well as for twisting the thread, as previously described, and can be supplied as plate, pipe, roller, or pin type heaters.

The configuration, size, rating, etc., of a heater are normally determined based upon the type and denier of the thread, speed and applied temperature required for processing the thread, the heating period, and purpose for which the thread is to be used. The specified quality of the thread to be produced is the final determining factor. Therefore, the heaters are manufactured and tested by carefully examining the quality of thread produced.

Heater temperature is normally set at between 100 and 300°C, since thread heat processing temperature must approximate the yield point of the thread filaments. Either electric or vapor heating can be applied.

1. Plate Heaters

Fig. 3 shown various types of plate heaters. They consist of encased (or exposed) metal plates wrapped with heat insulating material by which the thread filaments are heated through contact with. Plate heaters can be either encased or exposed, depending upon thread processing. Use of a casing (cover) has an increased heat insulating effect.

The heater plates used for drawing are normally flat plates and those used for twisting slotted flat plates.

Since the thread filaments have poor heat conductivity and since they are processed at high feeding speeds, in most cases the thread filaments are kept in close contact with and are heated by the plates over an extended length. However, they are sometimes passed through a heated pipe without contacting the inside of the pipe.

The exterior dimensions of the heater must be greater when a greater amount of the heat is required and feeding speed is increased or large denier is to be produced. They are normally 20 to 100 cm in length, and are sometimes as long as two meters.

It is also possible, where necessary, to pass the thread filaments around the plate several times to provide a greater heating effect.

For the heater to distribute heat uniformly, some means must be provided to compensate for heat loss at both ends of the heater unit.

Temperature detector elements are directly embedded in the plate for precise temperature detection and to provide instantaneous response to temperature changes.

Heat for electrical heaters can be provided either by nickel-chrome wire inserted between the plate and the base or a sheath heater casting directly into the plate.

Electrically heated plates are easy to manufacture and use, since both temperature detection and heating are accomplished electrically. They can be individually produced without restrictions as to external configuration and are, thus, adaptable for use

Fig. 3 Plate heater

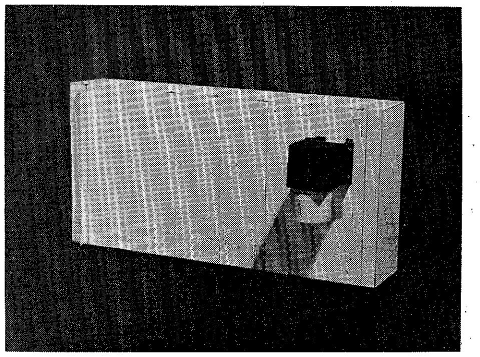

Fig. 4 Block heater

with almost any type of machine. On the other hand, each of these heaters requires individual temperature control and they are, therefore, difficult to build into a block.

The majority of electric plate heaters are rated within approx. 50 to 500 w.

In vapor heating, heat is applied to the contact plates which heat the thread filaments. The contact plates are heated by a thermal medium, which is in turn heated by an electric heater.

The thermal mediums used are water, Dowtherm, or SK oil, depending upon the required heating temperature.

Plate temperature for this type of heater is usually detected in terms of vapor pressure of the thermal medium and control is provided by a bellows which switches the heating wire on and off.

Fig. 4 shows a vapor type plate heater, or block heater. One of the outstanding advantages of this type of heater is that it consists of heaters for several spindles integrated into a single block, making it possible to control all of the heaters collectively. This feature along with its larger size results in the heater being less susceptible to cutting of the thread and other such failures.

However, this type of heater has the following disadvantageous features. The temperature of this type of heater may occasionally change due to decrease in the vacuum pressure inside the heater casing; its operating temperature range is restricted by the thermal medium employed; it may have harmful effects or cause discoloration from leakage of the thermal medium, where such thermal mediums are employed; and is subject to restrictions in both manufacture and external configuration due to their bulk since they consists of heaters for several spindles integrated into a single block.

2. Roller Type Heaters

Roller type heaters are employed as both heaters and drawing roller in a single unit.

The thread filaments pass around the rotating rollers, and are heated while making several turns around the roller. Use of this type of heating obviates the necessity for drawing the thread over a heater in contact with the heater as is done with plate heaters. This effectively minimizes the amount of friction applied to the thread and has some beneficial results in providing high quality thread.

Major factors to be considered in the design of roller type heaters are as follows:

- Providing assured uniform temperature distributed over the entire surface of the roller.
- Providing complete insulation of the bearing so that no heat is conducted from the roller.
- Providing appropriate means for detection and control of roller surface temperature.
- Providing an effective balance in heater/roller characteristics.

In general, roller heaters consist of a heater, or fixed ceramic cylinder wrapped with nickel-chrome wire, and a roller installed coaxially over the heater. An air gap is provided between the heater and the roller through which heat is transmitted as the roller rotates.

Heater temperature in conventional type roller heaters is detected from the heater and roller temperature is expressed as the given temperature corrected according to a specified temperature gradient, assumed to exist between the heater and the roller.

A conventional roller heater is shown in *Fig. 5*. This type of heater has the following disadvantageous features:

- More power is consumed due to high thermal resistance of air gap between the heater and the roller.
- It is difficult to maintain uniform heat distribution over the entire surface of the roller.
- There is no accurate means of measuring roller surface temperature, since the temperature is measured at the heater section.
- Transient response to thermal variations is delayed, since heating is accomplished through an air gap.

The source of this last problem, i.e., heating through an air gap, is the most pronounced drawback of conventional type rollers from the standpoint of instrumentation and heater control.

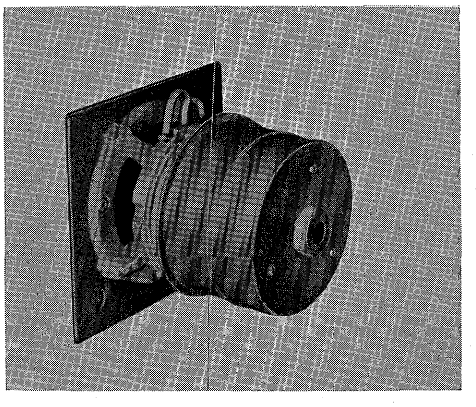

Fig. 5 Conventional roller type heater

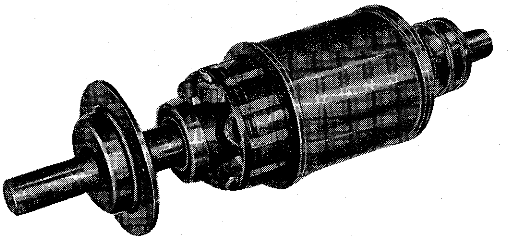

Fig. 6 Induction heated roller heater

To overcome these drawbacks two new types of roller heaters have been developed on a trial basis.

One type consists of a roller, heater, and temperature control, all of which rotate as a single unit. Since the three components are combined into a single unit, the temperature of the roller itself can be detected by detector elements embedded in the roller. Moreover, the detected temperature can be transmitted as it is to the controller within the same unit.

The other new type of roller heater, an illustration of which is shown in *Fig. 6*, employs high frequency induction heating.

In this type of roller-heater the problem of the service life of the heating wire is eliminated, since induction heating is applied by magnetic flux induced from a high-frequency power source. Also, not only is it a simple matter to distribute the temperature uniformly over the entire surface of the roller, but also quick response is provided to heat variations since heating is accomplished by evenly distributed magnetic flux. From the standpoint of construction, stationary salient-pole rotors (in the motor), around which the rollers rotate, serve as magnetic flux generators. This means that the roller is heated by magnetic flux induced by high frequency, 600 cps voltage, giving improved heating efficiency.

Of course, a high-frequency power supply is required for the aforementioned roller heater. However, this is no problem since simple, compact, low cost power supply units have been developed.

Thermistors are embedded in the periphery of rollers to detect the temperature of the roller itself.

A general purpose electronic control can be used as the temperature controller for this type of roller heater.

This heater has no slip ring and, therefore, requires no maintenance.

Roller heater specifications are generally as follows:

Outer diameter....................50 to 500 mmϕ
Revolving speed ....50 to 2000 rpm
Rated capacity....................0.2 to 2 kw

3. Hot Pins

Hot pins are those employed to set the drawing point of the thread filaments at a fixed point. Differing from the rollers, they are fixed, small tubular pins, around which the thread filaments pass, and heated by several turns around the pin.

Since the pin itself is fixed, the thread passes around and slides against the surface of the pin. Therefore, careful attention must be given to the hardness and machining of the pin contacting surface.

Heating of the hot pins is accomplished by micro sheath heaters cast in a metal block and snuggly applied to the pins by taper pins.

Temperature detection is accomplished by thermistors or thermocouples.

Principal hot pin specifications are as follows:

Outer diameter....................10 to 100 mmϕ
Rated capacity....................30 to 300 w

IV. CONTROL EQUIPMENT

In general, a draw-twister produces threads in production runs of 100 to 200 spindles each, with the number of heaters used corresponding to the number of spindles employed.

A large number of such draw-twister machine are provided in a spinning mill. The numerous heaters included in these draw-twister machines are controlled to uniform temperature by a single control unit. Therefore, in a sense, the control equipment can be considered as the heart of the heat processing system through which the heaters are regulated.

The temperature control range approximates the yield point of the thread filament and normally ranges from 100 to 250°C, although it may vary depending upon the nature of the thread to be produced. The degree of accuracy required for control is highly exacting, i.e., within ±1 to 2°C.

Disturbances in processing are caused by the thread being cut, setting the thread, opening and closing the heater case, fluctuations in source voltage, and changes in room temperature.

It is essential that the heaters be kept at their pre-set temperature by the control unit even when any of the aforementioned disturbance occur. This requirement, in turn, determines the amount of heater voltage to be provided for maintaining the heaters at the prescribed temperature under any given conditions. For example, in an actual case in which the heaters are On–Off controlled over a range of 140°C to their pre-set temperature limit of 200°C, and although the denier of the thread is increased, the temperature control range becomes larger. Control accuracy must be kept within the pre-set value.

Prerequisites for effective control equipment are accuracy, reliability, ease of maintenance and handling, interchangeability, flexibility with regard to temperature range, long service life, and economy. Moreover, special consideration must be given to automatic control of twisting machines so that operations can be performed almost unattended, notwithstanding the trend toward the use of a greater number of spindles.

The primary factor in temperature control is to establish a proper blance between the heaters, control equipment and voltage to be applied, depending upon the nature and extent of disturbance factors.

If these factors are not properly balanced in the design of the control equipment, effective control and production cannot reasonably be expected.

Subjecting heaters to temperatures outside their control range will quickly result in the thread being cut. In all cases, threads are processed by heating them to a temperature approximating their yield point. Therefore, if the temperature becomes too low or too high, the threads will naturally be broken.

The dyeability of the thread must be considered.

If the temperature is not kept within the control range, the thread will become discolored. This will result in an uneven coloration of the thread when it is dyed and it will not be possible to use the thread for weaving cloth. Furthermore, as previously stated, improper temperature control has an adverse effect upon the quality of thread, including the extent to which it is drawn and twisted and feel of the thread. These factors clearly indicate that proper temperature control is very important.

The overall concept of temperature control through the use of control equipment is described above. The following is a description of actual control applications. The methods described have all their advantages and disadvantages and should, therefore, be adopted accordingly in proper balance with the spinning machine used, depending upon the degree of equipment reliability, accuracy, and economy.

1. Thermostat Type Control System

The thermostat type control system is one in which temperature control of the heaters is accomplished using a thermostat installed in each heater to turn the applied voltage on and off. This is a simple, low-cost system. However, it has such drawbacks as temperature diffusion, resulting from lack of uniform temperature control and periodic change of the thermostats, difficulty of temperature setting (thermostat bears no scale or marking), and a more limited range of adjustment (there is no means of measuring the temperature on the surface of contact plate and it responds slowly to temperature change). For these reasons, this system is unsatisfactory from maintenace viewpoints as an increased number of heaters is applied, although it can be successfuly applied when there is only a limited number of heaters.

2. Block Heater Control Using a Thermal Medium

This control system, consisting mainly of some ten or so contact plates assembled into a single housing containing a thermal medium, provides temperature control of the thermal medium by turning a medium heating element on and off through detection of the vapor pressure of the medium. All contact plates are indirectly heated by the vapor from the medium. A constant relationship exists between the temperature and vapor pressure, making it possible to control the temperature through detection of the vapor pressure.

The present system has the advantage of being able to control some ten or more contact plates collectively at an extremely uniform temperature since the plates are heated by vapor contained within a single common unit. However, it also has some disadvantages in that the heaters are bulky and methods of installing the heaters on a machine are, therefore, limited; it is impossible to design these heaters with complex configurations; the heaters are subject to temperature drift from periodic change in the vacuum within the container; and leakage of the vapor from the thermal medium may damage or discolor the thread, depending upon the type of thermal medium used and may even have a toxic effect.

3. Group Heater Control Employing Master Heater

This control system consists mainly of a group of 10 to 20 heaters with one of the heaters used as a master heater to control all of the heaters in the group through control of the temperature of master heater.

This system permits the heater units to be constructed in groups. This reduces the price of the control equipment per spindle making this system economical. However, under this system, the master and slave heaters must be provided with uniform heating characteristics. If there is any disparity in temperature between master and slave heater characteristics, this disparity will be reflected as a loss of control efficiency. In actual practice, however, it is extremely difficult to match the characteristics of the slave heaters to that of the master heater. In other words, even though the master and slave heaters are initially matched to a given temperature, there will be a disparity in these temperatures over a period of time or temperature will vary from that prescribed. Moreover, if the master heater becomes defective, the slave heaters will not function properly, resulting in a considerable loss of material. If, on the other hand, a slave heater fails to operate properly, it will be completely out of control, since the master heater will have no effect upon that particular heater. In short, this system is effective for protection against such common disturbances as power source voltage fluctuations and variations in room temperature, but lacks proper control over the individual heaters with regard to other disturbance factors (in fact, these factors are the most critical), rendering this type of device ineffective for heater temperature control.

4. Individual Heater Control Using an Electronic On-Off Controller

This control system is a primary step toward adoption of simple non-indicating on-off controls in lieu of thermostats and indicating controls. The non-indicating on-off controllers used have been recently developed and are available at low cost.

The purpose of this system is to control each heater through a separate controller for each heater. The system accomplishes PI control and provides improved heater control, and has a wide temperature setting range.

Since there are no moving parts, controllers can be installed directly on the machine. It is of course possible to mount them together on a panel. Due to compactness, they also offer a better space factor. *Fig. 7* shows a temperature controller used under this system.

This system can be operated with the same set

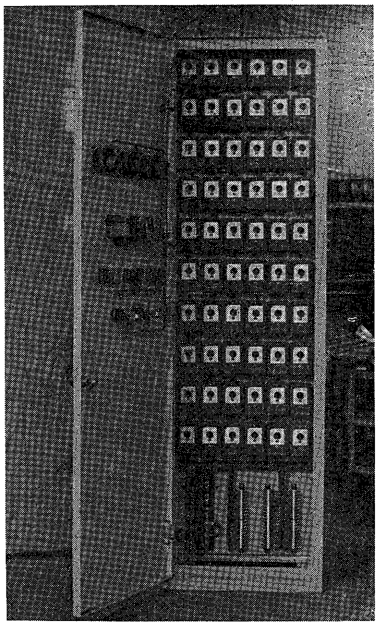

Fig. 7 Temperature controller

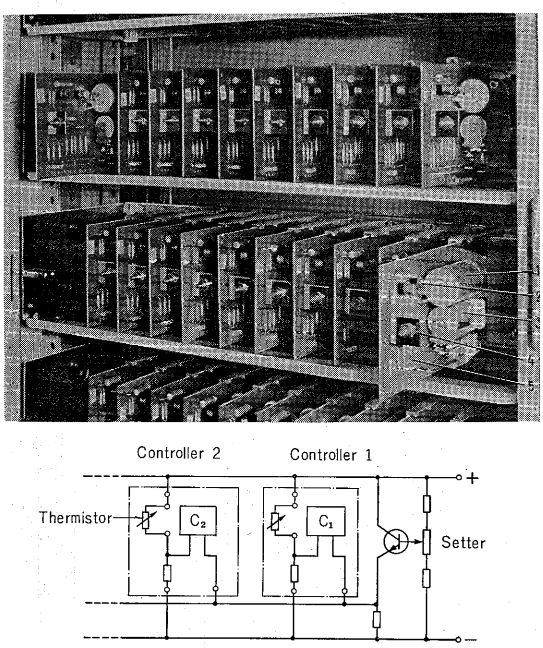

Fig. 8 Temperature control shelf

value for each controller. The controllers are normally mounted on a panel. Therefore, through further simplification by using a single setter in common for all controllers and by containing each controller within a single print board case (removing the individual control cases) and modifying a controller so that it becomes a single print board unit, the control equipment is made even more compact, and is more economical and easier to maintain. Another advantage of this system is that such an arrangement will eliminate setting errors and disparity among the controllers. *Fig. 8* shows the temperature control shelf and common-setter, individual control circuit employed in this system.

5. Scanning Control

The purpose of the scanning control is to provide individual control over the temperature of a large number of heaters through switching one controller. In some cases, a scanner is employed which also serves as a monitor. Under this system, it is possible to control all heaters individually by a single controller, so that the temperature of each heater is kept uniform and, with all factors considered, the cost per spindle is really quite low.

A schematic diagram and front view of the scanning monitor controller employed under this system are shown in *Figs. 9* and *11*, respectively.

There are two types of scanning controllers used for both control and monitoring: One type provides indications of abnormal heater temperatures for each point and the other provides indication of abnormal heater temperature by a common single lamp. The former is suitable for mills having fewer operators since it permits the operator to check only the temperature at points for which abnormal temperature is indicated. Since it gives the temperature indication separately for all points, the occurrence of abnormal heat affects the thread and this effect can be readily identified from the quality of the thread. The latter type is one in which the operator locates the point at which abnormal temperature is applied by operating the push-button switches to locate the specific point or points, and, therefore, involves some minor inconvenience. Nevertheless, this system can effectively used under some circumstances, since it also provides scanning control and since it is rare for both the controller and the heaters to become defective at the same time. In one case only two points indicated an abnormal condition when 100 heaters were checked every hour within a 24-hour period (Number of times tested: 2400).

An example of a scanning control unit is shown in *Fig. 12*.

Representative control conditions are as shown below:

- Disturbances (Room teperature variation, ±2%; disparity among heaters, ±3%; source voltage fluctuation, ±10%; load variation, 30%)
- Heater temperature: 250%°C
- Extent of operation: 30%
- Heater time constant: 60 minutes
- Controller sensitivity: 0.5°C
- Scanning period: 50 seconds
- Control accuracy (Static—max. deviation, ±1°C; Dynamic—max. temperature drop when setting thread on spinning machines, 3°C; recovery setting time, 3 minutes)

It should be noted that the floor space occupied by control panels in a spinning mill has recently reached such significant proportions with particular reference to the traffic of spinning wheels within the mill as to adversely affect layout and processing.

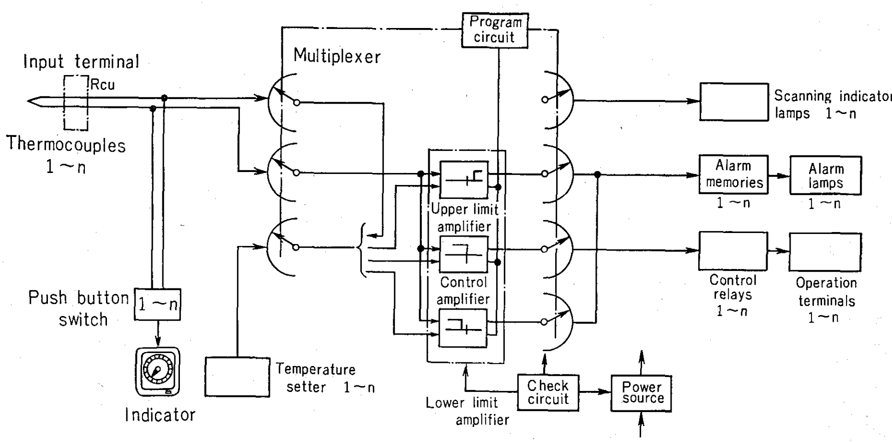

Fig. 9 **Systematic diagram of scanning monitor control**

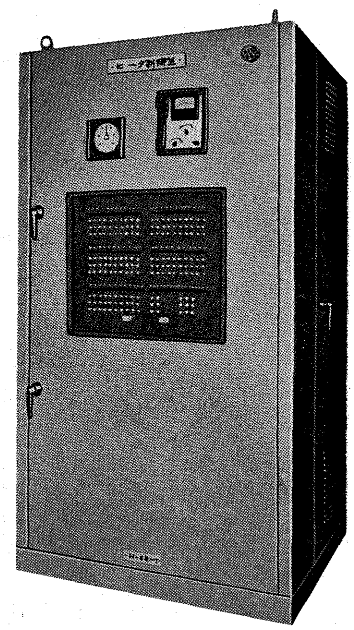

Fig. 11 **Scanning monitor controller**

To cope with this, an effort was made on a trial basis to develop a hanging type control panel which is as compact and light as possible. As a result, the compact scanning controller, shown in *Fig. 10*, was developed. This controller was greatly welcomed since it saved floor space which could be effectively used for other purposes.

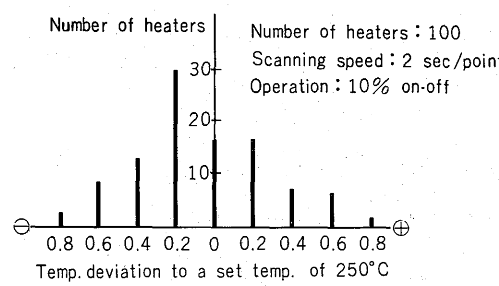

Fig. 12 **Example of scanning control**

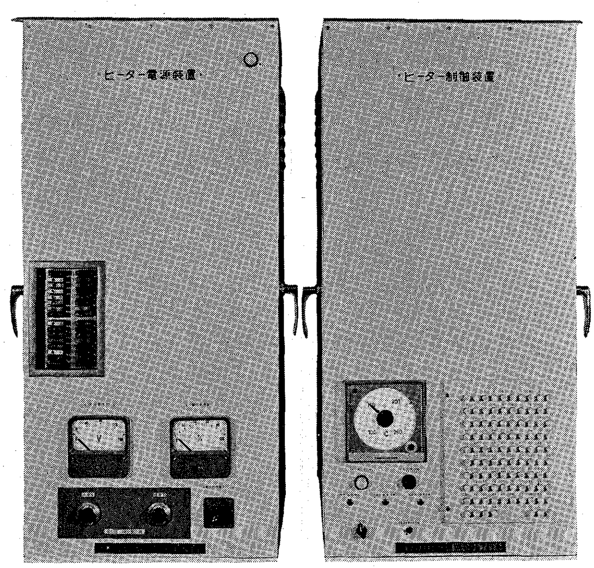

Fig. 10 **Compact type scanning controller**

V. POWER UNIT

The power unit provides power for the heaters and must be designed and constructed to permit control for selection of the most suitable power supply depending upon heater characteristics and the extent of disturbances.

Power is supplied to the heaters under a complete on-off operation or a two-position action, by which the controller selects either high or low voltage.

In either case, it is essential that the control be capable of precisely selecting the proper voltage from the power transformer within the required range. Optimum voltage setting is provided when setting is made in such a manner that the temperature is set according to the median controlled variable of a two-position action so that the heater will not be adversely affected by temperature offset. To select this optimum controlled variable, select the operating voltages so that the On relay and the Off relay provide a ratio of 1 to 1 as measured by a ratio meter inserted in the exciting winding circuit of the heater control relay group. The voltage may be selected by the following methods:

1) Tap selection method
2) Booster method
3) Thyristor method

VI. CONCLUSION

The foregoing is general description of development and the present status of heat processing of synthetic fiber thread and the applicable heaters and control equipment.

Since this filaments are processed at a temperature approximating their yield points, in actual operations more delicate problems are encountered.

From the experience obtained, it can be conclued that it is desirable to design the heater, control equipment, and power unit as a single unit and manufacture them as an overall equipment unit to guarantee final control results.