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NEW TYPE FUJI TRANZET

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I. INTRODUCTION

The Fuji TRANZET type–II has been used in many fields especially for temperature control in various fields of industry. More than 100,000 units of this type have been produced and are operating satisfactorily. This article will introduce the new Fuji TRANZET (hereafter referred to as the type–III) which is a controller incorporating new techniues based on the experience obtained with the type–II TRANZET. In order to increase reliability, thick-film hybrid integrated circuits are employed and in addition two patents and five utility model rights (including some now pending) apply to the type–III TRANZET. Detailed points concerning maintenance and handling have been considered on the basis of experience gained with the type–II TRANZET. The exterior is more attractive and compact.

II. FEATURES

1) Because of the new modern design, the TRANZET is more attractive, compact and lightweight.
2) Since integrated circuits are used in the control amplifier, control reliability has been improved.
3) Since adjustment of the external wiring resistance is performed by a variable resistor and push button switch combined in one unit, adjustment has been simplified. This fool-proof switch is automatically returned after the adjustment is completed and there is no need to worry about troubles arising from forgetting to return the switch.
4) Although the indicator is a set pointer, full scale display is possible.
5) The measuring element employs the taut-band suspension system which is resistant to shock and includes no friction. A long service life is thus assured.
6) Since fail-safe thermocouple burn-out protection is provided, there are no breakdowns due to thermocouple breaks.
7) In order to prevent misoperationdue to mechanical vibrations, an electrical anti-shock circuit with CR feedback is employed like in previous type and it is also easy to incorporate an oil damping function in the measuring element.

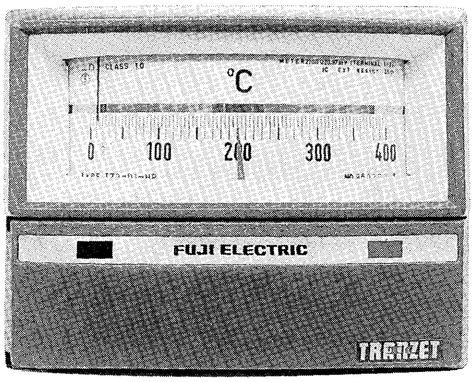


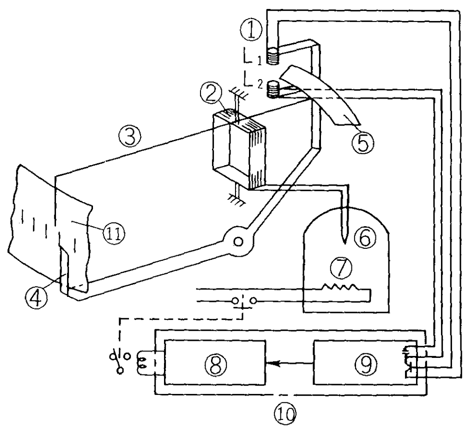
Fig. 1 TRANZET III

8) Since all necessary operating functions including setting control point, external wiring resistance adjustment and manual resetting are performed on the front surface, the type–III TRANZET is very easy to handle.

III. OPERATING PRINCIPLE

1. Operation

The operating principle of the TRANZET is shown in *Fig. 2*. The control amplifier is divided into two



① Detector coil
② Measuring element
③ Indicator
④ Set pointer
⑤ Screen vane
⑥ Thermocouple
⑦ Heater
⑧ Switching circuit
⑨ Oscillator circuit
⑩ Control amplifier
⑪ Scale plate

Fig. 2 **Principle of TRANZET III**

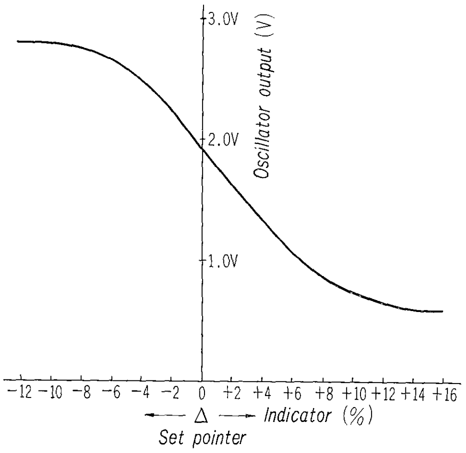


Fig. 3 **Relation between deviation and oscillator output**

blocks: an oscillator circuit and a switching circuit. Both blocks employ thick-film hybrid integrated circuits. Control operation is as follows.

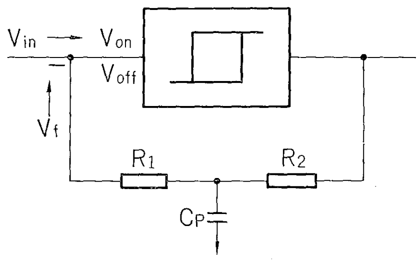
When the screen vane which is connected to the measuring element is inserted between two detector coils, the mutual inductance between the coils is altered and the oscillator output is reduced. The relation between the mechanical deviation between the set and indicated values of the measuring element and the oscillator output is almost proportional as shown in *Fig. 3*. By utilizing the proportional part of this relation, the mechanical deviation can obtained as oscillator output.

The oscillator circuit consists of a tuned base oscillator circuit and a rectifier circuit. The oscillator frequency is determined by the L and C constants of the tank circuit, and is approx. 150 kHz in this equipment. The oscillator output is applied to the switching circuit which includes a first order lag feedback circuit. If the oscillator output is raised to a certain value, the output of the switching circuit becomes ON and if it is reduced to a certain value, the output becomes OFF. This is a so-called two-position ON/OFF circuit. Therefore, if the relay is operated by this output, the relay will be either ON or OFF when there is some relation between the indicator and the set pointer. This device is therefore ON/OFF controller.

2. Time Proportional Control

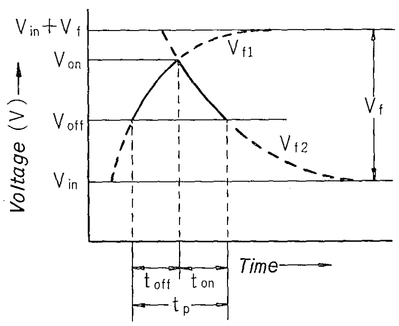
With the simple ON/OFF controller described previously, a fluctuation in the process variable arises and in order to keep this fluctuation small, the TRANZET performs time proportional control as described below.

When there is feedback of the first order lag to the switching circuit as shown in *Fig. 4,* time proportional control can be carried out. Because of the relation between the input and feedback in such a case, the switching circuit becomes OFF since the input is reduced and at that time, the feedback from



V_{in}; input voltage
V_{on}; voltage at which the relay is turned on
V_{off}: voltage at which the relay is turned off
V_f : final feed back voltage

Fig. 4 **Principle of proportional action**



t_{off}: time while output is off
t_{on}; time while output is on

Fig. 5 **Locus of feed back voltage**

the output to the input is applied to the input. In other words, negative feedback is used. This will be described in more detail using the symbols shown in *Fig. 4*. While the output in ON, input V_{in} is reduced and $V_{in} \leqq V_{off}$. The output is changed to OFF and feedback V_f from the output is appiled to the input. If the relation $V_{in}+V_f \geqq V_{on}$ exists, the output is switched back to ON and feedback V_f is removed in time (see *Fig. 5*). In the region where ON/OFF switching is performed continuously, i.e. the oscillating region, the input covers the following range.

$$V_{on}-V_f \leqq V_{in} \leqq_{off}$$

The range of this V_{in} is shown as a proportional band in proportional control operation.

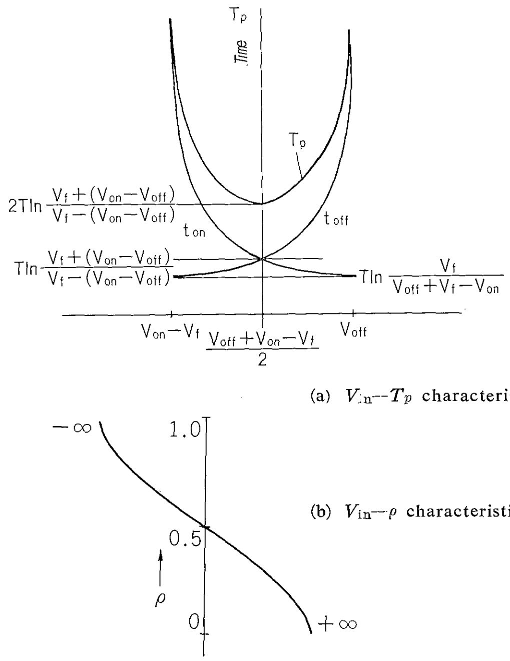
$$V_{f1}=(V_f+V_{in}-V_{off})(1-e^{-t/T})+V_{off} \cdots\cdots\cdots (1)$$

$$V_{f2}=(V_{in}-V_{on})(1-e^{-t/T})+V_{on} \cdots\cdots\cdots\cdots (2)$$

In these equations, T is the feedback circuit time constant $T=(R_1//R_2)\ C_p$. As the impedance of the signal source is small, it can be assumed that the impedance of the switching circuit is large. From equations (1) and (2), the following can be obtained.

$$t_{on}=Tln\frac{V_{in}+V_f-V_{off}}{V_{in}+V_f-V_{on}} \cdots\cdots\cdots\cdots\cdots (3)$$

$$t_{off}=Tln\frac{V_{in}-V_{on}}{V_{in}-V_{off}} \cdots\cdots\cdots\cdots\cdots\cdots\cdots (4)$$



(a) V_{in}—T_p characteristics

(b) V_{in}—ρ characteristics

Fig. 6 **Characteristics of proportional action**

$$T_p = t_{on} + t_{off}$$
$$= Tln\frac{(V_{in}+V_f-V_{off})(V_{in}-V_{on})}{(V_{in}+V_f-V_{on})(V_{in}-V_{off})} \cdots\cdots\cdots (5)$$

The output characteristics from the above equations are shown graphically in *Fig. 6*. The output is defined as the ratio of t_{on} to T_p. In other words, when the time ratio of the time in which the output is ON, is the output ρ, then:

$$\rho = \frac{t_{on}}{t_{on}+t_{off}}$$
$$= \frac{1}{1+l_n\left(\frac{V_{in}-{}_{on}}{V_{in}-V_{off}}\right)\Big/ l_n\frac{V_{in}+V_f-V_{off}}{V_{in}+V_f-V_{on}}} \cdots\cdots\cdots (6)$$

These characteristics are shown in *Fig. 6 (b)*.

3. Manual Reset

Manual reset which is unavoidable in proportional control was performed mechanically in the type–II, but in the type–III, an electrical system is used. This electrical reset is based on a system that the voltages at which the switching circuit is turned ON (V_{on}) and OFF (V_{off}) are shifted together with a variable resistor located in the front panel. The system is shown in *Fig. 7*.

IV. CONTSRUCTION

1. Indicator Unit

1) The measuring element is the main part of the controller since it detects the measured value and also mechanically detects the deviation between the measured and the set values. The element is of the external magnet moving coil type. If features a taut-band suspension for the moving coil, and further,

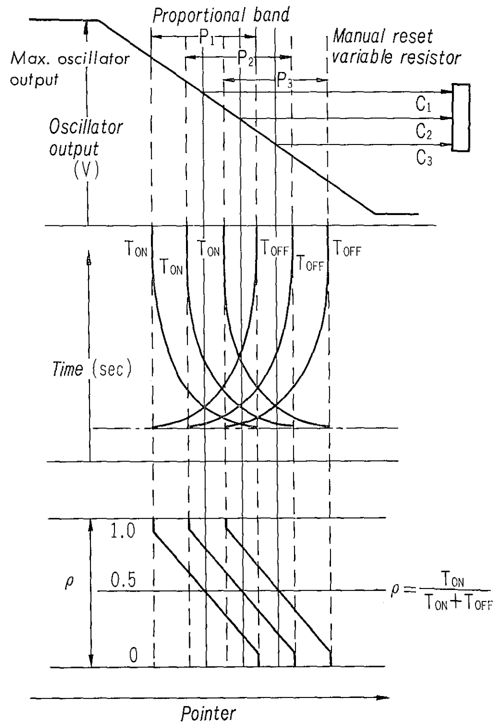


Fig. 7 **Illustration of manual reset**

the following considerations are paid as a meter for the controller.

(1) Full scale display is possible

In previous meters, the screen vane attached to the measuring element was small and therefore, it could not provide screening between the detector coils when the value was exceeded. A stopper was attached to the detector coils and the measuring element was designed so that the set value would not be exceeded. Therefore, full scale display was impossible. In this meter, the screen vane is connected to a movable part and the surface area is greater as shown in *Fig. 8*. Therefore, even if the set value is exceeded, the plate can act as a screen between the detector coils and control relay operation is maintained. There is no need for a stopper and full scale display is possible.

(2) Oil damping against the mechanical vibrations

Fig. 9 shows a sectional view of the measuring

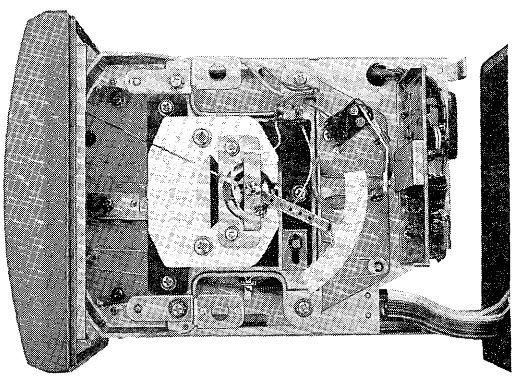


Fig. 8 **Top view of TRANZET III**

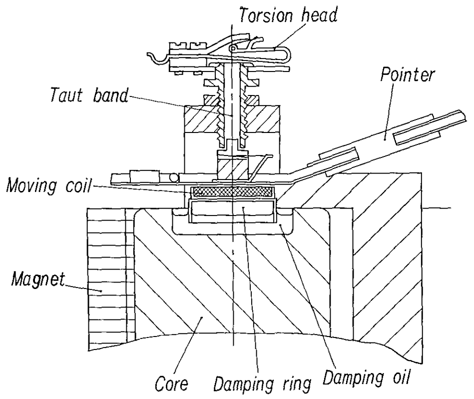


Fig. 9 **Sectional view of measuring element**

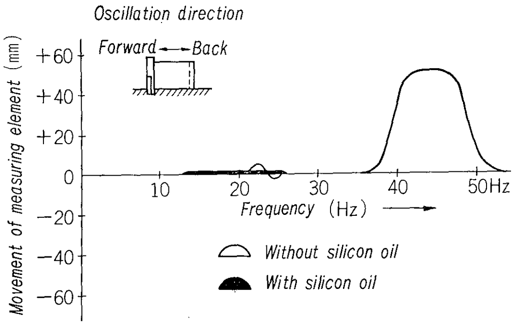


Fig. 10 **Antivibration effect of damping oil**

element. As cah be seen in this figure, there is a cylindrical hole in the upper part of the iron core. A cylindrical (helix shaped) damping ring attached to the moving coil is inserted in this hole. There is a gap of about 1 mm between the hole sides and the damping ring. Since there is usually no contact between the core and the ring, there will be no obstruction of the measurement. When damping oil (silicon) is put in the gap, the moving coil will be damped and even if there are external vibrations or shocks, the measuring element will not be moved. *Fig. 11* shows a comparison between the movement of the measuring element due to an external vibration with and without silicon oil. Silicon oil (viscosity : 10,000 c.s.) is used as the damping oil because there are few changes in viscosity and little vaporization in respect to temperature changes.

2) Measuring circuit

The measuring circuit differs according to the measuring input and the following types of circuits are used. In all cases, the input is converted to a constant current (100 μA).

Theremocouple input
- reference junction temperature compensator
- external wiring resistance adjuster
- thermocouple burn-out protection

Resistance thermobulb input
- bridge circuit
- constant voltage supply

(1) Thermocouple input

This circuit contains units for the above three

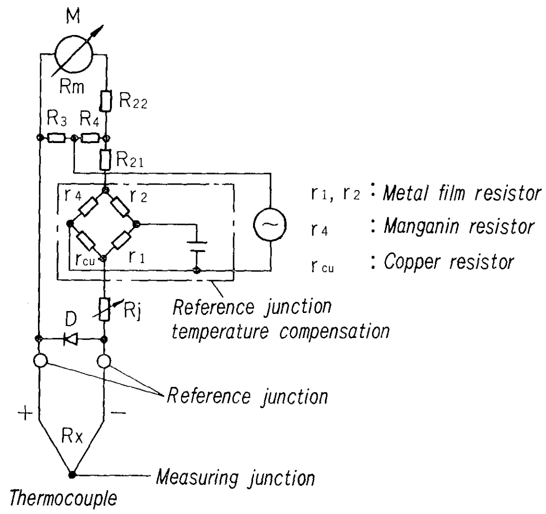


Fig. 11 **Circuit diagram of reference junction temperature compensator and thermocouple burn out protection**

functions combined in one circuit and supplied by a single power source. The operation and construction of each part of the circuit will be described.

(a) Reference junction temperature compensator

Fig. 11 shows equivalent circuits for the reference junction temperature compensator and the thermocouple burn-out protection. The thermo-electromotive force of the thermocouple is determined by the temperature difference between the measuring junction and the reference junction. Therefore, reference junction temperature changes will cause an error in the indication and must be compensated for. This compensator circuit is a bridge composed of a copper resistor and three resistors (two metal film resistors and one wire wound resistor). A voltage corresponding to the reference junction temperature is supplied to the measuring element.

(b) External wiring resistance adjuster

An equivalent circuit of the external wiring resistance adjuster is shown in *Fig. 12*. This circuit has its measuring element as the galvanometer M and a 4-arm bridge consisting of $R_x+R_j+r_{cu}$, r_4+R_{21}, R_3 and R_4 (r_1 and r_2 are omitted because $r_1=r_2\gg r_{cu}+r_4$). If the external wiring resistance values can be determined in a balanced condition. When the switch SW is turned to ON, a voltage is applied to the bridge and an unbalanced voltage arises due to the external wire resistance. However, and electromotive force equivalent to the ambient temperature arises in the thermocouple, the usual voltage supply is applied to

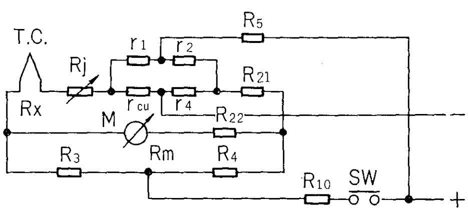


Fig. 12 **Equivalent circuit of external wiring resistance adjuster**

the reference junction temperature compensator and normal operation takes place. If the circuit variable resistor (R_j) is adjusted in this state so that $R_x+R_j=20\ \Omega$, the bridge becomes balanced and the measuring element indicates the measured temperature by means of the electromotive force in the thermocouple.

When the switch SW is turned to OFF, the measuring element shows the same value as when the switch was ON since $R_x+R_j=20\ \Omega$ already. Therefore, the external wire adjustment is finished when there is no change in the indication where the switch either ON (adjust) or OFF (measure).

(c) Variable resistor unit (R_j)

This resistor unit is used for adjustment of the external wire resistance as was described above and consists of a variable resistor and a switch (reed switch) in a single unit as shown in *Fig. 13.* The features of this resistor are (1) simple one-touch operation, (2) since the switch is of the push-button type, there is no need to worry about failing to return the switch to its original position after adjustment, (3) since the contacts of the variable resistor and switch are completely enclosed, it can be used in any environment.

The resistor unit consists of a permanent magnet (rubber magnet), a reed switch and a variable resistor. *Fig. 13 (a)* shows the construction while *Fig. 13 (b)* explains the operation. When the knob is pressed, the permanent magnet is moved away from the iron magnetic shield plate and makes contact with the reed switch. When this occurs, the switch contacts are magnetized by the N and S poles of the permanent magnet and they close. Also when the knob is pressed, the pin attached to its main shaft is inserted into the slit on the shaft of the variable resistor. When the knob is turned and the variable resistor operates, the external wire resistance can be adjusted. When the knob is released, the main shaft is returned to its original position by means of a spring force and the magnet poles N and S are short circuited with the magnetic shield plate. Then the contacts of the reed switch are no longer magnetized and opened.

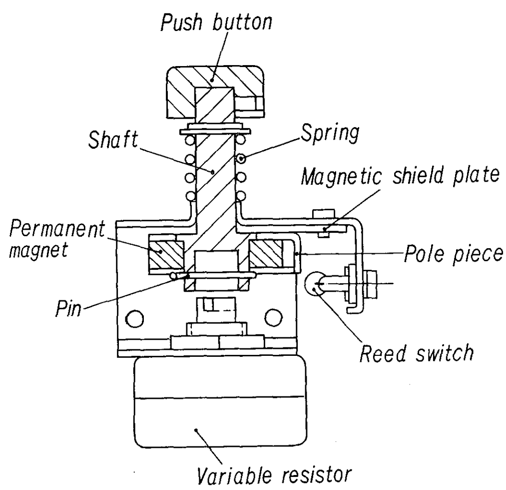


Fig. 13 (a) Construction of wiring resistance adjuster

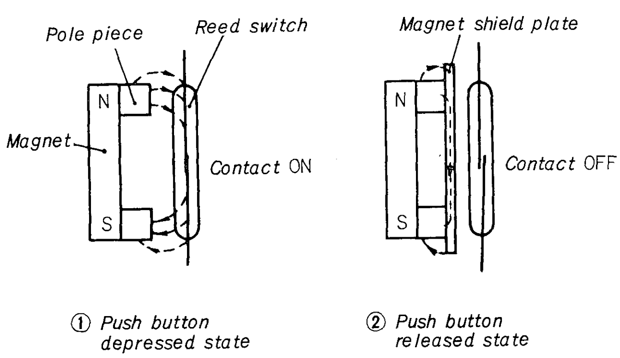


Fig. 13 (b) Principle of reed switch

(d) Thermocouple burn-out protection

This circuit is intended as a safety circuit in case the thermocouple breaks. When the thermocouple is broken during temperature control of heaters etc., the input to the controller becomes zero and the measuring element indicates zero. In a case as shown in *Fig. 2,* the heater may be overheated. In order to prevent such trouble a thermocouple burn-out protection circuit is provided.

This circuit consists of a bridge made up of the high resistances R_3 and R_4 the low resistances $R_{21}+r_4$ and $R_j+R_x+r_{cu}$ as well as a diode D which is connected in parallel with the thermocouple as can be seen in *Fig. 11.* The power supply for this circuit is AC. In the measuring condition, the bridge is balanced as was described in section (b) concerning the external wiring resistance adjuster and no AC current flows into the measuring element. Since the diode D has a high resistance in respect to the electromotive force which arises in the thermocouple TC, the measuring current flows in the measuring element through the circuit ($R_{21}+r_4+R_x+R_j+r_{cu}+R_m+R_{22}$). Therefore, there are no erroneous indications. However, when the thermocouple breaks, the diode D is not short circuited by the thermocouple and at each half wave of the AC current one arm of the bridge (low resistance: $R_x+R_j+r_{cu}$) is interrupted. In this way, the bridge balance is destroyed and a DC current rectified in the diode D flows into the measuring element. Since this current is designed to be greater than the input current of the measuring element for full-scale deflection (100 μA), the indicator goes off scale, and the detector coils are screened. Thus the control loop is switched to OFF.

2) Resistance thermobulb input

a) Bridge circuit

Fig. 14 shaws the measuring circuit for resistance

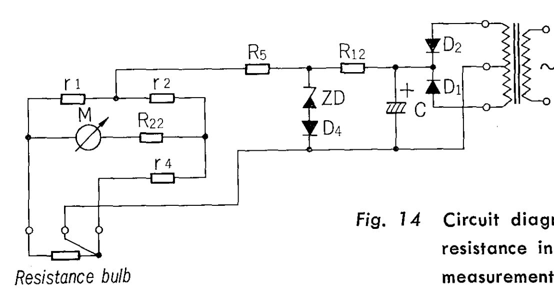


Fig. 14 Circuit diagram in resistance input measurement

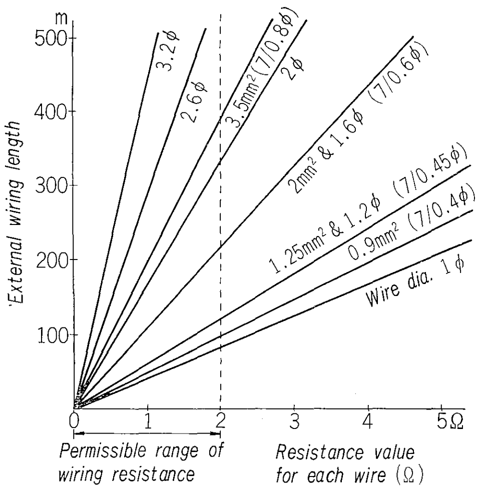


Fig. 15 **Relation between the resistance value and the external wiring length**

thermobulb input measurement. This circuit is composed of a bridge and constant voltge power supply, and a three wire system is used for connection of the resistance thermobulb. Therefore, the wiring resistance between the resistance thermobulb and the meter is in both arms of the bridge and there is no error in indication at the initial point on the scale. Indication errors at the maximum scale point also present no problem if the value of R_{22} is large. As a standard, the external wiring resistance is assumed to be 2 Ω or less and a circuit adjusting resistor (R_j) is not used. When the permissible external wiring resistance is limited within 2 Ω, there may be no problem in practice with ordinary wiring as shown in *Fig. 15* since the wiring is almost always over 100 m in length.

(b) Constant voltage supply

As shown in *Fig. 14,* this constant voltage power supply consists of a power supply rectification circuit, Zener diode ZD and diode D for temperature compensation. This circuit is a general type using a Zener diode and compensation of the voltage in respect to the ambient temperature utilizes temperature changes of the forward voltage drop of silicon diode D which has a temperature coefficient almos the reciprocal of that of the Zener diode.

2. Control Part

1) Control amplifier

Since thick film hybrid integrated circuits are used in this control amplifier, it is extremely compact. Field effect transistors (FET) are employed in the thick film hybrid integrated circuits and therefore the capacitors for time proportional operation are very small which also makes the amplifier more compact. *Fig. 16* shows a comparison between this thickfilm control amplifier of the type–II which has the same functions and is made of discrete parts.

The thickfilm circuits consist of a resistor pattern made of resistor paste printed and fired on an alumina substrate as well as a conductor pattern made of conductor paste printed and fired on the same substrate. The parts required are joined together. The integrated circuits in this amplifier consist of one oscillator and one switching circuit. The oscillator circuits contains one NPN transistor, two high frequency diodes, six capacitors and thick-film resistors. The switching circuits contains three NPN transistors, one PNP transistor, one field effect transistor, one diode and thick-film resistors. These make up the previously described switching circuit and its feedback circuit.

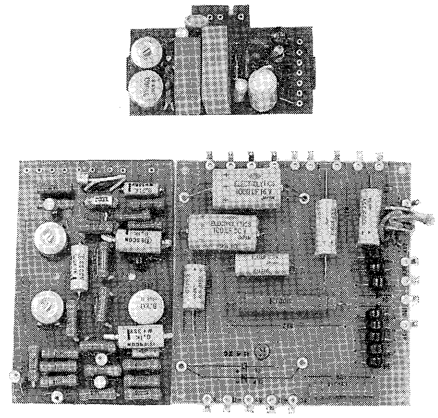


Fig. 16 **Comparison the TRANZET III's amprifier with TRANZET III's amp.**

Table 1 **Specifications TRANZET III**

Input voltage current resistance	Above 10 mV DC Above 100 μA DC Resistance variation more than 20 Ω
External resistance	Voltage input: less than 20 Ω Resistance bulb input: 2 Ω for each wire (3 wire system)
Indicating accuracy	±1%
Current sensitivity of measuring element	100 μA
Scale length	110 mm
Setting accuracy	±0.5% at full scale
Proportional band	Approx. 3% of full scalle
Cycle time	Approx. 30 sec (10 to 45 seconds continuously variable with the variable resistor in control amplifier)
ON–OFF differential gap	Less than 0.5% of full scalle
Output contact capacity	Max. 200 V AC 6 A 1 kVA (resistance load)
Power source	100/200 V AC ±15% 50/60 Hz
Power consumption	Approx. 10 VA
Ambient temperature	−10∼+60°C
Ambient humidity	Less than 90% RH
Weight	Approx. 3.5 kg

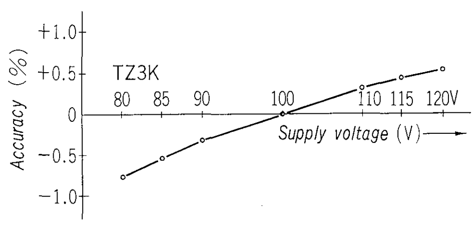


Fig. 17 Supply voltage characteristics of indicating unis

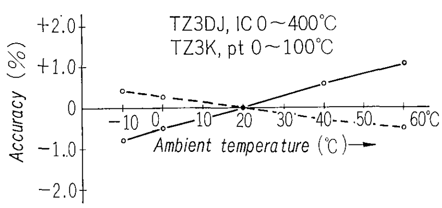


Fig. 18 Temperature characteristics of indicating unit

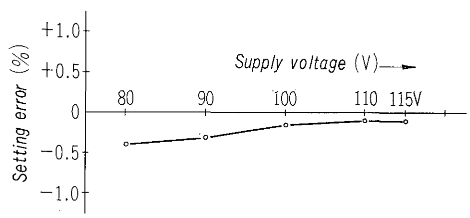


Fig. 19 Supply votlage characteristics of control unit

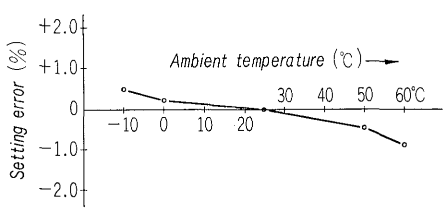


Fig. 20 Temperature characteristics of control unit

2) Output relay

This relay is the type HH22P–1 made by Fuji Elecrric. Service life is long since its contacts are protected with a varistor to quench sparks.

3. Housing

The housing consists of a front cover and a case. To make the exterior more attractive, it is coated with a leather tone of a stable color.

The front cover is of a special design to emphasize the scale. The lower half is in the form of a door and contains various operation knob. Since the cover is held in place by a ball lock systems which employs steel balls, the door can be easily opened just by pulling.

The case is made of iron for the measuring element not to be affected by external magnetic fields. The external terminals part on the back of the case are designed so that the terminals will not be damaged or short circuited by falling objects etc.

The specifications for the type–III TRANZET are listed in *Table 1*. *Figs. 17* to *20* show the voltage and temperature characteristics of the control and indicating units.