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APPLICATIONS OF POSITIVE TEMPERATURE COEFFICIENT THERMISTORS

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I. FOREWORD

The PTC (Positive Temperature Coefficient) thermistors are semiconductor materials with a large positive temperature coefficient. Ceramic semiconductors like doped $BaTiO_3$ or a mixture of $BaTiO_3$ with *Sr* and *Pb* are used. PTC thermistors can be roughly divided into a type whose resistance increase by several power of ten in the vicinity of the transition temperature (Curie Point) and a type whose resistance slowly increases with temperature. Recently, PTC thermistors have come to be used as components in such common appliances as electronic jars and color TV sets, and as control components in electric fans. Fuji Electric has been pushing commecialization and application of PTC thermistors for several years and is now actively marketing them. Because the PTC thermistor has a large positive temperature coefficient, it can be used for automatic damping of currents ranging from milliamperes to amperes by utilizing its self-heating or as a constant temperature heater whose generated heat is virtually unaffected by the applied voltage or ambient temperature and is considered to have a wide range of other applications. This article introduces the characteristics and applications of PTC thermistors studied by use and presents user application developments.

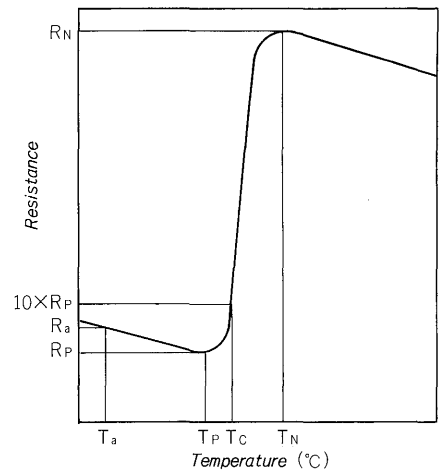


Fig. 1 Prototypical resistivity vs. temperature characteristics of PTC thermistor

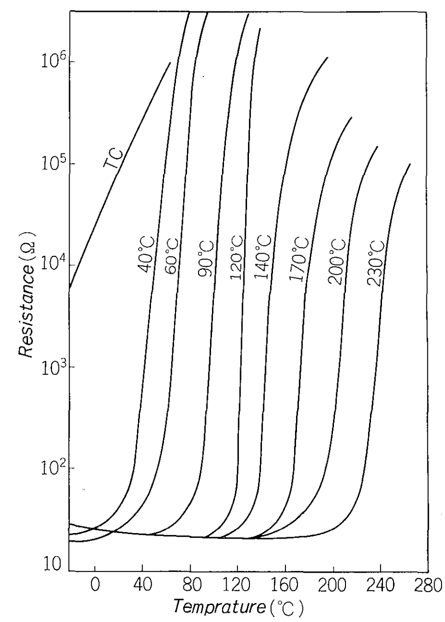


Fig. 2 Temperature vs. resistance relations of Fuji PTC thermistors

II. PTC THERMISTOR CHARACTERISTICS

The PTC thermistor differs from the common thermistor with its negative temperature coefficient in that part of its temperature—resistance characteristic has a positive temperature coefficient region. The pattern of this basic characteristic is shown in *Fig. 1*. As can be found from the figure, the temperature coefficient is negative at temperatures below Tp and above Tn and is positive at temperatures between Tp and Tn.

The temperature at which the temperature coefficient becomes positive is called the transition temperature at which the temperature coefficient becomes positive is called the transition temperature (Tc) and is defined by Fuji Electric as the temperature at which the resistance of the thermistor increases to $Rp \times 10$. This point almost coincides with the Curie point of ferroelectric ceramics. The transition temperature of barium titanate ceramic $BaTiO_3$ is 120°. However, this can be shifted to a higher side by replacing part of the barium with lead and to

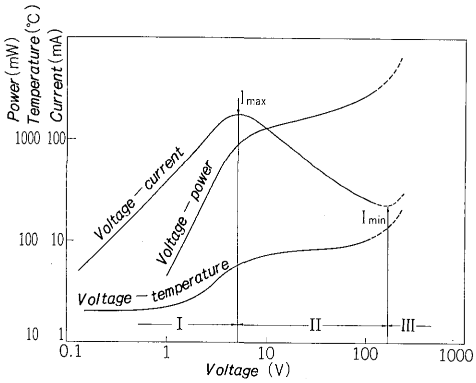


Fig. 3 **Static characteristics of PTC thermistors**

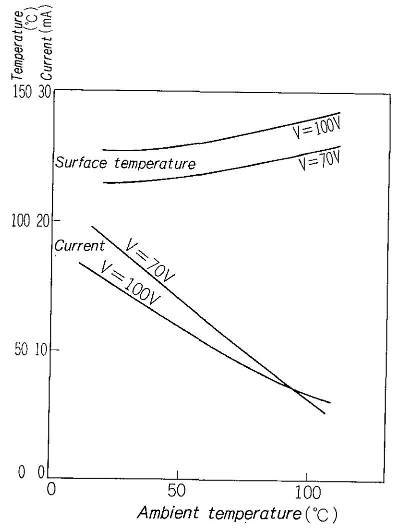


Fig. 4 **Variations of stable current and corresponding surface temperature rises of PTC thermistor due to ambient temperatures**

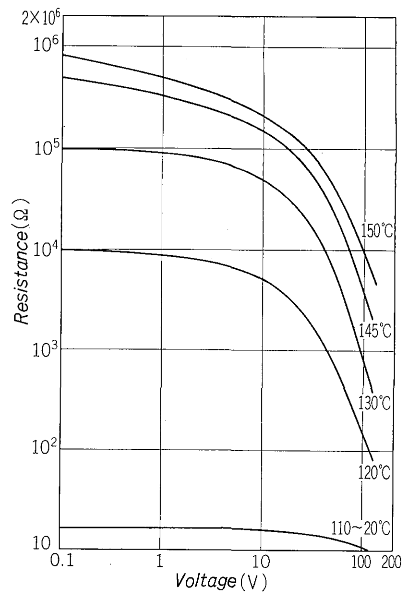


Fig. 5 **Voltage dependency of resistivity of positive temperature coefficient thermistor at various temperature**

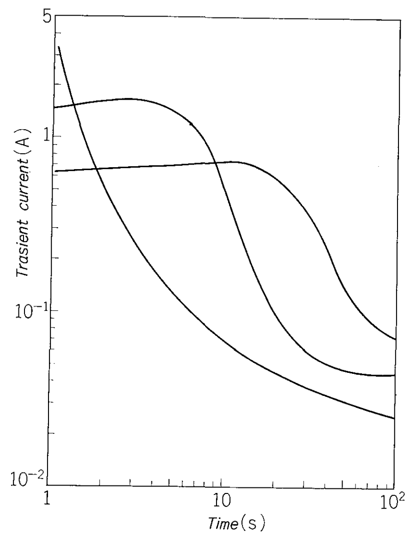


Fig. 6 **Dynamic characteristics of PTC thermistors**

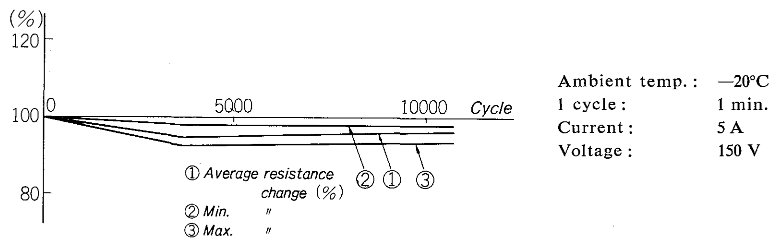


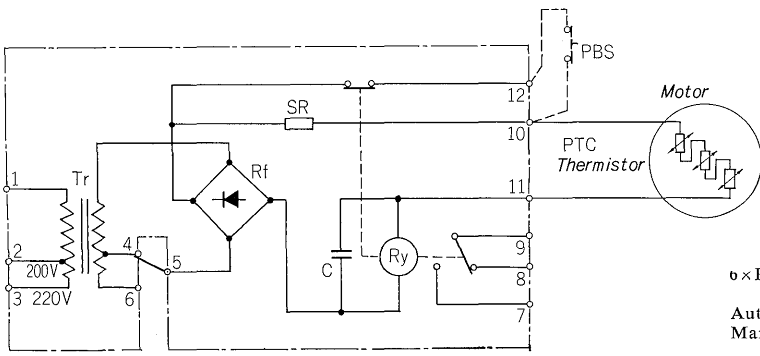
Fig. 7 **Intermittent loading test for PTC thermistor**

a lower side by replacing part of the barium with strontium. The temperature coefficient can also be changed greatly by varying the sintering conditions, etc.

Fuji temperature switching type thermistors from 40°C to 230°C in 10°C increments have already been serialized. Temperature compensation type elements are also available. Typical characteristics of Fuji PTC thermistors are given in *Fig. 2*. The static characteristics of PTC thermistors are given in *Fig. 3*. In region (I) the current is directly proportional to the applied voltage. In region (II), the current decreases with the applied voltage due to self-heating and the power remains almost constant. In higher voltage region III, current increases following voltage. These regions correspond to those of *Fig. 1*. The point at which the current is maximum appears between region (I) and region (II) and the point at which the current is minimum appears between region (II) and region (III). Region (I) and region (II) are normally used.

Because the element is thermally destroyed by runaway in region (III), this temperature must never be exceeded under any usage conditions. The variations of power consumption and surface temperature with applied voltages are shown in *Fig. 3*. In region (II) the changes is therefore considered suitable for constant temperature heating element applications. *Fig. 4* shows the surface temperature and current changes due to ambient temperature as a function of applied voltage. The resistivity increase is due to the exsistance of non ohmic grain boundaries in the polycrystalline ceramic. The height of barrier layer varies with the dielectric constant which depends upon the temperature and is a function of applied voltage. The latter is the same as the usual varistor effect. In this case, the separation of the characteristics of the PTC effect and varistor effect is impossible essencially. Since the latter operates in the direction which cancels the PTC effect, special care is required when considering PTC thermistor applications. An example of the varistor effect is given in *Fig. 5*. The change in the current in the transient state immediately after voltage is applied to the PTC thermistor is illustrated in *Fig. 6*.

Since self-heating causes the resistance of the PTC thermistor to increase when the applied voltage exceeds a certain value, the large initial current is



C thermistor: terminals 4— 5 shorted
5— 6 open
6×PTC thermistors: terminalz 5— 6 shorts
4— 5 ohens
Automatic reset: terminals 10—12 shorted
Manual reset: reset pushbutton switch (PBS) connected between terminals 10—12

Fig. 8 Connection diagram of overheat protector

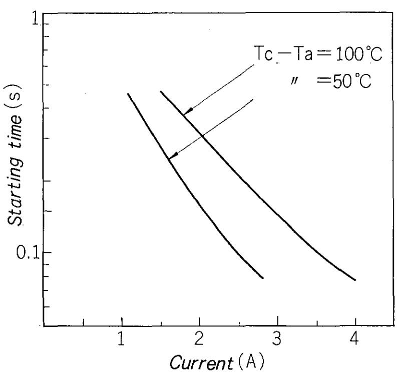


Fig. 9 Theoretical variation of damp ing time constant withincident-constant

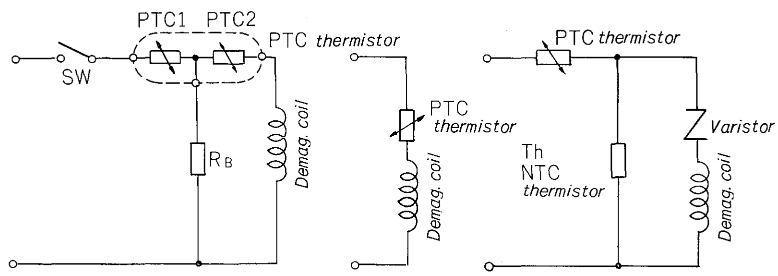


Fig. 10 Automatic demagnetizing ciracuits in color TV

abruptly reduced to a small constant value. This characteristic is being widely applied recently. In this type of application, fatigue of the solder used to attach the leads due to thermal shock poses a problem. However, we have solved this problem through the use of a unique pressure contact structure. The results of the intermittent loading test are given in *Fig. 6*.

III. PTC THERMISTOR APPLICATIONS

Studies have been conducted on the following applications utilizing the various characteristics of PTC thermistor. There are roughly four methods of using these elements, namely, (1) as a temperature sensor, (2) as a delay relay, (3) as a heater, and (4) as a modified version of (2).

1. Overheating Protection Switch

The abrupt increase of resistance with temperature shown by PTC thermistor can be utilized to produce an overheating protection switch for electric heaters and machines, fire alarms, etc. Fuji Electric employs the PTC thermistor for motor overheating protection. The element is a 3× 10× (thickness) 1.5 mm pellet resin molded in a 5 ϕ × 17 mm fiber glass sleeve, but it can also be housed in a copper pipe where strength is especially demanded.

These elements can be used up to 230°C in accordance with the insulation grade. Overheating is normally detected by burying the element at the terminal of the coil winding and the motor power source is interrupted by a relay unit. The wiring diagram of the Fuji overheating protector is shown in *Fig. 8*. Miniaturized elements having a pellet area approximately 1/13 of that given above are currently under developement. For this reason, response is considerably better than conventional types and operation of a relay at approximately 5 seconds is possible when installed to a Tc +50°C oil bath.

2. Applicationto Color TV Automatic Demagnetizing Circuit

Assume that electrodes are attached to both ends of a cylindrical rod having a thickness of α and then are can find the self-heating effect of the thermistor when the emission at the electrodes is infinite. Making the shaft of the cylindrical shaft one direction Z, we put the cylindrical are Z-direction, and assume that the temperature near $Z=a/2$ will reach Tc, then this part will have a high resistance, and automatic current damping will be produced. At this time, the temperature difference $\varDelta\theta$ between the face $Z=a/2$ and the electrodes will be

$$\varDelta\theta=\frac{a^2I^2}{\delta\kappa\sigma}\left(1-\frac{32}{\pi^3}e^{2\pi^2\kappa t/a^2C\rho}\right)$$

Where C: specific heat (0.55 w/°C cm), ρ: specific weight (5.3 g cm^{-3}), κ: thermal conductivity (10^{-2}w/°C cm), $1/\delta$: resistivity (Ω cm), I: current density (Amp/cm^2), $\varDelta\theta$: temperature rise (°C)

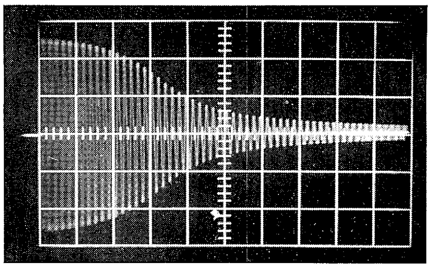


Fig. 11 Oscillogram of demagnetizing AC Current

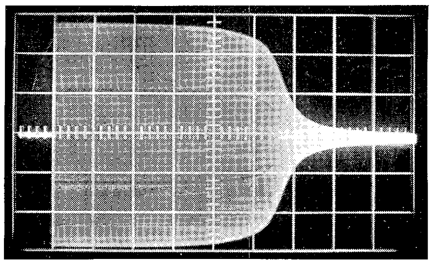


Fig. 13 Dypamic oscillogram of PTC thermistor

Since this equation is applicable when the incident current is large and current damping is performed in a short period of time, the time up to damping can be roughly calculated by making $\Delta\theta = Tc - Ta$, where Ta is the ambient temperature. If the threshold for current damping is written by t_{Damp}, then

$$t_{Damp} = -14.8\, a^2 \log \left(1 - \frac{0.08}{I^2 a^2} \sigma (Tc - Ta)\right)$$

The relationship between the incident current density and the threshold for current damping obtained by means of *Eq.* (1) is shown in *Fig. 9*. The size of the element can be determined from this relationship when the incident current is known.

A color TV receiver is affected by earth magnetism and the color will deteriorate when the direction of the receiver is changed. This is caused by the magnetization of the shadow mask inside the picture tube and the chassis, picture tube mounting fixtures, and other metal parts around the picture tube to the earth's magnetism cause the composite magnetic field of these magnetic fields and the earth's magnetism to bend the electron beam inside the picture tube slightly. In order to eliminate this, magnetic shielding and demagnetizing of the metal parts is required so that the earth magnetism has no effect. Demagnetizing can be performed by passing an alternating damping current through a coil which produced a magnetic field at the shield plate of the picture tube. The transient characteristics of the PTC thermistor can be used to provide this alternating damping current. When a voltage is applied to a PTC thermistor at room temperature, a current of several amps flows, but since the temperature of the PTC thermistor rises due to self-heating, the resistance of the thermistor increases and the current is reduced to several mA. Therefore, the desired effect can be obtained by connecting the demagnet-

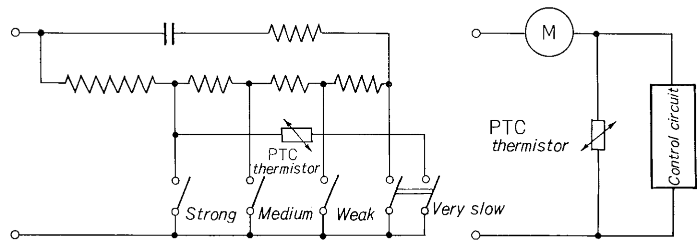


Fig. 12 PTC themistor application circuit for very low speedfan and electronic fan motor

izing coil in series with the PTC thermistor. Automatic operation with each operation of the power switch is primarily used in TV sets, but the contactless, small, high reliability PTC thermistor system is alwo finding wide use. Typical demagnetizing circuits using a PTC thermistor are shown in *Fig. 10*.

Circuit (a) combines two PTC thermistors, circuit (b) uses a single PTC thermistor, and circuit (c) uses the PTC thermistor in combination with other components. (when the PTC thermistor is merely connected in series with the demagnetizing coil), the steady state current is comparatively large and so a combination of (a) or (c) is normally used. The steady state current must be attenuated to mA or less. The waveform of the alternating damping current which flows in the demagnetizing circuit of (a) is shown in *Fig. 11*. The time constant is required below under 1 second owing to the transistorization of TV sets. The shape, resistance value, etc. of the element used is estimated from E_q. (1) or *Fig. 9*. The temperature of the PTC thermistor becomes about 70～80°C in operation self-heating when 100 V is applied to a thermistor having a transition temperature of $Tc = 60$°C. The resistance at room temperature differs with the circuit, but a 15～40 Ω, 14～15 ϕ (diameter) × 3.5 t (thickness) element is used. Since the current is large, a pressure contact structure is employed. The PTC thermistor is sure to be more widely used with the increased use of transistors and integrated circuits in TV sets.

3. Very Low Speed Fan and Electronic Fan Starting Compensation

Electric fans having a very low speed of 300～400 rpm and fans whose speed is continuously variable utilizing thyristors have recently been placed on the market. The PTC thermistor can be used for starting compensation in the so-called electronic fans whose speed is controlled and for starting combinations and damping resistance in very low speed fans having a low speed position. In this case, the PTC thermistor is utilized to dampen the fan starting current to the small current in very slow speed operation as the same as in demagnetizing color TV. An applicable circuit is illustrated in *Fig. 12*. The terminal board, spring, and PTC element are sealed in a 15.5× 16.× (thickness) 7.5 resin case

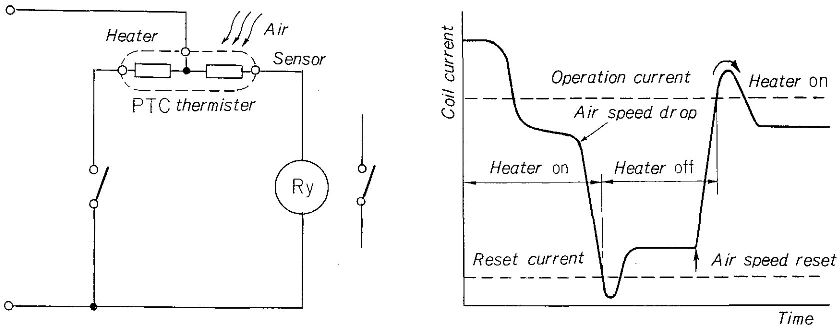


Fig. 14 **PTC thermistor airflow and its operation**

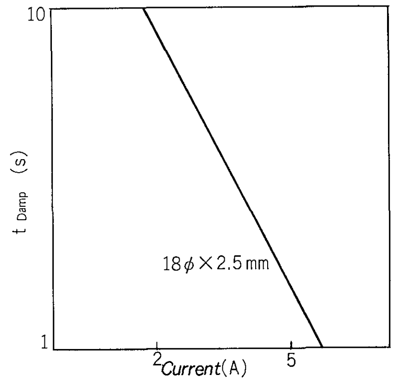


Fig. 16 **Damping time constant vs. incident current**

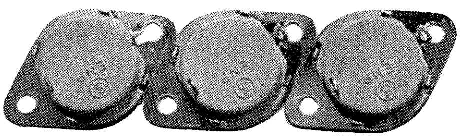


Fig. 15 **Photograph of PTC elements for starting compensation circuit in split-phase starting 1 φ induction motor**

and a pressure contact construction caulked with metal bands is used. Starting is performed when a 5~10 second starting current flows.

The specifications of the elements produced by Fuji Electric are given below.

Resistance at room temperature: 30 ±10 Ω
Transition temperature: 90 ±5°C
Usage voltage: AC 70 V

Its construction is simple and a large number of these elements are being manufactured for very low speed fan at low cost. Moreover, the demand for this type of fan is expected to increase in the future. Furthermore, a small 6 φ× 3 t element having a usage voltage of 50 V and soldered electrodes is also available.

4. Cleaner Dust Removing Motor Timer

There are various devices used in cleaners to remove the dust. Of these the PTC thermistor is used to limit the dust removing time in the 2 motor type which uses a small dust removing motor in addition to the main motor. The PTC thermistor is connected in series with the dust removing motor. Characteristic specifications are the same as fan use. This has been investigated as one method of automation and labor saving of home electric appliances.

5. Electronic Jar

The glass themos jar is used to maintain the temperature of rice, etc. in the home. The flavor is lost and it is difficult to maintain the temperature for a long period of time without spoiling. Recently, jars which maintain the temperature of rise at a high temperature (approximately 70°C) using the PTC thermistor as a heating element and thermostat have been placed on the market to solve this problem. The use of 2~3 elements about 18 φ in diameter can be used to obtain about 15~20 W of heat. When the heat produced by only the PTC thermistors is insufficient, it can be increased by adding a normal heater in series with the thermistors. However, in this case, the arrangement and construction of the heater and PTC must be amply investigated. PTC thermistors can not only be used as constant temperature heating elements of from several watts to several tens of watts to produce cheap constant temperature ovens. Its merits are automatic control of the temperature and there is no noise. The same usage method is also suitable for electronic pots.

6. Air Flow Relay

When self-heating is produced over the transfer point, the PTC thermistor becomes a high resistance and since the stational state ($IV = E\Delta\theta$) is maintained by balancing the incident power and thermal emission when the heat dissipation coefficient E is large, in other words, when the wind speed is large, current I is large and when the wind speed is small, I becomes smaller by one or two order of magnitude. A relay which is operated by the presence or absence of wind can be made by utilizing this current change. If the relay contacts are once opened by attenuation of the coil current, the relay remains open up to the operation current value. On the other hand, if the relay contancts are closed, they remain closed up to the reset current. As for operation of the circuit with the PTC thermistor at the detecting end and the circuit using a combination of two PTC thermistors as the heater, (1) when wind is present, the PTC themistor current is large, the relay is operated, and the heater is turned on. (2) when the wind speed drops, the operation of the heater also changes, the resistance of the detecting element increases abruptly, the relay is opened, and since the heater is disconnected, the coil current increases, but doesn't reach the operation current and the relay contacts remain open. (3) The wind speed is reset under this state and since the heater is off, the element temperature abruptly drops, the relay current exceeds the operation current and the contacts are closed. Therefore, the heater is turned on and the current drops below the operation current, but the

Table 1 **List of PTC thermistors**

Application / Type		Specification				Remaks
		Room temp. resistance (Ω)	Transition tempesature (°C)	Applied voltage (V)	Current (A)	
Motor overheating protection	NPX-06	①<70	90			
			100			
			110			
			120			
			130			Mass produced
			140			
			150			
	NPX-13		170			
	NPX14~21	<200	90~170			
Color TV demagnetizing air						
	PTV 10 P	① 25	60	100	5~6	14 $\phi \times 3$ t $\times 2$
	PTV 12 P	② 45	60	120		
Fan						
	ENP 300 KJ-01	① 30	90	70	1	12 $\phi \times 3$ t pressure type mass produced
	NPX-03	② 70	120	50	0.3	6 $\phi \times 3$ t solder type
Electronic jar and pot						
	NPX-04	60	120	100		18 $\phi \times$ 3 t pressure type
1 ϕ split-phase motor startnig						
	NPX-05	5	120	100		18 $\phi \times 0.25$ t pressure type

reset current isn't reached and the contacts remain closed. In this manner, the SW effectively protects machines in which the semiconductor rectifiers, etc. are forced cooled.

7. Split Phase Motor Starting

The PTC thermistor has recently become used instead of a governor SW. However, in this case, an incident current of about 10 A is required and since the starting time must be on the order of seconds, large PTC thermistor having a small $1/\theta$ is required. From E_q. (1), the starting time of an 18 $\phi \times 0.25$, $R=5\ \Omega$ element at an incident current of 5 A is about 1.4 seconds. The element developed by Fuji Electric is shown in *Fig. 17*. The relationship between the starting time and current is given in *Fig. 18*.

8. Other Applications

In addition to the applications utilizing the various characteristics of the PTC thermistor given above, it is also applicable to fir alarms, temperature control, level gauges, flow meters, electric blankets, relay operating delay, semiconductor and IC miniature constant temperature ovens, etc.

The PTC thermistors which have been commercialized are listed in *Table 1*.

IV. CONCLUSION

This article has described the applications of PTC thermistors while giving actual data centered around elements which have been investigated and used from the first developement of the PTC thermistor until the present time. The features of the PTC thermistor compared to the convention thermistor (having a negative temperature coefficient) are:

(1) Positive temperature coefficient without any thermal runaway and therefore extremely safe.
(2) High temperature cofficient required no special amplification.
(3) Since it is ceramic, the shape can be freely selected.
(4) Stable characteristic with little atmosphere dependency.

Thus there wider application is anticipated.