Thermistors for the Gradual Application of Heater Voltage to Thermionic Tubes*

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Summary—**Thermistors which are thermally-sensitive resistors having large negative temperature coefficients of resistance can be aptly used for the gradual application of heater voltage to thermionic tubes, thereby diminishing thermal transients and reducing mechanical failures. Full voltage is first applied to the thermistor and load in series and after temperature equilibrium is reached, the thermistors are shorted out. From a cold start thermistor resistance decreases by a factor of approximately 100 and heater resistance increases by a factor of 5 to 10. By selecting a set of series-connected thermistors to limit the current to a maximum of 120 per cent of the operating value during the voltage application, the initial voltage on the heaters will be less than 5 per cent of rated, and the voltage before shorting out, about 75 per cent of rated. Peak currents occur twice, once while the thermistors are in the circuit and again when the thermistors are shorted out at 90 seconds. One set of thermistors can be used to limit the current satisfactorily over a wide range of loads. The most favorable number of thermistors to connect in series is determined experimentally. Commercially available units in washer form can accommodate heater loads up to 1100 watts.**

Introduction

IN LARGE electronic systems, such as those employing large scale digital computers where the tube-count can run to tens of thousands, long tube life is a necessity. To extend tube life, one precaution that should be taken is the prevention of thermal shocks to the filaments caused by the large inrush currents upon the sudden application of power. Welds that secure the filament to the base pins become overheated and are likely to break after repeated stressing. In tubes where the filament is placed within the cathode sleeve, the filament wires lengthen rapidly and rub against the cathode, removing insulation from the filament wires and resulting in cathode-to-heater shorts. Sharp bends in folded filaments also develop stresses which cause open circuits.

Ideally, thermal shock would be minimized by the uniform acceleration and deceleration of the filament temperature to its operating value. Because such a scheme is impractical, many different methods are used to reduce the thermal effects. In some systems the filaments are continuously energized except for long-duration shutdowns. At the other extreme, elaborate devices gradually increase the voltage to the filaments when power is first applied. These devices are usually incorporated into the regulators which control the filament voltage for the entire system.

Large electronic systems, however, are generally subdivided into smaller logical sections which are packaged separately. The separate application and removal of power to the individual sections facilitates trouble shooting and minimizes the number of times the entire system is energized and de-energized. In such large installations, power is applied and removed more often from any given section by local control than by the control which operates the entire power system. Consequently, filament voltage is usually applied at the section level rather than at the systems level. For this purpose, thermistors, which are resistors having negative temperature coefficients of resistance, may be applied to give gradual filament heating.

Thermistors have been used in time delay applications, temperature measurements, and amplifier stabilizing circuits. At least one manufacturer has used them in series heater strings for television receivers. All of these are low current applications. This paper will discuss the use of thermistors to control more than one kilowatt of power. A physical description of typical commercially available thermistors and recommended mounting methods are presented in the Appendix.

Performance of Thermistors

Thermistor current ratings make them suitable for connection in the primary side of the transformers as shown in Fig. 1. The voltage is initially applied to the filaments with the thermistors in series by closing Contact A. The voltage across the filaments increases slowly and after an equilibrium voltage is reached the thermistor is shorted out by closure of Contact B. The fact that power is removed from the filaments abruptly is not as serious as sudden application because cooling of the filaments is due primarily to radiation, a slow process. To obtain a gradual increase of voltage, the thermal response of the thermistors must be much slower than that of the filaments. Otherwise the thermistor resistance decreases rapidly, and the filament voltage and current increase too rapidly. Fig. 2 shows a typical response of filament current when full voltage is applied directly to a filament load. The final current is reached in a few seconds. By applying thermistors which have a thermal response several times slower, the voltage across the filaments can be gradually increased. The thermal response is dependent on the heat capacity and the radiation properties of the thermistor.

Effect of Number of Thermistors in Series

From a cold start to the time of shorting, thermistor resistance decreases by a factor of approximately 100 and heater resistance increases by a factor of 5 to 10.

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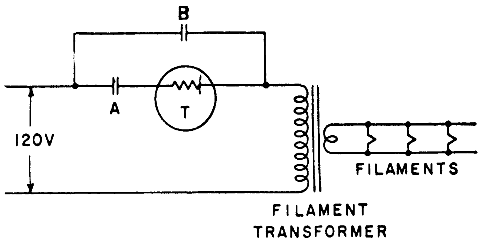

Fig. 1—Circuit for gradual application of voltage to filaments.

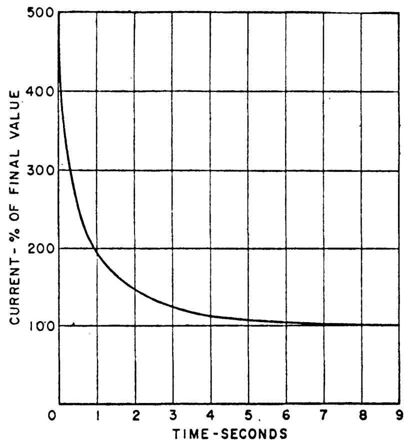

Fig. 2—Current response upon application of full voltage to a filament load.

Both of these characteristics are helpful. Because commercially available thermistors having current ratings above ½ do not have sufficient thermal capacity to obtain the slow thermal response required, they cannot be applied singly in series with the load. By electrically connecting a number of thermistors in series, the thermal capacity is increased without sacrificing the necessary current rating. The effect of varying the number of thermistors in series for a fixed filament load is shown in Fig. 3. For a particular curve, a peak of current occurs while the thermistors are in the circuit and another peak occurs when the thermistors are shorted out at 90 seconds. The tubes are ready to operate after two minutes. The first peak is caused by the rapid decrease in the thermistor resistance. As the number of thermistors is increased, the magnitude of the first peak is reduced and occurs at a later time. The magnitude of the second peak increases because of the lower voltage across the filaments before shorting of the thermistors. The most favorable number of thermistors is that which makes the two peaks equal. Any further increase in the number reduces the first peak but increases the second. By selecting the proper number of thermistors, the maximum current at any time during the gradual voltage increase and during shorting is limited to less than 120 per cent of the final value. The initial voltage on the filaments is less than 5 per cent of rated, and the voltage before shorting is about 75 per cent of rated.

Effect of Filament Load

The curves of Fig. 4 show that one set of thermistors can be used to limit the filament current satisfactorily for a wide range of loads. Two factors determine the

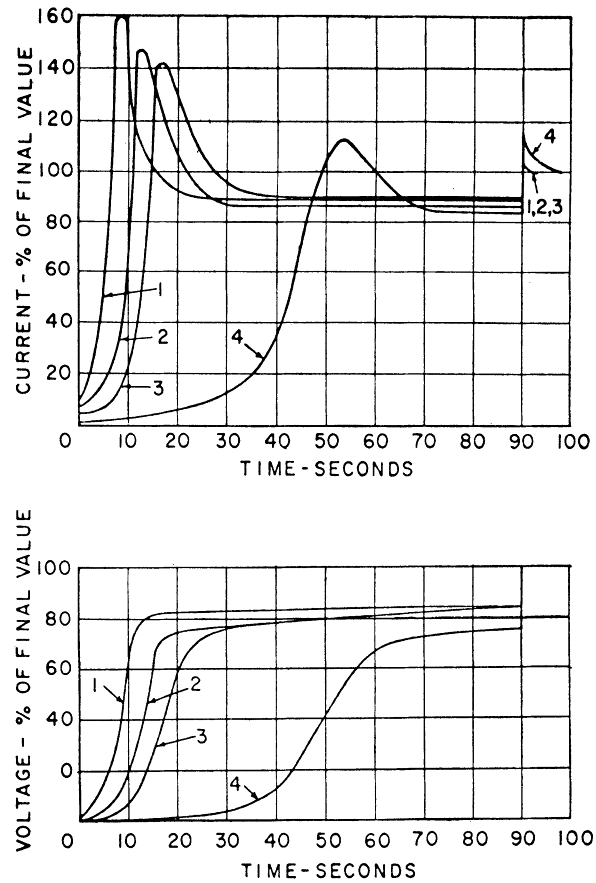

Fig. 3—Filament voltage application. Effect of number of thermistors in series, 1) 6 in series, 2) 8 in series, 3) 10 in series, 4) 12 in series.

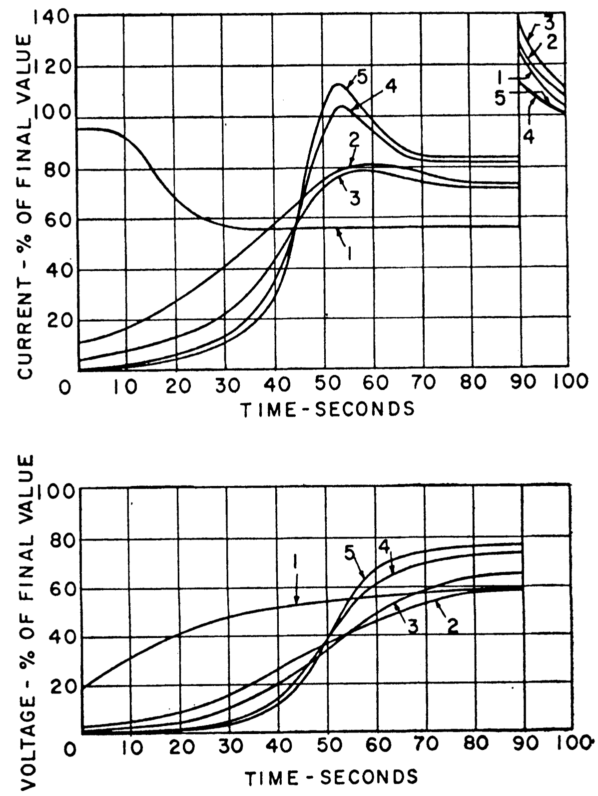

Fig. 4—Filament voltage application. Effect of filament load, 1) 5 per cent load, 2) 30 per cent load, 3) 50 per cent load, 4) 75 per cent load, 5) Full load.

magnitude of the current peaks. With increasing load, the ratio of load resistance to thermistor resistance decreases, resulting in a lower initial filament voltage. However, the increased current causes the thermistor to heat more rapidly and lower its resistance. These effects tend to cancel each other and allow application of one set of thermistors to a wide range of loads.

Table I gives the most favorable number and type of standard commercially available thermistors, as determined experimentally, for application to various loads up to 1100 watts. Grade 1 material is used for lower loads because it has a higher resistivity and a larger temperature coefficient of resistivity than grade 2. This is necessary to accommodate the high resistance of the minimum load application. Grade 2 is used for the higher loads because of the more favorable ratio of thermal response to resistance.

TABLE I

NUMBER OF THERMISTORS REQUIRED FOR VARIOUS FILAMENT LOADS

Transformer Primary Current (Ampere)	Grade of Material*	Washer Thickness†	Thermistor Rating (Ampere)	No. in Series
0–1.5	1	0.145	2.2	4
1.0–4.9	2	0.106	4.8	12
3.0–9.5	3	0.034	8.4	25

* See Appendix for definition of grade of material.
† All thermistors, washer type, 0.75 inch od and 0.28 inch id.

The lack of correlation between the thermistor ratings and the transformer primary currents in Table I is a result of the effort to obtain the most favorable number of thermistors for a wide range of loads. For a particular fixed load, the most favorable number of thermistors might be less than that shown in the table.

Possible Developments

It would be very convenient to reduce the number of thermistors required from that presented in Table I. It was thought that by attaching dissipators to the thermistor elements, the thermal capacity could be increased and the heat extracted faster, thus preventing a rapid increase in thermistor temperature and reducing the first current peak. However, experiments failed to show any appreciable improvement. It was deduced that there was insufficient heat conduction in the thermistor itself. Because of the nonhomogeneities in the crystal structure, a local hot spot develops, decreasing the resistance of this area and increasing the current flow, which generates more heat. This progression continues until a thermal equilibrium is reached. By electrically connecting several thermistors in series, the effect of a hot spot in a single or a few thermistors is reduced, resulting in a lowering of the magnitude of the current peak. If the crystal structure of thermistors could be made more homogeneous, it is very likely that fewer thermistors could be used and dissipators could be profitably added to increase the current rating.

The elimination of the contactor which shorts out the thermistors would also offer a great advantage in cost and simplicity. The curves of Fig. 3 indicate that the voltage across the thermistor is 25 per cent of the final filament voltage. It would be uneconomical to leave the thermistors in the circuit, consuming 25 per cent of the power. However, assuming a change in thermistor resistance of 100 to 1 and filament resistance of 1 to 5, and designing the circuit so that the initial filament voltage is 10 per cent of the final value, the final filament voltage would be greater than 98 per cent of rated. The thermistors could then be left in the circuit. The drawback is that a circuit so designed with commercially available thermistors makes the magnitude of the first current peak prohibitively large and the increase of filament voltage too rapid. This problem may be overcome by designing a thermistor with large thermal capacity and lower resistance; for example, by increasing the diameter while maintaining the same thickness.

Conclusion

Thermistors can be aptly used for the gradual application of filament voltage in vacuum tubes. Commercially available units can accommodate loads up to 1100 watts. At present, their thermal and electrical properties require that several be connected in series to give the desired voltage response. Based on comparative records between two large-scale digital computers at Massachusetts Institute of Technology (Whirlwind I and the Memory Test Computer), the failure rate of tubes in the computer with no provision for the gradual application of heater voltage was twice that of the computer which uses a motor generator set for the purpose. The number of filament failures, as a percentage of total tube failures was small (only 3.6 per cent) probably due to the fact that ruggedized tubes were used. Although this failure rate would be relatively insignificant in general applications, it becomes important in large computer systems which work around the clock. In such cases, a premium is placed on reliability and any unscheduled computer down-time is a serious problem. A thermistor filament control system will cost approximately 90 dollars per kilowatt to install as against 50 dollars per kilowatt for a system employing resistors, but will be 50 per cent more effective. If, however, the full potentialities of thermistors could be developed so that they could remain in the circuit and thus eliminate contactors, the installed cost of a thermistor system should drop to 10 to 15 dollars per kilowatt. The installation, then, would be economical purely on a cost basis with added reliability as a bonus.

Appendix

Description

Thermistors are thermally-sensitive resistors composed of the powdered oxides of manganese, nickel, and sometimes cobalt, which are pressed into the desired shape and sintered to yield a material whose electrical

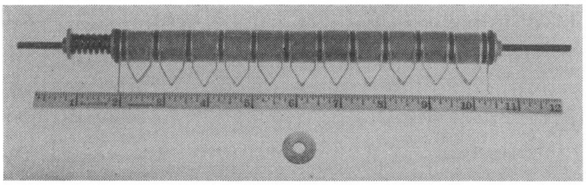

Fig. 5—Thermistor and thermistor assembly.

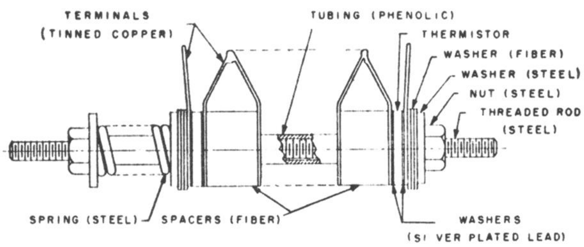

Fig. 6—Mounting for a set of series connected thermistors.

resistance decreases as its temperature rises. The thermal and electrical characteristics can be varied by changing the proportions of the oxides and the sintering temperature. There are two standard mixtures, designated as grade 1 and grade 2 material. Grade 2 material has higher resistivity and a larger negative coefficient of resistance than grade 1 material. While thermistors are made in various sizes and shapes, the washer type is suitable for filament voltage application because of its low ratio of electrical resistance to thermal capacity and its high current rating.

Mechanically, thermistors will withstand very great compressive forces but relatively small tensile forces. Further, thermistors have an appreciable negative temperature coefficient of expansion. Therefore, care must be taken when mounting thermistors that tensile forces are minimized and that allowance is made for the contraction and expansion.

Mounting

The recommended mounting for a set of washer type thermistors is shown in the photograph of Fig. 5 and the drawing of Fig. 6. The lead washers are used to equalize the pressure over the entire flat surface, thus minimizing any tendency to develop tensile forces. Silver plating the surfaces of the lead washer insures good electrical contact with the thermistor. Silver is used instead of tin because the melting point of the lead-tin eutectic is 180°C, and the temperature may reach 200°C when rated current is flowing through the assembly.

The wiring terminal is made the same diameter as the thermistor to equalize the pressure over the surface of the thermistor and to obtain uniform current density throughout the thermistor. The fiber washer and spacers electrically and thermally isolate the thermistors. The spring allows for thermal expansion and contraction while providing sufficient contact pressure. Excessive pressure will cause plastic flow of the lead washer and too little pressure will provide insufficient electrical contact. A satisfactory value for contact pressure has been found to be about 50 pounds per square inch of thermistor surface.

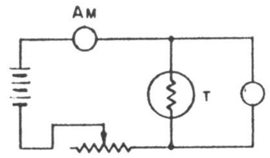

Fig. 7—Circuit for obtaining thermistor current rating.

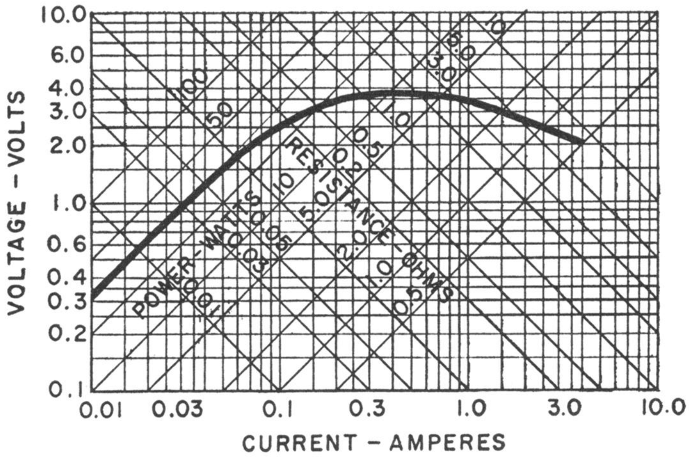

Fig. 8—Typical static volt-ampere characteristic for thermistor.

Rating

The current rating of a thermistor depends upon the type of mounting. The rating may be obtained by placing the thermistor in an oven at 200°C and measuring its resistance. The thermistor is then removed and allowed to cool to the ambient temperature at which it is to be used. It is then mounted as it will be in the final application. Current is then passed through it and slowly increased to such a value that its resistance is reduced to the same value as that obtained by the oven measurement. This value is its current rating for this mounting. A circuit for obtaining the current rating is shown in Fig. 7. The same circuit may also be used to obtain the static volt-ampere characteristic, for which a typical curve is shown in Fig. 8.

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