THICK FILM FAIL-SAFE RESISTORS

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The investigations of low resistance thick film fail-safe resistors are presented. Particularly the shape of a resistive path; the temperature of the central part of the resistor while increasing the power up to 4 Watts; the kind of composition material for the resistive path vs. extensometer effect, and the stability of the resistor are discussed.

1. INTRODUCTION

With the growth of the complexity of electronic circuits, the necessity of their protection seems to be indispensable. In particular, high power circuits should be safety protected. The fail-safe problem is of considerable width and of great significance for automatic control engineering. Damage of an electronic element can bring about serious consequences, as e.g. fire, hazards dangerous to human life, destruction of expensive devices or their elements, destruction of a batch during the technological process, etc.

Constructors of electronic circuits, including complex ones, design them in such a way as to avoid these grave and negative effects in the case of damage. One of the measures is to apply fail-safe resistors in suitably chosen or specially designed branches of an electronic circuit.[1]

Fail-safe resistors known to date are wire-wound resistors[2] made, for example, by Micron Electric Co. Ltd.[3] The production of these resistors is labout consuming when high resistance is involved due to a very thin resistive wire, and at very low resistance values it is difficult to obtain a hot spot because of using a thick wire.

2. EXPERIMENTAL RESULTS AND DISCUSSION

For years our Research Centre has been interested not only in hybrid circuits but also in thick film resistors of up to 16 Watts power. Based on the experiments made, a thick film fail-safe resistor has been designed.[4,5] At normal operation the power of 1 Watt is dissipated in this resistor. However, when damage occurs in the electric circuits causing the dissipation of the power of more than 4 Watts in the fail-safe resistor, a break is safety formed in it.

2.1   Resistor Properties

- Nominal power 1 Watt
- Resistance range 0.1 Ω to 1 kΩ
- Resistance tolerance $\pm$ 5% and $\pm$ 10%
- Changes in resistance after 1000 hours at P_n smaller than 5% at an ambient temperature of +70°C

- The size of the substrate of 96% Al_2O_3 equals 5 x 10 x 0.5 mm
- The resistor body is encapsulated in a thermocontractible tube
- The shape of the resistor is presented in Figure 1

2.2 Solutions of Problems

Two essential problems were solved during the preparation of this resistor, viz.

- resistance stability during application at the power of 1 Watt at an ambient temperature of +70°C

- effectiveness of 'damage in a safe way' at the power of more than 3 Watts during ca 5 minutes.

In order to attain such effects, it was necessary to analyze and study a few questions which concerned:

- approximate calculation of the maximum temperature of the resistor,

- determination of the hot spot area and the shape of isotherms by means of thermovision through the change of the resistive path shape,

- determination of the temperature diagram along the resistor main axis by means of thermovision,

- testing of the extensometer effect of resistors made of various compositions,

- stability tests at the time of 1000 hours

- analysis of the investigation results and conclusions.

Two assumptions were accepted for the thermal analysis of the resistor, i.e.

a) the increase in temperature is proportional to the loss of power.

The following straight line equation was obtained from calculation

$$\Delta T_1 = 2.57 \cdot 29.9 \, P$$

where the coefficient 2.57 results from the shape of the substrate and the shape of the resistor, whereas the coefficient 29.9 is from the substrate material and its thickness and P denotes electric power.

1) electrode layer
2) resistive layer
3) narrowing area of the
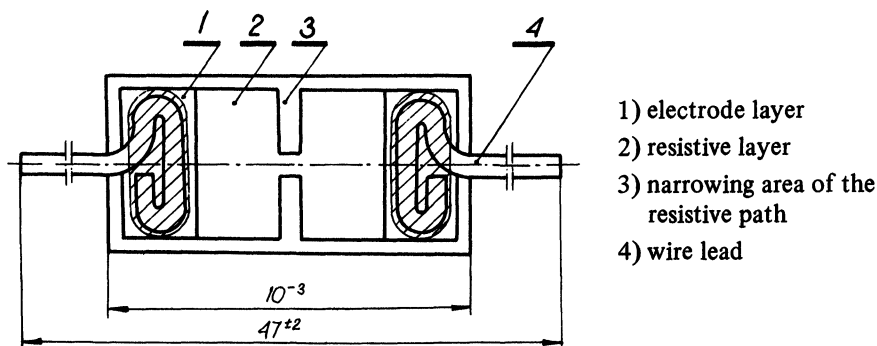   resistive path
4) wire lead

FIGURE 1   Fail-safe resistor without encapsulation.

b) the increase in temperature is connected with the power lost in the resistor by the exponential function. The following equation was obtained from calculation and measurements:

$$\Delta T_2 = 29.9 \exp/0.5P/$$

The coefficient 29.9 is the material coefficient as in (a). The coefficient of shape is connected with the index of the power 0.5. This value can be chosen from the measurements.

Figure 2 presents both curves and the dependences 1 and 2 shown by thermovision for two resistors.

Both ΔT_1 and ΔT_2 are not strictly accurate approximations. With the straight line ΔT_1 errors are smaller. The curve ΔT_2 has a form approximating empirical curves and is nearly parallel to curve 1.

It should be noted that exponential approximation does not solve the problems of low power, because the increase of temperature for P=O ought to equal zero. This does not happen with the curve ΔT_2.

The above divergence being taken into account, our efforts were concentrated on examining the distribution of isotherms at various constructional solutions of resistive paths. Isotherms were determined by photographing the thermovision images.[6] Figure 3 presents two from among numerous solutions, i.e. 3.1 a and 3.2 a, which allow one to draw conclusions concerning the choice of the resistive path design of the fail-safe resistor.

Isotherms copied from colour slides are shown in Figures 3.1 b and 3.2 b.
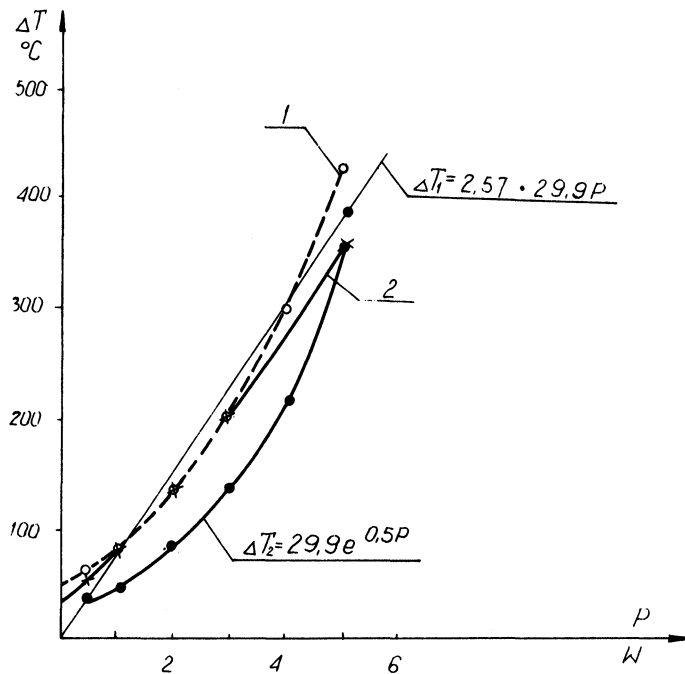
1 and 2 curves for two resistors obtained by means of thermovision. Straight line ΔT_1 and curve ΔT_2 obtained from calculation.

FIGURE 2   Dependence of the temperature increase ΔT at the hottest point on power P lost in the resistor.
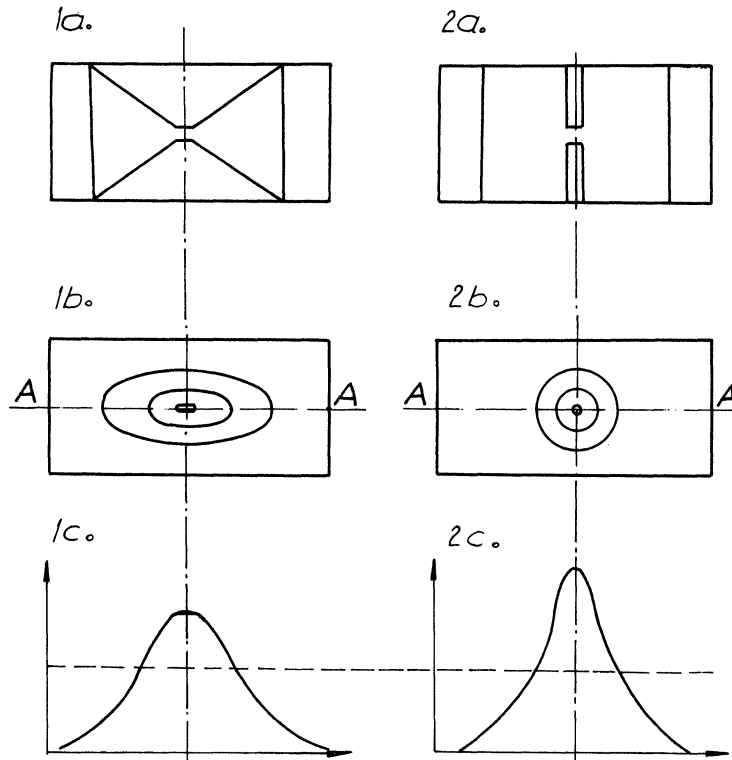
FIGURE 3   Effect of the resistive path shape on the isotherm shape and on hot spot maximum
temperature.

Figure 3.1 c and Figure 3.2 c present diagrams obtained through thermovision along
the resistor main axis. The axis is denoted by lineA–A in Figures 3.1 b and 3.2 b.

The more effective protection-ensured by the resistor, the slenderer is the curve in
Figure 3.2 c, and due to this larger ΔT occurs at the same power in the resistor. However,
it should be remembered that the growth of the slenderness of this curve is followed by a
rise in temperature at maximum power. Therefore, after having chosen the conditions
affecting the protection effect, the stability test should be made employing nominal
power and a maximum ambient temperature.

This general analysis and study of the fail-safe problem being completed, the construc-
tion of a series of resistors was started. When an alloy conductive compositon was used
for a resistive path very good parameters were obtained. When a resistive paste was
applied, difficulties in ensuring its proper stability was encountered. The main cause of
instability was the change due to the extensometer effect, the results of which investiga-
tion have been presented in Figure 4.

Figure 4a concerns the resistor of 3 ohms made of a resistive paste and shows mean
changes of $\bar{\delta}$ and an interval $\pm 3\sigma$ in the function of pressure onto the resistor substrate.
Maximum values reach +10% at loading of 3 kG, and ca +5% at a loading of 1.5 kG.
Figure 4b illustrates the interval $\pm 3\sigma$ for the resistor of 3 ohms made of a conductive
alloy paste. The changes presented in this figure can be neglected, since the mean value
does not exceed $\pm 0,1\%$, and the maximum values are within the limits of 0, 4%. Both
tests were made under identical conditions similar to the conditions and stresses which
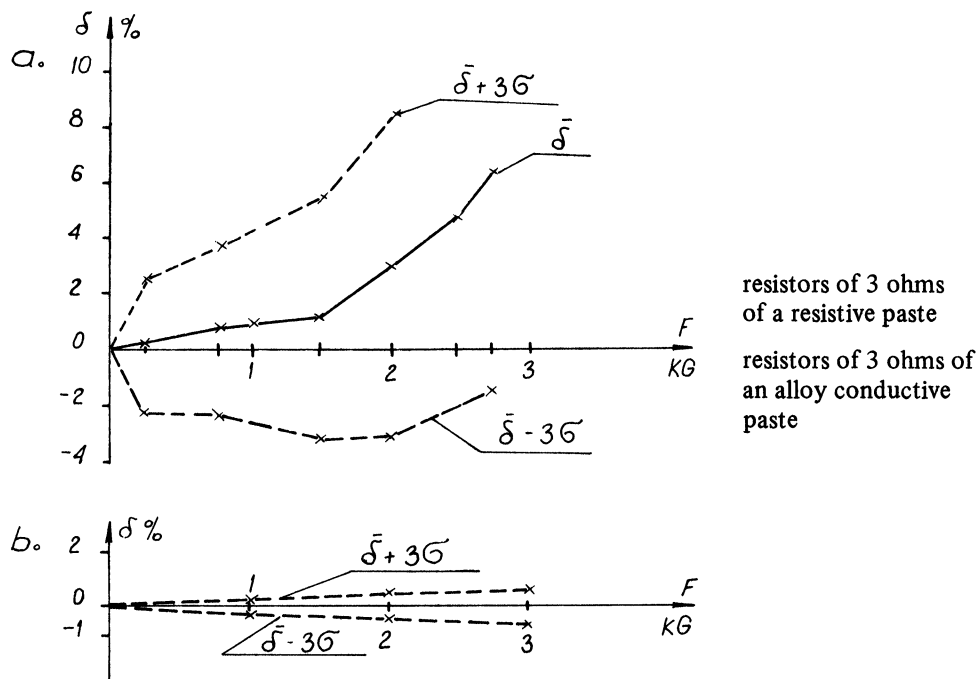
FIGURE 4   Resistance changes in the bending force function.

occur during the work of the assembled resistor; pressure being applied from the side opposite to the resistive film. In these two cases the pressure from the side of the resistive film gave smaller resistance changes.

Simultaneously the stability test was made during 1000 hours at an ambient temperature of +70°C and at power loading of 1 Watt.

In Figure 5 the curves denoted by 1 represent the mean values $\bar{\delta}$, whereas the curves denoted by 2 show the maximum changes δ max $= \bar{\delta} + 3\sigma$ of the fail-safe resistors.

It can be seen from the comparison of the curves that the stability of the resistors made of a conductive alloy paste is much better than that of the resistors made of a resistive paste. With the curves for the resistors of 3 ohms made of a conductive composition the maximum changes of δ max do not exceed 1.5%, and the mean ones are close to zero. With resistive compositions the mean value reaches 2, 5% and the maximum one equals ca. 5%, i.e. it is on the verge of the requirements this type resistors have to meet.

Despite the low resistivity of ca. 0.35 $\Omega/\square$ of conductive alloy compositions and some technological disadvantages encountered when resistors of relatively high resistance i.e. 3 ohms are produced from these pastes, their stability in the life test, as well as the insignificant extensometer effect were the factors deciding the choice of this composition for the production of fail-safe resistors.

3.   CONCLUSION

1) A thick film resistor can operate as a fail-safe resistor.

2) The smallest hot spot area has been obtained with the resistive path design according to Figure 1. ie narrowing of the resistive path equalling 0.6 × 0.6 mm.

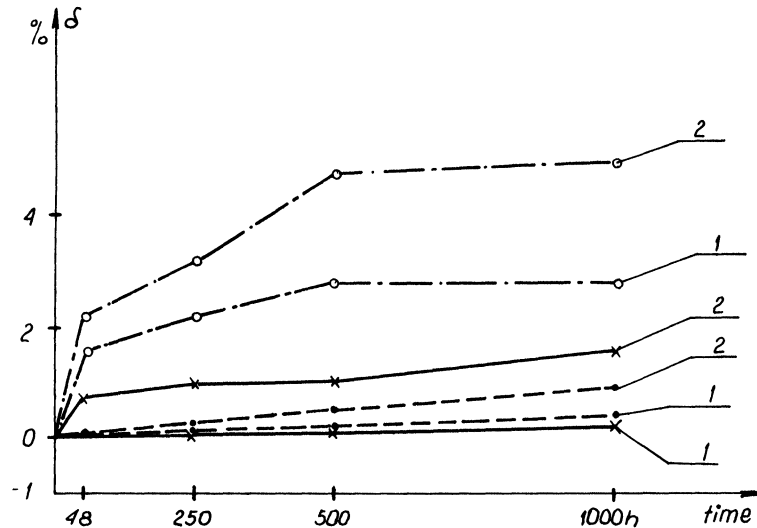FIGURE 5   Resistance changes δ in %% during stability test − − − − − − 0.68 ohm − conductive alloy paste, ————— 3 ohms − conductive alloy paste, −. −. −. − 3 ohms − resistive paste.

3) Resistive compositions containing ruthenium compounds of the resistivity ca. 1 $\Omega/\square$ do not produce sufficiently stable resistors mainly owing to a considerable extensometer effect.

4) To produce low resistance fail-safe resistors, conductive alloy compositions of 0.1 to 0.4 $\Omega/\square$ were employed; stability and load carrying ability of these resistors were good.

5) The results of the approximate theoretical calculations of temperature depart from those obtained in practice.

6) Basic conclusions concerning the resistor construction were obtained from contact-less photographs of the temperature distribution on the resistor by means of thermo-vision, at power loadings of 0.5 Watt to 4.0 Watt at the time up to 10 sec.

7) Isotherms on the fail-safe resistor should have a ring shape or that of an ellipse whose longer diameter ought to be perpendicular to the resistors main axis. On the other hand, the effect shown in Figure 3.2 c signals the deterioration of the protective ability.

8) At power loadings of 3 to 4 Watts during 5 min. every resistor subjected to testing was 'safely' damaged.

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