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Trimming studies on polymer thick-film resistors

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PVC–graphite polymer thick-film resistors were trimmed by a conventional air abrasive technique and the post-trim drift in resistance with time was found to be negative. The net decrease in resistance of trimmed resistors in a given time was found to be a function of resistor composition, cutting speed and temperature. Detailed studies showed this decrease to be due to a decrease in cut width with time. Two new methods, namely bombardment trimming and radiation trimming, were also tried for adjusting the resistance of these resistors and the results were compared with those obtained from abrasive trimming studies.

1. Introduction

The resistance adjustment of fired resistors forms an integral part of thick-film technology. This adjustment is done either by stripping off a portion of the resistor material by a narrow jet of abrasive particles (air abrasive trimming) or by the evaporation of part of the material from the substrate by a high-power laser beam (laser trimming) [1]. Though these trimming techniques and the associated post-trim drift in resistance have been studied in detail, these studies have been confined only to conventional metal oxide based thick-film resistors with high processing temperatures ($> 800^\circ$ C) [2–6]. Little is known about the trimming aspects of polymer-based thick-film resistors in spite of their growing importance in recent times. The present study has been undertaken to get some insight into these aspects. The study involves the air abrasive trimming of resistors based on PVC–graphite (PVC = polyvinyl chloride) and their subsequent post-trim drift behaviour. Some of the electrical properties of these PVC–graphite resistors have been investigated and reported earlier by us [7, 8]. The PVC polymer which is the binder in these resistors differs considerably in its mechanical properties, such as plasticity, from the borosilicate glasses which are the binders of conventional metal oxide thick-film resistors. Thus, based on this difference, an attempt has also been made in the present study to develop a couple of new methods for trimming these resistors.

2. Experimental procedure

2.1. Preparation of samples

Resistors of the compositions given in Table I with varying amounts of functional phase (graphite) and binder (PVC resin) were fabricated.

PVC substrates used for printing were cleaned by dipping in a solution of 10 g of potassium hydroxide and 25 ml ethanol in 75 ml deionized water for 12 h followed by rinsing in deionized water and drying [9]. Printing was done using a De Haart (Massachusetts, USA) thick-film screen printer (Model SP-SA-5) as described elsewhere [7]. The printed resistors were subjected to a series of thermal cycles between 298 and 393 K until stable values of resistance were obtained [8]. The cycling was done with the help of a DEK-1209 short-wave IR (Weymouth, Dorset, UK) dryer and each cycle was of 3 min duration.

2.2. Resistor trimming

2.2.1. *Abrasive trimming*

In this method, resistors were trimmed using a Comco (California, USA) MT-100 Microtrimmer and MB-101 Microblaster. Purified, compressed air was fed into the trimming unit. Two cutting speeds corresponding to 40 and 80 p.s.i. (276 and 552 kPa) were used leading to two sets of trimmed resistors. Each resistor was trimmed by 40% of its initial value using a precision decade resistance box (Muirhead No. 162103: accuracy $\pm$ 0.1 Ω) as standard. Trimming parameters were as follows:

Abrasive powder	Alumina (50 μm particle size)
Cut speed	40 and 80 p.s.i. (276 and 552 kPa)
Trim cut width	20 mil (508 μm)
Type of cut	L or P
Distance between resistor surface and nozzle tip	1 mm

In this method all resistors could be trimmed only upwards (increasing the resistance).

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TABLE I Resistor compositions

Component/Resistor	PG19	PG28	PG37	PG46
Graphite (wt %)	90	80	70	60
PVC (wt %)	10	20	30	40

2.2.2. *Bombardment trimming*
In this method the resistance value was adjusted by bombarding the resistor surface with alumina particles. The same Comco trimming unit as above was used for this purpose. However, the nozzle tip was removed as far away as possible from the resistor surface (3 cm) and alumina particles impinged on the resistor surface at very low speed (< 5 p.s.i. 34 kPa). Further, the substrate was kept in a transparent polythene cover to avoid direct contact between abrasive particles and the resistor material. In this method all resistors could be trimmed only downwards (decreasing the resistance).

2.2.3. *Radiation trimming*
Some of the polymer properties, such as chain length and degree of cross linking, may vary when exposed to high frequency radiation. This in turn may affect the resistance value. Thus in this radiation trimming, resistors were exposed to UV radiation of wavelength 350 to 500 nm for varied lengths of time and resistance change was monitored. The UV source of a Karl Suss Mask Aligner MJB-3 (Munchen-Garching, West Germany) and its exposure system were used for this purpose.

2.3. Post-trim drift behaviour
Post-trim drift in resistance of all the resistors with time was measured with a digital multimeter. Measurements were taken at a constant temperature of 298 K and over a period of approximately 150 days.

To see if the stabilization could be speeded up, the trimmed samples were subjected to thermal cycling between 298 and 373 K and resistance changes were noted.

TABLE II Post-trim drift in resistance of abrasive-trimmed resistors of different compositions after 3600 h at 298 K

Sample	Fraction of PVC (wt %)	Percentage change in resistance	
		Cutting speed 40 p.s.i	Cuting speed 80 p.s.i.
PG19	10	−2.46	−2.63
PG28	20	−2.29	−2.69
PG37	30	−2.57	−3.16
PG46	40	−2.75	−5.50

3. Results and discussion
The percentage change in resistance, 100 $(R - R_{\text{initial}})/R_{\text{initial}}$), with time at room temperature (298 K), in abrasive-trimmed resistors is shown in Figs 1 to 4 for samples PG19, PG28, PG37 and PG46, respectively. In these figures the logarithm of the percentage decrease in resistance is plotted against the logarithm of time. In Fig. 5, the percentage variation in resistance of abrasive-trimmed PG28 resistors is plotted against the number of thermal cycles. Fig. 6 shows the corresponding plot for bombardment-trimmed PG28 resistors. Table II gives the net change in resistance of abrasive-trimmed resistors at room temperature after 3600 h for different resistor compositions. The percentage change in resistance of PG28 with time under UV exposure is presented in Table III.

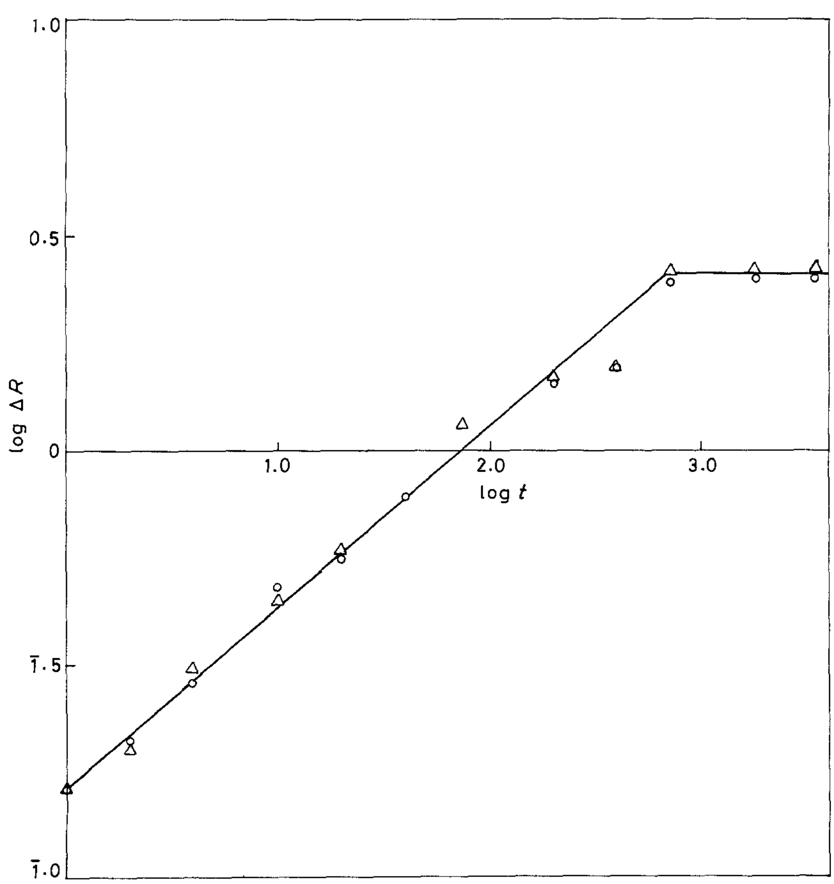

Figure 1 Change in log ΔR with log t for PG19, where ΔR is the percentage decrease in resistance and t the time in hours after abrasive trimming. Cutting speed: (○) 40 p.s.i. (276 kPa), (△) 80 p.s.i. (552 kPa).

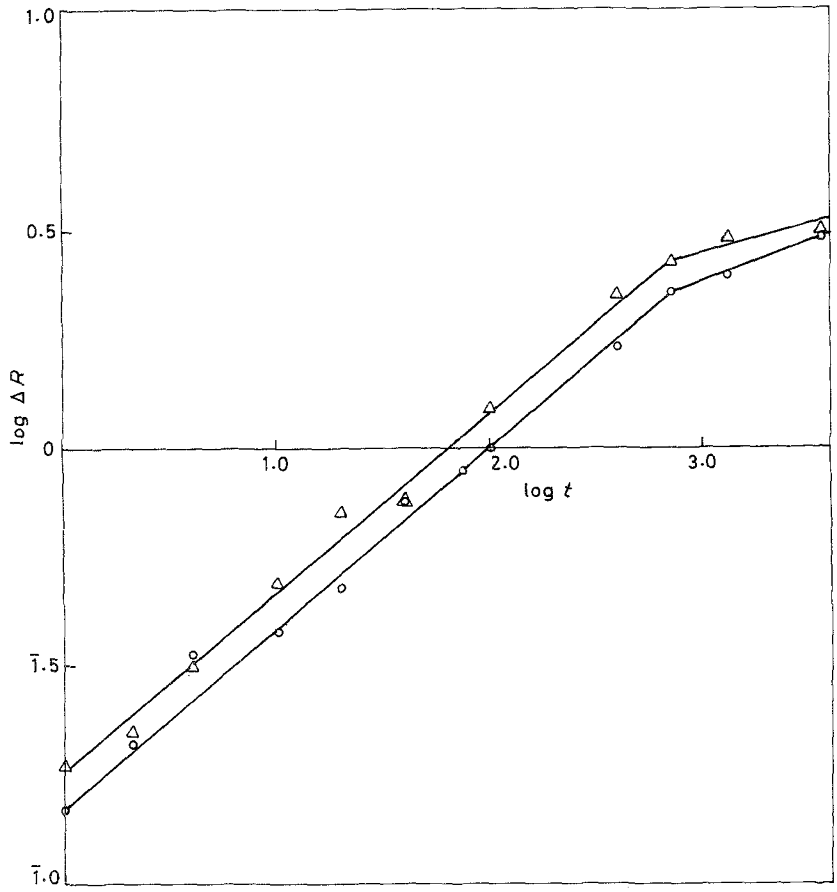

Figure 2 Log ΔR against log t for PG28: (○) 40 p.s.i. (276 kPa), (△) 80 p.s.i. (552 kPa).

3.1. Abrasive-trimmed resistors

In the case of abrasive trimming, the resistance of a given resistor increases with trimming due to the removal of material. Hence resistors can be trimmed only upwards. Figs 1 to 4 reveal that subsequent to trimming the resistances of these resistors decrease with time at room temperature. The decrease is a linear function of time and depends upon composition and cutting speed. This decrease during a given period of time increases with increasing amount of PVC in the resistor (Table II). Further, except in the case of PG19 (Fig. 1), in all other cases (Figs 2 to 4) the net

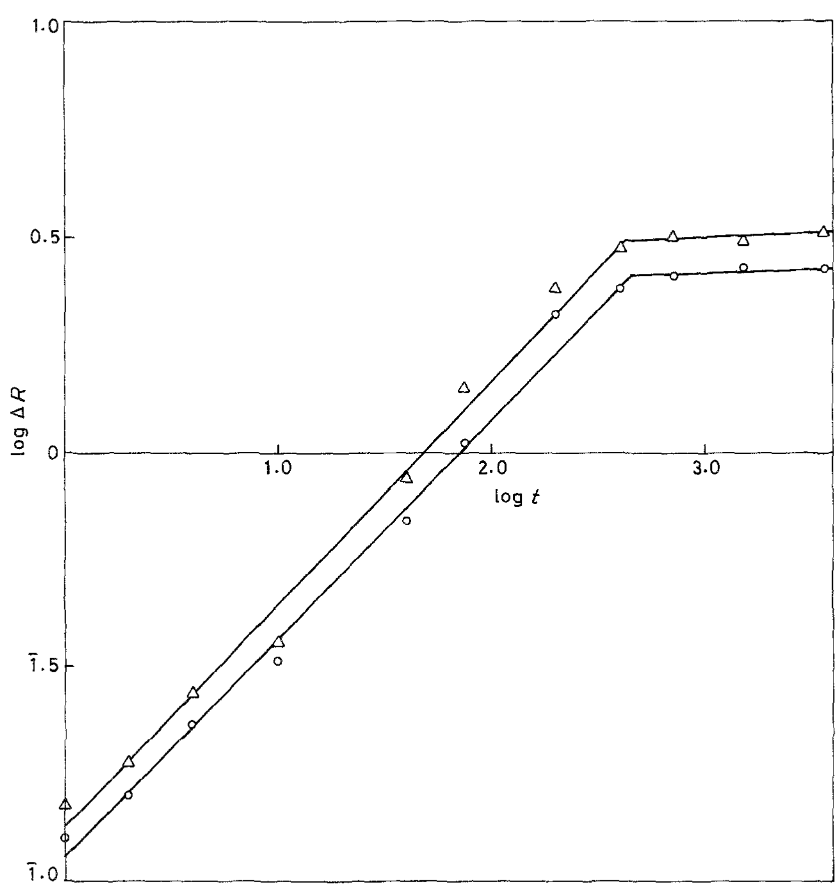

Figure 3 Log ΔR against log t for PG37: (○) 40 p.s.i. (276 kPa), (△) 80 p.s.i. (552 kPa).

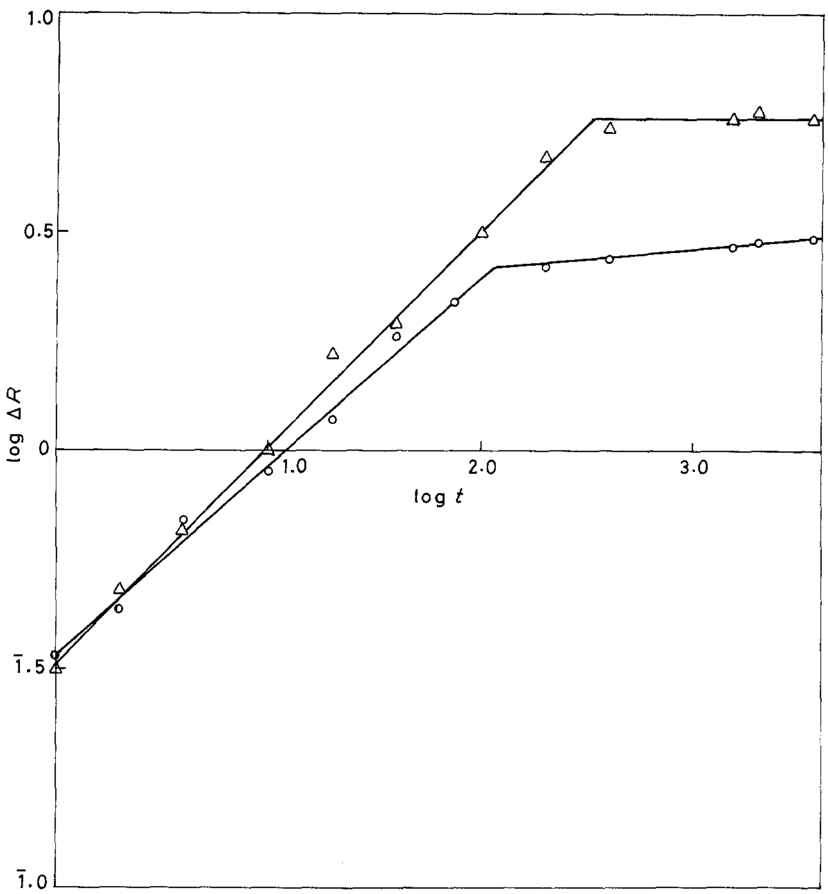

Figure 4 Log ΔR against log t for PG46: (○) 40 p.s.i. (276 kPa), (△) 80 p.s.i. (552 kPa).

change in resistance is found to be more when a higher cutting speed is used for trimming. This difference becomes a maximum for sample PG46, which has the maximum amount of PVC. From Figs 1 to 4 it appears that after a certain amount of time the resistances of the trimmed resistors reach a stable value. This stabilization can be achieved also by subjecting the samples to thermal cycling (Fig. 5). However, the net decrease is more here.

To account for the above resistance changes it is assumed that a small flow of PVC–graphite composite into the trimcut area near the cut boundary reduces the cut width and hence the resistance. To have a qualitative understanding how a decrease in cut width affects the resistance, trimming studies were carried out on Du Pont Birox (Du Pont, USA) resistors. Any particle flow as discussed above can be ruled out in these resistors, since the binder in this case is a borosilicate glass phase with a relatively high softening point [1]. This assures that the width and length of the cut do not change with time after trimming. These resistors were fabricated by printing DuPont resistor paste Birox 1431 (sheet resistance 1 KΩ/□) on a cleaned 2 in. × 2 in. (51 mm × 51 mm) alumina substrate, and were fired through a four-zone Watkins–Johnson conveyor furnace (Model 4CM-39) with a peak temperature of 840° C. DuPont Pd–Ag based conductor ink 9061 was used for making conductor pads. These resistors were subsequently trimmed with the Comco trimming unit with different cut-widths for a constant cut-length. The percentage decrease in resistance with cut width at a given cut length in these resistors is shown in Table IV. It is clear from this table that the resistance decreases with cut width, the decrease being more pronounced for larger cut lengths. These resistors are found to be stable with time.

TABLE III Resistance variation in PG28 resistors with exposure time under UV radiation

Exposure time (min)	1	5	10	15
Percentage variation in resistance	−0.59	−1.16	−1.68	−2.27

Direct evidence for the above assumption was obtained by following the dimensional changes in a PVC–graphite trimmed resistor (PG28) before and after stabilization (Table V). Thus the above-described PVC–graphite flow has a significant contribution towards the post-trim resistance decrease. Since this flow increases with temperature, the trimmed resistor subjected to heat treatment stabilizes to a lower value of resistance compared to the one left at room temperature. This is demonstrated in Figs 1 to 5, where the net decrease in resistance of trimmed resistors is of the order of 2 to 5% when left at room temperature and is about 12.5% when subjected to thermal cycling. It also appears that this flow is enhanced if the polymer fraction in the resistor increases (Table II).

These studies indicate that the decrease in the value of trimmed PVC–graphite resistors with time is due to a decrease in cut width due to plastic flow of the PVC composite.

3.2. Bombardment-trimmed resistors

Utilizing the plastic nature of PVC, attempts have been made to adjust the resistance value by bombarding

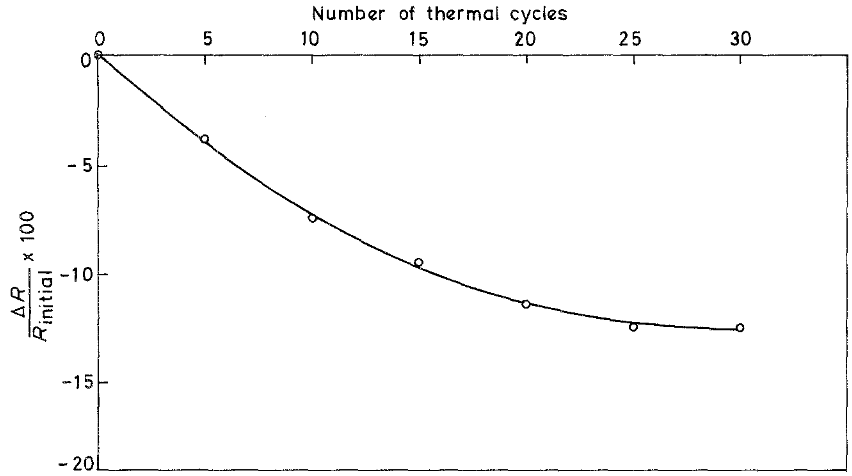

Figure 5 Percentage variation in resistance with thermal cycling for abrasive-trimmed PG28.

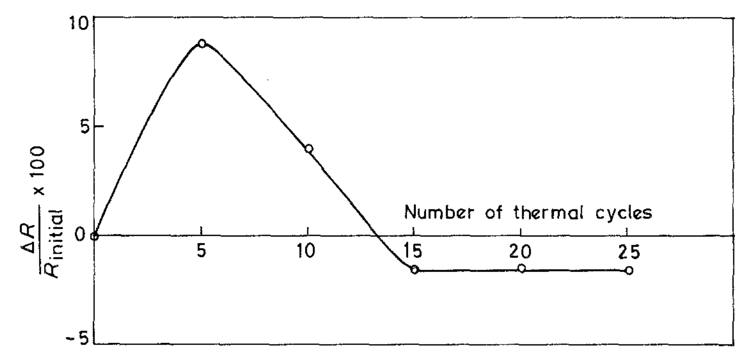

Figure 6 Percentage variation in resistance with thermal cycling for bombardment-trimmed PG28.

the resistor surface with alumina particles. It has been found that the resistance decreases with this trimming and hence all the resistors can be trimmed only downwards. This decrease may be due to compression of the PVC–graphite composite improving the particle–particle contact and thus decreasing the net contact resistance. It has been further found that these resistors also drift with time to a higher value. This change is about 3% and is perhaps due to relaxation of the stresses created during bombarding. To hasten this process of stress relaxation the resistors were subjected to thermal cycling. Fig. 6 shows that the resistance increases initially with thermal treatment and after five cycles starts decreasing. The resistance stabilizes to a lower value after 15 cycles. Comparison of Figs 5 and 6 clearly shows that the net drift in resistance is smaller with bombardment-trimmed resistors (1.6%) than with abrasive-trimmed resistors (12.5%). Also the former resistors get stabilized faster than the latter with thermal cycling.

3.3. Radiation-trimmed resistors

Attempts to alter the resistance by exposing resistors to UV radiation (Table III) have shown that this method is not very effective with the present polymer system. Even after exposing the entire resistor surface for as long as 15 min, only a small decrease in resistance has been observed. This insensitivity may be due to the thermoplastic nature of the PVC polymer. However, this method of trimming may be effective when the binder material is a thermosetting or crosslinking polymer in which the crosslinking is sensitive to radiation.

4. Conclusions

From the above studies it may be concluded that

TABLE IV Decrease in resistance per micrometer decrease in cut-width at different cut lengths

Trim length (μm)	900	800	700	600	500	400
Percentage decrease in resistance with 1 μm decrease in cut-width	0.21	0.16	0.11	0.09	0.07	0.05

TABLE V Changes in resistance and trim-cut dimensions of a few PG28 samples after 30 thermal cycles following abrasive trimming

Sample No.	Before cycling			After cycling		
	Resistance (kΩ)	Trim-cut length (μm)	Trim-cut width (μm)	Resistance (kΩ)	Trim-cut length (μm)	Trim-cut width (μm)
1	2.93	460	830	2.42	440	820
2	0.773	365	525	0.700	345	510
3	0.606	345	765	0.522	325	750

polymer-based thick film resistors may be trimmed either by conventional abrasive techniques or by the new bombardment technique explored above. While with the former, resistance is trimmed upwards, with the latter, resistance is trimmed downwards. Thus the use of a polymer as a binder gives an added advantage of trimming upwards or downwards over conventional metal oxide resistors with glass as a binder, which can be trimmed only to higher values of resistance. A small post-trim drift about 2 to 5% has been observed at room temperature in the trimmed resistors and with thermal cycling resistors can be stablized faster.

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