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Research Article

Multiple High Voltage Pulse Stressing of Polymer Thick Film Resistors

Busi Rambabu and Y. Srinivasa Rao

Instrument Technology Department, Andhra University College of Engineering (A), Visakhapatnam 530 003, India

Correspondence should be addressed to Y. Srinivasa Rao; srinniwasarau@gmail.com

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The purpose of this paper is to study high voltage interactions in polymer thick film resistors, namely, polyvinyl chloride- (PVC-) graphite thick film resistors, and their applications in universal trimming of these resistors. High voltages in the form of impulses for various pulse durations and with different amplitudes have been applied to polymer thick film resistors and we observed the variation of resistance of these resistors with high voltages. It has been found that the resistance of polymer thick film resistors decreases in the case of higher resistivity materials and the resistance of polymer thick film resistor increases in the case of lower resistivity materials when high voltage impulses are applied to them. It has been also found that multiple high voltage pulse (MHVP) stressing can be used to trim the polymer thick film resistors either upwards or downwards.

1. Introduction

The resistance adjustment of cured resistors forms an integral part of polymer thick film technology. The resistance adjustment is done either by removing a portion of the resistor material by a narrow jet of abrasive particles (Air abrasive trimming) or by the evaporation of the part of the material from the substrate by a high power laser beam (Laser trimming) [1–8]. The above trimming methods are used to trim the resistors upwards only. Downward trimming is not generally attempted because it calls for the addition of the materials to the film. There seems to be another method of changing the resistance by changing film conductivity to higher or lower values with high voltage pulses. High voltage pulses are applied to polymer thick film resistors to trim downwards by changing their conductivities [9–22].

For the first time, the possibility of trimming of polymer resistors either downwards or upwards by using high voltage impulses has been investigated in this work. In this paper, the results of investigation of performance of polymer thick film resistors after high voltage impulse stressing, using resistance measurements, are presented. Experiments-materials, test resistor, and terms of high voltage stressing and measurements are described in Section 2. Experimental results and discussion are described in Sections 3 and 4. The mechanism responsible for the change in resistance of polymer thick film resistors is described in Section 5.

2. Experimental Work

2.1. Resistor Fabrication. Polymer paste containing PVC and graphite has been prepared by first dissolving PVC granules in cyclohexanone and then blending graphite in to it. The graphite powder (average grain size: 45 microns) is prepared from a graphite block, supplied by Graphite India Limited, Bangalore, with electrical conductivity of $0.33 * 10^5$ mho/cm. The PVC powder is supplied by Calico Chemicals Limited, Bangalore, and has a density of 1.37 Mg/m^3. This paste has been used for printing resistors on alumina and PVC substrates with a screen printer supplied by De Haart, USA. These printed resistors are processed using the actual thick film processing of polymer based films [12–14]. The heat treatment involves drying at room temperature for 15 minutes, followed by curing at 100°C for four hours. The thickness of the cured sample is found to be in the range of 40 to 150 microns. Various PVC-graphite compositions used in making the paste are given in Table 1. The details of a typical thick film resistor

Table 1: Details of resistor compositions.

Graphite (%Wt)	PVC (%Wt)
90	10
80	20
70	30
60	40

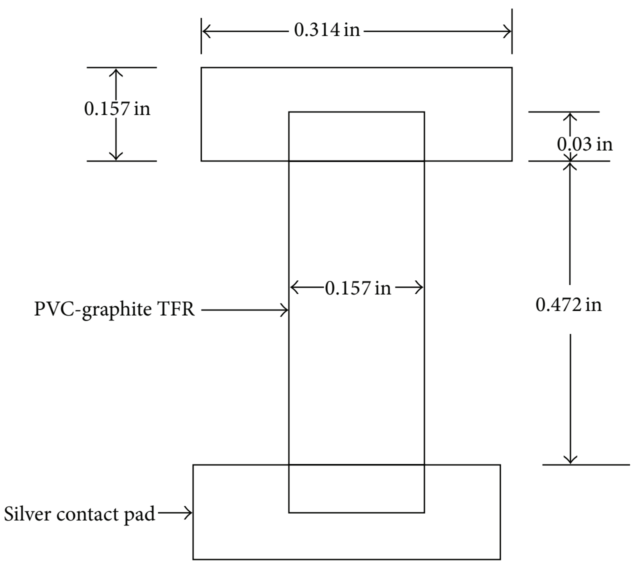

Figure 1: Structure of a typical polymer thick film resistor.

Table 2: Details of the thick film resistors fabricated.

S. number	Resistor width in mm	Resistor length in mm	Resistance
1	1	4	24 KΩ
2	2	8	55 KΩ
3	3	12	3.4 MΩ
4	4	12	3.9 MΩ
5	4	16	5.4 MΩ
6	4	18	11.01 MΩ

fabricated are given in Figure 1. Several resistors with different lengths and widths are fabricated and their details are given in Table 2. The resistance values of these resistors are measured under different conditions of electric fields and the results are described in Table 3.

2.2. Electrical Measurements. The setup used to apply high voltage pulses to the polymer thick film resistor is based on the one similar to the circuit described in the literature [9] as shown in Figure 2. It consists of AC power supply of 220 V, a resistor, a capacitor, one mechanical ON/OFF switch, and a variac. The pulse amplitude is in the range of 220 Volts to 300 Volts. The pulse duration is varied by changing the capacitor and resistor values and its value is between 1 and 100 microseconds. If more than 300 V is applied to polymer thick film resistors, they will enter into breakdown

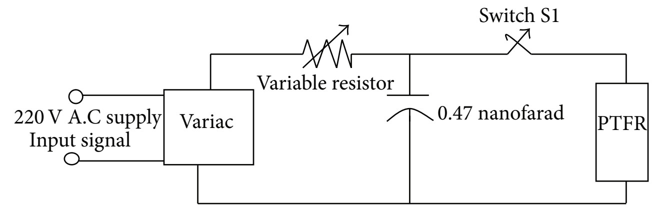

Figure 2: High voltage test circuit used to apply high voltage impulses to polymer thick film resistors (1 to 100 microseconds).

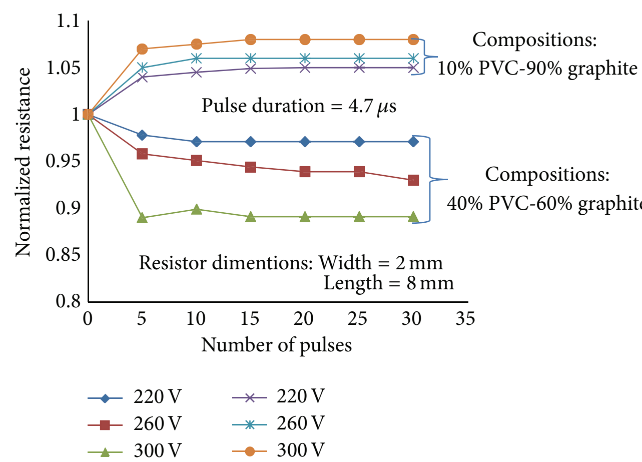

Figure 3: Normalized resistance variation with number of pulses for different pulse amplitudes.

region. So we called the voltages below the breakdown voltage are considered high voltages for these resistors. In the case of pulse measurements, the value of resistance is measured directly after it is subjected to high voltage pulses. Typical resistance versus number of pulses characteristics of these resistors are given in Figures 3–5.

3. Experimental Results

It is seen from the resistance versus number of pulses characteristics given in Figures 3, 4, and 5 that the resistance increases with the high voltages in the case of lower resistivity materials and the resistance decreases with the high voltages in the case of higher resistivity materials. Beyond a certain voltage level, the decrease or increase in resistance with high voltages is large. Accordingly, this gives rise to voltage-current characteristics similar to those of devices under electric breakdown. When the applied voltage is limited to this threshold value which increases linearly with the length of the resistor, the voltage-current characteristics are repeatable, showing that the value of resistance remains unchanged with the voltage. However, when the voltage exceeds the threshold value the resistance decreases or increases depending on the magnitude of the applied voltage and also the period during which the voltage is applied. Figure 3 shows the behavior of the resistor with the amplitude of the voltage pulses. It can be seen that the resistance decreases with increase in high voltage amplitude in the case of higher resistivity materials

Table 3: Resistance variation with high voltage pulses with different pulse durations of polymer thick film resistors with pulse amplitude = 260 V and pulse duration = 0.47 μs, 4.7 μs, and 47 μs for different PVC-graphite compositions.

(a) 60% graphite: 40% PVC

S. number	Pulse duration	Normalized resistance			
		After 5 cycles	After 10 cycles	After 20 cycles	After 50 cycles
1	0.47 μs	0.932	0.922	0.917	0.916
2	4.7 μs	0.913	0.907	0.901	0.901
3	47 μs	0.895	0.887	0.881	0.881

(b) 90% graphite: 10% PVC

S. number	Pulse duration	Normalized resistance			
		After 5 cycles	After 10 cycles	After 20 cycles	After 50 cycles
1	0.47 μs	1.157	1.160	1.160	1.160
2	4.7 μs	1.112	1.123	1.125	1.125
3	47 μs	1.092	1.115	1.119	1.121

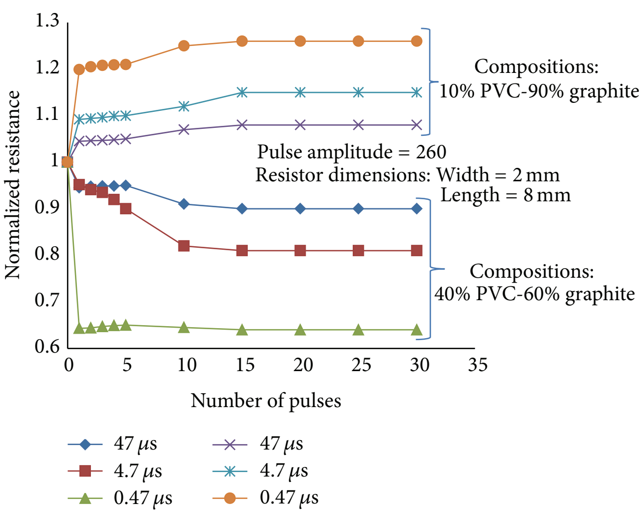

Figure 4: Normalized resistance variation with number of pulses for different pulse durations.

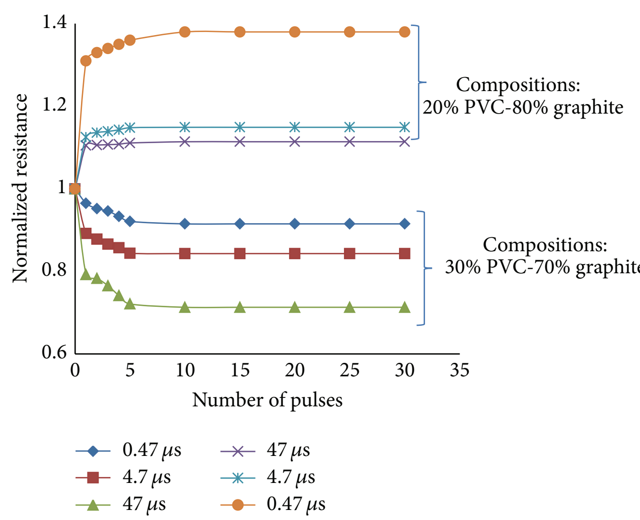

Figure 5: Normalized resistance variation with number of pulses for different compositions.

and the resistance increases with increase in high voltage amplitude in the case of lower resistivity materials when the pulse amplitude is greater than the threshold value with the same pulse duration. Figure 4 shows that the normalized resistance decreases in the case of higher resistivity materials and the normalized resistance increases in the case of lower resistivity materials with an increase in the pulse duration. Figure 5 shows that the normalized resistance decreases in the case of higher resistivity materials and the normalized resistance increases in the case of lower resistivity materials with an increase in number of pulses applied provided that the amplitude is greater than the threshold value. From all these observations, it may be concluded that the resistance of polymer thick film resistors decreases in the case of higher resistivity materials and the resistance of polymer thick film resistors increases in the case of lower resistivity materials, when the pulse amplitude is above a certain threshold value.

4. Discussion

In the case of frit glass based thick film resistors, it is well known that the application of high voltage pulses leads to some sort of micro welding between the conducting granules, which in turn leads to a decrease in resistance of high value resistors [9] (resistors prepared with resistive pastes with relatively low conducting phase). In the case of low value resistors, the resistance increases with the application of high voltage pulses due to snapping of conducting links [9]. In the case of polymer thick film resistors described in this paper, one cannot expect the welding of conducting phase, as it is extremely difficult to fuse graphite granules which are the conducting phase in these films. In the case of frit glass based thick film resistors, the application of high voltage pulses leads to increase in conductivity of low conductivity thick film resistors and leads to decrease in conductivity of high conductivity thick film resistors with local heating. But in the present work, when the high voltages are applied to polymer thick film resistors, the resistance decreases in the case of higher resistivity materials and the resistance increases in the case of lower resistivity materials with high voltages. This clearly shows that there is a phenomenon similar to local heating which arises due to high voltages and leads to formation of more conducting chains and breaking of the conducting chains. Therefore, the authors looked for a mechanism with local heating which can lead to decrease or increase in resistance with the application of a voltage. This has resulted in the following possible mechanism, which perhaps results in the reduction or increment in the resistance due to the application of high voltage pulses to the polymer thick film resistors.

5. Mechanism

Polymer thick film resistors described in this work contain conducting graphite granules dispersed in an insulating polyvinyl chloride. When an electric field is applied across it for very short duration, one expects a local heating to arise in the polymer thick film resistor surface as a result of high electrical field. This local heating melts the polyvinyl chloride polymer and evaporates, which results in the formation of more voids/cavities within the polymer thick film resistors. In the literature, the dependence of resistivity of these resistors on the diameters of cavities inside the polymer thick film resistors has been provided earlier [3]. The local heating produced with high voltage impulses for short duration is very high and causes the evaporation of insulator phase in the polymer thick film resistors and provides voids/cavities with larger diameters in the case of higher resistivity materials. When the diameter of the cavity of polymer thick film resistors becomes larger, this leads to increase in resistivity of these resistors. When an electric field is applied across polymer thick film resistors for short duration, it also produces a local heating in the case of lower resistivity materials. But this local heating is low in intensity, which results in some sort of curing within these resistor films. This local heating causes curing of polymer thick film resistors and is responsible for reduction in diameter of the cavities within these resistors. When the cavity diameter reduces, this results in decrease in resistivity of these resistors. In this way, the same electric field which applies to these polymer thick film resistors can cause decrease in resistance of higher resistivity materials or increase in resistance in the case of lower resistivity materials by the same applied electric field. Therefore, it is felt that the phenomenon responsible for reduction/increment in the resistance with the application of high voltage impulses is the local heating developed with high voltages within these resistor films and also the duration of the pulse applied to these resistors.

With an increase in the amplitude of the impulses, the change in the resistance is large. This indicates that the curing process/breaking of conducting links is enhanced because of the intensity of the local heating raised in these resistor films. With an increase in the duration of the pulses, the curing process/breaking of conducting chains will take place for longer periods. In addition, the resulting increase in curing process/breaking of conducting chains leads to a larger decrease or increase in resistance. Thus, it is seen that one can affect the decrease or increase in resistance in polymer thick film resistors through the application of voltage impulses with amplitude higher than the threshold value. This phenomenon can perhaps be used for either downward or upward trimming of these resistors. When resistors are subjected to high voltage pulses continuously, the voltage amplitude is higher than the threshold value and one expects the following feedback process to occur. With the application of voltage pulses with shorter pulse durations to a lower resistivity material, the breaking of conducting chains will take place. The creation of more and more cavities in these resistor films results in higher resistivities, which finally leads to the breaking of the resistors. With the application voltage impulses to a higher resistivity material, the clustering of conducting particles takes place more and more, due to the continuous curing of these resistor films, which results in continuous decrease in resistance of these resistor films. This process finally leads to the breakdown of these films just similar to the breakdown of electronic devices under electrical breakdown which is highly detrimental to circuits using these films.

6. Conclusion

This paper describes some investigations carried out on the trimming of polymer thick film resistors using high voltage impulses. It is reported that there is a reduction in the resistance in the case of higher resistivity materials and increment in the resistance in the case of lower resistivity materials with the application of high voltage beyond a certain (threshold) value which depends on the value of the voltage and the effective duration for which it is applied. It is also reported that the value of resistance continuously decreases or increases with time, leading to a runaway process (in the case of higher resistivity materials) or breaking of these resistor films (in the case of lower resistivity materials). By using this process, the polymer thick film resistor can be trimmed either upwards or downwards, just by applying high voltage impulses and the resistance change depends on the amplitude of the high voltage impulses above a certain threshold value and the effective duration for which high voltage impulses are applied to polymer thick film resistors.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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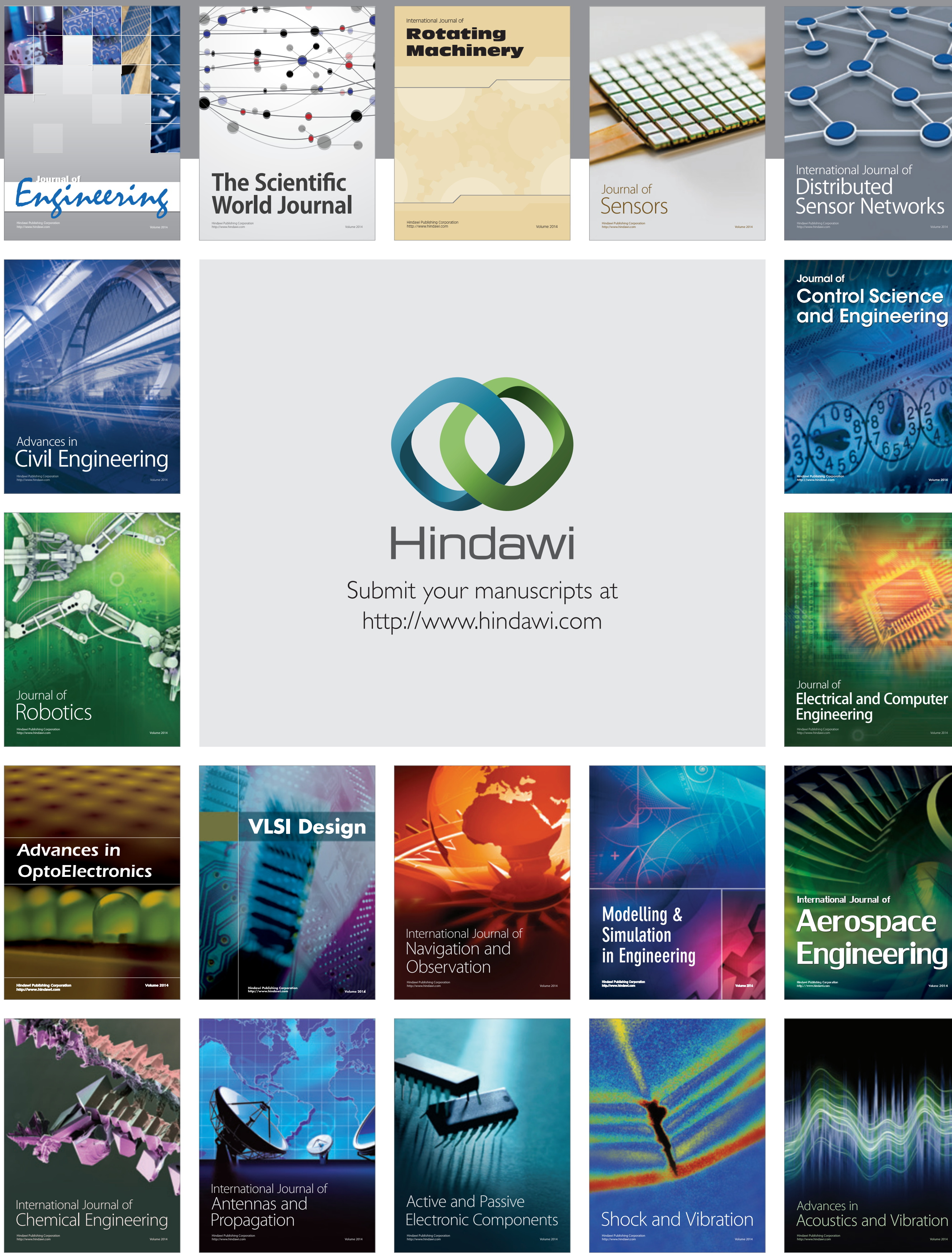
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