UDK 621.3:(53+54+621+66), ISSN 0352-9045 Informacije MIDEM 19(1989)3, Ljubljana

ACCELERATED TEST PROCEDURE FOR ESTIMATING PROPORTION OF EARLY FAILURES OF METAL FILM RESISTORS

Presented at 6th EuReData Conference on Reliability Data Collection and Use in Risk and Availability Assessment, 15-17 March 1989, Siena, Italy; published in Informacije MIDEM with kind permission of Springer Verlag.

Igor Likar, Štefka Kolenko

KEY WORDS: accelerated testing, metal fiml resistors, proportion of early failures, test conditions, Eyring mathematical model, reliability

ABSTRACT: The possibility of estimating the proportion of early failures using accelerated testing was investigated for metal film resistors. The aim of the investigation was to establish a test procedure equivalent to the standard endurance test. Thereby, a quick evaluation of a production lot would be possible to avoid long duration endurance tests on bad lots. In the paper a practical test procedure is presented together with accelerating test conditions which were determined by means of the Eyring mathematical model and on the basis of a series of accelerated tests performed together with the corresponding reference standard endurance tests on approximately 4600 test items. The proposed test procedure can be used as a simple tool for evaluating or/and comparing the reliability of individual lots in the manufacturing process as well as at the incoming inspection.

UGOTAVLJANJE DELEŽA ZGODNJIH ODPOVEDI KOVINSKIH PLASTNIH UPOROV S POSPEŠENIMI PRESKUSI

KLJUČNE BESEDE: pospešeno preskušanje, kovinski plastni upori, delež zgodnjih odpovedi, preskusni pogoji, Eyringov matematični model, zanesljivost

POVZETEK: Članek predstavlja izsledke raziskave, v kateri smo proučili možnosti ugotavljanja deleža zgodnjih odpovedi kovinskih plastnih uporov s pospešenimi preskusi. Cilj raziskave je bil določiti preskusni postopek ekvivalenten standardnemu preskusu zdržljivosti. S takim pospešenim preskusom bi bilo možno hitro oceniti posamezne proizvedene partije uporov in se na ta način izogniti dolgotrajnim preskusom zdržljivosti na približno 4600 preskušancih. Predlagani postopek za pospešeni preskus je uporaben za enostavno ocenjevanje ali/in primerjavo zanesljivosti, tako posameznih partij uporov v proizvodnem procesu kot tudi posameznih pošiljk uporov pri vhodni kontroli.

INTRODUCTION

Within the inspection procedures which are carried out during the qualification approval and quality assessment of electronic parts the endurance tests are most time-consuming. It is therefore in the great interest of the manufacturers to speed up the testing process or at least to get an approximate preliminary information on batch quality within a short time in order to avoid lenghty tests on bad lots. A simple accelerated life testing would also provide usefull information within a reasonable time frame for improvements and corrective actions in the manufacturing process.

This paper presents the results of an attempt to evaluate the quality of low-power metal film resistors in a short-duration test. The final objective of the investigation was to specify the operating and environmental conditions of an accelerated test that would be equivalent to the standard endurance test, e.g. such as prescribed in IEC Publications 115-1 and 115-2.

According to inspection procedures and environmental conditions given in these publications, the resistors are to be subjected to a test of 1000 hours at ambient temperature of +70 °C; the voltage shall be applied in cycles of 1.5 h on and 0.5 h off; this voltage shall be the rated voltage or the limiting voltage, whichever is the smaller; the sample size is 20 and the permitted number of defectives is 1 (group acceptance criterion); the item is considered defective if the change in resistance exceeds 1%. With the equivalent accelerated test the proportion of early failures should be assessed in a shorter time, e.g. within a shift (8 hours). The acceptance criterion should be equal or equivalent to the criterion prescribed for 1000 hour test (up to 5% proportion of failures).

All the experiments described in this paper were performed on the resistors of the manufacturer who ordered the investigation.

INITIAL ESTIMATION OF ACCELERATING CONDITIONS

A general study and a large scale of fundamental experiments concerning the accelerated life testing, which were previously carried out on passive electronic components, provided the guidelines for initially selecting the values of accelerating testing conditions within the appropriate scope. Three types of accelerated tests were conducted on metal film resistors in the course of this basic preliminary investigation: 1) tests with high voltage pulses at room temperature; 2) tests with different constant elevated voltages at room temperature; and 3) combined stressing tests at elevated (constant) temperature and voltage. The comparison of the cited accelerating techniques showed that the best effects could be achieved by combined voltage- temperature stressing. This mode accomplishes all three principal objectives imposed on accelerated testing:

a) short testing times - from 0.3 h to 13 h b) convenient values for temperatures and voltages, near rated values, which means that smaller risk exists to change the failure mechanisms; and c) well fitted mathematical model (for time-to-failure distribution as a function of combined electrical and temperature stress) that can be extrapolated to normal conditions of use.

The tests were conducted on metal film resistors of 0.33 W rated dissipation. The characteristics of the test samples were the following: rated resistance 301 kΩ, limiting voltage 250 V, isolation voltage 450 V, upper limiting temperature 155° C, temperature coefficient ±50 ppm/K and tolerance on rated resistance ± 1%.

For description of the expected time-to-failure as a function of loading, the Eyring mathematical model was chosen as it takes into account the influence of electrical and temperature stress as well as the interaction between them:

$$t = A.e^{b/kT}.e^{-S(c+d/kT)} \qquad (1)$$

where t is the expected time-to-failure, A, b, c and d are constants (model parameters), T is the absolute temperature, S is a normalized stress (other than temperature, e.g., dissipation), and k is Boltzmann's constant.

The parameters of the "main-population model" were determined by fitting the equation (1) to the results of a series of accelerated tests . 13 accelerated tests were performed at the following temperatures and voltages:

An automatic test system with capacity of 30 test specimens was formed around the HP 9836 Computer with Data Acquisition/Control Unit HP 3497 A and HP 3498 A Extender to control the testing and to evaluate the results.

The cumulative distributions of times-to-failure were plotted on Weibull paper. For the main populations, the failure points followed the straight lines with the slope $\beta > 1$ in all 13 cases.

Thereby, the assumption of the Weibull distribution was confirmed for the tested resistors. For illustration, Fig. 1 shows the distributions of two test samples subjected to340 V/175° C and 400 V/200° C. In the analysis and modelling, the early failures were neglected. The

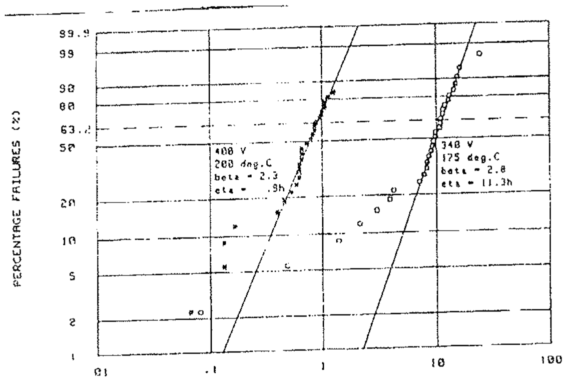

Fig.1: *Cumulative distribution of times-to-failure recorded in two accelerated tests on metal film resistors and plotted on Weibull probability paper*

parameters of the "main population model" were consequently determined on the basis of the mean characteristic lifetimes (ν), read-off from all 13 distributions which were accordingly re- drawn (without early failures). Graphical analysis and least- squares fitting were applied for determination of the parameters. For this purpose the model (1) is transformed into a more suitable expression:

$$\ln t = \ln A + b/kT - S(c + d/kT) \qquad (2)$$

This relation can be presented by two fields of straight lines if S and 1/T, respectively, are assumed to be constant. The pertaining equations, which evidently represent linear functions of 1/T and S, respectively, are namely:

$$\ln t = (b - S.d)/kT + \ln A - S.c \quad S = \text{const.} \qquad (3)$$

and

$$\ln t = -(c + d/kT).S + \ln A + b/kT \quad T = \text{const.} \qquad (4)$$

The calculation of parameters is briefly explained later in description of "early-failures model" determination. The obtained parameters (b = 1.579 eV, c = -2.776, d = 0.172 eV and A = 5.61 x 10^{-16} h) determine a model

	1	2	3*	4*	5	6*	7	8	9*	10*	11	12*	13	
Temperature	155	155	155	175	175	175	175	175	175	200	200	200	200	(oC)
Voltage	460	480	500	340	370	400	460	480	500	340	370	400	460	(V)

Remark: The results of tests denoted by asterix were later applied in defining the "early-failures model."

that fits very well to the results of the accelerated tests as shown in Fig. 2.

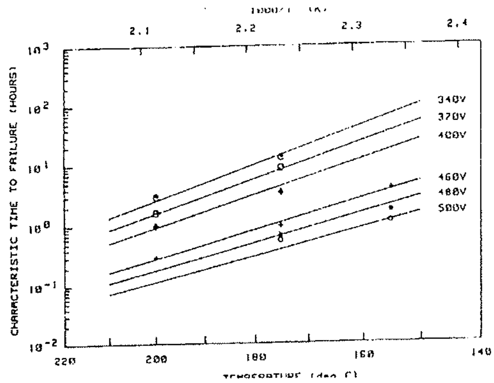

Fig 2: *Fitting of "main-population model" (straight lines) to results of accelerated tests (points)*

PARAMETERS OF "EARLY-FAILURES MODEL"

In the initial stage of the "equivalent test" investigation, the data on early failures recorded during the above basic experiments were applied as it can be expected that mainly early failures occur in standard 1000 hours endurance tests. The majority of test samples exhibited a considerable amount of early failures. The straight lines pertaining to selected failure distributions were drawn through the early failure points using least-squares fitting, and the times to the 5th percentile of failures were read off. This is the proportion of failures equivalent to the reference percentage of failures (approx. 5%) observed in standard 1000-hours endurance tests performed on 3 samples of 1000 resistors from the same batch. The 5th-percentile-points are plotted as points 2 to 7 in Fig. 3. As it is evident from Fig. 3, the selected distributions cover all three applied test temperatures (155°C, 175°C, and 200°C) and the minimal (340 V), a middle (400 V), and the maximal (500 V) voltage applied in accelerated tests. Each straight line in Fig. 3a is thereby defined by two points. The point 1, which is needed for the corresponding field of straight lines in Fig. 3b, has been read off from the line pertaining to 340 V in Fig. 3a. The lines were drawn through the points using the least-squares fitting, and their slopes (E_a and n, respectively) were calculated. The slope of the lines in Fig. 3a is denoted by E_a as it represents the activation energy according to Arrhenius law:

$$t = C.e^{E_a/kT} \qquad (5)$$

By comparing the expressions (1) and (5) we get the following relation between the activation energy and the model parameters b and d:

$$E_a = b - S.d \qquad (6)$$

In a similar way, the slope n of the lines according to equation (4) is related to parameters c and d:

$$n = c + d/kT \qquad (7)$$

The equations (6) and (7) express linear relationship between the slopes (E_a and n) and stress S and 1/T, respectively. The corresponding straight lines can be drawn as the best least- squares fit to the three known points for each line. The model parameters are calculated as the intersections on the ordinate (b and c) and the slopes (d). In this way, two values are obtained for d. We take the value that yields smaller spread of parameter A calculated for all observed points. A is finally calculated as the mean value of all parameters A pertaining to individual points.

The "early-failures model" defined by the obtained parameters ($A = 2.26 \times 10^{-11}$ h, b = 0.954 eV, c = -0.866, d = 0.070 eV) is not so well fitted as was the "main-population model". The major cause for this lies in the fact that the tested samples exhibited a small proportion of early failures and that the times to failures were not measured with sufficient accuracy, as they were recorded at discrete (relatively long) sample times. The model was nevertheless found to be appropriate for initial estimation of accelerating test conditions. It is presented graphically in Fig. 4 by a field of nearly straight lines for which the time to the 5th percentile of failures is constant. This presentation is suitable for reading-off the voltage-temperature stress required for attaining certain proportion of failures (corresponding to percent-

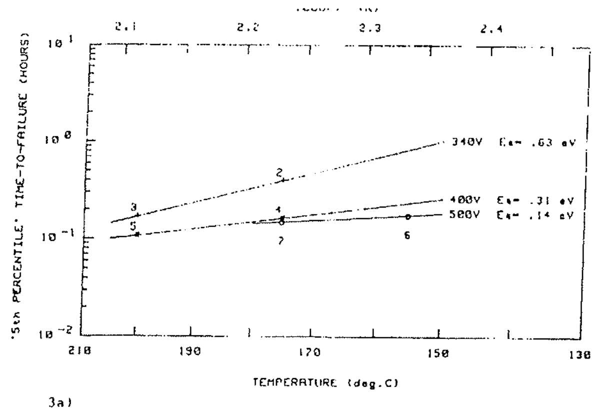

Fig 3 a: *"5th percentil" time-to-failure versus temperature and normalized dissipation, respectively, plotted on basis of selected accelerated tests*

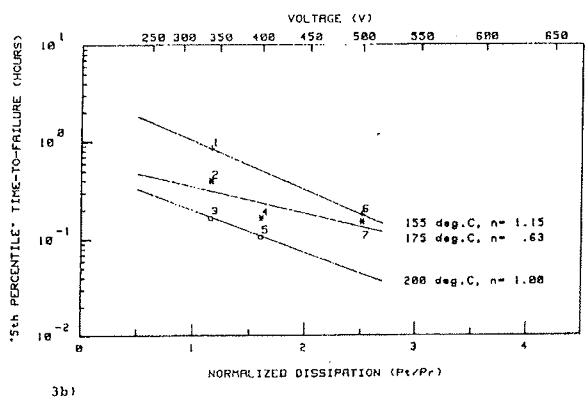

Fig 3b: *"5th percentil" time-to-failure versus temperature and normalized dissipation, respectively, plotted on basis of selected accelerated tests*

age of failures in 1000 hours in our case) in a predefined time.

SELECTING THE ACCELERATING CONDITIONS

When selecting the values of accelerating conditions on the basis of the defined "early-failures model", we have taken into consideration the following requirements in order to define a simple inspection procedure:

* The inspection should be performed within the time of a shift. An appropriate time must also be foreseen for measurements at the beginning and at the end of the test as well as for recovery of test specimens at room conditions (e. g. 1 hour to 4 hours).
* The stress - temperature and dissipation - should be equal for all resistance values.

In addition, the following statements were considered concerning the extrapolation of the model and the level of the test voltage:

* Voltage-temperature stress should be selected so that the model would not be extrapolated too far beyond the values that were used for its determination.
* The test voltage should not greatly exceed the rated voltage or the limiting voltage (250 V).

With the respect to the above criterions, the following initial values were selected:

* Test duration: 2 to 5 hours
* Temperature: 130° C - 155° C
* Voltage: corresponding to 1 to 1.5 times rated dissipation

The range that corresponds to these conditions is shown as the encircled area in Fig. 4. As the rated dissipation is very convenient for electrical loading, we calculated the corresponding temperature for the test time of 4 hours. This temperature is equal to 137° C.

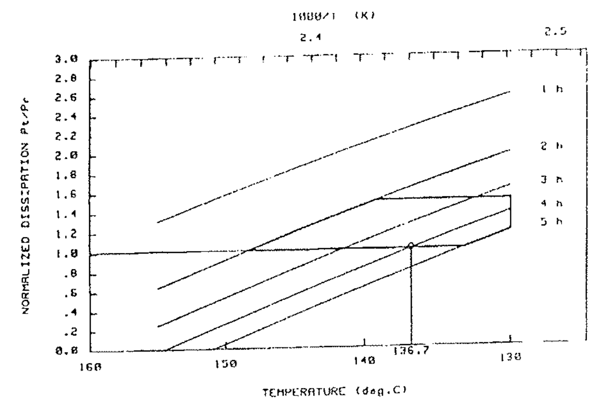

Fig 4: *"Early-failures model" presented by a field of straight lines for which the time to the 5th percentile of failures is constant*

ACCELERATED TESTS AT SELECTED CONDITIONS

To confirm the model and the selected conditions, we performed about 30 accelerated tests at 137° C. The tests were conducted on subsamples of different resistor batches for which the reference data from standard 1000-hours endurance tests were available. For 12 characteristic samples the results of 4-hours accelerated tests and the reference data from corresponding standard endurance tests are compiled in Table 1.

Beside the proportion of failures (r/N), the mean change in resistance (Δ R/R) and the standard deviation (σ) of change in resistance were recorded in reference as well as in accelerated tests. This was necessary first of all because of small proportion of failures observed on most reference and accelerated tests. In this way, we introduced three criterions for judging the equivalency of test conditions on standard and accelerated tests, respectively.

The rated voltage was applied to the resistors with the resistance of up to 301 kΩ. The voltage was decreased below the rated value for 1 MΩ and 2.2 MΩ resistors because too great resistance changes (twice the reference values) were observed at the rated voltage (575 V for 1 MΩ). The resistance changes were comparable to reference values at 400 V.

DISCUSSION AND CONCLUSIONS

For majority of test samples the proportion of failures as well as the mean changes in resistance and the standard deviations of resistance changes observed on accelerated tests were equal to the reference values. Besides, it can be noted that the bad batch of 249 kΩ-resistors exhibited substantially greater resistance change - 3-times the value that was observed for good batches.

These statements lead to a conclusion that the proportion of failures as well as the change in resistance together with its standard deviation are the appropriate criterions for confirming the "early-failures model" as

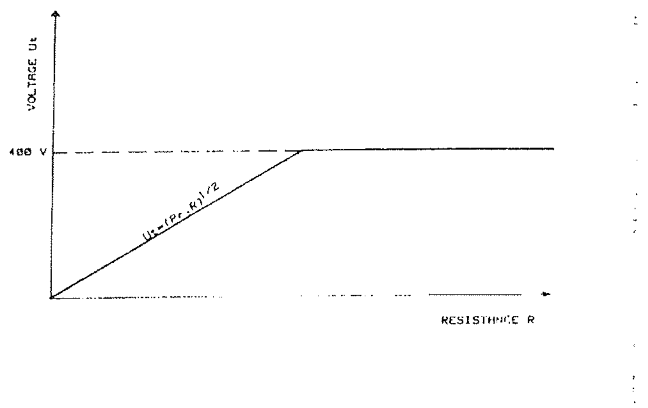

Fig 5: *Voltage-resistance relation for an accelerated test equivalent to the standard 1000-hour endurance test*

	Reference Tests			Accelerated Tests			
Sample	r/N	Δ R/R(%)	σ (%)	r/N	Δ R/R(%)	σ (%)	Ut(V)
301 kΩ	83/1000	0.316	0.087	2/30	0.214	0.110	315
10 Ω	1/200	0,275	0.285	0/20	0.248	0.140	1.82
				0/20	0.233	0.151	1.82
249 kΩ	197/200	-	-	9/30	0.866	0.089	287
				10/34	0.848	0.088	287
249 kΩ	0/1000	0.237	0.043	0/29	0.247	0.053	287
				0/40	0.305	0.032	287
1 MΩ	6/1000	0.132	0.079	1/30	0.137	0.065	400
150 kΩ	0/7	0.500	0.070	0/40	0.339	0.073	222
1 MΩ	0/6	0.300	0.050	0/40	0.471	0.091	400
2.26 MΩ	1/20	0.040	0.010	1/10	0.069	0.014	400
				0/40	0.032	0.100	400

r/N ... proportion of failures ΔR/R ... mean change in resistance

σ .. standard deviation Ut ... applied voltage in accelerated tests

Table 1. Results of some typical 4-hours accelerated tests at 137° C and comparative data of reference 1000-hours tests

well as the selected accelerating conditions, and finally also for evaluating the quality of the produced batch. We also conclude that a short-duration test can be designed using the selected accelerating conditions. The corresponding voltage-resistance relation is shown in Fig. 5.

In the following, we summarize the basic elements of an accelerated test which can be considered equivalent to the standard 1000-hours endurance test:

* Sample size: 20 specimens
* Test duration: 4 hours
* Ambient temperature: 137° C
* Applied voltage: constant direct voltage, corresponding to rated dissipation, or 400 V (whichever is the smaller)
* Time for recovery: more than 1 hour and less than 4 hours (at room conditions)
* Conditions for initial and end measurements: standard room conditions
* Failure criterion: resistance change ΔR/R >1%
* Acceptance criterion: permitted defectives equal to 1

The testing and analysis approach applied in the investigation is estimated to be appropriate for further work, which could lead to effective collection and evaluation of reliability data obtained from accelerated testing and which could finally permit faster determination of reliability characterictics.

REFERENCES

1. Institute for Quality Testing and Metrology, Ljubljana, Reports on Investigations "Development of Accelerated Life Testing", (1985/1986), and "Development of Screening Techniques for Assurance of Professional Quality in the Manufacturing Process of Electronic Parts", (1983/1984)

2. J. Nadrah, A. Pirih, I. Likar, "Accelerated Life Tests of Multilayer Ceramic Capacitors and Metal Film Resistors" Elektrotehniški vestnik, Ljubljana, 54 (1987)

3. IEC Publication 115-1 (1982), Fixed resistors for use in electronic equipment, Part 1: Generic Specification

4. IEC Publication 115-2 (1982), Fixed resistors for use in electronic equipment, Part 2: Sectional Specification: Fixed low-power non-wirewound resistors

Igor Likar, dipl.ing.
Štefka Kolenko, dipl.ing.
Inštitut za kakovost in metrologijo
Tržaška 2, Ljubljana

Prispelo: 10.08.1989 Sprejeto: 28.08.1989