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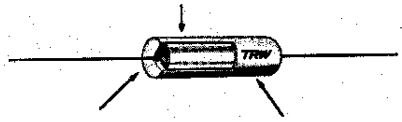
Reliability Analysis, High Voltage Plastic Capacitors



TRW Capacitors began development of a High Voltage Capacitor (2KV thru 16KV), metallized polyester dielectric, in 1970. During the following three years the applicable volts/mil stress, design configurations, parameter limits, and environmental capabilities were fully explored and proven. Prior to the general release of a 'High Voltage Capacitor' catalog line, the single remaining question was RELIABILITY. During February of 1974, TRW Capacitors contracted with Ogden Technology Labs, Fullerton, California, to perform a D.C. Matrix Reliability Test on the subject capacitors. This report is a summary of the 10,000 hour data completed in April of 1975.

Test Results and Conclusions

The TRW type X675HV capacitor has demonstrated a MTBF, at a 90% lower confidence limit, exceeding 260,000 hours when stressed at 85°C and full rated voltage. This MTBF capability can be achieved without sacrifice on degradation of associated capacitor parameters.

Test Specimen Description

The TRW Capacitor High Voltage line has been designated the X675HV. It consists of WVDC from 2,000 to 16,000 with capacitance values of .68 mfd and smaller. The standard design is metallized polyester with axial leads, tape wrap and epoxy endfill case. Insulation resistance is 30,000 megohms x MFD (need not exceed 30K megohms), and the dissipation factor is less than 1% at 1000 Hz.

D.C. Matric Reliability Test Description

The X675HV catalog series consists of ten (10) distinct capacitor designs. Eighteen (18) specimens were selected from each of the ten (10) designs, for a total sample size of one-hundred-eighty (180), and tested as follows:

60 units test at 75% of rated voltage
60 units test at 100% of rated voltage
60 units test at 125% of rated voltage

Perform test at 85°C
Perform test for 10,000 hours minimum (an additional 5,000 hours is currently underway).

Read capacitance and %D.F. every 1,000 hours (at 85°C)
Read I.R. every 2,000 hours (at 85°C)
Monitor for shorts continuously (Plus/minus 8 hours)

Reliability Analysis Techniques

1. Distribution Function
A chi-square distribution function, with a 90% lower confidence limit has been used for all reliability analysis.

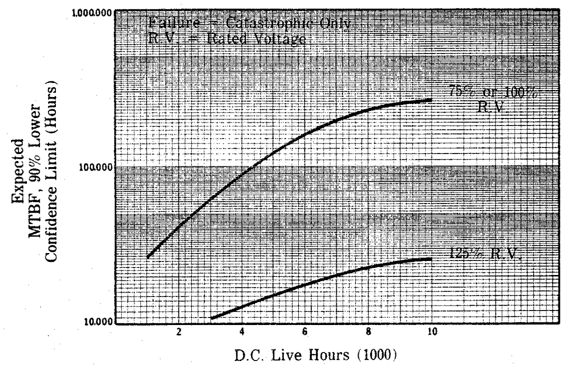
2. Curve Plotting
Linear regression analysis (method of least squares) was used for plotting reliability estimates.

1. Catastrophic Failures (shorts)
No catastrophic failures at either 75% or 100% of rated voltage occurred during the 10,000 hours of test (See Appendix A). This data indicates a MTBF (90% confidence limit) of greater than 260,000 hours at applications of rated voltage or less. Thirteen (13) catastrophic failures occurred at 125% of rated voltage (See Appendix A). This data indicates a MTBF of greater than 26,648 hours at applications of greater than rated voltage (See Fig. 1).

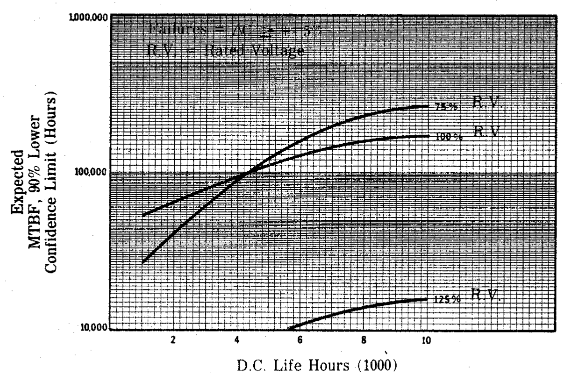
2. Parametric Failures (Parameter drift)
Insulation Resistance:
There was no discernible degradation in Insulation Resistance through the 10,000 hours of test.
Dissipation Factor:
There was no discernible degradation in %DF during the 10,000 hours of test.
Capacitance Change:
There were significant magnitudes of capacitance change during each 1,000 hours of test at the 125% of rated voltage test:

Test Voltage	Avg. Cap. Change at 10,000 Hours
75%	-.33%
100%	-.93%
125%	-34.32%

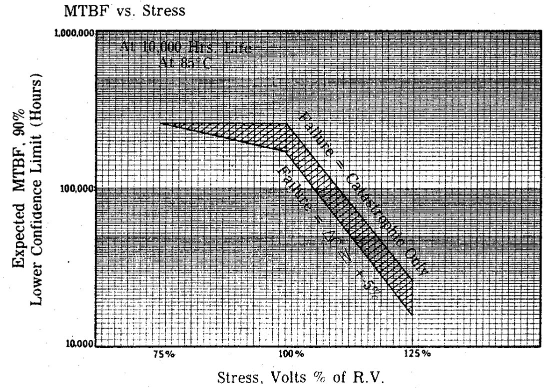
MTBF vs. Life



MTBF vs. Time



MTBF vs. Stress



The changes at 75% and 100% of rated voltage (less than -1%) appear normal; however, -34% capacitance change at 125% rated voltage indicated further analysis of this potential failure mode was required (See Appendix B). Following this analysis additional failure criteria of +-5% and +-10% capacitance change were established, and new failure criteria was established (See Appendix A). The new failure criteria does not significantly effect MTBF at 100% R.V. or less; however, at stresses greater than 100% the MTBF begins to be degraded. A capacitance change criteria of +-5% is consistent with most military and industrial requirements; hence, the plots in Figures 2 and 3 have not included the +-10% of criteria.

Validity of Results

The data was examined to see it it behaved in a "normal" manner. One criteria is to examine the "power law" where:

$$\frac{MTBF_1}{MTBF_2} : \frac{V_1}{V_2} \qquad \mathbf{K} = 5$$

which states that one would expect the MTBF ratios and voltage stress ratios to behave as the 5th power. The data was examined for values of "K" under different failure criteria (See Appendix A). It was expected that "K" should fall in the range 5 to 7. The data behaved as expected (See Fig. 4).

"K" vs. Failure Criteria

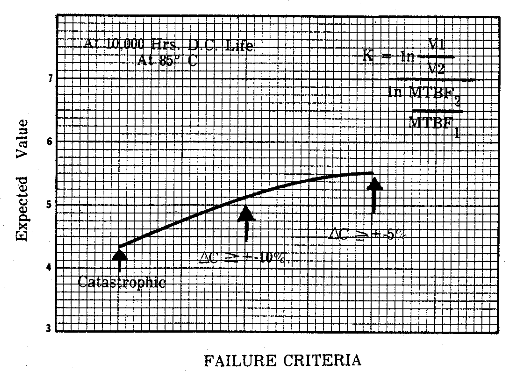


TABLE 1: MTBF VS. STRESS

Stress Voltage	Test Hours	Catastrophic: Failures (1)	Catastrophic: MTBF Actual (2)	Catastrophic: MTBF Trend (3)	$\Delta C \geq +\text{-}5\%$: Failures (1)	$\Delta C \geq +\text{-}5\%$: MTBF Actual (2)	$\Delta C \geq +\text{-}5\%$: MTBF Trend (3)	$\Delta C \geq +\text{-}10\%$: Failures (1)	$\Delta C \geq +\text{-}10\%$: MTBF Actual (2)	$\Delta C \geq +\text{-}10\%$: MTBF Trend (3)
75% RV	1000	0	26059	26059	0	26059	26059	0	26059	26059
	2000	0	52117	52117	0	52117	52117	0	52117	52117
	3000	0	78176	78176	0	78176	78176	0	78176	78176
	4000	0	104235	104235	0	104235	104235	0	104235	104235
	5000	0	130293	130293	0	130293	130293	0	130293	130293
	6000	0	156352	156352	0	156352	156352	0	156352	156352
	7000	0	182410	182410	0	182410	182410	0	182410	182410
	8000	0	208469	208469	0	208469	208469	0	208469	208469
	9000	0	234528	234528	0	234528	234528	0	234528	234528
	10000	0	260586	260586	0	260586	260586	0	260586	260586
100% RV	1000	0	26059	26059	0	26059	53317	0	26059	26059
	2000	0	52117	52117	0	52117	66938	0	52117	52117
	3000	0	78176	78176	0	78176	80560	0	78176	78176
	4000	0	104235	104235	0	104235	94182	0	104235	104235
	5000	0	130293	130293	0	130293	107804	0	130293	130293
	6000	0	156352	156352	0	156352	121426	0	156352	156352
	7000	0	182410	182410	0	182410	135047	0	182410	182410
	8000	0	208469	208469	1	123409	148669	0	208469	208469
	9000	0	234528	234528	1	138835	162291	0	234528	234528
	10000	0	260586	260586	1	154261	175913	0	260586	260586
125% RV	1000	6	5332	6153	19	2759	3990	13	3165	4213
	2000	8	8429	8431	20	4790	5296	16	5815	5809
	3000	9	11355	10708	22	6607	6602	19	7516	7406
	4000	10	13773	12985	22	8809	7907	22	8809	9003
	5000	12	14684	15262	24	10194	9213	22	11011	10600
	6000	12	17384	17539	26	22390	10519	23	12703	12197
	7000	12	20083	19817	29	13048	11825	23	14820	13794
	8000	12	22783	22094	29	13769	13131	23	16937	15391
	9000	13	23853	24371	33	13782	14437	27	16516	16987
	10000	13	26332	26648	35	14516	15743	30	16692	18584
				Plotted Data			Plotted Data			Plotted Data

(1) Failures: a) Catastrophic only; b) Catastrophic + $\Delta C \geq +\text{-}\ 5\%$; c) Catastrophic + $\Delta C \geq +\text{-}10\%$.

(2) $\text{MTBF} = \dfrac{2T}{X2(\infty\ \ 2r+2),\infty}$

Where
- n = number of items placed on test at time t = 0
- t* = time at which the life test is terminated
- θ = mean life
- r = number of failures accumulated to time t*
- r* = preassigned number of failures
- ∞ = acceptable risk of error, (.10)

T = Nonreplacement Tests = $\sum_{i=1}^{r} t_i + (n-r)t^*$
where t_i = time of the ith failure.

(3) Linear regression analysis, these data used for plotting reliability estimates.

(Expected MTBF)

Appendix "A" (con't)

TABLE 2: K VS. FAILURE CRITERIA
AT 10,000 HOURS

Failure Criteria	V1	V2	MTBF1	MTBF2	K
Catastrophic	125%	75%	26648		4.39
AC +-10%	125%	75%	18584	260586	5.15
AC +-5%	125%	75%	15743	260586	5.5

$$K = \frac{\ln \frac{V_1}{V_2}}{\ln \frac{MTBF_2}{MTBF_1}}$$

Appendix "B"

Upon conclusion of the 10,000 hour test, five of the catastrophic failures were dissected and examined. Of particular interest was the examination to determine the probably cause of capacitance decrease, when tested at more than rated voltage.

Findings

In all cases, it was found that significant areas of the capacitor plates (metallized plate) had been eroded/eliminated by 'clearing' actions. These plate erosions seemed to be most prevalent at the margins, and tended to indicate that once clearing started (because of accelerated levels), it was self perpetuating to the point that it caused an unbalanced condition in the capacitor which tended to cause more clearing. It was also indicated that the mechanical line-up of the margins and facing plate areas was critical. If the margins are not lined up properly, or, are not within the mechanical tolerances allowed during the metallizing process, then the unbalanced condition is further aggrevated.