



Life Testing of High-Value Annular Form Factor DC Link Capacitors for Applications with 105°C Coolant



Dr. Michael A. Brubaker

Co-Authors: Edward Sawyer, Terry Hosking, and Ted Von Kampen

SBE Inc.

May 17, 2011


PCIM 2011



The background features several technical drawings of a mechanical component. On the left, a semi-circular arrangement of eight small rectangular parts is shown with angular dimensions of 22.5°, 45°, and 4.99, and a radius of R0.39. In the center, a circular detail shows two rectangular parts with dimensions 0.6, 0.75, and a radius of R0.28. On the right, a vertical cross-section of a part is shown with dimensions 0.20 and 0.11. The word "Overview" is centered in a large, bold, dark grey font.

Overview



- Introduction
 - Life Testing Methodology
 - Life Test Results
 - Test to Failure Methodology
 - Test to Failure Results
 - Conclusions
 - Questions
- 
- A solid orange horizontal bar spanning the width of the slide at the bottom.



Introduction

- The SBE Power Ring Film Capacitor™
 - Annular form factor metallized polypropylene film
 - Very low losses
 - Very low temperature rise (well characterized)
 - High capacitance (1000 μF)
- Life expectancy is critical for automotive DC link applications
 - Conventional life testing data may not apply to this form factor => SBE life testing program

Introduction cont.



- Example: SBE 700D348 (600 V, 1000 μ F)






Life Testing Methodology



- Statistically significant sample population
 - 672 capacitors of 1000 μF (based on SBE 700D348 600V part)
 - 1200 lbs (540 kg) of PP
 - Total stressed area of 70,000 m^2
- Combined voltage and temperature stress test based on DOE Freedom Car specifications and customer inputs



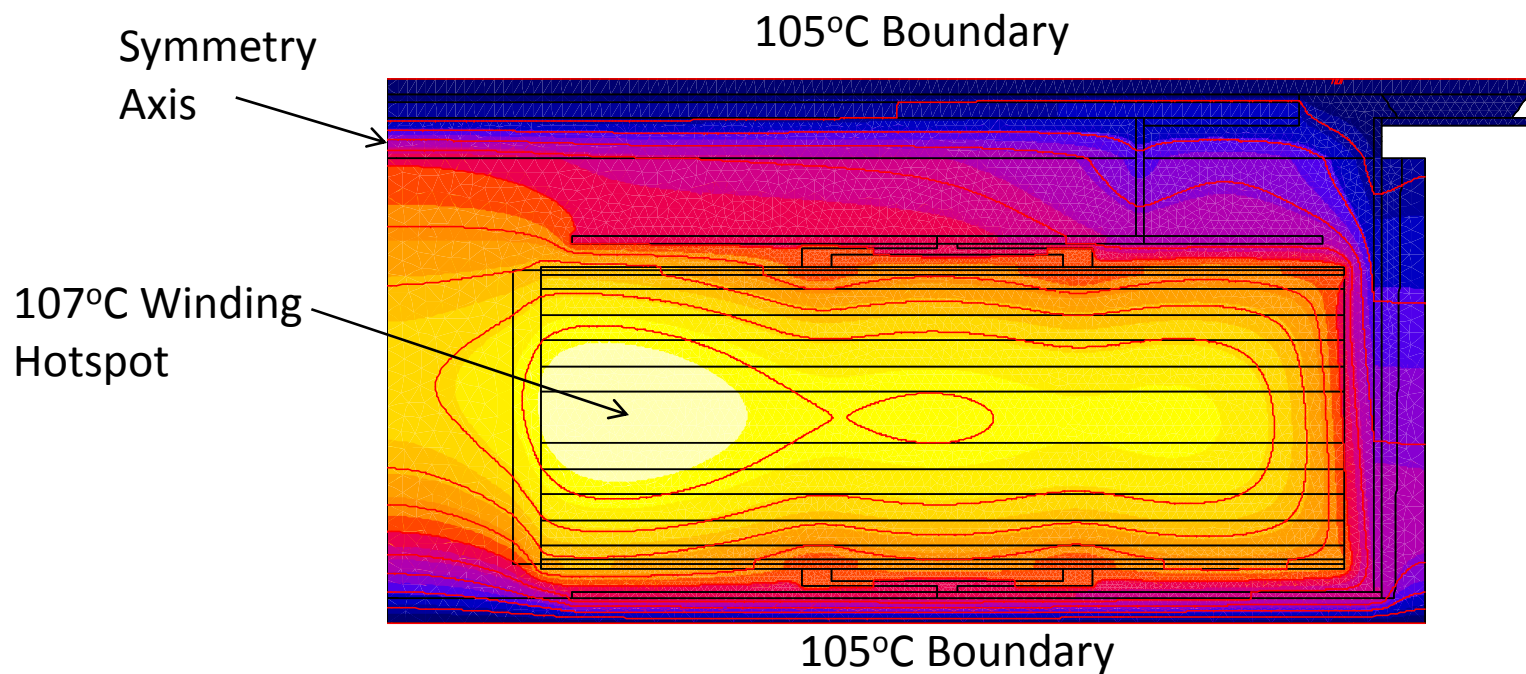
Life Testing Methodology cont.

- Hotspot temperature is a critical parameter for aging
 - SBE has developed an advanced capacitor simulation tool to address this issue
 - Material property measurements
 - Full-scale experimental testing
 - Complete loss formulation as input to transient thermal finite element analysis
- 

Life Testing Methodology cont.



- Consider 700D348 capacitor hotspot
 - 150 A ripple current at 20 kHz with 105°C coolant
 - Two-sided cooling



Life Testing Methodology cont.



- The final test matrix
 - Three groups of samples
 - Different voltage/temperature stresses


| Oven | Number of Units | DC Voltage | Temperature |
|------|-----------------|------------|-------------|
| 1 | 224 | 350 | 107°C |
| 2 | 224 | 400 | 107°C |
| 3 | 224 | 450 | 100°C |



Life Test Methodology cont.



- Notes:

- Each sample configured with an external indicator lamp set to switch on if excessive leakage current observed
 - Given expense of sample population, a “shake out” pre-test was run for one week prior to beginning the formal life test
 - Verify temperature control
 - Check voltage stability
- 

Life Testing Methodology cont.



- Rack mounted capacitors in test chamber





Life Test Results

- Summary of results
 - Five failures observed during pre-test “shake out”
 - Four of the pre-test failures can be attributed to an obvious film defect
 - Two failures observed during formal life test

| Oven | Temperature (°C) | DC Voltage (V) | Run Time (Hours) | Pre-Test Failures | Life Test Failures |
|------|---------------------|-------------------|---------------------|----------------------|-----------------------|
| 1 | 107 | 350 | 2500+ | 1 | 0 |
| 2 | 107 | 400 | 2500+ | 4 | 1 |
| 3 | 100 | 450 | 5000+ | 0 | 1 |

Life Test Results cont.



- Consider MTTF with two analysis methods

| Oven | Include Pre-Test Failures | Analysis | Temperature (°C) | DC Voltage (V) | MTTF (Hours) |
|------|---------------------------|---------------|------------------|----------------|--------------|
| 1 | Yes | Point Failure | 107 | 350 | 560,000 |
| 1 | Yes | Chi-Squared | 107 | 350 | 143,959 |
| 1 | No | Point Failure | 107 | 350 | Singular |
| 1 | No | Chi-Squared | 107 | 350 | 242,950 |
| 2 | Yes | Point Failure | 107 | 400 | 112,000 |
| 2 | Yes | Chi-Squared | 107 | 400 | 60,540 |
| 2 | No | Point Failure | 107 | 400 | 560,000 |
| 2 | No | Chi-Squared | 107 | 400 | 143,959 |
| 3 | Yes | Point Failure | 100 | 450 | 1,120,000 |
| 3 | Yes | Chi-Squared | 100 | 450 | 287,918 |
| 3 | No | Point Failure | 100 | 450 | 1,120,000 |
| 3 | No | Chi-Squared | 100 | 450 | 287,918 |



Life Test Results cont.

- Note that the exact times to failure are not known
 - “Soft” failures where voltage recovers after initial fault => leakage current indicator is only on for a short period of time
- A digital camera is now used to monitor the indicator lamps every two minutes
 - Essential for testing to failure



Life Testing Results cont.



- All capacitors measured at intervals during test
 - Check capacitance (no change)
 - Subject random sampling to full production test
 - Clearing
 - Withstand
 - No failures



Test to Failure Methodology

- Question remains as to end of life behavior
- Subject some samples to elevated temperature and voltage stresses
 - 15 groups of 10 samples
 - 600 V to 900 V
 - 85°C to 110°C
- Try to determine Weibull parameters



Test to Failure Results



- Testing shows a narrow threshold between safe operation and rapid failure as stresses are increased
- Weibull slope of less than unity
 - Decreasing failure rates in time
 - Suggests that samples start a new infant failure mode at each new stress level



Conclusions

- MTTF well beyond the DOE Freedom Car requirement of 10,000 hours demonstrated
 - Entire capacitor winding soaking at hotspot temperature
 - Chi-square results (excluding pre-test failures)
 - 107°C at 350 V: MTTF > 140,000 hours
 - 107°C at 400 V: MTTF > 100,000 hours
 - 100°C at 450 V: MTTF > 285,000 hours
- 100°C at 450 V test is still running in search of end of life (over 2.5 million unit hours to date)

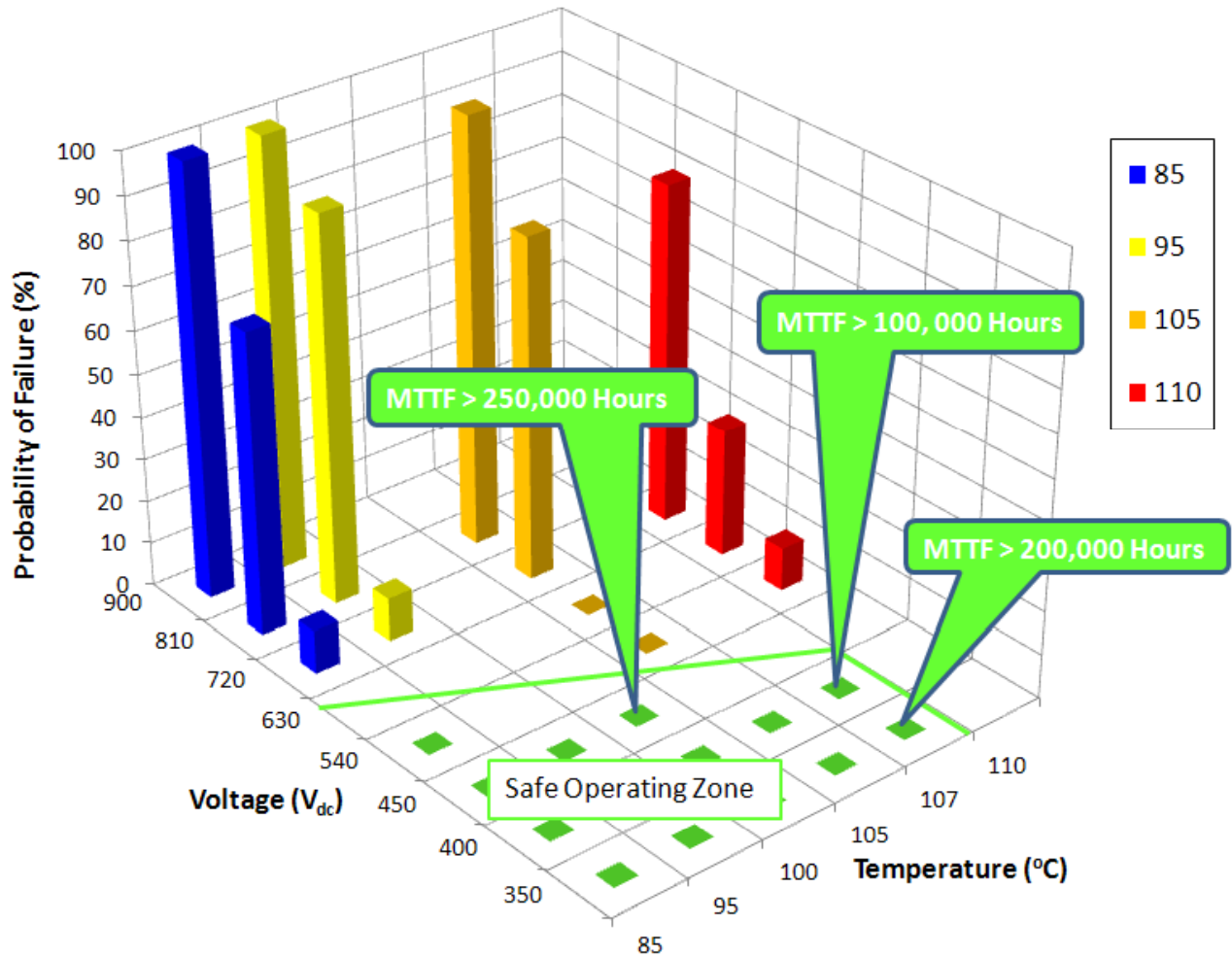


Conclusions cont.

- The life testing and test to failure data is best interpreted on a single graph
 - Safe operating regime defined by life testing results
 - Stress conditions outside the safe regime will lead to failure
 - There is not an obvious advantage in trying to balance reduced life against more aggressive rating



Conclusions cont.





- Annular form factor provides advantages
 - Low ESL
 - Low ESR
 - Low temperature rise
- Now validated in terms of mean time to failure under practical conditions



Conclusions cont.



- Please come and visit our booth
 - SBE, Inc.
 - Mike Brubaker
 - Jim Crawley
 - Hall 12, Stand 247
- Questions?