THE PERFORMANCE OF THE PERFLUOROCARBON LIQUID/PLASTIC FILM CAPACITOR TECHNOLOGY IN REPETITIVE DISCHARGE PULSE POWER SERVICE*

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Summary

At Sandia National Laboratories, we have developed a unique capacitor technology.[1,2] This technology is based upon impregnation of plastic film capacitor rolls with perfluorocarbon insulating liquids. At Los Alamos National Laboratory, we have installed and activitated a 300-kW capacitor modulator.

At the 3rd IEEE International Pulse Power Conference in June 1981, a program between the Los Alamos National Laboratory and the Sandia National Laboratories to evaluate this technology in repetitive discharge pulse power service was described in a paper by Bickford, Mauldin, and Sarjeant.[3]

Experimental data is beginning to flow from this program. Early results indicate lives of 10^7 cycles at 1 kHz for polysulfone and polycarbonate films at 3.5 kV/mil stress levels. At 100 Hz, polysulfone performed without failure to 7×10^6 cycles at 4.7 kV/mil before the test was halted with the samples still functional. This performance appears to be at least an order of magnitude above common capacitor technologies.

This paper is a current status report of this continuing program.

The Capacitor Technology

After intensive in-depth evaluation of the perfluorocarbon impregnants in capacitor research, development, and recently in production, we conclude that they represent the near perfect liquids for this application. No other single liquid displays their range of required properties. Perhaps their most outstanding properties as impregnants are their extremely low surface tensions (12 dynes/cm) coupled with low kinematic viscosities (0.4 centistokes). These result in unusually uniform void-free impregnation and wetting of the interior surfaces of plastic film rolls without need for such auxiliary measures as interleaved paper wicks. We believe that void-free impregnation and total wetting are essential to reliable capacitor performance. The following are some of the other unique discoveries made during the course of the research and development on this capacitor technology.

Capacitor Roll Looseness--A Critical Parameter

The Weibull plot of Figure 1 illustrates the criticality of highly controlled winding looseness on discharge life. The data plot labeled as ① in Figure 1 is performance typical of what would result from traditional winding technology. Group ① exhibits a double distribution. It was determined by detailed post mortem that those units indicating very early failures all failed at the start of the winding. It was found that excessive tightness existed there caused by a start-up procedure and the setting of the tensioning devices on the winder. Group ② data is the result of correcting the start-up procedure and loosening the tension devices. Note almost two orders of magnitude increase in discharge life resulting from these changes. This experience motivated us to expend considerable effort on basic winding technology. The result of this was equipment capable of winding looser yet with highly controlled tension. The performance improvement from this is the data plotted as Group ③. Note almost another order of magnitude increase in life. This experience has convinced us of the critical need for precision winding tightness control throughout the complete capacitor winding sequence.

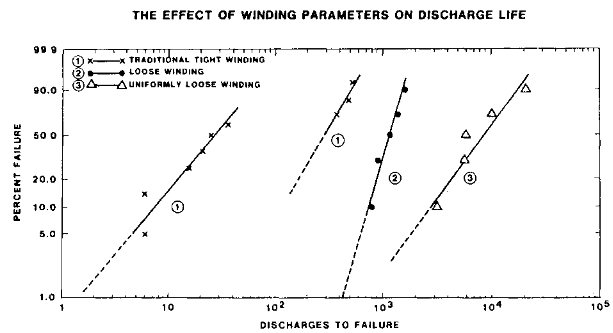

Figure 1. The Effect of Winding Tightness on Discharge Life.

Selective Gas Loading of Impregnant--An Aid to Improved Performance

A number of gases are quite soluble in the perfluorocarbon liquids. One of these is the electronegative gas, SF_6. We reasoned that dissolving SF_6 in the impregnating

*This work supported by the U.S. Department of Energy (DOE)

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUN 1983**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **The Performance Of The Perfluorocarbon Liquid/Plastic Film Capacitor Technology In Repetitive Discharge Pulse Power Service**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Division 2153 Sandia National Laboratories Albuquerque, NM 87185**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**3**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

liquid would improve its carrier-scavenging properties which should improve electrical performance. Figure 2 is a Weibull plot of data from such an experiment. Note the almost doubling of the characteristic life of those samples containing dissolved SF_6.

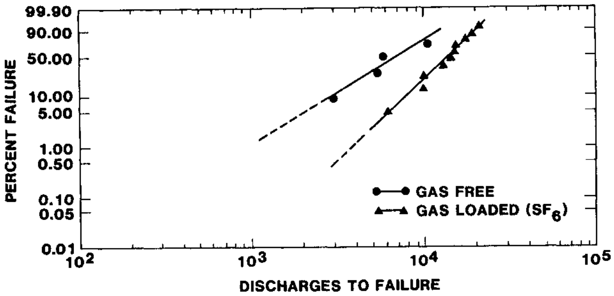

Figure 2. The Effect of Selective Gas Loading of Impregnant on Discharge Life.

The Los Alamos Test Facility

Los Alamos National Laboratory has installed a high-performance partial discharge analyzer (PDA) through the acquisition of the latest system from the James G. Biddle Company.

Also, there has been installed and activated a 300-kW capacitor modulator. It is configured to test and monitor several prototype capacitors simultaneously. The facility is equipped with extensive diagnostics so all electrical and environmental stress parameters can be accurately measured.

The Los Alamos/Sandia Joint Program Plans

A study of the literature and discussions with others in the field suggests that some form of thermal erosion at the foil edges is currently the most favored failure mechanism for capacitors in repetitive discharge service.[4,5] It is thought that the energy required to cause this thermal erosion derives from partial discharges and/or is deposited in the dielectric laminate through its dissipation factor component. The dielectric systems for this program have been specifically designed with features that moderate these influences as well as provide high-temperature capabilities.

An interesting property of the perfluorocarbon liquids is the dielectric strength of their vapors at pressure levels at or above standard atmospheric pressure. Under this condition, their vapors have almost the same dielectric strength as the liquids. This suggests the possibility of establishing an evaporative cooling cycle in the roll without great degradation in the dielectric strength of the system. This concept is illustrated in Figure 3. Figure 3 illustrates that, if a low temperature perfluorocarbon liquid is chosen, an evaporative coolant function will stablize the system temperature below that which would cause degradation of the critical electrical properties of the plastic film dielectrics.

Based upon this concept, the following film materials were chosen for the initial scan:

- Polysulfone.
- Polypropylene.
- Polycarbonate.

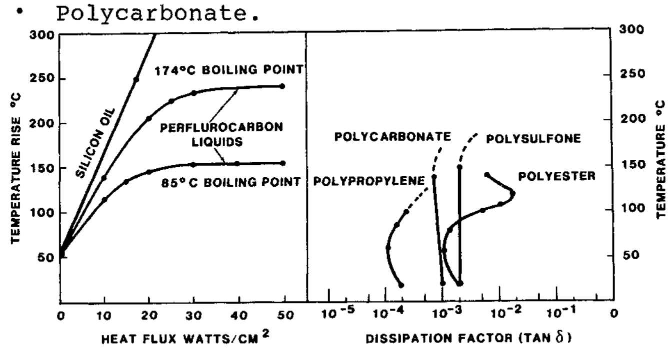

Figure 3. Thermal Matching of Impregnating Liquid to Plastic Film Dielectric

The test sample selected for this initial phase is a 0.2 μfd capacitor individually operated in the voltage range of 5-7 kV. These are connected together in "door knob" fashion to simulate series connection envisioned for future higher voltage designs.

Each test sample is being scanned by the PDA before being subjected to life test. The candidate films are then tested to find the most promising combinations. These combinations will then be tested over a range of field stresses in order to end up with a plot of life versus stress. Weibull statistics will be used to determine the life at the desired reliability.

Early Test Results and Tentative Conclusions

Our understanding from the literature and discussions with workers in the field is that current performance in high energy density repetitive discharge service at 100 Hz is in the 10^7-10^8 cycle range when operating at the 800-1200 V/Mil stress level. This dielectric system typically uses polypropylene film impregnated with a hydrocarbon or silicone oil. No particular performance reliability is specified in general.

Figures 4, 5, and 6 summarize the data obtained thus far in this program. Figure 4 is a plot of life vs field stress for polysulfone film impregnated with a low boiling temperature perfluorocarbon. This system gives lives in the 10^7 range at 3.5kV/Mil operating at 1KHz repetition rate. Squaring the ratio of the field stresses $(3500/1000)^2$ and multiplying by the dielectric constant ratio of polysulfone to polypropylene (3.2/2.2) one gets an energy density increase of over an order of magnitude over current performance. The polysulfone design was subjected to a limited frequency scan and at 100 Hz, a sample was still functional after 7 x 10^6 discharges at 4.7 kV/Mil when the test was halted.

Figure 5 illustrates the performance of the polycarbonate film. The polycarbonate design was studied for the effect of heat sink temperature on life. Figure 5 plots data taken at 3.5 kV/Mil for heat sink temperatures ranging from 35°C down to 18°C. Note the order of magnitude increase in life as the temperature is lowered between these extremes. We believe that this data strongly supports, if not proves, the evaporative cooling features of this design approach.

Figure 6 plots the performance of the polypropylene film design which was inferior to the other films. We believe this is due to the inferior high temperature capabilities of this film. This factor plus its lower dielectric constant suggests that it is out of the running for this service.

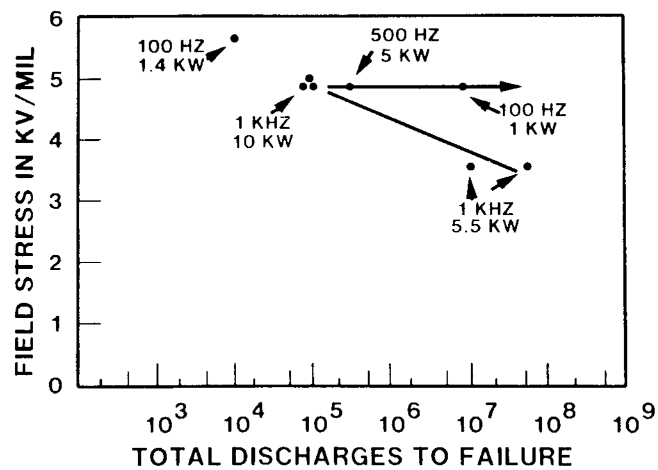

Figure 4. Discharge Life versus Field Stress and Frequency for Polysulfone/FC-72(SF_6 Loaded)

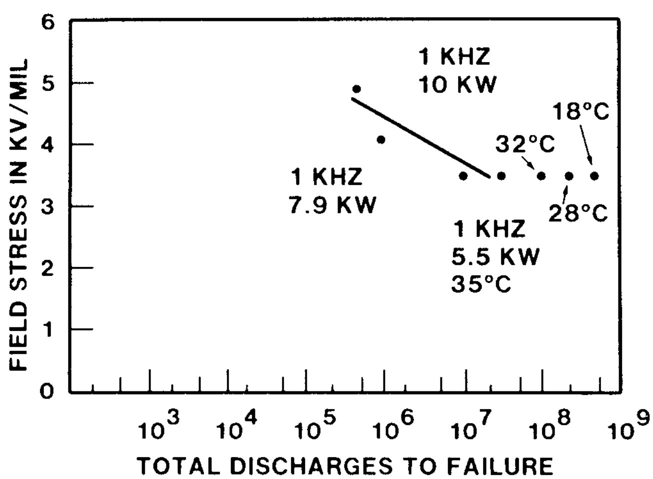

Figure 5. Discharge Life versus Field Stress for Polycarbonate/FC-72(SF_6 Loaded)

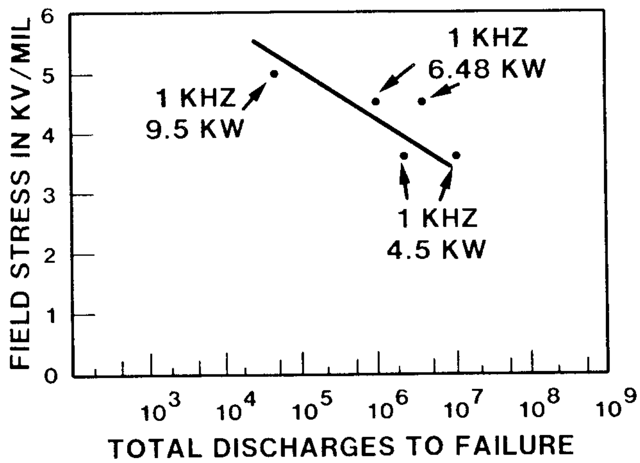

Figure 6. Discharge Life versus Field Stress for Polypropylene/FC-72(SF_6 Loaded)

Based upon these preliminary results, we believe that this capacitor system will permit at least an order of magnitude increase in energy density over current systems in repetitive discharge service, particularly for long life at high reliability.

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