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INFANT-MORTALITY TESTING OF HIGH-ENERGY-DENSITY CAPACITORS USED ON NOVA*

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DISCLAIMER

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Summary

Nova is a solid state large laser for inertial confinement fusion research. Its flashlamps are driven by a 60 MJ capacitor bank. Part of this bank is being built with high energy-density capacitors, 52 µF, 22 KV, 12.5 KJ. A total of 2,645 of these capacitors have been purchased from two manufacturers.

Each capacitor was infant mortality tested. The first test consisted of a high-potential test, bushing-to-case, since these capacitors have dual bushings. Then the capacitors were discharged 500 times with circuit conditions approximating the capacitors normal flashlamp load. Failure of either of these tests or if the capacitor was leaking was cause for rejection.

The test results were remarkably good. Less than 0.5 percent failed the pulsed-discharge test and less than 2.5 percent were rejected overall.

In addition, by testing each unit, LLNL was able to identify two systematic deficiencies in the manufacturing process. Both of these problems were easily remedied, but if they had gone undetected, a major problem in checking out the Nova bank would have ensued.

Introduction

The 52 µF, 12.5 KJ capacitor used on Nova was developed over a number of years and is described elsewhere.[1,2] During the course of development and the course of qualification of vendors LLNL tested 35 units each from three companies. The experience LLNL gained by this testing was incorporated into the final specification for the Nova capacitor. Based on this experience LLNL decided to test each capacitor purchased for Nova.

Purpose of Testing

There were two main reasons for performing infant mortality testing of the Nova capacitors. The first was to eliminate faulty capacitors from being installed in Nova. The second was to use this test as an acceptance criteria for delivered capacitors.

Weibull statistics describe the failure rate of a sample in the wear out mode. Early or infant mortality failures do not fall into this category nor are they described by the satatistics. Figure 1 shows the shape of the Weibull curve which slowly rises monotonically from the initial level. Projecting our data for the Weibull curve into the region of less than 1,000 shots would indicate a failure rate of less than .05%. This is not observed. In fact, prior data has shown that infant mortality failures range from 1 to 7 percent depending on the quality assurance plan of the vendor[3]. Applying this failure rate to the Nova Bank would mean MTBF's of 10 to 20 which is undesirable. In order to remove the infant mortality failures from the distribution we embarked on the following.

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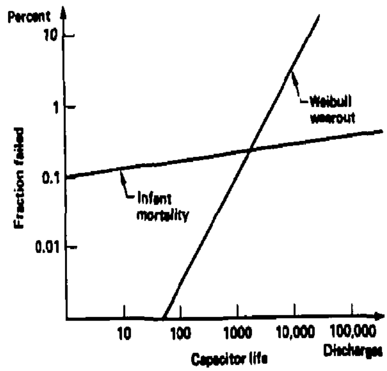

FIGURE 1

CAPACITOR FAILIURE VERSUS LIFE

It was felt that a company might lose up to two percent of a given lot due to flaws. We felt, however, that if a company lost more than five percent of a lot, there would be something seriously wrong in the manufacturing process and the entire lot would be rejected. Between two percent and five percent is a grey area. It was decided to judge the lots falling into this grey area by further testing of these lots. This testing consisted of life testing a small sample to a level of 10,000 shots. The details of the test conditions for the infant mortality test and life test are given below. The sample size to be life tested was chosen according to MIL-STD-105,[4] level I.

An example of how this life test worked is as follows. A lot of 99 capacitors is infant mortality tested and two units fail. Since more than 2 percent but less than five percent have failed, a life test is performed. MIL-STD-105 requires five of the units be tested. If two or more units fail the life test the entire lot is rejected.

In summary our lot acceptance criteria was:

2% or less failures	Lot accepted
5% or more failures	Lot rejected
2-5%	Life test lot

It was decided to perform the testing at LLNL for three reasons. First, the tests were controlled by LLNL. Second, this extensive testing would have been a burden on our suppliers. Third, LLNL felt the testing could be completed at lower cost by performing it at LLNL.

Test Conditions

Infant mortality testing consisted of three steps. The first step was a visual inspection for leaking impregnant. The second step was a high-potential test of the bushing to case insulation. The third step was a pulse discharge test that simulated normal operating conditions. Of the three steps, the pulse discharge test is the most important and only it was used for lot acceptance.

Leaking capacitors are always a problem. In Nova, all capacitors are placed on their sides. In order to find leaking capacitors before installation, LLNL specified the packaging of the capacitors for shipment from the companies to Livermore. LLNL required that all units were shipped on their sides, eight units to a pallet (See Figure 2). The bushings of the capacitors faced out. During shipment the bushings were protected by styrofoam or urathrane foam. During the entire testing process the capacitors never left their pallets. By keeping the capacitors on their sides, any potential leakers are discovered before installation in Nova.

FIGURE 2

PALLETS OF CAPACITORS READY FOR HIPOT TEST

In Figure 2 are shown three pallet of capacitors ready for the high-potential test. The bushing-to-case insulation is stressed to a level of 35 kVdc for 1 minute. Four units are tested together. This test was used to eliminate bad bushings.

The pulse discharge test simulated a flashlamp load, the normal load for the Nova bank. The actual test conditions were:

Charge voltage	24 kV
Charge time	12 seconds
Hold time	1 second
Peak discharge current	5 kA
Percent reversal	< 10%
Number of discharge for Infant Mortality	500
Temperature	25 ± 5 degrees C

Figure 3 shows three pallets of capacitors ready for pulse-discharge testing. A description of the test circuit and hardware are given below.

FIGURE 3

PALLETS OF CAPACITORS READY FOR PULSE DISCHARGE TEST

The life test consisted of performing the pulse-discharge test to a level of 10,000 discharges.

Failure of any of the above three steps was cause for rejection of a unit. The rejected units were returned for repair or replacement.

Test Circuit and Equipment

A schematic of the test circuits is shown in Figure 4. There are essentially 24 individual test circuits. Each capacitors is tested separately. Each circuit contains its own, 50 KV diode fanout (see Figure 5), size 'A' ignitron switch, 450 μH pulse forming inductor, 3.576 Ω load bank, and dump mechanism. All circuits are charged from the same power supply. The circuits are laid out and constructed to as much as possible duplicate normal operating conditions. Figure 6 is a photograph of the control racks and power supply.

The test was designed to run with minimum supervision. Each circuit was monitored by a current transformer. The outputs of these current transformers were inputed to a peak detector chassis. The peak detector chassis provides a window comparator. If the current in any circuit is too high or too low the test shuts itself down. When shutdown occurs, the test was "safed" out and the cause determined. If a failed capacitor was found, that capacitor was deselected. Each of our circuits were individually selectable by Ross switches in the fanout, so that, if a failure occurred, the failed circuit would be remotely disconnected and the test continued.

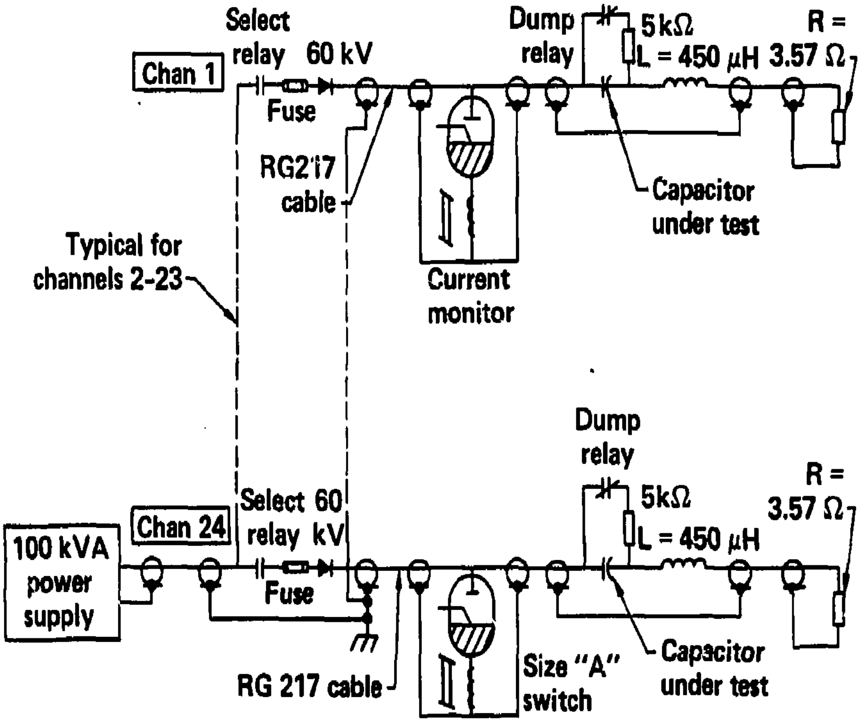

FIGURE 4

SCHEMATIC OF CAPACITOR TEST

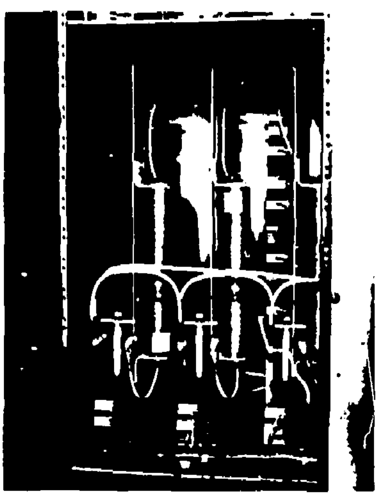

FIGURE 5

50 KV DIODE FANOUT

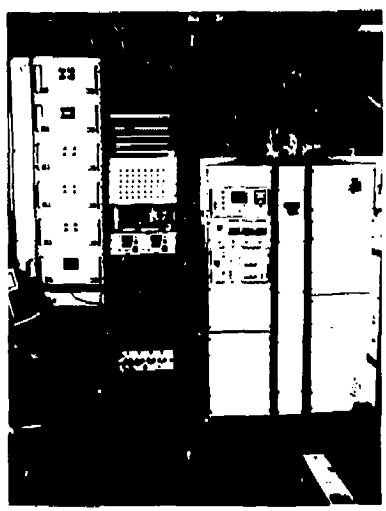

FIGURE 6

CONTROLS RACKS AND POWER SUPPLY

Operation consisted of testing 3 pallets of capacitors at a time. The pallets were placed into the test by a forklift. The capacitors were connected to their circuits and the test started. Usually, a little over two hours was required to run the test. To remove and install the pallets takes one man about one hour. While the test was running, the next three pallets would be prepared and high-potential tested.

Typically, one set of three pallets were tested each day. This required one technician for 6 hours per day and one technician for 1/2 hour per day. The second technician was needed for the high-potential test and for "safing" the test with a ground hook; whenever high voltage may be present two knowledgeable people are required for safety reasons. The first technician spent the rest of his time logging each capacitor and preparing the pallets for storage.

Test Results

The results were much better than anticipated, particularly the pulsed-discharge test results. Overall, the percentage failed for this test was only 0.38 percent for General Electric and 0.95 percent for Maxwell. It is interesting to note however, each company had one lot subjected to life testing; neither company had a lot rejected.

For each company, LLNL identified a systematic problem. The leaking capacitors and bushing failures for General Electric were, for the most part, traced to the same step in the capacitor assembly. Both problems resulted from improper tightening of the bushings. The leakers were caused by the bushings being not tightened enough and the high-potential failures resulted when the bushings were overtightened which cracked the insulator. General Electric began to check the torque on each bushing and these problems were eliminated.

For Maxwell, the first two lots delivered incurred all of the pulsed-discharge failures. The failed units were autopsied. It was discovered that the paper contained splices, and the units had failed at these splices. Maxwell, by working with their paper supplier and adding another quality-control check, eliminated this problem.

Without infant mortality testing, LLNL would not have uncovered these problems until much later in the construction phase of Nova. Failures like these would have severely impacted our construction schedule.

References

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2. D. K. Haskell, et. al., UCRL 86029; "Development of A High Density Energy Storage Capacitor for Nova", 9th Symposium on Engineering Problems of Fusion Research, Chicago, Illinois, October 1981.
3. B. Carder, Private Communication.
4. Military Standard, MIL-STD-105D, "Sampling Procedures and Tables for Inspection by Attributes", April 1963.

The results are summarized in Table I.

COMPANY	NO. OF LEAKERS	NO. THAT FAILED HIPOT	NO. THAT FAILED DISCHARGE	TOTAL TESTED
General Electric	39	10	8	2120
Maxwell	2	0	5	525

TABLE 1 TEST SUMMARY