Radiation Hardness Test of the Barrel Capacitor

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The barrel filter capacitor is the last remaining barrel component. Although the end cap TRT capacitor is proven to be radiation hard, it cannot be used for the barrel TRT because of the space constraint. Typically the capacitors made with NP0 material exhibit good radiation hardness characteristics but the capacitors with X7R showed mixed results. Because of the space problem, 1000 pf barrel filter capacitors have to be made of X7R.

One candidate for the barrel capacitors is made by Johanson with X7R material. Previous test at CERN showed mixed results, and the cause was not clear. It was reported that in one test, the capacitors were tested ok immediately after the irradiation, but failed after three months. In another test, no problem was reported. It should be noted that although the capacitors in both tests were made by Johanson, the lot numbers were different.

In this note, we report on a radiation hardness study of the ‘same’ capacitors (i.e., made by Johanson). The capacitors were purchased from four different vendors to make certain that they are from different lot numbers. The capacitors are rated for 2000 Volts.

Before the radiation test, they were tested for the HV robustness. In this test, fifty capacitors from each lot were connected to 2000 volts in parallel and suddenly discharged (shorted). The charging and discharging was repeated 3000 times. During the test, the total capacitance of the fifty capacitors, leakage current and arcing were monitored.

There were a couple of capacitors that failed because of the surface arcing (due to dirt?), but it was not regarded a problem. In some batches, the capacitance (of fifty capacitors) decreased slightly (less then a few %) during and after the test (The capacitance was not monitored as a function of time after the test). Even though there were some minor problems, we concluded that they passed the test and there was no lot dependence on the HV robustness.

The radiation hardness test was conducted using the NC State University research reactor called PULSTAR (http://www.ne.ncsu.edu/NRP/reactor_program.html). The PULSTAR Reactor is a 1 MW pool-type research reactor with 4% enriched, pin-type fuel consisting of uranium dioxide pellets in zircaloy cladding. This fuel gives the PULSTAR Reactor response characteristics that are very similar to commercial light water power
reactors. Several years ago, we used the reactor a couple of times to test glues and wire-joints.

The PULSTAR reactor.
A view of the reactor from the top. The top of the reactor is at the bottom of pipes. The sample is lowered through a curved pipe at the right side.

Twenty capacitors were taken from each lot (eighty in total). Ten of them were connected in parallel on a thin G10 plate (Figure below) using solder. These capacitors were connected to a Bertan HV power supply during the irradiation. The other ten were left in the package and irradiated. The samples were placed inside an aluminum tube (1.9 cm OD and 25 cm long) and placed near the reactor. The radiation consisted of fast neutrons, slow neutrons and gammas. The total neutron fluence was measured using cobalt foils and it varied from $1.2 \times 10^{14}$ to $9 \times 10^{14}$ /cm$^2$ (top to bottom) along the length of the tube. The fluence of $5 \times 10^{14}$ /cm$^2$ corresponds to ~50 years of LHC operation. The estimated gamma dosage was ~2 Mrad.
The capacitor assembly for the reactor test. There are ten capacitors connected in parallel.

Results

The irradiation took 60 minutes with 30% of the full 1 MW power. During the irradiation, the forty capacitors (in four groups with 10 capacitors in each group) connected to the HV power supply at 2000 volts exhibited no HV problem (HV trip). The leakage current before the irradiation was 0.4 µA and increased to 0.8 µA during the irradiation and no fluctuation was observed. When the reactor was turned off, the leakage current returned to 0.4 µA. After the test, the samples and tube were too radioactive to take out and were left in the pipe. After 7 days, the radiation level was low enough to bring to Duke. At the time of writing, the capacitors are still somewhat radioactive to handle and only the capacitors already connected to the HV lines are being tested. These capacitors (in four groups) have been re-connected to the HV (2000V for the first three weeks and 2500V for four weeks) supply and the leakage current has been less than 20 nA. The capacitance of each of the four groups was also measured and we found the change in the capacitance was within the measurement error (less than 1%).

Conclusion

We have tested eighty Johanson capacitors from four separate lots using the NC State Pulstar reactor. The capacitors were radiated up to 8x10^{14}/cm^2 fluence. Half of the capacitors were under 2000 volts during the irradiation. We observed no HV problem during the irradiation and seven weeks after the irradiation. The capacitance changed little and the difference was within our measurement error. All capacitors from the four lots behaved similarly. We are waiting for the radiation level to come down for further testing, such as charging-discharging test. Meantime, forty capacitors are connected to a HV and the current is being monitored. Based on the results so far, the Johanson capacitors should be safe for 10 years operation under the LHC environment.