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TITLE TESTING OF A 50 kA, 50 kV CURRENT INTERRUPTER WITH I^2T
PREHEATING AND LONG RECOVERY VOLTAGE

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TESTING OF A 50 kA, 50 kV CURRENT INTERRUPTER WITH I^2t PREHEATING AND LONG RECOVERY VOLTAGE¹

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ABSTRACT

The Confinement Physics Research Facility (CPRF) presently being constructed at Los Alamos is a next generation Reversed Field Pinch (RFP) plasma experiment. An inductive energy transfer system, employing a 50 kA, 50 kV dc current interrupter, is being utilized for initiating the plasma current. These performance requirements (50 kA, 50 kV) had yet to be realized in a reliable switching system, development of this current interrupter system was initiated.

A switch test bay with a 50 kA battery bank has been built at Los Alamos to test the interrupter in conditions which will exist in the CPRF experiment. Many switch parameters were measured to provide information on the current interrupting characteristics and reliability. Some of these diagnostics include voltage, current, pre and post I^2t contact resistance, opening speed and position, arc voltage, and stem temperature. To determine any long term changes, all shots and data channels are computer indexed, and may be easily recalled for review. Extensive testing was performed on Siemens D-10 vacuum interrupter. Test parameter space included 55 kA, 40 kV (per bottle); di/dt of 2250 A/ μ s, I^2t of 5×10^9 amp² sec; and 20 kV-200 msec RC recovery decay.

Circuit parameters effect opening reliability. Circuit data and the associated testing results will be presented along with long term trends of switch performance under "normal" conditions.

INTRODUCTION

Los Alamos initiated the construction of a series of new test bays for switch gear testing in September of 1987. Each of the three bays performs a specific function. A transportainer located next to the experimental building, houses a 50kA battery bank. The output cabling enters into the next bay, designated for battery bank switching and charging, as well as a no load switch test area. The largest, and final test bay, contains extensive hardware for dc vacuum interrupter (opening switch) development. In addition to interrupter development, support hardware for the CPRF energy systems are also developed, tested and characterized. Los Alamos designed hardware and systems that played a crucial part in the dc interrupter development, and will also find extensive use on ZT-H. This equipment is as follows:

- Siemens switch control and monitor
- High speed linear displacement monitor
- Switch resistance monitor
- Quad switch differential and arc voltage monitor

¹ Work performed under the auspices of the US DOE

- Capacitor bank and charging systems
- Fiber optic control and diagnostic family of hardware (10 boards and 8 chassis)
 - Chassis based
 - Camac based
- Differential bank voltage monitor
- Feedback regulated saturable reactor controlled H.V. supplies
 - with fiber optic remote controls
- Floating CVR diagnostic system
- Trigger systems
- 50kA, rated compact saturable reactors
- 50kA, 50kV transfer high speed transfer switches

With these systems and other support hardware, the Opening Switch Test Facility achieved its first 50kA and 50kV interrupting shot on December 21, 1988.

With the switch test facility configured as shown in Fig. 1, life and parameter scan testing of Siemens D-10 vacuum interrupter was initiated.

Fig. 1.

TESTING WITH HIGH PRIMARY I

A series of 100 tests were performed with fast recovery characteristics. It was hoped that with a fast recovery, one could minimize the counter pulse capacitor bank circuitry. (The counter pulse bank produces an artificial current zero, extinguishing the dc arc. This then permits the interrupter to open electrically). Testing with a primary I of 2250A/ μ s,

and a secondary I^2t of $45A/\mu S$, recovery characteristics were erratic. For 65% of the shots, voltage division between the 3 series vacuum interrupters was even (see Fig. 2). With 28% of the shots, the voltage division was uneven. Figure 3 shows switch 1 developing the majority of voltage ($\sim 35kV$), but the probability for any tube to recover in this fashion was evenly distributed. Examining the total recovery voltage for both cases gives an identical reading as shown in Fig. 4. Individual tube diagnostics must be available to determine these recovery characteristics. With 7% of the shots, switch 3 did not recover (Fig. 5). This characteristic was inherent in one tube only, not a random event. For this case, there was only a slight difference in the total recovery voltage. Operation at large I and V had other negative implications, insulation and cabling suffered premature failures, even though the network always opened.

Fig. 2

Fig. 3.

Fig. 4.

Fig. 5

I^2t AND LIFE TESTING

Before I^2t and 50 kA, 50 kV interrupter life testing could be initiated, thermal and I^2t characteristics needed to be determined. Testing with current waveforms planned for ZT-Hi (50kA ramp, $2.5 \times 10^9 I^2t$, 1/10 minutes), thermal equilibrium was attained after 17 shots. A maximum stem temperature of $125^\circ F$ indicates a low resistance. A specially designed diagnostic, a switch resistance monitor, measures resistance before, during, and after I^2t heating. This diagnostic also uses fast retractable probes for measurements that do not interfere with interrupting shots. Figure 6 shows a slight dependence of resistance upon I^2t heating, switch resistance increased slightly during the current ramp. Pre and post I^2t resistance changed from $70\mu\Omega$ to $90\mu\Omega$ for the three series interrupters. After completing 100 I^2t tests, a 1000 shot life test consisting of an I^2t pre-heat, quickly followed ($\sim 200mS$ delay) with a 50kA, 50kV interrupt ion, could then be initiated.

Fig. 6.

With modification of the counter pulse capacitor banks, primary and secondary I^2t was reduced to $580A/\mu S$ and $31A/\mu S$ as shown in Fig. 7. Due to improved deionization characteristics the lower I^2t always produced an even voltage division ratio, as shown in Fig. 8. With a single series set of interrupter tubes handling a $2.5 \times 10^9 I^2t$ s, along with a 50kA interrupt ion, it was thought contact welding and/or current induced popping forces would cause recovery problems. A high speed linear displacement transducer diagnostic of Los Alamos design found no such evidence of contact welding or popping. Throughout the remaining series of tests, contact travel characteristics remained as shown in Fig. 9 with a contact stroke time of $\sim 8.5mS$ and a relative timing of $600\mu S$. No attempt was made to adjust the tubes relative timing. Another method used to determine the interrupters 50kA suitability, is the tubes arc voltage. A low and stable voltage (30-40V) as shown in Fig. 10 indicates a diffuse arc.

- A significantly higher or erratic voltage would indicate plasma pinching. The contact relative opening time can also be determined, as well as unwanted pickup from capacitor bank switching. Testing was completed without a single vacuum interrupter or mechanism failure.

Fig. 7

Fig. 8

Fig. 9

Fig. 10

I^2t AND 50kA, LONG RECOVERY VOLTAGE TESTS

To permit long recovery voltage tests, the interrupter network was modified. Instead of using three series bottles, the middle bottle was shorted (with a busbar), this neutral node was then connected to a hard tube modulator. After the I^2t preheating, appropriate capacitor bank voltage settings quickly produced, a 50kA pulse and an 18kV recovery voltage per tube. Before this voltage (18kV) could decay significantly, the hard tube modulator of Los Alamos design produced an 18kV, 500mS (1/e) waveform as shown in Fig. 11. Unfortunately, a tube restruct on 7% of the shots. A diagnostic to determine which tube had restruct was not installed. It could be that tube 3 was restriking as in the high primary I conditions. If in fact this failure is related to a single tube, diagnostics would be able to give an indication a single tube needs replacement. Another interesting result is the restruct was always within 3 of recovery. There were no restriks delayed tens or hundreds of milliseconds.

Fig. 11

VACUUM INTERRUPTER DISASSEMBLY AND INSPECTION

After completing about 2,000+ shots, with 1400 directly related to specific tests, the vacuum bottles were opened. The contact surfaces were in rather poor condition. Evidence of damage from I^2t heating, contact welding, electrical arcing, and thermal fatigue can be noted by careful examination of Fig. 12. Contact puddling from I^2t heating is evident on the anode. These areas are localized near the central hub of the slots, particularly in the 10, 12, 2, and 4 o'clock positions.

Fig. 12.

positions. Contact welding may be seen on the cathode. A large pock mark (7 o'clock position) seems to have been caused by the sintered material fracturing from the cathode at a weak spot and sticking to the anode. Fatigue cracks can be seen on the anode; most pronounced on the lowest petal, near the central hub of the radial slots. Typical of arc damage, material build up on the edge may be seen on the anode (9 o'clock position). The result of material despositing on the anode was unexpected. Typically ionic material or molten material deposits on the cathode. The poor electrode conditions give rise for concern, and modification of the tubes internal construction should alleviate many of the problems. An unslotted version should not be susceptible to fatigue cracks. In actual operation, tubes will not cool before interrupting and cause welding (from 300mS delay). I believe the newer tubes will survive their 2,000 shot rated lifetime. When Los Alamos receives these newer bottles testing will confirm their integrity.

CONCLUSION

Los Alamos built a new 50kA, 50kV dc interrupter test bay system with a sophisticated array of diagnostics. To further simulate systems as planned for ZT-H, fiber optic controls and diagnostics were used throughout. Over one year after construction was initiated, various parameter scans were performed at the 50kA and 50kV levels. Further testing will quantify improvements in interrupter design technique.