PART FIVE.TWO
of a predictive
maintenance series

FLUKE®

Maintaining a super collider with insulation resistance testing

Application Note

Measuring tools: Fluke 1550B MegOhmMeter

Operator: Fermi National Accelerator Laboratory, high-energy facility

Test conducted: Capacitor, cable, matching MOVs, arrestors, power amp

Aerial view of Fermilab Accelerators, with the Main Injector under construction in back and Tevatron in the foreground

Even the most complex equipment is still the sum of its parts — and those parts need regular preventive maintenance.

That's the philosophy followed by Mitch Adamus, Senior Technician at Fermi National Accelerator Laboratory (Fermilab). Located outside of Chicago, Fermilab houses the Tevatron, the world's highest-energy underground particle accelerator, located inside a tunnel measuring 4 miles in circumference. The Tevatron accelerates protons and antiprotons, and the particles collide at enormous speeds, close to the speed of light. The resulting data helps some of the brightest minds in the world answer such questions as "How was the universe created? How does it work?"

As you'd expect, many exotic components lie within this complex equipment, along with regular wiring, connectors, and protective devices — all exposed to extremely high energy and subject to degradation. It's Adamus' job to ensure this complicated backend operates correctly on demand. That means scheduling component testing during lab downtimes, tracking performance, and predicting when parts need to be replaced to prevent untimely failures.

For insulation resistance testing and other kinds of high resistance tests, Adamus uses the Fluke 1550B MegOhmMeter.

Standard measurements

Cable tests

To ensure the integrity of large coaxial cables and high voltage cables in various systems, the technicians hi-pot them at 5 kV. "The high voltage cable is the typical point of failure," Adamus says, "When these fail, they break down at low voltages." The fault is usually apparent — these items don't degrade so much as fail outright because of the severity of the environment. "If they pass at 5 kV, we can assume they are good," Adamus says. "If they don't pass at 5 kV, we know they are bad."

Methodology

To hi-pot cables, Fermilab technicians set the 1550B to 5 kV. Then, they apply this voltage between one conductor and the cable shield. Because these cables fail catastrophically rather than deteriorate, the technicians are looking for pass or fail conditions. If the meter shows a high resistance, the technicians then test between another conductor and shield and repeat this process until they observe a failure (low resistance) or have tested all of the conductors.

Matching MOVs

The Fermilab technicians also use the 1550B to match Metal Oxide Varistors (MOVs) that form parallel groupings in various tube socket assemblies. These MOVs are for transient voltage surge suppression. They're grouped because a single MOV simply can't handle the energy of that environment. By grouping them, Fermilab effectively gets one large MOV.

But, there's a catch. Due to Kirchoff's Law, electricity will divide in reverse proportion to the resistances presented to it. This means that if the MOVs are not closely matched, one MOV will take the brunt of the surge and then fail — and that lowers the effectiveness of the group of MOVs.

Methodology

To test an MOV, Fermilab technicians put the 1550B in ramp mode and select the appropriate kV level. Then, they ramp up and note the breakover point (the voltage at which the MOV will conduct) for each MOV. This allows them to place MOVs in matched sets.

The MOV is a variable resistor. It has one lead on the hot, and one on ground. It acts like an open fuse (high resistance) until the voltage across its terminals reaches a certain value. Then, it changes its resistance — it "breaks over" and conducts (but only partially). MOVs behave much like spark gap arrestors, in that they are voltage limiting devices. MOVs work only because of Kirchoff's Law (electricity divides proportionate to the resistive paths presented to it). We use MOVs to conduct overvoltages to ground (or neutral, depending on the designer's intent in electronic devices — but always ground for electrical systems).

So, a 500 V MOV will allow a 480 V circuit to avoid seeing, say, a 2 kV spike. That portion above 500 V will be conducted to ground. But, not all 500 V MOVs break over at 500 V. Some will break over at 497 V, some at 514 V, some at 503 V, and so on. By testing each MOV, you can get matched sets for each power supply so the breakover is very close for all 3 phases.

Main Control Room of Fermilab's Accelerator Complex

Unique Fermilab measurements

Measuring spark gap surge arrestors

Fermilab uses spark gap surge arrestors as part of a repertoire of devices to protect equipment from high voltage transients. These spark gap devices are simple, rugged, and reliable – but Fermilab is using them in a unique way. As Adamus explains, "Commercial spark gaps are set, but ours are adjustable. So, we need to ensure they stay adjusted right."

The spark gap devices are so important that Fermilab uses two of them to protect the 150 KW radio frequency (RF) power amplifier. Adamus says, "These two are connected in parallel to the screen grid of the power tube to prevent voltage excursions greater than the specification. The ramp mode of the Fluke 1550B MegOhmMeter will verify the settings of these gaps at 3kV."

Fermilab had been looking for a way to set the spark gaps based on actual performance, not on the physical distance between the terminals. They had the idea of trying the 1550B to see if it could hold up to this kind of use — and it did.

Methodology

To conduct the tests, a technician connects across spark gap terminals. Then, the technician puts the 1550B in ramp mode and sets it for the 5 kV range. The next step is to ramp it up from zero to see that the spark gap "fires" (a spark jumps across the terminals) at 3 kV. If it doesn't jump the gap, he adjusts the gap until it does. If it does jump the gap, he adjusts the gap until it doesn't and then re-adjusts the gap until 3kV jumps it (setting 3kV as the trigger point, rather than having a gap that could be jumped by a lower value).

Capacitor tests

Fermilab technicians use the 1550B to conduct standard tests on high voltage capacitors and cables. They use the MegOhm-Meter to ensure the capacitor will withstand a given voltage. For example, Adamus says, "We connect to the 1550B to the leads of a capacitor, briefly. If the cap is leaking or faulted, the 1550B will let us know. We can read the resistance on the scale or watch the discharge indicator on the meter."

Methodology

To conduct a voltage withstand test (not a capacitance test) on a capacitor, the technicians set the 1550B to somewhere near the rated voltage of the capacitor. They briefly apply this voltage across the capacitor and observe the 1550B display. A good capacitor will rapidly ramp up to a high resistance as it charges. Any behavior other than this indicates a defective capacitor. For example, a leaking capacitor won't charge properly and this is reflected in the resistance reading. After charging, the technicians use the 1550B to discharge the capacitor. But if the 1550B does not show a discharge occurring, this means the capacitor did not charge at all, or it failed to store its charge due to leakage.

Measuring power amps

The 1550B is also critical for ensuring uptime of the power amps in each acceleration tunnel. As the power amps age, they develop problems. Adamus says, "They can develop internal shorts, and water leaks can short the screen circuit. We need to catch those problems before they interrupt important research." Because Fermilab uses particle acceleration, there is also some particle damage to associated cables and connectors. It's a bit like having cables running inside a sandblasting machine — eventually, the particles take their toll.

Adamus says, "We'll start getting faults and failures in the system. We break the connection midway — at the modulator — in the classic divide-and-conquer troubleshooting problem isolation method. Then, we hi-pot the amplifier cable back into the acceleration tunnel with 5 kV. If we measure in one direction from the mid-point and don't see high megohms, we know the problem lies in that direction."

If they determine the fault is in the tunnel, they need to ask for downtime. They then need to keep applying the "divide and conquer" technique until they isolate and identify the problem. The technicians must enter the tunnel with test equipment during short windows of time between experiments. They need to carry a portable high-potential tester to isolate the various components to quickly find and fix the problem. "We can't drag a 4-ft tall, 250 lb corded hi-potter into the tunnel," Adamus says.

View of Tevatron in A-Sector inside the Main Ring Tunnel

The battery power of the 1550B makes it particularly desirable in cramped work areas, where time is also a pressing factor. Before the 1550B, Fermilab technicians had to do the troubleshooting by visual inspection. Usually, the damage is visible, but finding it that way is time-consuming. With the 1550B, they shorten troubleshooting significantly.

Testing buswork

Buswork consisting of 1/4 inch thick copper beams carries 2500A into the tunnel. The Booster accelerator alone has eighteen 2500A power supplies. Adamas and the other technicians use the Fluke 1550B MegOhmMeter to "look for the resistance between these bars and anything grounded. These power supplies must be maintained off of ground potential."

Methodology

The 1550B measures resistance to ground at 1 KV, which provides a more than adequate voltage envelope for the power supplies. To conduct the test, the technicians set the 1550B to 1 kV. They measure between adjacent bars and between bars and nearby grounded objects (such as support brackets). The meter should show infinite resistance.

Other Fermilab machines that require components to be maintained off of ground potential include the Tevatron, the Linac (Linear Accelerator), the Main Injector and a variety of supporting rings that produce and store anti-protons.

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