TOOLS TO CONTROL LARGE SUPERCONDUCTING COLLIDERS

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Abstract
Fermilab's Tevatron accelerator is a cryogenically cooled four-mile ring of superconducting magnets that controls a 980 GeV beam. Superconducting magnets are expensive and take time to replace. To protect the magnets, Fermilab developed Quench Protection and Abort systems. To protect the people who maintain the magnets, Fermilab implemented ODH policies. This paper discusses these problems.

1. INTRODUCTION

Fermilab is a U.S Department of Energy (DOE) research laboratory, operated under DOE contract by Universities Research Association (URA). The Fermilab accelerator complex added the Tevatron, a cryogenically cooled particle accelerator, into its chain of accelerators in 1983. The Tevatron was constructed in Fermilab's Main Ring tunnel, a ring four miles in circumference. The accelerator is a separated function synchrotron that raised the operating energy of Fermilab from 400 GeV to ultimately 980 GeV.

2. IMPACTS

One of the first impacts we saw in operating the new accelerator was that the cycle time increased. The Main ring's cycle time ran at 8 seconds while the Tevatron runs between 60 and 200 seconds depending on the mode of operation. This longer cycle time meant that when tuning you had a much longer wait to find out whether your change was successful. The experimenters didn't mind the slower rep rate because the duty factor in which they received beam increased dramatically with the slower rate (1 second flat top Vs a 23 second flat top).

When tuning the Main Ring it was often quicker to intuitively adjust the tune rather than make a careful calculation of what you wanted changed. But since the Tevatron's tuning rate was so much slower it made more sense to actually figure out how much you wanted to move the beam before making an adjustment. In addition, the sensitivity of the superconducting magnets to beam losses meant you could not use the Main Ring technique of whacking the beam back and forth.

3. CRYOGENIC MAGNETS

The second, and by far the biggest, impact to operating a cryogenic accelerator was that these magnets could easily fail if the conductor went from superconducting to non-superconducting. The Tevatron magnet coils have a cross section of approximately 12 square mm. We run 4380 amps through this conductor. If the coil remains superconducting (no electrical resistance) then everything is fine and happy. But if the coil warms up so that the conductor develops a resistance, that high current will cause the conductor to fail. This is expensive, and worse it takes a week to replace the magnet.

4. PROTECTION & ABORT SYSTEMS

To protect against these kinds of failures, the Tevatron group had to develop a quench protection system to look for magnets that are to go non-superconducting. They came up with the Quench Protection Monitoring system, QPM for short. Some of the requirements for the QPM system were as follows:

- To get rid of the beam (initiate a beam abort) in a safe manner
- To turn off the power supplies and remove the energy from the magnets before the magnet failed
- To monitor itself and ensure that it was always on line and protecting the magnets
- To allow easy troubleshooting
- To quickly show what triggered the quench system. (The QPM contains a circular buffer where measurements of magnet behavior are recorded. When the QPM system senses a quench, the circular buffer is stopped, which allowed us to back up into time and figure out what caused the quench.)

Understanding what causes and, more importantly, how to avoid quenches are vital to Operations. Our biggest quench problem is caused by beam scraping. Uncontrolled beam losses, due to scraping, will warm the Tevatron magnet so that it’s no longer superconductive. In this situation, rather than waiting for a quench, it is preferable to quickly abort the beam into an external dump. Our Abort system has similar requirements to the QPM system:

- When triggered by losses or equipment failure, the abort system fires a set of single-turn kickers that remove the beam safely and quickly
- To quickly diagnose aborts. (Each Beam Position Monitor and Beam Loss Monitor talks to a circular buffer that store positions and losses through out the beam cycle. When the abort fires, all circular buffers for the BPMs and BLMs stop. This allows us to look back at the Tevatron orbit and loss patterns around the entire ring and see what they were doing in small increments before the actual abort occurred.)

5. BENEFITS

One of the positive side effects of the superconducting magnets was that successful operation prevented us from dumping vast quantities of beam on the magnets. The TeV magnets demanded better tuning, and the QPM and Abort systems dumped the beam at spots we specified. As a result, the residual losses in the Tevatron were far lower than during the days when the Main Ring was the final stage of acceleration.

6. ODH PROBLEMS

There are other problems related to superconducting magnets. They require large volumes of internal magnet cryogens. If a cryogenic relief valve opens on one or more of the magnets there is a possibility that the cryogens will displace oxygen in the tunnel, possibly creating an oxygen deficiency hazard (ODH). The whole cryogenic system is considered to be a pressure vessel. (During the Tevatron’s design stage a considerable amount of attention had to be paid to this by various safety committees.) This in turn makes accesses into these beam enclosures complicated. Fixed oxygen alarms were required throughout the Tevatron beam enclosures.

Anyone accessing the Tevatron tunnel is required to take a personal oxygen monitor that will alarm whenever the oxygen levels get below 19.5%. They also must carry a small tank that will give them 5 minutes of air for escape.

A two-man rule became mandatory for all accesses.

The cryogens also required the laboratory's medical department to certify that all workers who enter ODH enclosures are medically qualified to do so. To this end, a database had to be set up and the Operations Department required use it to check training and medical approval records for every worker before allowing tunnel access.

In addition to all this, moving heavy objects above or around cryogenic components in the tunnel required additional procedures to prevent accidental rupturing of the insulating vacuum or puncturing cryogenic supply lines.

7. OTHER PROBLEMS

1. Four miles takes too long to walk and takes too much time transporting equipment around to complete work, or to interlock, especially when everyone is waiting for beam. So operators and technicians drive the ring in electric golf carts. After a safety analysis was performed and fixed bumpers were added around vulnerable areas to prevent colliding golf carts from rupturing cryo and vacuum systems.
2. Ground faults are much harder to locate unless a cryogenic magnet ruptures its insulating vacuum line and spews its insulation around to be noticed.
3. Vacuum is much harder to leak check in cryogenic magnet systems. The Vacuum technicians need to rely more on time of flight methods for locating vacuum trouble spots. The number of vacuum connections went up a factor of five from the conventional system to the cryogenic vacuum system.
4. If cryogenic magnets warm, cryo-pumping within the vacuum chamber can release contaminates into the vacuum system. These contaminates can then block the smaller apertures in the cryo system causing flow problems. The fix requires a warm up and a decontamination cycle for that part of the ring affected, which typically causes a week down time.
5. We have more rotating equipment, in the form of compressors and expansion engines that require constant attention and higher maintenance.
6. We are more susceptible to power outages. If our cryo equipment is not started within 30 minutes of a site wide power outage or glitch, we are down for a week while we purify and re-cool the ring. Thunderstorms have a much bigger impact on cryogenic accelerators than conventional accelerators.
7. Control software is more complex and sophisticated due to the complexity of cryo systems, power supply systems, and beam tuning controls.
8. Our cryogenic machines use helium for cooling purposes; it is a non-renewable resource. We have developed methods of capturing gas accidentally lost due to quenches and such, but we must be regularly resupplied.

8. RESPONSIBILITES

Operators must be trained to work with the fire department for response to any ODH emergency. This requires being medically approved to use the Self- Contained Breathing Apparatus (SCBA) provided by the Fire Department. In addition to all this, the use of cryogenics requires more training for Operations Department personnel due to its controls system.

9. CONCLUSION

Encourage the development of air temperature superconductors.

Cryogenic machines are much more temperamental than conventional machines. Our system uses helium, which is a non-renewable resource. Cryogenic machines require refrigerators, a cryogenics group for maintenance, sophisticated quench protection systems, more time to replace failed magnets, has a bigger impact on operations due to weather conditions, and a much more complex and expensive set of instrumentation is needed for efficient beam diagnoses. And finally, it takes more time to train operators to deal with cryogenic systems and procedures.