Cryo crash test

Particle physicists have the reputation that they need to smash things up in order to find out what they are about. Sometimes accelerator physicists get to smash stuff up, too: a group of engineers and technicians recently crash-tested a full cryomodule. They wanted to find out what the 12-metre piece of kit would look like if somebody happened to use the beam pipe as a stepladder, drive a tunnel vehicle into a flange or decide to rip out a vacuum pump.

A module-shaped crash test dummy in the test bench.

Helium escapes through a safety flap of the cash test cryomodule's safety valve which protects the 2K cavity helium volume inside the cryomodule against too much pressure. Click here to download the video (3.5 MB).

For those readers who don't have much patience: sorry, the module would not look much different from the outside — the test showed that they are rather robust. For all those who want to know more: here's more. The worst thing that can happen to a cooled cryomodule under vacuum is for the different vacuum systems to break down. Engineers and technicians from DESY experienced this in their cryomodule test bench CMTB by running five cycles of letting room air into the insulation layers and the beam vacuum. Their goal, apart from getting to know their module in a crisis, was to pass European pressure vessel regulations for later cryomodule mass production for the European XFEL (European X-Ray Free-Electron Laser). In addition, they were looking for valuable input for the final design of the XFEL cryogenic system.

“Well, there was a rather loud noise and a massive cloud of helium at the safety valves,” says Bernd Petersen, crash test initiator and head of the DESY group that runs superconductivity and cryogenics. The group had simply let normal room-temperature air stream through a large vacuum pumping port and the beam tube flange. They flooded two kinds of spaces: the insulation vacuum in the body of the cryomodule and the vacuum at the very heart of the beam, inside the cavities. A FLASH / XFEL /ILC cryomodule (their design is remarkably similar) has two thermal shields, one at temperatures between 40 to 80 K , the second at temperatures between 4.5 K to 8 K. Inside the thermal shields the superconducting accelerating cavities are sitting in a liquid helium bath at 2 K within a helium vessel. If air at room temperature — that's about 300 K warmer than the temperature of the cavities — flows into the container, it freezes out immediately by condensing on the cold surfaces. The condensation energy is transferred to the helium, which vaporises and expands immediately. Under these test conditions, the air enters the insulation or beam vacuum almost at the speed of sound — that's where the noise comes from.

Crash-testing the insulation vacuum caused only minor damages at the outer shells of the multi-layer insulation and the outer thermal shield. The cryomodule could be cooled down again immediately after the test, and the testers noticed no decrease in the cavities' operating performance.

So much for the insulating vacuum crash test. What about the core of the accelerator: the beam pipe and the cavities? The group was keen to find out what would happen to the cavities and especially how long it would take for the warm air to travel from one side of the module to the other. The surprising find: it would take as long as five seconds. “That means that, if the beam tube would be broken close to warm/cold transitions in the XFEL linac, in principle you have a few seconds to close beam tube valves to save as many cavities as possible,” explains Petersen, clearly surprised, and pleased, by the result. “The impact on the cryogenic system is also much smaller than estimated before in worst-case scenarios.”

The air that flows into the pure vacuum of the cavities freezes out on the cold surfaces, shrouding the inside of the cavities in a layer of snow. The feared shock wave did not come, neither did the cavities' delicate niobium crack or crumble; instead, every single cavity froze neatly after the other. As the experts expected, attempts to bring the cavities back to operation showed a severe decrease of the RF performance. But they concluded that nevertheless an event like like this would not stop a linac run completely as long as only a few cryomodules are affected.

The data from the crash tests and a few other related experiments are analysed now and will be published soon. The module will now be taken apart and checked for damage in the alignment. Four of its cavities, those that had performed well during its life in FLASH before becoming a crash test dummy, will be taken out, cleaned and reused. Petersen hopes that the team can run a similar test with another module of the latest XFEL design that has built-in alignment monitors. “All these test make us a lot more secure and relaxed about the XFEL cryogenic design and the later operation of the linac. We know now that even after an accident of this scale, we could simply pump the air back out and switch the machine back on.”

-- Barbara Warmbein