

Profiting from the long view

Andrew Hutton looks at lessons from “cryomodule centuries” of SRF performance.

We can measure and analyse accumulated superconducting RF (SRF) operating experience in broad, high-level terms using the “cryomodule century”, or CC. Ten cryomodules operating for a decade, or 50 of them operating for two years, yield 1 CC. In the past, Tristan at KEK and HERA at DESY each accumulated more than 1 CC, and LEP-II accumulated nearly 4 CC. KEK-B, Cornell, and the Tesla Test Facility/FLASH have each accumulated a large fraction of 1 CC. In addition, well over half of the world’s SRF operating experience has taken place at two US Department of Energy nuclear-physics facilities: ATLAS at Argonne National Laboratory and the Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab.

Although a mere 25 years old – including more than 15 years of running SRF in CEBAF – Jefferson Lab has, in this sense, accumulated many centuries’ worth of operating experience, about 6 CC. This experience has made it possible for CEBAF to operate at energies exceeding 6 GeV, 50% above its design energy. These energies resulted from a refurbishment programme that sought to improve the 10 lowest-performing cryomodules of the 42¼ installed at CEBAF. Refurbishment involved fixing problems in the SRF accelerating cavities inside the cryomodules, applying the latest advances in SRF science and technology. Each of the 10 refurbished cryomodules has performed at least 50% better than the best of the original complement – at two and a half times the original specification.

In Hamburg, the European XFEL project will in its first decade yield more than 10 CC, roughly comparable to today’s combined world total. The main linacs of the International Linear Collider (ILC), however, will require cryomodules for some 16 000 SRF cavities. ILC’s first decade will yield some 186 CC – more than an order of magnitude greater than the world’s present total or XFEL’s projected total. What challenges will confront those who seek to operate the ILC and other future machines over long periods?



Andrew Hutton. (Courtesy G Adams/Jefferson Lab.)

At Jefferson Lab, ILC’s order-of-magnitude scale-up calls to mind the SRF pioneering of CEBAF, itself an order-of-magnitude scale-up from seminal SRF R&D that was conducted mainly at Cornell, KEK, DESY, and earlier at Stanford University. In the effort to head off or pre-compensate for operational difficulties, CEBAF’s scale-up challenges included higher-order modes, overall reliability in a many-cryomodule system and the fact that the beams to be accelerated had distinct properties not previously engaged. Yet, even though these and countless other pre-operational questions were attacked, actual practice, year in and year out, has turned up much that was simply unforeseen, and was probably unforeseeable. As a result, in CEBAF’s decade and a half of operating, about 1.5 refurbishments have been necessary per CC. Extrapolated, that would imply about 30 per year for the ILC.

Of course, extrapolations about the ILC and other future SRF machines are inevitably subject to errors. For one thing, experience to date involves operating gradients significantly lower than those planned for the ILC (and for the XFEL, as well). And at CEBAF and other operating SRF machines, most of the post-construction problems have already been corrected. For example, in SRF cavity processing, future accelerator builders won’t

have to re-learn the value of high-pressure rinsing, which removes the performance limitation of field emission – and which is helping the ILC high-gradient R&D programme to achieve significantly higher accelerating gradients than past machines have reached.

But both the XFEL and the ILC will push the (current) state of the art just as CEBAF pushed the (then) state of the art. So it is certain that the problems that these future SRF machines are sure to encounter will be new and different. Nevertheless, past experience is all that we have, and we should try to learn from it. Despite the uncertainties, strategies for spares will need to be developed. To maintain the operating gradient, failure rates will need to be estimated. CEBAF had one cryomodule failure per CC, but the failures appeared only after the first 7 years, or the first 3 CC. The failures exposed flaws but new problems are surely coming. CEBAF has also had gradient degradation of 1% per year from new field-emission sites caused by particulates inside the vacuum system. In sum, from our experience, any SRF machine needs to plan for refurbishments at a rate of 1–2 per CC.

In current SRF accelerators, cryomodules are independent, standalone entities that can (with some difficulty) be pulled out for refurbishment. In future SRF accelerators, the need to minimize static heat losses pushes the design toward more integrated accelerator systems, even at the cost of making replacement harder. Yet if extrapolation from current operating experience is valid, it will be important to have the ability to refurbish, which means that it will be necessary to avoid having cryomodules that are difficult to extract. It’s the continuation of a longstanding design conflict: tight integration of systems improves performance, but makes repair harder.

SRF operating experience now has a long standing – many cryomodule centuries of it, in fact. This experience base constitutes an imperfect yet vital tool. And for all of us, there’s profit in looking back in order to see forward. *Andrew Hutton is Jefferson Lab’s associate-director for accelerators.*

Programmable DC Power

High Current Solutions



Genesys™ family

750W 1U Half rack to 15kW 3U full rack

Outputs to 600V and 1000A

Built in RS-232 & RS-485 Interface

Parallel Current Summing

Optional Interfaces: LXI Compliant LAN

IEEE488.2 SCPI Multi Drop

Isolated Analog

3 day expedited delivery on most models

High Voltage Solutions

a.i.e. family

Capacitor Charging: 1-50kV, 0.5-30kJ/sec

Continuous DC: 1-50kV, 0.5-50kW

Turn-key systems: 60kW-1MW+

Water and Air-cooled designs

Parallel Operation for Higher Power

Full Remote and Local Controls



N1471

Another Module of the New NIM Programmable HV Power Supply Family



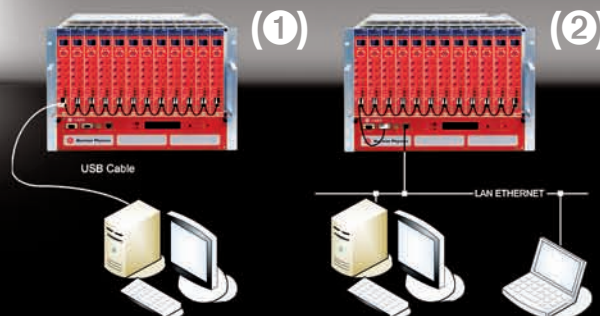
Can be a System!

- Remote control up to 128 channel
- Modules daisy-chained can operate in several Crate
- Optional Software Tool (SW1470) for remote control

Module control can take place either locally (graphic colour display) or remotely via USB (①) or RS485 (①).

It is also controllable via TCP/IP (②) through the Smart Fan Unit of CAEN NIM 8301 crate.

Suitable for Germanium detectors.



High Performance - Low Cost - Low Ripple - High Resolution

- 5.5kV 300 μ A (①); Ripple <5 mVpp (③)
- Selectable positive or negative polarity
- Very high current resolution (500 pA (②))
- Programmable ramp-up/ramp-down (1-500 V/s)
- Individual channel kill
- Interlock logic for board enable
- Under/Over-Voltage Status alarm
- Overcurrent and max. voltage protection
- SHV coaxial output connectors
- Common floating return

Model	# Ch	V Full Scale	I Full Scale	Vset/Vmon res.	Iset/Imon res.	Max Ripple
N1470/A/B	4/2/1	$\pm$ 8 kV	3 mA ^(①)	0.2 V	50 - 5 ^(②) nA	10÷30 mVpp
N1471/A/B	4/2/1	$\pm$ 5.5 kV	0.3 mA	0.1 V	5 - 0.5 ^(②) nA	5 mVpp ^(③)

(①) Max power: 9W (<3kV), 8W (>3kV) (②) Optional Imon x 10 zoom (③) @ 4kV/100 μ A