https://doi.org/10.1142/9789811278952_0025

Chapter 25

SRF Cryogenic Test Facility for the HL-LHC

L. Tavian[a], G. Vandoni[a] and W. Venturini Delsolaro[b]

[a]*CERN, ATS-DO Unit, Genève 23, CH-1211, Switzerland*
[b]*CERN, SY Department, Genève 23, CH-1211, Switzerland*

Several test stands were assembled for testing integrated operation of individual components with and without beam. Amongst these, at CERN, the SPS SRF test stands allows to qualify crab cavity modules with beam, while the test facilities situated in the SM18 buildings underwent important upgrades for testing SRF single-crab-cavities, SRF modules, superconducting cryomagnets and cold powering systems. Other test stands are available off-site in the framework of collaborations. This chapter describes the test facilities at CERN and presents a summary overview of the other test facilities outside of CERN.

1. Introduction

The HL-LHC requests that superconducting devices (RF cavities, magnets and links) to be individually tested prior to their final installation. For this purpose, existing test facilities have been upgraded and a new cryogenic test stand has been created to test crab cavities (Chapter 7) in operation with proton beams. Collaborations with external institutes have also boosted cryogenic test capability for the project, off CERN site. This chapter describes these different test facilities, with emphasis on the SPS crab cavity test stand and SM18 facilities and the list of off-site facilities.

2. The SPS SRF Test Stand

With the SPS stand aims to provide a test bench to explore the operational performance of superconducting RF crab cavities – and more generally, SRF cavities – throughout a wide range of proton beam parameters, as described in Table 1, under safe conditions for the equipment and the personnel.

Table 1. SPS beam parameters as used for the 2018 tests.

Energy	26 – 450	GeV	Coast energy	55, 120, 270	GeV
Intensity	$0.05 – 1.3 \times 10^{11}$	p/bunch	Bunch length	< 2.0	ns
RF Voltage	3.0 – 7.0	MV			
Long. emittance	0.35 – 0.5	eVs	Betatron tunes	26.12, 26.18	
$\beta_{x,y}$	40, 80	m	Dispersion	-0.5	m

The choice of long straight section 6 – a region dedicated to beam extraction to the LHC and North Area – was dictated by a conveniently large tunnel section, low radiation dose and the presence of a 15 m long free drift zone, close to the access tunnel. The advantages of the presence of a substantial underground technical alcove, a 20 tons freight lift with large spans and the BA6 surface technical hall were further assets. To minimize impact of the tests on beam time, infrastructure and services were designed to allow for full remote control. The SPS main RF is synchronized to the test bench RF via a 4 km, ~1 s delay long fibre optics link. The SPS beam instrumentation is used to monitor orbit centering, RF phase scans, bunch rotation.

2.1. *The test bench*

To overcome critical aperture restriction by the cavities for extracted beams and mitigate the potential detrimental impact of the cavities operation on the beam during normal operation, a motorized lateral translation table was designed as integral support of the test stand. The remotely steered table movement spans 51 cm with positioning reproducibility and precision of some microns. Two overhead rails hooked at the tunnel vault hold chain hoists for handling of heavy equipment (up to 4 tons) on the table during installation work.

The beam vacuum line is split into two branches by two Y-shaped articulated vacuum chambers fitted with highly flexible bellows: one branch has SPS standard round pipe for circulating and extracted beam, while the other connects to the beam vacuum of the cryomodule under test. Thanks to the articulated continuous vacuum line, the module is parked out of the beamline during regular operation and is transferred into the beamline during cavity tests without the need to break the beam vacuum. Vacuum valves sectorize the zone, separating cold from warm areas. Neighboring vacuum chambers are carbon-coated to reduce secondary electron emission and thus mitigate electron cloud and related pressure increase. Two button beam position monitors are inserted in the cryomodule vacuum sector. The cryomodule rests on the transfer table via three jacks allowing for positioning range of ± 4.5 mm.

Space economics and equipment modularity directed the choice of cryogenics towards a displaceable helium refrigerator, with movable compressor and cold-box connected to a fixed distribution system. The cold-box, installed underground in a technical alcove, is fed by warm helium gas from the surface compressor and boosted to 7 g/s liquefaction rate by liquid nitrogen from a vertical transfer line. Liquid helium is conveyed to the proximity cryogenics equipment of the cryomodule via an 80 m transfer line flanked by 2 valve-boxes. Connection to the ancillary distribution unit on the moving table is via flexible lines. Refrigeration up to 3.5 g/s at 1.9 K is attained with two large pumping units located close to the test stand.

Two Inductive Output Tubes (IOT) of 60 kW cw, installed in the surface building, supply RF power to the two cavities via coaxial transmission lines. Flexible connection to the cavity power couplers on the cryomodule and ancillary RF charges and circulators is achieved via two V-shaped RF transmission lines with rotating joints.

Cryomodule instrumentation, in particular the frequency scanning interferometric position monitoring of the cavities, is connected with flexible yet robust cables and optical fibers, bundled and protected to follow the table movement. Few water lines for RF charge-and-circulator cooling are also conveyed from the distributed SPS water supply lines to the transfer table via flexibles.

An integrated set of interlocks protect the equipment and the SPS. It is thus impossible to set the table into movement if the vacuum valves are not closed, protecting the SPS against leaks from the dynamically stressed vacuum bellows. Likewise, the position of the table dictates the beam permit or the beam extraction command. Protection of personnel against cryogenic hazard in an elsewhere warm machine is ensured by a distributed network of oxygen deficiency detectors. The SPS access system steers also the interlocking of RF power to the cavities, to eliminate the risk of exposure to X-rays.

In the future, the test stand could be easily upgraded to test superconducting magnets in proton beams.

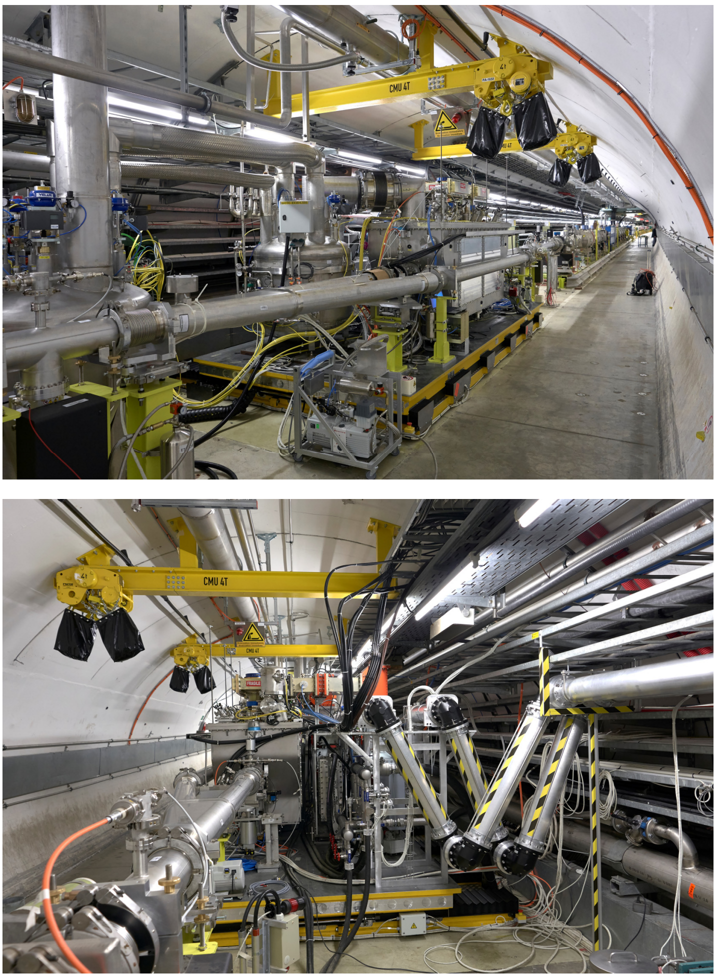

Fig. 1. The SPS SRF test stand, seen from upstream (top) and downstream (bottom).

3. The SM18 SRF Test Stand

The SM18 facility hosts also a large, fully equipped superconducting RF preparation and testing area. The SRF facilities comprise a 254 m^2 complex of clean rooms, staged from ISO5 to ISO4 class, partially joined in a cascade of communicating spaces and equipped with a high pressure ultra-pure water rinsing cabinet with rotating and translating nozzle, delivering up to 1 m^3/hr of 18 MOhm-cm water at 100 bar. The four vertical cryostats for single cavity testing and 2 large bunkers for cryomodule testing, are entirely screened in concrete for radiation protection. An accelerator-grade access system ensures the protection of personnel. The test benches, connected to the cryogenic system of SM18 via an underground transfer line, share a large preparation area equipped with supporting structures for the cryostat inserts. The vertical cryostats can operate between 4.5 K and 1.9 K. They feature earth magnetic field compensation, presently in upgrade, pumping systems and vacuum diagnostics in dust-free, slow pumpdown mode, and Oscillating Superleak Transducers and Transition Edge Sensors for second sound detection. The two bunkers are connected to RF power systems – one klystron of 300 W and solid-state amplifiers up to 20 kW. SRF cavity locking is achieved by means of modern digital LLRF systems based on self-excited loops, as well as on traditional phase locked loops. All remote control and testing equipment for each of the 4 cryostats and the two bunkers is located in a dedicated control room.

4. The Test Facilities for Cryomagnets and Cold Powering Systems

The current CERN cryogenic test facilities located in the SM18 buildings, designed for the series test of LHC superconducting devices, have been upgraded to fulfil the new HL-LHC needs. A new test bench allows for vertical tests of magnets at nominal current (up to 20 kA) before their final integration. In addition, five existing LHC horizontal test benches will be upgraded by increasing their test current up to 20 kA and by adapting their mechanical interfaces to the new HL-LHC cryomagnets. One existing LHC horizontal test bench will be upgraded, increasing its test current to 20 kA and adapting their mechanical interfaces to the cold powering assemblies of the superconducting link, more detail in Chapter 10. The existing test bench used to qualify the superconducting link demonstrators will be upgraded for the individual qualification tests of the series of HTS current leads. In order to fulfil the test rate of the HL-LHC series components in parallel with the test of the Inner Triplet String (see Chapter 24), the installed helium liquefaction capacity has been increased from 750 to 1800 l/h by adding a new liquefier.

In the framework of collaborations, cryogenic test stations are available in different institutes for testing superconducting magnets and RF crab cavities. Table 2 list the different test facilities available for the qualification of HL-LHC devices (see also Chapter 26).

Table 2. Available test facilities.

Test facility location	HL-LHC devices	Test conditions*
CERN SPS	RF crab-cavity cryomodules	at 7 MV and 2 K with proton beam
CERN SM18	Q2A & Q2B magnets	at 20 kA and 1.9 K (V)
	Q1, Q2A, Q2B & Q3 cryomagnets	at 20 kA and 1.9 K (H)
	D1 and D2 cryomagnets	at 13 kA and 1.9 K (H)
	Corrector magnet packages	at 0.2 - 2 kA and 1.9 K (H)
	SC links and current feed boxes	at 0.6 - 20 kA and 4.5 - 300 K
	Current leads	at 0.6 - 20 kA and 20 - 300 K
	Cold diodes	at 20 kA and 4.5 K
	RF crab-cavity cryomodules	at 7 MV and 2 K (H)
	Dressed crab cavities	at 7 MV and 2 K (V)
US FNAL	Q1 & Q3 cryomagnets	20 kA and 1.9 K (H)
US BNL	Q1 & Q3 cryomagnets	20 kA and 1.9 K (V)
US JLAB	Dressed crab cavities	at 7 MV and 2 K (V)
Canada TRIUMF	RF crab cavity cryomodules	at 7 MV and 4.5 K (H)
Japan KEK	D1 magnets	at 13 kA and 1.9 K
Sweden FREIA	Q2 & CP corrector magnets	at 2 kA and 1.9 K (V)
	Dressed crab cavities	at 7 MV and 2 K (V)
Italy INFN	D2 magnet models and prototypes	at 13 kA and 1.9 K (V)
	CP corrector magnets	at 0.2 kA and 4.5 K (V)
China IMP	D2 corrector magnets	at 0.6 kA and 4.5 K (V)
France CEA	Q4 model	at 16 kA and 1.9 K (V)

* Horizontal test (H), Vertical test (V)