IOP Conference Series: Materials Science and Engineering

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To cite this article: A Perin *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **278** 012112

IOP Conf. Series: Materials Science and Engineering **278** (2017) 012112 doi:10.1088/1757-899X/278/1/012112

Upgrade of the cryogenic infrastructure of SM18, CERN main test facility for superconducting magnets and RF cavities

A Perin, F Dhalla, P Gayet and L Serio

CERN, Technology Department, 1211 Geneva 23, Switzerland

E-mail: antonio.perin@cern.ch

Abstract. SM18 is CERN main facility for testing superconducting accelerator magnets and superconducting RF cavities. Its cryogenic infrastructure will have to be significantly upgraded in the coming years, starting in 2019, to meet the testing requirements for the LHC High Luminosity project and for the R&D program for superconducting magnets and RF equipment until 2023 and beyond. This article presents the assessment of the cryogenic needs based on the foreseen test program and on past testing experience. The current configuration of the cryogenic infrastructure is presented and several possible upgrade scenarios are discussed. The chosen upgrade configuration is then described and the characteristics of the main newly required cryogenic equipment, in particular a new 35 g/s helium liquefier, are presented. The upgrade implementation strategy and plan to meet the required schedule are then described.

1. Introduction

Superconducting magnets and superconducting Radio-Frequency cavities are essential components of CERN current and future particle accelerators. For the development of the required technologies and for testing the operational devices at cryogenic temperatures, CERN operates a number of facilities, ranging from individual component tests to the final validation of the full scale magnets and cavities before installation. SM18 is the largest of these facilities, dedicated mainly to testing large magnets and superconducting RF cavities as well as other specific devices [1]; this is for example where the dipole and quadrupole cryo-magnets of the LHC were tested in 2002-2007 [2-5]. In addition to cryogenic testing SM18 is also a major area for conditioning and integrating the RF cavities before installation in the accelerator facilities

The High Luminosity LHC (HL-LHC) project [6], will use new superconducting magnets and superconducting “crab” RF cavities. The development of these new devices requires first an extensive R&D program and then full tests of the series produced items before installation into the LHC. In addition, it is planned to perform a type test of a full scale string of the final focusing triplet of magnets for the HL-LHC (HL-LHC string). All these tests are planned to be performed in SM18; the ramping up of the testing requirements has already started and will accelerate from 2019 with the planned test and installation of new 11 T dipole magnets in 2020 [7]. In parallel, SM18 also provides the cryogenics for testing various devices and components like superconducting links, current leads, superconducting cables and diodes as well as other specific experiments for cryogenics research or physics.

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2. SM18 layout and test systems

The SM18 complex is located on the French territory part of CERN, next to the Meyrin site of CERN. In addition to the main test hall (SM18) it includes also several buildings for cryogenic equipment, electrical infrastructure and cooling water. Figure 1 shows an overview of the SM18 complex. The main SM18 building, with dimensions of 120 m x 60 m is where the test systems and most of the low temperature part of the cryogenic infrastructure and the purification system are located. Building SH18 houses parts of the room temperature cryogenics infrastructure (compressors, warm pumping units) and building SW18 contains electrical equipment (transformer, power converters), the pre-cooling/warmup helium compressors and the demineralized water cooling stations.

2.1. The existing cryogenic infrastructure of SM18

The cryogenic infrastructure supplies liquid helium at 4.5 K and provides a low pressure helium pumping capacity for systems operating in superfluid helium at 1.8 K – 2 K Table 1 lists the main components of the cryogenic infrastructure and Figure 2 shows a schematic view of its main elements and of the main test systems installed in SM18.

Liquid helium is produced by a Sulzer/Linde cold box with a capacity of up to 25 g/s of liquid helium in liquefaction mode. The liquid helium is supplied to a 25 m^3 dewar operating at 1.6 bar and is then distributed to the test benches through several valve boxes and cryogenic lines.

Several test systems need to operate in superfluid helium at temperatures below 2 K: this is achieved by lowering the pressure on a saturated helium bath (directly in contact with the tested device or through a heat exchanger). The low pressure warm pumping system includes three low pressure pumps (WPU) with a combined flow of up to 12 g/s with corresponding heaters to warm the cold helium flow.

For faster cooling and warming of heavy devices, like superconducting magnets weighing up to 30 tons, SM18 is equipped with two helium Cooldown-Warmup Units (CWU). These units are cooled by

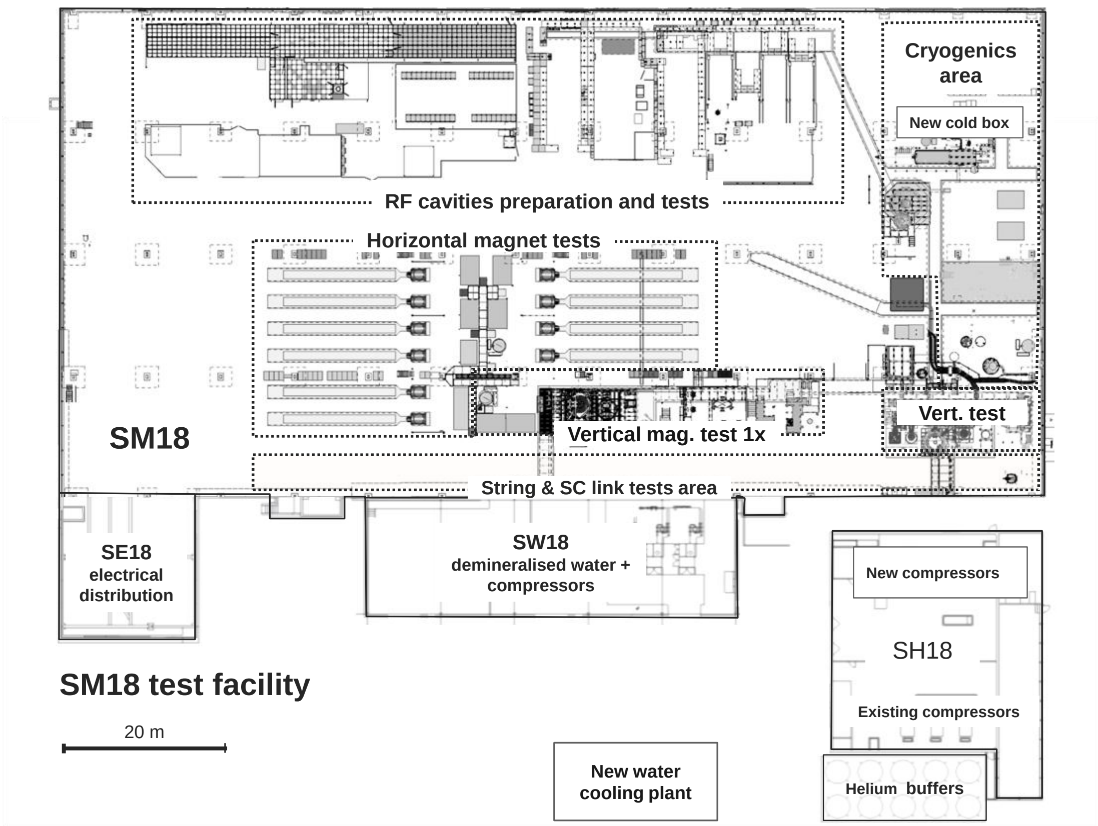

Figure 1. Layout of the SM18 complex, showing the main test and support areas.

Table 1. List of the main components of the existing cryogenic system of SM18.

System	Description
Refrigeration	
Cold box	6 turbines, 25 g/s of liquid helium in liquefaction mode. 6 kW equivalent @4.5 K with LN_2 boost.
Compression station	3 He compressors (350 g/s @ 19 bar), 1.6 MW electrical power + Oil removal system
Low pressure Pumping	
2x Warm Pumping unit	2x 6 g/s at 12 mbar, 2 x 32 kW heaters
Pre-cooling to 80 K & warming up	
2x LN2 CWUs	LN2 cooled, 2x 120 kW at 80 K
3x compressors	3x 78 g/s at 13 bar
He purification system	
5x Low pressure balloons	5x 80 m^3 at 1 bar
3x HP compressors	3x 130 NM^3/h at 200 bar, 40 kW
2x HP purifiers	200 NM^3/h at 150-180 bar
Helium storage	
Liquid helium	1x 25 m^3 liquid helium storage at 1.6 bar, 1x 10 m^3 mobile
Room temperature	9x 80 m^3 at 18 bar
LN2 supply	2x 50 m^3 tanks

LN_2 and the circulation of helium is performed by dedicated compressors with each a maximum flow of 78 g/s at a pressure of 13 bar; each unit can extract up to 120 kW at 80 K and is also equipped with a 200 kW helium heater for the warmup phase.

Due the constant connection/disconnection of new equipment to the cryogenic system, the returning helium frequently includes a significant amount of impurities; this impure helium is managed by a purification system that includes five low pressure balloons, three high pressure compressors and two purifiers that have a combined purification capacity of 200 Nm^3/h.

2.2. Existing and future test systems

Table 2 lists the main test systems present in SM18: magnets can be tested on multiples test benches down to 1.9 K either fully assembled in the form of complete cryo-magnets on horizontal test benches or as "naked" cold masses in recently installed vertical cryostats [8]. Cavities can also be tested as fully assembled cryo-modules or as "naked" cavities both at 4.5 K and 2 K [9]. In addition the tests benches for complete devices, test benches for measuring superconducting cables, diodes and current leads are also operated in SM18.

Starting in 2017, it is planned to add tests systems for superconducting links (superconducting cables inside of a cryogenic line) for HL-LHC [10], both for prototype tests and for the validation of the series systems. The first of these systems is being installed in 2017 and further adaptation of existing benches for this task is planned for the period 2018-2021.

The installation of a full scale string of the final focusing inner triplet magnets of the HL-LHC project is planned for 2021. This will require a dedicated cryogenic distribution system and specific modifications of the operation that are not completely defined as the test program for the HL-LHC string is currently being finalized.

3. Cryogenic requirements

A study was performed in 2015-2016 to determine the cryogenic requirements for the future test program and to identify the possible capacity limitations, based on existing data and estimated testing rates.

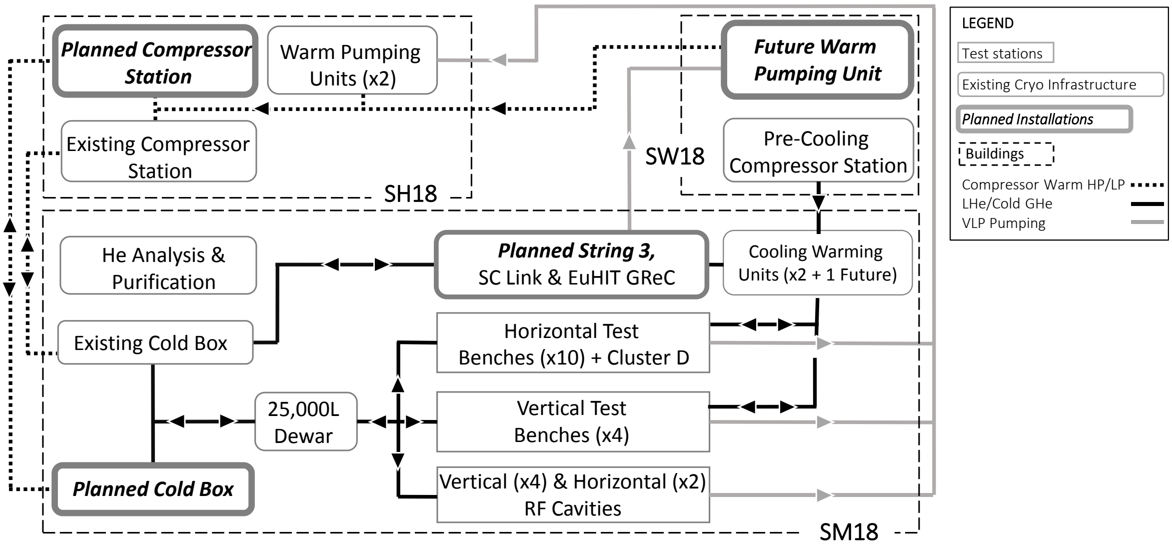

Figure 2. Overview of the main components of the SM18 cryogenic test facility.

The main test programs that will run in SM18 in the coming years are shown in Table 2. The baseline requirements were defined on the basis of the foreseen test plans and on the estimated loads. After this analysis, the retained assumptions needed for covering the requirements for the main test benches were:

- Magnet test benches: 2 vertical and 2 horizontal magnets cold tested / month with 2 magnets powered simultaneously.
- Superconducting Cavities: 1 cavity test/2 weeks in vertical test benches and 1 cryomodule test every 6 month in horizontal test benches.
- Parallel test of a superconducting link and/or the IT String
- Possibility of additional individual systems tests on dedicated facilities

Table 2. List of the main test systems of SM18.

Test System	Description	Status
Horizontal magnet test benches (x10)	Tests of SC cryo-magnet @1.9 K, up to 13 kA, max. 15 m long	operational
Vertical magnet test benches (x4)	Tests of magnets in vertical cryostats @1.9 K, up to 20 kA	operational
Test station for current leads and diodes	Testing of current leads and diodes up to 20 kA	Operational
RF cavities test benches (6x)	4 vertical: 2x at 4.5 K and 2x at 2 K	Operational
	2 horizontal: 1x at 4.5 K and 1x at 2 K	Construction
Superconducting links test bench	Tests of superconducting links, supercritical helium supply.	Construction
HL-LHC string	Tests of a string magnets for HL-LHC	Planned 2021
High Reynolds test bench	System for performing tests at high Reynolds numbers	Operational

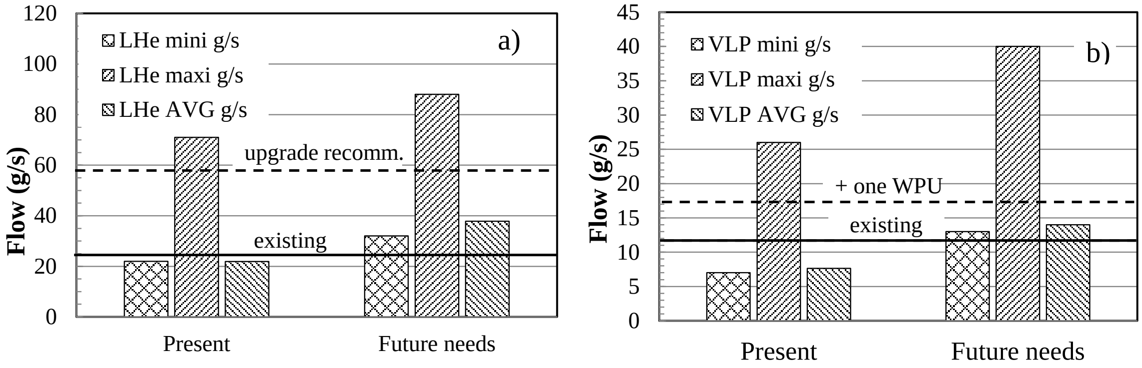

Figure 3. Baseline testing requirements for liquid helium supply (a) and for very low pressure pumping (b).

The cryogenic requirements for each test were validated by benchmarking against measured values during a one month period. Figure 3 shows the present and future requirements based on these assumptions.The graphs show the minimum requirements (mini) while running only the low consumption test benches (no special tests), the maximum requirements while running all the test benches without any restriction and the average value calculated using the above assumptions averaged on a one month period. The estimated future average requirements are 14 g/s for the low pressure pumping and 38 g/s for the liquid helium supply. A baseline design overcapacity of 50 % (58 g/s) on the requirement for liquid helium is considered necessary to be able to carry out the full test program with no constraints from the LHe production (e.g. unplanned tests, repeated tests and components with low performance), guarantee the testing of the superconducting links and operation of the HL-LHC string while not limiting the tests of magnets and cavities testing and ensuring an acceptable flexibility for the long term testing program. For the pumping capacity, the line shown in the graph corresponds to the addition of one WPU unit (6 g/s). The definition of a recommended future upgrade for the low pressure pumping is discussed later in this article (see §4.2).

The future requirements as a function of time, based on the test program available at the time of the study (mid 2015) and on the estimated loads for each test system, were plotted and compared to possible upgrades. The results of this study for the liquid helium supply is shown in Figure 4. As can be seen, an upgrade of 35 g/s, in addition to the existing capacity, guarantees to fulfil the requirements even during the peak load period starting in 2021.

Table 3. List of the main tests to be performed in SM18 in the period 2017-2023.

Test program	Period
Validation of spare devices	permanent
R&D magnets & cavities for HL-LHC	present - 2023
R&D and series tests for SC links	present – 2022
HL-LHC string of magnets	2021 - 2022
Other R&D and measurement	permanent

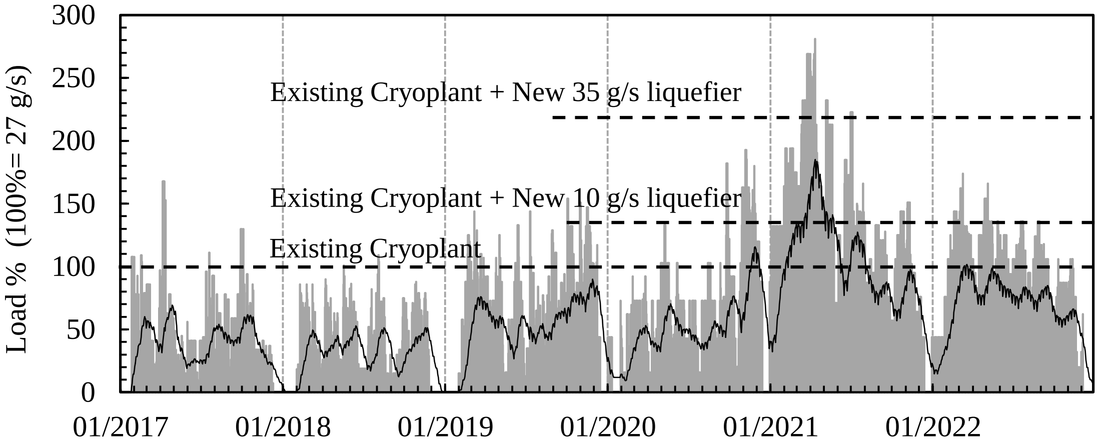

Figure 4. Estimated liquid helium requirements for the period 2017-2022. Daily values (bars) and 30 days moving average (line). 100% is the currently installed capacity of 27 g/s.

4. Upgrade of the cryogenic infrastructure

4.1. Upgrade of the liquid helium supply

The study of requirements shows that an increase of the helium liquefaction capacity of about 35 g/s is necessary to not impose limitations on the test program. However, as such an upgrade represents a significant investment, an additional study was performed to evaluate the impact, in terms of cost reduction and potential delays, of more limited upgrades of the liquefaction capacity of 25 g/s and 10 g/s. The study is based on published cost estimators [11] and recent experience. Figure 5 shows the results of the evaluation. The analysis shows that with a significantly smaller upgrade of 10 g/s, the cost could be decreased by about 50%, but this would generate a yearly delay of more than a month, which is not acceptable. With a 25 g/s upgrade, the cost would be reduced by about 10% but with a significant risk of delay to the HL-LHC program.

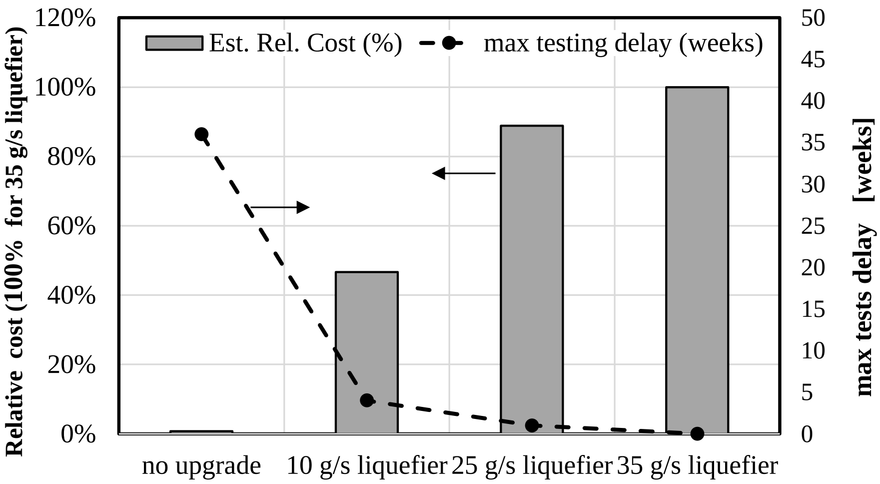

Figure 5. Evaluation of the impact on cost and maximum delay to the test program of additional liquefaction capacity of 10g/s, 25 g/s and 35 g/s. The cost is relative to the baseline configuration with a 35 g/s liquefier.

Following the study it was decided in early 2016 to launch the procurement of a new 35 g/s helium liquefier to be operational at the end of 2019. An order for the fabrication of this liquefier has been placed with an industrial contractor in the first half of 2017.

4.1.1. Characteristics of the new 35 g/s liquefier. The new liquefier has been specified for a maximum capacity of 35 g/s to comply the peak demand but, as can be seen in Figure 4, most of the time a lower capacity is required. Therefore the technical specification requires the new liquefier to be designed for an optimal efficiency at a liquefaction rate of 17.5 g/s while limiting the maximum electrical power at peak capacity to 1.5 MW. The compressor station of the new plant will be installed in available space in building SH18 and the cold box will be installed in the main SM18 building.

It is envisaged to use the new liquefier as the main source for liquid helium for the SM18 test benches and to dedicate the existing refrigerator mainly to special testing programs like the HL-LHC string. The infrastructure will be configured to ensure a full redundancy for the liquid helium supply.

4.2. Possible upgrade of the low pressure pumping system

The identified average requirement for the very low pressure pumping capacity is 14 g/s, to be compared with the current capacity of 12 g/s. However the value taken into account for the requirements of the HL-LHC string were not completely finalized and new high load test benches are under commissioning; this results in some uncertainty in the future pumping requirements. In view of this uncertainty it has appeared premature to take a decision on a possible upgrade for the existing WPUs: the approach is to plan all the necessary utilities and space reservation in the framework of a global upgrade of the utilities of SM18 to have the possibility to add a WPU a later stage. A formal decision on the upgrade is expected in 2017.

4.3. Upgrade of other cryogenic systems

The unknowns concerning the HL-LHC string test program have delayed the final decision on the upgrade of other cryogenic systems. With the currently performed evaluation the possible envisaged upgrades are: an additional CWU dedicated to the HL-LHC string with its associated infrastructure and additional warm buffers. A formal decision on the upgrade is expected in 2017.

4.4. Upgrade timeline

The specification for the new 35 g/s liquefier was issued in September 2016. The delivery of the liquefier is scheduled for April 2019, with an operational capability in the fourth quarter of 2019. The decision concerning the complete upgrade is expected to be taken in 2017. The full upgrade is planned to be operational by the end of 2020.

5. Conclusions

A study was performed to determine the requirements for the SM18 cryogenic infrastructure due to the intensifying test program required by CERN new projects after 2019 and beyond. The study showed that an increase of 35 g/s in the peak liquefaction capacity is necessary to comply with the new requirements. The study also showed the possible necessity to upgrade the low pressure pumping capacity, but the uncertainty on the requirements has not yet allowed to validate this upgrade. Possible other upgrades include an additional cooldown/warm-up unit for the HL-LHC string and additional helium warm storage buffers. Following the outcome of the study, a new optimized 35 g/s liquefier has been ordered in 2017 and will be installed in April 2019. With the planned upgrade, fully operational in 2020, the SM18 cryogenic infrastructure will comply with the testing requirements of the HL-LHC project and with future CERN R&D programs.

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