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Status and commissioning results of the helium refrigerator plant for the European XFEL

L. Blum[1], H. Wilhelm[1], B .Petersen[2],T. Schnautz[2]

[1] Linde Kryotechnik AG, Daettlikonerstrasse 5, 8422 Pfungen, Switzerland

[2] Deutsches Elektronen Synchrotron DESY, Notkestrasse 85,22607 Hamburg, Germany

E-mail: lars.blum@linde-kryotechnik.ch

Abstract. The European XFEL project is under construction at DESY in Germany. The superconducting XFEL linac is supplied by the XFEL helium refrigerator plant. This plant consists of two existing refrigerators, which were in service for the HERA storage ring until 2007. Since the XFEL linear accelerator requires cryogenic cooling at 2K, the existing cryogenic infrastructure had to be modified. Two of the three existing HERA helium refrigerators were required to cover the design heat load of the XFEL-linac. The refrigerator infrastructure was extended by a 2 K cooling loop, whose main component consists of a string of four cold compressors generating approximately 1.7 kW isothermal cooling capacity at 2K. The step by step commissioning and extension of the accelerator as well as the future upgrade option of the heat load demanded an extremely high turn down ability, a particular challenge for 2K cold compressor strings. The commissioning of the helium refrigerator infrastructure is underway and should be completed soon. The current status of this project, commissioning results and particular challenges are presented.

1. Introduction

The new scientific infrastructure project at the German Electron Synchrotron (DESY) in Hamburg, Germany, the European X-ray Free Electron Laser (XFEL), has been presented in previous publications [1-3] in detail. In the first part of the XFEL, high energy electrons are produced in a superconducting linac, which requires cryogenic cooling at 2 K. The existing cryogenic infrastructure at DESY servicing the Hadron-Electron-Ring-Accelerator (HERA) was designed for providing cryogenic cooling at 4.5K and consequently had to be modified in order to meet the new requirements.

In 2011 Linde Kryotechnik AG was awarded to engineer, procure, install and commission the XFEL helium refrigeration plant based on an economical process and plant concept. Two of the three existing HERA helium refrigerators were required to cover the design heat load of the XFEL-linac. The existing refrigerator infrastructure was overhauled, modified and extended by a 2 K cooling loop, whose main component consists of a string of four cold compressors generating approximately 1.7 kW isothermal cooling capacity at 2K. Details of the conceptual design have been reported previously [4,5].

The commissioning of the helium refrigerator infrastructure is underway and should be completed very soon. The current status of this project, commissioning results and particular challenges are presented.

2. Process and plant layout

The demand for an economic process and plant concept resulted in the lowest possible total cost of ownership, i.e. an optimization of capital and operational expenditure. The two existing 4.5K helium refrigerators were reused in order to lower the investment. New equipment was required for the cryogenic distribution system, consisting of the interconnecting transfer lines and a distribution box DB54, and the cold compressor box CB44 (c. figure 1). The two 4.5K helium refrigeration systems and the distribution box DB54 are located in the refrigeration hall, whereas the cold compressor box CB44 and the superconducting linac are located 150m away underground in the XFEL tunnel.

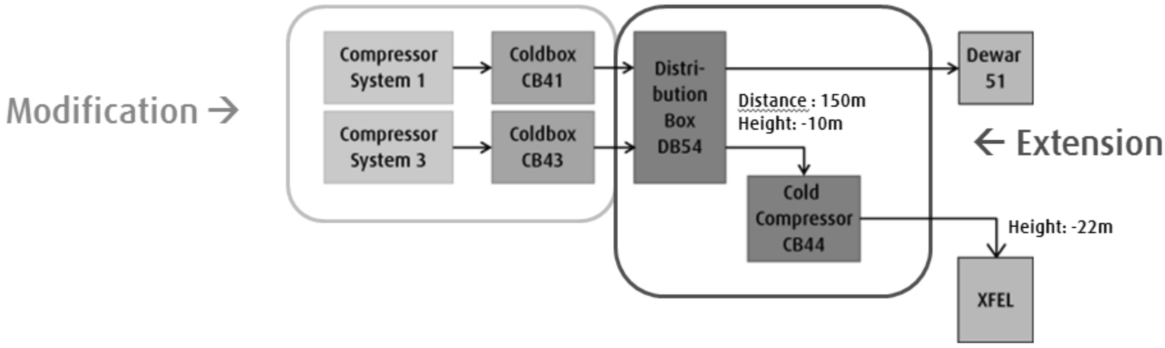

Figure 1. Simplified block diagram of the XFEL helium refrigeration system.

The process layout of the two identical 4.5K refrigeration coldboxes was modified to integrate the additional 2K circuit, to meet the new heat load requirements at the different temperature levels as well as to improve the coefficient of performance and consequently to lower the electrical power consumption. Details of the modifications have been presented previously [4]. The current configuration of the equipment had to be designed for the so-called 17.5 GeV case, as listed below in table 1 (given with and without margin).

Table 1. Heat load specification for the XFEL helium refrigeration system.

Cooling loop	Unit	Case 17.5 GeV		Case 20 GeV
		w/o margin	with 50% margin	with 50% margin
2K isothermal	kW	1.46	1.90	2.46
CC string	g/s	74.0	96.0	143
5-8K Shield	kW	2.40	3.59	4.15
40-80K Shield	kW	16.0	23.9	30.0

However, a possible future upgrade of the linac to 20 GeV had also be to be considered leading to higher heat loads, as shown in table 1. The adaption of the XFEL refrigeration system to the higher heat loads is possible without having to cut and weld equipment, i.e. it is possible by minor modifications of valves and cold machines only. The latter components are able to cover this requirement by considering the maximum load case for the overall design. In order to improve efficiency and turn down ratio of the 17.5 GeV case, easily exchangeable parts like flow parts were designed for this latter case.

3. Commissioning concept

The commissioning and performance testing of this complex cryogenic helium installation demanded for a step by step start-up and commissioning of each sub-system, starting with the individual compressors and continuing these works downstream the system until the cold compressor box CB44 was fully integrated in the operation of the complete helium refrigeration system.

The commissioning procedure was divided into three phases, where phase 1 was related to the over-atmospheric part, including the 4.5 K helium coldbox system and the distribution box DB54 with attached testbox. In phase 2 the previous setup was extended including now the cold compressor box CB44 located directly next to the DB54. In phase 3, CB44 was moved down to the XFEL tunnel at its final location and connected to DB54 by a 150m long transfer line.

4. Results

4.1. Performance of over-atmospheric part system

During phase 1, the validation of the over-atmospheric part system included the performance demonstration of each individual 4.5K helium sub-system. The individual loads were simulated by test heaters equipped at the individual circuits. The two shield loads could be simulated directly. The performance of the 2K circuit was simulated without the CC-string, i.e. the 2K supply was fed to the simulation heater, which warmed the helium gas up to the discharge temperature of the CC string, which is about 25 K. The results of these measurements are listed in table 2 below. The benchmark for this case was set to the 17.5 GeV loads without safety margin. The expected performance was obviously exceeded.

Table 2. Comparison of expected and measured performance.

Cooling loop	Unit	Case 17.5 GeV (w/o safety margin)	Measurement	
			CB41	CB43
2K isothermal	kW	n.a.	n.a.	n.a.
CC string	g/s	74.0	99.9	99.9
5-8K Shield	kW	2.40	2.71	2.77
40-80K Shield	kW	16.0	18.3	18.0

4.2. CC pump down performance

The CC pump down performance was demonstrated during Phase 2 after having set up the controller parameters. Due to the fact that the test box was directly attached to the CB44, the volume of the CC suction was very small. Any instability in the 2 K circuit has direct feedback to the CC suction with negligible damping, a very high benchmark for the performance of the controller setup of the CC string. The result of the CC string start up and pump down is presented in figure 2 below. Note that the small volume is pumped within short time. With the XFEL linac connected, the pump down will take longer.

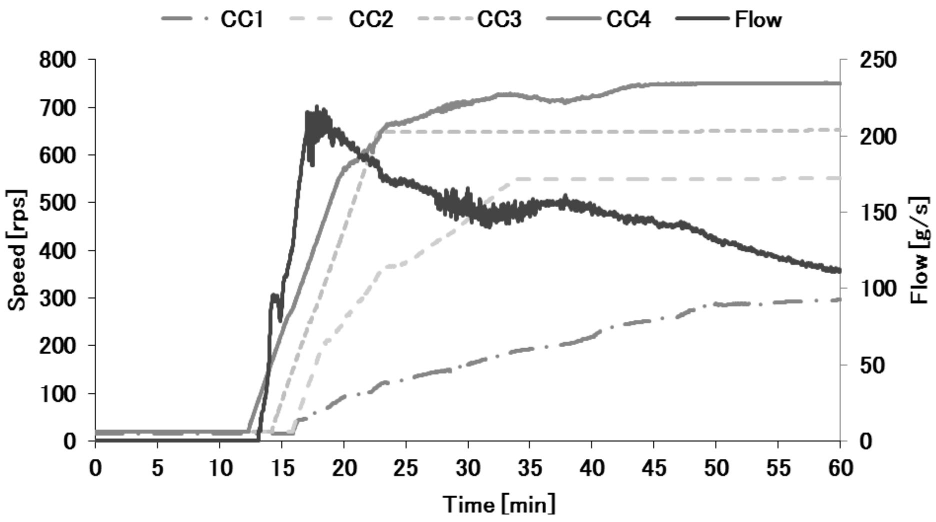

Figure 2. Flow and CC speed trends during pump down.

4.3. Performance of the complete refrigeration system

During phase 3 of the commissioning, all the equipment was in its final location. At the connection of CB44 to the XFEL downstream system, a test cap including simulation heaters was installed. It shall be noted that the 2K heat exchanger is not in the current scope. The 2K supply is fed to the simulation heater and finally lead to the CC suction.

At first, only one 4.5 K helium refrigerator was performance tested in conjunction with the cold compressor box CB44. The test results are shown in table 3 below. Each system was able to exceed the benchmark case, which was case 17.5 GeV without safety margin.

Table 3. Comparison of expected and measured performance.

Cooling loop	Unit	Case 17.5 GeV (w/o safety margin)	Measurement	
			CB41	CB43
2K isothermal	kW	n.a.	n.a.	n.a.
CC string	g/s	74.0	99.6	99.9
5-8K Shield	kW	2.40	2.79	2.77
40-80K Shield	kW	16.0	18.1	18.0

Subsequently the complexity of the system was increased and the two 4.5 K helium refrigerators were operated in parallel in conjunction with the cold compressor box. There are two critical paths with this system setup: At first, the guaranteed performance has to be demonstrated and secondly the control concept has to be efficiently balance the two individual 4.5 K refrigerators, which are directly connected at their cold end to service the individual cold circuits. The application of a cascade control to each string was the key to succeed in the latter critical item. In table 4, the result of the performance test with regard to the guarantee case is summarized. Obviously, the guaranteed performance was exceeded by far.

Table 4. Comparison of guaranteed and measured performance.

Cooling loop	Unit	Performance	
		Guaranteed	Measured
2K isothermal	kW	(1.90)	-
CC string	g/s	96	106.6
5-8K Shield	kW	3.59	4.00
40-80K Shield	kW	23.9	25.9

An additional important performance guarantee is related to the pressure stability at the CC suction, a feature which is particularly important for the efficiency of high performance cavities in linac systems. The specification required the pressure instability for 24 hours to be less than 2% within a pressure range of 24 to 31mbara. Considering the small volume upstream of the CC suction, the challenge for the controller setup is even harder. In Figure 3 a pressure trend and its instability analysis are presented. The result was able to cover the expectation: The measured pressure instability was better than the expectation of 2% within 24 hours.

A further important test was performed to demonstrate the turn down capability of the refrigeration system. Due to the step by step start-up and addition of cryo-modules within the XFEL linac, the helium refrigeration system will have to provide a fraction of the guaranteed performance only. In table 5, the turn down mode using mixed cycle is presented. Thereby the discharge pressure at the CC is lowered to 720 mbara or better, the suction pressure at the warm compressor is lowered. The complete flow from the 2 K loop is fed to the CC, compressed and injected to the 4.5 K helium refrigerator. The result presents that the 2 K flow can be reduced by 30% along the CC string, by using mixed cycle mode.

In a second case, the flow at CC discharge was partially returned to the CC suction by using a CC bypass. The flow along the CC string is not reduced, however the turn down capability is much broader than in the case before. The flow from the 2 K load can be reduced to 11 g/s by simultaneously maintaining the overall pressure ratio along the CC string. This result is significant in terms of enabling the continuous operation of the CC string when having to turn down the 2 K loop return flow. This case represents the first stage of the XFEL commissioning when the injectors are present only.

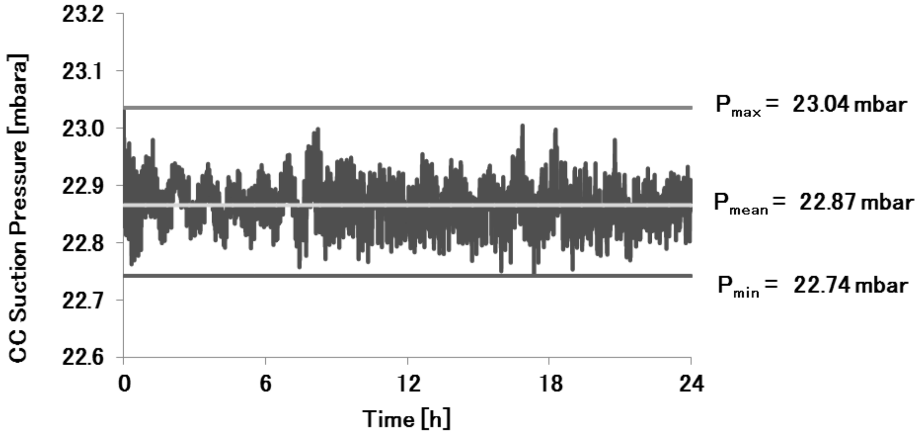

Figure 3. Pressure trend at CC suction and instability analysis.

Table 5. Turn down modes and capabilities.

Cooling loop	Unit	Turn down	
		Mixed Cycle	Bypass Operation
2K loop	g/s	75.0	11.0
CC string	g/s	75.0	101
CC discharge pressure	mbar	720	1100
5-8K Shield	kW	3.15	0.0
40-80K Shield	kW	20	1.0

5. Conclusion

Most of the performance tests of the XFEL helium refrigeration system were successfully completed and impressive results could be presented. The last function tests and the demonstration of the long term reliability over 800 consecutive hours have to be performed. It is expected to conclude the commissioning soon.

Acknowledgement

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