Available online at www.sciencedirect.com
ScienceDirect
Physics Procedia 67 (2015) 868 – 873
Physics Procedia

25th International Cryogenic Engineering Conference and the International Cryogenic Materials Conference in 2014, ICEC 25–ICMC 2014

XFEL injector-1 cryogenic equipment

E. Pyata[a] *, L. Belova[a], T. Boeckmann[b], M. Kholopov[a], V. Konstantinov[a], V. Kulikov[a], D. Sellmann[b], A. Zhirnov[b], N. Zolotukhina[a]

[a] *Budker Institute of Nuclear Physics BINP, Novosibirsk, 630090, Russia*
[b] *Deutsches Elektronen-Synchrotron DESY, Hamburg, 22607, Germany*

Abstract

Two accelerator cryomodules will be delivered for the XFEL injector-1. It comprises: an end cap of the 1.3 GHz cryomodule, a feed cap with Joule-Thomson box of the 3.9 GHz cryomodule, a feed box, a valve box and a transfer line connecting the feed cap with a feed box. The first injector will be located at the minus 7th level of XTIN. At this level the end cap, two accelerator cryomodules and the feed cap with the Joule-Thomson box are placed. The feed box and the injector valve box will be located at the minus 4th level. The cryogenic supply of the first injector`s accelerator cryomodules are separated from the supply of the second injector`s cryomodules and linac in the main tunnel.

Peer-review under responsibility of the organizing committee of ICEC 25-ICMC 2014

Keywords: cryogenics; superconducting accelerator modules; XFEL; linac

1. Introduction

The European X-ray Free Electron Laser XFEL linac consists of two parallel injectors, a booster section, two bunch compressor sections and the main linac cryomodules [1]. The injectors are intended to deliver the beam to the boosters and the main linac. Only one injector system will be installed within the present first stage of the project. Space is foreseen for a second, parallel injector system, located directly above the first one, which could be used

* E.Pyata. Tel.: +7-383-329-4594; fax: +7-383-330-7163.
E-mail address: e.e.pyata@inp.nsk.su

Peer-review under responsibility of the organizing committee of ICEC 25-ICMC 2014
doi:10.1016/j.phpro.2015.06.146

later to increase the uptime of the facility for the benefit of the users. The main components of the injector are an RF gun, from which a visible laser extracts electron bunches, which are then subject to a high accelerating gradient; a system of accelerating cavities 1.3 GHz and 3.9 GHz which accelerate the electrons up to 120 MeV; and a series of focusing and diagnostic equipment to ensure the necessary beam quality.

The injector cryogenic system is designed to supply the cryomodules of the first injector with 5 K helium mass flow as well as cooling with 40 K helium mass separately from the supply of the cryomodules in the main tunnel.

2. Description of the XFEL injector cryogenic equipment

The XFEL injector cryogenic equipment (XICE) will be supplied with cold helium from the XFEL linac valve box (XLVB). XICE has to provide the following operation modes of injectors:

- stand-alone operation of each injector; the main linac is warm;
- stand-alone operation of each injector (in pulse mode); the main linac is cold;
- two injectors operation (each injector in pulse mode); the main linac is cold;
- cool down/warm up independent from the other injector (warm or cold) and the linac (warm or cold).

For the continuous operation of two injectors, 50 g/s of 5 K helium mass flow as well as 20 g/s 40 K helium mass flow are needed. The liquefaction rate of 16 g/s is necessary for covering the refrigeration requirements at 2 K. The 2 K liquid helium will be supplied by isenthalpic expansion of the 4.5 K helium, which will be sub-cooled to 4.5 K before expansion by means of a heat exchanger for fluid sub-cooling. A cold compressor system will therefore be used to lower the helium vapour pressure to 31 mbar.

The XICE is designed in a modular structure and consists basically of two 'layers'. The structure of XICE is shown in Fig. 1.

The cryogenic supply is subdivided into two 'layers' in order to operate the injectors independently from each other, to avoid air condensation on cryogenic valves during exchange and installation of modules, and to reduce the consequences of leaky valves. For each cryogenic circuit one valve is placed in the injector valve box and the other in the related feed box. As a result all cryogenic supply and return tubes are separated by two cryogenic valves in series from the cryomodules of each injector.

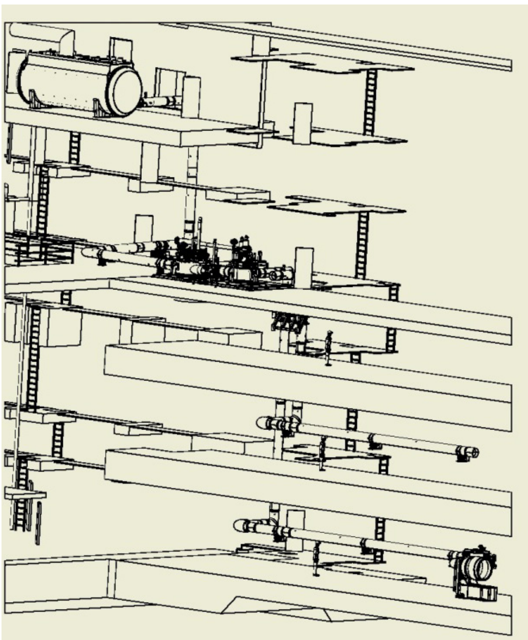

Fig. 1. The structure of the XFEL injector cryogenic equipment.

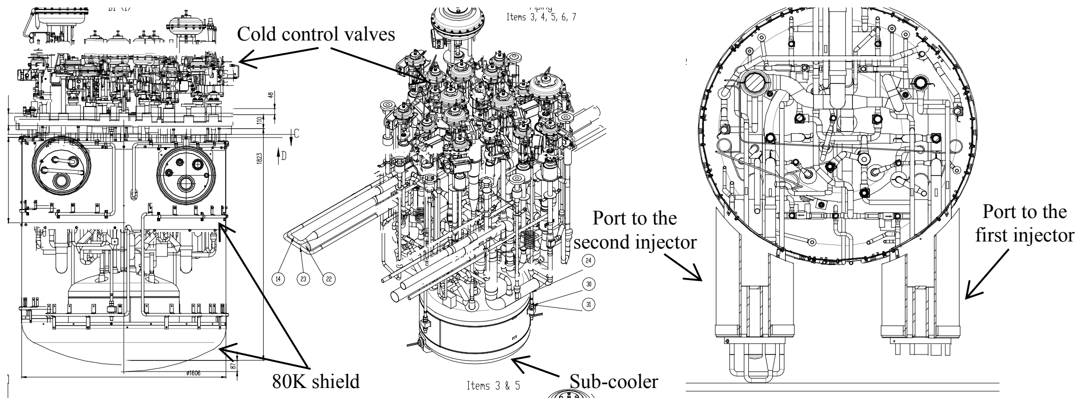

Fig. 2. The views of the injector valve box.

The XFEL injector valve box (XIVB) houses a 4.5 K LHe sub-cooler vessel to compensate for heat losses of upstream cryogenic components for all operation modes of injectors and to cool a 5.16 K forward flow down to 4.45 K. The injector valve box is connected to the feed box XI1FB of the first injector and the feed box XI2FB of the second injector. By the transfer line XI1TL the feed box XI1FB is connected to the feed cap XI1FC representing the second layer of the injector's structure. By the transfer line XI2TL the feed box XI2FB is connected to the feed cap XI2FC representing the second layer of the injector's structure too.

3. Design of injector cryogenic equipment

The design of the cryogenic equipment, calculation of the mechanical loads, stresses and heat loads were done at BINP according to DESY requirements as it has been done in the design of the test benches for XFEL cryomodules [2]. The boxes include vacuum vessels, a supporting structure, 80 K thermal shields with multiple layers insulation, pipework and valves for the cold circuits, cold terminals for connections of transfer lines, transfer lines, helium relief valves, pipework and valves for warm circuits, pipework and valves for purge circuits and instrumentation [3], [4].

3.1. XFEL injector valve box

The XFEL injector valve box is intended to sub-cool the 5 K helium supply from the XLVB distribution box to 4.5 K and to distribute the sub-cooled 4.5 K helium as well as the 40 K helium gas supply from the XLVB to the two injectors. The 4.4 K vaporized helium from a LHe storage vessel of the XIVB and 80 K return gas from the injectors will be collected and fed into the 4.5 K and 80 K return pipes respectively. The 3D models and cross sections of the valve box are shown in Fig. 2.

XIVB contains a LHe storage vessel with a heat exchanger placed at the bottom of the vessel for sub-cooling the supercritical helium flow in order to provide stable operating conditions in supplying the injectors with ~4.5 K helium. The sub-cooler vessel has a total volume about 300 litres.

The design of the LHe storage vessel includes the related components as the heat exchanger, the device for preliminary phase separation, the heaters, the LHe level gauges and other instrumentations.

To optimize the amount of metal hoses needed to compensate for the forces in all operating modes of the valve box cold mass calculations were made by the program Caesar II. The optimized layout of the cryogenic lines is shown in Fig. 3. Similar calculations were performed for all pipe lines of the boxes, cold and warm transfer lines.

3.2. XFEL injector feed box

XI1FB transfers the sub-cooled 4.5 K helium as well as the 40 K helium gas supply from the XIVB valve box to the first injector. 3D models and main parts of the feed box are shown in Fig. 4.

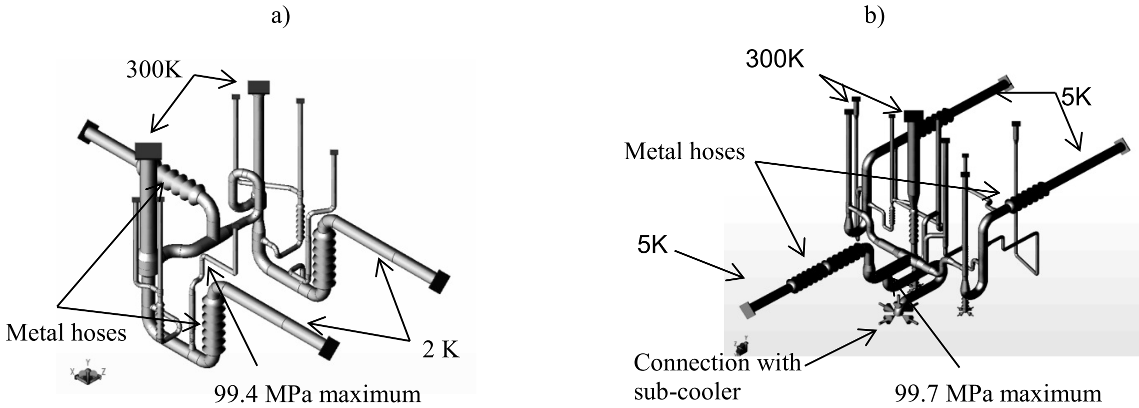

Fig. 3. The calculation of stresses of the 2 K return pipe line at a tested pressure of 5.72 bar and temperature 2 K (a); and the 5 K return pipe line at a tested pressure of 28.6 bar and temperature 5 K (b).

3.3. XFEL injector feed cap transfer lines

The XFEL injector feed cap transfer lines connecting the feed boxes with the XFEL injector feed caps supplies the caps with helium for the 4.5 K and 40 K circuits. The transfer lines contain the following internal pipes: DN20 4.5 K go pipe, DN50 5 K return pipe, DN20 40 K go pipe, DN20 80 K return pipe, DN150 2 K vapour return pipe.

All pipes are surrounded by a thermal shield manufactured out of aluminium. The 80 K return pipe which serves as a shield cooling line is attached to the shield so as to ensure good thermal contact. The inner pipes are supported within the vacuum shell with a minimum of thermal load and friction (e.g. G11 structure and support balls), see Fig. 5.

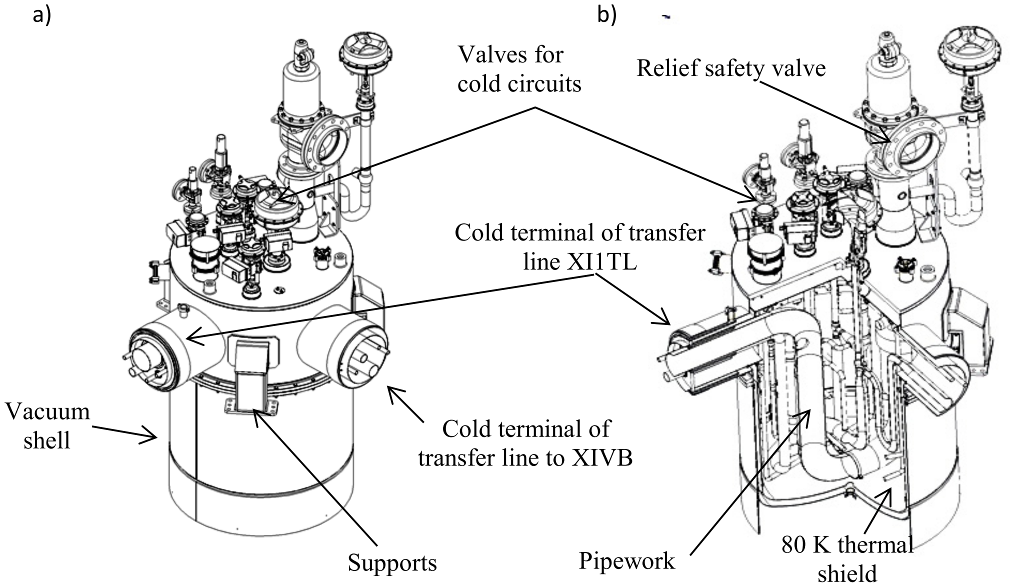

Fig. 4. 3D models of XFEL injector feed box in assembly (a) and with angle cross section (b).

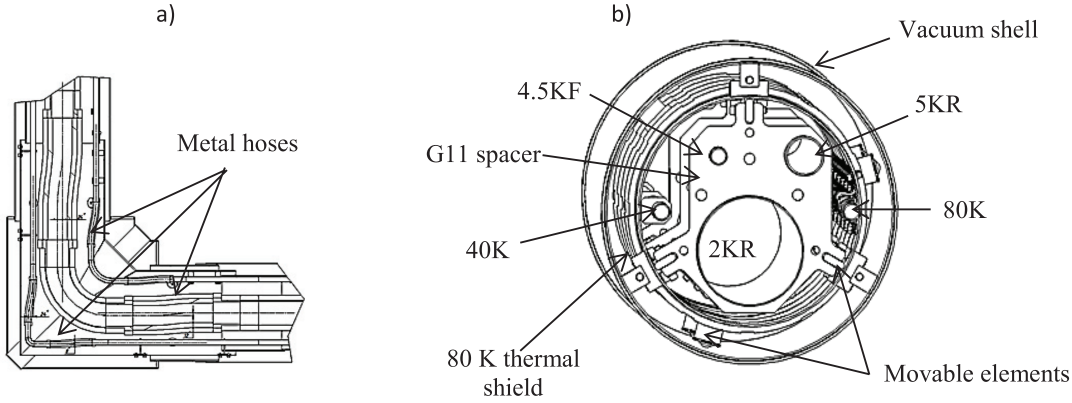

Fig. 5. Longitudinal section of the angle part (a) and cross section of the injector transfer line (b).

The assembly consisting of all internal pipes and the shield is surrounded by a DN450 vacuum shell. All process pipes can be abruptly cooled down from room temperature to operating temperature, or abruptly warmed up from operating temperature to room temperature, independent from each other.

The support system of the transfer lines including fixed, sliding-springs supports and vertical pendants is designed to compensate loads for all operating conditions and accidents. Stresses and deformation of injector transfer line for an incident case at which liquid helium 4.5 K misses into the protected vacuum of XITL and the vacuum shell temperature of about 80 K. are shown in Fig. 6.

3.4. XFEL injector end cap and feed cap

The XFEL injector feed cap (XI1FC) represents an interface between the XI1TL transfer line and the injector accelerator module string. XI1FC includes the feed cap, JT box as well as the L-shaped transfer line connecting the JT box to the feed cap.

The JT box is intended for throttling the 4.5 K forward flow to the 2 K forward flow and supplying cool down and warm up flow of the accelerator module string.

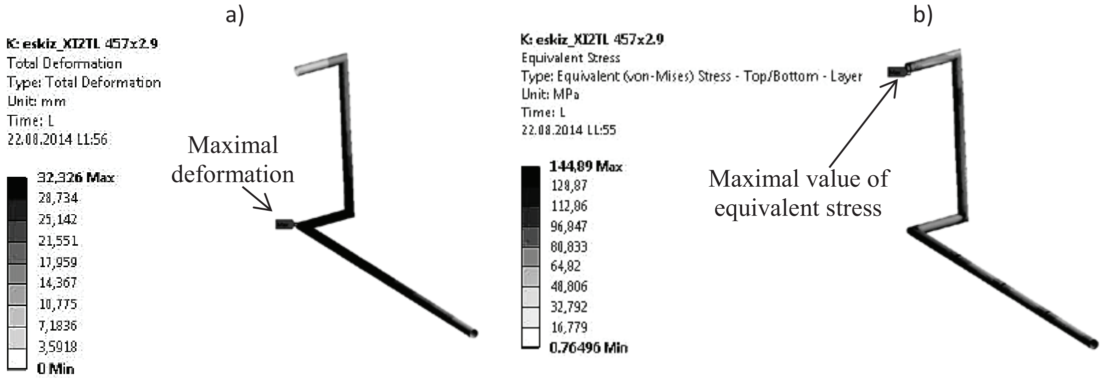

Fig. 6. Deformations (a) and stress (b) of XI2TL transfer line for an incident case.

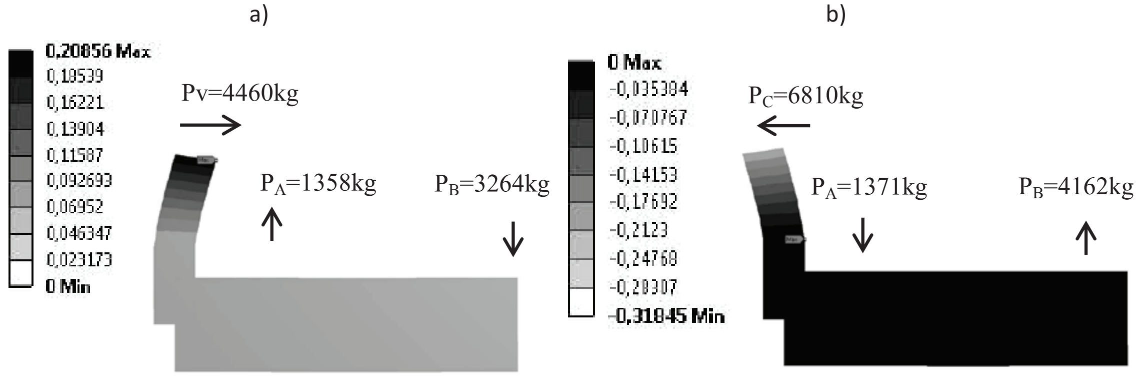

Fig. 7. The calculated deformations of the support when pumping (a) and in the case of a breakdown at P=2.2 bar (b).

The end cap is intended for completing the cooling circuits by short circuiting the process pipes, and for closing the vacuum volume of the accelerator module.

Calculations of forces and loads of the supports of the injector end cap and feed cap are shown in Fig. 7. A source of the forces in the injector Feed Cap, End cap and modules is pressure acting on the flexible components (as bellows and metal hoses) both in the system cryogenic pipe lines and in the vacuum vessels. In this case, the forces are determined by the product of the effective bellows cross-section area by the pressure value in the pipe lines and vacuum vessel with respect to the atmospheric pressure. We have developed the construction components of the supports which compensate these forces.

The adjustment possibilities of the supports are ± 12 mm in vertical and transversal directions and ± 8 mm in longitudinal direction.

4. Conclusion

The design of all components of the XFEL injector cryogenic equipment is completed by BINP. The transfer lines, feed cap with JT-box and end cap were delivered to DESY and installed in January-April 2014. The injector feed cap and end cap were adjusted relatively to each other and to the beam axis with an accuracy better than ±0.5 mm. This equipment is presently under going pressure and vacuum tests. The last part of the equipment will be delivered and mounted in the XFEL buildings by the end of 2014.

References

1. Y. Bozhko, Lierl, H., Petersen, B., Sellmann, D., Zolotov, A., "Requirements for the Cryogenic Supply of the European XFEL Project at DESY," in *Advances in Cryogenic Engineering 51B,* edited by J.G. Weisend II et al., AIP Conference Proceedings, Melville, New York, 2006, pp. 1620-1627.
2. Y. Bozhko, Anashin, V., Belova, L., Boeckmann, T., Kholopov, M., Konstantinov, V., Petersen, B., Pivovarov, S., Pyata, E., Sellmann, D., Wang, X.L., Zhirnov, A., Zolotov, A., "Test stand for testing serial XFEL accelerator modules," in *Advances in Cryogenic Engineering* AIP Conference Proceedings; Vol. 1434 Issue 1, p1100-1107 (2012).
3. T. Böckmann, Clausen, M., Gerke, Chr., Prüß, K., Schoeneburg, B., Urbschat, P., "New Process Controls for the HERA Cryogenic Plant," in *Advances in Cryogenic Engineering 55B,* edited by J.G. Weisend II et al., AIP Conference Proceedings, Melville, New York, 2010, pp. 1205-1212.
4. P. Ryan, Datskov, V., Kirby, G., Bottura, L., Perez, J.C., Borgnolutti, F., Jenninger, B., "Precise Thermometry for Next Generation LHC Superconducting Magnets," Applied Superconductivity, IEEE Transactions on, Volume:24 , Issue: 3, Article #9000905, ISSN 1051-8223, (2014).