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TEST STANDS FOR TESTING SERIAL XFEL ACCELERATOR MODULES

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ABSTRACT

The superconducting accelerator module is the key component of the European X-ray Free Electron Laser (XFEL) project to be built at DESY Hamburg. The XFEL linear accelerator will consist of 100 accelerator modules in order to produce pulsed electron beam with the energy of 17.5 GeV. All accelerator modules have to be tested after the assembly and before being installed in the accelerator tunnel. The tests will take place in the Accelerator Module Test Facility (AMTF) being constructed at DESY. Besides test stands for testing superconducting cavities and magnets constituting the accelerator modules, AMTF will come with three test stands for testing the completed accelerator modules. This paper describes layout of the test stands within the AMTF, cryogenic design of the test stand, design issues of principal components and schedule.

KEYWORDS: Cryogenics, test facilities, superconducting accelerator modules

INTRODUCTION

The European X-ray Free Electron Laser (XFEL) is under construction at DESY since June 2007. The XFEL superconducting linear accelerator will produce pulsed electron beam with the energy of 17.5 GeV [1] and will consist of nearly 800 superconducting niobium 1.3 GHz nine cell cavities. Eight cavities and one superconducting magnet package will be assembled in one accelerator module representing an accelerating unit of

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the linear accelerator. Each accelerator module is 12 m long. The cavities and magnets will be cooled in a liquid helium II bath at 2 K.

In total about 100 accelerator modules will be required for XFEL. All superconducting components of the accelerator modules as well as the completed accelerator modules shall be tested in order to use the test results as a feedback into the series production. For the test purposes the Accelerator Module Test Facility (AMTF) is under construction at DESY. The AMTF will comprise one test stand for testing the magnets [2], two vertical test cryostats for testing the cavities and three test stands for testing the accelerator modules [3]. These test facilities are contributions from Poland (Wroclaw University of Technology - WUT), Russia (Budker Institute of Nuclear Physics - BINP) and Germany (DESY) to the XFEL Project.

The XFEL Cryomodule Test Bench (CMTB) for testing prototypes of the accelerator modules is in operation at DESY since 2006 [4]. The experience gained during the tests was taken into account by DESY while preparing technical specifications for the AMTF test stands. The design and manufacturing works for all three test stands are taken over by BINP.

LAYOUT OF THE TEST STAND

All three test stands look similar except some minor differences. Within the AMTF test hall, the area of 12.4x48.6 m² is allocated to each test stand and comprises RF, test and mounting areas and the cryogenic supply (FIGURE 1).

The RF area includes mainly a modulator, a pulse transformer and a vertical klystron. The klystron produces radio frequency of 1.3 GHz and 5 MW output power. This power is delivered to the test area by wave guides placed inside a floor channel. In order to protect the environment from being spoiled by oil contained in the transformer, the transformer as well as the modulator and the klystron is placed inside an oil sump.

The mounting area serves for preparation of the delivered accelerator module for tests and for attaching the individually tuned waveguide distribution system to the tested accelerator module before its transportation to the XFEL tunnel.

The test area is surrounded by concrete shielding for establishing radiation safety in the test hall. The shielding is made of ore loaded concrete blocks 3 m high and 0.8 m thick. One concrete block in the front side of the shielding is designed as movable one. The block is placed on rails extending to the test and mounting area. The test area within the shielding includes a support structure, feed box, end cap, feed cap and waveguide distribution system for delivery of RF power to each of 8 main couplers of the accelerator module. The feed box is supplied with 5/8 K and 40/80 K helium circuits from a valve box via a connecting

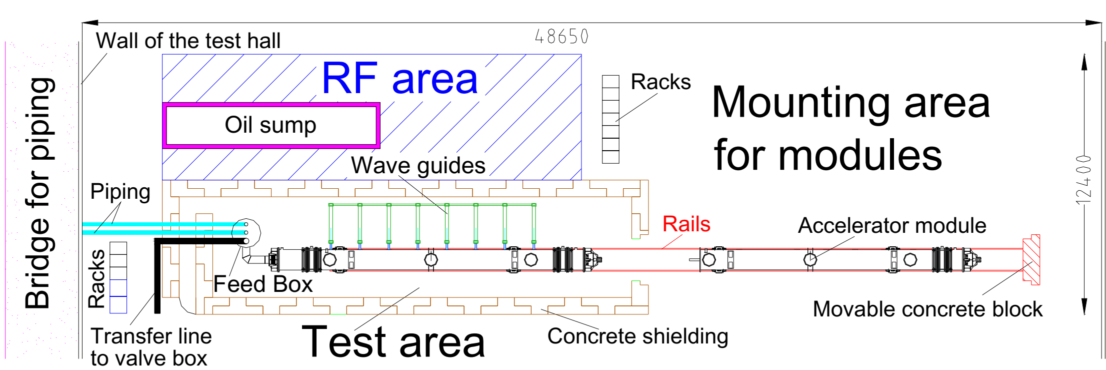

FIGURE 1. Layout of one test stand within the AMTF test hall.

transfer line. The feed cap is connected to the feed box by an L-shaped transfer line and supplies the 2 K, 5/8 K and 40/80 K cryogenic circuits to the module.

A bridge for piping is placed outside the test hall and carries piping necessary to supply the feed box with helium at ambient temperature. The piping is connected to compressors of the XFEL refrigerator and to the vacuum pump station.

SUPPORT STRUCTURE

The support structure holds the accelerator module as well as the end and feed cap. The support structure consists of a fixed and movable support (FIGURE 2). The fixed support weights 2 t and is about 2 m high and 2.6 m long. The support holds the feed cap and is firmly fixed to the ground. The movable support weights 7 t and is nearly 2 m high and 13 m long. The support is placed on rails and holds the accelerator module and the end cap. The movable support transports the accelerator module between the test and mounting area. The support is moved with the help of an electrical tractor ("pusher").

Each support comprises two vertical frames for attaching the feed respectively end cap. An alignment tool is provided to make possible alignment of the feed or end cap by ±8 mm both in vertical and transversal direction. Each support contains also a trolley to ensure shifting the sliding muff covering the connection place between the process pipes of the accelerator module and those of the feed or end cap without involving the hall crane.

The movable support contains two adjusting mechanisms for alignment of the accelerator module. They are capable to align the module by ±20 mm in longitudinal, ±25 mm in transversal and ±15 mm in vertical direction.

In the test position the movable support is attached to the fixed one by bolting together the connection flanges of the supports. The supports are designed so as to withstand and transfer to the ground forces resulting from normal operation of the module vessel at vacuum as well as from fault conditions at the pressure of 2.2 bar.

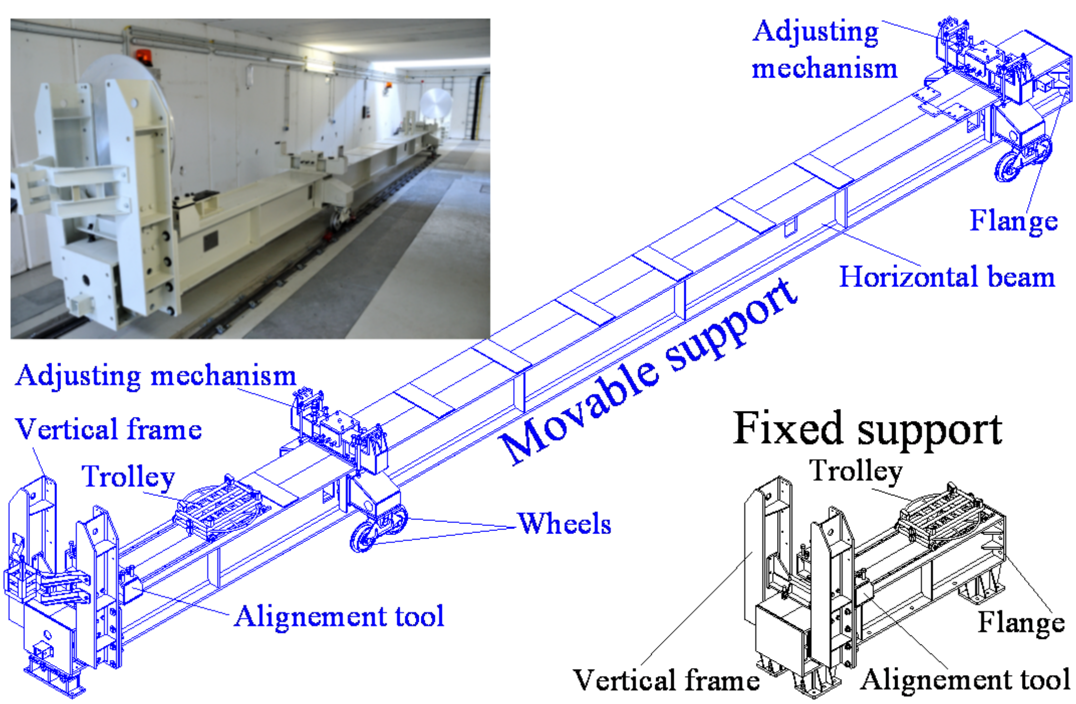

FIGURE 2. View of the movable and fixed support.

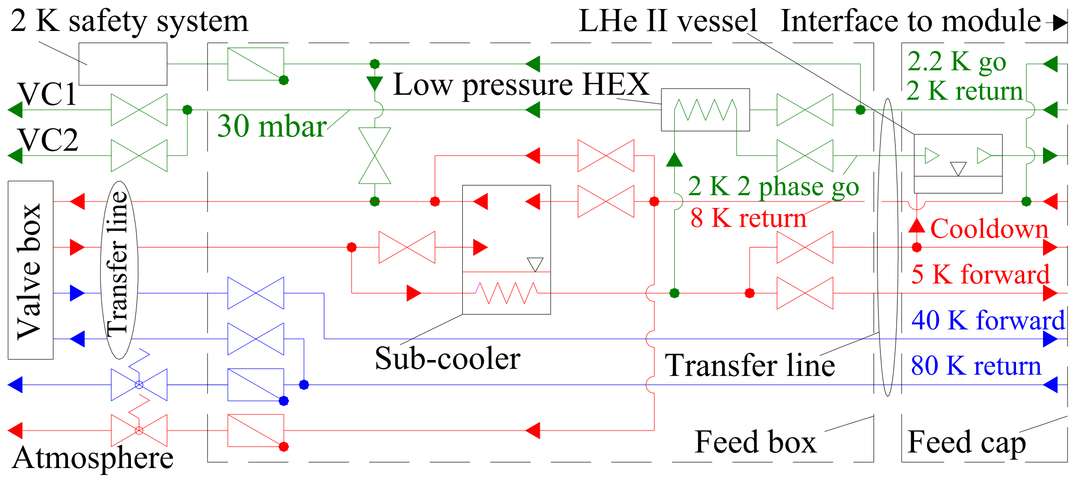

FIGURE 3. Flow scheme of the test stand.

CRYOGENIC DESIGN

The cryogenic flow scheme of the test stand is shown in FIGURE 3. Each test stand is supplied with cryogenic fluids from the valve box via the transfer line carrying 4 pipes for the 40/80 K and 5/8 K cooling circuits. (The circuits are named according to the layout of the XFEL linear accelerator. The real circuit temperatures at the test stands may differ from the nominal ones.) The controllable cooling down or warming up a test stand is accomplished by mixing warm and cold helium flows.

The 40/80 K circuit is supplied with helium at 40 K temperature and a pressure up to 16 bar. The circuit is intended for cooling the 40/80 K thermal shields of the feed box, L-shaped transfer line, feed cap, accelerator module and end cap (not shown in FIGURE 3). The shields are thermally connected to the 80 K return pipe.

The 5/8 K circuit is supplied with helium at 4.5 K temperature and a pressure up to 4 bar. One purpose of the circuit is to cool the 5/8 K thermal shields of the feed cap, accelerator module and end cap. The shields are thermally connected to the 8 K return pipe. A part of helium is throttled in a sub-cooler kept at about 1.2 bar pressure; another part goes through an integrated heat exchanger to compensate for heat load of the transfer line. The return flow is also throttled in the sub-cooler. The total helium vapor flow from the sub-cooler goes then to the valve box.

The 2 K supply flow is branched off at 4.4 K from the 5 K supply flow downstream of the sub-cooler and cooled down to 2.2 K in a low pressure heat exchanger by the 30 mbar helium return vapor flow entering the heat exchanger at 2 K. After being throttled through the following JT valve, the resulting flow of two phase helium II/vapor enters the liquid

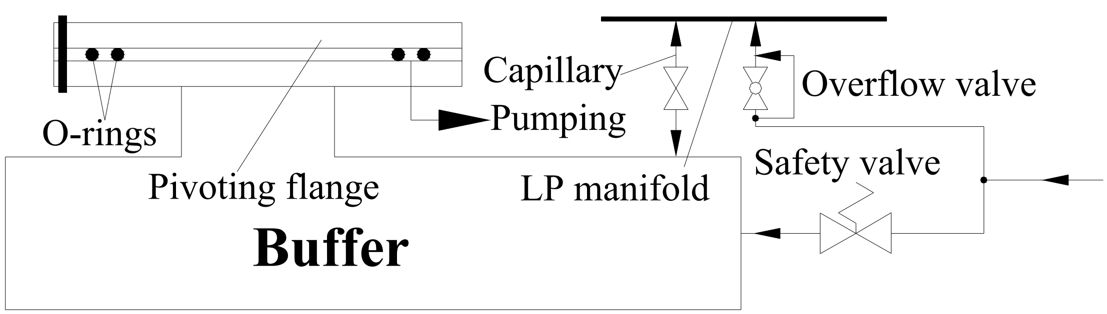

FIGURE 4. The 2 K safety system.

helium II vessel equipped with a heater and level meter for controlling the level of the fluid. The outlet of the vessel is connected to the corresponding pipe of the accelerator module. The helium vapor after the heat exchanger at 30 mbar and 3.5 K maximally 10 g/s goes then to a set of warm vacuum pumps through a ribbed pipe located on the bridge for piping. There the cold helium is warmed up to ambient temperature by heat transfer to air. For reasons of redundancy, two sets of vacuum pumps (Leybold Oerlikon) are installed. The test stands can be switched to each set of vacuum pumps. Both sets of vacuum pumps, each consisting of 12 units of one rotary vane pump and one roots blower are designed for 20 g/s at 20 mbar. Each set of the vacuum pumps is equipped with two flow meters at its discharge site for measurements of the evaporated vapor flow of the helium II bath to detect the heat load to the 2 K circuit.

All safety valves for cold circuits are equipped with check valves to avoid thermal oscillations. The safety valves for the 40/80 K and 5/8 K circuits with the set pressure of 20 bar blow into atmosphere outside the test hall. The safety system for the 2 K circuit operating under atmospheric pressure includes a safety valve blowing into a DN250 buffer filled with helium at a pressure slightly above the atmospheric one through a capillary connected to a low pressure manifold (FIGURE 4). One end of the buffer is equipped with a port closed by a pivoting flange sealed by double O-rings. The space between the O-rings is kept under vacuum. The flange will open at a pressure exceeding 1.4 bar. In order to avoid opening the flange caused by minor failures, an overflow valve with slightly lower set pressure blowing into the low pressure manifold is installed parallel to the safety valve.

The heat load budget for one test stand amounts to 100 W, 20 W and 5 W respectively for the 40/80 K, 5/8 K and 2 K circuit.

FEED BOX DESIGN

The feed box is of vertical design and consists of a vacuum vessel resting on three supports fixed to the ground, 40/80 K thermal shield, 4 cold terminals for connection of transfer lines, pipework and valves for cold circuits, the sub-cooler vessel with the heat

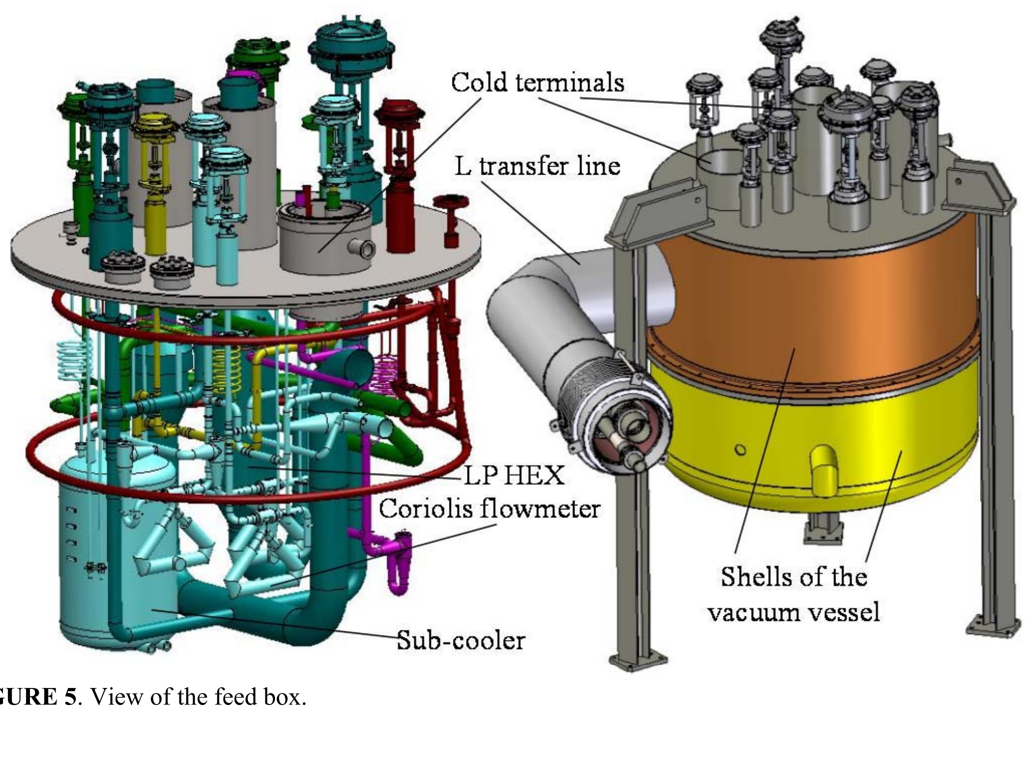

FIGURE 5. View of the feed box.

exchanger and the low pressure counter flow heat exchanger (FIGURE 5). The vacuum vessel as well as the thermal shield consists of two shells to make possible disconnecting and lowering the bottom section for accessing the internal components of the feed box. The supports of the vacuum vessel are designed so as to allow extraction of the shells through the space between supports. The vacuum vessel has the diameter of 1400 mm. The height of the feed box from the ground to the lid of the vacuum vessel is 2 m.

The 40/80 K cooling pipes are attached to the front side and to the upper shell of the thermal shield. The bottom shell is passively cooled via detachable copper braids brazed to the upper shell.

The sub-cooler vessel has total volume about 50 liters. The embedded heat exchanger is of tubular type in order to withstand maximal credible temperature difference. The heat exchanger consists of a bundle of 4 helical tubes arranged in 10 turns. The heat exchanger is immersed in liquid helium.

The basic design of the low pressure heat exchanger was developed by Fermi National Accelerator Laboratory (IL, USA.) The heat exchanger is of spiral tube type consisting of 2 finned tubes spirally wound on a mandrel and fitted in a shell representing DN200 pipe. The mandrel is DN100 pipe closed on one end.

Each of three cold terminals placed on the lid of the vacuum vessel is equipped with a vacuum barrier. The vacuum barrier separating the vacuum space of the feed box from that of the feed cap is placed at the end of the L-shaped transfer line. The transfer line will be attached to the feed box at the manufacturer premises and transported to DESY as one unit.

FEED AND END CAP DESIGN

The purpose of the feed cap is to perform transition from the L-shaped transfer line coming from the feed box to the accelerator module. This concerns the vacuum vessel, thermal shields and the 2 K, 5/8 K and 40/80 K process pipes. The feed cap includes a

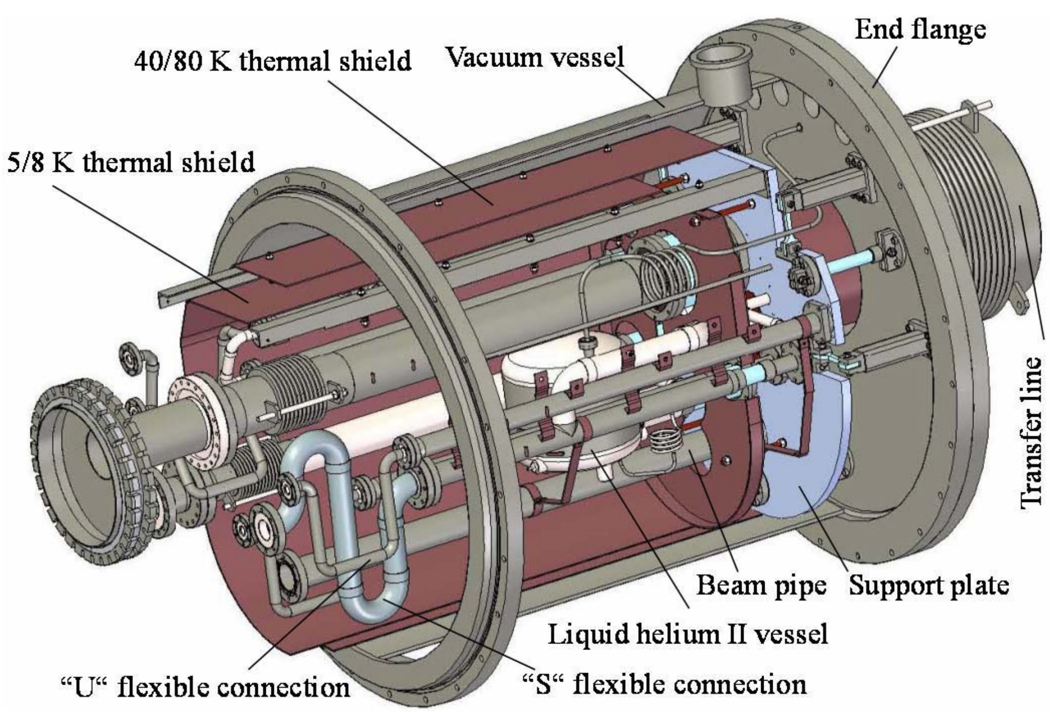

FIGURE 6. View of the feed cap.

vacuum shell, end flange, support plate, 40/80 K and 5/8 K thermal shields and process pipes (FIGURE 6). Additionally the feed cap contains the liquid helium II vessel with a volume of 13 liters for controlling the level of liquid helium II at 2 K in the cavities and magnet package. Compared to the CMTB design [4], the vessel moved from the end cap to the feed cap in order to simplify the design of the end cap which shall multiple times be moved between the test and mounting area and make available the control of level of liquid helium II for other devices like e.g. the cryostat-adapter [3].

The vacuum shell of the feed cap is sufficiently long (~1.2 m) to hold the sliding muff while exchanging accelerator modules. All process pipes are supported by the support plate being a part of the 40/80 K thermal shield. The support plate is in turn supported by the end flange attached to the vertical frame of the fixed support. The supports between the end flange and the support plate take forces both in axial and transversal direction. The end flange and the support plate have each an opening for the beam pipe; the end flange has also an opening for the L-shaped transfer line. The feed cap comprises temperature sensors necessary for measurements of heat loads to the cooling circuits of the module.

Each process pipe of the feed cap is terminated by a welded ConFlat® flange. Most of the interface connections between the process pipes of the feed cap and those of the accelerator module are accomplished by means of “U“- or “S”-shape flexible connection pieces each terminated at either end by a loose ConFlat® flange. The interface connections to the DN300 2 K vapor return pipe and to the DN65 2 K two phase pipe are realized with the help of bellows. The flexible interface connections shall compensate for manufacturing tolerances and for contractions of the process pipes of the accelerator module.

The purpose of the end cap is to complete the cooling circuits of the accelerator module by connecting the forward and return pipes of each circuit with each other, and to close the vacuum volume of the accelerator module. The end cap includes all main components inherent to the feed cap except the liquid helium vessel. The vacuum shell is about 0.6 m long. The end flange of the end cap is attached to the vertical frame of the movable support. Unlike the feed cap, the support plate has no openings for the process pipes.

MOUNTING SEQUENCE

The delivered accelerator module will be placed on the dedicated mounting area. After removal of vacuum covers protecting each side of the module during transportation, the separately delivered sliding muff will be put on the module at its end cap side. Then the accelerator module will be installed on the movable support and moved to the test area by the pusher. In the test position the movable support will be attached to the fixed one. After having aligned the module on the movable support, the wave guides will be connected to the main couplers, and the process pipes of the feed and end cap will be connected to those of the accelerator module. This will be followed by installation of connecting thermal shields and closing the sliding muffs. Then vacuum and cryogenic tests will start. The RF tests will begin after having installed the movable concrete block in its test position.

After completion of the tests, the tested accelerator module will be placed on the storage place within the test hall. The test results will be used by an RF team to assembly and individually tune the wave guide distribution system. This will afterwards be attached to the tested module and transported into the XFEL tunnel.

INSTRUMENTATION

Basically, the instrumentation and controls for the test stands will look similar to those described in [4] and [5] except the following differences. For improving precision of the heat load measurements for the 40/80 K circuit, the Pt1000 temperature sensors in the feed cap are replaced by calibrated TVO temperature sensors. The orifices used in CMTB for measuring flow rates are replaced by flow meters of Coriolis type not only for better accuracy but also to get rid of thermal oscillations provoked by capillaries used for measuring pressure difference across the orifices.

In order to make possible conditioning the RF power couplers in warm state and provide at the same time access to the test area, a safety interlock system is introduced. The system shall ensure that temperature of the cavities is above 273 K. This excludes generation of high electrical fields and appearance of resulting dark currents even with low power RF. For this purpose, the pipe carrying the two phase helium II/vapor for supplying the cavities is equipped with temperature sensors at two places – one at the feed cap, the other at the end cap. Also the pipe for cooling down the cavities is equipped with temperature sensors at the feed cap only. Each place contains two pairs of Pt1000 temperature sensors; the pairs must come from different manufactures. Within one pair one sensor serves for redundancy. At the same time, the status of one sensor within a pair is read by a safety PL controller. The RF power will be enabled only when all interrogated sensors will show temperatures above 273 K and all readings will be within the span of 10 K.

SCHEDULE

The both vacuum pump sets are installed and commissioned. Installation of the warm piping on the bridge is completed. Design of all components of the test stands is completed by BINP and manufacturing started. The first support structure was delivered to DESY and mounted in February 2011 (FIGURE 5 left upper corner.) The first test stand will be put into operation in October 2012 while the remaining ones in December 2012. The valve box will be manufactured by Demaco and put into operation in June 2012. Starting from January 2013 the required test rate of the accelerator modules of one unit per week should be achieved.

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