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VERTICAL TEST SYSTEM FOR SUPERCONDUCTING RF CAVITIES AT PEKING UNIVERSITY*

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Abstract

A new vertical test system (VTS) for superconducting RF cavities has been designed and constructed at Peking University. This facility is designed to operate at a temperature of 2 K and with pumping speed of 10 g/s for helium gas at 30 mbar. In this paper, we present the structure design, modification of 2 K system, ambient magnetic field and radiation shielding, LLRF and the test run of this VTS.

INTRODUCTION

The VTS facility is designed to test superconducting RF cavities ranging from 325 MHz low β cavities to 1.3 GHz high β cavities at 2 K. Most of the cryostat of VTS is assembled under the ground level in a well that was prepared for the facility. The upgraded cryogenic system can work at a pumping speed of 10 g/s for helium gas at 30 mbar to meet the requirement of vertical test. A 1 kW, 1.3 GHz RF system with its low level RF (LLRF) control system has been developed for the VTS. A two-layer structure to shield the magnetic field is installed in the VTS. A set of radiation shielding modules has been designed and constructed to ensure the ambient dose rate during the operations are below the prescribed level.

MAJOR SYSTEMS DESCRIPTION

The layout of VTS and its cryostat is shown in Fig. 1. Most of the cryostat is installed into a concrete well that has a diameter of 1.3 m and a depth of 5 m. The upgraded 2 K system is assemble in the building next to the cryostat. Multiple pipes connect the old and the upgraded 2 K system with the cryostat. They work together to provide competent conditions for measuring the cavities.

VTS Cryostat

The VTS cryostat consists of a vacuum vessel, a thermal shield and a helium vessel. The vacuum vessel has a 112 cm diameter and a depth of 430 cm. It is made of 304 stainless steel with the thickness of 1 cm. The thermal shield is installed within the vacuum vessel. It can significantly reduce the heat loss between the helium and room temperature. The thermal shield is made of 3 mm thick cooper with a cooper tube twining around it. The cooper tube has a diameter of 1 cm and is used to transport liquid nitrogen to maintain the temperature of thermal shield below 80 K.

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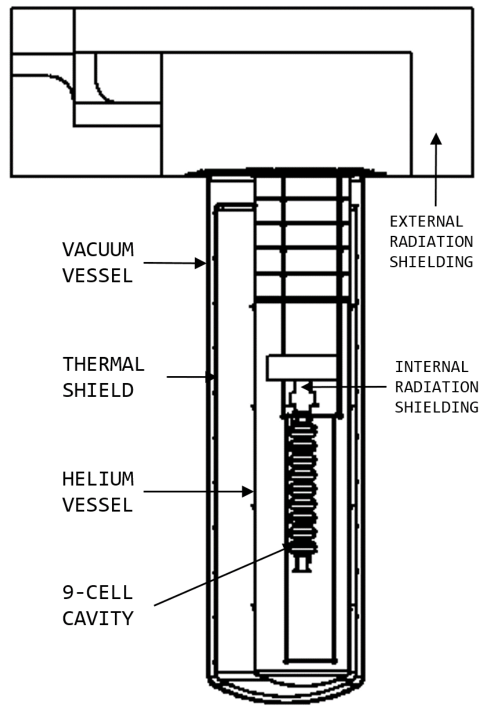

Figure 1: Layout of VTS and cryostat.

The picture of the helium vessel is shown in Fig 2. The helium vessel has an inner diameter of 70 cm and a depth of 366 cm, holding 2000 L liquid helium during the operations. In order to reduce the residual magnetism, which will have a negative effect on the performance of the cavities, the helium vessel is made of 316L stainless steel with the thickness of 2 mm.

Modification of 2K System

The schematic diagram of the 2 K system is shown in Fig. 3. Before the construction of VTS, Peking University already introduced a liquid helium system from the Linde Group. It contains a helium gas compressor, L410 helium liquefier and a 2000 L helium dewar. The modification of 2 K system includes a new 2 K valve box, upgrade of the 2 K pump unit and a new helium recovery and purification system.

The pictures of the old pump unit and the new pump unit is shown in Fig 4 and Fig 5. The old pump unit can work at the pumping speed of 3.2 g/s, and the speed of the new one is 6.8 g/s. During the test, the heated helium gas is extracted

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Figure 2: Helium vessel.

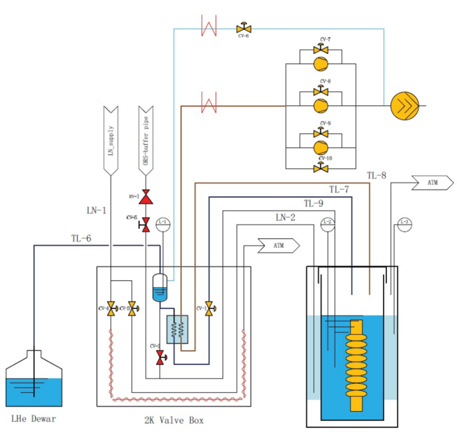

Figure 3: Schematic diagram of the 2 K system.

by the combined action of the old and new pump unit, thus provide a pumping speed of 10 g/s at 30 mbar.

The helium recovery and purification system is deployed to purify the helium gas that is extracted from the helium vessel before it goes back to the helium loop. The main components of the system is a 30 m^3 gasbag, a 20 m^3/hour piston compressor and a 20 m^3/hour helium purifier. The system can purify helium to more than 99.999%.

Figure 4: The old pump unit.

Figure 5: The new pump unit.

Magnetic Shielding

During the cooling down of the cavities, the residual magnetism will be trapped. When the cavities are in superconducting states, the magnitude of the external magnetic field will influence the surface resistance. This two processes will degrade the Q factor of the cavities. The geomagnetic field at Beijing is about 500 mG and the material like stainless steel also have residual magnetism. Therefore, it is important to shield the cavities from the magnetic field.

The magnetic field shielding is achieved through a two-layers shielding structure. The goal of the magnetic shielding is to reduce the residual magnetic field to less than 10 mG at the test region. The room temperature outer layer of the shielding structure is on the inner wall of the vacuum vessel. It is made of 1 mm Amumetal® with a length of 380.2 cm and a diameter of 110.6 cm. The outer layer is deployed to shield the geomagnetic field and the residual magnetism of the vacuum vessel. The inner layer of the shielding structure is on the inner wall of the helium vessel. It is made of 1 mm Cryoperm 10® with a length of 350 cm and a diameter of 69 cm. It is installed to shield the residual magnetism of the components in the VTS and helium vessel.

After the installation of the helium vessel and the inner magnetic shielding layer, a measurement is performed to testify the effect of the two-layer shielding structure. The residual magnetic field in the test region of VTS is measured with respect to depth and various positions. The results shows that at the center and edges of the helium vessel, the magnetic field is less than 10 mG. That meets the VTS operation requirement.

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Radiation Shielding

During the test, the imperfections or residual dust contamination in the cavity will enhance the local electric field significantly [1]. When testing high-gradient cavities, the field-induced electrons will be generated and the radiation will damage the environment [2].

In order to reduce the radiation damage to environment and personnel, a set of radiation shielding modules has been designed based on the simulation results from FLUKA [3]. There are two components in the radiation shielding module. The internal shielding, which is placed on the test stand insert. And the external shielding, which is placed over the cryostat top plate during the test operations.

The internal shielding comprises a pair of lead disks of 100 mm thick mounted above the cavity, and a polyethylene disk of 200 mm placed above the lead disks.

The external shielding consists of a fixed wall and a movable cover with its drive system (Fig 6). The fixed wall has a maze tunnel to let the parts such as pipes and controlling cable to go thought and connect the VTS cryostat. The cover moves on rails fixes on the concrete ground of the building. The cover has a top structure with a 1 cm thick stainless shell and 28 cm thick concrete in it. The other three sides of the cover are 1 cm thick stainless shell with 48 cm thick concrete.

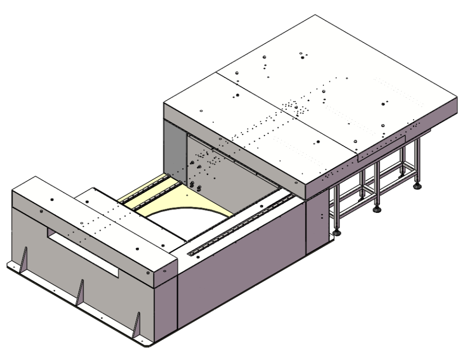

Figure 6: The external radiation shielding.

The simulation result of dose rate distribution is shown in Fig 7. For the source term, we utilized CST® [4] software to find the field emission site that will cause the largest number of electrons which will hit the upper flange with high energy. The collision informations was imported to FLUKA by input card SOURCE. The result shows that only a small amount of radiation will leak into the environment. The dose rate above the VTS cryostat and under the external radiation shielding is about 3 μSv/h.

Low Level Radio Frequency System

The Low level RF (LLRF) system of VTS is based on a PKU LLRFv2 system. Two input signals, pickup and forward, were first down converted to a intermediate frequency (IF) of 30.72MHz. A high speed ADC then sample the IF signals with IQ sampling method, producing the I and Q component of each signal. After low passed filtering, the

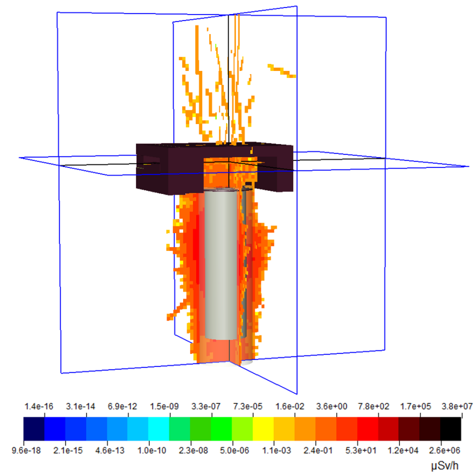

Figure 7: The calculated prompt dose rate distribution during testing a TESLA 9CELL cavity.

I/Q component were translated to amplitude and phase component with CORDIC algorithm, thus acquired the phase difference of forward and pickup signal. The output DAC was driven by a numeral controlled oscillator with its phase controlled by the phase difference signal, and output amplitude set by the operator. High level control and GUI interfaces are based on Python/PyQt (see Fig 8), providing parameters tuning, data monitoring and logging.

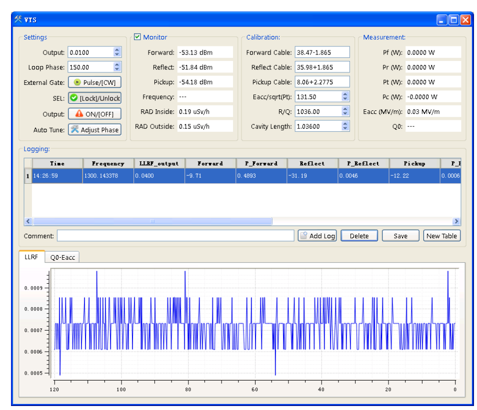

Figure 8: The interface of the control system of VTS.

COMMISSIONING OF VTS FACILITY

The commissioning trial of the VTS was conducted on April 11, 2017 (see Fig 9). A TESLA 9CELL cavity was placed in the VTS with low temperature compatible RF cables and temperature sensors. A total of 2000 L liquid helium was utilized to fully immerse the cavity. In order to test the quality factor and accelerating gradient, RF power was coupled to the cavity. Two radiation dosimeter were placed inside and outside the movable cover to measure the dose rate during the commissioning run. The vertical test results of the 1.3 GHz TESLA 9Cell cavity at 2 K and 1.8 K is shown in Fig 10.

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Figure 9: The preparation for the commissioning trial.

At the temperature of 1.8 K, the quality factor of the cavity is 1.28×10^{10} when the accelerating gradient is 27.23 MV/m. At the temperature of 2 K, the quality factor of the cavity is 1.04×10^{10} when the accelerating gradient is 26.79 MV/m. According to the study done by Fermilab [5], we removed the internal radiation shielding during the commissioning trial. This have a great impact on the dose rate under the movable cover. The maximum dose rate was about 8 mSv/h, while the dose rate outside the cover is maintained at the natural background level.

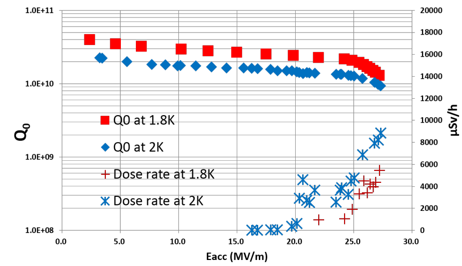

Figure 10: Q_0 and radiation level with respect to the E_{acc} in the commissioning trial.

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