

## 1.3 GHz SRF TECHNOLOGY R&D PROGRESS OF IHEP

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### Abstract

IHEP started the 1.3 GHz SRF technology R&D in 2006 and recently enters the stage of integration and industrialization. After successfully making several single cell and 9-cell cavities of different shape and material, we designed and assembled a short cryomodule containing one large grain low-loss shape 9-cell cavity with an input coupler and a tuner etc. This module will perform horizontal test in 2016 with the newly commissioned 1.3 GHz 5 MW klystron and the 2 K cryogenic system. Beam test with a DC photocathode gun is also foreseen in the near future. We report here the problems, key findings and improvements in cavity dressing, clean room assembly, cryomodule assembly and the liquid nitrogen cool down test. A fine grain TESLA 9-cell cavity is also under fabrication in a company as the industrialization study.

### INTRODUCTION

IHEP started to build a 1.3 GHz superconducting accelerator cryomodule in 2009 and completed the design, prototyping and testing of all the key components (9-cell cavity, input coupler, tuner, cryomodule) in late 2013 [1]. Then the cavity was dressed with the helium vessel and magnetic shielding, and assembled with cold part of the input coupler, gate valves and beam tubes etc. in the clean room. First-time cryomodule assembly was done in July 2014 and 2 K line cold leak was found during the liquid nitrogen cool down test. After solving the cold leak problem and improving the related vacuum system, the reassembled cryomodule finally met the requirement for the high power horizontal test. The newly commissioned 2 K cryogenic plant and 1.3 GHz RF power source are ready to use for the test. A fine grain TESLA-like 9-cell cavity has been fabricated. Two fine grain TESLA 9-cell cavities are under fabrication as industrialization study.

### CAVITY DRESSING AND CLEAN ROOM ASSEMBLY

#### Cavity Dressing

After processing and vertical test in Fermilab [2], the large grain low-loss 9-cell cavity (IHEP-02) was filled with nitrogen gas and shipped back to IHEP. TA2 transition rings were electron-beam welded to the NbTi55 end plates of the cavity, and then the TA2 helium vessel was TIG welded to the transition rings in a glove box. An

adapter ring and the bellow on the helium vessel were used to avoid cavity deformation during welding. The upper, lower and lateral surfaces of the four supporting legs were milled to final dimensions after welded on the vessel. The magnetic shield cylinder was inserted between the helium vessel and the cavity (Fig. 1).



Figure 1: Cavity dressing with magnetic shield and helium vessel.

#### Clean Room Assembly

The 9-cell cavity in the helium vessel was assembled with the gate valves, field pick-up, HOM coupler feedthroughs, cold part of the input coupler, beam pipes, bellows and angle valves etc. (Fig. 2, 3). Particle free flange assembly method was used to guarantee no contamination.

Very careful components, tools, consumables, fixtures and environment etc. cleaning and quality control were performed before assembly. Components were cleaned and blown-off to Class 10.

Slow pump down (130 ml/min) with a mass flow control and slow venting (0.2 L/min) with high purity nitrogen gas were routinely used in leak check, back filling and flushing. Beam pipe assemblies were baked out for 12 hrs at 120 °C before assembled to the cavity.

During assembly, the seat side of the two gate valves was assembled opposite to the cavity flange by mistake. The allowable differential pressure of the valve is 2 bar in either direction. The leak rate will be a little higher, but tolerable. The cleanliness is considered to be OK. The cavity has been always kept in vacuum by the two gate valves since the final leak check of the clean room assembly to avoid any contamination.



Figure 2: Input coupler cold part and gate valve assembly.

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Figure 3: Cavity beamline assembly in clean room.

### *Tuner Installation and Notch Filter Tuning*

After the cavity clean room assembly, the two phase pipe was welded to the helium vessel. A slide-jack tuner (Fig. 4) was installed with a magnetic shielded cryogenic motor, an encapsulated piezo stack with additional round head to avoid shearing force, a piezo load sensor, a displacement sensor and two cameras and lights to monitor the gear.



Figure 4: Tuner and piezo.

The HOM coupler notch filters were tuned that the external  $Q_s$  of the fundamental mode were larger than  $2E12$  at room temperature (cavity in vacuum). The external  $Q$  reduced to around  $2E11$  when the cavity was in the isolation vacuum (at room temperature and 80 K), which is still OK for the fundamental mode filtering. Due to cross talk between the input coupler and HOM coupler of the same side, the notch filter was tuned until the transmitted power reached minimum.

## **CRYOMODULE ASSEMBLY AND LIQUID NITROGEN COOL DOWN TEST**

### *Cryomodule Assembly and Alignment*

The cavity beamline was hung on the gas return pipe of the module. Cavity alignment was done as follows: Cavity axis 2 mm lower than design to compensate vertical thermal shrink. Cavity axis 0.25 mm lateral offset to the opposite side of the input coupler to compensate different material shrinkage.

Magnetic shield caps for the cavity end cells were installed outside of the helium vessel. The two phase pipe and the HOM coupler cans and feedthroughs were connected with thermal anchors for better cooling.

Then RF cables, thermal sensors, multi-layer isolations, 5 K and 80 K shields, thermal anchors etc. were installed. Module alignment was done after the cold mass was inserted and assembled with the vacuum vessel. At last,

the warm part of the input coupler was mounted in a local clean room (Fig. 5).

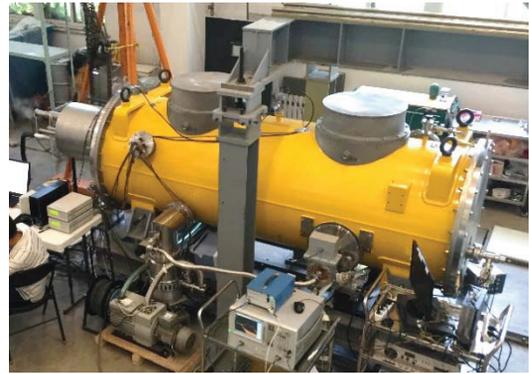


Figure 5: Assembled cryomodule.

### *80 K Cool Down Test*

During the first liquid nitrogen 80 K cool down test, cold leak occurred in cryogenic lines. By improving the outside cryogenic connections (welding instead of many seals), the leak was found to be in 2 K line inside the cryomodule. In order to get the liquid nitrogen level (the installed superconducting helium liquid level meter can't be used for the liquid nitrogen), we put thermal sensors inside the two phase pipe and gas return pipe and on many positions, and welded a liquid baffle plate in the gas return pipe (Fig. 6 and Fig.7). There was no leak when liquid nitrogen was in the two phase pipe and gas return pipe. Leak happened only when liquid nitrogen flowed over the liquid baffle and touched the blank flange of the gas return pipe for a while. The 2 K line was leak-tight when the module was warmed up. Therefore, the reason of cold leak is the large thermal gradient ( $> 100$  K) between the top and bottom of the gas return pipe flange.

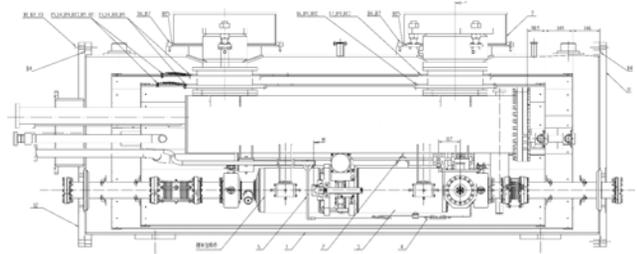


Figure 6: Cross section of the 1.3 GHz short cryomodule.



Figure 7: Liquid baffle plate welded in gas return pipe.

In the last liquid nitrogen cool down test, the liquid level was always kept lower than the top of the two phase pipe, and the module was leak tight (isolation vacuum  $2.5E-4$  Pa) during the whole test (Fig. 8). The cavity was

cooled down to 80 K with the vacuum of 1.2E-7 Pa. The coupler cold window was cooled to 183 K with the vacuum of 1.1E-6 Pa. The 5 K and 80 K shields reached 163 K and 113 K respectively.

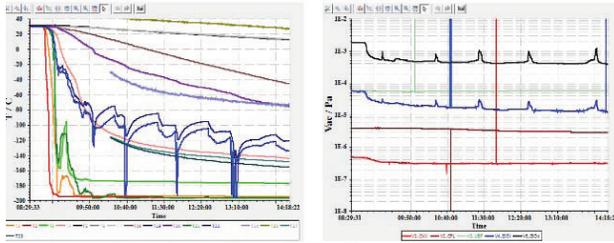


Figure 8: Cryomodule 80 K cool down test curve.

Since no liquid is allowed in the gas return pipe during 2 K operation and the cool down rate will be much slower than the liquid nitrogen test, there will be no cold leak risk for this module (except the possible superfluid leak). We will perform 2 K cool down test soon to check vacuum performance.

A 1300 L/s turbo molecular pump (effective pumping rate 571 L/s) was used for the isolation vacuum. A 100 L/s ion pump and 400 L/s Non-Evaporable Getter (NEG) pump were used for the cavity vacuum pumping via the beam tube in one side.

### Cavity Frequency and Tuner Test

The cavity frequency in vacuum was 1297.439 MHz after the vertical test, 1297.27 MHz after helium vessel welding and clean room assembly, 1297.52 MHz after tuner assembly and stretching. Because the cavity was soft, it was expanded 2.9 mm by the atmosphere pressure in the helium vessel under cryomodule isolation vacuum. As a result, the final frequency was 1300.52 MHz at 80 K and the tuner and piezo can't touch the helium vessel flange to tune the cavity. In 2 K superfluid helium test, the cavity frequency will go down to about 1299.7 MHz because of the low pressure in the helium vessel, and reached 1300 MHz by about 1 mm tuner expansion.

The tuner stroke is 3 mm and works well in the 80 K test. The piezo performance is good at room temperature.

### CRYOPLANT AND RF SOURCE

The 2 K cryogenic system (Fig. 9) was commissioned in early 2015. The main specifications are: refrigeration 1020 W@4.5 K, liquefaction 302 L/h, mixed mode 352 W+200 L/h, total pumping 8000 m<sup>3</sup>/h@3100 Pa (200 W@2 K). 2 K valve-box and transfer lines for the module horizontal test were installed.



Figure 9: 2 K cryogenic system.

The 1.3 GHz klystron (TH2104C) is ordered from Thales Electron Devices. It can deliver up to 5 MW peak and 100 kW average power in long pulses up to 2 ms.

The Marx modulator is capable of delivering 130 kV, 140 A, 1600 μs pulses at a rate of 5 Hz. The design employs a stack of sixteen 12 kV Marx modules that generate high-voltage output pulses directly from a 12 kV input supply voltage. The advantages are higher efficiency, smaller physical size, and a modular architecture that provides better reliability and cost effective PC board-level integration.

The commissioning of the modulator and klystron is ongoing now (Fig. 10).



Figure 10: 1.3 GHz 5 MW klystron and Marx modulator.

### 9-CELL CAVITY INDUSTRIALIZATION

A fine grain TESLA-like 9-cell cavity has been fabricated (Fig. 11) and will be processed and tested in collaboration with KEK. Two fine grain TESLA 9-cell cavities are under fabrication as industrialization study.



Figure 11: TESLA-like 9-cell cavity.

### CONCLUSION

1.3 GHz SRF technology has been developed in IHEP for 10 years from single cell cavity to module integration and infrastructure construction. The module performs well in the liquid nitrogen test. High power horizontal test of the cryomodule and more cavity R&D are foreseen in the near future.

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