IHEP 1.3 GHz LOW LOSS LARGE GRAIN 9-CELL CAVITY FABRICATION, PROCESSING AND TEST

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Abstract

The combination of the low-loss shape and large grain niobium material is expected to be the possible way to achieve higher gradient and lower cost for ILC 9-cell cavities, and will be essential for the ILC 1 TeV upgrade. As the key component of the "IHEP 1.3 GHz SRF Accelerating Unit Project", a low-loss shape 9-cell cavity with full end groups using Ningxia large grain niobium (IHEP-02) was fabricated at IHEP in 2012. The cavity was processed (XMP and EP) and tested at FNAL in 2013. The cavity processing, test performance and gradient limitation are reported in this paper.

INTRODUCTION

1.3 GHz superconducting radio-frequency (SRF) technology is one of the key technologies for the International Linear Collider (ILC) and future ERL and high energy section of the high intensity proton linac in China. IHEP is building a 1.3 GHz SRF Accelerating Unit to demonstrate this technology. All the key components have been fabricated and tested including the low-loss shape large grain 9-cell cavity (IHEP-02) [1].

The ILC post-TDR R&D addresses both the gradient and Q_0 needed for the 1 TeV upgrade. With an improved cavity cell shape and optimised material properties, 9-cell niobium cavities should be able to reach gradients in the range of 40–60 MV/m [2]. For this purpose, IHEP has been developing the low-loss shape large grain cavity since 2006 [3]. In 2012, we made the IHEP-02 cavity with full end groups (Fig. 1) and collaborated with FNAL to perform surface processing and vertical testing.

CAVITY FABRICATION

Based on the first 9-cell cavity experience, the dumbbell and equator welding were done with better quality. The frequency and length of both the dumbbells and end groups were precisely controlled by RF measurement, reshaping and trimming.

The end group design of this low-loss cavity is similar to the TESLA cavity except larger input coupler port diameter, and larger distance between the HOM couplers and the end cell. The HOM characteristics were measured after cavity EBW. The external Q values of most of the dangerous higher order modes are below the ILC limit [4].

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Figure 1: IHEP-02 1.3 GHz low-loss large grain 9-cell cavity with full end groups.

Due to the complicated structure and weld procedure, we made lots of weld tests and repairs for the end groups. Lessons were learned in EBW shrinkage, deformation and thermal conduction allowance etc. (Fig. 2).

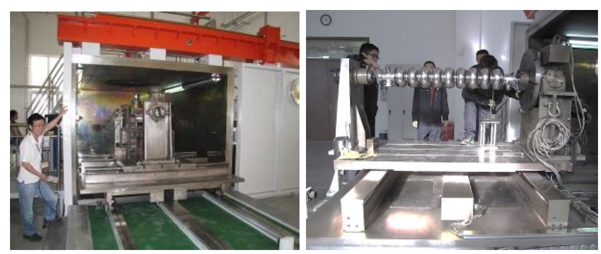

Figure 2: IHEP-02 9-cell cavity EBW.

The fundamental mode notch filter of the HOM coupler was adjusted as a practice (Fig. 3). The extrapolated notch frequency is 1280 MHz and 1248 MHz.

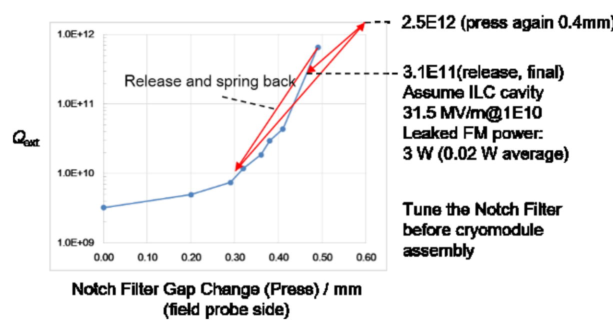

Figure 3: HOM coupler external Q adjustment of the fundamental mode on the field probe side.

CAVITY PROCESSING

The cavity was processed with FNAL and ANL SRF infrastructures [5]. The main processing procedures are (Fig. 4): 200 μm CBP (tumbling) to mirror surface, 40 μm EP, heat treatment 800 °C 3 hr, pre-tuning, 20 + 10 μm EP, ultrasonic cleaning, HPR, 120 °C bake 24 hr.

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Figure 4: IHEP-02 cavity processing, inspection, tuning and assembly at FNAL and ANL.

CBP (XMP)

Recently, FNAL extended the known CBP (centrifugal barrel polishing or tumbling) techniques to fine polishing (called Extended Mechanical Polishing, XMP), producing mirror-like finishes with <15 nm RMS (root mean square) roughness [6]. This is an order of magnitude less than the typical roughness produced by the electro-polishing (EP) of niobium cavities, thus less EP is needed compared to the baseline processing recipe.

XMP removed most of the defects near IHEP-02 equators, but several big ones remained. By optical inspection with automatic Kyoto camera system, all the remained defects were in the joint points of grain boundaries and weld beads (Fig. 5).

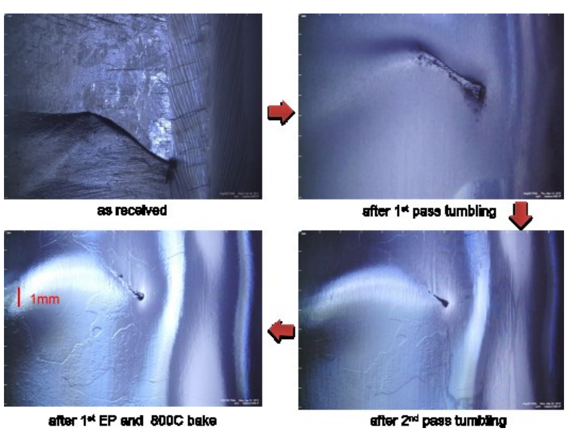

Figure 5: Pictures of the equator weld area near a large grain boundary.

EP

Although BCP treated large grain 9-cell cavities can reach 20~28 MV/m without Q-slope, experience has shown that EP is still a necessary surface-processing step to reach high gradient for large grain 9-cell cavities.

The EP cathode rod is 33 mm (no mesh because of small iris of the low loss shape). More masking was added at the irises and end group locations. We reduced the normal voltage (18 V) to the measured plateau of the IV curve (15 V) of IHEP-02.

After the second EP of 20 µm (total 60 µm), we found vacuum leak on the weld of one HOM leg and housing. The cavity was leak tight in the as-received check. Non-full-penetration electron beam weld was the reason of leak. We performed a TIG weld repair and then made additional 10 µm EP.

Outgassing

Enormous hydrogen in the cavity was outgassed during heat treatment after intensive CBP and light EP. The hydrogen pressure dropped nearly two orders of magnitude after outgassing.

VERTICAL TEST

In the vertical test (Fig. 6), thermal sensors and second sound (OST) system were installed. To keep the cavity as clean as possible, the cavity was closed by an angle valve without active pumping.

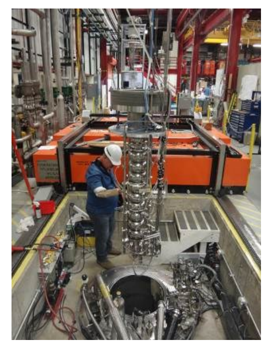

Figure 6: IHEP-02 cavity in FNAL vertical test facility.

The cavity quenched at 20 MV/m with $Q_0 = 1.4\times10^{10}$ at 2 K (Fig. 7), 298 degree in cell#9, 2 mm from the equator (Fig. 8). The quench location has sharp and deep grain boundary step made during half cell pressing (Fig. 8). By the passband mode test, all the other cells reach around 40 MV/m except cell#1 symmetrically limited by cell#9. Figure 9 shows Q_0 at different temperatures. The relatively low Q_0 and slight Q-slope may be caused by remained hydrogen or defects heating up. There are about 5 defects similar to the quench defect in the cavity.

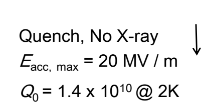

Figure 7: Vertical test result of IHEP-02 cavity.

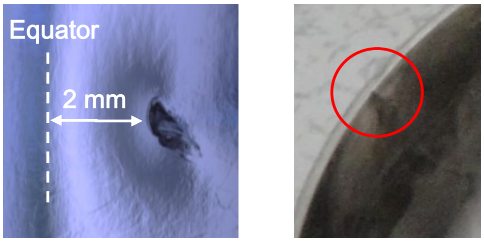

Figure 8: Quench defect in cell#9 (left), grain boundary step of the half cell after pressing and trimming (right).

Figure 9: Cavity Q_0 at different temperatures.

The measured Lorentz force detuning factor (LDF) of the cavity in the frame is - 2.5 Hz/(MV/m)^2. When dressed with the helium vessel and slide jack tuner, the LDF is expected to reduce to around - 1 Hz/(MV/m)^2.

The measured pressure sensitivity of the cavity is - 93 Hz/mbar. The required helium pressure stability is ± 0.1 mbar (~ 10 Hz) for the horizontal test and beam operation.

FREQUENCY AND FIELD FLATNESS

After CBP and 1st EP, the π-mode frequency was only 0.5 MHz lower than as received. It was 3-4 MHz higher than our estimation. Due to this abnormal frequency change, we tuned the cavity from 1300.2 MHz to 1297.4 MHz and got 97 % field flatness. The cavity is 10 mm shorter than the design length.

The cavity frequency under vacuum after vertical test is 1297.439 MHz, within the tuner range to reach 1300 MHz after cooling down in the cryomodule.

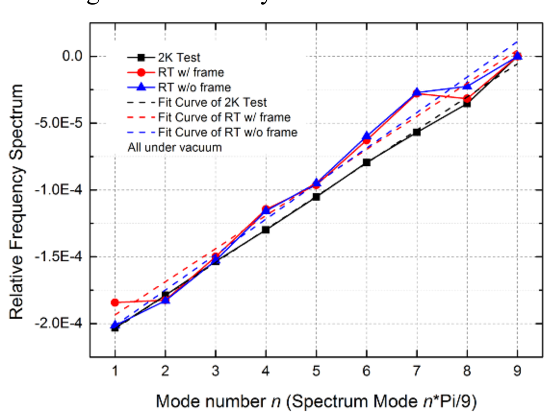

Figure 10: Cavity relative spectrum change compared to the spectrum after pre-tuning.

To estimate the field flatness change from the cavity frequency spectrum, we use the method in reference [7]. Figure 10 shows the difference between the frequencies ratio of each mode (measured and reference) and the ratio of π-mode. The mean squared error is calculated for relative spectrum and its linear fit curve shows the deviation of cavity field flatness. The calculated mean deviation is 3.4 kHz at 2 K with frame, 12.5 kHz at room temperature (RT) with frame, 10.6 kHz at RT without frame, all under vacuum. Thus the field flatness in the 2 K test is about 95 %, and the field flatness of the free cavity under vacuum after vertical test is around 90 %.

SUMMARY

IHEP 1.3 GHz low-loss shape large grain 9-cell cavity with full end groups reached 20 MV/m without field emission in the first pass processing and vertical test at FNAL. The cavity frequency and field flatness are controlled in the required range. We will weld the helium vessel, assemble the magnetic shield and install the cavity to the IHEP ILC-TC1 cryomodule at the end of 2013 and make horizontal test in 2014.

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REFERENCES

[1] J. Gao, et al., "Status of the IHEP 1.3 GHz Superconducting RF Program for the ILC", IPAC'13, Shanghai, May 2013, WEPWO018, p. 2355

[2] C. Adolphsen, et al., *ILC Technical Design Report Vol. 3.I* (2013), 28

[3] J.Y. Zhai, et al., "IHEP 1.3 GHz Low-Loss Large Grain 9-cell Cavity R&D", SRF'11, Chicago, July 2011, WEIOB06, p. 611

[4] H.J. Zheng et al., "HOM Parameters Simulation and Measurement Result of IHEP02 Low-Loss Cavity", IPAC'13, WEPWO026, p. 2372

[5] C. Ginsburg, et al., "Superconducting RF Cavity Production Processing and Testing at Fermilab", LINAC'10, Tsukuba, Sept. 2010, THP026, p. 815

[6] C. Cooper, et al., "Mirror-smooth surfaces and repair of defects in superconducting RF cavities by mechanical polishing", Superconductor Science and Technology, 26 (2013) 015011

[7] A. Sulimov, et al., "Description and First Experience with the RF Measurement Procedure for the European XFEL SC Cavity Production", IPAC'11, San Sebastian, September 2011, MOPC086, p. 277

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