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FABRICATION, TREATMENT AND TEST OF LARGE GRAIN CAVITIES*

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Abstract

Development of SRF technology has been included in the project of Soft X-ray FEL (SXFEL) for a hard X-ray FEL plan in China which would be operated in CW mode. Six 9-cell TESLA type cavities as well as several single-cell cavities made of Ningxia large grain niobium material have been fabricated by Peking University for achieving high gradient and high intrinsic quality factor Q_0. The measurements of gradient and Q_0 have been carried out with a new vertical test system at PKU. The process of fabrication, surface treatment and test results of these large grain cavities are presented in this paper.

INTRODUCTION

Researches on large grain superconducting cavities have been carried out for more than ten years. It is reported that the average intrinsic quality factor Q_0 of large grain niobium cavities at 2 K is higher than standard fine grain Nb cavities [1-3]. SRF technology has been developed at Peking University (PKU) since 1990's. Researches on large grain cavities were started from 2005. A series of large grain cavities were fabricated and tested, including single cell, 2-cell, 3.5-cell cavities. The gradient of a single cell and a 2-cell cavity made of large grain niobium was larger than 40 MV/m and the quality factor was higher than 1×10^{10} [4-5]. A 3.5-cell large grain cavity was fabricated for DC-SRF photoinjector and the gradient of the cavity reached 23.5 MV/m, Q_0 value is higher than 1.2×10^{10} in vertical test at Jlab [6]. 5 years ago, we fabricated four 9-cell TESLA type cavities, among which two large grain cavities PKU2 and PKU4 showed good performances. The maximum gradient of PKU2 reached 22.4 MV/m and Q_0 was about 2×10^{10} at the highest gradient at 2 K [7]. The E_{acc} of PKU4 was 32.6 MV/m and Q_0 was above 1.0×10^{10}, which fulfilled the requirement for ILC both in gradient and intrinsic quality factor [8]. PKU2 and PKU4 were installed in the 2×9-cell cryomodule and operated for electron beam loading experiments successfully.

In recent years, development of SRF technology has been included in the project of Soft X-ray FEL (SXFEL), which is the pre-research for a hard X-ray FEL plan in China which would be operated in CW mode. The purpose is to develop SRF technology and test the production capability of multi-cell superconducting cavities. Due to the advantage in Q_0, large grain cavities were chosen as the candidate for cavity production. Six 9-cell TESLA type large grain cavities were fabricated, treated and tested by Peking University. The results are presented in this paper.

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FABRICATION AND TREATMENT OF LARGE GRAIN CAVITIES

The fabrication and part of treatment of large grain cavities are finished at Ningxia Orient Superconductor Technology Co., Ltd. (OSTEC). OSTEC was founded jointly by Ningxia Orient Tantalum Industry Co. Ltd (OTIC) and Peking University in 2011, in order to promote the SRF technology and meet the increasing demand for superconducting cavities in China and around the world. Field flatness tuning, final treatment and vertical test are carried at Peking University.

Fabrication

Six large grain 9-cell cavities were fabricated with deep drawing, precise machining and vacuum electron beam welding in early 2017, see Fig. 1. The large grain niobium sheets with RRR > 250 was produced by OTIC. Investigation shows the phonon peak of OTIC large grain niobium can be recovered by heat treatment at a temperature of more than 800°C [9]. The length and frequency of the 6 cavities are given in Table 1. The length of NXPKU3 is shorter than the standard length because of technical reason.

Figure 1: Large grain 9-cell TESLA cavities.

Treatments

After fabrication and RF measurement, a series of treatments were applied to the cavities, including standard BCP, pure water rinsing, HPR and high temperature annealing, etc. A total of 210 μm of inner surface was removed by BCP for each cavity to remove the impurities during the fabrication. High pure water rinsing and HPR were used after BCP to remove the remaining acid. After BCP, the cavities were annealed in a high temperature furnace for fabrication stress releasing and hydrogen

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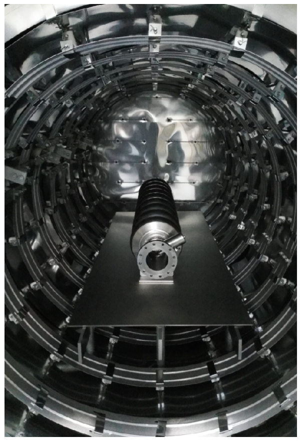
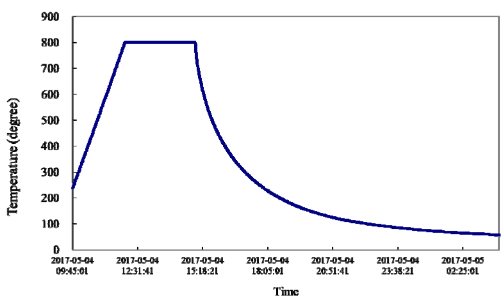
degassing. The cavities were kept at 800°C for 3 hours and then annealed to room temperature. Figure 2 shows the high temperature furnace and a typical annealing curve for large grain cavities.



(a)



(b)

Figure 2: 800°C high temperature treatment for 9-cell cavity (a) high temperature furnace (b) temperature curve.

Field Flatness Tuning

Frequency and field flatness tuning after BCP and annealing is necessary for multi-cell cavities to guarantee the accelerating gradient. The initial flatness of the 6 large grain 9-cell cavities was 57%~75%. The tuning was carried out at the flatness tuning platform at PKU. The field flatness was tuned to ~95% for each cavity. The initial and final flatness was shown in Table 1.

Table 1: Parameters of Large Grain 9-cell Cavities

Cavity #	Length (mm)	Freq. after fabrication (MHz)	Initial Flatness	Final Flatness
1	1282.6	1301.286	69.9%	96.6%
2	1288.0	1300.940	57.3%	94.6%
3	1266.4	1301.079	66.7%	95.1%
4	1284.2	1301.089	75.6%	95.0%
5	1284.1	1301.301	63.0%	95.3%
6	1283.4	1301.034	60.0%	96.6%

VERTICAL TEST OF LARGE GRAIN 9-CELL CAVITIES

Vertical Test System

A Vertical Test System (PKU-VTS) is designed for vertical test of superconducting cavities from 4.2 K to 2.0 K or even lower temperature at PKU. The VTS dewar consists of vacuum vessel, liquid helium vessel, liquid nitrogen shield, inner magnetic shield, outer magnetic shield and cavity insert, etc., see Fig. 3. The earth magnetic field inside the dewar is lower than 10 mGs by using double magnetic shields. Commissioning showed that the cooling capacity of PKU-VTS is larger than 210 W at 2 K with a maximum helium mass flow of 10 g/s at 30 mbar.

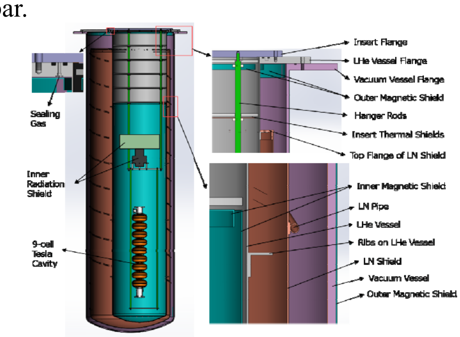


Figure 3: PKU Vertical Test System.

Vertical Test of Cavities

After field flatness tuning, the cavities are transferred to clean room for ultrasonic cleaning, flanges assembly, HPR, antenna assembly and leak check, after which the cavities will be vertical tested at PKU-VTS. The main processes of 9-cell cavities are as following:

- BCP (180 μm)
- HPR
- 800 °C degassing/annealing
- BCP (30 μm)
- Field flatness tuning
- Ultrasonic cleaning
- HPR
- Flanges assembly
- HPR
- Assembly to insert and VTS
- Vertical Test

All the cavities were test at both 2.0 K and 1.8 K. Figure 4 gives the Q vs E curves for all the six large grain cavities. The accelerating gradients are larger than 25 MV/m except for NXPKU3. The intrinsic Q values at 2.0 K of most cavities are around 2×10^{10} at 16 MV/m, which is the operating gradient for China hard X-ray FEL facility. The ratio of Q_0(1.8K)/Q_0(2.0K) at 15-16 MV/m is about 1.6, which provides an option of running at 1.8 K for XFEL. The low E_{acc} and Q_0 of NXPKU3 might be due to HPR problem. During the HPR process for NXPKU3, the rod of HPR system stopped moving and the HPR jet hit the same height for long time. The cavity suffered strong field emission. NXPKU3 was sent to OSTEC for additional BCP and will be vertical tested again.

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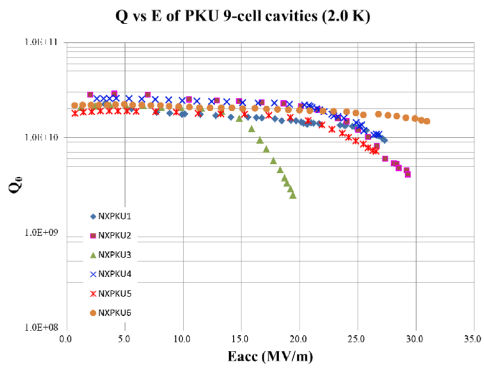
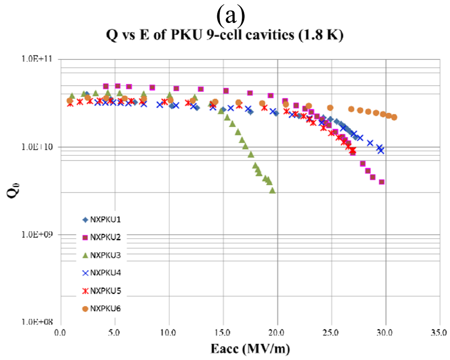


(a)



(b)

Figure 4: Vertical test result of six large grain 9-cell cavities. (a) 2.0 K (b) 1.8 K.

The gradients of the cavities are limited by field emission and power. Radiations occurred from 15-20 MV/m in the vertical tests. The reasons for field emission are under investigation.

Next Plan

Surface treatments are important for superconducting cavities. The 6 large grain 9-cell cavities are etched only with BCP. No EP devices are available for 9-cell cavities in China at present. High gradients for 9-cell cavities have been obtained at DESY by EP [10]. N-doping technique has been developed to improve the Q_0 of superconducting cavities [11-13]. We will do researches to improve the performances of superconducting cavities by EP treatment and/or N-doping method. Several 1.3 GHz single cell cavities, including one large grain cavity, are fabricated for earlier stage researches. A simple EP device is set up for single cell cavity electropolishing. Preliminary investigation is in progress.

CONCLUSIONS

Six large grain 9-cell TESLA cavities are fabricated, treated and tested by Peking University, which verified the production capability of 9-cell cavities. After 210 µm BCP and 800°C annealing, the gradients of 5 cavities are larger than 25 MV/m. The intrinsic Q values of most cavities are around 2×10^{10} at 16 MV/m and at 2.0 K. Further treatments will be carried out to improve the gradients and intrinsic Q values of superconducting cavities. The progresses on SRF technology have accumulated experiences for hard X-ray FEL plan in China.

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