IMPROVING GRADIENT OF 9-CELL SRF CAVITIES AT PEKING UNIVERSITY*

J. Hao, J.E. Chen, L. Lin, K.X. Liu, X.Y. Lu, S.W. Quan, F. Wang, H.M. Xie, B.C. Zhang, K. Zhao, F. Zhu

Institute of Heavy Ion Physics & State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China

Abstract

Four 9-cell TESLA superconducting cavities have been fabricated with Ningxia OTIC niobium material, including two fine grain and two large grain niobium cavities. The cavities have been tested after post treatments. At the early stage (PKU1 and PKU2), the gradient was about 23 MV/m. The gradient of PKU3 reached 28.6 MV/m, but the Q is low. The newest large grain 1.3 GHz 9-cell TESLA type SRF cavity (PKU4) has been made with careful control of machining, improved surface treatment and electron beam welding. The maximum of gradient is 32.4 MV/m and the intrinsic quality factor (Q_0) is 1.3 $\times 10^{10}$, which meet the requirement for ILC both in accelerating gradient and quality factor.

INTRODUCTION

SRF technology has been developed at Peking University (PKU) since 1990's. In the early stage, single cell cavities were fabricated and tested. The gradient of a single cell cavity made of large grain niobium reached 43.5 MV/m and quality factor was higher than 1×10^{10} [1]. In recent years, a SRF Energy Recovery Linac test facility (PKU-SETF) was initiated by the PKU SRF group to provide coherent radiations as a mid-term goal [2]. The PKU-SETF consists of mainly a 5 MeV DC-SRF injector and a cryomodule of 9-cell TESLA cavity working at 2 K for accelerating electrons to 15-20 MeV. 9-cell 1.3 GHz SRF cavities have been studied for PKU-SETF based on the obtained experiences of SRF technology. We choose TESLA type cavity for R&D on multi-cell cavities because TESLA cavities have been widely used in superconducting accelerators, for example, free electron laser facility FLASH [3] and the European XFEL facility [4], ELBE [5], etc. The first 9-cell cavity (PKU1) without end groups was finished in 2008 [6], which verified the material and the fabrication technology. Two 9-cell cavities (PKU2 and PKU3) with end groups were fabricated and the accelerating gradients were between 20 to 30 MV/m [7]. A new 1.3 GHz 9-cell TESLA type superconducting cavity (PKU4) has been fabricated with careful control of machining, better field flatness tuning, improved surface treatment and electron beam welding (EBW). The accelerating gradient and intrinsic quality factor reached the requirements for ILC.

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9-CELL SUPERCONDUCTING CAVITIES AT PKU

Researches on 9-cell cavities have been carried out at PKU since 2006 with pure niobium material made by Ningxia Orient Tantalum Industry Co. Ltd (OTIC). The electron-beam welding was cooperated with Harbin Institute of Technology (HIT). After a series successful fabrication of single cell, 2-cell, 3.5-cell and 5-cell cavities, the first 9-cell cavity (PKU1) without end groups was finished and the maximum gradient is 23 MV/m and the Q_0 is 6×10^9, limited by RF power [6]. This cavity verified the fabrication techniques such as deep drawing, machining, RF measurement, surface treatment, field flatness tuning, electron beam welding, etc.

At the same time, researches had been started on end groups for a complete 9-cell cavity. Two 9-cell cavities (PKU2 and PKU3) with end groups were fabricated in 2009. PKU2 was fabricated with large grain niobium material. After pre-treatments, the cavity was sent to Jlab for vertical test. The first vertical test result showed the E_{acc} was 19.5 MV/m at 2.0 K with the Q_0 9×10^9. The cavity was treated at 800 °C for 2 hours and followed with 30 μm EP and 120 °C baking for 48 hours to improve the performance. The maximum gradient reached 22.4 MV/m finally at both 2.0 K and 1.8 K. The Q_0 is about 2×10^{10} at the highest gradient.

PKU3 was fabricated with fine grain niobium sheets. The performance evaluation of PKU3 was done with collaboration between Jlab and PKU. After electropolishing, 800 °C heat treatments, HPR and 120°C baking, the maximum accelerating gradient reached 28.6 MV/m at Q_0 of 4×10^9. PKU3 is the first nine-cell cavity with end group components in China reaching a gradient usable for the ILC. The quality factor is low. The observed decrease of quality factor versus the gradient was due to the field emission by the sharp edges in the iris electron-beam welding regions.

EFFORTS TO HIGH GRADIENT

Since the high Q_0 of large grain superconducting cavities fabricated at PKU, we continue researches on large grain 9-cell cavities. Based on the accumulated experiences on 9-cell cavities, we tried to improve the fabrication techniques. To keep the homogeneity of each cell, the dumbbells were tuned carefully by pushing or pulling at the flatness tuning machine according to the RF measurements before equator trimming. More sample

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welding experiments were done with double cups before equator welding. Parameters were optimized according to sample welding. There were some deformations at the equators of dumbbells because there were only several grain boundaries for large grain niobium sheet and the stress is not uniform after deep drawing. Before the equator welding, the equator of the adjacent two dumbbells was placed at available position by rotating the dumbbells to make the two equators fit together. After all the efforts, the new large grain 9-cell cavity PKU4 was completed in mid-2012, see Fig. 1.

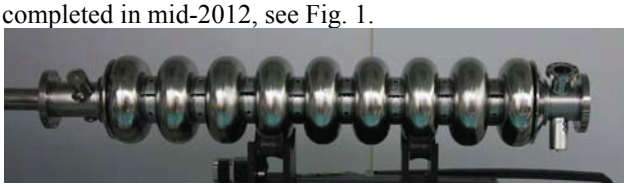
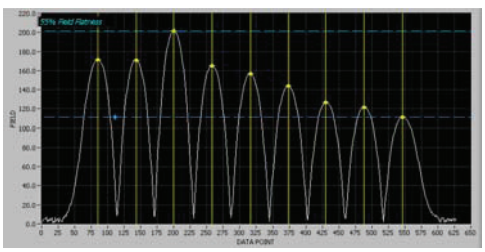


Figure 1: large grain 9-cell superconducting cavity (PKU4).

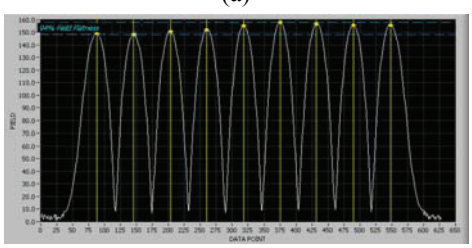
Optical inspection, RF measurement, field flatness measurement and pre-BCP were done on PKU4 after fabrication. Optical inspection showed some welding defects near equator area. Field flatness tuning was not done due to the planned transportation. After pre-treatments, PKU4 was sent to KEK for treatments and vertical test under the collaboration between KEK and PKU.

Field Flatness Tuning

The initial field flatness of PKU4 was 55% after the fabrication and the fine field flatness tuning was needed. Because the stress of large grain material is not uniform at different area of the cavity, five cycles of field flatness tuning were performed totally. The final field flatness was 94%. No more tuning was applied to avoid the possible break of the cavity. Fig. 2 showed the field flatness before and after the tuning.



(a)



(b)

Figure 2: field flatness of PKU4. (a) before flatness tuning (b) after flatness tuning.

Surface Treatment and Vertical Test

The main treatments for PKU4 are as following: ultrasonic cleaning, buffered chemical polishing, electropolishing, high temperature annealing, high pressure rinsing, and baking.

The surface of PKU4 was removed about 20 μm by BCP after fabrication and field flatness measurement. Then the cavity was degreased by ultrasonic cleaning with pure water and detergent for 3.5 hours. The first EP process was performed to the cavity, which made a surface removal of 120 μm. Some small defects were removed by EP. After the first EP, the cavity was treated at 750 °C for 3 hours and annealed to room temperature during 3 days. Then the cavity was assembled to the supporting frame, followed by degreasing process. A final EP of 5 μm was applied. After degreasing for 1 hour, the cavity was high pressure rinsed for 6 hours. The last treatment before vertical test was baking at 140 °C for 48 hours.

After all the treatments, PKU4 was assembled to the vertical test stand for cold test. The first vertical test result showed that the accelerating gradient E_{acc} of the cavity reached 23.8 MV/m and the Q_0 was 6.9×10^9 at highest gradient, see Fig. 3. No field emission was found during the test. The Q_0 was somewhat affected by the pickup antenna because the transmitted quality factor Q_t of the antenna was lower than usual, which led to more loss on the pickup antenna. Temperature mapping (T-mapping) was used to measure the temperature distribution on the surface of the cavity during vertical test. T-mapping showed that the quench location was at the 3rd cell from the fundamental power coupler side. Optical inspections were applied both after the first EP and after the vertical test. Some defects were found in the inner surface near equator area and the defects locations were identical with the quench location determined by T-mapping.

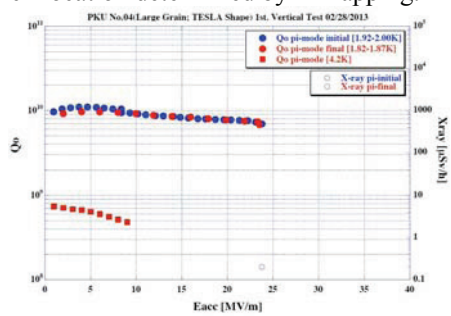


Figure 3: the first vertical test result of PKU4.

To improve the performance, local grinding technique was used to remove the defects around the quench location of PKU4. After local grinding, another 20 μm EP was done to the cavity followed by 7 hours HPR and baking at 140 °C for 44 hours. After the above processes, the second vertical test was carried out. At this time, the pickup antenna was shortened to make the Q_t close to 10^{11}. The test result (see Fig. 4) showed that the maximum E_{acc} of PKU reached 32.4 MV/m and the Q_0 at $E_{acc,max}$ was 1.3×10^{10} at 1.5 K. At 1.8 K, the E_{acc} was 32.6 MV/m and

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the Q_0 was still above 1.0×10^{10}. PKU4 has reached the requirement for ILC both in gradient and intrinsic quality factor.

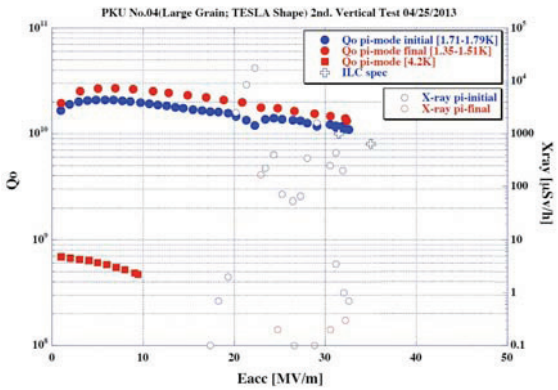

Figure 4: the second vertical test result of PKU4.

CONCLUSIONS

Based on many years technical accumulation, progresses on SRF cavity with high accelerating gradient have been made at Peking University. 4 9-cell TESLA cavities have been fabricated and tested. All the gradients are above 22 MV/m. The Q values for large grain cavities are higher than 1.0×10^{10}. The maximum gradient reached to 32.4 MV/m and Q_0 is above 1×10^{10} for the newest large grain 9-cell cavity PKU4. It is the first cavity which has reached the requirement for ILC both in accelerating gradient and intrinsic quality factor in China. More researches for high gradient and Q value will be carried out in the near future.

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