SRF ACTIVITIES AT PEKING UNIVERSITY*

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Abstract

Superconducting RF technology has been developed at Peking University for more than 20 years. In the recent years, the researches are mainly focused on producing high performance superconducting cavities and installing the DC-SRF photocathode injector as well as related 2K cryogenic facility and other auxiliary equipment. The cavities designed and fabricated by Peking University mainly include TESLA type 9-cell cavities, 1.3 GHz 5-cell cavity for high current electron beam acceleration and 450 MHz spoke cavity for low energy proton acceleration. Vertical tests of the cavities indicate that the cavities show good performances and can be used for superconducting accelerators. The gradient of a 9-cell TESLA type cavity with end groups (PKU3) reaches 28.6 MV/m. To promote the industrialization process in China, a new company, Ningxia Orient Superconductor Technology Co., Ltd., was founded jointly by Ningxia OTIC and Peking University in 2011. The goal of this company is to produce various types of superconducting cavities and pure niobium materials with high quality.

INTRODUCTION

Superconducting RF technology has been developed at Peking University (PKU) since 1988. In the past twenty years, significant progresses have been made on superconducting cavities. Based on the preliminary experience accumulated at the early years, the first superconducting cavity in china, an L-band high beta cavity using Chinese niobium sheets, was fabricated by Peking University in 1994. At the end of 20th century, Nb-Cu sputtering technology was developed for construction SRF QWR as a post Tandem accelerator. In the new century, efforts are made on high quality superconducting cavities for superconducting accelerators of free electron laser facility which is supported by China ministry of science and technology. Technologies for fabrication of multi-cell cavities are developed and a series of multi-cell cavities have been fabricated at PKU. To promote the SRF technology and meet the increasing demand for superconducting cavities in China and around the world, the idea to set up a company was agreed between PKU and Ningxia Orient Tantalum Industry Co. Ltd (OTIC). After 2 years preparation and based on the obtained SRF technology, a new company, Ningxia Orient Superconductor Technology Co., Ltd., was founded jointly by Ningxia OTIC and Peking University in 2011. In this paper, the recent progresses on SRF activities at Peking University are reported.

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PROGRESSES ON SRF CAVITIES

Technologies on fabrication of SRF cavities have been developed at PKU in the recent years. A series of superconducting cavities with Ningxia niobium have been fabricated, including both large grain cavities and fine grain cavities, single-cell to multi-cell cavities, high beta and low beta cavities.

Large Grain Cavities

Peking University has started researches on large grain niobium superconducting cavities since 2005. A series of large grain cavities have been made with Ningxia material by PKU under the collaboration with OTIC and Jlab. A 1.3 GHz single-cell cavity and a 2-cell TESLA type cavity were tested by Jlab and DESY respectively. Gradients are higher than 40 MV/m and Q values are higher than 1×10^{10} for both cavities [1,2]. A 3.5-cell large grain cavity for DC-SRF photoinjector is fabricated and the accelerating gradient reaches 23.5 MV/m and the Q_0 is above 1.2×10^{10} at the highest gradient [3].

Based on the above researches, a TESLA type 9-cell large grain cavity (PKU2) with end groups was fabricated at the end of 2009. After flatness tuning and RF measurement, the cavity was sent to Jlab for cold test. After 100 μm BCP, the cavity was degassed at 600°C for 10 hours. Another 80 μm BCP was added before the first cold test. At the first test in 2010, the maximum E_{acc} was 19.5 MV/m at 2.0 K with the Q_0 9×10^9, limited by quench. After the test, optical inspection was performed and defects were found near the equator electron beam welding seams. To improve the performance, the cavity was treated at 800°C for 2 hours and followed with 30 μm EP and 120 °C baking for 48 hours. The new RF test showed obvious improvement. The maximum gradient reached 22.4 MV/m at the final test at both 2.0 K and 1.8 K, see Fig. 1. The Q_0 is larger than 1×10^{10} at the high gradient: 2.0×10^{10} at 2K and 3.2×10^{10} at 1.8 K for 20 MV/m. The high Q value is very helpful to superconducting accelerator for ERL.

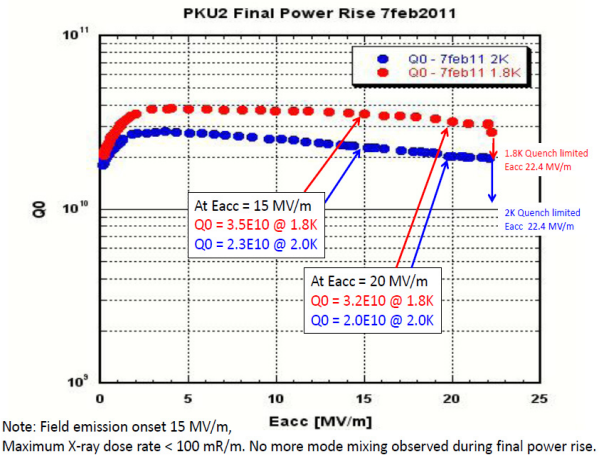


Figure 1: vertical test result of PKU2.

Two more large grain 9-cell cavities will be fabricated for the next step. We hope to avoid the defect near the welding seams so as to improve the accelerating gradient.

Fine Grain 9-cell Cavities

Besides large grain cavities, fine grain SRF multi-cell cavities have been made at PKU. 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 [4]. This cavity verified the material and the fabrication technology.

A new 9-cell fine grain TESLA type cavity (PKU3) with end groups was fabricated in 2009. After field flatness pre-tuning with the PKU tuning facility, PKU3 was sent to JLab in April 2010 for performance evaluation. After optical inspection of electron-beam welding seams, the cavity was ultra-sonic cleaned and etched for 10 μm of inner surface removal by buffered chemical polishing, followed by field flatness tuning. The flatness was 95.5%, which shows no degradation of cavity mechanical dimensions due to transportation. Successful bulk electropolishing of PKU3 was made. Furnace vacuum heat treatment was applied to the cavity at 800°C for 2 hours. After the field flatness was tuned to 97.9%, a light electropolishing of 25 μm was done. After high pressure water rinsing and clean room assembly, the first RF test was done. The maximum accelerating gradient was 20 MV/m at Q_0 of 2.3×10^9, limited by field emission. After partial disassembly, additional high pressure water rinsing was done, followed by the second RF test. The maximum accelerating gradient reached 28.6 MV/m at Q_0 of 4×10^9, limited by RF cable heating, see Fig. 2. The observed decrease of quality factor versus the gradient (Q-slope) might be due to the field emission by the sharp edges in the iris electron-beam welding regions. PKU3 is the first nine-cell cavity with end group components in China reaching a gradient usable for the ILC.

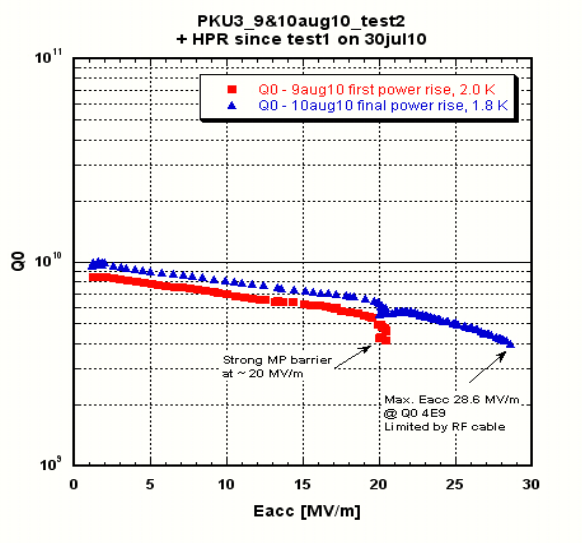


Figure 2: vertical test result of PKU3.

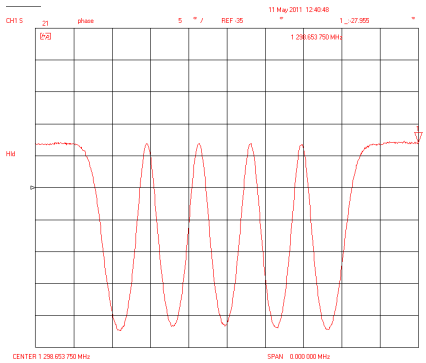
5-cell Cavity for High Current Accelerator

A 1.3 GHz 5-cell superconducting cavity is designed and fabricated by PKU. The cavity is a test cavity for high current accelerator under the collaboration between PKU and ANL. The designed parameters are shown in Table 1. The dies for deep drawing were designed and manufactured. After deep drawing, machining and RF measurements of components, the EB welding of the 5-cell cavity was finished in early 2011. The field flatness is 98.6% after tuning and the frequency is 1298.65 MHz at room temperature, see Fig. 3.

Table 1: Design parameters of 1.3 GHz 5-cell cavity

Frequency [MHz]	1300
Number of cell	5
R/Q (Ω)	466
E_{pk}/E_{acc}	2.43
B_{pk}/E_{acc} [mT/(MV/m)]	4.6
Geometry Factor	276
Coupling coefficient [%]	3.62
$K_{//}$ for σ_z=1mm [V/PC]	5.52
$k_{\perp}$ for σ_z=1mm [V/PC/m]	7.56
R_{iris} [mm]	41.2
R_{pipe} [mm]	48.7

(a)



(b)

Figure 3: 1.3 GHz 5-cell cavities for high current accelerator. (a) 5-cell cavity (b) field flatness after pre-tuning.

Spoke Cavities

Peking University has started the R&D program of single spoke cavity (SSC) [5]. The cavity is designed and fabricated for the HI-13 Tandem at CIAE. The designed frequency of the spoke cavity is 450 MHz and β=0.2. The designed parameters are shown in Table 2. In the PKU SSC Mark II, further optimization at magnetic field storage energy region is done to minimize B_{peak}/E_{acc} at the expense of E_{peak}/E_{acc}.

Table 2: Parameters of PKU single spoke cavity

Parameters	**PKU SSC**	**PKU SSC Mark II**
Frequency [MHz]	450	450
Beam pipe diameter [mm]	30	30
Geometrical beta	0.2	0.2
Transit time factor	0.80	0.80
G [Ω]	73	88
R/Q [Ω]	179	211
E_{peak}/E_{acc}	2.65	2.86
B_{peak}/E_{acc} [mT/(MV/m)]	5.22	3.90

Mechanical studies of the single spoke cavity are carried out to control the impacts of the various mechanical deformations. According to the optimization, six radial niobium stiffening ribs are added to the re-entrant region, and four niobium stiffening ribs are presented on the cylindrical portion of the cavity. The stiffening ribs significantly reduce the stress at iris and the maximum stress point is changed from the cavity body to the stiffening ribs. It also provides enough places for cavity tuning. The fabrication of the cavity is finished after the optimization, see Fig. 4.

After the fabrication, RF test and field flatness tuning were done to the single spoke cavity. Considering the shrinkage of cooling down to 4 K, the frequency will be changed by +0.62 MHz. Adding the effect of vacuum, the target frequency of room temperature tuning is 451.14 MHz. After the tuning process, the frequency is 451.27 MHz and the field flatness is still above 98% without special tuning for field profile.

The cavity was sent to Jlab for cold test. Preliminary test showed the gradient is 3 MV/m [6].

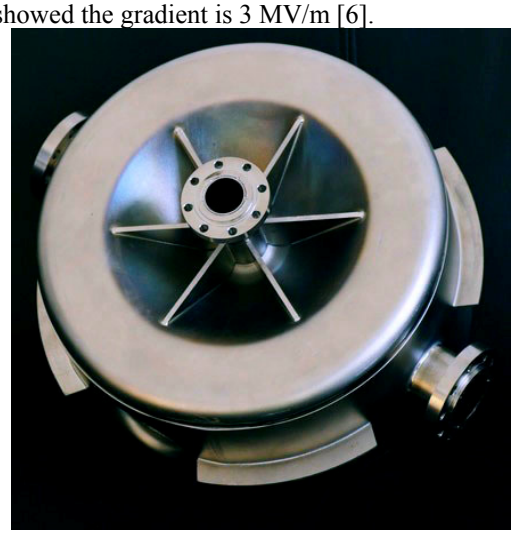


Figure 4: 450 MHz single spoke cavity.

EFFORTS TO INDUSTRIALIZATION OF SRF CAVITIES

SRF technology is more and more used in large scientific facilities around the world. In the future, a large quantity of superconducting cavities will be demanded for future project such as XFEL, ADS, ILC, etc. Only industrialization can fulfil the increasing requirement of SRF cavities.

Peking University started to pay attention to industrialization several years ago. PKU has deep cooperation relationship with OTIC for many years. Both parts agree to promote the industrialization of SRF cavities in China.

OTIC has developed the technology for production of high pure niobium material. High pure niobium sheets can be provided to laboratories around the world to fabricate SRF cavities. PKU has done researches on SRF cavities and accelerators for more than 20 years and a lot of experiences on SRF technology have been accumulated. Test results of a series of superconducting cavities qualified both the material produced by OTIC and the fabrication technique at PKU.

Based on the progresses, PKU and OTIC decided to organize a company to drive the SRF technology. The conception was born in 2009. After 2 years preparation, a new sub-company called Ningxia Orient Superconductor Technology Co., Ltd., run jointly by OTIC and PKU, was founded in February 2011 as a forward-looking action. It is dedicated to superconducting materials and components supply and the main purposes of the company are to develop SRF technology and promote its industrialization process. We hope the company can not only provide high quality superconducting materials, but also provide various types of superconducting cavities including TESLA type cavities, high current cavities, mid to low

beta cavities, etc. A new workshop is designed and will be set up in Ningxia soon. The material preparation, deep drawing, machining, EB welding, high temperature treatment will be done in Ningxia. A new EB welding machine is contracted and will be commissioned next year. PKU is in charge of RF measurements, quality control, surface treatment and vertical tests of the cavities. The vertical test system is financed and will be built at PKU. We expect that the first multi-cell cavity is to be fabricated by the company within 2 years.

CONCLUSIONS

Progresses on SRF cavities have been made at Peking University in recent years. A series of large grain cavities have been fabricated and the test results show good performance. Three 9-cell TESLA type cavities are fabricated and the maximum gradient is 28.6 MV/m. A 5-cell prototype cavity for high current accelerator is fabricated for ANL. Sing-spoke cavities are designed and fabricated for proton acceleration. Based on the SRF technology for fabrication of superconducting cavities, a new company, Ningxia Orient Superconductor Technology Co., Ltd., was founded jointly by Ningxia OTIC and Peking University, to promote the industrialization process of SRF cavities in China

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