CPC(HEP & NP), 2012, **36**(2): 156–159 **Chinese Physics C** Vol. 36, No. 2, Feb., 2012

Cold RF test and associated mechanical features correlation of a TESLA-style 9-cell superconducting niobium cavity built in China*

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Abstract: The RF performance of a 1.3 GHz 9-cell superconducting niobium cavity was evaluated at cryogenic temperatures following surface processing by using the standard ILC-style recipe. The cavity is a TESLA-style 9-cell superconducting niobium cavity, with complete end group components including a higher order mode coupler, built in China for practical applications. An accelerating gradient of 28.6 MV/m was achieved at an unloaded quality factor of 4×10^9. The morphological property of mechanical features on the RF surface of this cavity was characterized through optical inspection. Correlation between the observed mechanical features and the RF performance of the cavity is attempted.

Key words: superconducting cavity, unloaded quality factor, field emission

PACS: 29.20.Ej **DOI:** 10.1088/1674-1137/36/2/010

1 Introduction

The superconducting radio frequency (SRF) cavity is an enabling technology for many accelerator-based sciences. Peking University launched its 9-cell cavity program in 2004. Up to now, three 9-cell cavities have been built by Peking University SRF Group, two fine grain cavities and one large grain cavity. All of them are 1300 MHz TESLA-style 9-cell cavity specification [1]. The first fine grain cavity, without high order mode (HOM) couplers and other parts at the end-groups, has been tested at the Thomas Jefferson National Accelerator Facility, and it achieved an accelerating gradient of 23 MV/m with no quench [2]. The cavity reported in this paper is the second fine grain 9-cell TESLA-style cavity and is the first full fine grain 9-cell cavity with complete end-group components including the input coupler port, HOM coupler ports and pick-up field probe port. It is made of high purity niobium (Residual Resistivity Ratio 300) sheets produced by Ningxia Orient Tantalum Industry Co. Ltd. The cavity parts are formed using a standard deep drawing method. After trimming for weld prep and chemical etching, the cavity parts are joined together using an electron beam welding method. After initial tuning for field flatness, the

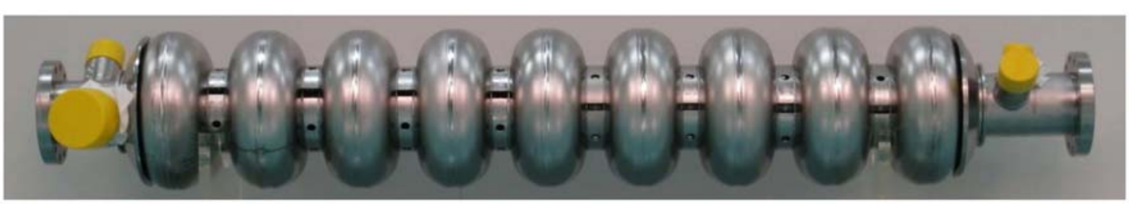

Fig. 1. The 9-cell TESLA-style superconducting RF niobium cavity PKU3.

Received 27 May 2011
* Supported by Major State Basic Research Development Program of China (973 Program)

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cavity was sent to the Thomas Jefferson National Accelerator Facility for processing and RF testing at cryogenic temperatures. Fig. 1 shows a picture of the completed cavity. This paper presents the chemical treatment history, the correlation between the cavity RF performance and the observed mechanical features.

2 Chemical treatment history and RF test

When this cavity was received at Jefferson Lab, it was treated in accordance with the base line ILC procedure [3]. After a 10 μm Buffer Chemical Polish (BCP), a 120 μm surface of this cavity was etched by a heavy Electric Polish (EP) treatment, followed by 2 h of vacuum furnace heat purification at 800 ℃. Subsequently, 25 μm light EP followed by 48 h of 120 ℃ low temperature baking was performed. High pressure rinsing (HPR) followed each treatment.

Then the first cold RF test for this cavity was performed by setting the π mode frequency 1300.507 MHz at 2 K low temperature. During the first power rise, the initial Q_0 value was 7.2×10^9 at a low field of 2 MV/m. As the applied field was increased, field emission appeared at 7.4 MV/m, distinguished at 11.3 MV/m (X-ray dose rate 4 R/h). At 16 MV/m, a massive field emission was initiated, and the Q_0 value degraded afterwards. In order to alleviate the field emission, RF processing was performed during the second power rise. Later, during the third power rise, the Q_0 value recovered. Eventually, the gradient reached 20 MV/m, and the Q_0 value was 2.5×10^9 (see Fig. 2).

Based on the undesirable field emission during the first RF test, the cavity was disassembled and HPR

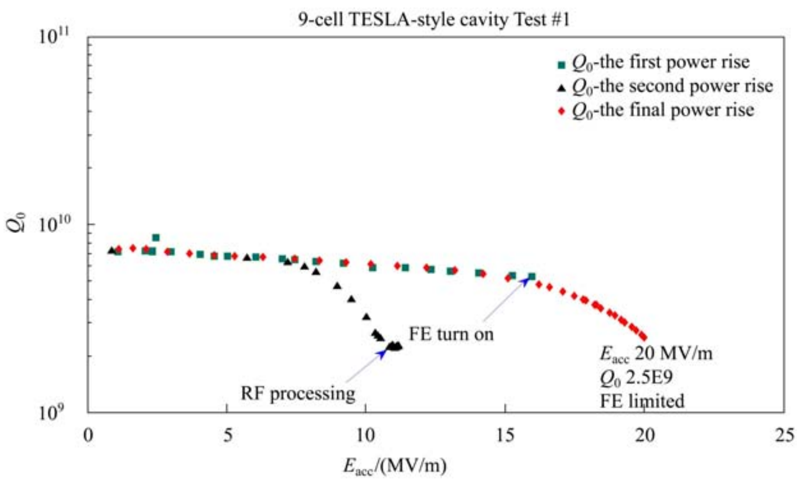

Fig. 2. The first RF test of PKU3.

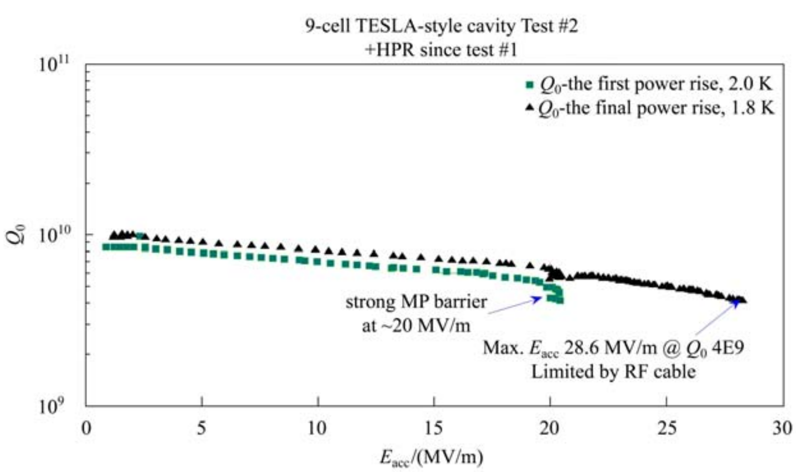

Fig. 3. The second RF test of PKU3.

was performed to remove any spots that were suspected of causing field emission. During the first power rise of the 2nd test, low field Q_0 achieved 8.4×10^9 at 2 K. This was a 17% improvement over the initial test, as shown in Fig. 3. The first Field Emission induced X-ray was observed at 9.1 MV/m. Above 15 MV/m, each time the field was raised, there would be quench events. Eventually, a maximum gradient of 20.5 MV/m was attained, being limited by radiation.

The cavity was then pumped down to 1.8 K, and the power was raised again. At 20 MV/m, massive field emission was initiated. Some CW RF conditioning was carried out at this gradient. Finally, the gradient reached 28.6 MV/m at $Q_0=4\times10^9$ (see Fig. 3), limited by RF cable limitation, with no quench.

3 Discussion under optical inspection technology

The inspection tool used here is a high-resolution optical inspection machine ("Kyoto camera") loaned to the Jefferson Lab by KEK. A detailed description of the Kyoto camera can be found in Ref. [4]. Based on this inspection, the condition of the as-built cavity surface was documented in great detail. By tracking surface features and correlating them with the final RF test results, a criterion may be established which can be in turn used for the quality control of improved cavity fabrication. Similar efforts have been initiated at many other labs such as DESY [5] and KEK in the frame work of the European X-Ray Laser project and SRF cavity R&D for the ILC.

Since recent studies suggest that many performance-limiting defects are at or near the electron beam welding joints [6], special attention was given to this place (Electron Beam Welding (EBW) joints), including the weld itself and the associated heat affected region, at the iris and equator locations.

3.1 Cat-eye shape spot

On initial receipt of the cavity, an optical inspection of the inner surface was carried out prior to any chemistry procedure being applied. Some dust and suspicious spots (so-called cat-eyes) were found on the inner surface. Subsequently, 10 μm BCP etching was performed. After that, we observed this cavity again, and found that almost all the cat-eye shaped spots were removed. As shown in Fig. 4, a suspicious spatter which has a cat-eye shape was completely removed by 10 μm BCP. Typical results for all the noted spots are as follows (Fig. 4).

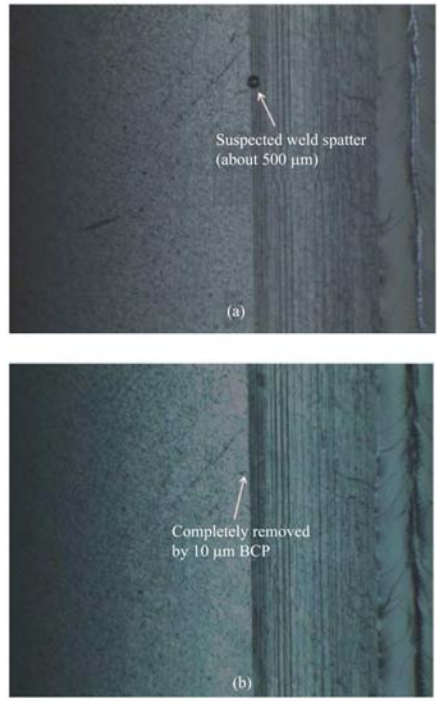

Fig. 4. A cat-eye spot was removed by 10 μm BCP. (a) Image before 10 μm BCP. (b) Image after 10 μm BCP.

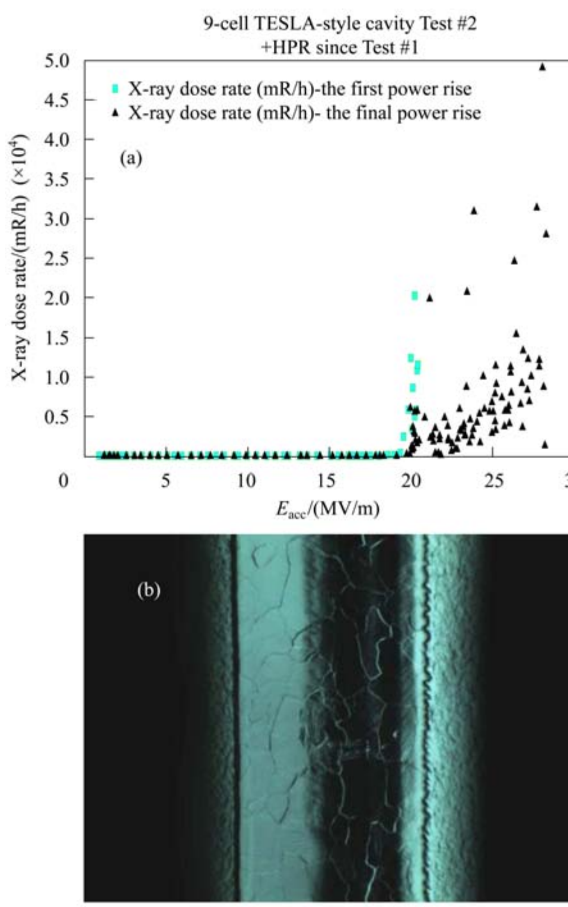

Fig. 5. (a) X-ray dose rate measurement during the second RF test. (b) Sharp edges found on one iris of PKU3.

3.2 Field emission

After the 1st RF test, Re-HPR 2 passes were performed to remove the potential particle which would cause field emission, but massive field emissions were still experienced. During the second test, at $E_{\rm acc}$ 28 MV/m, the X-ray dose rate reached 5×10^4 mR/h as shown in Fig. 5(a).

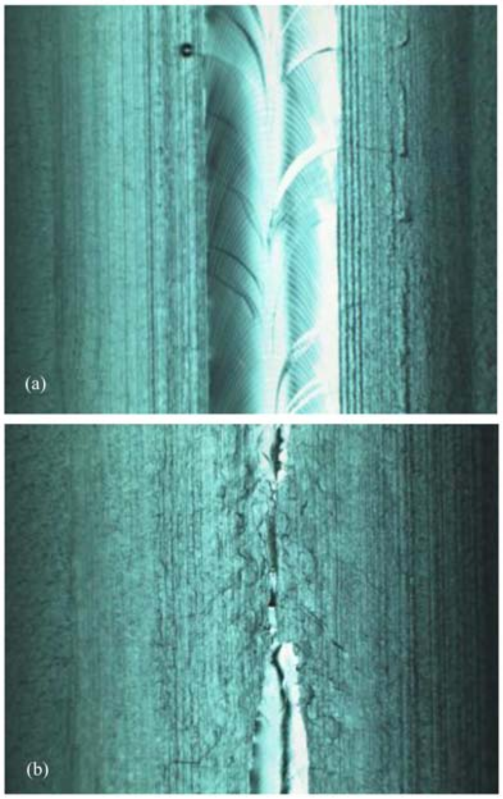

Fig. 6. (a) Typical equator EBW joint with smooth under bead. (b) Non-uniform weld in the overlapping region of some equator EBW.

A review of the optical inspection history identified sharp edges on the iris of this cavity (Fig. 5(b)). It is suspected to be a kind of defect candidate which can induce the observed field emission.

3.3 Low Q_0 value

During the second RF test, the gradient of this cavity reached 28.6 MV/m, but the unloaded factor $Q_0 = 4\times10^9$ is relatively low. A review of the optical inspection record identified several equator EBW areas with partial penetration.

In general, the inner surface of equator EBW joints appears to be smooth, and the re-crystallized grains and welding pool ripples are typical of a full penetration weld (Fig. 6(a)).

In some places, however, in particular at the overlapping region of the equator weld, the EBW becomes non-uniform in width or even lacks full penetration (Fig. 6(b)).

4 Summary

This is the second fine grain 9-cell cavity from Peking University. It was fabricated with an HOM coupler and end group parts. The ability to reach $E_{\rm acc}$=28.6 MV/m without quench indicates a big improvement in the cavity fabrication process developed in China and it demonstrates that we can use our home-made cavity to support the PKU-FEL program.

The author would like to express thanks to Dr. Geng for his support and helpful discussions during the course of this work.

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