SERIES TESTS OF HIGH-GRADIENT SINGLE-CELL SUPERCONDUCTING CAVITY FOR THE ESTABLISHMENT OF KEK RECIPE

T. Saeki#, F. Furuta, K. Saito, Y. Higashi, T. Higo, S. Kazakov, H. Matsumoto, Y. Morozumi, N. Toge, K. Ueno and H. Yamaoka, KEK, 1-1 Oho, Tsukuba-shi, Ibaraki-ken, Japan
M. Ge, IHEP, Beijing 100080, China
H. S. Kim, Kyungpook National University, 1370 Sankyuk-dong, Buk-gu, Degu 702-701, Korea
R. S. Orr, University of Toronto, Toronto M5S 1A7, Ontario, Canada / JSPS, Japan

Abstract

We have performed a series of vertical tests of single cell Nb superconducting cavities at 2 degrees Kelvin. These tests aimed at establishing the feasibility of reaching an accelerating gradient of 45 MV/m on a routine basis. The cavity profiles were all of the KEK low loss design and were fabricated from deep-drawn Nb half cups using electron beam welding. The cavity surface preparation followed an established KEK procedure of centrifugal barrel polishing, light chemical polishing, high temperature annealing, electro-polishing, and finally a high pressure water rinse. Of the six cavities tested, three exceeded 44 MV/m on the first test and the rest of three also exceeded 44 MV/m after additional electro-polishing. This clearly establishes the feasibility of this gradient.

INTRODUCTION

We are planning to construct Superconducting RF Test Facility (STF) at KEK for the R&D of ILC accelerator in the next four years [1]. Although we are planning to install four TESLA-like 9-cell cavities and four high-gradient Low-Loss (LL) type 9-cell cavities into STF, the feasibility of the LL cavity and the KEK recipe had not been studied rigorously. In order to check the feasibility, we performed series tests using six LL-type single-cell cavities which are surface-treated by the KEK recipe.

In this article, the fabrication of six LL-type single-cell cavities, details of the KEK recipe, the proof of principle of 50 MV/m with the LL-type single-cell cavity, and the results of series tests will be presented.

FABRICATION OF SIX LL-TYPE SINGLE-CELL CAVITIES

The cell-shape of LL-type cavity for STF is designed at KEK in collaboration with DESY to achieve the gradient of 51 MV/m. It was named as ICHIRO cavity after a famous Japanese baseball player because his back number is 51. The cell-shape is optimized to have the relatively lower Hp/Eacc ratio of 36 Oe/(MV/m) if compared with TESLA type [2]. The ICHIRO 9-cell cavity has three different cell-shapes where a central-shape for central seven cells and two different shapes for end-cells. The six ICHIRO Single-cell (IS) cavities have the same cell-shape as the central-cell of ICHIRO 9-cell cavity. Twelve Nb sheets were deep-drawn into half-cups and six cells and twelve beam-pipes with the diameter of 60 mm were assembled into six IS cavities by Electron Beam Welding (EBW). We named these six IS cavities as IS#2, IS#3, IS#4, IS#5, IS#6, and IS#7.

#takayuki.saeki@kek.jp

KEK RECIPE

The fabricated six IS cavities were surface-treated by the KEK recipe. The KEK recipe consists of Centrifugal Barrel Polishing (CBP), light Chemical Polishing (CP), annealing / degassing, Electro-Polishing (EP), High-Pressure Rinse (HPR), and baking. The details of each process are followings.

Centrifugal Barrel Polishing (CBP)

This process removes the inner surface of cavity mechanically. Stones and water are put into the cavity and it is tumbled by a special machine. The schematic action of CBP and the picture of the CBP machine are shown Figure 1. This process aims at removing defects of Nb material and obtaining smooth surface at the EBW-seam.

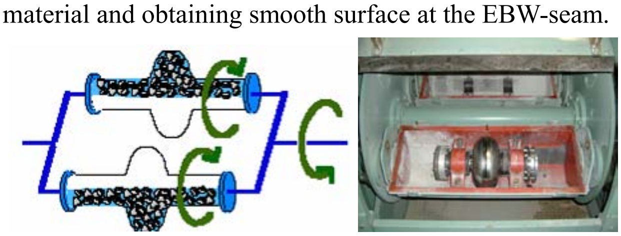

Figure 1: Centrifugal Barrel Polishing (CBP).

It takes 4 hours for one CBP process. The removal thickness per process depends on the kind of stones to use. We have one kind of rough-stone and three kinds of fine-stones. The removal thickness of a rough-stone process is about 30 um, and that of a fine-stone process is about 10-20 um. The default KEK recipe includes three rough-stone processes and three fine-stone processes, which remove about 135 um in total. But the total removal thickness depends on the roughness of EBW-seam at the equator of cell. The removal thicknesses of six IS cavities were ranging from 135 um to 235 um.

Light Chemical Polishing (CP)

This process removes the inner surface of the cavity chemically. The purpose of light CP is to remove contamination in CBP and prepare smooth surface before EP. The chemical is the mixture of HF(46%), HNO_3(60%) and H_2PO_4(85%) at the volume-to-volume ratio of 1 : 1: 1. The removal speed is about 1 um/min. at the temperature of 25 ^{O}C. The removal thickness is 1 um for the KEK recipe.

Annealing / Degassing

In order to release the mechanical stress of the cavity and to remove hydrogen gas in the material, annealing / degassing is performed at 750 ^{O}C for 3 hours. The temperature and duration are optimized for the cavity performance and cost in the KEK recipe.

Electro-Polishing (EP)

The setup of EP at Nomura Plating Co. / KEK is shown in Figure 2. The EP acid solution is the mixture of HF(46%) and H2SO4(>93%) at the volume-to-volume ratio of 1 : 10.

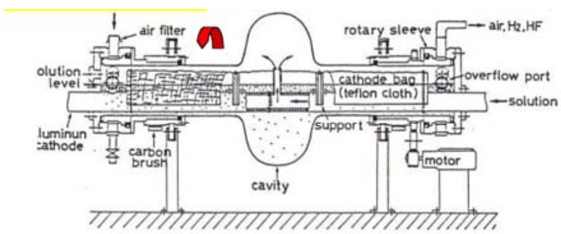

Figure 2: Setup of EP process at KEK.

During an EP process, the cavity is rotated horizontally at 1 rpm. Typical voltage and current for a single-cell cavity process is about 20 V and 40 A. Details of EP at KEK is found elsewhere [3]. In the series tests, the removal thickness was 80 um.

High-Pressure Rinsing (HPR)

Immediately after EP process, the cavity is rinsed with Pure-water (PW) and then High-Pressure Rinse (HPR) is applied. In a HPR process, pressurized Ultra-Pure Water (UPW) comes out from a nozzle inserted in a cavity and the UPW hits the inner surface of cavity which is lifted up and down with rotational motion. The specification of UPW includes resistivity = 18 M Ohm cm, TOC = 10 – 20 ppb, and bacteria count = 0 – 5 counts / mL. The HPR process was applied for 1 hour.

Assembly and Baking

After HPR process, the cavity is moved into a class-10 clean-room for assembly with an RF input-coupler and pick-up antenna on each end of cavity, respectively. After pumping the inside of cavity, the cavity is baked at 120 ^{O}C for 48 hours to defuse the oxidation layer on the inner surface of cavity. After the baking, a valve at the vacuum port of input-coupler is closed to keep the vacuum of the inside of cavity in the following vertical test.

PROOF OF PRINCIPLE FOR 50 MV/M WITH ICHIRO SINGLE-CELL CAVITY

In the series tests, IS#4 reached the gradient (Eacc) of 53.5 MV/m at the Q factor of 7.83e9, which is the world record. The Q-versus-Eacc plot for this measurement is shown in Figure 3. This test clearly shows that the proof of principle for the gradient of 50 MV/m by ICHIRO-shape single-cell cavity.

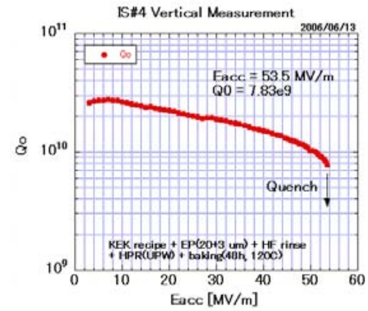

Figure 3: Q vs. Eacc plot for IS#4. The gradient of 53.5 MV/m is the world record in SRF single-cell cavity.

SERIES OF VERTICAL TESTS

After all six IS cavities were treated with the KEK recipe, the first vertical test was done for each cavity. The resultant Q-versus-Eacc plots are shown in Figure 4.

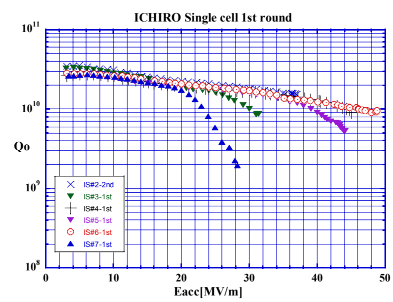

Figure 4: Q-versus-Eacc plots for six IS cavities on the first trial of the KEK recipe.

The IS#4, #5, and #6 achieved the gradient of >44 MV/m, but the rest of three failed as shown in Table 1. Thus the yield rate of IS and the KEK recipe is 50 % on the first trial. The failed three tests are limited by field-emission (IS#7), Q-slope (IS#3), and quench (IS#2).

Why is the Yield Rate 50% for >44 MV/m?

We classified the sources of failure into three categories. Failures by easy-mistakes in HPR or assembly in clean-room arising particle-contamination are classified as category-1. These failures might cause Field-Emission (FE) and should be recovered by re-HPR. Failures from sulphur- or oxidation-contamination in EP are classified as category-2, which might cause Q-slope, and might be recovered by light-EP with fresh EP acid or light-CP. Failures by defects of material or roughness at the EBW-seam are classified as category-3, which might be recovered by CBP with heavy removal.

50% Failure were Recovered

In order to recover the three failed cavities, we applied additional surface-treatments as shown in Table 1. We firstly applied re-HPR, and also tried HF-rinsing for 20 minutes with the removal thickness of 0.2 um as a pilot

Table 1: Results of series tests with six ICHIRI Single-cell (IS) cavities.

Surface treatments		**IS#2**	**IS#3**	**IS#4**	**IS#5**	**IS#6**	**IS#7**
KEK recipe	Eacc [MV/m]	36.9	31.4	45.1	44.2	48.8	28.3
	Q factor	1.53e10	8.66e9	9.07e9	5.38e9	9.56e9	1.94e9
+ Re-HPR		37.6	32.7	42.7		51.4	29.9
		1.42e10	7.27e9	5.66e9		7.78e9	1.1e10
+ HF rinse + HPR		37.1 *	36.7	50.4 *		50.2	30.0 *
		1.64e10	1.43e10	9.97e9		3.9e9	3.33e9
+ CP (10 um) + HPR + Baking						41.0	40.5
						6.65e9	5.57e9
+ EP (fresh acid, 3 um) + HPR + Baking		41.6 *	40.3 *	41.1 *			
		1.00e10	1.28e10	1.17e10			
+ EP (20-30 um)+EP (3 um) + HPR + Baking		47.1		47.8			
		1.06e10		7.81e9			
+ EP (20-30 um)+EP (3 um) + HF rinse + HPR + Baking			44.7 *	53.5			43.9 *
			9.8e9	7.83e9			1.17e10

study of recipe. The Q-factor of IS#7 was recovered, but there was no significant improvement in gradients. Secondly, we applied light-CP (10 um) and light-EP (3 um) with fresh EP acid. The gradients were improved up to around 40 MV/m as shown in Table 1. Finally, we tried normal EP (20-30 um) + EP (fresh acid, 3 um) and optional HF-rinse. Then all failed cavities successfully reached the gradient of >44 MV/m. These results clearly show that the source of failure exists within the depth of around 30 um (category-2).

No Hydrogen Q-disease

In the series tests, we checked hydrogen Q-disease by re-measuring cavities after warming-up and keep them at around 100 K for more than 12 hours. In total, we tested 8 times with 4 cavities. No Q-disease was found. The tests in which Q-disease check was done are marked at the right-side of Eacc number with an asterisk in Table 1.

Histograms of Gradients

We made a histogram of gradients for all tests. We counted even several repeated tests for one surface-treatment, where we just added liquid He, warmed-up to 100K and so on. The histogram has the mean of 38 MV/m and the sigma of 9 MV/m. After removing tests with FE and Q-slope, we made the histogram of the gradient as shown in Figure 5, where the mean is 44 MV/m and the sigma is 6 MV/m.

SUMMARY AND ACKNOWLEDGEMENTS

In the series tests of six IS cavities, three cavities exceeded the gradient of 44 MV/m on the first trial of the KEK recipe. The rest of three also exceeded 44 MV/m after additional EP (20-30 um) + EP (fresh EP acid, 3 um) and optional HF-rinse. This clearly shows that the source of the failure exists within the depth of around 30 um. There was no hydrogen Q-disease found in the tests. The mean and sigma of the gradients for all tests without FE and Q-slope are 44 MV/m and 6 MV/m, respectively. We would like to acknowledge Nomura Plating Co. and Cryogenic Science Center at KEK.

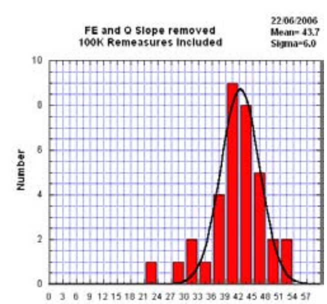

Figure 5: Histogram of the gradients in the tests

REFERENCES

[1] K. Saito, "SRF test facility towards ILC", this proceedings.

[2] F. Furuta et al., "Experimental comparison at KEK of high gradient performance of different single cell superconducting cavity designs", this proceedings.

[3] K. Saito et al., "R&D of Superconducting Cavity at KEK", Proceedings of 4th Workshop on RF Superconductivity, Vol. 2, Aug. 1989, KEK, Japan.