OPTIMIZATION OF SURFACE TREATMENT OF HIGH GRADIENT SINGLE CELL SUPERCONDUCTING CAVITIES AT KEK

F. Furuta*, K. Saito, T. Saeki, R. S. Orr, H. Inoue, Y. Morozumi, T. Higo, Y. Higashi, H. Matsumoto, S. Kazakov, H. Yamaoka, K. Ueno and M. Sato
KEK, High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba 305-0801, Japan

Abstract

We have continued the study of a series of single cell superconducting cavities at KEK. These tests are for establishing surface treatment that would reliably allow cavities to reach gradients over 45 MV/m in vertical tests. The all cavity have the low loss (LL) shape [1]. They were fabricated from deep drawn niobium half shells with RRR=300 using electron beam welding. The KEK cavity preparation so called KEK recipe followed by the cavity fabrication. Early results from this series test demonstrated that reaching gradients as high as 50 MV/m was feasible, however, the yield rate was of order 50%. In this paper we will report our studies of further improvement of the surface treatment aimed at increasing the yield rate.

INTRODUCTION

In past ten years, the gradient of niobium superconducting RF cavity seems to be saturated around 40 MV/m. The question is whether this is due to technical limitation or fundamental one due to niobium material. A thesis of the fundamental limitation was proposed by K.Saito in 2001 [2], where the RF critical field H_{CR} was estimated to be 1750 ±150 Oe. The TESLA cavity shape has a 42.6 Oe/[MV/m] of Hp/Eacc ratio so that it corresponds to accelerating field Eacc of 41MV/m. It was proposed to use a new cavity shape with a lower Hp/Eacc ratio, then Eacc~50MV/m would be possible even under the magnetic RF limitation [2,3]. On the other hand new cavity designs with lower Hp/Eacc ratio were proposed in 2002. One is the Low loss (LL) shape by J. Sekutowicz [1] and the other is Re-entrant (RE) shape by V. Shemelin. [4]. KEK made a small modification on the LL shape with the cell taper angle 89^{O} (LL) to 90^{O}, of which shape is called as IS here. Cornell group has demonstrated 46MV/m with RE-entrant cavity using their own electropolishing technique in 2004 [5]. We have made a more systematic study to verify Saito's thesis, using three different cavity shapes; LL, RE, and IS. In this paper, the proof of principle of 50 MV/m with these new cavity shapes is presented with explaining details of the KEK recipe and the results of series tests.

PROOF OF PRINCIPLE FOR 50 MV/M

Three cavities with low Hp/Eacc were fabricated; RE by Cornell [4], LL and IS by KEK. The comparison of the shape is shown in Fig. 1 (IS is not presented here but very similar to LL). RF cavity parameters are summarized in Table 1. Since RE and LL shapes have 15% lower values in Hp/Eacc ratio than that of TESLA one, it is expected to reach a higher gradient of 47-53MV/m. The RE cavity was fabricated in Cornell University. It was annealed at 1400 °C before shipping to KEK. All other cavities were made at KEK without such a high-temperature annealing. After the cavity fabrication, we applied them the KEK standard recipe as the surface preparation. The details of KEK recipe were described in the next section. After the surface preparation, these cavities were evacuated and baked at 120 °C for 48hours. Then they are closed with

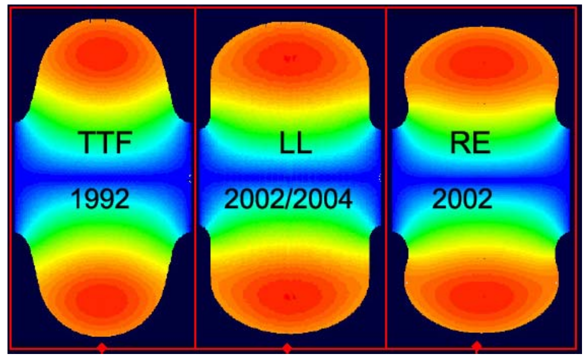

Figure 1 : Comparison of single cell shapes.

Table 1: Cavity RF parameters

	TESLA	LL	RE
Diameter [mm]	70	60	70
Ep/Eacc	2.0	2.36	2.40
Hp/Eacc [Oe/MV/m]	42.6	36.1	37.8
R/Q [W]	113.8	133.7	120.6
Γ [W]	271	284	280
Eacc max [MV/m]	41.1	48.5	46.3

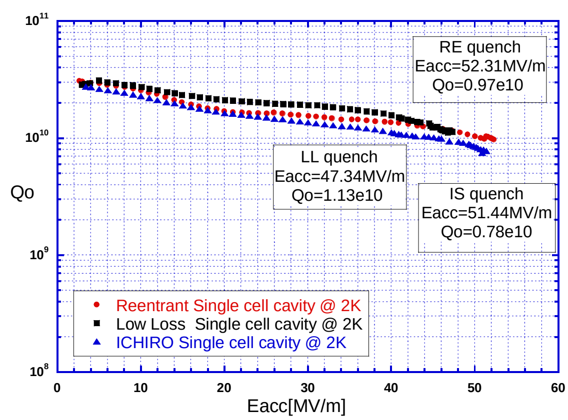

Figure 2: The best result of each cavity shape.

*furuta@post-cbandlc.kek.jp

metal valve and tested in a vertical cryostat at 2 K. The best result of cavity performance is the achieved highest gradient 52.3MV/m with Qo=0.97e10 @ 2K. For the LL and IS cavities, Eacc achieved 47.3MV/m with Qo=1.13e10, and 51.4 MV/m with Qo=0.78e10, respectively. These results fit Saito's theoretical estimation (Fig. 3). As seen in Fig. 4, a new breakthrough to Eacc~50 MV/m was achieved. These results also have convinced us the current KEK recipe.

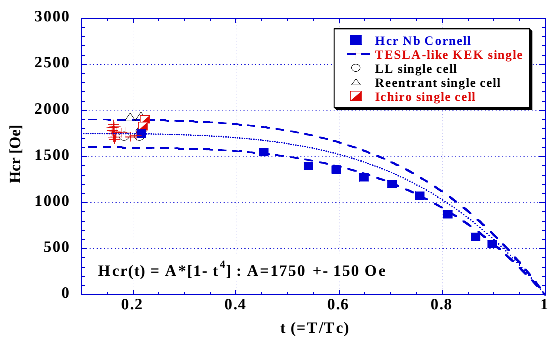

Figure 3: The experimental RF critical field.

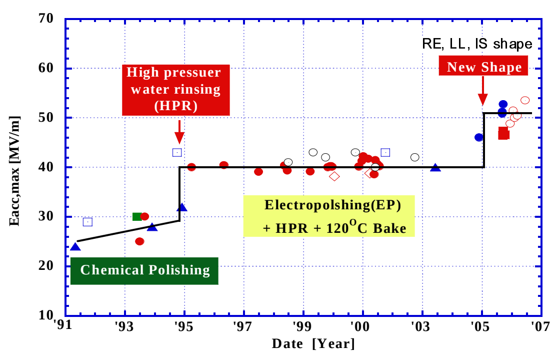

Figure 4: The breakthrough to 50MV/m.

KEK STANDARD RECIPE

After this principle proof of the 50MV/m with new shapes, we performed a series of tests with IS cavities in order to check the yield rate of high gradient. These six cavities were surface-treated by the KEK recipe. This recipe consists of centrifugal barrel polishing (CBP), light chemical polishing (CP), annealing, electropolishing (EP), high-pressure ultra pure water rinsing, and baking. The details of each process are followings.

CBP removes the inner surface of cavity mechanically. Stones and water are put into the cavity and they are tumbled by a special machine [6]. This process removes large defects on cavity inner surface and makes smooth the equator EBW seam locating high surface magnetic field region.

The light CP removes the inner surface by 10 μm to eliminate abrasive contamination during the CBP. The chemical is the mixture of HF (46%), HNO_3 (60%) and H_2PO_4 (85%) of a volume ratio 1:1:1. The removal speed is about 10 μm/min. at the temperature of 25 °C.

In order to release the mechanical stress of the cavity and to degas hydrogen absolved during the CBP, annealing is performed at 750 °C for 3 hours. The temperature and duration are optimized for the cavity mechanical performance and cost.

Original ideas and basic studies of EP at KEK are found [7]. The EP acid is the mixture of HF (46%) and H_2SO_4 (>93%) of a volume ratio 1: 10. During electropolishing, the cavity is kept horizontally and rotated at 1 rpm. Typical voltage is about 20 V and current 40 A (50mA/cm^2) with single cell cavity. The acid temperature in the cavity is below 35°C. In the series tests, the removal thickness was 80 μm.

Immediately after the EP process, the cavity is rinsed with ultra pure water followed by HPR. In the HPR process, pressurized ultra pure water (UPW) comes out of nozzles inserted in a cavity and the UPW jet hits the inner surface of cavity that is lifted up and down with rotational motion. The specifications of UPW are the resistivity > 18 M Ohm cm, TOC < 20 ppb, and bacteria count < 5 counts / mL. The HPR duration is one hour.

After the HPR process, the cavity is transported to KEK in a couple of hours in a wet condition and in a vertical position. It is moved into a class10 clean room to put an RF input coupler and pick-up antenna on each end beam pipe of the cavity. After pumping down, the cavity, it is baked at 120 °C for 48 hours to diffuse the oxygen contamination on the inner surface. After the baking, a metal valve at the vacuum port of input coupler is closed to keep the cavity vacuum in the following vertical test.

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 Q-versus-Eacc plots are shown in Figure 5. The IS#4, #5, and #6 achieved the gradient of >44 MV/m, but the rest three failed as shown in Table 2. Thus the yield rate of 45MV/m level was 50 % on the first trial. The three tests are limited at the gradient of 28~37 MV/m by field emission and quench.

The failures were classified into three categories. Failures by mistakes in HPR or assembly in clean room resulting in particle-contamination are classified as category-1. The field emission (FE) would be due to this category. These failures might should be recovered by re-HPR. Failures due to sulphur or oxidation contamination in EP are classified as category-2, which might cause Q-slope or field emission, and might be recovered by light-EP with fresh EP acid or light-CP.

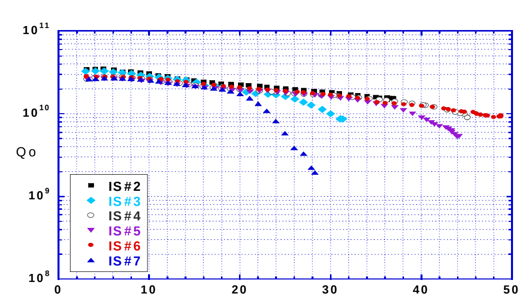

Figure 5: The first trial results for six IS cavities.

Failures due to defects of material or roughness at the EBW seam are classified as category-3, which might be recovered by CBP with heavy removal.

In order to recover the three failed cavities, we applied additional surface-treatments as shown in Table 2. We firstly applied re-HPR, and also tried HF-rinsing for 20 minutes as a pilot study of recipe. The Q-factor of IS#7 was recovered, but there was no significant improvement in gradients. Secondly, we applied light-CP (10µm) and light-EP (3 µm) with fresh EP acid. The gradients were improved up to around 40 MV/m as shown in Table 2. Finally, we tried normal EP (20-30 µm) + EP (fresh acid,

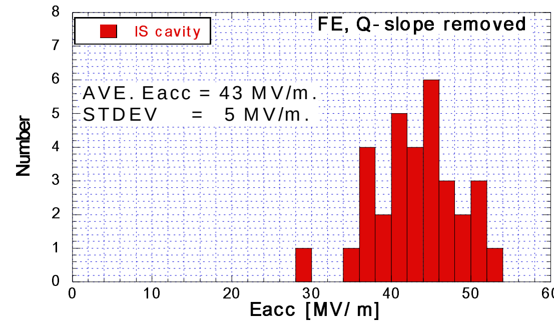

Figure 6: Histogram of the gradient in the tests.

Table 2: Results of series tests of six ICHIRO Single-cell (IS) cavities

		IS#2	IS#3	IS#4	IS#5	IS#6	IS#7
KEK Recipe	**Eacc**	**36.9**	**31.4**	**45.1**	**44.2**	**48.8**	**28.3**
	Qo	**1.33e10**	**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		**37.1 ***	**36.7**	**50.4 ***		**50.2**	**30.0 ***
+HPR		**1.64e10**	**1.43e10**	**9.97e9**		**3.9e9**	**3.33e9**
+CP (10um)						**41.0**	**40.5**
+HPR+Baking						**6.65e9**	**5.57e9**
+EP (fresh acid, 3 um)		**41.6 ***	**40.3 ***	**41.1 ***			
+HPR+Baking		**1.00e10**	**1.28e10**	**1.17e10**			
+EP (20-30um)+EP (3um)		**47.1**		**47.8**			
+HPR+Baking		**1.06e10**		**1.17e10**			
+EP (20-30um)+EP (3um)			**44.7 ***	**53.5**			**43.9 ***
+HF rinse+HPR+Baking			**9.80e9**	**7.89e9**			**1.17e10**

3 µm) and optional HF-rinse. Then all failed cavities successfully reached the gradient of 45 MV/m level. These results clearly show that the source of failure stay within the depth of around 30 µm (category-2). In the series tests, we also checked hydrogen Q-disease by re-measuring cavities after warming-up and keep them at around 100 K for longer 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 2.

STATSTICS OF THE GRADIENT

We made a histogram of reached gradients for all IS cavities results. We counted even several repeated tests for one surface treatment like the test where we just added liquid He, warmed-up to 100K and so on. The histogram has the mean of 38±10 MV/m. After removing FE and Q-slope, we made the histogram of the gradient as shown in Figure 6, where the mean is 43±5 MV/m.

SUMMARY AND ACKNOWLEDGEMENTS

Three new cavity shapes of RE, LL, and IS with low Hp/Eacc were fabricated and tested. These cavities achieved a gradient of between 47MV/m and 52MV/m. In the series tests of six IS cavities, the yield rate was 50% with 45 MV/m level on the first trial of the KEK recipe. The rest three also exceeded 45 MV/m level after additional EP (20-30 µm) + EP (fresh EP acid, 3 µm) and optional HF-rinse. This clearly shows that the source of the failure exists within the depth of around 30 µm, which suggests us the limitation by contamination. 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 43 MV/m and 5 MV/m, respectively. We would like to acknowledge Nomura Plating Co. and Cryogenic Science Center at KEK.

REFERENCES

[1] J. Sekutowicz et al., JLAB-TN-02-023, June 2002.
[2] K. Saito, Proc. of 10th Workshop on RF Superconductivity, Tsukuba, Japan, 2001.
[3] K. Saito, Proc. of 11th Workshop on RF Superconductivity, Lubeck/Travemunde, Germany, Sept. 2003.
[4] V. Shemelin et al., Nulc. Instr. And Meth. A496 (2003) 1.
[5] R. Geng et al., Cornell Univ. SRF reports, SRF041014-03, 2004.
[6] T. Higuchi et al., Proc. of 10th Workshop on RF Superconductivity, Tsukuba, Japan, 2001.
[7] K. Saito et al., Proc. of 4th Workshop on RF Superconductivity, Vol. 2, KEK, Japan, Aug. 1989.