EXPERIMENTAL COMPARISON AT KEK OF HIGH GRADIENT PERFORMANCE OF DIFFERENT SINGLE CELL SUPERCONDUCTING CAVITY DESIGNS

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Abstract

We have performed a series of vertical tests of three different designs of single cell Niobium superconducting cavities at 2 degrees Kelvin. These tests aimed at establishing that an accelerating gradient of 45 MV/m could be reached in any of the designs, while using the standard KEK surface preparation. The designs tested were the Cornel re-entrant shape (RE), the DESY/KEK Low Loss shape (LL), and the KEK ICHIRO series. The cavities underwent surface preparation consisting of centrifugal barrel polishing, light chemical polishing, electropolishing, and final a high-pressure water rinse. All three kinds cavities were used in a series of vertical tests to investigate details of the surface treatment. When using ultra-pure water for the high pressure rinse, the LL cavity reproducibly exceeded a gradient of 45 MV/m, the RE design reproducibly reached a gradient of between 50 MV/m and 52 MV/m, and three of the six ICHIRO cavities reached a gradient of between 45 MV/m and 51 MV/m.

INTRODUCTION

High pressure rinsing (HPR) with ultra-pure water has brought a breakthrough with the niobium superconducting RF cavity, however, the gradient seems to be saturated around 40 MV/m. The question is in still technical limit or fundamental limitation due to niobium material. A thesis of the fundamental limit was proposed by K.Saito [1]. He estimated the critical field H_{CR} is around 1750 ±150 Oe (Fig.1). The TESLA cavity shape has a 42.6 Oe/[MV/m] of Hp/Eacc ratio. It corresponds to 41MV/m. He proposed to use a new cavity design with a lower Hp/Eacc ratio, then still ~50MV/m would be possible even under the magnetic RF limitation [2]. We have made a study to verify his thesis, using three different cavity shapes; Low loss (LL), Reentrant (RE), and ICHIRO shape (IS). This paper presents a new breakthrough of 50MV/m by these new shapes.

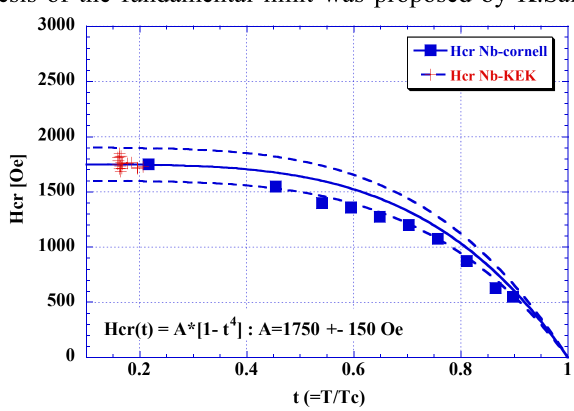

Figure 1: Fitting results of the experimental RF critical field.

CAVITY DESIGN

Three cavities with low Hp/Eacc were fabricated; RE by Cornell [3], LL by DESY [4], and IS by KEK/DESY in principle LL. The comparison of the shape is shown in Fig. 2. Cavity RF parameters are summarized in Table 1. Since RE and LL shape have a 15% lower in Hp/Eacc ratio than that of TESLA one, it is expected a higher gradient of 47-53MV/m.

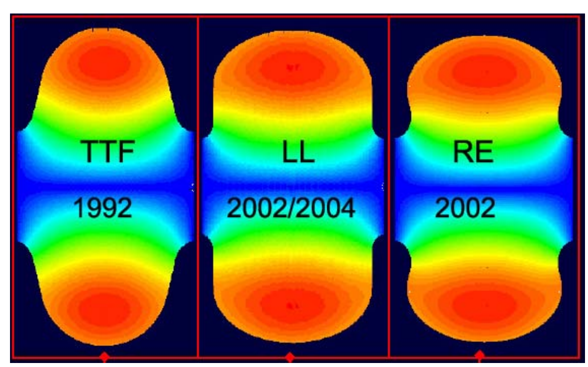

Figure 2: Comparison of single cell shapes.

Table 1: Cavity RF parameters

	TESLA	LL	RE	IS
Diameter [mm]	70	60	60	61
Ep/Eacc	2.0	2.36	2.21	2.02
Hp/Eacc [Oe/MV/m]	42.6	36.1	37.6	35.6
R/Q [W]	113.8	133.7	126.8	138
Γ [W]	271	284	277	285
Eacc max [MV/m]	41.1	48.5	46.5	49.2

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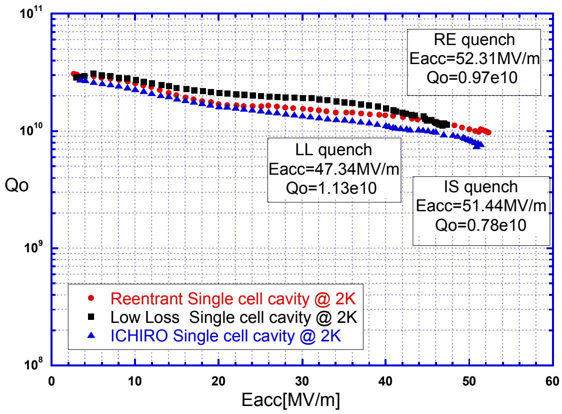

Figure 3: The results of high gradient measurements.

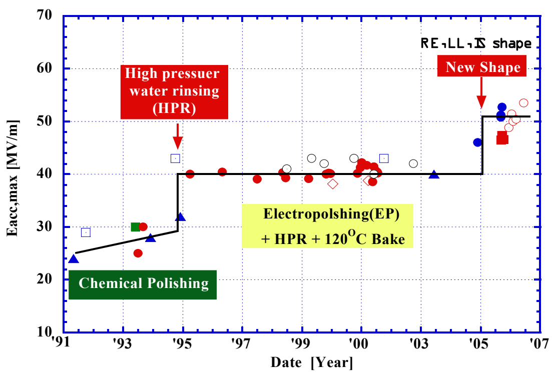

Figure 4: The breakthrough in high gradient of 50MV/m.

VERTICAL TEST AND RESULTS

After the cavity fabrication, we applied them the KEK standard recipe as the surface preparation, which consists from centrifugal barrel polishing (CBP), buffered chemical polishing (BCP, 10 µm), annealing at 750 °C for 3 hours, electropolishing (EP, 80 µm), high pressure rinsing with ultra-pure water at 7 MPa for 1hour (HPR), assembling in class 10 clean room and evacuation with baking at 120 °C for 2 days [5]. The RE cavity was fabricated in Cornell University. They annealed it at 1400°C before shipping KEK. After the surface preparation, these cavities were tested in a vertical cryostat at 2 K.

The best results of cavity performance are shown in Fig. 3 as gradient (Eacc) versus Qo plot. For the RE cavity, the gradient achieved 52.3MV/m with Qo=0.97e10 @ 2K. For the LL and IS cavity, 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. As seen in Fig. 4, a new breakthrough of 50 MV/m was achieved.

REPRODUCIBILITY

In order to check the reproducibility with the experimental result, HPR and vacuum evacuation were repeated for the RE and the LL cavities. The reproducibility of the high gradient was confirmed on both cavities in 5 vertical tests. The results are shown in Fig. 5. With the RE cavity, the average maximum field was 51.6 MV/m, the standard deviation was 1.0 MV/m. With the LL cavity that was 45.9 MV/m and 1.3 MV/m. The high reliability of our procedures for HPR, cavity assembling and evacuation were also convinced in these tests. The temperature dependence of high field was also checked with the RE cavity (Fig. 6). The maximum fields did not depend on temperature between 1.5 K and 2.0 K.

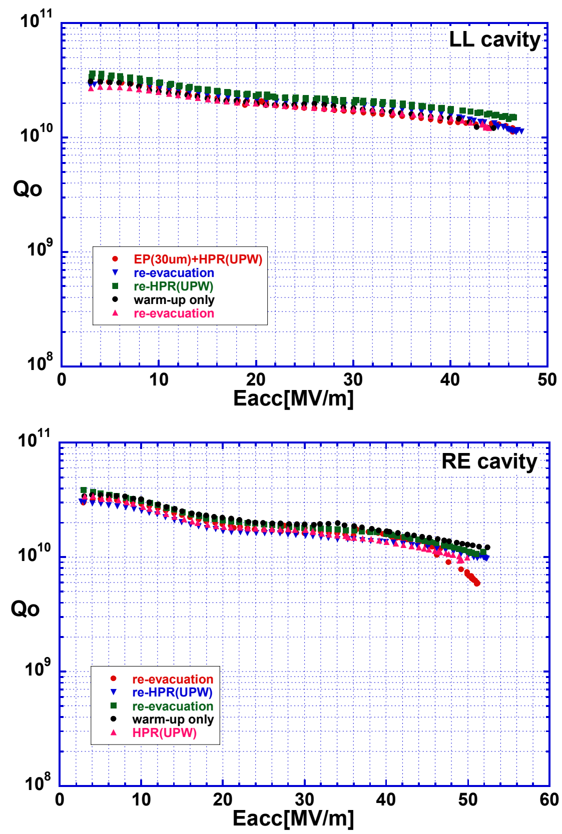

Figure 5: The reproducibility of high gradient.

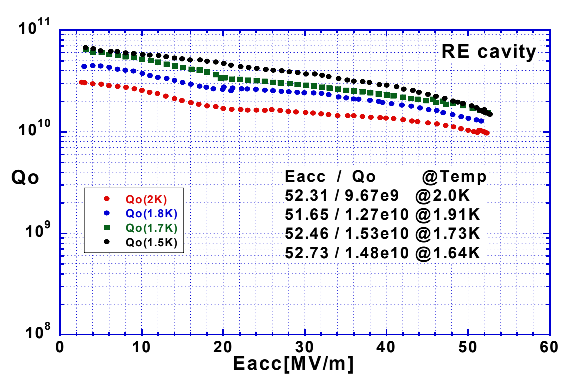

Figure 6: Temperature dependence of gradient.

FIELD EMISSION ANALYSIS

The field emission phenomenon was compared on the cavity shapes. This phenomenon has usually been analysed in terms of Fowler-Nordheim (FN) theory. In FN theory, a field enhancement factor; β represents the local field on the emission site. For the SRF cavity, the value of β can be estimated using two-dimensional plot of Δ(1/Qo) versus E_p, in which Δ(1/Qo) is calculated from 1/Qo versus Ep^2 plot [6]. The βs of new shapes estimated from the analysis of field emission (Fig. 7) are summarized in table 2. The IS cavity has much smaller β value of 16 in comparison with the RE cavity (60) and the LL cavity (30).

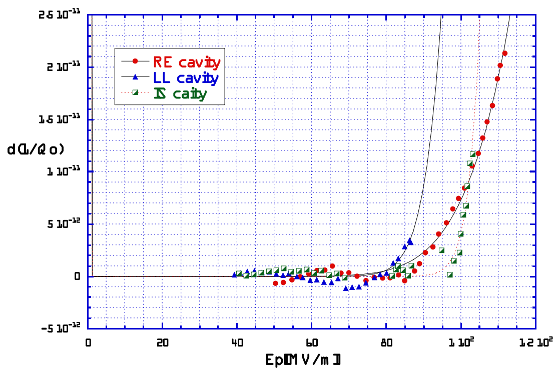

Figure 7: Analysis of field emission.

Table 2: Field enhancement factor β

Cavity	Field enhancement factor β
RE	60
LL	30
IS	16

CRITICAL FIELD FITTING

The experimental RF critical fields estimated with new cavity shapes fit Saito's theoretical estimation value of 1750 ± 150 Oe (Fig. 8).

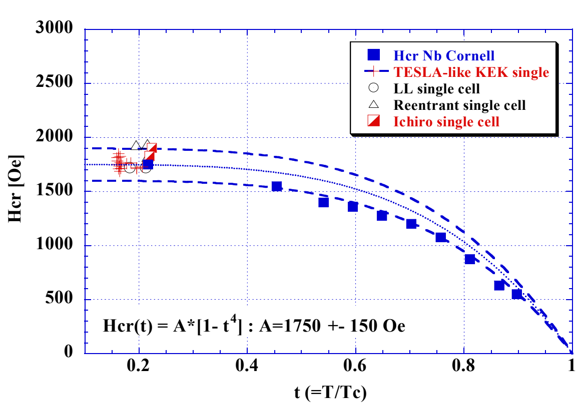

Figure 8: The experimental RF critical field with new shapes.

CONCLUSIONS

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. The reproducibility with the experimental results was confirmed in several vertical tests. In that test, the reliability of the KEK recipe was also convinced. In comparison with the field emission analysis, the IS shape is superior to RE and LL in terms of field enhancement. As a next step, the investigation for the quality control of KEK recipe is on going in KEK [5].

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