AN UPDATE ON THE STUDY OF HIGH-GRADIENT ELLIPTICAL SRF CAVITIES AT 805 MHZ FOR PROTON AND OTHER APPLICATIONS*

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Abstract

An update on the study of 805 MHz elliptical SRF cavities that have been optimized for high gradient will be presented. An optimized cell shape, which is still appropriate for easy high pressure water rinsing, has been designed with the ratios of peak magnetic and electric fields to accelerating gradient being 3.75 mT/(MV/m) and 1.82, respectively. A total of 3 single-cell cavities have been fabricated. Two of the 3 cavities have been tested so far. The second cavity achieved an E_{acc} of ~50 MV/m at Q_0 of 1.4 x 10^{10}. This result demonstrates that 805 MHz cavities can, in principle, achieve as high as, or could even be better than, 1.3 GHz high-gradient cavities.

INTRODUCTION

SRF cavities have been successfully used for various applications [1]. Regarding the accelerating gradient (E_{acc}), a handful of single-cell cavities have achieved >50 MV/m [2, 3], close to the limit of Nb SRF cavities due to Nb's presumed RF critical magnetic field of ~200 mT at 0 K. Also, 1.3 GHz 9-cell cavities have achieved up to 42-44 MV/m [4, 5]. While most of the high-gradient cavity research is focused at 1.3 GHz owing to the future International Linear Collider (ILC) project, we have been studying the possibility of high gradient SRF cavities at 805 MHz for applications that require, or benefit from, high gradients at 805 MHz.

DESIGN, FABRICATION AND SURFACE TREATMENT

Based on the successes at other institutions in achieving >50 MV/m with so-called low-loss (LL) and re-entrant (RE) shape cavities [6], cavity shape optimizations have been performed at LANL. The detailed optimized parameters are shown in Ref. [7]. Among the 3 designed shapes, we decided to fabricate "standard" shape, which, in terms of the cross sectional view, looks like somewhere between TESLA-TTF shape and LL shape as shown in Fig. 1. This shape is more suited for cleaning with high-pressure water rinsing due to the ease of draining.

Half cells were deep drawn from fine grain RRR>250 Nb sheets and electron beam welded at TJNAF. Three single-cell cavities were fabricated and 2 of them have been tested so far. The detailed result of the first cavity was reported in Ref. [7]. Despite a failed chemical polishing, the result was surprisingly good, i.e., E_{acc} ~ 22.5 MV/m limited by available power.

The second and third cavities underwent buffered chemical polishing (BCP) and high-pressure water rinsing (HPR) at TJNAF since the HPR facility at LANL was temporarily unavailable. The cavities were then transported to LANL with a plastic cap on each beam pipe port. At LANL, the input and pick-up power couplers were attached in a class-100 clean room. The input power coupler was a moveable type and connected to the bottom beam pipe with a vacuum line as shown in Fig. 2.

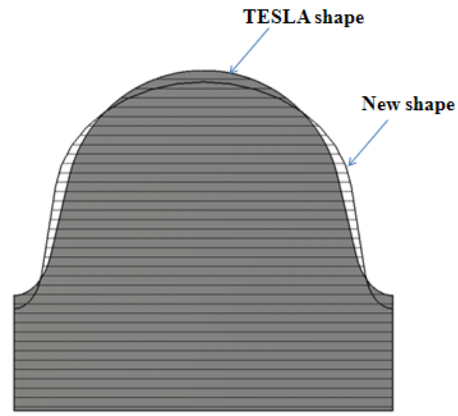

Figure 1: A comparison between TESLA shape and new "standard" design. The shapes have been scaled to the same cell length for comparison.

Figure 2: The 805 MHz cavity with a moveable coupler and a vacuum line attached at the bottom.

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COMPARISON WITH OTHER HIGH-GRADIENT CAVITIES

Table 1 shows the comparison of various parameters including surface treatment with 2 high-gradient cavities.

Table 1: Comparison of the KEK, Cornell and LANL Single-cell Cavities That Showed Remarkably High Gradients

Parameter	KEK Low-loss Shape [3, 8]	Cornell Re-entrant Shape [2, 9]	LANL New "standard" Shape
Resonant frequency [MHz]	1300	1300	805
Beam pipe inner diameter [mm]	61	60	100
E_{pk}/E_{acc}	2.02	2.12	1.82
B_{pk}/E_{acc} [mT/(MV/m)]	3.56	3.50	3.75
R/Q [ohm]	138	140	130
Geometrical factor [ohm]	285	283	279
Measurement temperature [K]	2	2	2.0-2.1
Maximum E_{acc} [MV/m]	53.5	59	50
Maximum E_{pk} [MV/m]	108	125	91
Maximum B_{pk} [mT]	190	207	188
Q_0 at maximum field	7.8 x 10^9	4 x 10^9	1.4 x 10^{10}
Surface treatment	KEK recipe*1 + EP (20-30 um) + EP (3 um) + HF rinse + HPR + Bake (120 °C x 48 h)	Ti purification (1300°C x 2 h + 1200°C x 4 h) + CBP (300 µm) + Bake (750 °C x 3 h) + EP (110 µm) + HPR + Bake (120 °C x 48 h)	BCP*2 (150µm) + HPR + Bake (115-130°C x 48 h)

*1: KEK recipe consists of Centrifugal Barrel Polishing (CBP) of 135-235 µm, light Chemical Polishing (CP) of 1µm, baking at 750°C for 3 hours, Electro-Polishing (EP) of 80 µm, High-Pressure Rinse (HPR) with ultra-pure water, and low-temperature baking at 120°C for 48 hours.

*2: Buffered Chemical Polishing uses a mixture of HF, HNO_3 and H_3PO_4 at a volumetric ratio of 1:1:2, whereas CP uses the ratio of 1:1:1. BCP is slower than CP, but can reduce the temperature increase during the polishing.

TEST RESULTS

The cavity #3 was tested before #2 since a wall thickness measurement of the cavity was done earlier, accidentally.

The cavity was pumped down with a turbo pump unit followed by a 30 L/s ion pump. The cavity was then baked at 115-130°C for 48 hours under vacuum before cooling down.

Figure 3 shows the $Q_0 - E_{acc}$ curves at 4 K and 2 K. The error bars correspond to the fact that the measured low-field Q_{pickup} was 14% higher than the value measured in May 2010, i.e., 8.36 x 10^{11} vs. 7.36 x 10^{11}.

There were some electron activities in the cavity where one can see some increase of Q_0 from ~32 MV/m in Fig. 3. The final limit for both 4 K and 2 K were quenches. No detectable (>50 mR/h) radiation was detected on the cryostat lid.

As shown in Fig. 3, the maximum E_{acc} was ~50 MV/m at 2 K. This is more than twice the previous record (~22.5 MV/m with cavity #1). Figure 3 also includes the design values of SNS high-β, European XFEL and the ILC. While we need to wait for multi-cell cavity results, 805 MHz cavities seem to be a good candidate for high-gradient applications in the future. They might be better than 1.3 GHz cavities for electron machines as well.

CONCLUSIONS AND FUTURE PLANS

It was demonstrated that, in principle, 805 MHz cavities can get to very high gradients. Since the intrinsic BCS loss scales with f^2, it shows higher Q_0 at ~2 K compared to 1.3 GHz cavities as long as the residual resistance is sufficiently low, which reduces the cryogenic cost. Furthermore, as shown in Table 1, the beam aperture is 30-40 % larger than 1.3 GHz cavities, thereby reducing the beam impedances and easing alignment tolerances.

One remarkable fact, regarding the cavity treatment, is that this cavity was neither electro-polished nor high-temperature treated (>130°C). This could simplify the costly and lengthy surface treatment process considerably.

We plan to ship the cavity to TJNAF to test the cavity at TJNAF for cross-checking LANL's measurement results. Also, LANL plans to modify and improve their surface inspection system to inspect the cavity in a class-100 clean room to avoid secondary contamination.

Additionally, if funds are available, we plan to design multi-cell cavities at β = 1 and β ~ 0.8, and fabricate/test them to verify the ability of high gradients with multi-cell (6 or more cells) cavities.

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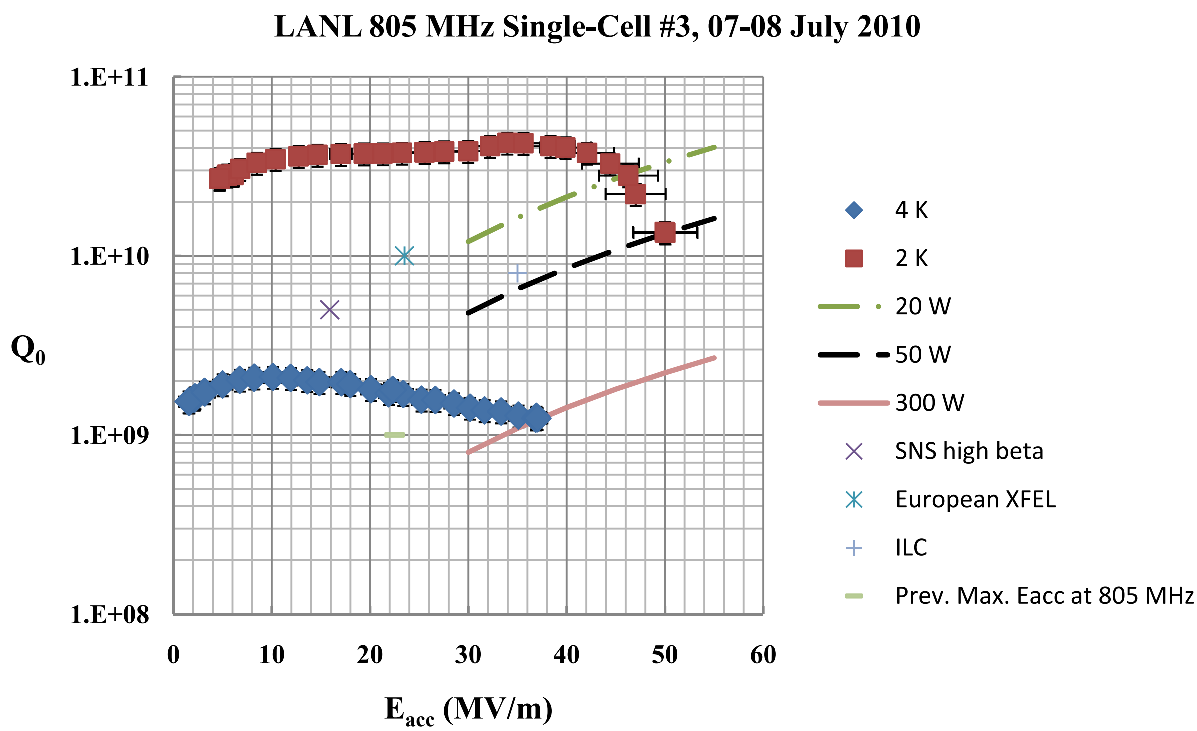

Figure 3: Q_0 - E_{acc} curves of the new LANL 805 MHz single-cell cavity #3, together with the dissipated cavity power lines and design gradients for SNS, European XFEL and ILC as references as well as the previous maximum E_{acc} [7].

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