Development of 1.3 GHz Medium-β Structure with High Gradient

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Abstract

As a new application of superconducting RF cavities, a proton superconducting linac is remarked recently, which is proposed for the neutron science or nuclear waste transmutation. For such an application, one has to design the medium-β structure which has an inexperienced shape in this field. It has a squeezed shape, so many issues are worried about the cavity performance: multipacting, field emission so on. To see quickly what kind of difficulty is there, we designed a 1.3 GHz medium-β structure and cold tested. There was no serious problem on the cavity performance in such a structure.

1. Introduction

KEK started collaborative R&D three years ago with JAERI on medium/high-β superconducting rf cavities for a proton linac proposed for the neutron science and nuclear waste transmutation at JAERI [1]. In this planning machine, sc-cavities are used in the proton energy of 100 MeV - 1.5 GeV, and operated at the surface field of Ep = 16 MV/m. Here, Ep is the maximum electric surface peak field. RF frequency is presently chosen as 600 MHz. The β-value changes from 0.43 to 0.92 in this energy range. Here, β is v/c. v is a proton velocity and c is the light velocity. Medium-β structure has a squeezed shape for its cell length to match the proton advanced length in the half period of the microwave. Namely the cell length is a $\beta\lambda/2$. Here, λ is the wave length of the microwave. As a result, Ep/Eacc and Hp/Eacc have a large number. Here, Hp is the maximum surface magnetic field, and Eacc is the accelerating field gradient on the beam axis. We have never experienced such a shape. In such a shape, field emission or multipacting might be much severer than β=1 structure. To see quickly what problems are there in this shape, we fabricated a 1.3 GHz medium-β (= 0.45) structure by KEK in-house based on our standard technology on TESLA R&D. The cavity attained 10.4 MV/m in Eacc,max (Ep = 53 MV/m) without any problem. It was confirmed that there is no serious problem principally on the cavity performance with the medium β-structure. In this paper the result is presented.

2. Cavity shape, fabrication and preparation

2-1. Cavity parameter and Features of medium-β structures

In Fig.1, the designed cavity shape is presented. The cavity parameters calculated by SUPERFISH code are summarized in Table 1 with some information needed for surface treatment. To see the feature of the medium β structure, the typical cavity parameters with β = 1 structure are also presented in this table.

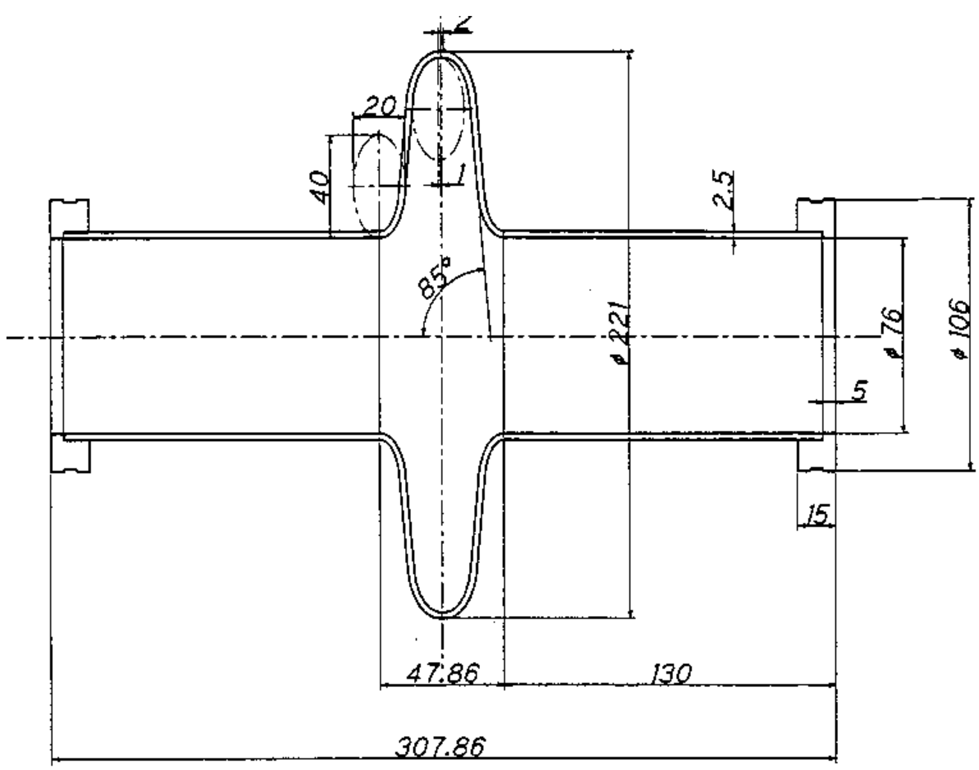

Fig. 1. Designed cavity shape.

β - value	β = 0.45	β = 1
Frequency [MHz]	1296	1296
Unloaded Q (for copper)	12044	29380
R/Q [Ω]	7.4	110
Γ(geometrical factor) [Ω]	112.3	266
Ep/Eacc	5.1	1.89
Hp/Eacc [Oe/MV/m]	133	43.2
Eacc/SQR(P·Q)	57.00	90.57
Beam tube diameter [mm]	76ϕ	76ϕ
Inner surface area [cm^2]	1534	1575
A weight per 1μm material removal [g]	1.31	1.35

Table 1. Cavity parameters. *The parameters with β=1 structure are also presented to see the feature of the medium β structure.*

For this cavity design, the smallest b in the JAERI project was chosen because the cavity performance of such a medium b structure is most worried. One can see several features on the medium b structure : 1) ratios Ep/Eacc and Hp/Eacc are about three times bigger comparing to the b = 1 structure, 2) the unloaded Q value is less than a half of the b = 1 structure, 3) R/Q is very small.

2-2. Fabrication

The cavity was fabricated by the following KEK in-house procedure, which is the same procedure developed in the TESLA R&D activity at KEK. The niobium material is from Tokyo Denkai with RRR = 200. Half cells were formed by deep drawing from sheets of 260 mm in diameter and 2.5 mm thick. They were trimmed, then slightly chemical etched by 10-20 mm with 1:1:1 BCP acid to clean up the whole the surface. The electron beam welding (EBW) for the equator section of the cell was done from inside. Rolling a niobium sheet with 2.5 mm thick, electron beam welded it, a tube was fabricated for the beam pipe. It was cut into halves, then a mandrel was pass through them to make a real circle. Niobium flanges were electron beam welded on the end of pipe. They were jointed to the cell at the iris from outside by EBW with a defocus beam.

2-3. Preparation

The completed cavity was barrel polished for one week at KEK, and the material removed weight was 46g. This number corresponds an averaged removal of 35 μm. Barrel polishing (BP) has a highest removal rate at the equator section for the β=1 structure [2], but the material removal rate is reduced due to the squeezed shape. Then, the cavity was chemically polished to remove the embedded abrasive contamination by BP before annealing. The cavity was annealed (760 ^{o}C x 5 hr) to prevent the hydrogen Q-disease [3], subsequently electropolished by 30 μm and high pressure rinsed (58 kgf/cm^2, 1.5 hr). Then the first cold test was done. After that, additionally we had CP by 50 μm to much remove the equator section, then electropolished by 30μm. Then the second cold measurement was carried out.

3. Cold tested results

The results of cold measurements are presented in Fig.2 and 3. Fig.2 shows the measured temperature dependence of surface resistance (Rs) in the first measurement. The data was fitted by the well known BCS formula :

$$Rs\ (T) = A/T \bullet \exp(-\Delta/k_B T) + Rres \qquad (1).$$

Here, A is a constant number, T is a measurement temperature of the cavity, k_B is the Boltzmann constant, and Rres is constant number as called residual surface resistance. The band gap energy (Δ/k_B) of niobium material obtained from the data fitting is:

$$\Delta/k_B = 18.1 \quad [K] \qquad (2).$$

This value agrees with ones measured for β = 1 structures. The estimated Rres was 8.6 nΩ, which consists with other measurements.

Fig.3 is the result of Qo-Ep curve at 1.8 K, and includes the results of two experiments. In the first measurement, maximum peak field reached to 33.7 MV/m. This number is twice higher comparing to the target value of the JAERI project, in which cavities will be operated at Ep =16 MV/m. X-ray was observed from Ep = 30 MV/m but processed out easily. The field limitation seems to be a thermal breakdown. We suspected that the material removal of equator section was not enough because the area is hard to be removed by EP due the squeezed shape. Therefore, we took CP by 50 μm which could remove the surface more uniformly than EP. To achieve high gradients it is important to take EP as a final finishing [2]. So, we additionally took a final EP by 30 μm for this cavity. As a results, the maximum peak field was upgraded to 53 MV/m without x-ray. The light Q-

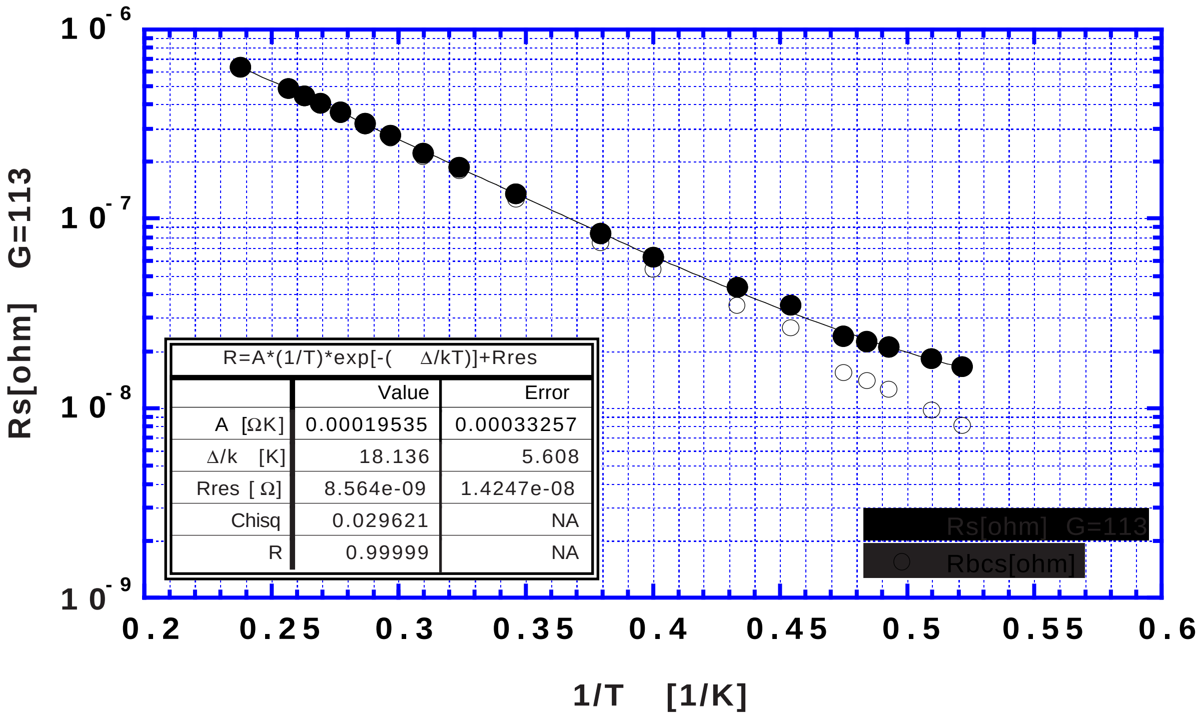

Fig. 2. Temperature dependence of surface resistance of the cavity.

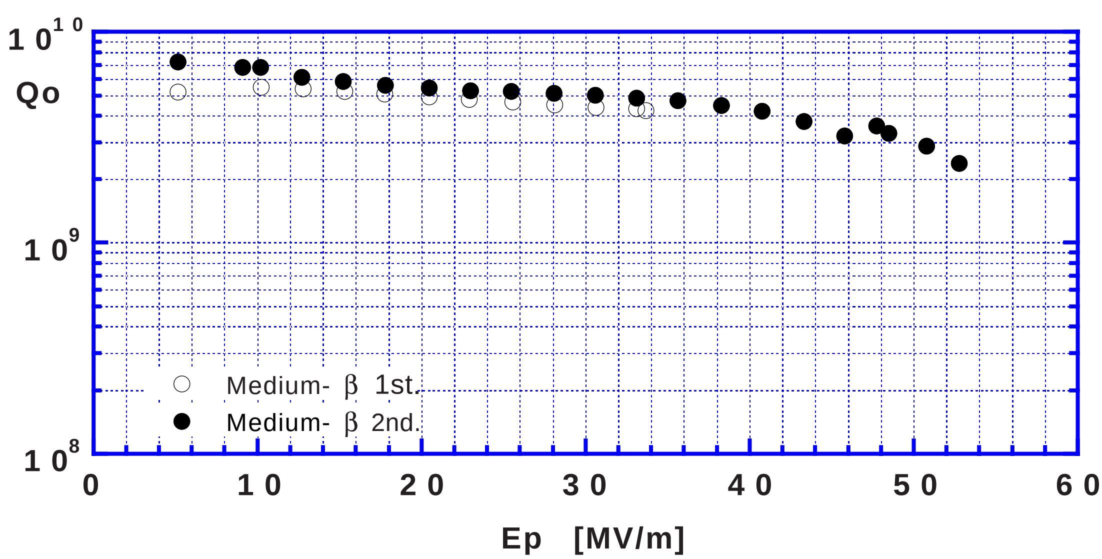

Fig. 3. Cold tested results on Qo-Ep curve.

degradation over Ep = 41 MV/m seems to be thermal heating. Qo value is lower comparing to the b = 1 structures, which is owing to the squeezed shape as mentioned before.

4. Discussion

For the medium-β structure, we worried about multipacting and field emission because of the squeezed shape. This cavity was designed for the smallest β of the JAERI project design. Any serious multipacting was not observed. The ratio of Ep/Eacc = 5.1 is rather high but any field emission was not observed. The field limitation seems to be thermal quench. The Q-degradation from Ep = 41 MV/m seems to be thermal heating. The result of Ep = 53 MV/m with the maximum peak field is higher over than three times for the target value. This number corresponds to Eacc = 30 MV/m for the β = 1 structure. We can see no difference on cavity performance even for the specially squeezed shape. This result shows there is no problem principally with such a structure.

5. Conclusion

The medium-β structures which will be adopted to proton superconducting linac like the JAERI project have not been tested before. Multipacting, field emission or thermal quench due to the squeezed shape, or higher Ep/Eacc ratio and Hp/Eacc are worried. To see what kind of problem is there, we have fabricated a 1.3 GHz medium-β superconducting rf cavities based on our TESLA R&D technology and characterized the cavity performance by cold measurements. The maximum peak field reached to 53 MV/m which is the comparable value to the L-band β = 1 cavities. This number is three times higher than the target value of the JAERI project. Any multipacting or field emission was not observed. We have confirmed there is no problem principally in the medium-β structure.

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