# HOM ANALYSIS AND DESIGN OF ITS REMOVAL SYSTEM FOR 3RD HARMONIC RF CAVITY IN PLS*

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*Abstract*

Pohang Accelerator Laboratory has prepared to SRF 3rd harmonic cavity to increase beam lifetime and to damp orbit instability by lengthening electron bunch in PLS. The SRF cavity was developed and its vertical test was done already with success. Higher order modes were analyzed to optimize its performance in beam orbit. Most of them are not effective to electron beam, while the others have possibility to impact orbit stability. These harmful HOMs can be removed by HOM absorber installed in beam pipe.

## INTRODUCTION

Pohang light source (PLS), 3rd generation synchrotron machine has provided synchrotron radiation with 26 beamlines from 1994. PLS achieves its goal in view of quantity and also shows design performance in quality through R&Ds to improve beam stability. But more improvements in some parts of machines are necessary to meet users' intricate requirements such as beam stability, brightness and photon energy. The efforts to improve beam quality are limited in some parts due to design characteristics of accelerator. For example, without change of magnetic configuration beam size can not be reduced any more to increase brightness of photon beam.

The barrier to increase brightness of photon beam can be overcome by change of magnetic lattice in storage ring. It is high priority in PLS to get smaller emittance of electron beam. The target is less than 10 nm from 16 nm. The reduction of beam size also makes beam lifetime cut down to less than 6 hours in average from 20 hours at beam current 200 mA. This is because that higher charge density in a smaller electron bunches causes Touschek scattering more actively, resulting in reduction of beam lifetime.

The R&D of 3rd harmonic RF cavity started to increase beam lifetime and to improve beam stability in storage ring in 2004. The feasibility study for its effects on electron beam in view of beam dynamics was done 2004 [1] and experimental study were done also in 2006.

## DESIGN

The 3rd harmonic superconducting RF (SRF) cavity is auxiliary for the normal conducting main cavities to improve beam quality and lifetime. It is designed to be worked by passive power, i.e., the required energy to control the length of electron bunches is induced by passage of electron beam. The passive works save space in storage ring and makes the system simple. The required voltage to lengthen beam lifetime is 0.7 MV as small as one superconducting RF cavity produces it.

The low loss type with elliptical shape is adjusted to 3rd harmonic SRF cavity for PLS matched to the condition of PLS operation parameters. The primary modification from low loss type is that iris diameter is as big as 78 mm to remove HOMs effectively, in spite of reduction of cavity quality factor, Q. In our design Q is not issue anymore because it is big enough by using superconducting material. The 3 dimensional profile is shown in Figure 1.

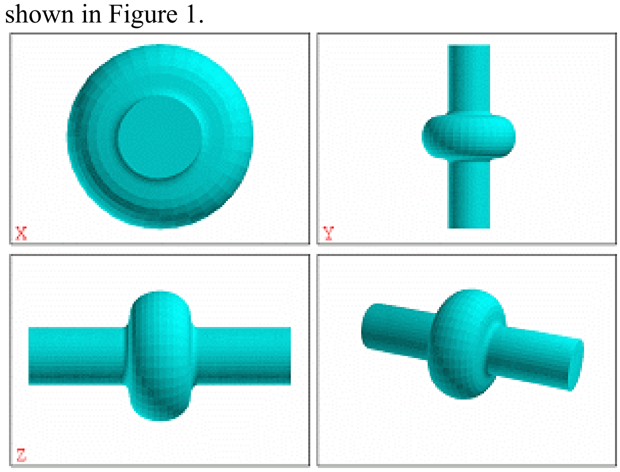

Figure 1: 3D model of 3H SRF cavity

The physics design such as geometrical shape, electromagnetic fields, pressure distribution, loss distribution and so on was done by RF computation code, SUPERFISH and MAFIA. The distribution and level of accelerating field computed by SUPERFISH are shown in Figure 2.

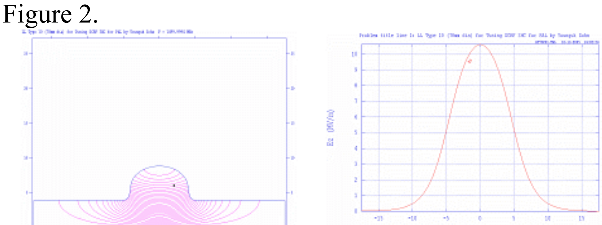

Figure 2: Distribution (left) and intensity (right) of accelerating field

As depicted in Table 1 the peak magnetic field is only 222.6 Oe, which is much lower than critical magnetic

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fields of superconducting Niobium at 1500 MHz, ~1400 Oe. Also it can be known that Q and R/Q are maintained to be large in spite of big iris diameter, compared to an usual SRF cavity.

Table 1: Primary parameters of SRF cavity

| Property | Unit | Value |
|---|---|---|
| Frequency | MHz | 1500 |
| Unloaded Q | - | 3.29E+08 |
| Shunt impedance | Ω/m | 1.43E+12 |
| R/Q | Ω | 89.61 |
| Geometric factor | Ω | 292.07 |
| $E_{peak}/E_{acc}$ | | 2.03 |
| $H_{peak}/E_{acc}$ | Oe/(MV/m) | 44.5 |
| $E_{acc}$ | MV/m | 5.0 |
| $H_{peak}$ | Oe | 222.57 |
| $E_{peak}$ | MV/m | 10.13 |
| Wall loss | W/cell | 16.9 @4.2K |
| Wake loss factor | V/pC | 0.21 |
| Surface resistance | Nano -Ω | 885.5 |

## FABRICATION

Nb discs with RRR 200 were produced from Tokyo Denkai, Japan, of which diameter and thickness were 270 mm and 2.8 mm. The thickness deviations from measurement were -50 ㎛ to 20 ㎛.

The cavity was fabricated with usual, but most proven way in series of deep drawing - trimming - electron beam welding (EBW). The average profile errors of half cells were within ±350 ㎛ with respect to design. Those are mainly due to machining errors of pressing dies and spring-back of Nb disc. Thermal contractions of cells were also considered in trimming half cells. Before welding single cell with electron beam to prevent including impurities in welding pool and not to make voids in welding bead, all cavity components were degreased strong alkaline solution and polished with strong acid compound with nitric, phosphoric and fluoric acids by volume fraction of 1:1:1. Figure 3 shows 3$^{rd}$ harmonic SRF cavity, fabricated.

To get clean and smooth RF surface, an usual recipe of superconducting RF cavity after fabrication, such as mechanical grinding (so called centrifugal barrel polishing: CBP), chemical polishing with acids (CP), heat treatment and high pressure water rinsing (HPR) in sequence were adopted. All rough welding beads, scratches, oil and other impurities can be removed by CBP. CBP was repeated 13 times with 4 different grinding chips then about 250 ㎛ in depth was removed. The chemical polishing makes grinded surface smooth as fine as surface roughness of several microns (less than 5 ㎛) with 30 ㎛ removal of RF surface. Electropolishing (EP) was not adopted because the design accelerating e-filed of PLS SC3H cavity was medium level.

The cavity was baked for 3 hours in a vacuum heat treatment furnace of 750 °C to remove gases such as hydrogen, oxygen, nitrogen and others or to push in bulk Nb part.

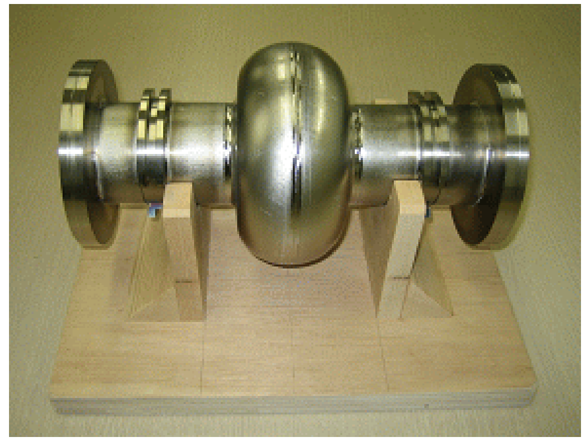

Figure 3: 3$^{rd}$ harmonic SRF cavity for PLS

## VERTICAL TEST

To confirm cavity performance, surface resistance, resonant frequency with temperature and accelerating electric field & quality factor were evaluated by experiment in vertical cryostat which test temperature and vacuum were 4.2-2K and order of $10^{-9}$-$10^{-8}$ Torr.

In microwave, superconducting material has still resistance in contrast to DC current due to skin effect, similar to AC normal current, and residual resistance of material. The former can be evaluated easily with BCS theory, in which the resistance of RF superconductors are function of temperature and applied frequency. While the other is dependent on material quality, i.e. impurities. So to reduce resistance high RRR material and heat treatment are very helpful.

The cavity preparations were done with KEK recipe [2]. The surface preparation for first vertical test were that

- o Mechanical grinding welding bead in iris
- o Centrifugal barrel polishing (CBP): ~250 ㎛ removed
- o Light chemical polishing (CP): ~10 ㎛ removed
- o High pressure water rinsing (HPR) with pure water: 20 minutes
- o Heat treatment (annealing): 3 hours @750 °C

then stayed one months, filled by Argon gas. Just before test following processes were done

- o Degreasing by ultra-sonic water pool: 30 minutes
- o Chemical polishing with fresh acid: 60 ㎛
- o High pressure water rinsing: 45 minutes
- o Drying @ Class 10 clean room: 1 hour
- o Cooling down @ cavity vacuum level, $6\times10^{-9}$ mbar

After these two step preparations the first VT was done. To confirm the first result, second VT was tried with additional recipes

- o Warmup to room temperature over night
- o Bakeout 12 hours @120°C in situ with test assembly

Then, second VT was done.

Figure 4 shows measured resistances with temperature change 4.2K to 2K, in which solid line was theoretical values from BCS model and symbols were measured data. The variable resistances can be explained with BCS theory, meanwhile saturated values are due to residual resistance.

The frequency was measured from 1499.484 MHz to 1499.701 MHz with temperature 4.2K to 2K. (design frequency: 1500 MHz)

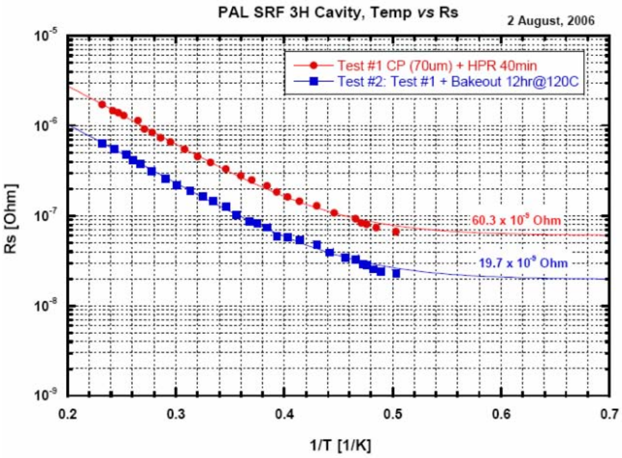


Figure 4: Surface resistance with temperature

Figure 5 shows accelerating electric field and quality factor, in which maximum performance is 25.2 MV/m at $Q_0 = 9.21\times10^9$ from two VT. During VT there was no symptom of field emission and multipacting. The test was limited only from quenches. This implies that there is a barrier to apply more RF power, approaching critical magnetic field. Even though quench, 25.2 MV/m is thought to be good performance without electricpolishing.

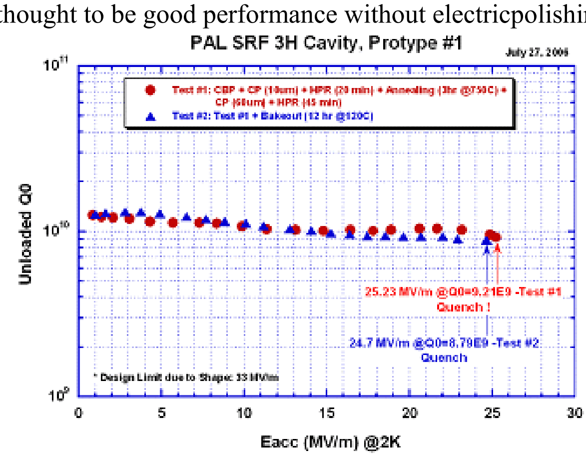


Figure 5: Measured accelerating electric field and $Q_0$

## ESTIMATION OF HOM TO ORBIT BEAM

The 18 harmful HOMs which have possibility to be against to the beam orbit of storage ring were selected by evaluating R/Q of HOMs. Then, all these HOMs were checked whether they produce couple-bunch instability or not as follows; the threshold impedance of it is given by

$$R_{th} = \frac{2E_0}{\tau_\beta e \beta_\perp I f_0} \tag{1}$$

Where $E_0$ is beam energy, $\tau_b$ transverse radiation damping time, $\beta_\perp$ betatron function in the position of RF cavity and I beam current. When the RF cavity is not connected to an external circuit, a coupling impedance of nth mode is given by

$$Z_n(f_n) = \left(\frac{R_T}{Q_a}\right) Q_a \cdot \frac{1}{1 + jQ_a\left(\frac{f_n}{f_a} - \frac{f_a}{f_n}\right)} \tag{2}$$

where the $f_n = nf_0 - f_\beta$ is the spectrum frequency nearest to the resonant frequency of the concerned mode, $f_a$ the resonant frequency, $Q_a$ the unloaded Q and $R_T$ the shunt impedance of mode. When

$$\mathrm{Re}[Z_n(f_n)] < R_{th} \tag{4}$$

the coupled-bunch instability does not arise. From these estimation, all HOMs arisen from designed cavity does not affect on beam stability.

## CONCLUSION

This, first prototype is to confirm its basic parameters. The primary parameters are proper as 3rd harmonic cavity. Also HOMs arisen from this cavity are not severe on orbit beam according to theoretical evaluation. We will fabricate two-cell cavity for 2nd prototype which will be installed PLS if it shows same performance as 1st one.

The performance of developed SRF cavity is thought to be reasonable to be installed in storage ring. This is the first SRF cavity, developed, i.e. designed and fabricated in Korea. Through this R&D project we got important technologies and useful experiences such as

- o Design SRF cavity
- o Fabrication techniques, as pressing dies and cell fabrication, electron beam welding
- o Surface preparation
- o Vertical test

## ACKNOWDGEMENT

We appreciate sincerely collaborations from K. Saito in KEK and Peter Knesle in JLab, who helped surface preparation and vertical test, respectively.

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