

## STUDIES ON HIGHER ORDER MODES DAMPER FOR THE 3RD HARMONIC SUPERCONDUCTING

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### Abstract

To investigate the higher order mode (HOM) damping in the higher harmonic cavity for Shanghai Synchrotron Radiation Facility(SSRF) when using HOM absorbers, simulations have been done for changing the position and the length as well as the thickness of ferrite of HOM damper. The best values under which the  $Q$  value of HOMs can be greatly lowered and the impedance of harmonic cavity will be below the impedance threshold have been decided.

### INTRODUCTION

The SSRF is a 3.5GeV synchrotron light source that has been constructed in Shanghai, China. The emittance of the SSRF storage ring is designed very low while the current remains 300mA. The beam lifetime is one of the important aspects for SSRF, high harmonic cavity usually be used to increase the lifetime, and the longitudinal parasitic coupled-bunch instabilities can be suppressed by the hhc cavity [1]. A third harmonic cavity is a common choice to increase the lifetime without deteriorating brightness, and in several light sources, it has been operated successfully such as ALS [2], NSLS [3], BESSY-II [4]. The Shanghai Superconducting Cavity Key Laboratory undertook the design and fabrication of this passive third harmonic superconducting cavity.

Table 1: Parameters of a single cell HHC cavity for SSRF

frequency	1499.69 MHz
fundamental mode	TM010
cavity voltage nominal	0.5 MV
cell length	100 mm
slope angle	90
beam pipe radius	41.5 mm
iris circular radius	16 mm
equator radius	90.1 mm

The damped structure for the 3rd harmonic superconducting cavity has large beam pipe, Most of the HOMs go through this pipe and are absorbed by HOM absorber. The HOM absorber for SSRF requires sufficient HOM damping, power handing capability, UHV (ultra high vacuum) compatibility, free of particulates. We choose the ferrite C48 that be made by Countis.

### THRESHOLD OF THE MULTI-BUNCH INSTABILITY

From the accelerator physics of the SSRF, we want to pay more attention to minimizing the impedance that can cause the single or coupled bunch instability. The growth rate of the instability should be less than synchrotron radiation damping.

The threshold of longitudinal multi-bunch instability should be [5]

$$R_{//} < \frac{2v_s(E/e)}{f_r|\eta|\tau_s I_0} = \frac{2 \times 7.42 \times 10^{-3} \times 3.5 \times 10^9}{f_r \cdot 4.2 \times 10^{-4} \times 3.49 \times 10^{-3} \times 0.3} = \frac{118.115}{f_r(\text{GHz})} (k\Omega) \quad (1)$$

Here  $v_s$  is the number of longitudinal oscillation wave,  $f_r$  is the HOMs frequency,  $\eta$  is the slipping phase factor,  $\tau_s$  is the longitudinal instability growth time,  $I_0$  is the beam current.

And the threshold of the transverse multi-bunch instability should be

$$R_{\perp} < \frac{2 \times (E/e)}{\tau_{\perp} f_0 I_0 \beta_{\perp}} = \frac{2 \times 3.5 \times 10^9}{6.97 \times 10^{-3} \times 0.694 \times 10^6 \times 0.3 \times 10} = 482.4 k\Omega/m. \quad (2)$$

Here  $\tau_{\perp}$  is the transverse instability growth time,  $f_0$  is the revolution frequency,  $I_0$  is the beam current,  $\beta_{\perp}$  is the transverse  $\beta$  function.

For SSRF, the transverse instability which caused by the superconducting cavity can be damped soon. The longitudinal shunt impedance is very critical, so the longitudinal multi-bunch instability should be highly paid more attention. The transverse magnetic(TM) monopole modes basically influence the longitudinal shunt impedance of the multi-bunch instability.

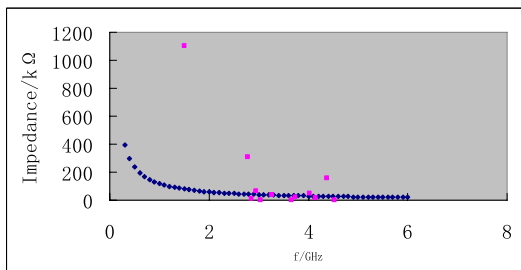


Figure 1: SSRF threshold of longitudinal multi-bunch instability

Fig1 shows the SSRF hhc cavity threshold of the TM monopole impedance between the frequency range from 0.2GHz to 4.5 GHz. From the figure, we can see that the TM<sub>011</sub> (TM0-ME01) at the frequency 2.773 GHz beyond the threshold of the multi-bunch instability.

From above analysis, we know the absorber which can suppress the TM monopole modes is the key issue for the high harmonic cavity. And R/Q of the TM<sub>011</sub> is the largest except for the TM<sub>010</sub>'s, so the TM<sub>011</sub> mode should be suppressed much more, it is the most dangerous mode among the HOMs.

### DESIGN OF THE HOM ABSORBER

#### Optimization of size and location

The frequency and Q value to design the size and location of the absorbers with the help of computer code can be calculated. The damped Q's of the monopole modes can be calculated by SEAFISH. Lossy materials are accommodated in SEAFISH through the use of a complex of ε and μ. The dependencies of location, ferrite length and thickness on Q were studied for the TM<sub>011</sub> mode since this mode was expected to be more dangerous and to generate major power. The permittivity ε and the permeability μ of the ferrite C48 have been measured by CLS. [6]

Fig2 shows the Q as a function of the distance from the beginning of the beam pipe in case of a 10cm long ferrite layer, thickness is another parameter, e.g. t=3mm means the thickness of the ferrite layer is 3-mm. It can be concluded that the ferrite with the thickness of 4mm and the distance from the beginning of the beam pipe of 12cm should be most effective in the maximum absorption of the whole HOM power.

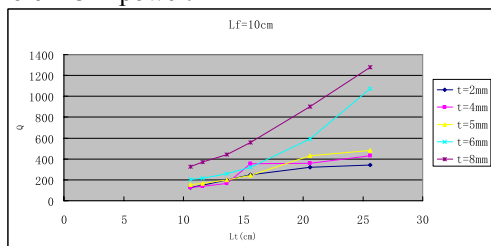


Figure 2: Q as the function of the distance from the beginning of the beam pipe and the thickness of the ferrite was taken as another parameter

Fig3 shows the Q as a function the length of the ferrite layer, it can be seen that the Q does not change much

when the length of the ferrite layer is greater than 8cm, so the length of we choose is 10cm.

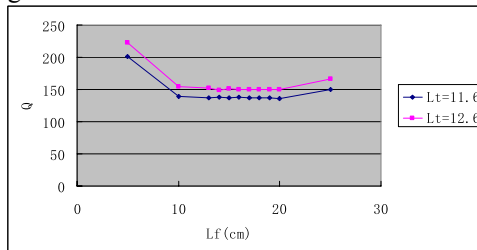


Figure 3: Q as the function of ferrite length

#### Loss factor

Loss factor is the energy lost when a unit charge goes through a structure. It is important to estimate the power and the power absorbed in the absorbers. For designing the HOM absorber, we must get the HOM power that should be damped.

There are no computer codes that can calculate the structure with the lossy materials. But the loss factor of the structure without the lossy materials and the loss factor of HOM absorber are not superposed, we can calculate those separately.

We used a computer code ABCI to calculate the loss factor structure, including cavity, beam pipe, and taper. Because ABCI calculates all the modes, for getting the loss factor of the HOM, we calculated the loss factor of the TM<sub>010</sub>. The HOM power can be expressed as<sup>[7]</sup>

$$P = k_l \times I_{beam}^2 \times T_c / N \tag{3}$$

From Equation (3), we can get the HOM power, here I<sub>beam</sub> is the beam current, T<sub>c</sub> is the revolution time, and N is number of the beam bunches, k<sub>l</sub> is the loss factor of the HOM.

Table 2 shows the result which was calculated with ABCI for the structure without ferrite at the 4mm bunch length.

Table 2: Parameters of a single cell HHC cavity of SSRF

loss factor of all the modes (calculated by ABCI)	0.4489 V/pC
loss factor of TM010 (calculated by SURPERFISH)	0.2127 V/pC
HOM power (without absorber)	0.2322 kW
HOM power (designed)	1 kW

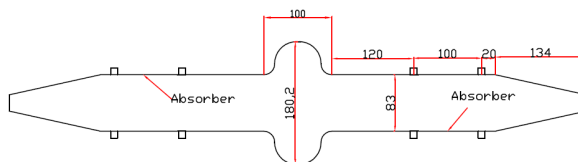


Figure4: SSRF 3rd harmonic superconducting cavity shape

## THE SIMULATION OF THE CAVITY WITH FERRITE

To verify the design of the HOM absorber, the  $Q$  of the HOM was calculated one by one in the whole spectrum. We can get the  $Q$  of the HOMs of the cavity by Superfish for monopole modes and by CLANS for dipole modes. Results show that most of the HOMs have been reduced below 100 including transverse modes and longitudinal modes.

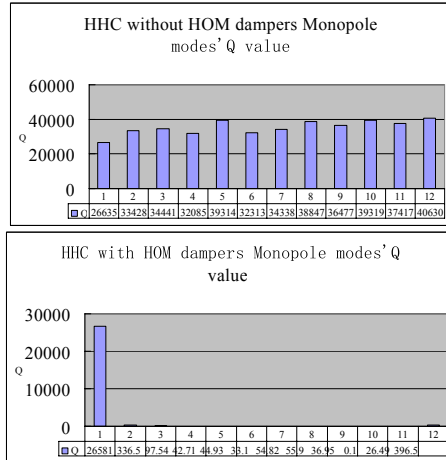


Figure5:  $Q$  of the monopole modes without absorber and with absorber

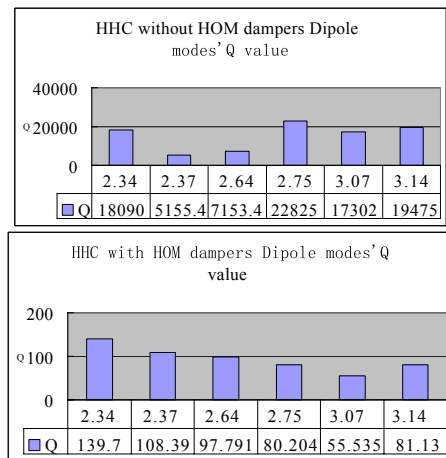


Figure6: the  $Q$  of the dipole modes without absorber and with absorber

We also calculated the longitudinal multi-bunch instability with absorber, Fig 8 shows that the shunt impedance of all the monopole modes is below the threshold.

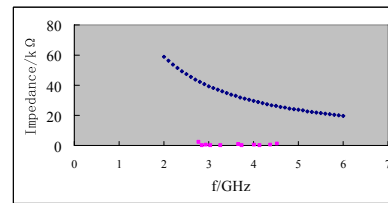


Figure 7: SSRF threshold of longitudinal multi-bunch instability with absorber

## CONCLUSIONS

The simulations for the impedance and  $Q$  in SSRF 3<sup>rd</sup> harmonic superconducting cavity with damper show that the HOM impedance can be damped below the threshold and most of the HOMs have been reduced below 100 including transverse modes and longitudinal modes. Through the program Superfish for optimization of size and location, the position and the length of the HOM absorber as well as the thickness of the ferrite had been determined, and after getting loss factor of the HOM, the HOM power need to be absorbed had been calculated.

## REFERENCES

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