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LONGITUDINAL EFFECTS OF TRAPPED HOMS IN SHANGHAI COHERENT LIGHT FACILITY

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Abstract

Shanghai Coherent Light Facility (SCLF), a superconducting accelerated structure-baesd FEL device, is now under development at Shanghai Institute of Applied Physics, Chinese Academy of Sciences. We investigate effects of cryogenic losses caused by trapped longitudinal high order modes (HOM). Results of calculations are presented for losses caused by HOMs excitation in the acceleration RF system of the continues-wave (CW) linac of SCLF.

INTRODUCTION

Shanghai Coherent Light Facility (SCLF), a superconducting accelerated structure-based FEL device, is now under development at Shanghai Institute of Applied Physics, Chinese Academy of Sciences [1]. We believe that completed SCLF will provide hard coherent X-ray radiation for a broad spectrum of basic research applications. Superconducting RF (SRF) technology has been chosen in order to minimize power consumption and operational cost of the facility, because SCLF is required to operate in continuous wave (CW) regime. The linac schematic is shown in Figure 1. Main acceleratoring elements of SCLF linac are TESLA 1.3 GHz 9-cell elliptical cavities [2]. The linac is segmented into four sections named as L0, L1, L2 and L3. The 3.9 GHz third harmonic cavities [3] will be used in the section L1 of the linac for linearizing the longitudinal beam profile. An idealized beam current spectrum without time and charge jitter is calculated.

Power of losses in 1.3 GHz cavity and 3.9 GHz cavity due to monopole HOMs are the subject of calculations.

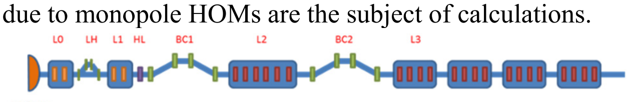

Figure 1: Schematic layout of SCLF main linac.

BEAM SPECTRUM

Amplitude and frequency of the main lines of the beam current spectrum directly affect probability and intensity of HOMs in SRF accelerating structures.

Two cases of the beam in the SCLF are considered in this paper.

Case 1 is that the bunch repetition frequency is assumed to be constant and equal to 1 MHz, and total change Q_b=300 pC, and calculated beam spectrum is shown in Figure 2.

Case 2 is that the bunch repetition frequency is assumed to be constant and equal to 0.6 MHz, and total change Q_b=100 pC, and calculated beam spectrum is shown in Figure 3.

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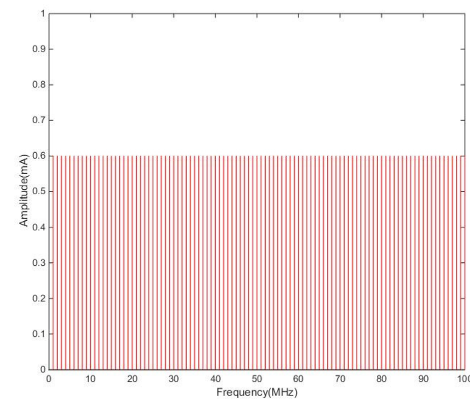

Figure 2: The idealized beam spectrum of Case 1.

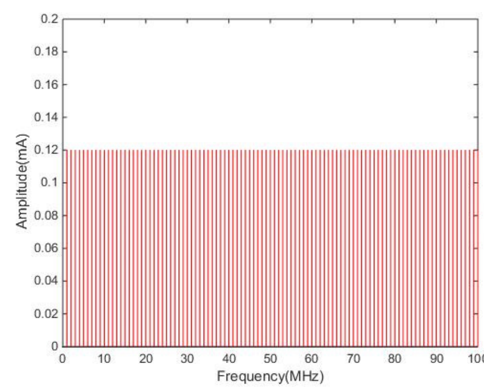

Figure 3: The idealized beam spectrum of Case 2.

CAVITY HOM SPECTRUM

The spectrum and impedance of the higher-order modes in the SCLF will be evaluated in this section. The main contribution of HOM loss comes from the frequency mode with the highest impedance mode and frequency approaching the main line of the beam spectrum.

We evaluate HOM spectrum of 1.3 GHz Tesla-type cavity using CST simulation [4] and 3.9 GHz third harmonic cavity using SUPERFISH code [5]. HOM can be characterized as trapped or propagating by their relation to the beam pipe cut-off frequency. And frequency of the trapped modes is below f_{cutoff}, while the propagating modes have frequency above f_{cutoff}. In this paper, only trapped HOMs are considered. For longitudinal monopole modes the cutoff frequency in a cylindrical pipe is defined as $f_{cutoff} = 2\pi c\frac{X_{01}}{r} \approx 2\pi c\frac{2.4048}{r}$, where X_{01} is the first root of $J_0(r)$ the Bessel function of the first kind of order 0. For 1.3 GHz

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Tesla-type cavity $f_{cutoff} = 2.94$ GHz, and for 3.9 GHz third harmonic cavity $f_{cutoff} = 5.74$ GHz.

Results of spectrum calculation of 1.3 GHz Tesla-type cavity and 3.9 GHz third harmonic cavity are shown in Figure 4 and Figure 5 respectively.

Figure 6 show the spectrum about impedances vs frequency of 1.3 GHz Tesla-type cavity and 3.9 GHz third harmonic cavity.

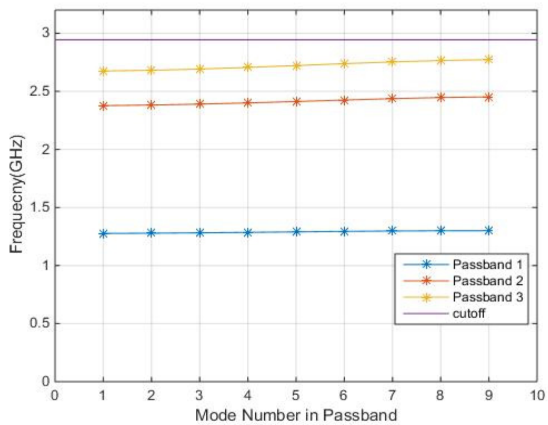

Figure 4: Spectrum of monopole HOMs in 1.3 GHz Tesla-type cavity.

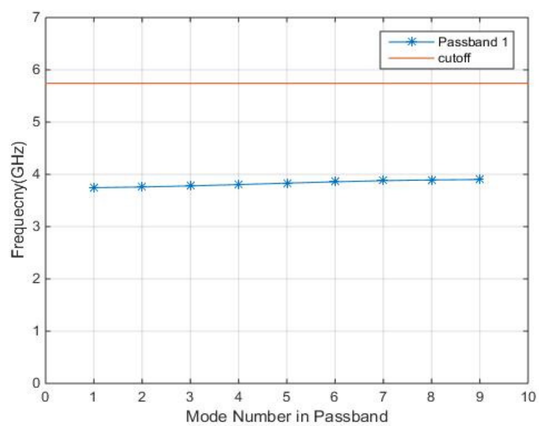

Figure 5: Spectrum of monopole HOMs in 3.9 GHz third harmonic cavity.

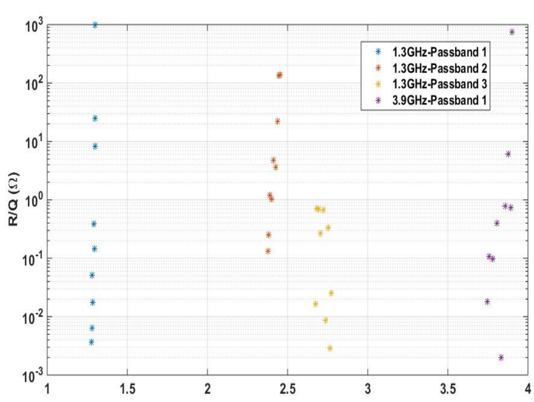

Figure 6: Impedance of monopole HOMs in 1.3 GHz Tesla-type cavity and 3.9 GHz third harmonic cavity.

POWER LOSS CALCULATION

The beam going through a cavity excites eigenmodes of the cavity. The main accelerating mode is compensated, but there are also high order modes (HOM) in the cavity. Excitation of HOMs leads to losses of beam power. It is necessary to know which modes the cavity has to evaluate these losses. As we know shapes of cavities, we can get all needed information using CST simulation. After that we can calculate losses as it is described below.

Surface resistance of superconducting Nb, according to [6] is

$$R_s = R_{res} + R_{BCS} \tag{1}$$

where $R_{res} = 10$ nΩ, and BCS part is parameterized as

$$R_{BCS}[\Omega] = 2 * 10^{-4} \frac{1}{T[k]} (\frac{f_n[GHz]}{1.5})^2 e^{\frac{-17.67}{T[k]}} \tag{2}$$

Trapped modes may have higher value of Q_h. We use the following values in our analysis: $Q_h = 2 \cdot 10^5$, 10^6, 10^7.

Total power loss in the cavity walls is calculated as sum of losses by individual beam harmonics.

Power of losses can be calculated as

$$\mathrm{P} = \sum_{n=1}^{N} \sum_{m=1}^{M} \frac{1}{8W_0} (\frac{R}{Q})_m \frac{\tilde{I_n}^2 R_s \omega_m^3 A_{mm}}{(\omega_n^2 - \omega_m^2)^2 + (\frac{\omega_n \omega_m}{Q_h})^2} \tag{3}$$

where

$$A_{mm} = \oint H_m^2(z) ds = \int_0^L 2\pi r(l) H_m^2(l) dl \tag{4}$$

RESULTS

To accurately estimate the probability of resonance HOM excitation produced by a beam component in a SCLF linear accelerator, a statistical analysis must be carried out, which requires the propagation of HOM parameters (frequency, impedance and quality factor). We take into account manufacturing mechanical tolerances to obtain this information. Acceleration mode is supposed to be perfectly adjusted so its frequency exactly 1.3 GHz or 3.9 GHz are used in calculations respectively. About 3000 random runs are made for each cavity in order to estimate probability of the RF losses per cryomodule [7].

HOM couplers and power coupler (Qh) will remove part of HOM power. Measurements of Qh for trapped modes at DESY (J. Sekutowicz) and Fermilab (T. Khabiboulline): Qh < 2·105. Small variations in cavity geometry because of manufacturing tolerances may cause this value to change. Trapped modes may have higher value of Qh. Therefore, the following values will be used in our calculations: Qh =2·105, 106, 107.

Distribution of power loss about two beam cases in 1.3 GHz Tesla-type cavity walls and 3.9 GHz third harmonic cavity walls is shown in Fig. 7, Fig. 8, Fig. 9 and Fig.10 re-

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pectively.

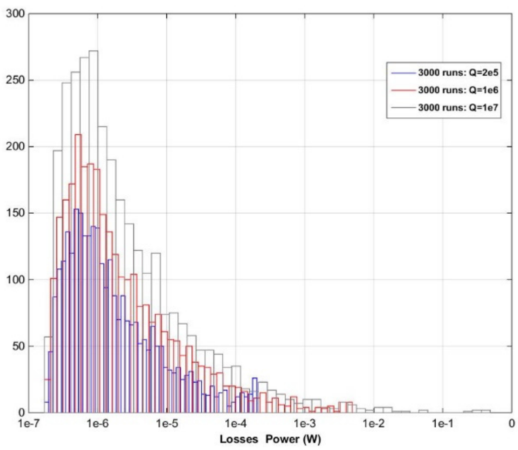

Figure 7. Calculations of the power losses in the 1.3 GHz Tesla-type cavity of Case 1.

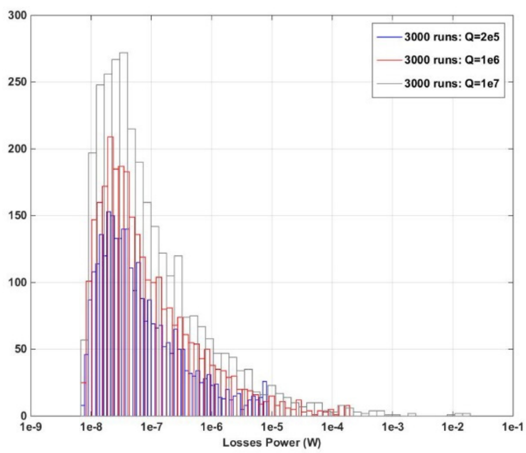

Figure 8. Calculations of the power losses in the 1.3 GHz Tesla-type cavity of Case 2.

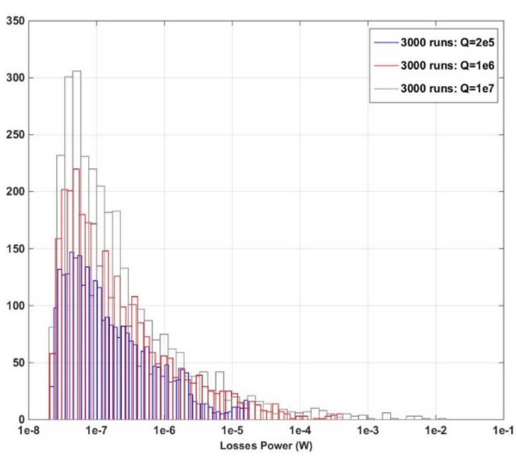

Figure 9. Calculations of the power losses in the 3.9 GHz third harmonic cavity of Case 1.

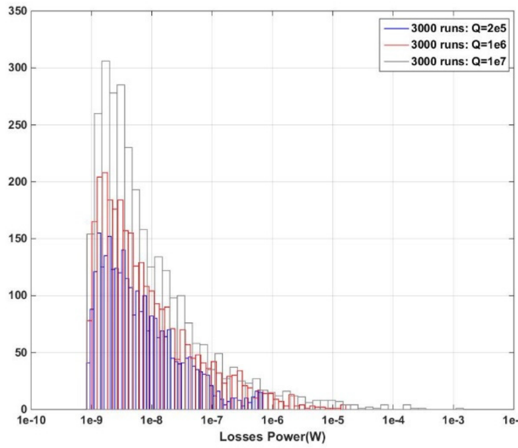

Figure 10. Calculations of the power losses in the 3.9 GHz third harmonic cavity of Case 2.

CONCLUSION

The median power loss, which corresponds to probability of 0.5, is approximately 1 μW and 0.1 μW respectively for trapped modes of 1.3 GHz Tesla-type cavity and 3.9 GHz third harmonic cavity in case 1.

Once in a while, due to random variation of its frequency, a single HOM in one cavity may come close to resonance. In this case power losses in 1.3 GHz Tesla-type cavity and 3.9 GHz third harmonic cavity may increase up to 100 mW and 10 mW respectively, although probability of such event is extremely low, it is less than 1 mW and 0.1 mW respectively.

Comparing case 1 and case 2, we can conclude that the lower Q_b and f_{rep} of the bunch, the smaller the power losses.

We also conclude, that power losses due to resonace excitation of monopole HOM are very small.

ACKNOWLEDGMENT

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