ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPRB081

DESIGN STUDY ON HIGHER HARMONIC CAVITY FOR ALS-U*

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Abstract

The ALS upgrade (ALS-U) to a diffraction-limited light source [1] depends on the ability to lengthen the stored bunches to limit the emittance growth and increase the beam life time. Higher harmonic cavities (HHCs), also known as Landau cavities, have been proposed to increase beam lifetime and Landau damping by lengthening the bunch. We present an optimized 1.5 GHz normal conducting HHC design for the ALS-U with a superconducting-like geometry using multi-objective genetic algorithm (MOGA) for lower *R/Q*. The optimization goal is to reach the required shunt impedance while maintaining a relatively high *Q* value of the cavities. To minimize the coupled bunch instabilities, higher-order mode (HOM) of the HHC as well as corresponding impedance are explored and characterized.

INTRODUCTION

The Advanced Light Source Upgrade (ALS-U) will upgrade the current ALS storage ring to a multi-bend achromat lattice as a diffraction-limited light source. In low to medium energy storage ring light sources, the beam lifetime is usually dominated by Touschek scattering. As the definition goes:

$$\left(\frac{1}{\tau}\right)_{Touschek} \propto \frac{I_{bunch}}{\varepsilon^2\gamma^3\sigma_l\sigma_x\sigma_y} \tag{1}$$

Options for lifetime increase each own different advantages and disadvantages. Increasing the transverse beam area leads to the reduction of brightness to limit where coupling reduces the momentum acceptance. Since the RF voltage in already relatively large, increasing the momentum acceptance is not practical. Decreasing the bunch current requires of running with smaller gap. A particularly attractive method to improve the beam lifetime is to reduce Touschek scattering by using a HHC to lengthen the bunch [2]. A passive third harmonic cavity is used for bunch-lengthening and instability-suppressing at ALS. The lengthening of the bunch will also help reduce higher order mode heating of all vacuum chamber components, improving stability in general. In this paper, we present a preliminary design of an optimized 1.5 GHz normal conducting HHC.

In passive operation, the harmonic voltage is generated from the beam itself without additional power input. Passive operation of the harmonic cavities has obvious advantages because of the reduction of operation costs. However, the controlling of the bunch length is generally less flexible and makes the effect of the cavities on the beam depend on the beam filling structure. The presence of a long gap in the beam filling is known to induce beam-loading transient effects that may compromise our ability to control the beam as intended. Transient beam loading effect generated by the non-uniform filling pattern causes a variation of harmonic phase and reduces the lengthening effect as well as bunch lengthening effect crucially.

The important HHC physics parameters are the shunt impedance R_S and the fundamental-mode resonance frequency ω_r. The fundamental mode quality factor Q is also important in passive harmonic cavities because it determines the detuning value. For ALS-U, two options are being considered for the upgrade, indicating either re-use of the current 3rd order cavities already operating in the ALS or the installation of newly designed cavities. In this study we restrict our analysis to the latter, designing and optimizing a new HHC for ALS-U.

The ALS currently operates with three 3rd-harmonic cavities, each with R_S = 1.7 MΩ. To lower the RF voltage applied to the main RF cavity, the optimum shunt impedance need to be lowered to 1.35 MΩ [3]. Furthermore, in consideration of the power loss, using only a single HHC to reach the optimum shunt impedance is not desirable.

CAVITY DESIGN

The original design of ALS HHC is based on a conventional re-entrant cavity shape. The use of nose cones as well as the cavity shape are carefully optimized for higher shunt impedance. Figure 1 presents the 3D model of cavity body with dampers. The parameters of the cavity are listed in Table 1 (where the definition of R_S is $R_S = V^2/2P$) [4]. To reach a much favourable performance, the required value for *R/Q* is around 30 Ω.

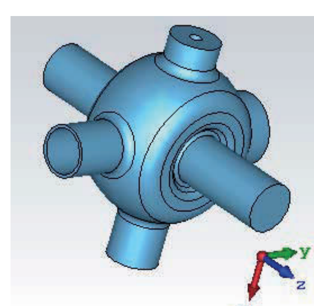

Figure 1: 3D model of the 3rd harmonic cavity of ALS.

* Work supported by the Director of Office of Science of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231
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Table 1: Harmonic Cavity System Parameters (Number of cavities: 3)

Parameters	Values
Frequency *f*	1.5 GHz
Maximum Voltage per cell	125 kV
Bore diameter	5 cm
R/Q	80.4 Ω
Meas *Q*	21000
Meas R_s	1.69 MΩ
Power per cell	4.6 kW

First-Step Design

In correspondence with the physics requirement, a low *R/Q* elliptical shape is designed using MOGA. The design process is presented in [5]. *R/Q* and the cavity length become two conflict objectives and 3 candidates are chosen for comparison as listed in Table 2. The field distribution along longitudinal axis as well as the current is compared in Fig. 2 as well as the current ALS cavity. After evaluation, the one with the lowest *R/Q* is chosen as a base for further study and its field distribution is shown in Fig. 3.

Table 2: Candidates Chosen from Pareto Front

Parameters	No.1	No.2	No.3
f (MHz)	1509.24	1508.45	1509.60
Cavity half length (mm)	80	76	71
R/Q (Ω)	26	30	35
Q	36375	35407	33796
R_S (MΩ)	0.946	1.062	1.182

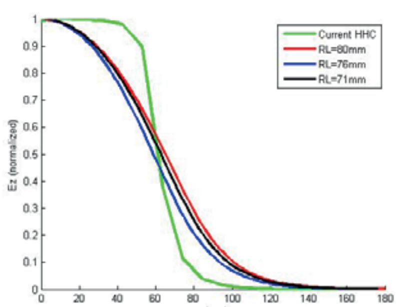

Figure 2: Normalized field along longitudinal axis. (RL is short for right limit which refers to the cavity half length).

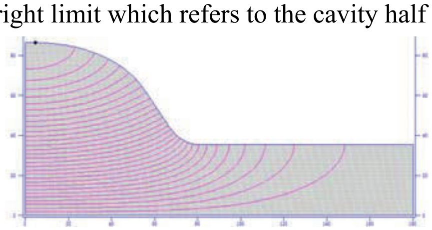

Figure 3: The chosen geometry with electromagnetic field distribution.

Further Revision

Analysing the above optimized cavity shape, the higher order modes (HOM) are investigated utilizing the simulation codes CST Microwave Studio [6] and Omega 3P [7]. Two dangerous polarized modes are shown at around 1523 MHz next to the fundamental mode 1509 MHz as is shown in Fig. 4.

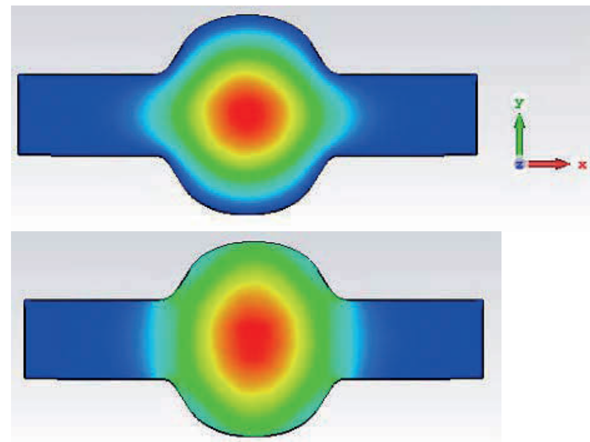

Figure 4: Cross-section of the two polarized modes.

There's a compromise between the cavity side slope, cavity length and beam pipe radius, which directly influence *R/Q* and the frequency of the higher order modes next to the fundamental mode. After further optimization, the revised cavity body 3D model is presented in Fig. 5. The beam pipe radius is 35 mm and *R/Q* is lowered to 34 Ω.

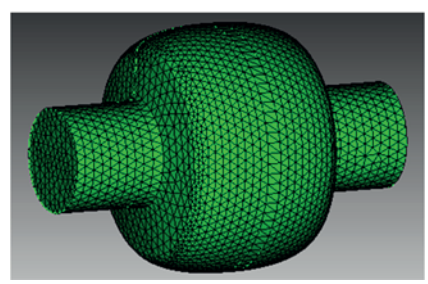

Figure 5: 3D model of further revised design.

HOM Characterization

To characterize the beam coupling impedance of the cavity, we have simulated its wakefield and beam coupling impedance with CST Particle Studio [6] to identify the resonant modes with significant contribution to the beam impedance.

In the wakefield simulation, the beam is located 5 mm away in the x direction from the cavity center. The longitudinal and transverse wakefields are integrated around the cavity center. Figure 6 shows the simulation process and the results are presented in Fig. 7.

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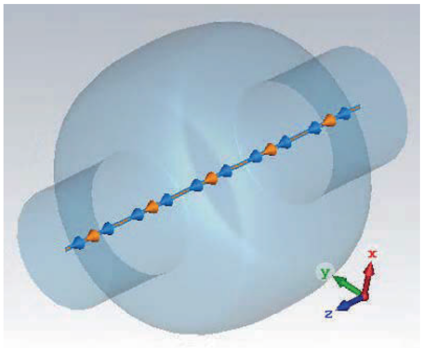
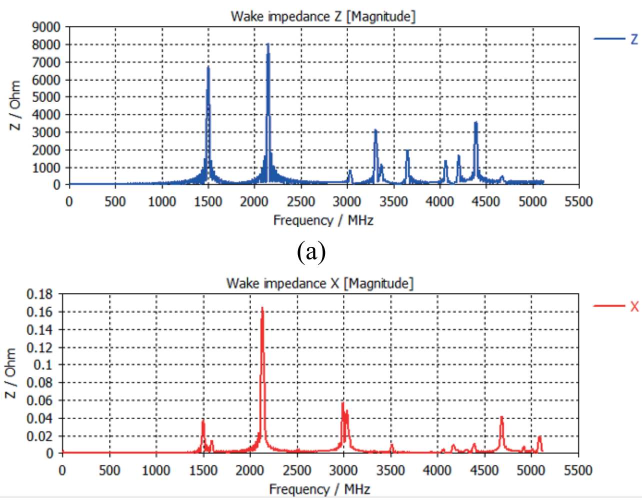


Figure 6: Simulation process.



(a)

(b)

Figure 7: (a) Longitudinal wake impedance, (b) Transverse wake impedance.

The beam pipe cut-off frequencies are 2.5 GHz for TE_{11} mode and 3.3 GHz and TM_{01} mode, so the main focus range of frequencies is under 3.5 GHz. From the wakefield simulation results, the major contributors to the beam coupling impedances are longitudinal modes TM_{011} at 2.2 GHz, transverse modes TM_{110} at 2.3 GHz and at TM_{120} at 3 GHz. Damping schemes will be investigated.

SUMMARY

In this paper, we presented the preliminary design of a new higher harmonic cavity with a low *R/Q* in terms of the physics requirement. We have identified the higher order modes with significant beam coupling impedance below the beam pipe cut-off frequencies. Damping schemes will be further explored next step.

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