A WAVEGUIDE OVERLOADED CAVITY KICKER FOR THE MAX IV BUNCH-BY-BUNCH FEEDBACK SYSTEM

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Abstract

The Higher-Order Modes (HOMs) in the main and the 3:rd harmonic cavities are driving longitudinal Coupled-Bunch Mode Instabilities (CBMIs) in the MAX IV 3 GeV storage ring. This far, negative feedback has been applied in the longitudinal plane by two stripline kickers. However, the maximum longitudinal feedback voltage provided by the striplines is rather weak, and a Waveguide (WG) overload cavity was therefore designed. Due to the long bunch length in the MAX IV storage rings, a relatively low center frequency of 625 MHz is selected. The new cavity kicker is being manufactured, and will be installed in the 3 GeV ring in June 2017. In this paper, the RF and mechanical design of the cavity is presented.

INTRODUCTION

The MAX IV facility in Lund, Sweden consists of two storage rings for production of synchrotron radiation, and a Short-Pulse-Facility (SPF) [1]. The two rings are designed for 3 GeV and 1.5 GeV, respectively, where the initial beam commissioning of the former has recently been completed, and commissioning of the latter was started in September 2016. Both rings will be operating with top-up injections delivered by a full-energy injector [2].

The 3 GeV ring is operating with a Bunch-By-Bunch (BBB) feedback system, where the signal processors are delivered by Dimtel [3]. In this ring, there is one horizontal and one vertical stripline installed, and they are dedicated as actuators for feedback in the transverse plane. At the moment, the two striplines are simultaneously operating as longitudinal actuators as well, as described in [4]. However, the longitudinal voltage provided by the striplines is rather weak, and a WG overloaded cavity based on the original DAΦNE design [5] that is dedicated for longitudinal feedback has therefore been designed. The new cavity will be installed in the 3 GeV ring in June 2017.

The commissioning of the BBB feedback system in the 1.5 GeV ring will start in the second half of 2017.

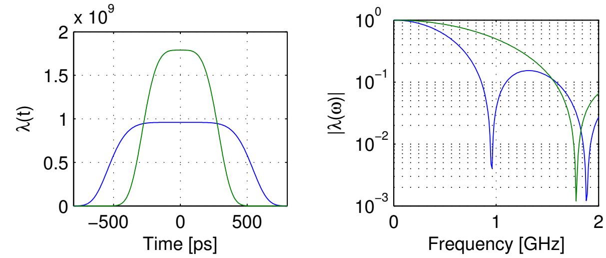
KICKER REQUIREMENTS

The first step when designing the cavity is to determine its center frequency f_c and its Bandwidth (BW). The minimum required BW in order to suppress all CBMIs is $f_{RF}/2$ = 50 MHz if f_c is chosen so that $f_c = f_{RF}(1/4 + n/2)$, $n \in \mathbb{N}$. f_{RF} = 100 MHz is the operating frequency of the MAX IV ring RF system. f_c in similar cavities might vary between 900 MHz [6] and 1900 MHz [7], and is often carefully chosen and optimized for the conditions at the facility where it is installed. Choosing a high f_c has several advantages such as a more compact cavity and a higher achievable shunt impedance, $R_{||}$. Another advantage with a higher f_c is that all the potentially harmful HOMs are shifted upwards in frequency as well. The shunt impedance is defined as $R_{||} = |V_{||}|^2/2P_{\mathrm{rms}}$, where P_{rms} is the rms power supplied to the cavity by the amplifiers. The voltage gain, $V_{||}$, is defined as

$$V_{||} = \int_{-L}^{L} |E_z(z)| e^{j(kz+\varphi)} \mathrm{d}z \quad (1)$$

where $E_z(z)$ is the on-axis longitudinal electrical field, $k = \omega/c_0$ is the wave number, $2L \to \infty$ is the integration length, and φ is an arbitrary phase.

When selecting f_c, one also has to consider the long ring bunches at MAX IV. Currently, both rings have double RF systems with passive 3:rd harmonic (Landau) cavities for bunch lengthening. There are also future plans to operate with a triple RF system in the 3 GeV ring in order to increase the bunch lengthening further by adding 5:th harmonic cavities as well. If the filling pattern is uniform, each bunch has a normalized longitudinal profile in time domain, $\lambda(t)$, so that $\int \lambda(t)\mathrm{d}t = 1$. $\lambda(\omega)$ is the same bunch profile in frequency domain, and $\lambda_z(z)$ is the normalized spatial profile where $c_0\lambda_z(c_0t) = \lambda(t)$. Figure 1 shows $\lambda(t)$ and $\lambda(\omega)$ during ideal bunch lengthening with a double and a triple RF system. If f_c is too high, the head of the bunch obtains a kick with a different direction compared to its tail, and the net kick over the bunch can be zero in a worst-case scenario. The average voltage gain over the normalized electron bunch V_{avg} is



(a) (b)

Figure 1: (a) shows the normalized longitudinal profile of a bunch in time domain, $\lambda(t)$, and (b) shows the same profile in frequency domain, $|\lambda(\omega)|$. The green curves are for a double (100 MHz + 300 MHz) and the blue curves are for a triple (100 MHz + 300 MHz + 500 MHz) RF system during ideal bunch lengthening.

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$$V_{\text{avg}} = \int_{-L}^{L} \lambda_z(z') \left\{ \int_{-L}^{L} |E_z(z)| e^{j(k(z-z')+\varphi)} \mathrm{d}z \right\} \mathrm{d}z'$$
$$= V_{||} \int_{-L/c_0}^{L/c_0} \lambda_z(c_0 t') e^{-j\omega t'} c_0 \mathrm{d}t' = \lambda(\omega) V_{||} \quad (2)$$

As seen in Figure 1 (b), f_c must be relatively low in order to keep a high kick efficiency. A good compromise between a compact cavity geometry and fairly high V_{avg} is to set $f_c = 625$ MHz. Here, $|\lambda(\omega)|$ is 0.77 and 0.40 for a double and a triple RF system, respectively.

CAVITY DESIGN

A simple pillbox cavity with $f_c = 625$ MHz would have a radius of 184 mm. However, it was decided to decrease the cavity radius so that a standard steel pipe with an inner radius of 100 mm can be used as the cavity lateral surface. f_c is therefore shifted downwards with a coaxial loaded structure with long nose cones. The nose cones also increase the geometry factor, $R_{||}/Q$, due to field focusing. Initially, the optimization of the 2D rotation-symmetrical unloaded cavity volume was performed in a MATLAB [8] with livelink to COMSOL [9]. Here, $R_{||}/Q$ was optimized for the fundamental mode while it was kept as low as possible for the first rotation-symmetrical HOMs. Four ridged WGs are added to the unloaded cavity, and they are optimized to achieve the necessary BW of the fundamental mode, but also to damp unwanted HOMs.

Figure 2 shows a 3D model of the assembled cavity. The nose cones and the ridged WGs are milled into two copper bodies. Each copper body is braced to a steel flange and then attached to the flanges that are welded to the outer steel pipe. In order to improve the vacuum in the vicinity of the cavity, an ion pump is added to the design, where the pumping occur via grids on the outer pipe (see Figure 2). The grids are parallel to the surface currents, $\mathbf{J} = \hat{\mathbf{n}} \times \mathbf{H}$, on the cavity inner lateral surface of the fundamental mode, and their presence has a neglectable effect on the cavity performance.

Proper electrical contact between the outer tube and the copper bodies are provided by contact springs as in the ELSA design [10], where the springs are placed in grooves in the copper body. Contact between the inner conductor of the coaxial feedthrough and the copper body is provided by gold plated socket connectors that are screwed to the latter as seen in Figure 2. These socket connectors are the same type as the female inner pin at the N-type connector of the feedthroughs.

SIMULATIONS

As mentioned above, the first step was to optimize the unloaded cavity, and $R_{||}/Q$ of the rotation-symmetrical eigenmodes up to 4.5 GHz can be seen in Figure 3. $R_{||}/Q = 162\,\Omega$ for the fundamental mode.

In order to reduce the requirements on mechanical tolerances and to improve the gain flatness, a somewhat larger -3 dB BW of 70 MHz (590 MHz - 660 MHz) was chosen.

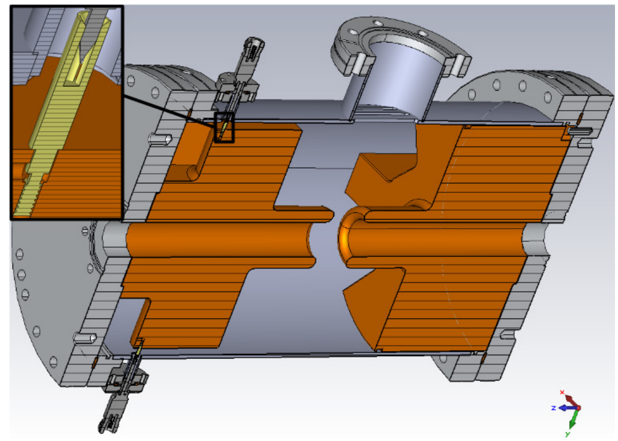

Figure 2: A 3D model of the cavity. The socket connector can be seen in the zoomed area.

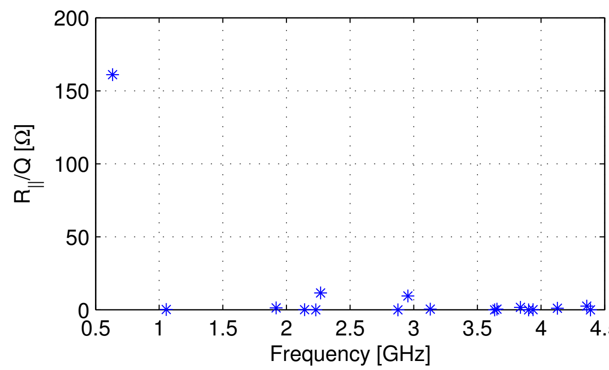

Figure 3: The simulated values of $R_{||}/Q$ for the rotation-symmetrical eigenmodes of the unloaded cavity up to 4.5 GHz.

Figure 4 shows the simulated common-mode S-parameters when the four WGs have been added. Here, the two physical downstream ports form the first logical port, while the two physical upstream ports form the second logical port. As seen, f_c has been shifted slightly downwards in frequency in order to keep the desired BW. Figure 5 shows $R_{||}(\omega)$ obtained in COMSOL. $R_{||}(\omega)$ decreases more rapidly at higher frequencies which is mainly because the transit time factor decreases with frequency.

Figure 6 shows the real part of the longitudinal beam impedance, $\Re(Z_{||}(\omega))$, obtained in GdfidL [11]. As seen, the WGs are effectively damping the HOMs up to ≈ 3 GHz. At higher frequencies, the eigenmodes are more narrow-banded up to ≈ 8 GHz where the broadband region starts due to the TM_{01} cut-off frequency of the beam pipe. For optimum bunch lengthening with the double RF system, the power lost in the structure by the beam is ≈ 460 W when the filling pattern is uniform at a beam current of 500 mA. Because of the narrow bunch spectrum in Figure 1 (b), almost all power lost by the beam is induced in the fundamental mode, and it is dissipating in the external coaxial terminations, and not in the cavity itself. Since the loaded quality factor, $Q_L = 8.9$, of the fundamental mode is very low, contributions from coherent multi-turn wakefield superposition are neglectable.

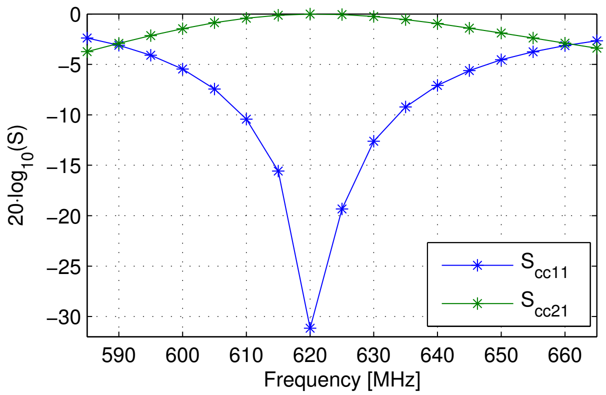

Figure 4: The simulated common-mode S-parameters of the cavity.

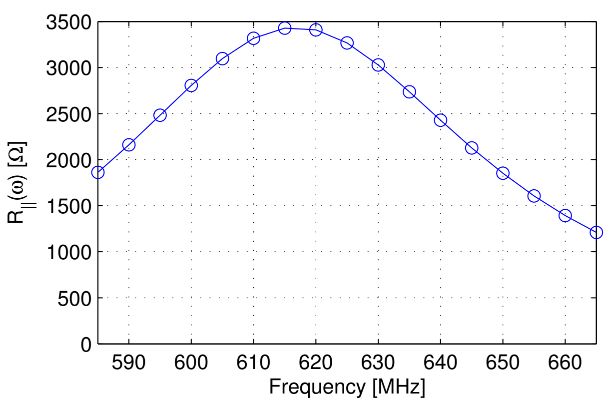

Figure 5: The longitudinal shunt impedance $R_{||}(\omega)$ obtained in COMSOL.

CONCLUSIONS AND FUTURE WORK

This far, the longitudinal BBB feedback in the MAX IV 3 GeV ring has been provided by two striplines. However, the striplines are very weak longitudinal actuators, and in order to increase the kick voltage, a waveguide overloaded cavity has been designed and is being constructed. Due to the long bunches at MAX IV, a relatively low cavity center frequency of 625 MHz was chosen in order to keep a high kick efficiency. The cavity will be installed in June 2017.

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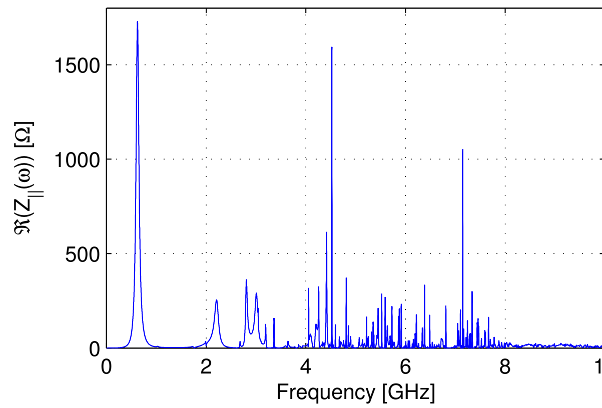

Figure 6: The longitudinal beam impedance $\Re(Z_{||}(\omega))$ obtained in GdfidL.

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