INFLUENCE OF MECHANICAL VIBRATION ON BUNCH SHAPE MONITOR PHASE RESOLUTION

D. Chermoshentsev†[1,2,3], A. Feschenko[2], S. Gavrilov[1,2]
[1] Moscow Institute of Physics and Technology, Moscow Russia
[2] Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia
[3] Skolkovo institute of Science and Technology, Skolkovo, Russia

Abstract

Bunch Shape Monitor with three changeable deflectors was designed and manufactured for UNILAC, CW LINAC and proton linac of GSI-FAIR project. The length of BSM RF-deflector for UNILAC was large, that increased the influence of external mechanical vibrations on the BSM operation. The model for mechanical and electrical analysis of BSM RF-deflector and design solutions for vibration damping are presented.

INTRODUCTION

Bunch shape monitor (BSM) [1] uses the technique of a coherent transformation of a temporal bunch structure into a spatial charge distribution of low energy secondary electrons through RF-modulation. The main part of BSM is a RF-deflector. The RF-deflector electric field is a superposition of electrostatic focusing and steering fields and RF-deflecting field, thus enabling simultaneous focusing and RF-scanning of the electrons. Typically, BSM deflectors are RF-cavities based on parallel wire lines with capacitive plates. After the deflector intensity of secondary electrons beam registered by electron multiplier. Electrical length of the deflectors is usually quarter-wave (QW) or half-wave (HW) (Fig. 1).

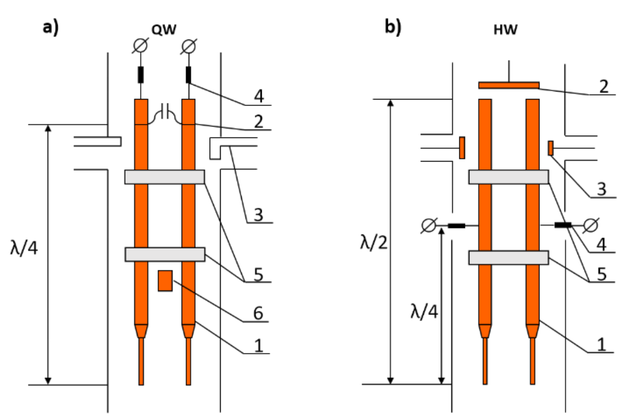

Figure 1: Scheme of a) QW-type and b) HW-type RF-deflectors. 1 – electrodes, 2 – main tuning, 3 – RF - feedthrough, 4 – HV - feedthrough, 5 – isolating holders, 6 – extra tuning.

BSM with three changeable deflectors was fabricated for GSI linacs: UNILAC, CW linac and Proton linac.

At lower frequencies, length of the RF-deflector increases that makes the device more unstable to external mechanical vibrations. One of possible reasons causing such vibrations can be vacuum pumps, located near the BSM. The problem of external vibrations was faced for the first time during the tests of BSM GSI UNILAC. Since operation RF-field frequency for UNILAC is low – 108.408 MHz, the RF-deflector is long – 610 mm.

The external vibrations can lead to instability of electrical operational frequency of RF-deflector, which is crucial problem for measurements.

The mechanical and electrical analysis of the BSM was provided to find a solution how to eliminate this effect.

EXPERIMENTAL RESULTS

The oscillations of the registered secondary emission electrons beam intensity were obtained. Usually, phase measurements are provided with the phase steps from 1° to 5°, that seems sufficient for typical bunch lengths.

In the Fig. 2a-c the results of BSM measurements are shown for different phase steps. Experimental points were taken for each beam pulse with 3.6 Hz repetition rate. The curve clearly shows modulation with the period equal to about 3.2 s. The amplitude of modulation can be estimated from Fig. 2a and is equal to 4÷5°. The fluctuations of the secondary electron beam intensity disappear with increasing of a phase step (Fig. 2b, c). Obviously, that the oscillations appear during the experiment if the average time of the electric field phase adjustment inside the deflector is more times less than the characteristic vibrations period. For the period of oscillation, about 3.2 s and the amplitude about 5°, the modulation of 2.5° is completed at the quarter of the period, i.e. about 0.8 s. The phase of RF-field is adjusted by 0.29° during this time.

The Fig. 2a-c shows that the modulation decreases with the phase step 0.5° and disappear completely with the phase step 2°.

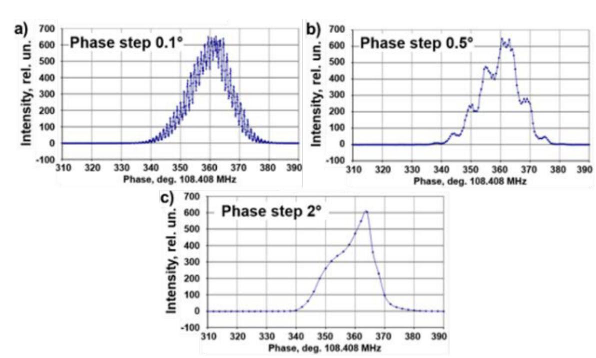

Figure 2(a -c): Experimental bunch shape measurements.

Displacements of the vacuum pump changed the effect quantitively but did not remove it completely.

† dmitriy.chermoshentsev@phystech.edu

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MECHANICAL ANALYSIS

Further simulations were provided for case of UNILAC 108.408 MHz BSM. Electrodes of RF-deflector can be approximately described as cantilever. The analysis of mechanical vibrations for BSM electrodes was done in COMSOL Multiphysics [2] with "Structural mechanics" module.

A damping effect is included to the model. The isotropic structural loss factor $\eta = 2 \cdot 10^{-3}$ for copper and $\eta = 3 \cdot 10^{-2}$ for ceramic were taken by [3].

The geometry in the model consists of the couple of rods which bound by ceramic isolators and soldered to the copper jumper. Simulations shows that mechanical quality factor of electrodes is Q=500 and system relaxation time is t=1.3 s.

According to eigenfrequency analysis, electrodes frequencies of the main and the second eigenmodes are about 61 Hz and 377 Hz correspondingly. The main eigenmode oscillations is shown in the Fig. 3.

Harmonic perturbations in the frequency range from 10 to 500 Hz were applied to the isolators in OZ-direction for the amplitude-frequency analysis. The amplitude-frequency characteristic is presented in the Fig. 3. The second eigenmode amplitude is much less than the main one, that is why the second mechanical eigenmode can be neglected in the further electrical analysis.

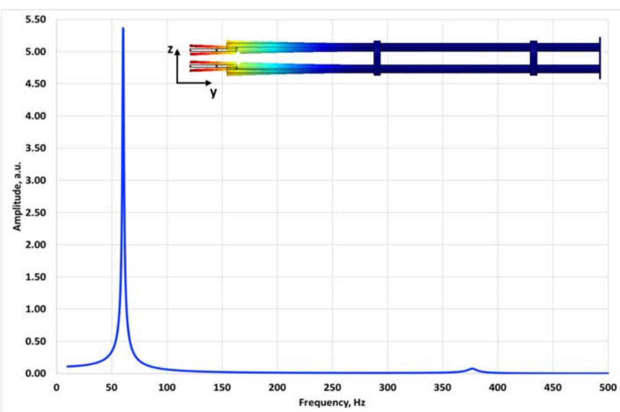

Figure 3. Resonant curve of the electrodes; the main mechanical eigenmode of electrodes.

The mechanical vacuum pumps vibrations spectrum consists of frequencies multiple to a rotor operational frequency and can be approximately considered as polyharmonic. It is an approximation of the real vibration spectrum of mechanical vacuum pumps, since the ideal spectrum is splattered under the influence of the temperature, different defects of details, errors during manufacturing, changes of the system parameters etc.

In practice it is impossible to manufacture identical electrodes, hence their eigenfrequencies will be some different. It was suggested that this difference is a reason of low frequency modulation of electron beam intensity described before.

The eigenfrequencies of the rods were considered as 61.2 Hz and 61.5 Hz correspondingly. Simulations showed that under the impact of external short pulses nonidentical electrodes oscillate with their eigenfrequencies. At this case the difference between electrodes oscillations forms beats (Fig. 4). Difference 0.3 Hz between electrodes eigenfrequencies is corresponded to modulation period 3.33 s.

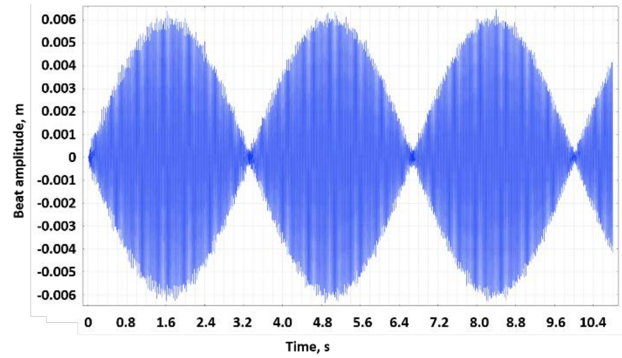

Figure 4: Difference between oscillation amplitudes of 61.2 Hz and 61.5 Hz.

ELECTRICAL ANALYSIS

In the case of BSM, the plates of the electrodes play the role of capacitor. The main mechanical eigenmode of electrodes (Fig. 3) allows one to assume that oscillations of the plates under the influence of external vibrations shift the value of the resonator electrical eigenfrequency by changing of the system capacity.

The electric field inside QW-deflector for the operational electrical mode is mainly localized between the plates (Fig. 5).

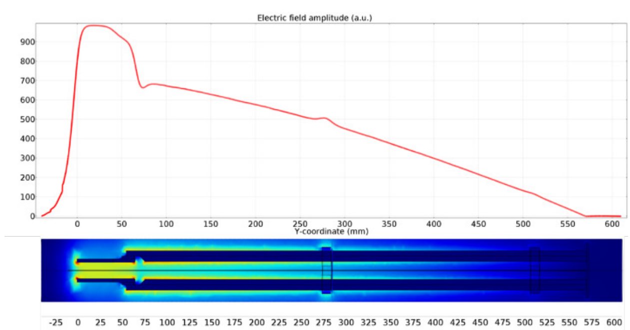

Figure 5: The E_z – field distribution along the axis of deflector.

The RF-deflector can be described as LC-tank. RF-deflector is a resonator and energy input to the deflector is realized by an inductive loop. The phase of a wave in the deflector and the input wave is not equal, and the phase difference can be determined from the theory of forced oscillation in electrical LC-tank.

Turning out the mathematical calculations finally it is described by (1):

$$\delta\varphi \approx 2Q\frac{\Delta\omega}{\omega_0} = -Q\frac{\Delta C}{C} \qquad (1)$$

The observed phase shift, quality factor, and eigenfrequency values are φ=5°, Q=560 and ω_0=108.408 MHz correspondingly in the case of UNILAC deflector. According to estimations, the frequency

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difference is about $\Delta\omega = 8.5$ KHz, that corresponds to $\Delta\omega/\omega_0 \approx 8 \cdot 10^{-5}$. Relative capacitance changing is about $C_0/C \approx 2 \cdot 10^{-4}$ at this case.

For capacitance calculation, the model of RF-deflector was created in "Electric currents" module. The typical RF-voltage between plates of the BSM electrodes is 1 kV. According to mechanical analysis the amplitudes of electrodes oscillations are small, and it is possible to consider that the plates of the electrodes are parallel. In simulations a capacitance was calculated for different distances between parallel plates.

Finally, using mechanical analysis and electrical analysis the dependences between phase shifts and deflector accelerations were determined (Fig. 6). The typical phase resolution of BSM is 1°, so a maximum phase shift is about 1° seems acceptable for proper measurements. According to the model in case of BSM GSI the acceleration of RF-deflector corresponded to 5° phase shift, was about 4 m/s^2.

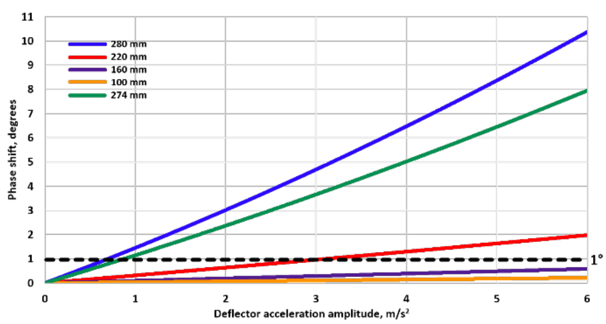

Figure 6: Phase shift vs. external acceleration for different bottom isolator position.

DESIGN SOLUTION

The amplitude of plates oscillations can be damped by a decreasing of the cantilever length. The dependences between phase shifts and external accelerations for different bottom isolator positions were obtained (Fig. 6).

The solid green curve represents the dependence for initial geometry of 108.408 MHz BSM. Simulation showed that for reaching of the necessary phase resolution values, the cantilever length should be decreased to 100-200 mm. In case of 108.408 MHz BSM, it was decided to install an additional isolator for 100 mm distance. To damp the parasitic oscillations the third electrode holder made of PEEK^{TM} was added (Fig. 7). PEEK^{TM} was selected due to twice smaller permittivity and dielectric loss tangent compared with MACOR^{TM} used for the original holders. In spite of the higher strength of the electric field at the new holder, the adjustment range of the frequency tuner appeared to be sufficient and no extra rework was needed.

Figure 7: Photo of the deflector with extra PEEK holder.

CONCLUSION

One of possible ways for BSM mechanical and electrical stability improving is using more isolators or pull down the bottom one. But it is necessary to consider that increasing number of isolators leads to more energy losses at the system due to higher electric field strength near the electrodes plates, and as a result to less quality factor of the deflector. Therefore, it is very important to complete full simulations of the BSM at the step of preliminary design.

The second possible solution for vibrations damping is to use a symmetrical design of RF-deflector without a cantilever, but at this case the overall size of the deflector becomes larger and it can be fitted with the size of an installation place. The length of the symmetrical deflector can be decreased by using special additional electrodes plates which decrease the effective electrical length and capacity of the deflector, and, correspondingly, the length of the operation wave also will be decreased. The main problem of the symmetrical deflector with additional plates is a frequency tuning. The operational RF-field frequency is very sensitive to plates positions, that leads to a problem of its accurate adjustment.

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