ELECTRODYNAMIC CHARACTERISTICS OF RF-DEFLECTOR FOR BUNCH SHAPE MONITOR

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Abstract

Bunch shape monitors, based on a transverse RF-scanning of secondary electrons, are used for measurements of particles longitudinal distribution in bunches at different linear ion accelerators. The phase resolution of such monitors depends crucially on accuracy of fabrication and tuning of RF-deflector, thus preliminary simulations of its electrodynamic characteristics are of importance for subsequent commissioning of the monitor. Simulations of basic operational electrodynamic parameters and some experimental results are presented.

INTRODUCTION

Bunch shape monitor (BSM) [1] uses the technique of coherent transformation of a temporal bunch structure into a spatial charge distribution of low energy secondary electrons through RF-modulation [2]. The main part of BSM is RF-deflector. The deflector is combined with electrostatic lens, thus enabling simultaneous focusing and RF-scanning of the electrons. Typically, BSM deflectors are RF-cavities based on parallel wire lines with capacitive plates. Electrical length of the deflectors is usually λ/4 or λ/2 (Fig. 1). The electrodes with deflecting plates 1 are supported by ceramic insulators. Focusing potentials are supplied at a zero electrical field points via ceramic resistors 4, which are used to diminish the influence of external connections.

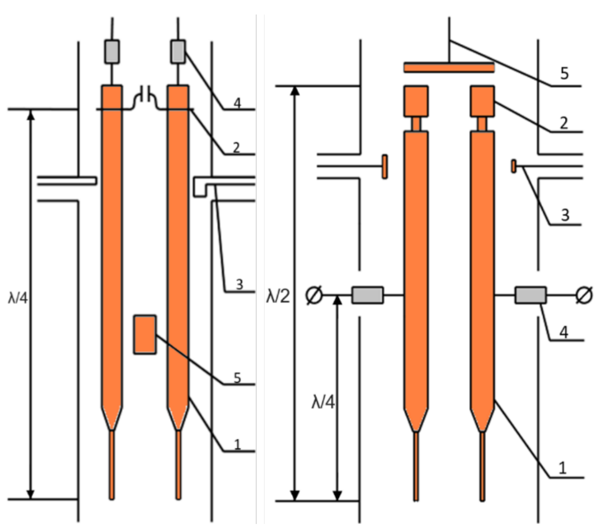

Figure 1: Scheme of λ/4 (left) and λ/2 (right) RF-deflectors.

In λ/4-type deflector resonant frequency is adjusted by moving jumper 2. The jumper consists of two collets connected by ceramic capacitors. Coupling loops 3 are used to drive the cavity and to pick up the RF-signal.

In λ/2-type deflector resonant frequency is adjusted by changing the length of the electrodes with screws 2. Capacitive couplers 3 are used for driving and control.

Tuners 5 with different geometries are intended for fine frequency tuning of both cavity types from outside vacuum. Tuning of RF-deflectors includes adjustment of resonant frequency and input matching of RF-couplers to minimize reflections.

For proper operation, a deflector development should begin from preliminary calculations of its electrodynamic parameters, such as: resonant frequency, quality factor and equivalent impedance as well as S-parameters.

RESONANT FREQUENCY

Development process of BSM is based on COMSOL Multiphysics, that provides comprehensive simulations of all characteristics, including RF-parameters [3].

A frequency of RF-deflecting field should be equal or multiple to the RF-field frequency in the accelerator. Geometry of the RF-cavity can be simply calculated via Eigenfrequency solver. However these simulations should take into account positions of ceramic insulators (electrode holders), which change the resonance frequency crucially, because of rather high relative permittivity (about 10).

If the deflector is tuned in the air, it needs extra tuning from outside vacuum after pumping, due to the shift of resonance frequency. The exact values depend on the temperature and humidity of the air, but the difference is rather small (less than 100 kHz for operational frequencies) and can be easily compensated (Fig. 2) by fine tuner, which geometry and stroke can be simulated preliminarily.

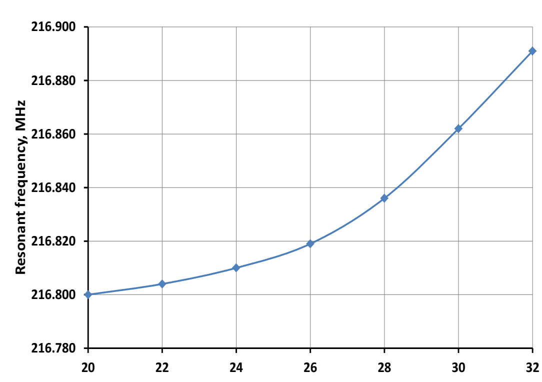

Figure 2: Example of experimental dependence between resonant frequency and tuner position in the λ/4-type deflector with operational frequency 216.816 MHz.

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STANDING WAVE RATIO

S11-parameter, defining standing wave ratio (SWR), depends on geometry and position of coaxial RF-couplers: washer for capacitive drive (Fig. 3) and loop for inductive drive (Fig. 4).

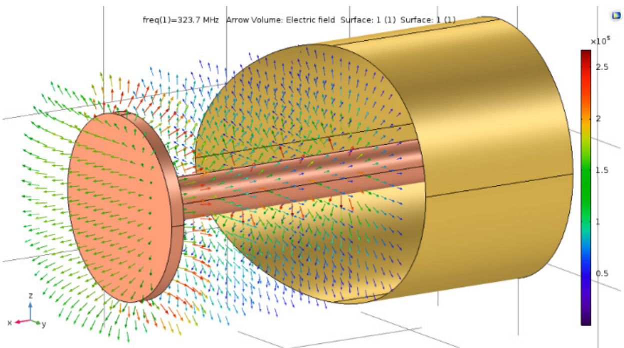

Figure 3: Electric field of capacitive coupler (washer).

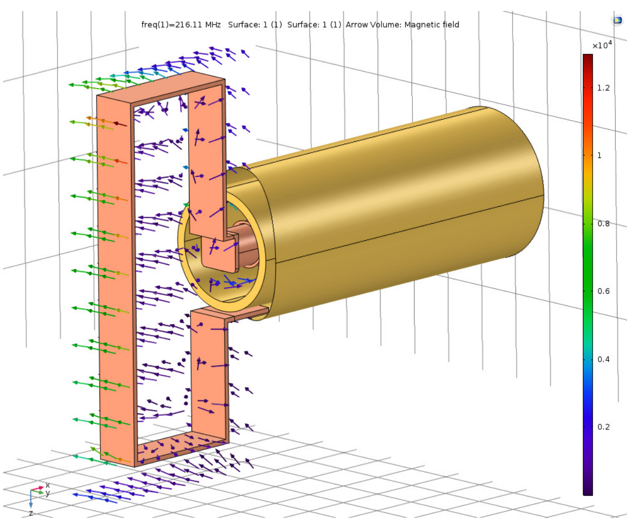

Figure 4: Magnetic field of inductive coupler (loop).

SWR can be tuned by adjusting of the distance between the electrode and coupler. However the geometry of a loop or diameter of a washer should be preliminarily simulated to find optimum values for fabrication (Fig. 5).

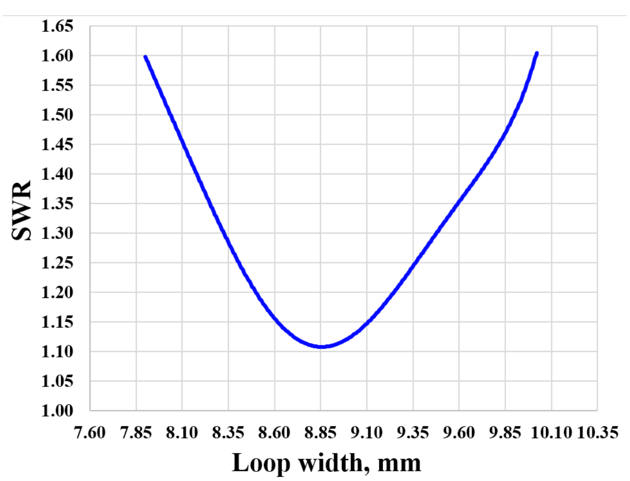

Figure 5: Simulated dependence SWR vs. coupling loop width (with constant length 27 mm).

EQUIVALENT IMPEDANCE, Q-FACTOR & INSERTION LOSS

The RF-cavity parameter of importance for electron deflection is an equivalent impedance $R_e = U_d^2/2P$, where U_d is the amplitude of RF-deflecting voltage between the plates and P is RF-power dissipated in the deflector. Simulations and real operation show, that the power, required for typical U_d = 1 kV, is less, than 10 W, that can be provided easily by relatively compact RF-amplifier [4].

Typical value of unloaded simulated Q-factor is about 1000 ÷ 1500 and depends on positions of ceramic insulators (Fig. 6) in electrical field because of non-zero dielectric loss tangent. Positions of insulators is mainly defined by their function as mechanical holders and cannot be changed arbitrarily.

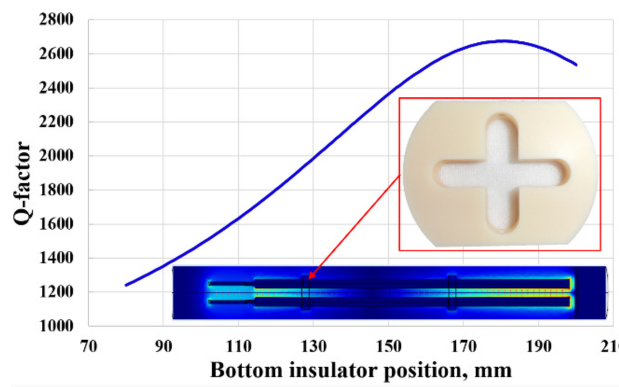

Figure 6: Q-factor vs. insulator position in λ/2 deflector (color shows amplitude of electric field in the deflector).

Loaded Q-factor as well as insertion loss, can be measured by network analyzer in terms of S21-parameter (Fig. 7) due to the presence of the special pick-up coupler.

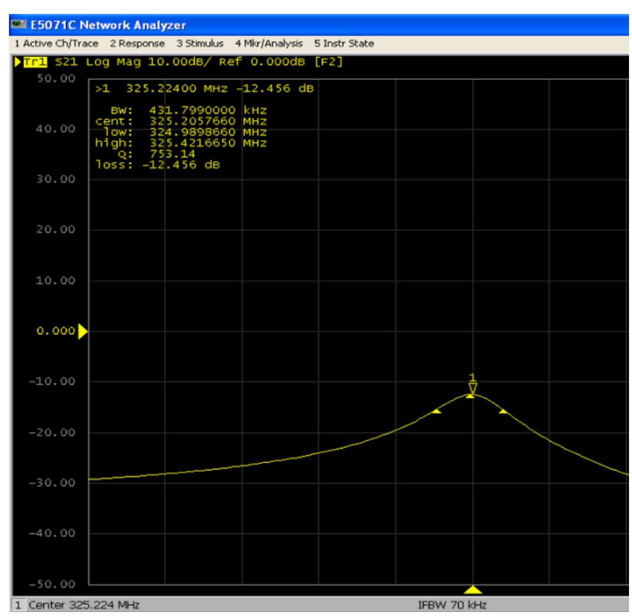

Figure 7: S21 measurements by network analyzer.

One should note, that neither insertion loss nor standing wave ratio is changed when the resonant frequency of the deflectors is adjusted.

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RF-SIMULATION FEATURES

There are two main problems in RF-simulation of BSM deflector. The first one is the presence of ceramic parts: capacitors in λ/4-deflector (Fig. 8) and isolating holders. RF-characteristics of ceramic depend on the frequency of electromagnetic field and may vary from part to part significantly due to fabrication and storage conditions. It means, that only experimental measurements at given frequency for parts from the same consignment can give relevant calibration curve for the model.

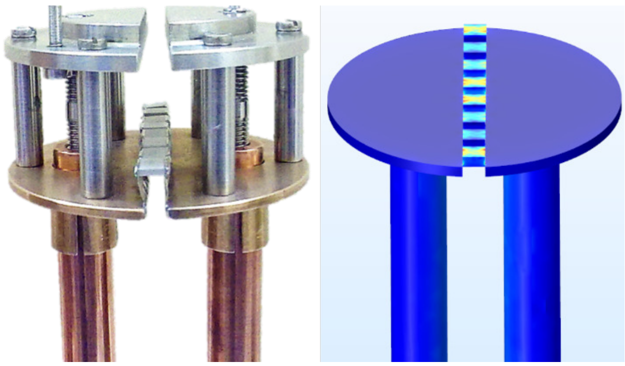

Figure 8: Jumper with ceramic capacitors in λ/4-deflector: photo (left) and simplified model (right).

The second problem is a big discrepancy (up to 10^3 times) between sizes of various deflector parts, that leads to problems in meshing for finite element model. Some effects in transition zones between different parts (Fig. 9) can be lost in this case, that results in inaccurate numerical values even for basic RF-parameters, like resonant frequency or Q-factor. The efficient solution is an adaptive mesh with manual meshing for separate parts and tuning the order of finite elements.

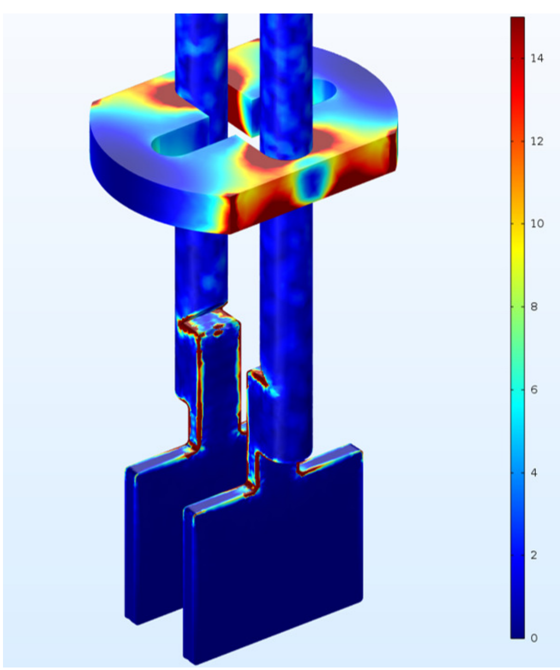

Figure 9: Simulated distribution (in a. u.) of electromagnetic power loss density in ceramic isolator and electrodes with plates at adaptive mesh.

CONCLUSION

A number of electrodynamic parameters of BSM RF-deflector: resonant frequency and quantities derived from S-parameters – should be calculated before its fabrication. Simulated results, based on finite element model in COMSOL Multiphysics, are in a good agreement with experimental measurements.

The final values are defined by many unpredictable conditions. For example, there is a slight change of the resonant frequency due to connection of the cables supplying focusing high voltage. This change is within 20 kHz and depends on the length of the connecting cables. However such small discrepancies can be adjusted by fine tuners foreseen in the deflectors.

Simulations of loss parameters are rather sensitive to a mesh quality, so manual meshing with control of transition zones between deflector parts may be determinative for precise relevant calculations.

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