ELECTRO-DYNAMIC CHARACTERISTICS OF RF WOBBLER CELL FOR HEAVY ION BEAM*

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Abstract

Intense heavy ion beam is very efficient tool to generate high energy density states in macroscopic amounts of matter. As result it enables unique methods to study astrophysical processes in the laboratory under controlled and reproducible conditions. For advanced experiments on high energy density physics the cylindrical target irradiated by hollow cylindrical beam is required. This combination provides extremely high densities and pressures on the axis of imploding cylinder [1-3]. A new method for RF rotation of the ion beam is applied for required hollow beam formation. The RF system consisting of two four-cell H-mode cavities is under development for this purpose now. The cavities frequency has been chosen 297 MHz, which is sufficient for uniform target illumination at 100 ns pulse duration [4].

The deflecting electrodes shape has been optimized to provide the uniform deflection of all particles in beam's cross-section [5, 6]. The prototype of the deflector cell was constructed. A measured electro-dynamic characteristics are presented. As well frequency corrections methods are considered in this paper.

INTRODUCTION

The general layout of the deflecting system is shown on Fig. 1. A beam goes through two pairs of deflecting plates where the RF voltage is applied. A beam gets a horizontal deflection at the first pair of plates and vertical at the second. As it is well known, the deflecting field should have a 90 degrees phase incursion between pairs of plates in order to make a circle beam.

The most effective interaction between RF deflecting field and a beam can be achieved if the beam's time-of-flight through one deflecting plates pair doesn't exceed the half of the RF period $D=\beta_z c/2f$, where β_z – is a normalized longitudinal speed, c – speed of light and f – field frequency. Otherwise the transverse electric field changes the direction between plates.

Beam dynamics simulation has shown that such deflection system with electric deflecting field amplitude of 10 MV/m and field frequency of 297 MHz might deflect a $_{59}Co^{27+}$ beam with energy 450 MeV/u for maximum 1.4 mrad. It is not enough for required quasi-hollow beam formation because of the experimental beamline length.

In order to overcome the limitation for high energy beam deflection, a principle of resonant interaction of the beam with multi-cell RF structure is suggested.

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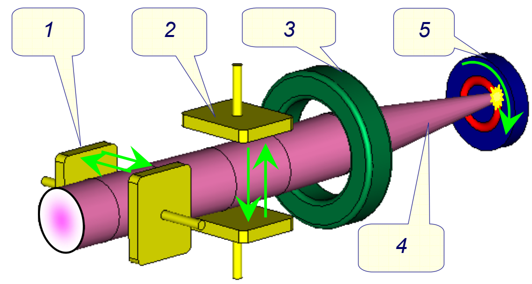

Figure 1: The general layout of the deflecting system. 1 – x-deflector, 2 – y-deflector, 3 – focusing system, 4 – ion beam, 5 – target.

Every cell must have length $D=\beta\lambda/2$, where β is the normalized particle velocity and λ is the RF wavelength as Fig. 2 shows.

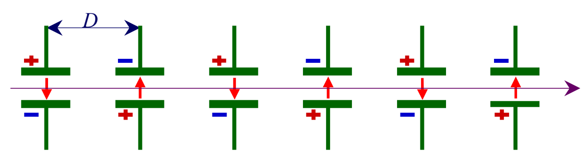

Figure 2: Multi-cell RF structure.

If the resonant condition is fulfilled, any particle crosses the cell centers at the constant phase of RF field regularly increases the transverse momentum dependently on the phase value.

Therefore, particle deflection $\Delta\alpha$ may grow with the length of the deflecting cavity L as the next formula shows:

$$\Delta\alpha(rad) = \frac{eZ \cdot E_{ef}}{m_o c^2} \cdot \frac{\sqrt{1-\beta^2}}{\beta^2} \cdot L \qquad (1)$$

where eZ, m_o are the charge and the rest mass of the ion, respectively; β is the normalized particle velocity; E_{ef} is the effective deflecting field, which can be found by integration of the transverse field component $E_\perp$:

$$E_{ef} = \frac{1}{D} \cdot \int_0^D E_\perp(z) \cdot \sin\left(\frac{\pi}{D} \cdot z\right) \cdot dz \qquad (2)$$

This value may be interpreted as a main travelling wave harmonic of the transverse electric field, continuously interacting with the particles.

According to a scheme of the multi-cell RF deflection, the transverse electric component of the electromagnetic field should be dominant in the real deflecting cavity, being periodically varied along the longitudinal axis. In practice, the H_{11n} oscillating mode in the cylindrical cavity is the closest to the desired field distribution. Here n is the number of field variations along the full cavity length. Fig. 3 shows a general view of the four-cell deflecting cavity.

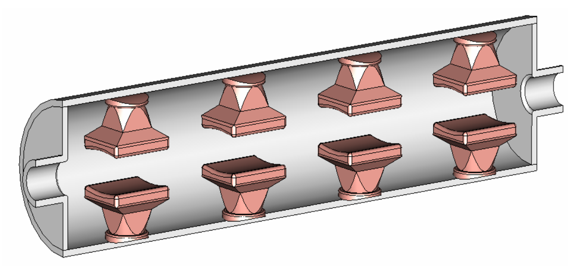

Figure 3: The general view of the four-cell deflecting cavity.

Main calculated parameters of the deflector cell were presented in [5]. The prototype deflecting cell has been constructed and manufactured (Fig. 4).

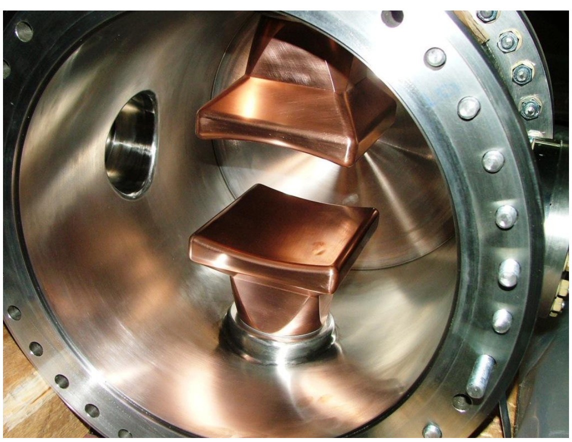

Figure 4: The prototype deflecting cell.

THE PROTOTYPE CELL ELECTRO-DYNAMICS CHARACTERISTIC`S MEASUREMENT

After manufacturing, all geometrical sizes of the prototype deflector cell were measured. The measurement has shown that some elements of the prototype cell had inaccuracies. The general inaccuracies are given in Table 1. The parameters highlighted with red have a strong influence on the resonant frequency.

Regardless of the fact that prototype had manufacturing inaccuracies a measurement of the electro-dynamics characteristics was carried out. It allowed us to research all possible dependencies resonant frequency on different elements of the prototype cell. As well as find possible methods for frequency tuning.

Table 1: The general inaccuracies of the deflector cell

Parameter	Model	Prototype
The inner diameter of the cavity, mm	342	341
Distance between electrodes, mm	100	98.6
Electrode’s edge radius, mm	8	7
Electrode’s base height, mm	22	21
Electrode’s base edge radius, mm	4	3

Taking into account prototype inaccuracies, deflector cell simulation has shown that resonant frequency equaled to 294.5 MHz.

The measurement of the electro-dynamics characteristics of the prototype deflector cell was done by using network analyzer Agilent Technologies E5061A. Measurement has shown that resonant frequency equals to 294.2 MHz. As well as measured quality factor equals to 11150. The main electro-dynamic parameters of the deflector cell are given in Table 2.

Table 2: The main electro-dynamics parameters of the deflector cell

Parameter	Unit	Value
Simulated resonant frequency in the cavity without geometrical inaccuracies	MHz	296.6
Simulated one in the cavity with geometrical inaccuracies	MHz	294.5
Measured one in the prototype	MHz	294.2
Simulated quality factor		12000
Measured quality factor		11150

From Table 2 one can see that measurement of the electro-dynamics characteristics of the prototype deflector cell has a good correspondence with the simulated one with geometrical inaccuracies.

The research of the distance between electrodes and electrode’s edge radius influence on resonant frequency was carried out. The resonant frequency dependence on the distance between electrodes is shown on Fig. 5.

From Fig. 5 one can see that 1mm changes in the distance between electrodes will change the resonant frequency by more than 1 MHz. The same is true for the frequency dependence on the electrode’s edge radius. Changing the edge radius by 1 mm will change the resonant frequency by about 1 MHz. The resonant frequency dependence on the electrode’s edge radius is shown on Fig. 6.

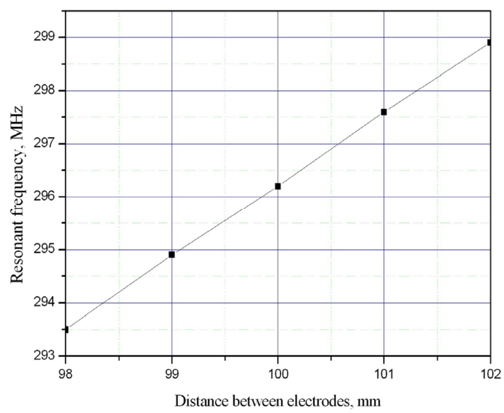

Figure 5: The resonant frequency dependence on the distance between electrodes.

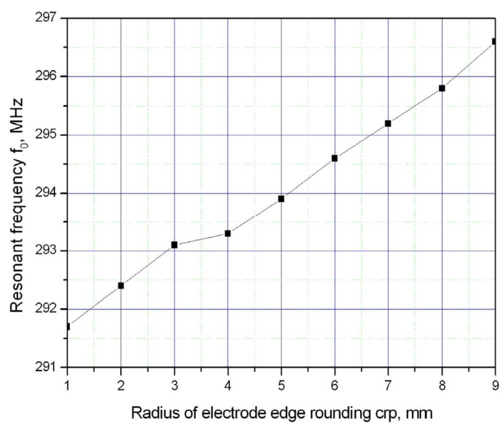

Figure 6: The resonant frequency dependence on the electrode's edge radius.

However, cavity construction isn't allowed the changing a distance between electrodes. As well as changing the electrodes edge radius. Thus additional tuners are needed.

TUNING OF THE PROTOTYPE CELL

For the tuning of the electro-dynamic characteristics of the prototype cell two cylindrical tuners with diameter equals to 85 mm and varying height from 0 mm to 50 mm were foreseen. Simulation has shown that such tuners inserted into deflector cavity increase the resonant frequency by 2 MHz. It isn't enough for the increasing of the resonant frequency to the required 297 MHz.

To increase the resonant frequency to 297 MHz, the following solution was proposed: mounting a ring shape tuners on the end flanges. The cone form for the ring shape tuners were chosen to decrease a probability of the multipactor effect. Simulation influence of the ring shape tuners parameters, thickness (t) and height (l), to resonant frequency was done and shown on Fig. 7.

From Fig. 7 one can see that for the increase in the prototype deflector cell's resonant frequency to 297 MHz the thickness and height of the ring shape tuners should be equal to 40 mm and 35 mm correspondingly. These tuners were manufactured and then mounted on end flanges. Electro-dynamic measurement has shown that resonant frequency equaled to 296.96 MHz.

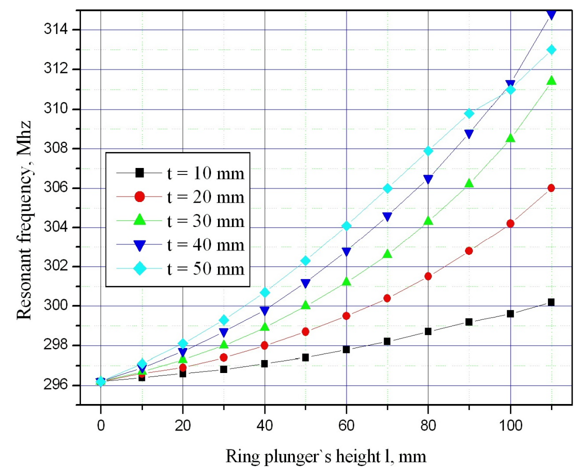

Figure 7: The resonant frequency dependence on the ring shape plungers height and thickness

The deflector cell prototype was mounted on the test stand for further power injection test.

CONCLUSION

The prototype deflector cell was constructed and manufactured. The measurement of the prototype's geometrical sizes has shown that some parameters have inaccuracies. Moreover, simulation has shown that some sizes of the deflector cell have a strong influence on resonant frequency. The higher attention should be spare to the accuracy of these elements.

The measurement of the electro-dynamics characteristics of the prototype deflector cell has shown that resonant frequency equals to 294.2 MHz and differs from desired one on 2.8 MHz. Foreseen tuners are able to increase frequency not more than 2 MHz. Two ring shape tuners with thickness equals to 40 mm and height equals to 35 mm mounted on end flanges increase the resonant frequency on 2.8 MHz to 296.96 MHz.

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