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BEAM OPTICS VERIFICATION FOR A QWR*

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Abstract

Quarter-wave resonators (QWRs) are being widely used in linear accelerators (linac) for acceleration of ions with low-β velocity. Two effects of this kind of cavities are the beam steering effect and RF defocusing effect caused by geometric asymmetry and the offset of input beam. Measurement for these two effects has been conducted by beam position monitors (BPM) and wire in a QWR type buncher whose frequency is 162.5 MHz at Institute of Modern Physics (IMP), Chinese Academy of Sciences (CAS). Since the experimental result and simulation result matches well, beam optics has been verificated, such that beam central position and beam envelope could be predicted in simulation and an online orbit correction program will be developed in the future.

INTRODUCTION

QWRs, being widely studied and built in many laboratories for accelerating of ions in the velocity range from 0.01c to 0.3c[1], are cylindrical and coaxial cavities who have an up-down asymmetry with respect to the beam axis. Because of lacking of symmetry, QWR will lead to beam steering and RF de-focusing. Both horizontal magnetic field and vertical electric field will produce steering in the direction of the resonator axis. The beam deflection, moreover, depends on the particle position, which will create emittance growth and beam spill, especially in high intensity proton linac[2]. Beam envelope will also increase because of RF defocusing effect.

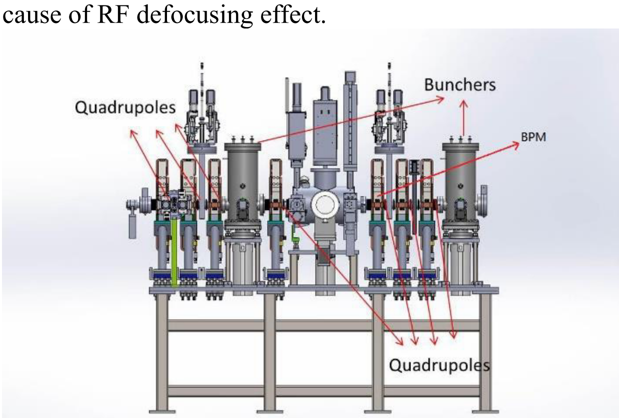

Figure 1: Layout of MEBT of C-ADS Injector II.

Based on the initial simulation and beam experiment, QWR will lead to considerable beam deflection and beam envelope increase. Beam optics verification for the QWR has been carried out based on beam experiment which is conducted on the MEBT of C-ADS injector II. In the experiment, the first buncher and the BPM are used as shown in Figure 1[3]. By comparing the experimental result with the simulation result, beam steering effect and RF defocusing effect could be calculated.

The simulation code we used is TraceWin.

BEAM STEERING EFFECT IN QWR

Figure 2 shows the QWR buncher cavity and the electromagnetic field distribution. The blue line presents the longitudinal electric field Ez along the cavity axis, the red line presents the vertical electric field Ey×10, and the black line presents the horizontal magnetic field cBx. Compared with the accelerating component Ez, the transverse electric field Ey and the horizontal magnetic field Bx will cause dipole component field. Thus, both horizontal magnetic field and vertical electric field will produce beam steering in the vertical direction and RF defocusing in transverse direction[4].

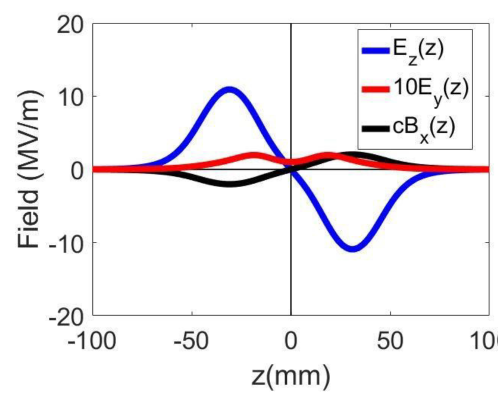

Figure 2: QWR field distribution.

In a RF cavity, beam energy gain is associated with the cavity voltage V0 and the RF phase φ as shown in the following equation:

$$\Delta U = qV_0TL\cos\varphi$$

Considering the asymmetrical electric and magnetic field, beam steering effect will vary with the voltage and RF phase:

$$\Delta y' = -\frac{\Delta U}{\gamma mc^2\beta}\tan\varphi\left[\frac{\cos\left(\frac{\pi d_y}{\beta\lambda}\right)}{\beta\sin\left(\frac{\pi d_y}{\beta\lambda}\right)}K_{EY}(y)+K_{BX}(y)\right]$$

where $\Delta y' \approx \Delta p_y / p$ is the deflection angle produced by the QWR, and $\Delta U, m, \varphi, \lambda$ are the particle energy gain, rest mass, RF phase and RF wavelength respectively. While d is the gap-to-gap distance, d_y is an effective gap-to-gap distance for the transverse electric field E_y. The

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electric deflection and the magnetic deflection is shown in the up equation where $K_{EY} = \overline{E_Y}(y) / \overline{E_Z}$ and $K_{BX} = \overline{B_Y}(y) / \overline{E_Z}$.

RF DEFOCUSING IN QWR

For longitudinal stability, it is longitudinal focusing, which requires the synchronous phase to be negative. Thus, the RF fields are increasing in time and it is generally incompatible with local radial focusing from those fields.

The nonzero field components of the synchronous space harmonic experienced by a particle of phase φ_s were obtained as

$$E_z = E_0 T I_0 (Kr) \cos \varphi_s$$

$$E_r = -\gamma_s E_0 T I_1 (Kr) \sin \varphi_s$$

$$B_\theta = -\frac{\gamma_s \beta_s}{c} E_0 T I_1 (Kr) \sin \varphi_s$$

The radial momentum impulse delivered to a particle over a length L is

$$\Delta(\gamma\beta\gamma') = -\frac{\pi q E_0 T L \sin \varphi_s}{mc^2 \gamma_s^2 \beta_s^2 \lambda} r$$

For longitudinal stability, the sign of φ_s is negative, therefore the radial impulse is positive, which means an outward or defocusing impulse[5].

BEAM EXPERIMENT

The beam experiment was conducted on the MEBT of C-ADS injector II at IMP and the beam status is shown below:

Table 1: Beam Status

Parameter	Value	Unit
Particle	proton	—
Energy	2.12	MeV
Current	2.3	mA
Pulse width	80	us
Pulse frequency	1	Hz

Beam Steering

In the experiment, beam steering effect is affected by the voltage, the RF phase and beam input position at the entrance of the buncher. Beam center position at the BPM is recorded by scanning the three parameters.

In a phase sweeping period, beam center position detected by BPM varied because of beam steering effect as shown in figure 3. The variation was different according to different voltage and RF phase of the buncher.

Since beam steering effect could be expressed by the peak-to-peak value of beam center position at BPM during phase seeping, beam steering effect contributed by x is 0.600 mm, while it is 0.609 mm when considering both x and x'. The ratio of the two contribution is 1.5%. It suggests that beam steering effect contributed by the input angle x' is 1.5% of that contributed by the input position x.

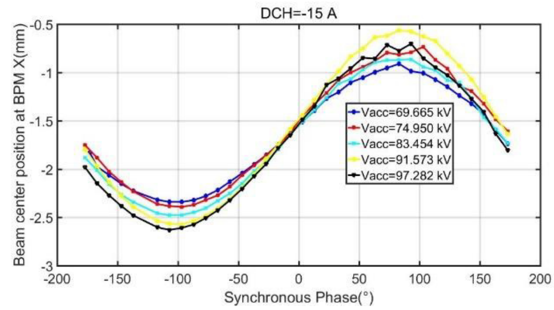

Figure 3: Beam center position at BPM.

Considering electrical and magnetic field distribution, the buncher is symmetrical in horizontal direction but asymmetrical in vertical direction, so beam center position at BPM doesn't vary during phase sweeping when horizontal input position x=0, but it still varies in vertical direction even if vertical input position y=0.

In simulation, beam input position x and y at the entrance of the buncher is scanned from -3 mm to 3 mm. Each result in different voltage and different DCH/DCV is compared with the experimental result, until the error between experimental result and simulation result is the least. At x=-0.98 mm and y=0.63 mm, the result nearest to the experiment is found as shown in Figure 4.

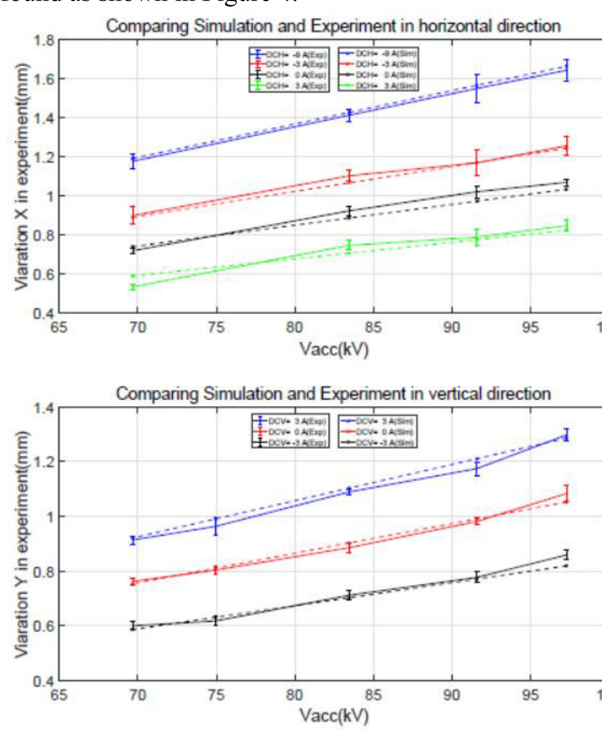

Figure 4: Simulation and experiment comparison.

The root-mean-square (RMS) error is 3.36×10^{-2} mm and 4.13×10^{-2} mm in horizontal and vertical direction respectively, about 4% of the experimental result.

RF Defocusing

RF defocusing effect is affected by the voltage of the RF phase of the QWR. In the experiment, the synchronous phase was set at -90° to guarantee that the longitudinal

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focus is the most, thus, the RF defocusing effect is transverse direction is the biggest. By scanning the amplitude of the QWR, beam profile is measured by moving the wire.

In the measurement, the wire scans from -25 mm to 25 mm with the step length of 0.5 mm in horizontal and vertical directions. The simulation and experiment is shown in figure 5.

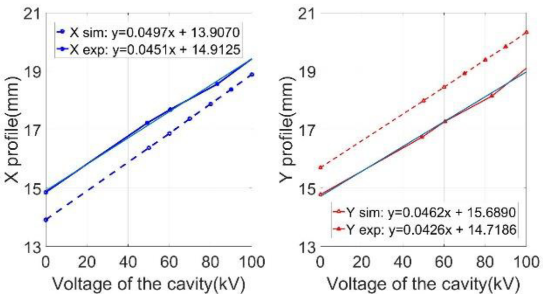

Figure 5: Beam profile.

Since the linear coefficient R^2 is 0.9987 in the two directions correspondingly, the measurement result is very close to linearity.

The slope represents RF defocusing effect, and the slope deviation between experiment and simulation in the two directions is less than 10%:

$$Ds_x = \left| \frac{0.0497 - 0.0451}{0.0497} \right| = 9.3\%$$

$$Ds_y = \left| \frac{0.0462 - 0.0426}{0.0462} \right| = 7.8\%$$

CONCLUSION

Beam steering effect and RF defocusing effect are measured in the QWR type buncher. The simulation result and experimental result matches well and the beam optics of the cavity has been verified. By comparing the measurement result and the simulation result, the input position at the entrance of the buncher is calculated and the result is x=-0.98 mm and y=0.63 mm. Thus, beam center position and beam profile can be predicted in simulation as long as the machine parameters are given, based on which a program for online orbit correction will be developed.

REFERENCES

[1] C. Zhang *et al.,* Analytical study on beam steering in low-β superconducting quarter wave resonators, *Nuclear Physics Review* 27 (4), 2010, pp. 436-439.

[2] A. Facco *et al.,* "Study on beam steering in intermediate β superconducting quarter wave resonators", in *Proc. PAC2001,* pp. 1095-1097.

[3] S. C. Huang *et al.,* Design and RF test of MEBT buncher cavities for C-ADS Injector II at IMP, *Nuclear Instruments and Methods in Physics Research A,* 799 (2015) pp. 44-49.

[4] H. Jia *et al.,* Analytical study on beam steering in low-β superconducting quarter wave resonators, *Nuclear Physics Review* 27 (4), 2010, pp. 436-439.

[5] T. P. Wangler *et al., RF Linear Accelerator,* 2008, pp. 436-439.