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DEFLECTING CAVITIES FOR PROTON BEAM SPREADER IN CiADS PROJECT*

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Abstract

Chinese initiative Accelerator Driven Subcritical System (CiADS) is supposed to accelerate continuous 162.5MHz, 10 mA (or higher) proton beam to 500 MeV (or higher energy) with a superconducting driver linac. More application scenarios based on this high power intensity proton linac are now under considerations. Beam spreader system based on deflecting cavities for multiple users simultaneous operation are discussed in this paper, as well as the RF structure options for the equal eight- and nigh- beam-line split schemes.

INTRODUCTION

Deflecting cavities for beam separation were originally proposed at CEBAF and SLAC [1, 2]. With proper RF cavity resonant frequency, and appropriate bunch phase, the incoming bunch train could be separated to two ways or there ways equally, as shown in Fig. 1.

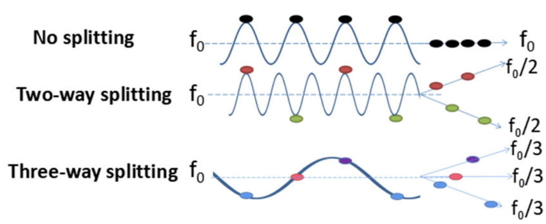

Figure 1: Two-way and three-way equal splitting scheme with deflecting cavities.

More beam lines could be achieved by repeating this process on each split beam line, with the second and the third class of deflecting cavities [3], as shown in Fig. 2 and Fig. 3. With seven cavities classified into three categories, the incoming bunch train with repetition frequency f_0 could be separated to eight bunch trains with equal repetition frequency $f_0/8$. With four cavities classified into two categories, the original bunch train f_0 could be split ted to nine $f_0/9$ bunch trains.

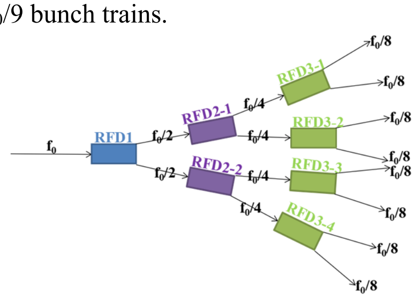

Figure 2: Eight beam lines with seven deflecting cavities classified into three categories.

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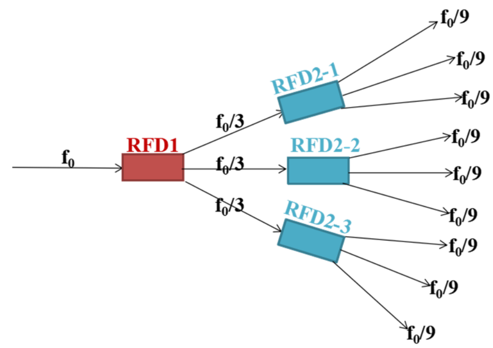

Figure 3: Nine beam lines with four deflecting cavities classified into two categories.

RF FREQUENCY OF THE DEFLECTING CAVITY

For the two-way splitting scheme, the RF frequency of the deflecting cavity (RFD1) could be $f_0/2$, $3f_0/2$, 5f0/2, and higher, as shown in Fig. 4. For the three-way splitting scheme, the RF frequency of the deflecting cavity (RFD1) could be $f_0/3$, $4f_0/3$, $7f_0/3$, and higher, as shown in Fig. 5. Here f_0 is the incoming bunch repetition frequency.

For the second class cascading deflecting cavities (RFD2), the incoming bunch repetition is $f_0/2$ and $f_0/3$ for the two-way and three-way splitting scheme, separately. For 162.5 MHz proton bunches, RF frequencies of the deflecting cavities in each cascading scheme for the eight-beam-line scheme and nigh-beam-line scheme are summarized in Table 1.

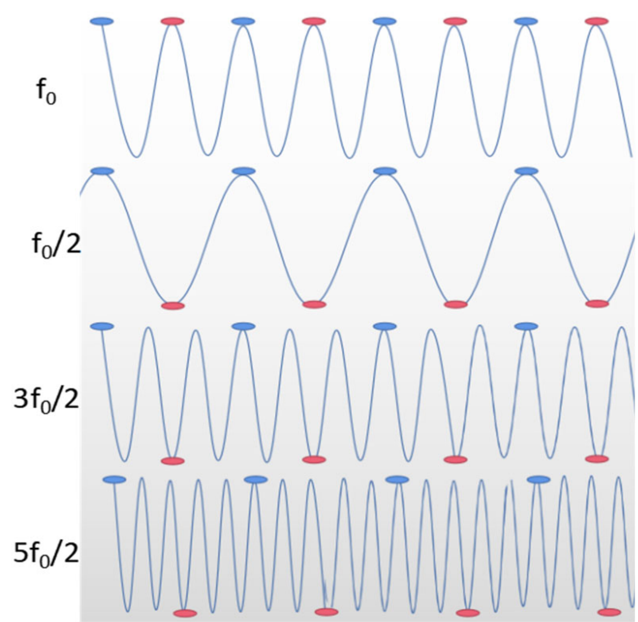

Figure 4: Two-way splitting scheme with RF deflecting cavity frequency equal to $f_0/2$, $3f_0/2$,$5f_0/2$.

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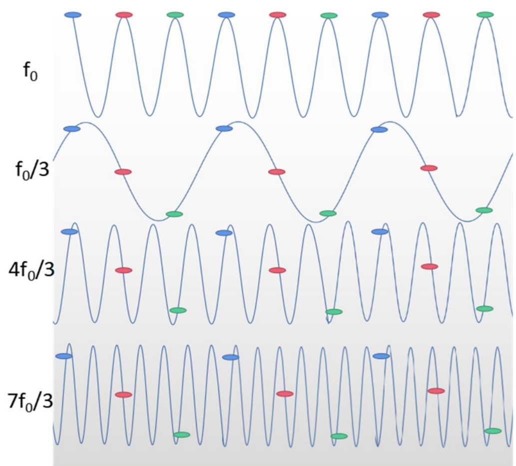

Figure 5: Three-way splitting scheme with RF deflecting cavity frequency equal to $f_0/3$, $4f_0/3$, $7f_0/3$.

Table 1: RF frequencies (up to 450 MHz) of the deflecting cavities in each cascading scheme for the eight-beam-line scheme and nine-beam-line scheme (unit: MHz).

	Eight-beam-line	Nine-beam-line
RFD1	81.25,	54.17,
	243.75,	216.67,
	406.25,	379.17,
	or higher	or higher
RFD2	40.625,	18.06,
	121.875,	72.22,
	203.125,	126.39,
	284.375,	180.56,
	365.625,	234.72,
	446.875	288.89,
	or higher	343.06,
		397.22
		or higher
RFD3	20.3125,	
	60.9375,	
	101.5625,	
	142.1875,	
	182.8125,	
	223.4375,	
	264.0625,	
	304.6875,	
	345.3125,	
	385.9375,	
	426.5625,	
	Or higher	

Higher RF frequency are help to make the cavity more compact. However, higher RF frequency means large deflecting field curvature and derivation during the traveling period of bunches, which will finally result to transverse emittance dilution. The stronger the kick, the larger the emittance growth. Lower frequency is help to reduce the emittance, however, the cavity size is cumbersome. Final cavity frequency should be determined with considerations of both the cavity size and beam dynamic requirement.

DEFLECTING VOLTAGE AND RF POWER ESTIMATION

Consider a charged particle with rest mass m and charge q incident on the deflecting cavity on the beam axis with the kinetic energy E_k, the deflecting voltage V_{def} for given kick angle θ could be derived as [4]:

$$V_{\mathrm{def}} = \frac{E_{\mathrm{k}}}{\mathrm{q}} \tan\theta \frac{\alpha+2}{\alpha+1}$$

$$\alpha = \frac{E_{\mathrm{k}}}{\mathrm{mc}^2}$$

Here c is the speed of light.

For 500 MeV Proton bunches, the required deflecting voltage is 825 kV for 1 mrad kick angle. The required bunch separation at the Lambertson-type septum magnets is about 40-50 mm, to limit the drift distance to 10 meter, the required kick angle is about 5 mrad in the deflecting cavity, thus resulting about 4 MV deflecting voltage. RF power losses for given beam energy and kick angle could be estimated with:

$$P = \frac{\left(\frac{V_{\mathrm{def}}}{\sin\varphi}\right)^2}{R_{\mathrm{sh}}}$$

Here φ is the phase angle of the micro-bunch to the RF phase. For the two-way and three-way splitting scheme in Fig. 1, φ is 90 degree and 60 degree, separately. Rsh is the cavity shunt impedance, which is in the magnitude of ~100s MΩ for normal conducting cavities. The estimated RF power is larger than 100 kW, thus multiple normal conducting cavities are required. To make the system more compact, superconducting cavities are considered.

SUPERCONDUCTING RF DEFLECTING CAVITIES

Several superconducting RF deflecting structures were proposed and developed during the past decades of years, like elliptical cavities operating in the dipole TM110 mode [5], the double quarter-wavelength cavity [6], the RF-dipole cavity [7], and so on. For 162.5 MHz proton bunches, double quarter-wavelength cavity with compact geometry and great mechanical stability are considered. Section view of the cavity structure is shown in Fig. 6.

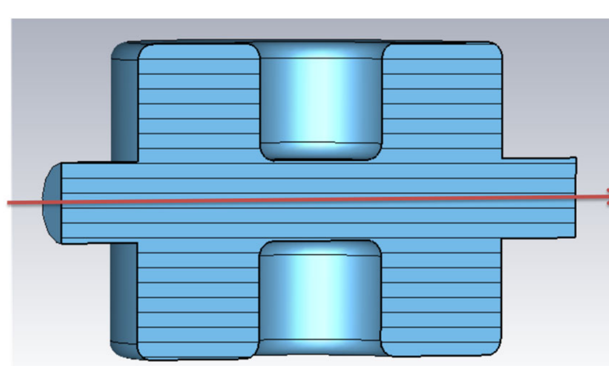

Figure 6: Section view of the double quarter-wavelength cavity with beam axis.

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The electromagnetic field distribution of the cavity is shown in Fig. 7. Charged particles passing through the cavity will be deflected by both the transverse electric field and the transverse magnetic field.

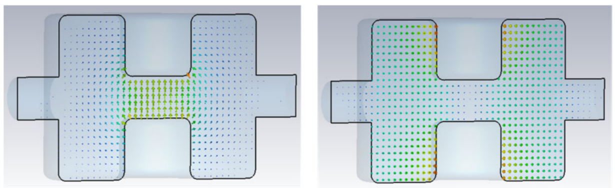

Figure 7: Transverse electric field distribution and magnetic field distribution for a 243.75 MHz double quarter-wavelength deflecting cavity.

For RFD1 in the eight-beam-line scheme, 81.25 MHz, 243.75 MHz and 406.25 MHz double quarter-wavelength cavities were studied. Main parameters of these cavities are summarized in Table 2. Note that, the longitudinal size is calculated with beam pipes that long enough to make sure the leak field is less than 0.1% of the maximum values. And the vertical size is defined for vertical deflecting scheme.

Table 2: Main parameters of 81.25 MHz, 243.75 MHz and 406.25 MHz double quarter-wavelength cavities.

Frequency (MHz)	**81.25**	**243.75**	**406.25**
Aperture (mm)	100	100	100
R_t/Q (ohm)	2540	571	244
G (ohm)	63	111	114
E_{pk}/V_{def} (1/m)	3.71	11.2	20
B_{pk}/V_{def}(mT/MV)	3.79	13.8	29
Longitudinal Size (mm)	900	700	520
Horizontal Size (mm)	800	538	323
Vertical Size (mm)	1300	390	316

To provide 4 MV deflecting voltage, two 243.75 MHz cavities are preferred with appropriate cavity size and safety surface electric and magnetic field. Further optimization of the cavity geometry with considerations of beam dynamics and mechanical stability.

For the second and third class RFD2 and RFD3 cavities, 203.125 MHz and 223.4375 MHz cavities with similar size and characteristics are considered.

CONCLUSION

Beam spreader system based on deflecting cavities for multiple users simultaneous operation are discussed in this paper. Eight-beam-line scheme based on the two-way splitting and Nine-beam-line scheme based on three-way splitting are discussed. Superconducting double quarter-wavelength cavities were considered for the separation of 162.5 MHz 500 MeV proton bunches. Further optimization on the cavity geometry including reduce the cavity size, increasing the mechanical stability with consideration of the beam dynamics requirement.

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