LOSS CONCENTRATION AND EVACUATION BY MINI-WIRE-SEPTA FROM CIRCULAR MACHINES FOR SPALLATION NEUTRON SOURCES

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I. INTRODUCTION

Efficient loss management is crucial in high-intensity circular machines like neutron sources, and those using superconducting magnets. Collimator systems have been designed or are under intensive study [1]. The common problem of collimation is the outscattering from the collimator faces which are most frequently hit at shallow depth. In this situation high collection efficiency can only be achieved by two-or-more-stage, double-jaw, systems requiring betatron phase advances approaching 2π. As the outscattering is isotropic, both transverse planes are affected and the system layout becomes a two-dimensional problem. Any convincing single-stage collimation system would be simpler to operate and is likely to be less expensive. The possible physical evacuation of the lost beam towards a remote dump can drastically reduce the radioactivity level in the tunnel. Moreover, fitting a two-stage system into an existing machine is difficult and in general not very promising. In this situation a wire septum may be the only satisfactory solution.

II. BASIC FEATURES OF THE MINI-WIRE-SEPTUM (MWS)

An earlier study of the potential of thin predeflectors like foils or wires for improving collimation efficiency [2] has already indicated the superiority of such a special wire septum over all other types investigated. This article goes a step further and suggests its "upgrading" into a single-stage collimator. Figures 1a, 1b show a schematic comparison between a conventional septum and a MWS. The prefix "mini" in the designation MWS refers to some of its salient features: (i) its short length, which is essential for (ii) its reduced gap width requiring (iii) comparatively low operating voltage.

Also new is the use of low Z, ultra-thin wires of diameters ≤0.05 mm. Due to their small cross-section, these wires experience strong deflection and bulge out of the ideal plane by a few mm, rendering their precise alignment impossible. On the other hand, a perfect septum is of limited value in loss collimation anyway: different loss mechanisms varying along the acceleration produce varying envelope slopes; in fact, perfect alignment is rather undesirable as it is easily seen that a particle approaching a row of wires in their plane will hit them all until it is scattered out - into the gap, or back into the vacuum pipe as in the case of a massive collimator. On the contrary, in the misaligned MWS, particles perform multiple passages across the septum wire area before receiving the full final kick. For the above reasons, a misaligned septum performs better in simulation, and it is thus not surprising that the non-ideal septum does as well.

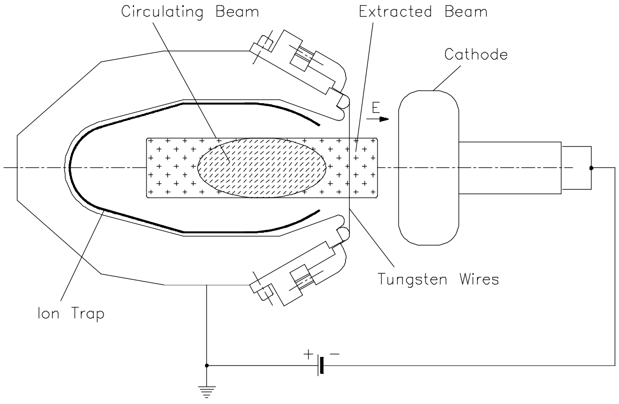

Figure 1a: Conventional wire septum

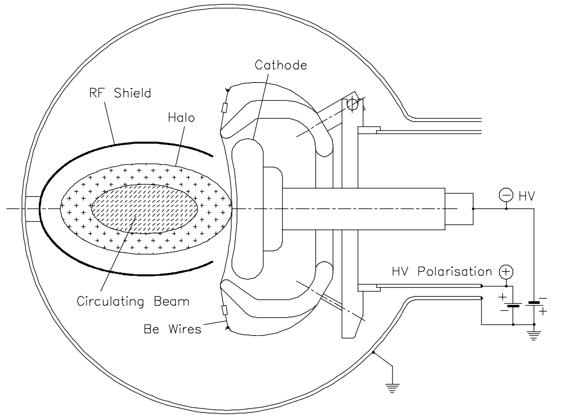

Figure 1b: Mini-Wire-Septum for loss extraction.

To keep the MWS simple and robust, bulk metal cathodes (allowing fields of 4-5 MV/m) are preferable to oxidised aluminium ones (10 MV/m). If the wires are polarised to a few kV, there is no leakage field in the useful aperture and ion traps can be avoided.

III. PHYSICAL PARAMETERS OF THE MWS

The parameters are chosen to fit the synchrotron of the projected AUSTRON neutron spallation source [3]. The deflection angle θ_s of a wire septum is given by $\theta_s = (eE_0 l)/(\beta pc) = 2.5$ MeV$/(\beta pc)$ with the maximum field $E_0 = 5$ MV/m admitted by metal cathodes and a length of

$l = 0.5$ m. In the energy range relevant for AUSTRON II (130 MeV - 1.6 GeV), θ_s varies from 10.2 mrad to 1.14 mrad. The gap width necessary to allow multiple passages is about 10 mm, limiting the cathode potential to 50 kV, still within simple HV technology. The wire polarisation potential is given by $V_W = (1/2\pi)\ E_0 a\ ln(a/d\pi)$ = 13.7 kV for d = 0.05 mm diameter (beryllium) wires at a = 5 mm distance. The force on each wire is then $F_x = \varepsilon_0 a E_0^2/2$ = 0.028 N/m and the maximum deflection $x_B = \varepsilon_0 a E_0^2 h^2/(16T)$ = 3.45 mm for a tensioning force T of 0.2 N corresponding to 20% of the breaking strength of Be, and a septum height h = 100 mm. The importance of this bulging, which can attain even more impressive values for machines with large apertures, necessitates the hollow cathode shape sketched in Figure 1b. The hollow shape of the collimation aperture is no disadvantage, as inclined collimator faces in connection with the inevitable linear coupling are in fashion [4, 5].

IV. SIMPLE ANALYTICAL DESCRIPTION

The basic function of the MWS has been described in [2] by a simple "thin-lens" model for a septum of vanishing length in two-dimensional geometry. The distribution of the centres of the misaligned wires is described by a normalised (from $-\infty$ to ∞) gaussian $p(x)$ of standard deviation σ. The deflection angle as a function of the entrance coordinate x then becomes

$$\theta_s(x) = \theta_s F(x/\sigma)$$

with $F(x)$ being the integral of $p(x)$, where θ_s is the deflection of the ideal septum given above. From elementary multiple-scattering theory one obtains the r.m.s. scattering angle

$$\theta_W/x) = [13.6\ \mathrm{MeV}/(p\beta c)]\ [N d^2 \pi p(x/\sigma)/(4\sigma X_0)]^{1/2},$$

with $N = l/a$ the number of wires and X_0 the radiation length (350 mm for Be). The set of parameters of sec. II and III and σ = 1 mm yields $\theta_W(x) = 0.32\ \mathrm{MeV}/(p\beta c)\sqrt{p(x/\sigma)}$. At the maximum of the gaussian $\theta_W(0) = 0.13\ \mathrm{MeV}/(p\beta c)$ which is to be compared with the value for the perfect septum (the average path length per wire is $d\pi/4$)

$$\theta_W = [13.6\ \mathrm{MeV}/(p\beta c)]\ [N d\pi/(4\sigma X_0)]^{1/2} = 1.44\ \mathrm{MeV}/(p\beta c).$$

The latter value is only a little less than that of the deflection angle $\theta_s = 2.5\ \mathrm{MeV}/(\beta pc)$. Figure 2 visualises the kicks according to the above expressions for the ideal and the misaligned septum in phase space; the shaded areas represent the possible re-entrance coordinates at subsequent turns, substantially reduced for the imperfect septum. Note that all angles scale with $(p\beta c)$, i.e. the relations given above hold at all energies. Absolute deflection angles become very small at higher energies and for efficient operation above 1 GeV two or three MWSs may have to be staggered, possibly in the same tank.

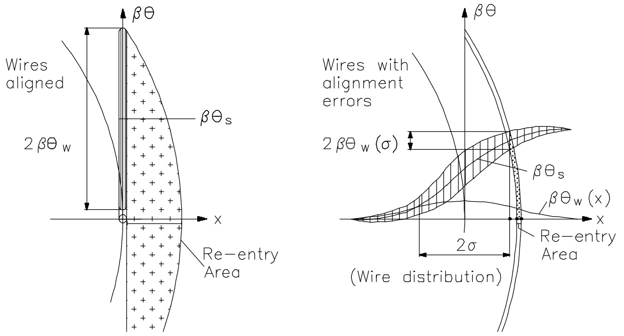

Figure 2: 'Thin-lens' model of a wire septum.

V. RESULTS OF THE SIMULATION MODEL

The thin-lens model misses non-negligible effects of the finite length of the MWS and needs to be complemented by tracking studies. The ACCSIM tracking code [6] features a wire septum element that can simulate perfect or misaligned wires in plane geometry, including the interaction with matter. The growing beam halo is modeled by an annulus in phase space drifting slowly (here at 0.5 m/s) into the septum. The three cases of interest are (a) the ideal MWS, aligned with the envelope of the 'halo', (b) the same but slightly misaligned, and (c) a 'real' septum with a gaussian distribution of wire position errors of standard deviation σ = 0.5 - 1 mm. Figure 3 a, b, c shows the trajectories of one *single* particle through the septum for these cases, while Figure 4 a, b, c shows the corresponding phase plane plots for the septum exit and *ten* particles. The last exit coordinates (before the particles hit the downstream collector) are marked by asterisks.

The test particle passes the aligned septum only twice (Fig. 3a): the lower (first) pass hits the end of the wire row and is strongly scattered to the outside, gaining emittance. This is the prerequisite that it can re-enter as shown with large amplitude and negative angle, obviously an unfavourable case. In Figures 3b, c the particle passes five times and is barely scattered. The most interesting feature of cases (b), (c) can be seen in Figures 4b, c: the gap between the final and earlier exit points, not present in Figure 4a. The study of a number of cases has shown that this gap is even more pronounced for larger standard deviations σ >1 mm of the wire distribution. There one would place the face (transformed to that location) of a second, magnetic septum for definitive loss evacuation.

To test the MWS in a realistic model, three septa were inserted into the lattice of AUSTRON II at the foreseen horizontal, vertical and momentum collimator locations. With these insertions H^- injection at 130 MeV and RF capture were tracked with ACCSIM.

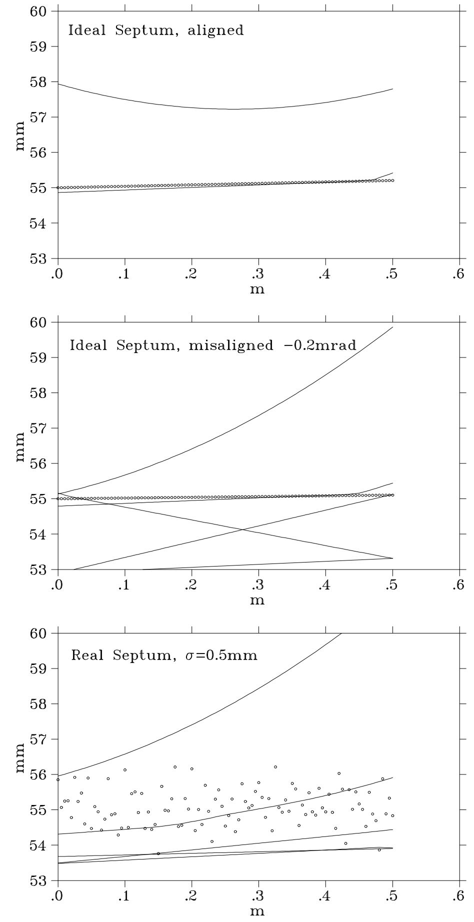

Figure 3a, b, c (top to bottom): Wire locations and trajectories in physical space of a test proton of 130 MeV through a wire septum with a field of 5 MV/m.

The basic loss mechanisms are then multiple scattering in the Al stripper foil and RF capture loss. The downstream collectors were assumed to be ideal absorbers. The collimation efficiency of the septa turned out to be 97.2 % while under identical conditions three graphite collimators achieved 94.7 %.

VI. CONCLUSION

A specially designed small wire septum provides cleaner single-stage loss collection in simulation than a two-stage, massive collimator system. Such a septum presents no major technological problems.

VII. ACKNOWLEDGMENTS

I wish to thank F. W. Jones for the upgrading of the ACCSIM code, M. Thivent for advice on septum technology and Mrs. B. Hadorn for the execution of the figure drawings.

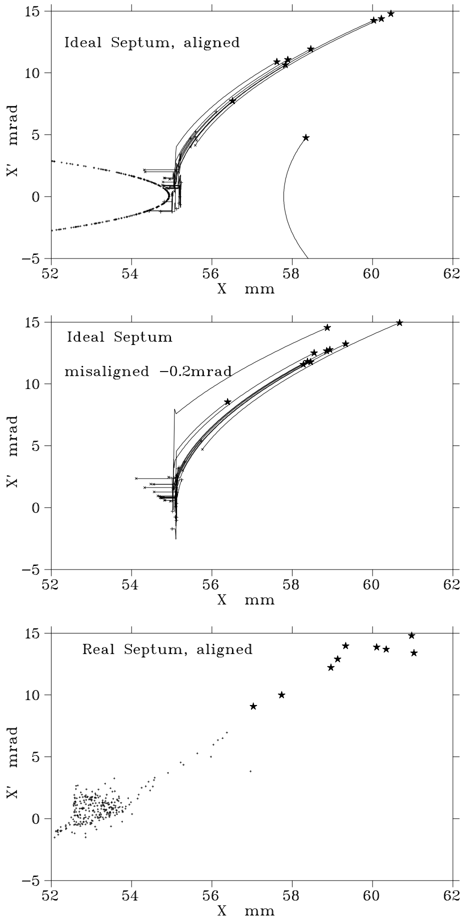

Figure 4a, b, c (top to bottom): Phase space trajectories (not in 4c, as they would confuse the presentation) and exit coordinates of 10 particles extracted by a wire septum; final exits marked by an asterisk. 'Halo' model annulus in 4a.

VIII. REFERENCES

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