PROPOSED VARYING AMPLITUDE RASTER PATTERN TO UNIFORMLY COVER TARGET FOR THE ISOTOPE PRODUCTION FACILITY (IPF) AT LANSCE*

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Abstract

The Isotope Production Facility (IPF) at LANSCE[1] produces medical isotopes strontium-82 and germanium-68 by bombarding rubidium chloride and gallium metal targets respectively with a 100 MeV proton beam, 230 uA average current. Rastering the proton beam is necessary to distribute heat load on the target and target window, allowing higher average beam current for isotope production. Currently, we use a simple circular raster pattern with constant amplitude and frequency. The constant amplitude raster pattern does not expose the target center to beam and few isotopes are produced there. We propose a raster pattern with varying amplitude to increase isotope production at the target center, achieve uniform beam flux over the target, and expose more of the target surface to beam heating. Using multiparticle simulations, we discuss the uniformity of target coverage using the proposed varying amplitude raster pattern, compare with the constant amplitude raster pattern currently used, and consider dependencies on transverse beam size, beam centroid offset, and macropulse length and repetition rate.

INTRODUCTION

Beam rastering for IPF is controlled by a horizontal and a vertical steering magnet[2]. The steering magnets are modulated by the same frequency generator with maximum bandwidth 5 kHz. Steering magnet amplitude can be controlled separately via digital controllers. During production, IPF receives 625 μs long marcopulses at an uneven 40 Hz rep rate, consisting of micorpulses separated by 5 ns due to the RF acceleration at 201.25 MHz. Due to the raster frequency and pulse length, there are ~3 raster revolutions during a macropulse.

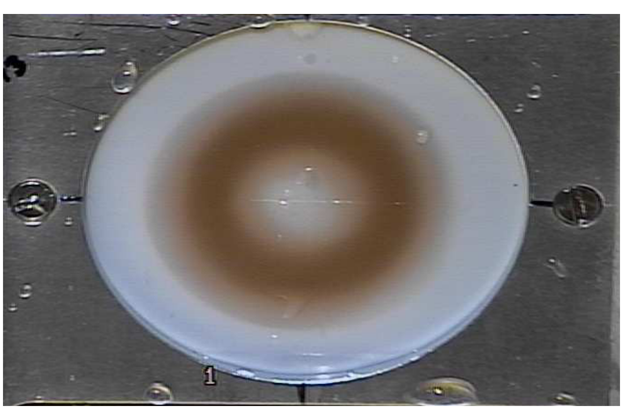

Figure 1: Measured beam at the IPF target by foil irradiation: 300 s exposure time at 2 Hz, 7 μA average current.

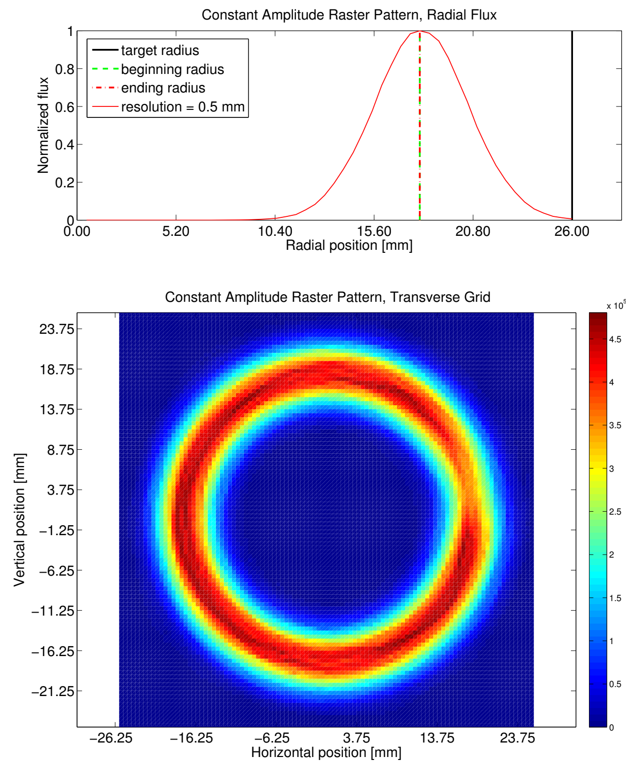

Figure 2: Simulated beam at the IPF target with constant radius 18 mm: 1 macropulse, beam $\sigma = 2.5$ mm, gird resolutions 0.5 mm. Top: beam flux binned radially. Bottom: beam binned transversely.

The current raster pattern is a simple circle with 18 mm radius. The beam measured at the IPF target by foil irradiation is shown in Fig. 1, and a one macropulse simulation (described later) using the constant amplitude raster pattern is shown in Fig. 2. The beam appears wider in measurement, but the foil coloration results from heating effects which saturate. It is clear from both measurement and simulation that little beam hits the target center and few isotopes are produced there. This is an inefficient use of expensive solid targets.

The goal of this investigation is to obtain a raster pattern

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that yields uniform target coverage with the constraints of the present equipment. Uniform beam flux on the target utilizes more of the target, lowering heat load by spreading the beam over a larger surface. This allows for an increase in average current. Steering the beam center increases the overall flux because less beam hits the collimator.

AMPLITUDE VARIATION

We tried to achieve uniform beam coverage in a single marcopulse using a spiral-type raster pattern (constant frequency, varied amplitude), but given the constraints of the present equipment ($\sim$3 rastering revolutions in a macropulse), we determined it is not possible. Our studies show uniform coverage is possible if the last revolution of the spiral is within a radius of $\sim$2 rms beam widths. For our beam with typical rms beam width 2.5 mm, the raster frequency necessary for uniform beam coverage in one marcopulse is $\sim$25 kHz.

However, uniform coverage in one macropulse is not required because isotope production and heating effects have longer time scales. We will concentrate on obtaining uniform radial flux and rely on the pulse-to-pulse phase shift between the raster frequency and the beam rep rate to fill in the transverse grid after several macropulses.

We take advantage of the circular symmetry and separate the rastering into radial and azimuthal components

$$\begin{pmatrix} x_0 \\ y_0 \end{pmatrix} = R(t) \times \Phi(t) = R(t) \times \begin{cases} \cos(2\pi f t + \phi) \\ \sin(2\pi f t + \phi) \end{cases} . \quad (1)$$

For simplicity, we choose to keep a constant frequency azimuthal component and vary the amplitude of the raster pattern to achieve a uniform radial flux.

We define a radial grid. The area of the bins, or rings, increase with position. The area of the i^{th} ring with outer radius r and width Δr is $A_i(r) = 2\pi(\Delta r)r - \pi\Delta r^2 = A_{i-1}(r - \Delta r) + 2A_0(\Delta r)$, where $A_0(\Delta r) = \pi\Delta r^2$ is the area of the inner most radial bin. We desire the amount of beam in each radial bin to be proportional to the area of the ring. We equate the amount of beam in a radial bin with the time the raster pattern spends in the bin and define a time unit τ, which amounts to the beam equivalent for area $A_0(\Delta r)$. Thus, the raster pattern must be present in the four inner radial bins for 1, 3, 5, and 7τ time units respectively. This is a square root dependence, $R(t) \sim \sqrt{\tau}$, which duplicates the result in Ref. [3]. The proposed amplitude variation raster scheme with the square root dependence is illustrated in Fig. 3.

SIMULATION

The simulation results shown in this paper are generated with a simple multiparticle simulation. For each micropulse (5 ns time steps) in a macropulse (625 μs long), a 2D gaussian distribution of 10,000 particles and rms widths $\sigma_x = \sigma_y = 2.5$ mm (as determined by beam measurements with a harp) is generated with beam centroid determined by the rastering pattern shown in Fig. 3. The particles are binned to a 0.5 mm radial grid and to a grid of

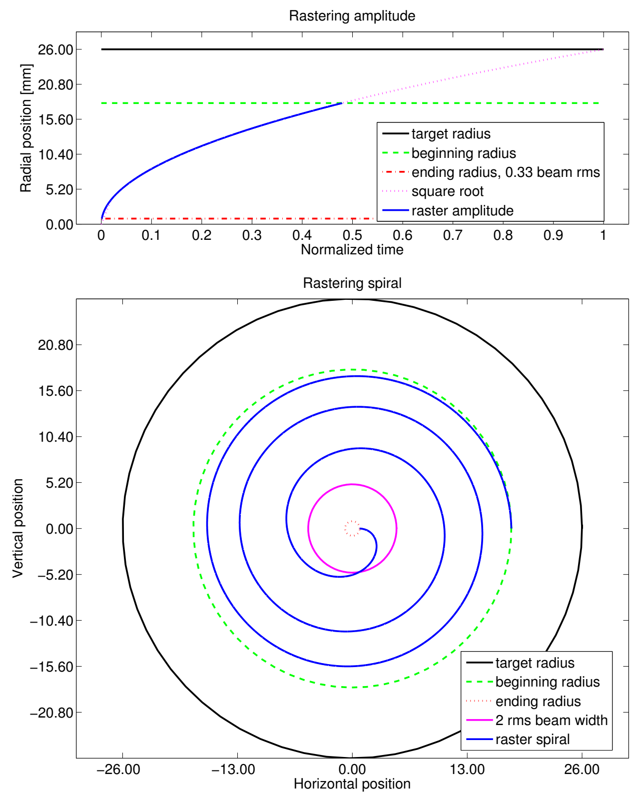

Figure 3: Amplitude variation raster pattern for 1 macropulse: radial position of the raster pattern (top) and horizontal and vertical position of the raster pattern (bottom) on the IPF target.

0.5 mm square bins. The simulation can run for multiple macropulses, in which case, it calculates the phase shift between the raster frequency and the beam rep rate. After all micropulses from all macropulses are binned, the number of particles in each radial bin is divided by the area of the ring to obtain the beam flux, which is graphed in the top plots of Figs. 2 and 4.

UNIFORM TARGET COVERAGE

The result of a single macropulse simulation with the square root amplitude variation is shown in Fig. 4. This raster pattern produces an even radial flux out to $\sim$13 mm with only 5% variation.

The amplitude variation covers more of the target than in the constant amplitude case. However, there is still a bit of the target that is not hit by beam and a corresponding "hot spot" that receives about twice as much beam. Note, the "hot spot" is only $\sim$20% more than the hottest location in the constant amplitude raster pattern. Even though the amplitude variation raster pattern yields a uniform radial flux, the transverse grid is not uniformly covered with a single macropulse. However, we observe very uniform transverse coverage when we run 1 s worth of macropulses at an uneven 40 Hz rep rate as in typically IPF production, Fig. 5.

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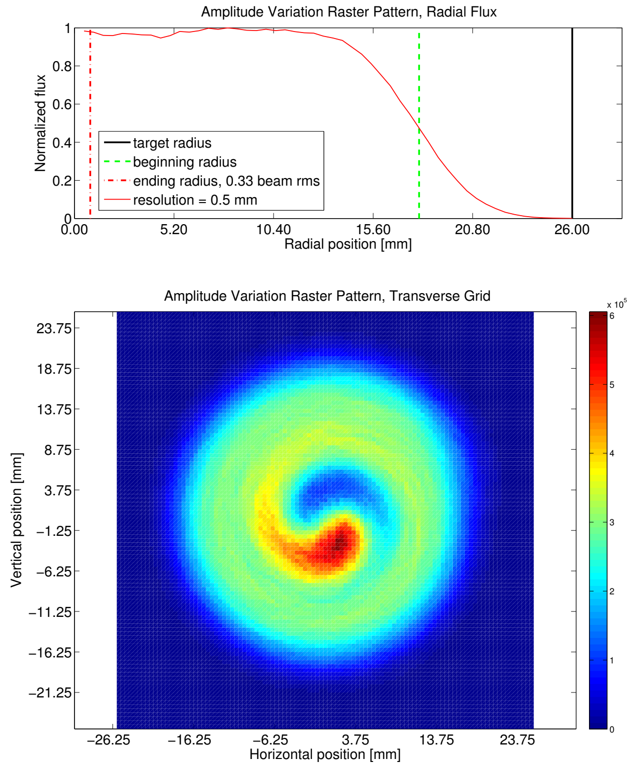

Figure 4: Beam simulated at the IPF target using the amplitude variation raster pattern with beginning radius 18 mm and ending radius 0.83 mm (0.33σ): 1 macropulse, beam σ = 2.5 mm, gird resolution 0.5 mm. Top: beam flux binned radially. Bottom: beam binned transversely.

Note the small dip in beam flux at the center of the target in Fig. 5, which is determined by the transverse beam size and the minimum raster amplitude. In optimization studies, we found that a minimum raster radius of $\sim$0.2σ smoothed the beam flux at the center of the target the best.

BEAM DEPENDENCIES

The transverse beam size changes the smoothness of the beam flux when filling the center of the target with a single macropulse and the edge fall-off effects. Smaller beam size will expose less of the target center to beam, sharpen the fall off of the beam flux on the target, and require higher raster frequency to uniformly cover the target in a single macropulse.

The raster spot on the target is only shifted with upstream steering. This is consistent with current operations, though beam signal on guard rings and collimator will be less because the amplitude variation raster pattern moves most of the macropulse way away from the outer radius.

The macropulse length has little direct effect. Longer pulse lengths lead to more raster revolutions which is better for faster uniform coverage. There is a lower limit on the macropulse length in which the amplitude variation scheme does not readily lead to uniform coverage, even after 1 s.

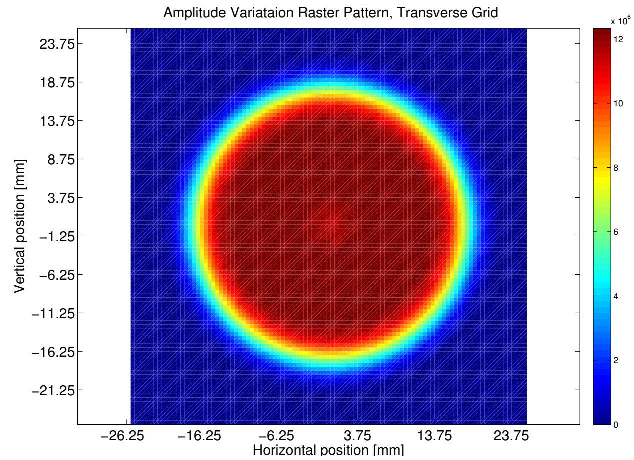

Figure 5: Beam simulated at the IPF target using the amplitude variation raster pattern with beginning radius 18 mm and ending radius 0.66 mm (0.33σ): 40 macropulses at uneven 40 Hz, beam $\sigma = 2$ mm, gird resolution 0.5 mm.

At least one raster revolution per macropulse is required for the amplitude variation raster pattern to yield uniform target coverage. Thus, typical tune up beam of 150 μs long macropulses ($\sim$0.7 raster revolutions) will not uniformly fill the transverse grid. Likewise, the beam rep rate does not have much effect on the accumulative effects of the amplitude variation raster scheme unless the raster frequency is a multiple of the 60 Hz machine rep rate. Our studies showed uniform target coverage for a series of macropulses at 1 Hz, even 4 Hz, and uneven 40 Hz.

CONCLUSIONS

We have shown through multiparticle simulation that uniform coverage of the IPF target at LANSCE is possible with existing equipment. We determined that the amplitude variation of the rastering should be proportional to the square root of time. Although the amplitude variation raster scheme does not uniformly cover the target transversely in once macropulse, it achieves less than 5% variation in uniformity after 1 second at production beam parameters. We also considered effects of the raster spot on the target with respect to beam size, steering, and macropulse length.

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