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.

Beam and accelerator parameters

- Beam
  - Macropulse length 625 us
  - Uneven 40 Hz
  - Micropulses separated by 5 ns
- Raster[2]
  - One horizontal, one vertical steering magnet
  - Maximum raster frequency 5kHz
  - Separate digital controllers for amplitude
  - ~3 raster revolutions per macropulse
- Target
  - 26 mm radius

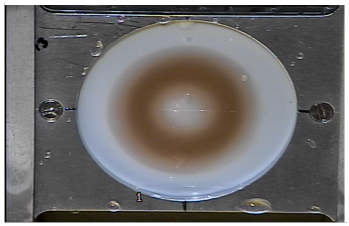
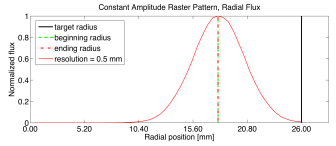


Figure 1: Measured beam at the IPF target by foil irradiation: 300 s exposure time at 2 Hz, 7 uA average current.

Constant Amplitude Raster Pattern

- Current raster pattern is a simple circle
  - Constant amplitude and frequency
  - 18 mm raster radius.
- Compare measurement (Fig. 1) and simulation (Fig. 2) of beam on target
  - Beam appears wider in measurement
  - The foil coloration results from heating effects which saturate
- Clear from both measurement and simulation that no beam hits the target center
  - Few isotopes are produced
  - Inefficient use of expensive solid targets.



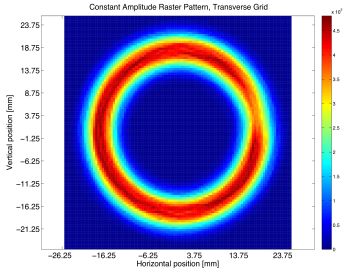


Figure 2: Simulated beam at the IPF target with constant radius 18 mm: 1 macropulse, beam σ = 2.5 mm, gird resolutions 0.5 mm. Top: beam flux binned radially. Bottom: beam binned transversely.

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Amplitude Variation

- Unable to uniformly cover target with single marcopulse using a spiral-type raster pattern
  - Due to ~3 rastering revolutions in a macropulse
- Uniform coverage is possible when the last revolution is within a radius of 2σ
  - For typical beam 25 kHz raster frequency is necessary
- Uniform coverage in one macropulse is not required
  - Isotope production and heating effects occur on longer time scales
- Concentrate on uniform radial flux
  - Rely on pulse-to-pulse phase shift between raster and beam rep rate to fill the transverse after several macropulses.
- Separate rastering into radial and azimuthal components
  - Choose to only vary the amplitude to achieve a uniform radial flux

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

- Define a radial grid
  - Area of the bins, or rings, increase with position

$$A_i(r) = 2\pi(\Delta r)r - \pi\Delta r^2 = A_{i-1}(r - \Delta r) + A_0(\Delta r)$$

  - Beam in each radial bin must be proportional to the ring area
  - Equate amount of beam in bin with time raster pattern spends in the bin
  - Define time unit τ, which is the beam equivalent for area $A_0(\Delta r)$
  - Thus, the raster pattern must be present in the four inner-most bins 1, 3, 5, and 7τ respectively
  - Square root dependence, $R(r) \approx \sqrt{t}$, duplicates the result in Ref. [3]
- The Amplitude variation raster scheme is illustrated in Fig. 3.

Simulation

- Generate raster pattern
- Generate total radial and transverse grids
- For each macropulse
  - Calculate phase between raster and beam based on beam rep rate
  - For each micropulse
    - Generate 2D Gaussian beam with beam width σ
    - Place beam on target at raster pattern location
    - Bin particles in radial grid
    - Bin particles in transverse grid
- Divide radial grid by bin area to obtain the radial flux

The simulation can run with different number and length macropulses, beam rep rates, transverse and radial grid resolutions, beam widths, raster patterns: circle, two circle, spiral …

References

[1] M.S. Gulley, ``Isotope Production Facility Beam Line Commissioning Plan", LANL memo, LANSCE-6-03-072, Oct.14, 2003.

[2] R. Meyer, ``Specifications for Rastering Magnet Coils", IPF Specification Number IPF-SPC-0599-0017-00-R00, (1999).

[3] Y.K. Batygin, et al., ``Uniform target irradiation by circular beam sweeping", Nucl. Instrum. Methods Phys. Res. A **363**, 128 - 130 (1995).

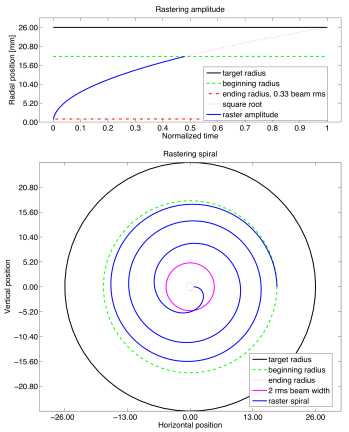
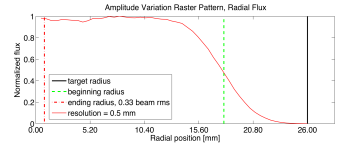


Figure 3: Amplitude variation raster pattern for 1 macropulse: radial position of the raster pattern (top) and horizontal and vertical position of the raster pattern (bottom) on the IPF target.

Uniform Coverage

- Single macropulse simulation with amplitude variation is shown in Fig. 4
  - Raster pattern produces an even radial flux out to ~13 mm with only 5% variation
  - Covers more of the target
  - Part of target still not hit by beam
  - ``Hot spot" that receives ~20% more than the hottest location in the constant amplitude raster pattern.
- We observe very uniform transverse taregt coverage after 1 s beam at an uneven 40 Hz rep rate as in typically IPF production, Fig. 5

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 σ = 2 mm, gird resolution 0.5 mm.



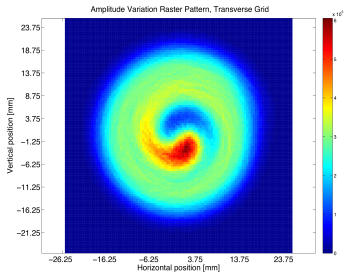
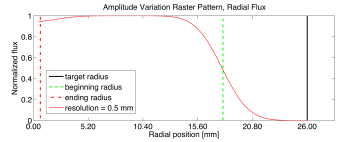
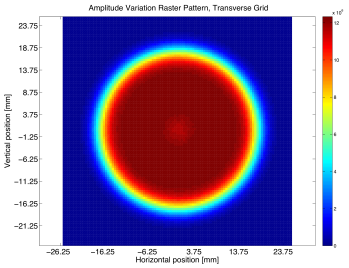


Figure 4: Beam simulated at the IPF target using the amplitude variation raster pattern with beginning radius 18 mm and ending radius 0.83 mm (0.33σ): 1 macropulse, beam σ = 2.5 mm, gird resolution 0.5 mm. Top: beam flux binned radially. Bottom: beam binned transversely.





Conclusion

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.