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VARYING AMPLITUDE RASTER PATTERN FOR HIGH POWER ISOTOPE PRODUCTION TARGETS*

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Abstract

The Isotope Production Facility (IPF) at LANSCE [1, 2] produces medical radionuclides strontium-82 and germanium-68 by bombarding rubidium chloride and gallium metal targets respectively with a 100 MeV proton beam, 230 μA average current. Rastering the proton beam is necessary to distribute beam power deposited as heat in the target and allow for higher average beam current for isotope production. We currently use a single circle raster pattern with constant amplitude and frequency. In this paper, we demonstrate two different varying amplitude raster patterns (concentric circle and spiral) to achieve uniform target coverage and expose more target volume to beam heating. In this proof-of-principle experiment, we compare beam spot uniformity measured by irradiating films and foils for both raster patterns.

INTRODUCTION

A horizontal and a vertical steering magnet perform the beam rastering for IPF [3]. 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 typical production, IPF receives 625 μs long macropulses, yielding with the raster frequency ~3 raster revolutions per macropulse.

The current single circle production raster pattern with typical 15 mm radius results in the beam spot at the IPF target shown in Fig. 1. All beam heat is deposited in the thin ring and little beam hits the target center. The goal of this proof-of-principle investigation is to demonstrate that with minor modifications to existing equipment, an amplitude varying raster pattern (concentric circle or spiral) can "fill in" the target center, distributing the beam heating over more target volume, and yielding uniform target coverage.

RASTER PATTERNS

We demonstrate two different amplitude varying raster patterns: concentric circle and spiral [4, 5]. Both methods have a square root amplitude and sinusoidal frequency dependence with time, Fig. 2.

$$\begin{pmatrix} R_x \\ R_y \end{pmatrix} = A(t) \times \Phi(t) \sim \sqrt{t} \times \begin{cases} \cos(2\pi f t + \phi) \\ \sin(2\pi f t + \phi) \end{cases} \quad (1)$$

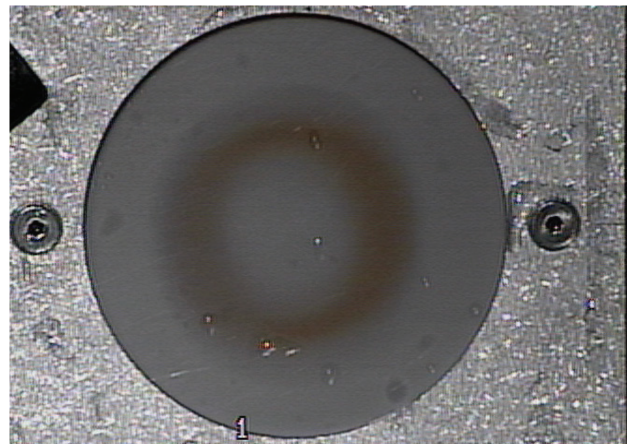

Figure 1: Beam spot at the IPF target with the single circle production raster pattern measured by film irradiation.

In the concentric circle method, the raster amplitude is constant for each macropulse. The amplitude changes in between macropulses, executing the square root dependence with more larger radii circles and fewer smaller radii circles. The uniform beam spot is achieved in several macropulses. Due to equipment protection considerations, we do not execute the pattern in order of radii size. Instead, we "mix up" the radii as observed in Fig. 2. In this paper, we study a concentric circle pattern with 100 different radii.

In the spiral case, the square root amplitude dependence is executed during each macropulse by spending more time at larger radii and less time at smaller radii. A macropulse-to-macropulse phase shift due to the raster frequency and the 120 Hz machine repetition rate rotates the spiral to give the uniform beam spot on target after several macropulses. Care was taken to ensure that the raster frequency was not a multiple of the 120 Hz machine repetition rate, as this would yield a zero degree macropulse-to-macropulse phase shift.

SET UP AND MEASUREMENT

We set up for this experiment with a 5 Hz repetition rate to IPF in order to achieve ~10 μA average current (for equipment protection reasons) using the production peak current, 3.4 mA. After each raster pattern was loaded into the controller, we inserted a measurement stack into the IPF target position. The measurement stack held a 0.5 mm thick polyethylene film and a 1 mm thick titanium foil. We simultaneously irradiated both film and foil with 100 macropulses of rastered beam. The plastic film image was captured with

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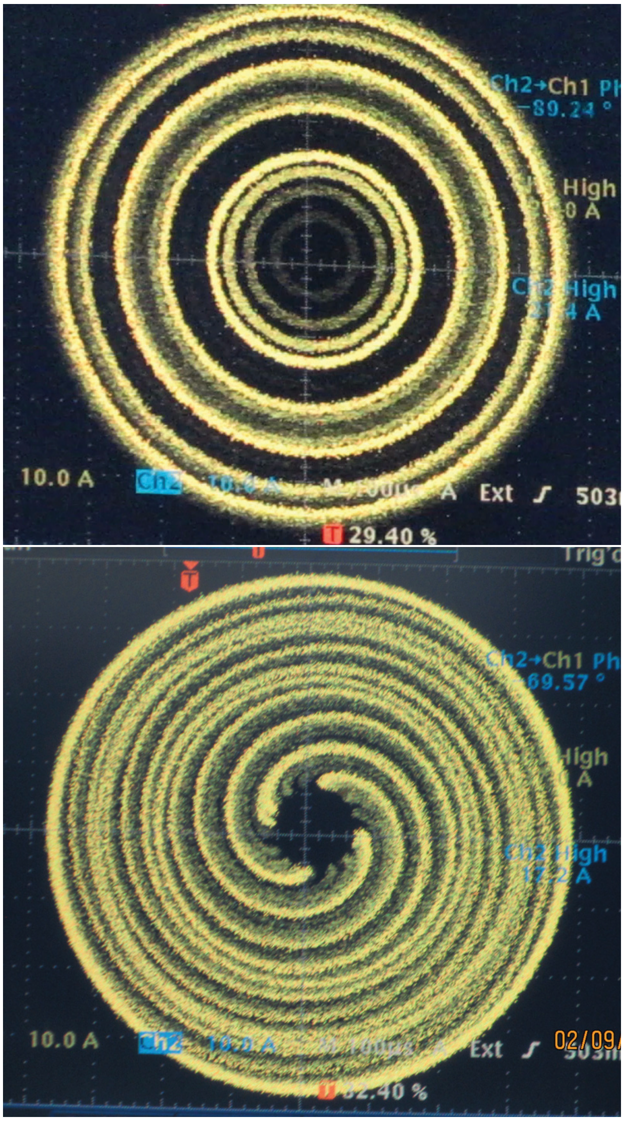

Figure 2: The raster amplitude waveforms observed by current viewing coils at the raster steering magnets for the concentric circle (top) and spiral (bottom) patterns with oscilloscope persistence for several macropulses.

a camera and analyzed with ImageJ [6] to yield immediate beam spot information. The foils were autoradiographed with phosphor screens and analyzed after the experiment. Both techniques yield qualitative information on the beam spot at the IPF target.

RESULTS

The beam spots produced by the concentric circle and spiral raster patterns are plotted in Fig. 3. Both new raster patterns more completely fill in the target center, spreading the beam heating over more target volume than the single circle production pattern, Fig. 1.

Note in Fig. 3, the spiral pattern beam spot has a slightly hollow dip in the center. It appears that the minimum raster radius was not achieved during the exposure. This result could be due to a limitation in the command speed of the controller or response of the raster steering magnets. Either way, the hollow dip at the beam spot center can be filled in completely through optimization, which we did not do for this proof-of-principle demonstration.

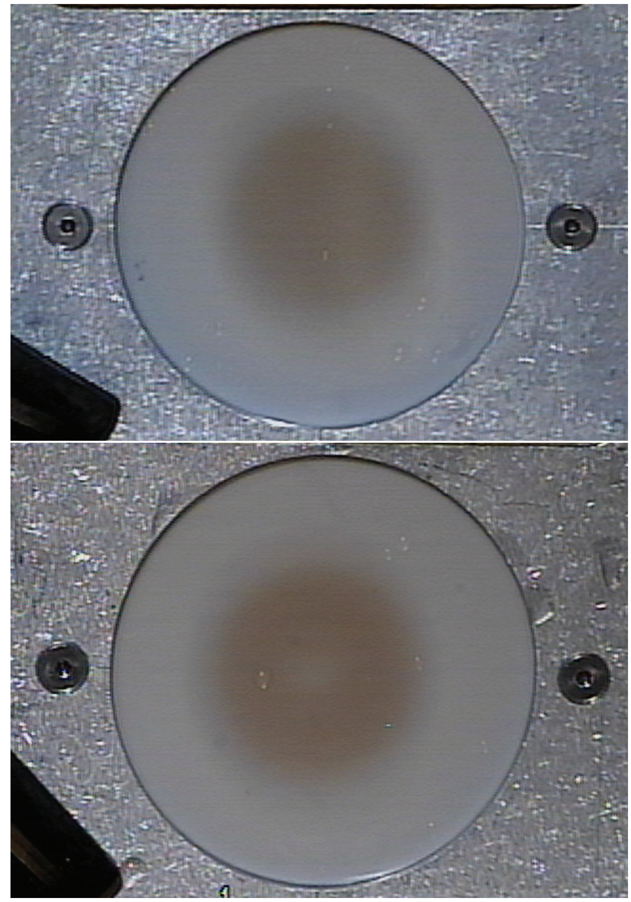

Figure 3: Beam spots at the IPF target produced using the concentric circle (top) and spiral (bottom) raster patterns measured by film irradiation.

To visualize target coverage uniformity, we plot the beam spot line profiles for each raster pattern in Fig. 4. We define the line profiles as a one dimensional cross-section cut through the beam spot distribution center. Figure 4 clearly shows that the concentric circle and spiral raster patterns fill in the target center. We observe the hollow dip in the spiral beam spot center, which is an ∼18% reduction of the maximum but much smaller than the single circle production beam spot with a hollow dip that has an ∼71% reduction of the maximum. The uniformity of the concentric circle line profile flattops is clearly observed. Note also the amplitude varying raster patterns can be optimized by increasing their outer radius to match the width of the single circle production pattern, spreading the beam spot over even more of the target.

The beam spot uniformity after 100 beam pulses, plotted in Fig. 5, is of interest because it describes the evenness of

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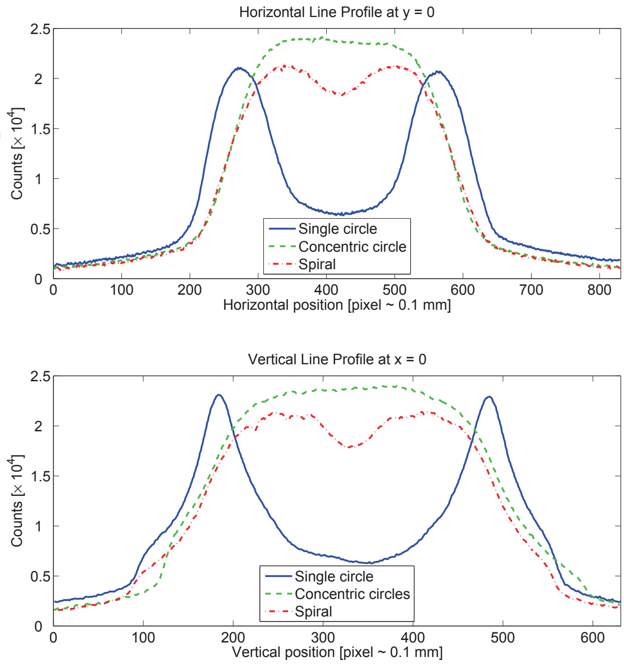

Figure 4: The horizontal (top) and vertical (bottom) beam spot line profiles at the IPF target measured by foil irradiation for single circle production (blue), concentric circle (green), and spiral (red) raster patterns.

beam heating. We determine the uniformity variation by calculating the standard deviation of counts from the irradiated foil measurement over the flattop region of the beam spot, typically 10 mm radius. For comparison, we normalize the variation to the average value over the distribution flattop. The concentric circle beam spot uniformity variation is 1.5% of the average at 10 mm. Because of the hollow dip at the spiral beam spot center, the uniformity variation at 10 mm radius is 9.2%. If the contribution from the hollow dip is ignored, the spiral beam spot uniformity variation at 10 mm radius is 2.1%, comparable with the concentric circle uniformity variation. This very encouraging result indicates uniform target heating.

CONCLUSIONS

We demonstrated both a concentric circle and a spiral amplitude varying raster pattern in a proof-of-principle experiment. We showed that both raster patterns cover the target center better than the current single circle production raster pattern. The concentric circle pattern yielded a beam spot with ~1% uniformity variation at 10 mm radius. The spiral method did not completely cover the target center, leaving a hollow dip that can be corrected via optimization. If the hollow dip is ignored, the spiral beam spot had ~2% uniformity variation at 10 mm radius.

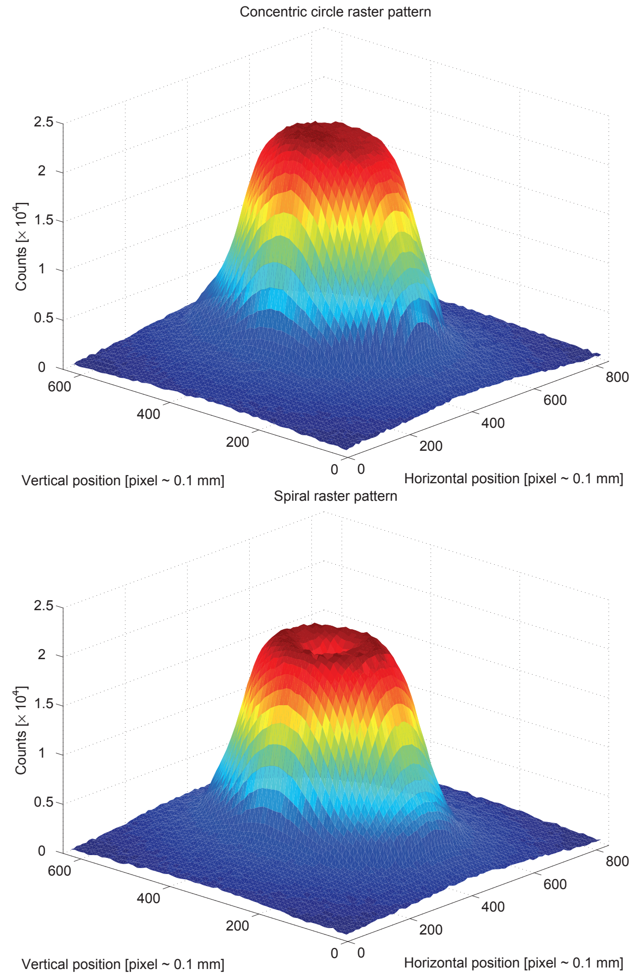

Figure 5: The beam spot at the IPF target measured by foil irradiation for the concentric circle (top) and spiral (bottom) raster patterns.

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