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Dynamic Jaw Correction of Gravity-Induced Geometrical Effects on the RefleXion X1 System for Improved Targeting Accuracy

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ABSTRACT

Purpose: Gravity exerts a force on the X1 causing gantry flexion, albeit small, that can be minimized to improve targeting accuracy while it is rotating. This study sought to demonstrate the mitigation of gravity-induced effects by improving the centering of the jaws using a custom-made phantom.

Methods: An in-house developed 4 ball phantom with 4 metallic balls on a plane and megavoltage detector (MVD) were used to characterize 1) jaw offset 2) centering of fields and alignment of the radiation isocenter (i.e. starshot). These data were modeled for jaw correction as function of gantry angle. For this test, the projected jaw MVD images and calculated jaw positions offsets at isocenter were used to keep the fields centered along Y axis at all gantry angles. This was done by adjusting the jaws in real-time and were verified using the MVD. Finally, film tests of jaw divergence per TG-148 were completed with and without jaw correction.

Results: The projected field motion ranges in IEC-Y improved from 0.48 mm before correction to 0.03 mm after correction, demonstrating the mitigation of jaw motion. Film jaw divergence testing showed mean jaw offset at isocenter (IEC Y) of -0.29 mm without correction, and 0.04 mm with correction.

Conclusion: The study showed that jaws can be used to correct gravity-induced structural deflections and was confirmed with external film measurements. This study improved field centering accuracy, which can potentially translate into improved targeting accuracy.

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INTRODUCTION

The mechanical structures of radiation therapy systems with a rapid-rotation ring gantry must be designed to handle significant forces due to acceleration and gravity while maintaining precise alignment of components in space. This results in a cost/benefit tradeoff since a perfectly stiff structure will not be cost effective or achievable.

Most of the mechanical system positioning error comes from deflection of the frame and components due to gravity. This error is repeatable for a given gravity orientation.

The X1 System has a fan beam in which the IEC Y extent of the field is controlled by jaws. The jaws are servoed to hold position relative to the jaw position feedback to small error values. However, the entire jaw assembly and gantry frame are moving relative to fixed isocenter. Measurements taken using a custom in-house 4-Ball Phantom and associated software showed the projected jaw field center shifts in Y around +/- 0.25mm.

For this investigation, the jaw center field shift data was used to create offsets to the servo position to compensate for gravity deflection and a second set of 4-Ball data was taken to verify new projected jaw field position.

METHODS AND MATERIALS

An in-house developed 4 ball phantom with 4 metallic balls on a plane and megavoltage detector (MVD) were used to characterize 1) jaw offset 2) centering of fields and alignment of the radiation isocenter (i.e. starshot).

Images of 4-Ball phantom were captured at multiple gantry positions and analyzed by an in-house software to fit a curve to data relative to gantry angle for expected and measured ball centroids using a 10 degree of freedom model fit. Sets of 100-200 images were taken with gantry spinning at 5-6 rpm where rotational acceleration forces are insignificant compared to traditional static gantry positions used for film images. The analysis used two sets of images, where each set was acquired in less than 1 minute.

The output from the 4-Ball tool includes both jaw position and MLC beamlet position with all data projected to isoplane.

These data were modeled for jaw correction as function of gantry angle. For this test, the projected jaw MVD images and calculated jaw positions offsets at isocenter were used to keep the fields centered along Y axis at all gantry angles. This was done by adjusting the jaws in real-time and were verified using the MVD. Finally, film tests of jaw divergence per TG-148 were completed with and without jaw correction.

RESULTS

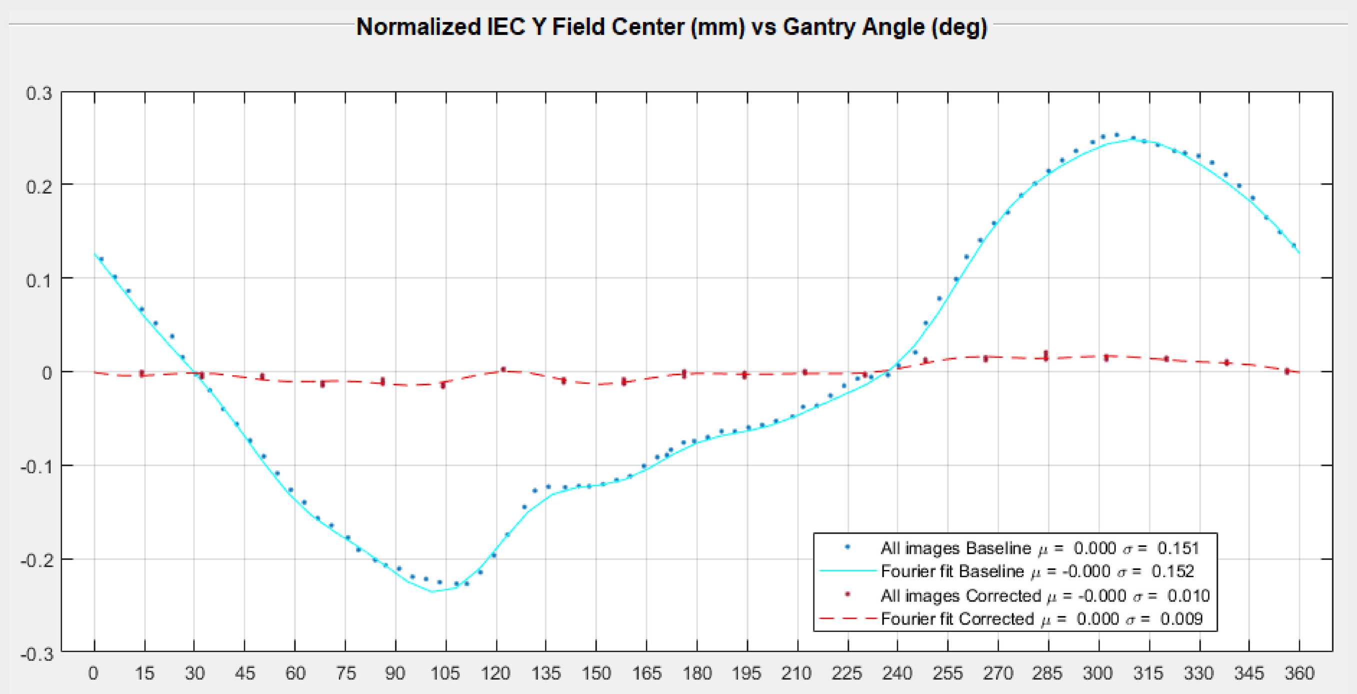

Figure 1. Normalized IEC Y Field Center from 4 ball with and without jaw correction

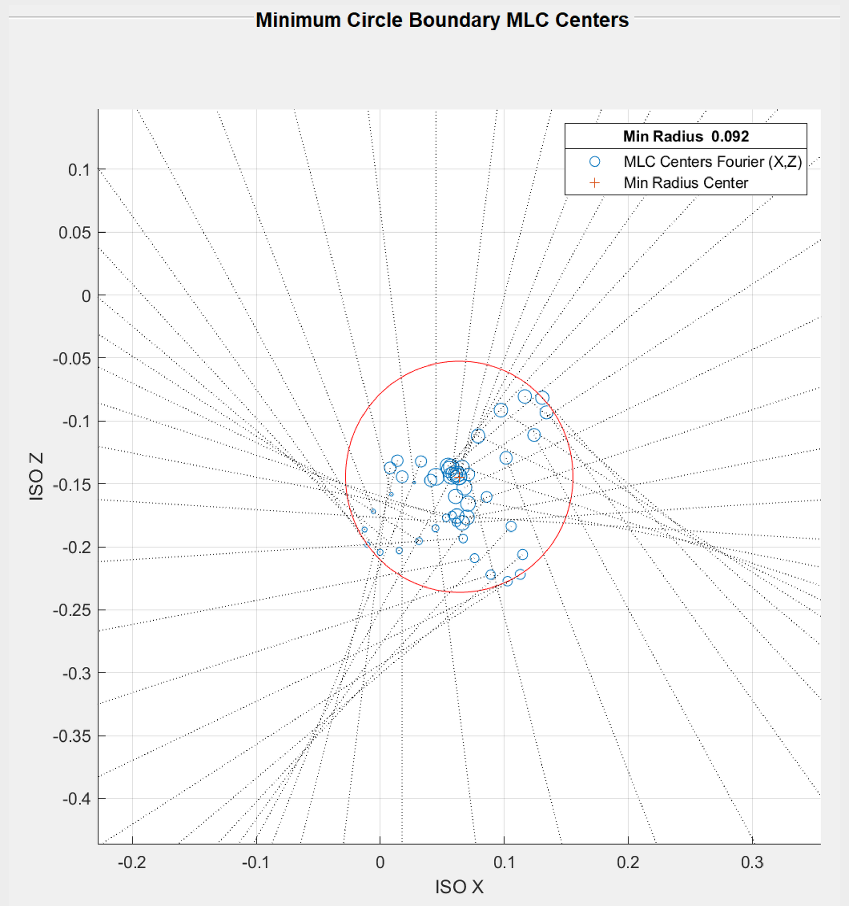

Figure 2. 4-Ball simulation of 50-Point Star Shot

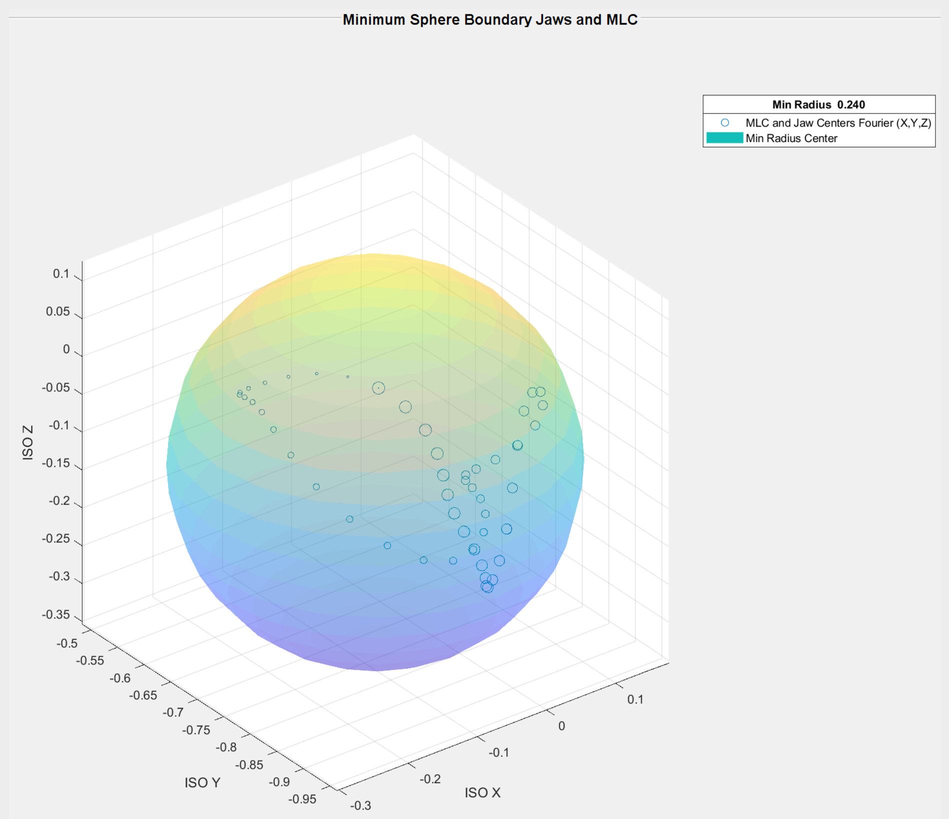

Figure 3. 4-Ball Iso-Sphere output baseline

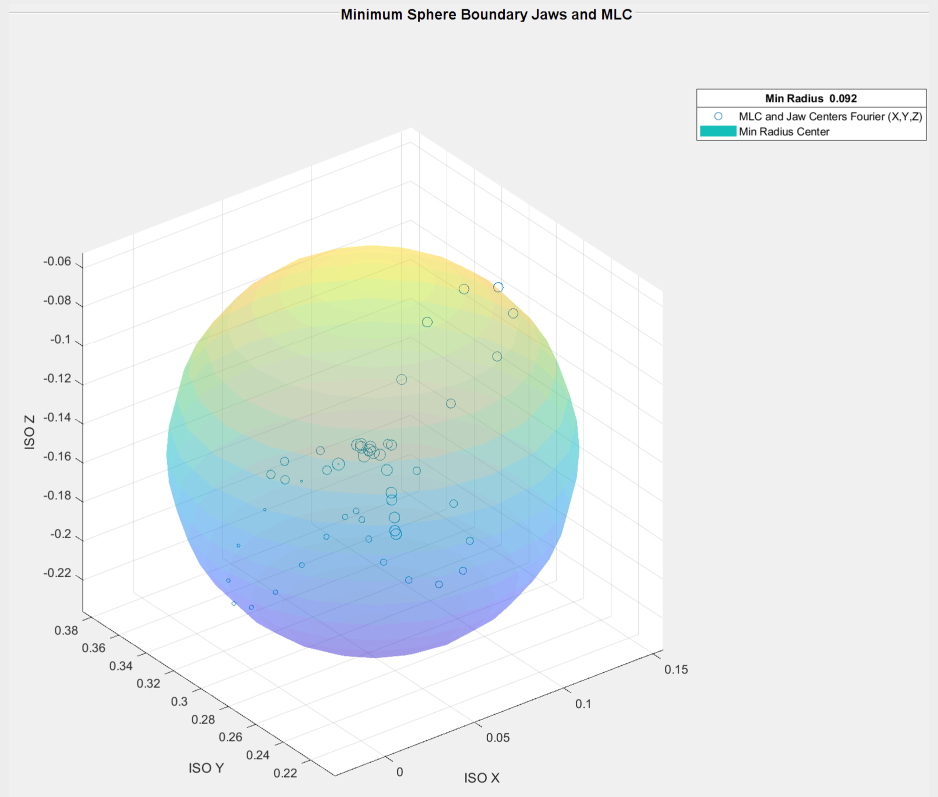

Figure 4. 4-Ball Iso-Sphere Output Corrected

DISCUSSION

The X1 system has non-rotating collimator that makes it more challenging to find the location of the isocenter. The existing standard test uses film measurements and calculations, which assume similar triangles and cannot capture error at all gantry angles. The standard TG-148 jaw divergence output values cannot be directly compared to 4 ball Jaw Center offset.

The tested system had a 0.09 mm minimum tangent radius in the X-Z plane. The Iso-Sphere 4 ball output extends star shot centerlines to the IEC Y dimension for a minimum spherical fit to the beam centerlines. Results show that the minimum tangent spherical radius for the baseline was dominated by jaw motion at 0.24 mm. After correction, the jaw motion was now smaller than the MLC offset so the MLC offset determined the minimum spherical radius of 0.09 mm.

This study showed that our in-house phantom and MV detectors can capture radiation field deviations at all gantry angles, allowing for real-time correction by compensating them with jaw offsets as the gantry rotates.

Table 1. Baseline and Corrected Test Output Values

	Baseline	Corrected
4-Ball Jaw Center Motion (+/-mm IEC Y)	0.24	0.02
Film Jaw Divergence (mm)	-0.29	0.04
4-Ball Star Shot Min Radius (mm)	0.09	0.09
4-Ball Iso Sphere Min Radius (mm)	0.24	0.09

CONCLUSIONS

The study showed that jaws can be used to correct gravity-induced structural deflections and was confirmed with external film measurements. This study improved field centering accuracy, which can potentially translate into improved targeting accuracy.

REFERENCES

1 **Katja M. Langen et al**. QA for helical tomotherapy: Report of the AAPM Task Group 148. *2010*