A 3D Star Shot to Determine Axes of Rotation

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ABSTRACT

Star shots are a method to determine gantry, collimator and couch axes of rotation. A new technique to extend this traditional 2D method to 3D relates all three axes to each other.

THEORY

A traditional star shot is a 2D technique exposing film to radiation slits. The slits are rotated about an axis, forming a star at the center of rotation.

Figure 1. A 2D star shot

To move to 3D, wrap a film on a cylinder instead of laying it flat on a phantom. Slits are exposed using all three axes of rotation.

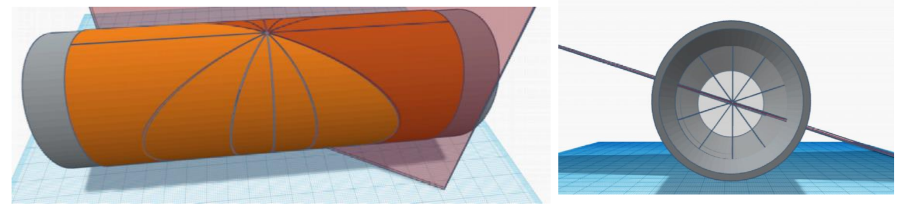

Figure 2. Collimator and couch rotations form 2D-like star shot patterns. Gantry rotation forms a virtual star shot.

The slit exposures form cylinder sections. When the film is unwrapped these sections appear as either lines or sinewaves.

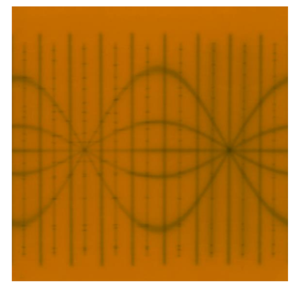

Figure 3. A 3D star shot

A star pattern represents an approximate axis center. It is described by the smallest circle that touches each line/sine going through this center. For the collimator axis there is one such circle where the radiation enters the film and one where it exits. Likewise for the couch axis. The gantry axis has a virtual star and circle at each end of the cylinder.

THEORY

Connect the entrance/exit circles center-to-center with a line. This line represents an axis.

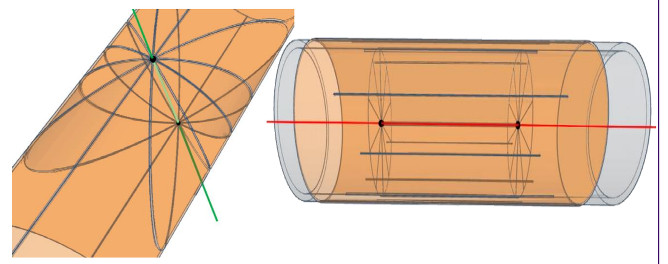

Figure 4. Connect entrance and exit stars

The final step is to find the point in 3D space that is closest to all three axes. That point is the center of the smallest sphere to touch each axis. The sphere's diameter d is scored as the QA value.

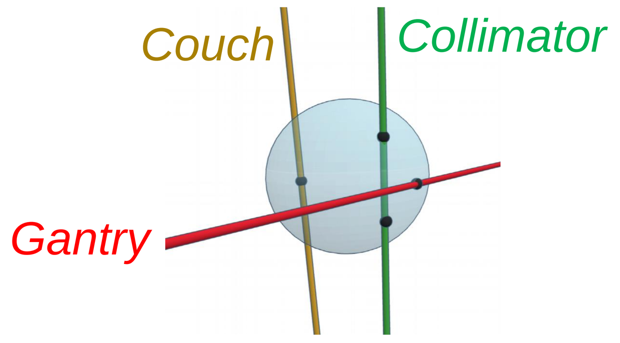

Figure 5. Find the smallest sphere touching each axis

CPQR's Medical Linear Accelerator's tests AL11 – AL15 require $d \leq 1$ mm.

MATERIALS AND METHODS

A cylindrical phantom was built to hold an 8x10 sheet of GAF chromic film. An exterior cylinder was added as buildup.

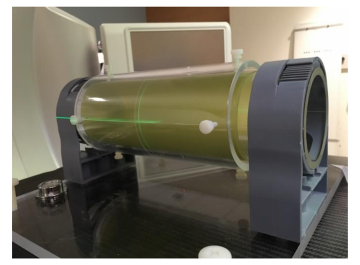

Figure 6: Cylindrical Phantom Diameter = 3.25"

The isocenter is aligned to the cylinder's center and gantry axis to the cylinder's axis. We expect the radiation isocenter to be at the cylinder's center which is at the mechanical center.

Exposures were taken with the 6FFF beam on a Varian TrueBeam linac. 300 MU were delivered per slit with settings:
Collimator = 0, Couch = 0 & Gantry = 0, 40, 80, … , 320
Couch = 0, Gantry = 0 & Collimator = 15, 45, 75, 345, 315, 285
Collimator = 0, Gantry = 0 & Couch = 0, 30, 60, 90, 330, 300

RESULTS

Comments: Settings for exposures can differ depending on circumstances.

A film such as in Figure 3 is binarized and the location of each white dot is a data point to be fitted by a curve. Multiple curves are used for each film.

Zoom in to the center of a star. At this scale, each fitted curve is linear. To find the smallest circle that touches each line, pick all possible sets of three lines. Each set forms a triangle with a unique inscribed circle. The largest of these inscribed circles satisfies the criteria of being the smallest circle that touches every slit exposure that make up the star.

Pair up exit and entrance circles and join their centers with a line. These connecting lines represent the associated axis.

The gantry's star is virtual. Pick a star at each end of the cylinder. Find the circle at each end and join their centers to represent the gantry axis (see Figure 4).

Find the point P that is closest to the three axes lines (see Figure 5). The point P will be the center of a sphere that touches all three axes. Two of the axes lines will be tangent to this sphere and the third will cut through the sphere. The largest distance of P to a line represents the sphere's radius and hence the diameter score. Table 1 summarizes the results for the film in Figure 3.

If the cylinder is well aligned to the mechanical isocenter, the location of point P represents the position of the radiation isocenter relative to the mechanical isocenter. These are separated by a distance of 0.31 mm in the example in Table 1.

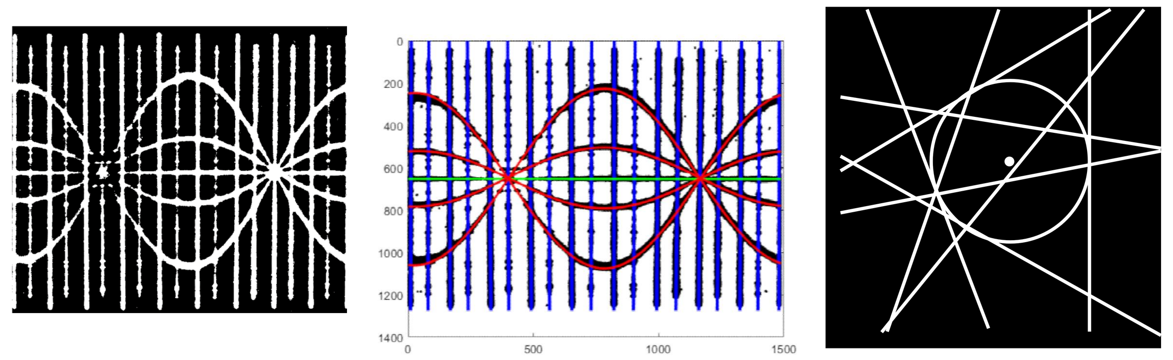

Figure 7. Binarize and fit the lines and sines. Use fitted curves to find the smallest circle touching each curve at the center of the star

TABLE 1 Results for the film in Figure 3

Smallest sphere	
Diameter	0.5085 mm
Center P	(−0.25, 0.042, 0.19) mm
Distance from P to gantry axis	0.2543 mm
Distance from P to couch axis	0.2543 mm
Distance from P to collimator axis	0.2353 mm

DISCUSSION

The 3D star shot is robust technique for determining the radiation isocenter. The theory of cylindrical sections is not sensitive to the orientation of the planes that cleave the cylinder. The radiation isocenter can be found, independent of this orientation. Below are two examples of cylinders that were poorly aligned to the mechanical center. The radiation isocenter may differ significantly from the cylinder's center but it will nevertheless be well identified.

This technique was designed to be cost effective, using a single sheet of film per study. The phantom is inexpensive to construct. The 3D star shot fulfills the requirements for confirming the suitability of a linac for stereotactic radiosurgery.

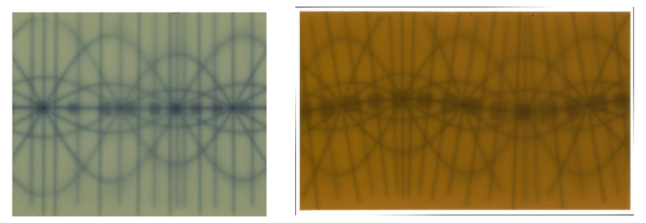

Figure 8: Misaligned phantoms change the appearance of the slits exposures but not the information content. Left is a 1 cm lateral shift & right is a 10° rotation. These are still represented by lines and sines and the radiation isocenter will be well identified by this method.

CONCLUSION

A new technique for measuring the coincidence of all three rotation axes on a linear accelerator is presented. This is a suitable technique for CPQR's guidelines, and will test a linear accelerator's readiness for stereotactic radiosurgery applications.

REFERENCES

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- Corns R, Yang K, Ross M, Bhandari S, Aryal M, Ciaccio P. A 3D star shot to determine the gantry, collimator, and couch axes positions. J App Clin Med Phys. 2022; e13623. https://doi.org/10.1002/acm2.13623