Measuring Couch Motion Accuracy with X-ray Beam Fluence

Rudi Labarbe, M.S. and Brett Nelson, M.S.
IBA Particle Therapy, Belgium and Logos Systems, Scotts Valley, CA

Introduction

The accuracy of radiosurgery systems can be verified and maintained with quality assurance (QA) procedures performed on a regular schedule. Typically these procedures focus on the operational health of the mechanical delivery system for the radiation (gantry or robot), the beam shaping multi-leaf collimators, and the energy profile of the X-ray or proton beam radiation source. To ensure that radiation is delivered accurately to the patient, it is also essential that the patient treatment couch and the electro-mechanics be examined periodically. This report examines the use of an imaging system with innovative scintillator geometry to record the position of an IBA proton therapy treatment couch as it was moved through a series of linear displacements.

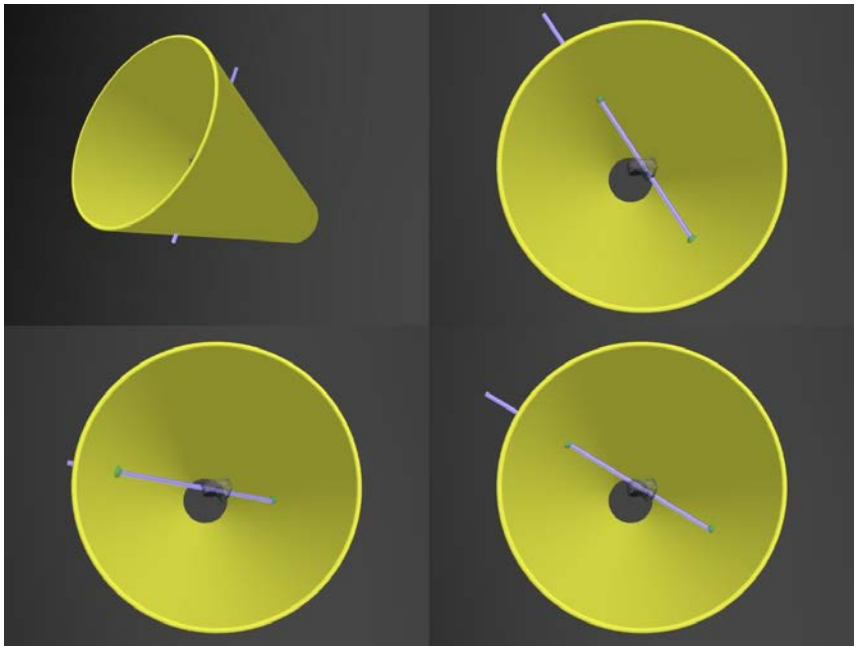

Figure 1 – X-ray or Proton Beam Interaction with the XRV-100 Scintillator

The heart of the XRV-100 phantom (Logos Systems, Scotts Valley, CA) consists of an imaging cone (*Figure 1*) laminated with Gadox X-ray scintillator phosphor. As ionizing radiation passes through the cone, two spots of visible light are formed by Compton scattering at the entry and exit points of the beam. These two spots precisely define the path of the radiation beam through three-dimensional (3D) space. By calculating the beam vector and position from these spots, the XRV software can track the gantry or robot in real-time. Alternatively, the gantry can be stationary while the imaging system monitors the patient couch as it moves through various positions during the course of a simulated treatment.

Materials and Methods

The XRV phantom was placed on the IBA treatment couch as shown in *Figure 2* such that movement along the couch in the negative Y direction could be easily captured. The IBA gantry was rotated to an overhead position (0 degrees) and an X-ray source of approximately 150 kV within the aperture enclosure was used to project photons through the MLC forming a square beam approximately 8.4 mm on a side. Position measurement tests were performed with the beam stationary and the couch moving along its Y axis. The negative Y axis movement of the couch corresponds to negative Z axis movement of the beam spots upon the XRV imaging cone. The imaging cone dimensions allowed the X-ray beam position to be captured and measured along a distance of 60 mm.

The pattern of the test was to expose the phantom with X-rays for approximately 1 second, move the couch in the negative Y direction a random distance, and then repeat. The X-ray beam was manually energized by push button, so the actual duration of the beam fluctuated around the 1 second target.

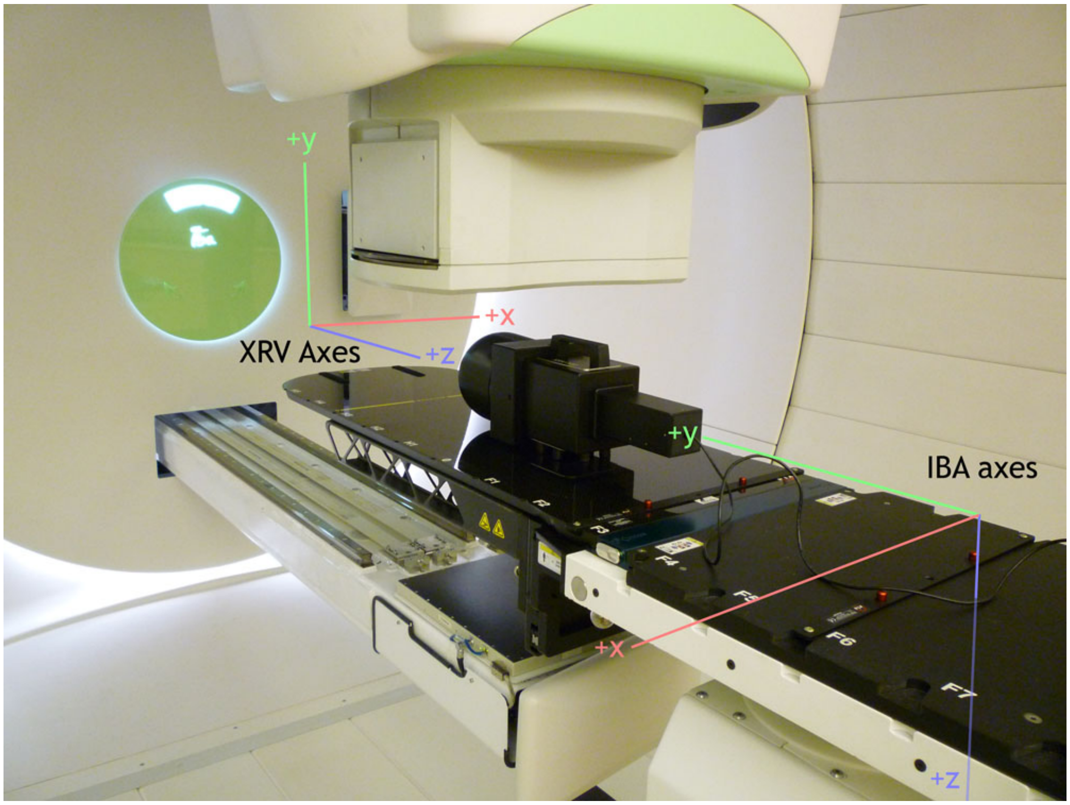

Figure 2 - Phantom Positioning on Couch with Corresponding Coordinate Systems

The XRV imaging cone is manufactured with reference holes precisely machined at 10 millimeter Z axis intervals along the top, bottom, and sides of the cone. These holes can be backlit to form a cross shaped pattern that is used for calibration at the factory or in the field. These holes can be seen at the bottom of *Figure 3* and range from 40 millimeters to 110 millimeters from the cone base flange on the left side of the image.

Factory calibration also involves the use of a radiographic measuring bar that can be temporarily fastened to the imaging cone. The measuring bar has X-ray opaque fiducials mounted at 10 millimeter intervals along its length. The bar is shown attached to the cone base flange at the top of *Figure 3*.

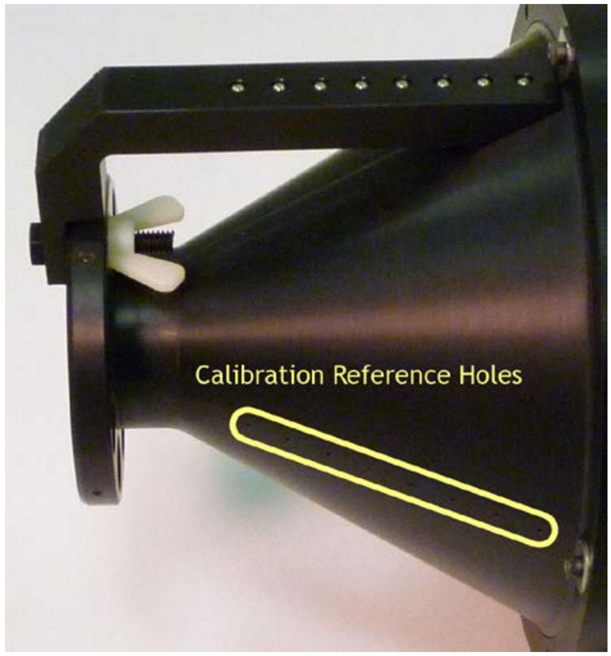

Figure 3 - Imaging Cone with Radiographic Measuring Bar Attached

Figure 4 shows the pattern of dots formed by the reference holes when the cone is backlit. The software uses the position and spacing of the dots on this 2D camera image to calibrate 3D locations on the inner cone surface. The outer surface of the cone is usually covered with a shroud in order to darken the phantom interior. This optical calibration system of backlighting the cone and updating the software parameters is used each time the phantom is transported in its carrying case.

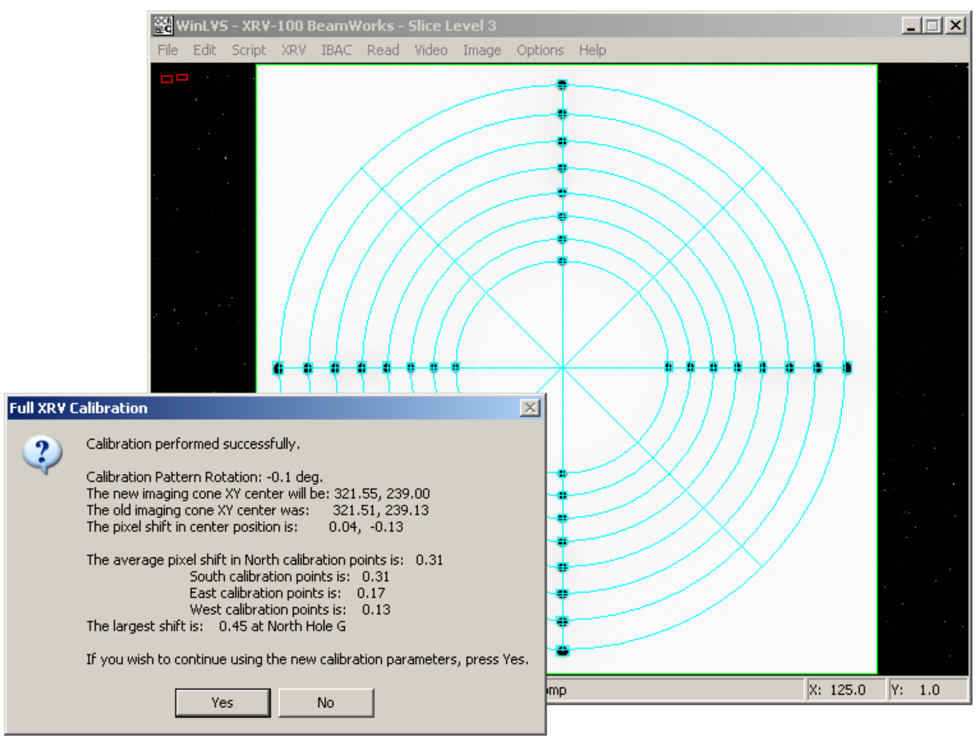

Figure 4 - Calibration Reference Hole Measurements

Data Representation

The initial XYZ couch position during the test was -.3, -.03, -13.58 centimeters according to the IBA data monitors in the treatment room. The corresponding XRV imaging cone Z axis position was 102.9 millimeters. The couch was moved in an increasingly negative Y axis IBA position (decreasing Z axis XRV position) 44 times until it reached a maximum excursion at -6.37 cm. The couch was then moved in the positive Y direction several times until it was back near its starting location. *Figure 5* shows the XYZ positions of the couch at beam 29 and beam 47.

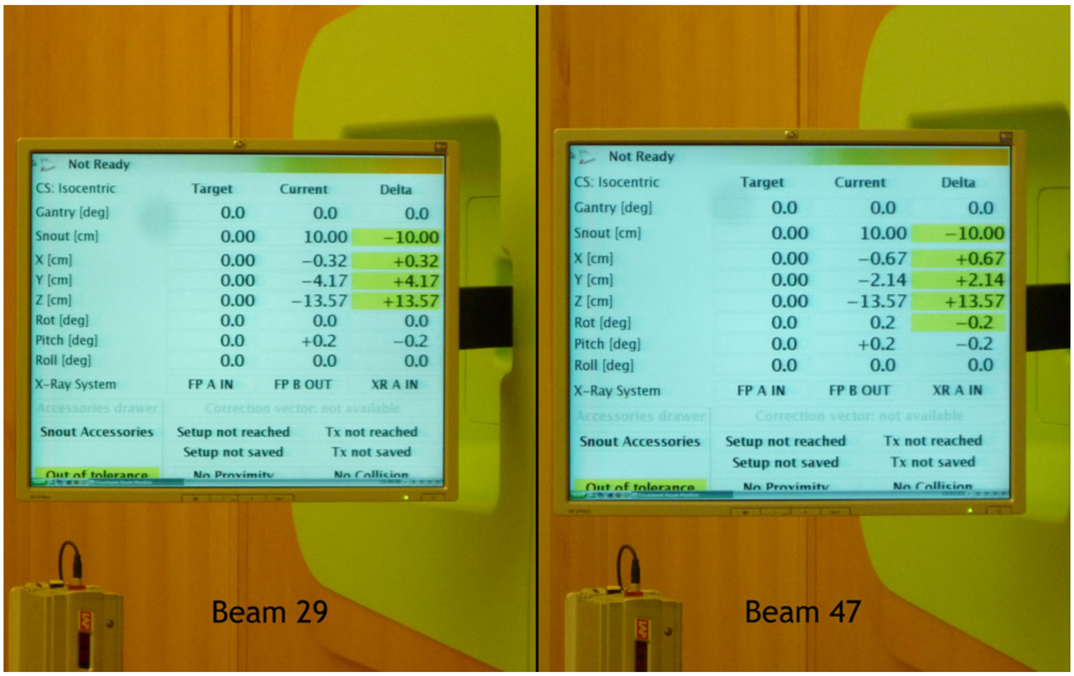

Figure 5 - Proton Therapy Couch Position Monitor

While the X-ray beam was pulsed at each new couch position, the XRV software was monitoring the beam spot activity on the inside of the imaging cone, detecting the start of new beams, calculating beam metrics, and archiving beam images and data to disk. The XRV digital camera used a frame rate of 10 frames per second, a shutter period of 100 milliseconds, and a gain of 7.2 dB to produce beam spots of optimal brightness for analysis. Each captured beam was integrated over approximately 7-8 frames depending on how long the X-ray control button was pushed. Beam data was saved in a comma separated variable (CSV) format that was later input to a spreadsheet.

Figure 6 shows the square beam spots captured at four couch positions superimposed on a single image. The outer blue ring corresponds to a distance of 110 millimeters from the cone base flange and the inner blue ring corresponds to a distance of 40 millimeters. The spacing between each of the concentric rings is 10 mm. The width of the top beam spot along the arc is measured to be 9.01 mm. The measurement in the vertical direction (also called radial) was 9.13 mm.

The beam enters the cone vertically yielding a brighter entry spot at the top and a dimmer exit spot at the bottom. As shown above in *Figure 2*, the XRV positive X axis maps onto the IBA couch negative X axis and the XRV positive Y axis maps onto the IBA negative Z axis.

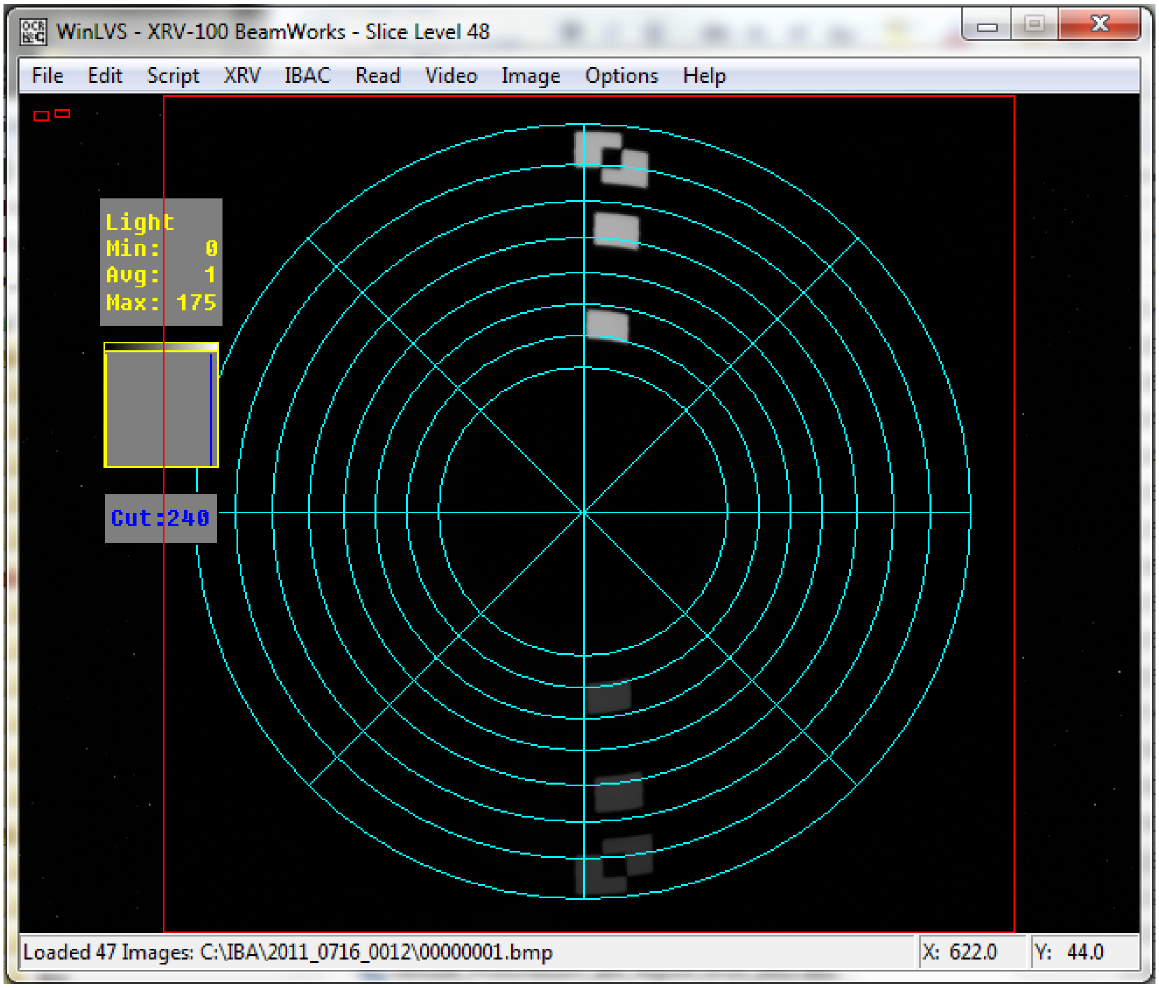

Figure 6 - Superimposed Beam Spots from 4 Couch Positions

The four couch positions in *Figure 6* starting from the top are at beams 1, 48, 47, and 46. These correspond to couch Y axis positions of -.03 cm, -.42 cm, -2.14 cm, and -5.02 cm. It can be seen from the overlap of the entry beam spot for beam 1 and 48 that there is a several millimeter drift in the X position of the beam from the start of the test to the end. This is also evident in the change of X location from -.32 cm to -.67 cm (delta of 3.5 mm) in the "Current" columns of *Figure 5*. The cause for this was that the buttons that control the couch X axis were briefly pressed in the process of positioning the couch Y axis for beams 46, 47, and 48. This unplanned movement along the X axis does not interfere with measurements along the Y axis.

Test Results and Analysis

The couch Y axis IBA position readings were: -.03, -.08, -.39, -.42, -.46, -.84, -1.36, -1.42, -1.44, -1.48, -1.50, -1.61, -1.65, -2.13, -2.15, -2.18, -2.31, -2.45, -2.50, -2.77, -2.86, -3.09, -3.32, -3.36, -3.38, -3.45, -3.59, -3.84, -4.17, -4.23, -4.26, -4.39, -4.47, -4.58, -4.69, -4.89, -5.00, -5.07, -5.13, -5.22, -5.30, -5.32, -5.40, -5.75, -6.37, -5.02, -2.14, and -.42 centimeters. These positions were also captured by the XRV software and archived to disk starting at the initial cone Z position of 102.9 millimeters.

Shown in *Figure 7* is a linear regression of all the couch and XRV phantom measurement points. The absolute value of the couch positions are used in order to facilitate a more convenient representation of the data. The fitted slope of .9991 demonstrates excellent agreement between the two datasets indicating that the non-linearity between the XRV measurements and the internal measurements of the treatment couch electro-mechanics is less than .1%.

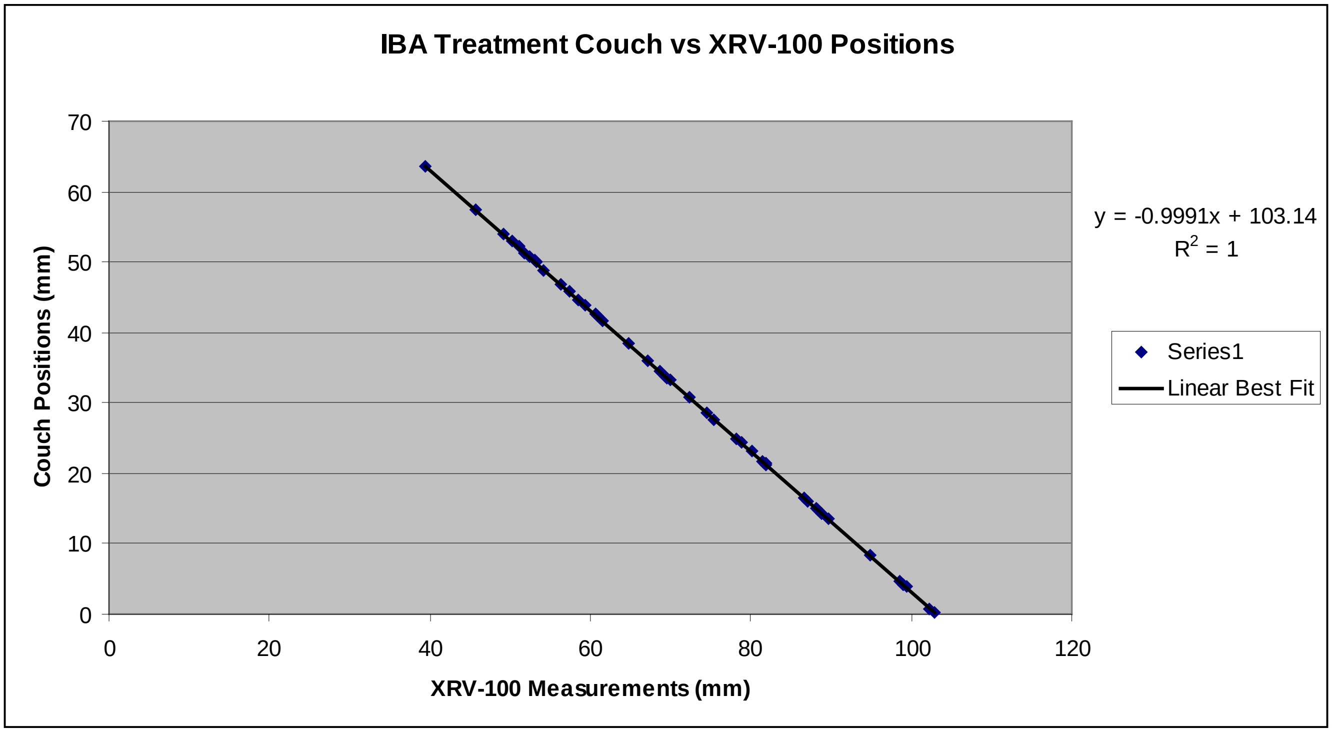

Figure 7 – Linear Regression of the Couch positions versus the XRV-100 Measurements

The XRV measurements can now be used as the x value input to the fitted line equation to produce idealized y value couch positions. As an example, using the second XRV reading of 102.307 mm, the resulting couch measurement according to the fitted line would be 102.21 – 103.14 or -.925 mm giving a delta of .1 mm from the actual reading of -.08 cm (-.8 mm).

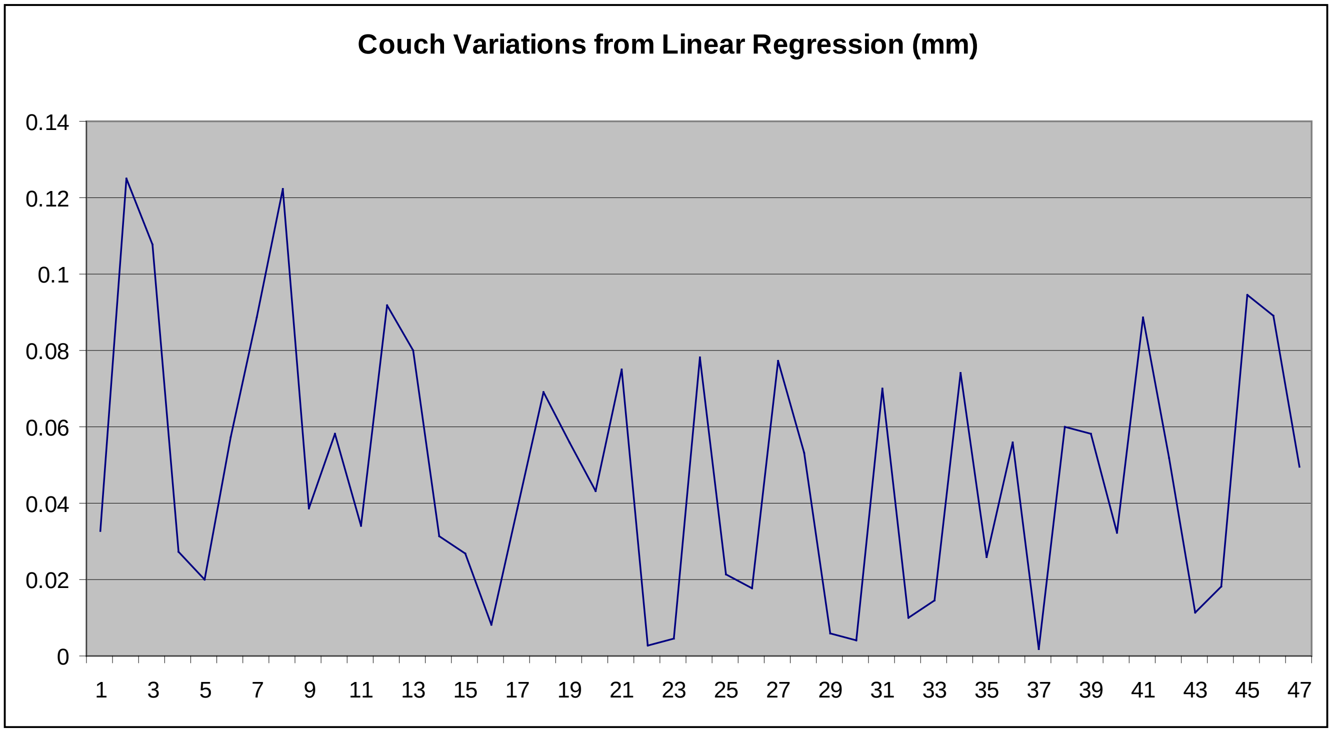

Figure 8 – Variation of Couch Measurements from Linear Regression equation

Figure 8 contains the absolute value of all the deltas between the couch measurements and the fitted line couch values when using the XRV measurements for input as X into the equation for the line. The largest delta is .1 mm and is located at the second XRV reading. The average of the values in *Figure 8* is .05 mm and represents the combined reporting error of both the couch electro-mechanics and the XRV hardware/software.

Conclusion

The measurement data demonstrates that the average variation of the IBA couch positions versus the XRV-100 measured positions along a single axis of motion was .05 mm with the maximum variation being .1 mm. These values represent the combined measurement error of the two systems and it is beyond the scope of this study to further isolate the individual accuracy of the couch or the XRV system. Therefore, the XRV-100 phantom maximum measurement error along the imaging cone Z-axis was less than .1 mm and the average error less than .05 mm. These error values are well within the published .2 mm margin of the XRV-100 device.

Contact Information

Rudi Labarbe, M.S.
System Engineer

IBA Particle Therapy
Chemin du Cyclotron 3
1348 Louvain-la-Nueve
Belgium

Brett Nelson, M.S.
Director of Engineering

Logos Systems Int'l
175 El Pueblo Road
Scotts Valley, CA 95066
www.logosvisionsystem.com
Phone: 831-600-6101

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