THE INFLUENCE OF LINAC AND BEAM SCANNING SYSTEM MECHANICAL COMPONENTS IN RELATIVE DOSE MEASUREMENTS

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Abstract. Due to the tolerances given by the linear accelerator (LINAC) producer regarding the variability of mechanical movements, this work is focused on the influences of the mechanical components position in relative dose measurements such as percentage depth-dose distributions (PDD) and dose profiles. Those measurements represent an essential role in modelling the radiation beam accurately in the treatment planning system (TPS), such that the radiation therapy treatments can be delivered as intended. The main aspects of this work are to estimate the measurement uncertainty itself by statistical means and to provide a practical workflow to be performed prior to starting the dosimetric measurements.

Key words: relative dose measurements, scanning system, beam modelling, linear accelerator.

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1. INTRODUCTION

The basics on implementation of a radiotherapy treatment workflow starts with the acceptance and commissioning of the LINAC. According to the vendor's criteria and tolerances, the acceptance part is focused on checking if all the parameters are as expected for the specific configuration. This includes both checking the LINAC and the TPS data transfer. Regarding the LINAC, besides the mechanical and imaging parameters, one of the most important is the beam component. Starting from checking the nominal energy of the beam by means of PDD up to checking the beam alignment and symmetry by means of dose profiles. All these beam parameters usually fit in the manufacturer's tolerances but for a good clinical practice, care should be taken when accepting those values. According to international protocols [1, 2], the values of those parameters have an upper threshold on their values, especially beam symmetry and flatness, and should not deviate from the baseline up to a certain degree. From an idealistic perspective, before finishing the acceptance, it would be desirable to tune the values as close as possible to the ideal value. This perspective is very helpful for the next step which is the TPS commissioning [3, 4, 5]. Since the parameters are as close as possible to the ideal value, it is very easy to observe future deviations and correct them accordingly.

Care should also be taken from the point of view of the mechanical components of the LINAC since all the measurements rely on collimation, source to surface distance (SSD), beam projection, etc. For a better understanding of the LINAC geometry a representative scheme of the gantry, its rotation axis and the collimator devices are depicted in Fig. 1.

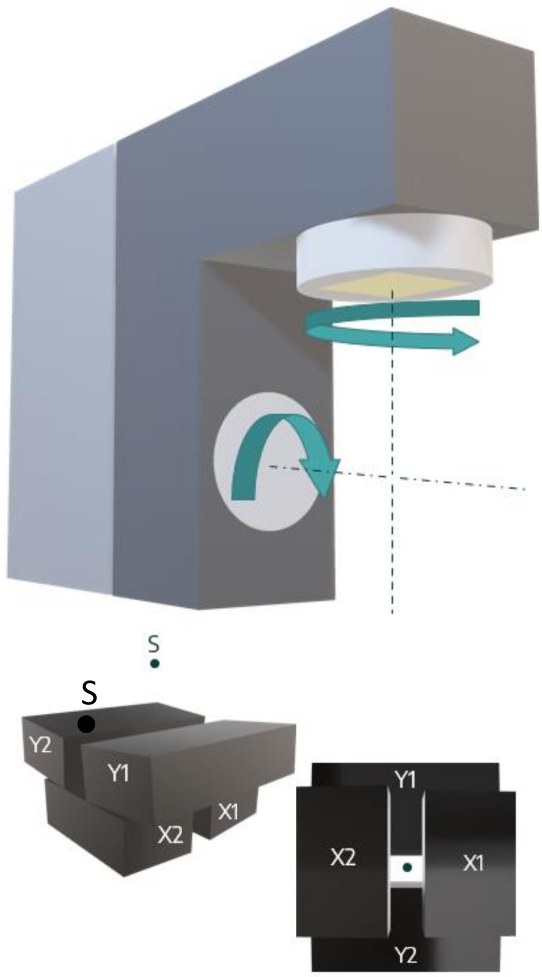

Fig. 1 – Representative model of the LINAC, with the rotation axis of the gantry and of the collimator. Secondary collimator point of view relative to the radiation source (Color online).

Right before starting all the measurements for commissioning, all the equipment should be checked for proper functioning. This includes the detectors that will be used for relative and absolute dose measurements, electronics and connection cables. Finally, the mechanical elements of the water scanning system itself should be checked since this is the base of all movements of the detectors inside the water medium.

Largely, if all these steps are checked, with proper knowledge of the international dosimetric protocols for both large and small fields and a very well-organized schedule, in principle, the measurements of the TPS commissioning should follow a smooth path, before going to the dose calculation algorithm testing.

This paper aims to investigate the uncertainties of relative dose measurements, mostly PDDs and dose profiles, the influence of mechanical components of the LINAC and of the water scanning system on beam modelling, recommending a short workflow prior to performing any kind of dosimetric measurements from the quality assurance program.

2. MATERIALS AND METHODS

The measurements were performed on a TrueBeam STx LINAC, for a photon beam produce by a 6 MeV pre-accelerated electron beam. The measurement system was a BeamScan by PTW-Freiburg, using for the data analysis incorporated software, MEPHISTO. Regarding the detectors, as a field detector a PinPoint 3D (Type 31022) was used and as a reference detector a Semiflex 3D (Type 31021).

Before starting the desired measurements, the Auto-Setup step was performed to take the baselines for beam alignment, beam tilt and phantom rotation. The beam alignment was performed for a 10 cm × 10 cm field size, at 10 cm depth from surface and at 30 cm depth, thus considering the beam tilt. All these steps were performed before a warm-up of the ionisation chamber by irradiating around 1000 MU, or until the current displayed by the electrometer is stable.

The general setup assumes a 100 cm source to surface distance (SSD), the field ionisation chamber positioned parallel with the beam axis [6, 7] and displaced to consider the effective point of measurement (EPOM) for the relative dose measurements. The reference chamber is placed for each individual field size (according to the desired measurement) with at least half of the sensitive volume of the chamber at one of the corners of the field size, so that when performing radial and transversal beam profiles, there should not be any beam attenuation.

For the initial measurements, to determine the measurement uncertainty, a set of 20 PDDs and radial profiles were performed. Analysing these data, a 95% (mean at each point ± 2σ) confidence level was considered as a reference for future comparison. The measurements were performed with a continuous movement of the mechanical system of 10 mm/s for both PDDs and beam profiles.

The following analysis assume either a variation in the speed of displacement of the camber by the beam scanning system, variation of the position of the reference chamber in the beam, closer of further away from the irradiation head, rotation of the gantry, collimator or the jaws, or setting wrong the source to surface distance. All those relative measurements will be compared with the ones of a correct measurement, considering the measurement uncertainty, thus observing the influence of different mechanical aspects of the system on the relative dose measurements.

In the first place, jaws hysteresis was investigated. In this test, jaws were set to the desired field size (2 cm × 2 cm; 10 cm × 10 cm and 20 cm × 20 cm) first time from a larger field and second time from a smaller field. Those measurements were performed at 1.5 cm, 10 cm and 20 cm depth, for both radial and transversal directions, and the analysed parameter was the field size. In order to check the effect of this phenomena, a threshold of ± 1 mm was set, according to the most advanced treatment technique used clinically, and its maximum allowed deviation according to international recommendations [1, 2, 8].

Another element that can affect the dose algorithm modelling is accuracy of the field size. In this manner, for the field sizes stated above, a variation of ± 2 mm was applied to the collimation, and then the resulted measurements were compared to the 95% coverage interval measured in the first part of this work. For this analysis, only the PDDs were of interest since the dose profiles give direct information of the dosimetric field size.

Regarding the gantry tilt, the position of the gantry was set to 0.1, 0.5, 1, 1.5 and 2 degrees and the measurements were performed for all field sizes stated above, at 1.5 cm, 10 cm and 20 cm depth. Besides analysing the field size and dose differences, central axis displacement was also analysed, for both radial and transversal profiles.

The variation of collimator position was also performed and analysed in the same manner as for gantry tilt, both for PDDs and dose profiles.

In the case of SSD variation, the measurements were performed after varying the SSD up to ± 2 mm and analysed by means of fields size.

3. RESULTS AND DISCUSSIONS

By measuring the 20 PDDs and dose profiles the measurement uncertainty was determined. It can be seen that for dose profiles, the measurement uncertainty is dependent on the depth at which the measurement is performed, especially more prominent in the beam region, at shallower depths, due to the contamination electrons and low energy scattered photons from the irradiation head. This is shown in Fig. 2.

In order to establish the optimal mode of measurement, both the 95% ($\pm 2\sigma$) and 99% ($\pm 3\sigma$) coverage interval were compared with the set of measurements performed in different conditions. The approach stated above was necessary in this test since due to the high movement speed of the beam scanning system mechanism, significant noise arises, especially near the depth of maximum dose. This can be seen in Fig. 3. Compared with a 95% coverage interval obtained from the set of 20 PDD measurements, only the very low movement speed continuous scans (0.2 mm/s up to 1 mm/s) and step-by-step measurements with the measurement time per step higher than 0.5 s, could be considered reasonable measurements with low uncertainty. The placement of reference chamber closer to the irradiation head (Ref*1 scan – Fig. 3) and closer to the water surface (Ref*2 scan – Fig. 3) was also evaluated and the results showed that placing the detector closer to the irradiation head and also using a build-up cap, will increase the detected current, thus increasing the sensitivity of measurement of the noise. This is especially useful when no reference chambers with a detection volume larger than 0.1 cm^3 are available.

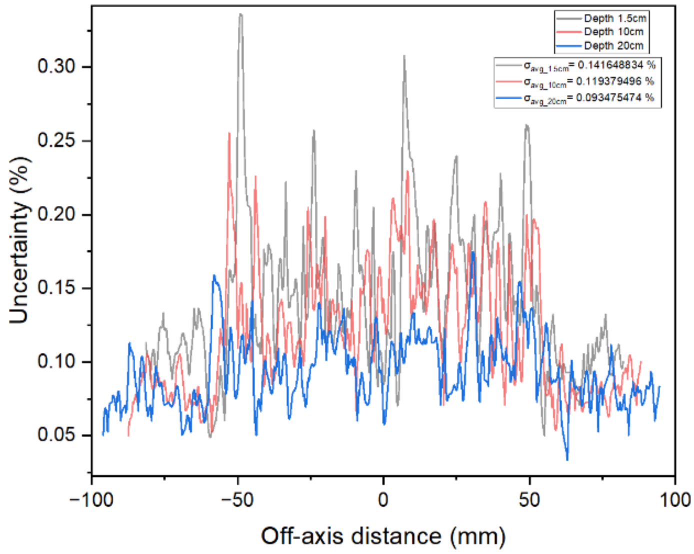

Fig. 2 – Measurement uncertainty in dose profiles at different depths (Color online).

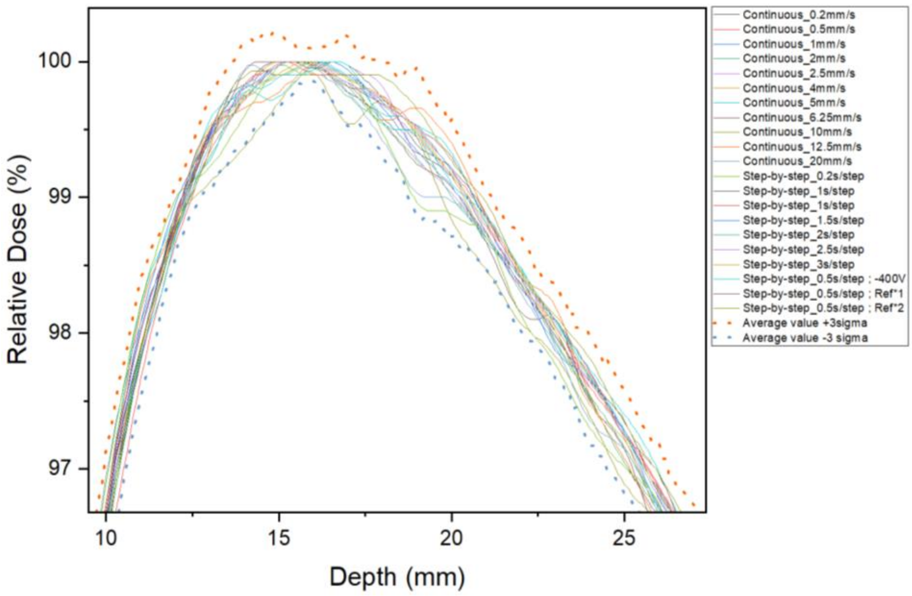

Fig. 3 – Continuous and Step-by-step PDD measurement influences near depth of maximum dose (Color online).

Regarding the jaws hysteresis measurements, it can be seen that for all analyzed field sizes, the jaws that collimate the aperture on the transversal direction have a more prominent effect (Y jaws). This might occur due to the placement of the Y jaws further away from the point at which the measurements are performed, compared with the X jaws. Also, this phenomenon remains constant at all depths at which the measurements were performed, which can be seen from Fig. 4. In absolute value, this phenomenon influences the dosimetric field size up to approximately 0.1–0.2 mm, which, from a relative point of view becomes more and more significant in small field sizes.

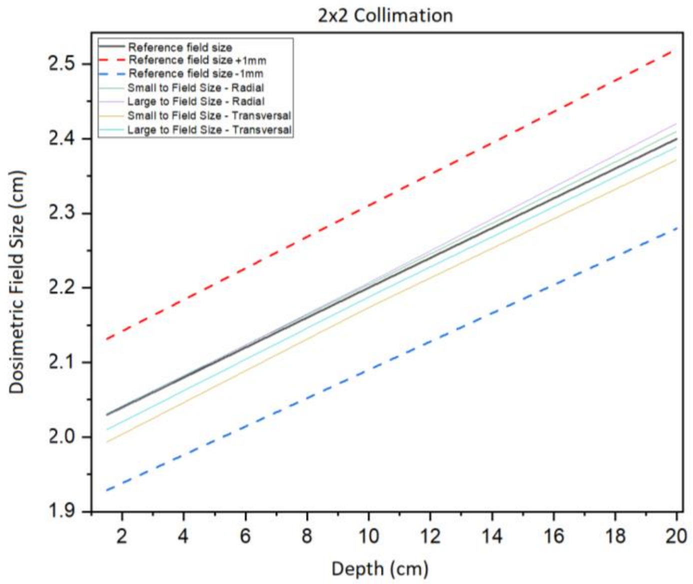

Fig. 4 – Hysteresis influence on dosimetric field size of a 2 cm × 2 cm collimated beam profile (Color online).

Performing PDD measurements with the jaws set to ± 2 mm from the desired field size, has shown that for a 2 × 2 collimation, there is a significant difference of dose at all depths, up to 0.5%, surpassing the 95% interval, while for larger field sizes this surpassing is not present anymore, leaving room for misinterpretation. This test was performed in this manner to consider a possible practical situation in which PDDs are measured prior to dose profiles, thus giving the possibility of continuing the measurements with a faulty field collimation. This result is displayed in Fig. 5.

For the next test, the gantry position was varied from 0.1° up to 2° and PDDs, radial and transversal dose profiles were measured. Regarding the PDDs, the only significant difference is for the smallest field mentioned in this paper, especially for depths deeper than 15–20 cm, leading to a difference of up to 5% at 30 cm depth, as can be seen in Fig. 6. Also, from literature it was stated that for smaller fields than 2 cm × 2 cm the beam inclination or gantry position is a critical element when performing PDD measurements because at deeper depths, if not accounted for, even for a 1° tilt, the detector will start measuring out of field dose, thus reducing the measured dose significantly.

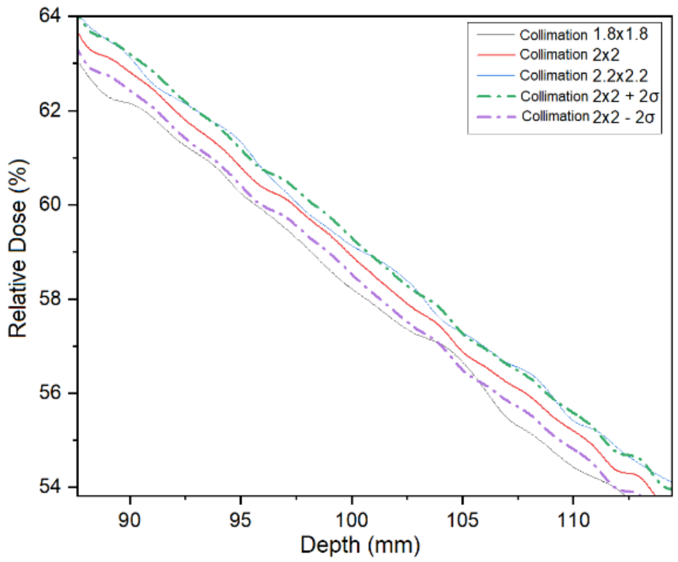

Fig. 5 – Influences of jaw calibration on PDD measurement of a 2 cm × 2 cm collimated beam (Color online).

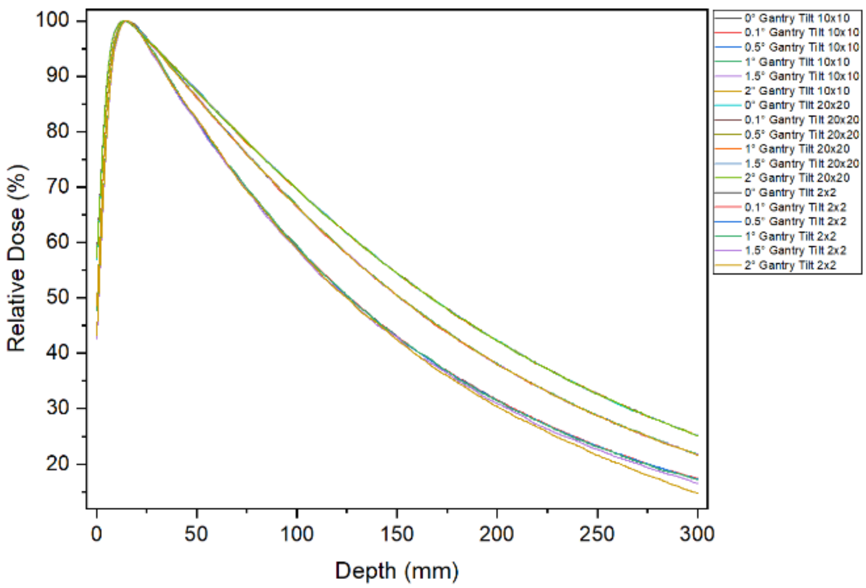

Fig. 6 – Gantry tilt influence on PDD measurements (Color online).

Regarding the dose profiles, the radial dose profile, on the X axis, exhibits a central axis (CAX) shift, that goes up to 8 mm in the case of a 2 cm × 2 cm field, measured at 20 cm depth. In the case of the transversal dose profiles, on the Y axis, this behavior is not distinguishable at all from this point of view due to the direction of scanning and the direction of rotation of the gantry. This behavior is shown in Fig. 7.

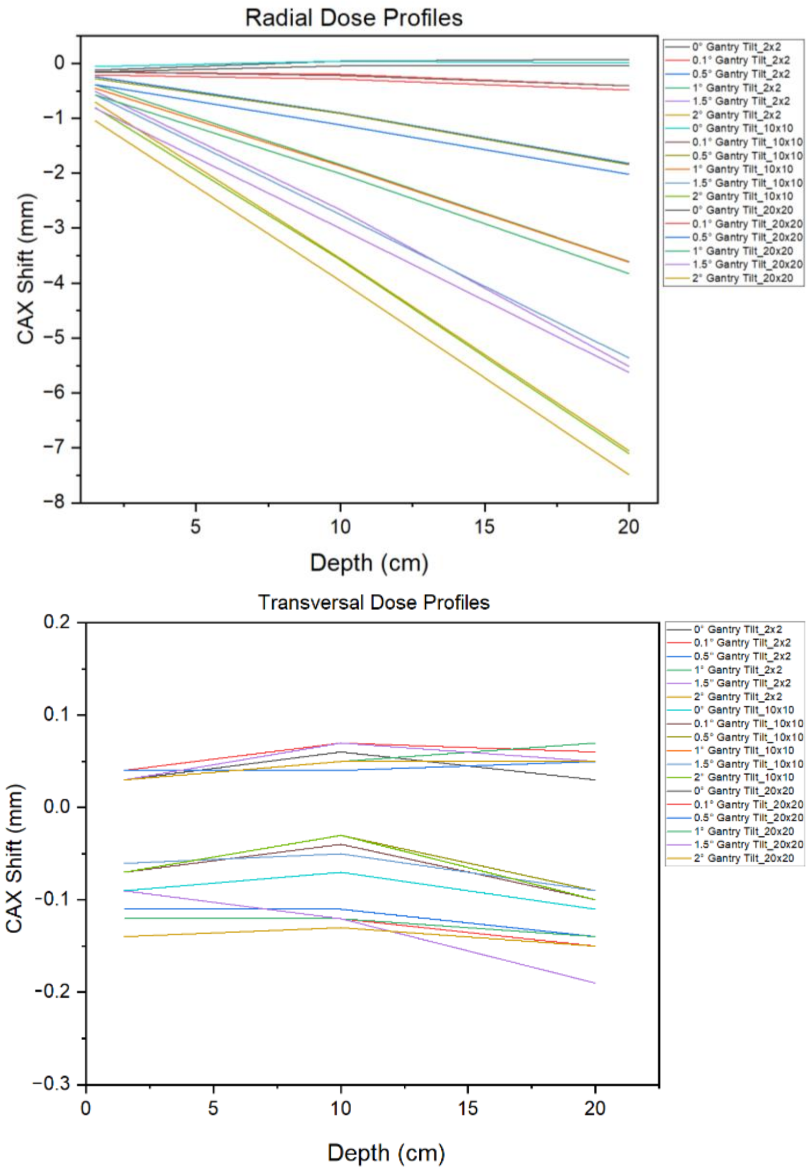

Fig. 7 – CAX shift in radial and transversal dose profiles caused by gantry tilt (Color online).

The same type of test was also performed on the collimator rotation, but no significant changes in the relative dose measurements could be observed.

Another set of measurements were performed by varying the SSD from 100 cm by ± 2 mm but also, no changes were observed compared with a coverage interval of 95% from a normal measurement.

Those last two statements give rise to the possibility of a set of measurements that can be performed under non-reference conditions, thus enhancing the measurement error that can occur.

4. CONCLUSIONS

Considering the result for each individual test stated into this work it can be said in general that significant care should be taken before starting a series of measurements especially if those measurements will serve a as reference. This becomes more significant when the measurements that need to be performed will be the base of dose calculation algorithms, especially on treatment planning systems that do not come with a preconfigures set of measurements. Another important aspect is that the LINAC model and its specific components will give the guidelines for the expected values. For the analyzed TrueBeam ST × LINAC, which was designed to perform stereotactic treatments with required positioning errors of each component less than 1 mm, there are more sophisticated control systems of each independent component in order to achieve the desired tolerance level.

In order to have a reliable set of measurement, one must study very carefully the literature and the international recommendations and what to expect from each individual type of measurement with the available dosimetry equipment.

From a practical perspective, keeping in mind all the details and possible errors that can occur, stated in chapters above, one must perform a mechanical verification of the machine, especially all the components that have a direct influence on the dosimetry, correct or recalibrate accordingly, then to perform the dosimetric measurements as intended. Even though the test might seem quite insignificant at first, such as a mechanical verification of the position of the gantry, collimator with the help of a digital level or a field size verification with the help of a millimetric paper, those elements can add-up and thus in the end increase the error of measurement to an unacceptable level. Such mechanical checks should be also performed on the mechanical components of the beam scanning system, so that a normal operation can be assured.

All these elements should be put together in a quality assurance program so that, independent on the medical physicist that is going to perform the dosimetric measurements for any purpose, the quality of the measurements and the results themselves could be easily and reliably compared to the reference measurements.

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