The LoniMover and accuracy

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Background

When using linear actuators in CT dosimetry, both in sweep or step mode, it is imperative that they are performing well in terms of absolute position in space and time.
Note that linear actuators have been used in radiotherapy dosimetry for ages.

Methods

This technical note uses known accuracy data for components and feedback data from the motor control system to determine an uncertainty budget for The LoniMover system.

The motor control system has a built-in recording function that provides information about two important accuracy parameters during a sweep; speed and RegError as a function of time.
The RegError is the actual difference between present position and target position. The target position is derived from time and target speed internally in the motor control system.

By using the LoniMover QC program (Lonitech AB, Sweden) these parameters can be extracted and used for further analysis of motor accuracy. The software executes a 300 mm sweep at different speeds and samples about 500 data points over each sweep.
Output is a graph of the measurement points as well as the mean and/or standard deviation (STD) of the measurement points. The range of the calculations is limited to 50 - 250 mm to minimize the effect of ramping.

Uncertainties

Table 1. Uncertainty budget

	Value	Unit	Impact
Screw accuracy[1]	0.6	µm/mm	High
Screw repeatability[1]	1.5	µm	Low
Motor position resolution[2]	1.6	µm	Low
Motor speed resolution[2]	0.025	mm/s	Low
Motor RegError resolution[2]	0.4	µm	Low
Motor internal clock frequency stability[1]	40	ppm	Low
Motor internal clock frequency tolerance[1]	30	ppm	Low

Given that the target speed and position have the same precision as the corresponding values in the LoniCT software (speed with one decimal place and position with two decimal places) the screw accuracy together with motor performance has the highest impact on accuracy.
The accuracy of the screw affects the error in the actual distance between two (2) positions compared to target distance.

If the internal clock frequency of the motor can be considered constant and accurate (40 ppm stability and 30 ppm tolerance), reported speed and RegError from the motor control system can also be considered true.

Sweep accuracy

Dose data collected during a sweep is a function of time. If we know the target speed, we can transfer data from the time domain to the position domain and perform further calculations of e.g. FWHM.

The RegError is the actual difference between present position and target position values. The target position is derived from time (considered to be a true value) and target speed (a constant) internally in the motor regulator.
The STD of the RegError can be considered to be the position error at any given position along the sweep and is usually depending of speed.

The true speed of the system is not used in the accuracy evaluation. The only important factor here is the deviation from the target position value at any given point along the sweep.
There is, of course, a strong correlation between actual speed and RegError, but the latter is much easier to use in this context.

If using The LoniMover in sweep mode to determine, for example, FWHM, these calculations are based on two (2) positions calculated from the measured dose profile data.

[1] From manufacturer data sheet
[2] Derived from a combination of manufacturer data and screw lead

The error at these two positions are depending on both the STD of RegError and the screw accuracy, which is a function of distance between them.
We don't know the true distance between these two points but can, with good conscience, use the calculated FWHM value in the error estimation.

The maximum error can then be considered to be approximately the sum of two STDs for RegError (one for each point) and the error resulting from the screw accuracy between these points.

Typical statistics from the LoniMover QC software and measured FWHM for a 160 mm beam in Table 2 below. Figure 1 shows a typical dose distribution for a wide CT-beam. Appendix shows the LoniMover QC software screens.

Table 2. Typical output from the LoniMover QC software for a sweep @ 100 mm/s and typical measured FWHM of a 160 mm CT-beam.

	Value	Unit
Mean speed	99.98	mm/s
STD of RegError	2.2	µm
Measured FWHM	165.4	mm

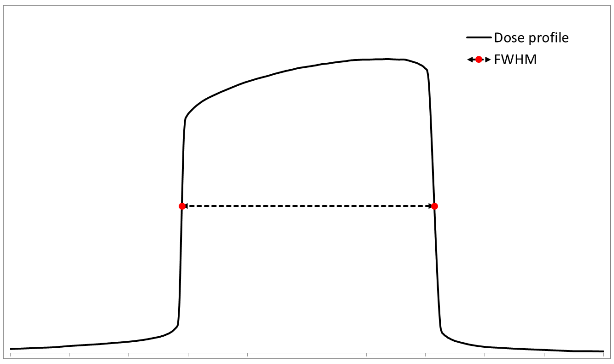

Figure 1. Typical dose distribution for a wide beam in CT.

With data from Table 1 and Table 2 the error in FWHM for a 160 mm CT-beam can be calculated to be approximately:

2 x (STD RegError) + (FWHM) x (Screw accuracy) =
2 x 0,002 mm + 165.4 x 0.0006 mm =
0.004 mm + 0.10 mm = **0.104 mm (0.6 ‰)**

Please note that the biggest contribution to the error originates from the screw's accuracy which is dependent on measured FWHM and that STD RegError is considered to be constant at given speed.

The screw accuracy is a tabulated maximum value and true accuracy is probably better. For this note we apply the "worst case scenario" principle and use the tabulated value.

For measured FWHMs of smaller beam widths the error originating from screw accuracy is lower, i.e. for a FWHM of 10 mm the maximum total error is approximately 0.02 mm.

Step accuracy
For static positions, only the error originating from screw accuracy is relevant.
From Table 1 the screw accuracy is 0.0006 mm per displaced mm.

If using The LoniMover to extend the integration length of a 100 mm pencil ionization chamber, according to IEC 60601-2-44 Ed. 3:A1, the distance between positions is 100 mm and the error is then approximately:

100 mm x 0.0006 mm/mm = **0.06 mm (0.6 ‰)**

for each position.

Conclusion
When using The LoniMover in practical situations, the position errors are on the order of 0.05 - 0.1 mm, for both sweep and step mode.
The included LoniMover QC software can be used to monitor system performance over time.

Please note that uncertainties arising from the measuring instrument used in conjunction with The LoniMover are not addressed in this technical note.

Appendix
Screenshots from the LoniMover QC software: