Pre-failure characterization of faulty MLC drivetrains using Trajectory Logs

J. KOWALSKI [1], E. WOLF [1], N. KUMAR [1], D. MOYER [2], B. McGILL [1], M. LAMBA [1], D. IONASCU [1]
1 University of Cincinnati College of Medicine, Cincinnati, OH, USA
2 Lehigh Valley Health Network, Allentown, PA, USA

JULY 12–16 2020 VIRTUAL
JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

INTRODUCTION

Modern linear accelerators rely on the simultaneous movement of numerous multi-leaf collimator (MLC) elements (leaves) for accurate dose delivery. During delivery of a modulated field, leaves involved in aperture shaping undergo hundreds of rapid, forceful changes in speed and direction that constantly stress the associated drivetrains and frequently induce failures. The gradual nature of drive-train deterioration and relative insensitivity of current clinical QA practices often result in these service disruptions occurring unexpectedly and causing unnecessarily long treatment delays.

AIM

During all treatment deliveries, Varian linear accelerators consistently record a suite of machine parameters – including MLC leaf positions - in binary files known as trajectory logs.

The primary goal of this project was to develop and validate a set of software tools and a methodology that could leverage this machine data to identify degraded leaf drive-trains prior to interlock activation, thus enabling pre-failure repairs and minimization of overall machine downtime.

METHOD

A program was written in Python which utilized an open-source code base (*Pylinac*) for trajectory log conversion to plain text. Additionally, a set of modules was developed for data manipulation, graphical analysis, and record creation and accessed via a custom graphical user interface (Figure 1) to improve ease of analysis.

An in-house script was used to create a pair of 360° arcs* that would subject MLC leaf drivetrains to sustained, high-stress conditions (maximum speed calls with varying gravitational and frictional effects). This was done to increase the error signal-to-noise ratio in order to improve detection rates.

Technique validation was carried out by replacing random, functioning drive screws with sub-critically degraded variants and identifying the site of replacement with our software in a blind test.

*All testing was conducted on a Varian TrueBeam linear accelerator (v2.5) with a Millenium 120 MLC.

RESULTS

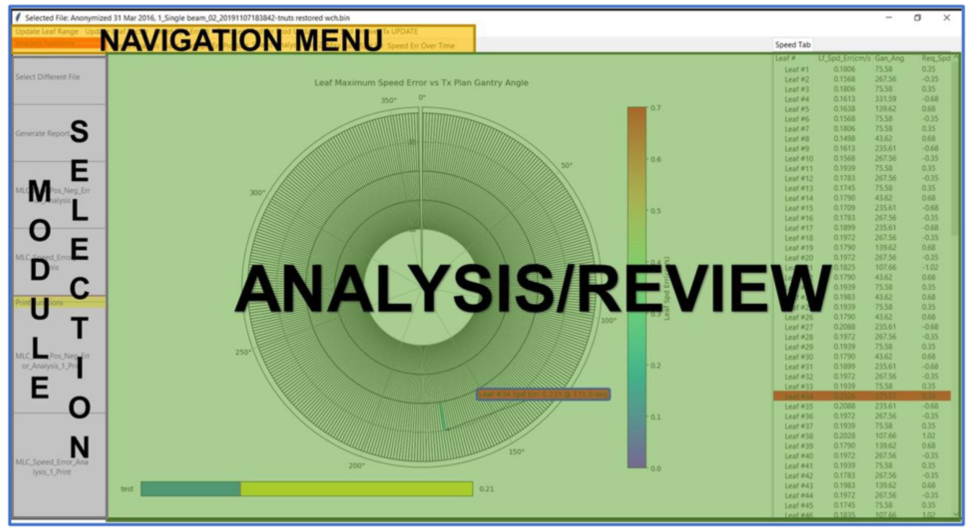

Figure 1 – The Graphical Interface. *Data manipulation, graphics creation, and report generation is controlled from* ***Module Selection****. The user then conducts their review of the data within the* ***Analysis*** *space, leveraging* ***Navigation Menu*** *functions to explore figures in greater detail.*

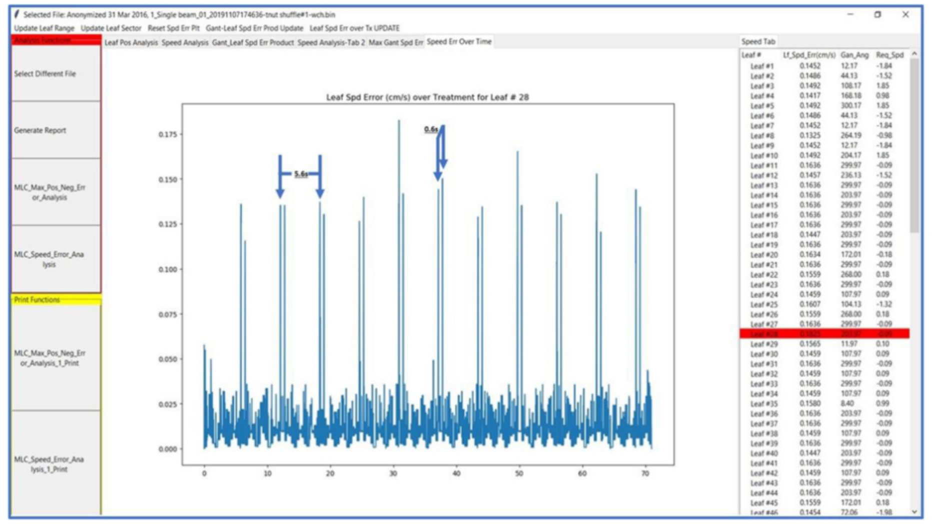

Figure 3 – Speed Error vs time. *Data shown was collected from a user-selected single leaf over a single 360° arc. Temporal spacing between error spike pairs corresponded with leaf motion reversals (~5.6 s) while spacing* <u>*within*</u> *spike pairs correlated with control point spacing (~0.6s).*

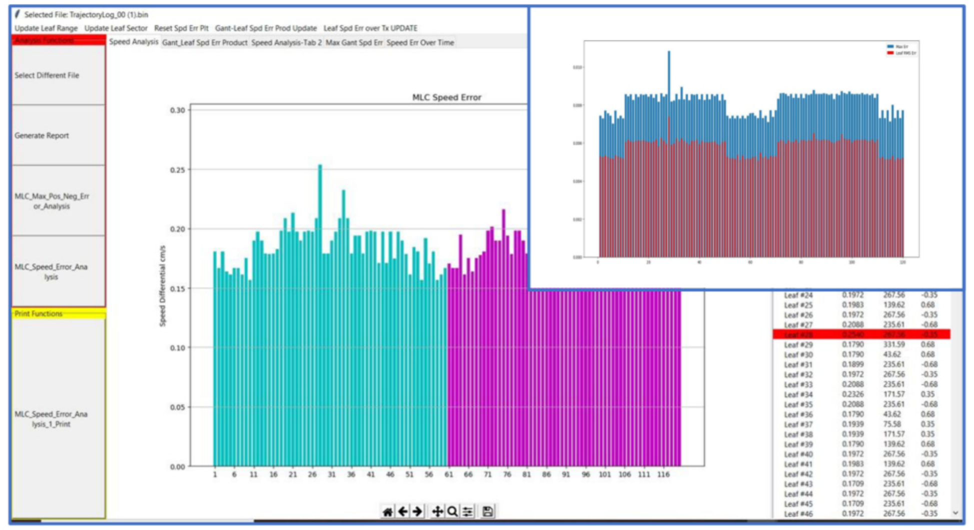

Figure 5 – Maximum Speed Error by Bank (*inset:* Maximum Position/RMS Error in blue/red). *Collimator-wide speed and position error data from a representative test arc clearly identifies the faulty drive-train. The development of multiple metrics was primarily motivated by a desire to separate singular events from developing trends.*

Arc number	Maximum Leaf Speed Error [$\frac{cm}{s}$] @ Gantry Angle [°]	Max Leaf Position Error [cm] (Interlock = 0.25cm)	Leaf Position Error RMS [cm]	Leaf
1a	0.1835 @ 204°	**0.0108**	.00723	A28
1b	0.2540 @ 267.6°	**0.01084**	0.0074	A28
2	1.5752 @ 254.3°	**0.032**	0.0086	A12
3	0.2657	0.0087 [1]	0.0062 [1]	A38
4a	0.2024 @ 72.1°	**0.0200**	0.0075	A24
4b	0.2757 @ 43.6°	**0.0497**	0.0091	A24
4c	0.1914 @ 43.9°	**0.0143**	0.0075	A24
4d	0.2757 @ 43.6°	**0.0736**	0.0115	A24
4e	0.1914 @ 43.0°	**0.0612**	0.0104	A24

Figure 2 – Leaf speed and position error data *collected from a series of test arcs delivered with randomly placed, degraded drive screws ("t-nut") installed. Log analysis conducted with our software revealed clear separation in error magnitudes between the modified drivetrain and the rest of the bank in all arcs (15-20% above baseline), up to 95% below the interlock threshold.*

[1] *non-global maximum*

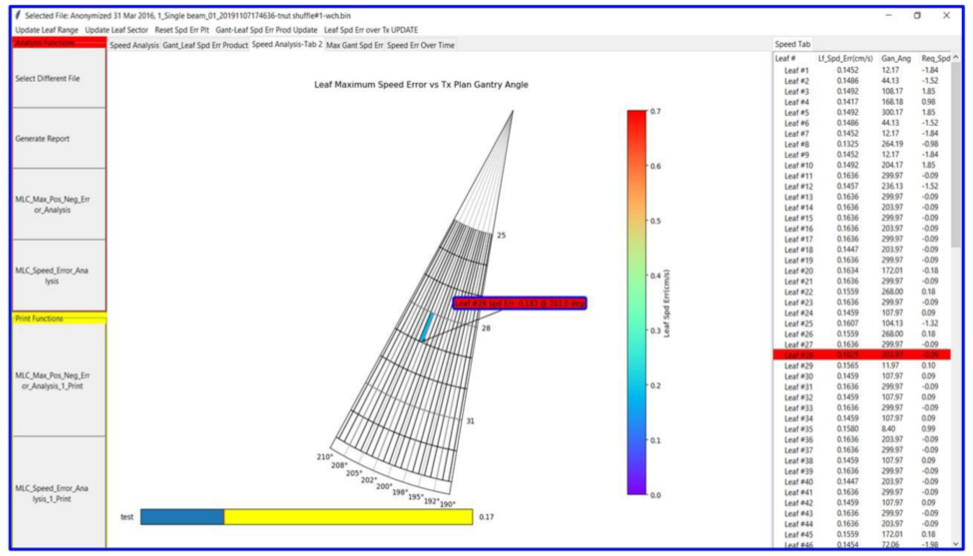

Figure 4 – Polar plot of maximum MLC speed error as a function of gantry angle. *The software allows users to quickly spot global error trends, and then drill-down as necessary with sub-arc and MLC subset views. Flexible thresholding further simplifies the process of outlier identification.*

CONCLUSIONS

Our testing methodology demonstrated that MLC position and velocity deviations can serve as reliable indicators of leaf drive-train wear at levels far below interlock thresholds. This project also demonstrates the need for an amplification mechanism (stress to the drivetrain) in order to achieve consistent detection.

Review of position and velocity deviations as a function of time revealed strong correlation with moments in which the motion of a given leaf was reversed, suggesting that rapid, back-and-forth cycling of leaves at high speeds may result in even clearer differentiation between functioning and degraded drivetrains over shorter timespans than were achieved with the techniques employed here.

CONTACT INFORMATION

Please direct all inquiries to kowalsjp@mail.uc.edu.