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An alternative effective method for verifying the multileaf collimator leaves speed by using a digital-video imaging system

Ing-Ming Hwang [a], Jay Wu [b], Keh-Shih Chuang [c], Hueisch-Jy Ding [d,*]

[a] Department of Medical Imaging & Radiology, Shu Zen College of Medicine and Management, Kaohsiung, Taiwan, ROC
[b] Institute of Radiological Science, Central Taiwan University of Science and Technology, Taichung, Taiwan, ROC
[c] Department of Biomedical Engineering and Environmental Sciences, National Tsing-Hua University, Hsin-Chu, Taiwan, ROC
[d] Department of Medical Imaging & Radiological Sciences, I-Shou University, No. 8, Yida Rd., Yanchao Township, Kaohsiung, Taiwan, ROC

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ABSTRACT

We present an alternative effective method for verifying the multileaf collimator (MLC) leaves speed using a digital-video imaging system in daily dynamic conformal radiation therapy (DCRT) and intensity-modulation radiation therapy (IMRT) in achieving increased convenience and shorter treatment times. The horizontal leaves speed measured was within 1.76–2.08 cm/s. The mean full range of traveling time was 20 s. The initial speed-up time was within 1.5–2.0 s, and the slowing-down time was within 2.0–2.5 s. Due to gravity the maximum speed-up effect in the X1 bank was +0.10 cm/s, but the lagging effect in the X2 bank was −0.20 cm/s. This technique offered an alternative method with electronic portal imaging device (EPID), charged coupled device (CCD) or a light field for the measurement of MLC leaves speed. When time taken on the linac was kept to a minimum, the image could be processed off-line.

1. Introduction

Since the development of intensity-modulated radiation therapy and the computer-controlled multileaf collimator system became dynamic, radiation therapy has been launched into the dynamic millennium. The dynamic multileaf collimator "sliding window" technique was one of the methods used to deliver the modulated intensity distributions. To minimize delivery time, it was desirable to move the leaves as quickly as possible. Leaves sequencers typically adjusted each pair of leaves to its maximum speed [1,2].

The use of a dynamic MLC to deliver intensity-modulated beams presents a problem for conventional verification techniques. A study on the use of films for verifying dynamic MLC treatments had been submitted by Bhardwaj et al. [1], Sarkar et al. [3], Chow and Grigorov [4], Chui et al. [5], Wang et al. [6], and Mubata et al. [7], but the task was not only time-consuming but also limited the frequency of use and made patient use impractical. The use of electronic portal image device (EPID) to track MLC leaves during beam delivery has been shown to provide a solution to this problem [8]. Various authors have reported the use of EPID systems as a solution to the problem of dynamic MLC beam verification [8–12] and some have tried to use the kilovoltage-imaging panel equipped on the linac [13].

Due to the limited spatial resolution in the absence of sharp edges, optical distortion, dosimetric non-linearity and fixed-pattern noise, the use of video-based EPID imaging for leaves speed measurement was limited [9,10,14]. Zygmanski et al. [15] proposed that a determination of the maximum leaves speed required DCRT, which resulted in examination of the beam's-eye view (BEV) projections. Evans et al. [8] said that commercially available portal imaging systems could be used to verify dynamic MLC beam delivery and leaves speed with suitable modification.

The stability of leaves speed could affect the intensity profile to be generated. The acceleration and deceleration of the leaves when they moved from one segment to the next might also cause undesirable artifacts in the delivered intensity profile. Thus, to accept the MLC assembly, leaves speed, the maximum speed of leaves and/or carriages should be verified according to Report No. 72 of the AAPM. The individual leaf should move in a continuous and smooth motion over their range of travel. Leaves lagging behind might be an indicator of a problem, which could lead to the failure of MLC, and it should be addressed as soon as possible [2]. They concluded that it was necessary to verify the leaves speed both as the parts of a pretreatment patient and as periodic linear accelerator quality assurance (QA) [9].

According to the Multileaf Collimator System Manual (Siemens Medical System, Inc. Oncology Care Systems Group, Concord, CA, USA, 2000) for leaves speed adjustments, it is mentioned to drive

* Corresponding author. Tel.: +886 7 615 1100x7815/7801; fax: +886 7 615 5150.
E-mail address: hujydi@isu.edu.tw (H.-J. Ding).

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the leaves, to monitor them during the process, to verify leaves speed, to adjust leaves, and then to move the leaf one by one to determine whether the speed was acceptable. But it still did not provide any useful method to accurately measure leaves speed.

Digital-video [16,20] and camera images [17] used for linear accelerator quality assurance program and assistant of treatment planning have been used more recently. In this study, an alternative method for quick, efficient and radiation-free leaves speed measurement by using a digital-video image on a Siemens double-focused MLC system in conjunction with a BEAMVIEW (PLUS) EPID was presented and used to measure each leaves speed of the system.

2. Materials and methods

A Siemens PRIMUS linac with double focus MLC system (Siemens Oncology Care Systems, Concord, CA) was used. The Siemens MLC assembly consisted of two banks (X1 and X2) of 29 leaves defining collimation along the *X*-axis, with the center 27 leaves 1 cm wide (at 100 cm isocenter) and the outer leaves at each end 6.5 cm wide. According to the Siemens Linac Acceptance Test Procedure (ATP) document (Siemens Oncology Care Systems, Concord, CA), leaves in each bank could travel from +20 cm to −10 cm over the isocenter [13]. The cross-hair reticule was to be inserted in the accessory holder in slot 1 to determine the actual

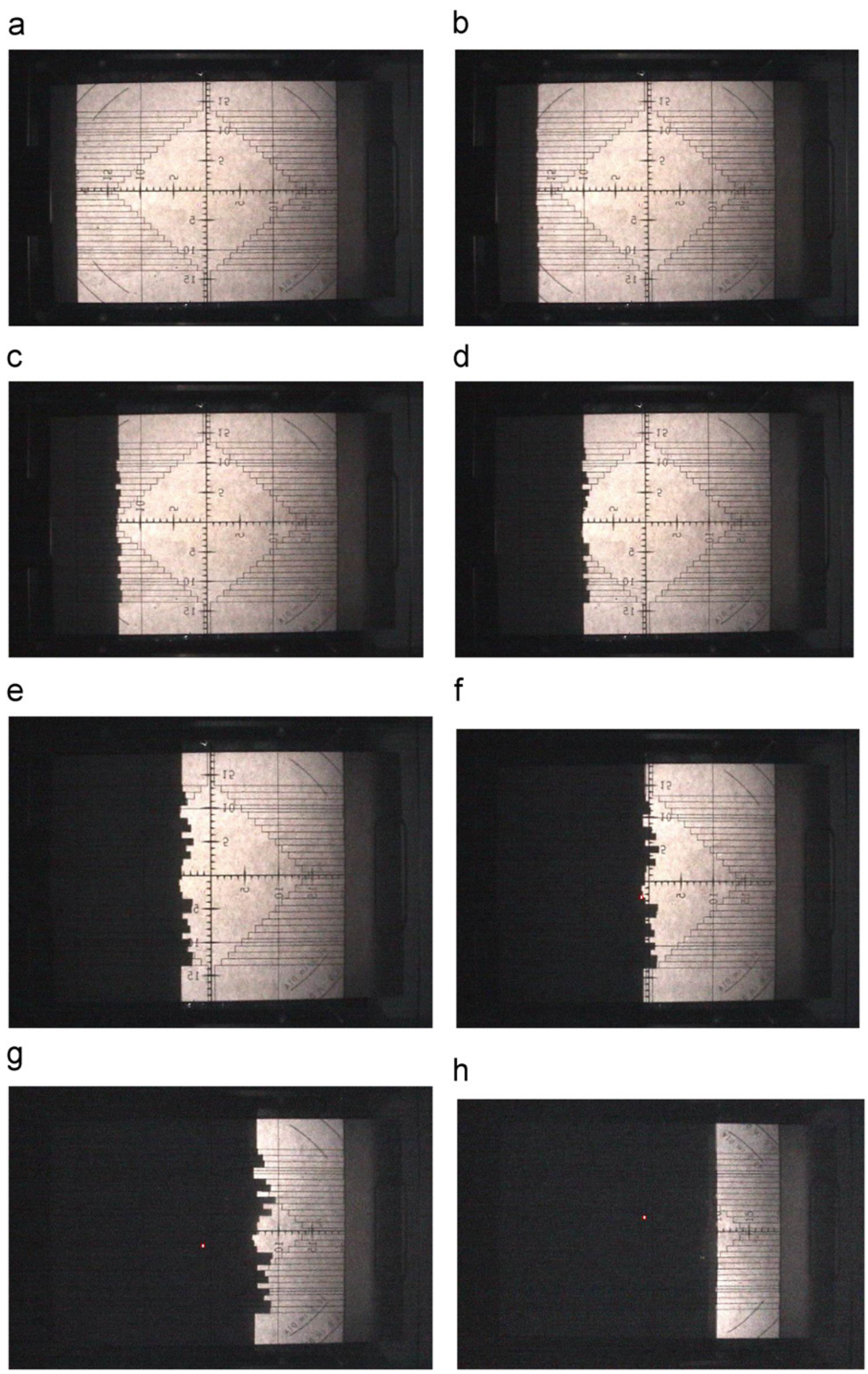

Fig. 1. Images (a)–(h) show the sequence of Simens Primus Linac X1 MLC leaves bank motion images at collimator and gantry angle of 90° with the MLC check tray overlaid onto the leaves shadow.

length scale at isocenter, and the MLC check tray of the linac was inserted into the slot of tray lot to identify each leaf's shadow image.

A "Sony" digital camera (DCR-TRV20) was set up on the raised couch top and aimed at the cross-hairs to take moving images of the MLC leaves bank in standard procedure (SP) mode. The capture speed of the motion picture was 0.01 s/frame and totaled 29 frames for 1 s of recording time. When the record was ready to be made, only one leaves bank was moving and the other bank would be kept fully retracted to avoid collision. The leaves were continuously in motion actuated by the hand control pendent in the treatment room without beam on the linac.

Leaves sag could affect the dose delivery. This component sag was dependent on the gantry and collimator rotation. The effect was more complicated for an MLC system than a standard treatment head. When the gantry was in a non-vertical position, gravity would act upon the leaves depending on the collimator rotation [18]. Considering two "worst case" of orthogonal situations, (a) leaves were aligned with the direction of gravity, and (b) leaves were perpendicular to the direction of gravity [19]. The gantry then was rotated in a horizontal direction (90°) to observe the effect of gravity force on the leaves motion in a vertical direction of each bank (collimator at 0°). This step was to examine the worst situations of leaves motion, and to rotate the collimator 90° to evaluate the horizontal direction motion speed of each leaf.

Each frame of the image consisted of 680,000 pixels, with dimensions of approximately 0.5 mm × 0.5 mm for each pixel. The captured digital-video images were then transferred to a Pentium-4 personal computer (1.4 GHz processor, 512 MB RAM, and 40 GB hard disk) running the Windows 2000 Operation System via IEEE 1394 inter-face card. Then, the most standard graphic software, MGI Video Wave 4.0, was used to save the video image in *.avi files. After the video images were loaded, they were analyzed to determine the motion speed of each leaf. For this purpose, we used MATLAB V6.0 (Mathworks Inc., www.mathworks.com) to analyze each image frame. One frame was taken per second and a total of 23 images were used to analyze the speed of each leaf bank with full range traveling.

3. Results

Fig. 1 (a)–(h) shows a series of eight digital-video images acquired during motion of X1 bank, with the MLC check tray overlaid onto the leaves shadow.

The speeds of both bank leaves were analyzed and are shown in Table 1. In column 2, X1 bank leaves were shown to move vertically downward. Data in column 3 showed that the bank moved horizontally from the right to left side (i.e. from couch to gantry side) at collimator 90°. Column 4 showed the speed-up effect of gravity force on X1 bank by subtracting the data in column 3 from column 2. The speed of X2 bank is shown in columns 5 and 6, and the lagging effects are shown in column 7. According to Table 1, the horizontal direction moving speed is within 1.76 (X1 bank, No. 19) to 2.05 (X2 bank, No. 10) cm/s. Leaves speed did not exceed any of the cases reviewed [14]. The speed-up effect of gravity force X1 bank leaves was within –0.04 (leaves No. 27) to 0.10 (leaves Nos. 6 and 19) cm/s. The lagging effects on X2 bank leaves were within –0.05 (leaves Nos. 9, 11 and 20) to −0.20 (leaves No. 1) cm/s.

Fig. 2 shows the analyzed result of the X1 bank leaves motion downward at collimator angle 0° (dashed line), and horizontally at collimator angle 90° (solid line). In this figure, the speeding-up effect of the gravity was clearly observed.

Table 1
The leaves speed in cm/s of both X1 and X2 banks. Column no. 2 indicated the X1 bank leaves move vertically upward. Column no. 3 showed that the bank moved horizontally from couch to gantry side when the collimator angle was at 90°. Column 4 shows the speed-up effect of gravity of X1 bank (subtracted the data in column no. 3 from column no. 2). The speed of X2 bank (column nos. 5,6) and lagging effect are shown in column no. 7.

Speed leaves no.	Coll. 0° X1 bank (↓)	Coll. 90° X1 bank (←)	X1 speed-up effect	Coll. 0° X2 bank (↑)	Coll. 90° X2 bank (→)	X2 lag effect
1	1.89	1.91	−0.02	1.65	1.85	−0.20
2	2.01	1.97	+0.04	1.76	1.87	−0.11
3	2.03	2.00	+0.03	1.81	1.92	−0.11
4	2.08	2.04	+0.04	1.83	1.94	−0.11
5	2.02	1.97	+0.05	1.73	1.83	−0.10
6	1.93	1.83	+0.10	1.73	1.83	−0.10
7	1.93	1.95	−0.02	1.88	1.96	−0.12
8	1.95	1.95	+0.00	1.95	2.01	−0.06
9	1.87	1.86	+0.01	1.84	1.89	−0.05
10	2.00	1.98	+0.02	1.96	2.05	−0.09
11	2.04	2.02	+0.02	1.87	1.92	−0.05
12	2.06	2.02	+0.04	1.93	2.02	−0.09
13	1.93	1.92	+0.01	1.79	1.89	−0.10
14	2.04	2.00	+0.02	1.79	1.88	−0.09
15	1.91	1.92	−0.01	1.76	1.88	−0.12
16	1.98	1.96	+0.02	1.74	1.81	−0.07
17	2.02	1.99	+0.03	1.76	1.83	−0.07
18	2.07	2.04	+0.03	1.76	1.87	−0.11
19	1.86	1.76	+0.10	1.95	2.02	−0.07
20	1.82	1.80	+0.02	1.93	1.98	−0.05
21	1.95	1.92	+0.03	1.78	1.87	−0.09
22	1.94	1.93	+0.01	1.85	1.94	−0.09
23	1.87	1.87	+0.00	1.89	1.97	−0.08
24	2.04	2.00	+0.04	1.80	1.87	−0.07
25	2.04	2.00	+0.04	1.92	1.98	−0.06
26	1.99	1.94	+0.05	1.86	1.92	−0.06
27	1.81	1.85	−0.04	1.92	1.98	−0.06
28	1.92	1.89	+0.03	1.91	1.98	−0.07
29	1.78	1.81	−0.03	1.65	1.82	−0.17

Fig. 3 shows the speed variation of both maximum and minimum speed leaves of X1 bank during the traveling period. Fig. 3(a) shows the curve of X1 bank moving downward vertically to the ground, and the same bank moving horizontally from the couch to gantry side is shown in Fig. 3(b).

Fig. 4 shows the analyzed result of the X2 bank leaves motion upward at collimator angle 0° (solid line) and horizontally at collimator angle 90° (dashed line). In this figure, the lagging effects of gravity are observed.

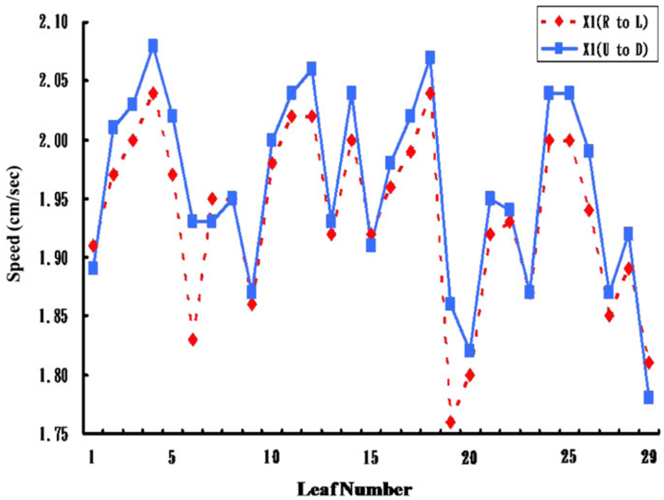

Fig. 2. The analyzed result of the X1 bank leaves motion downward (↓) at collimator angle 0° (dashed line) and horizontal (←) 90° (solid line) at gantry angle at 90° was shown. The speed-up effect of the gravity on X1 bank was observed from the separation of these two curves.

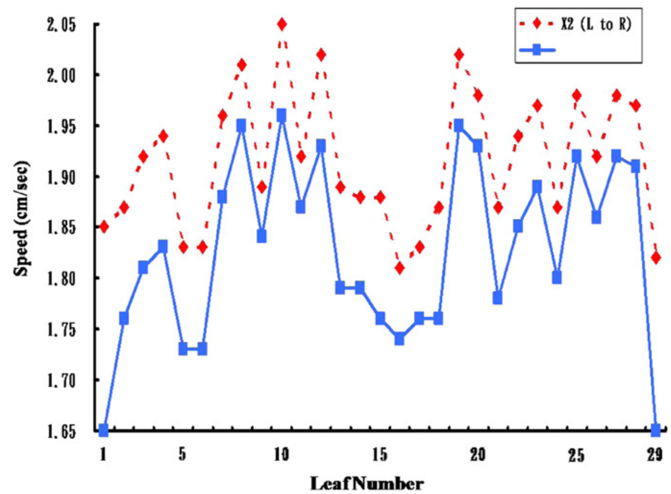

Fig. 4. The analyzed result for the X2 bank leaves motion upward (↑) at collimator angle 0° (solid line), horizontally at collimator angle 90° (→) (dashed line) at gantry angle 90° is shown. In this figure, the lagging effect of gravity was observed.

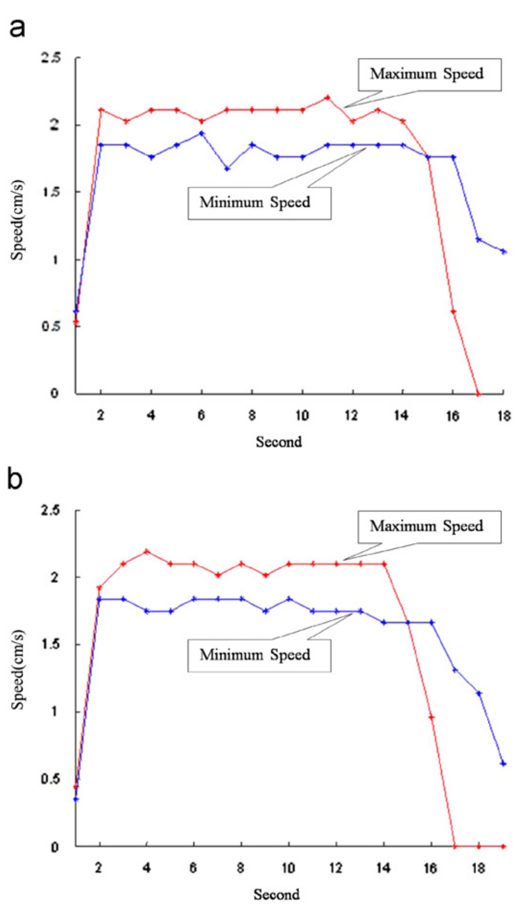

Fig. 3. The velocity variation of the maximum and minimum speed leaves of X1 bank from the initiation to complete stop during the motion period is shown. (a) the curve of X1 bank moved from up to down vertically to the ground at gantry at 90° and collimator at 0°. (b) the same bank moved horizontally from couch to gantry side at gantry at 90° and collimator at 90°.

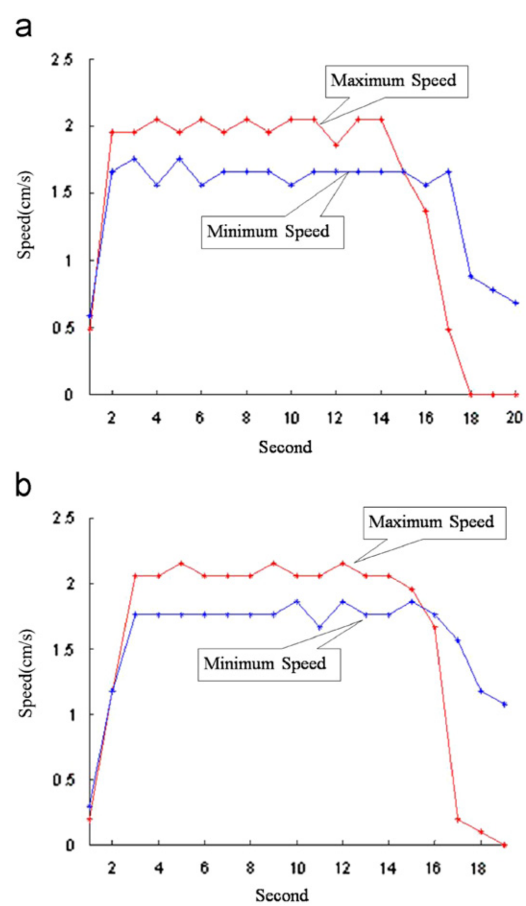

Fig. 5. The velocity variation of the maximum and minimum speed leaves of X2 bank during the motion period is shown. (a) the curve of the X2 bank moved from down to up side against gravity force vertically to the ground at gantry 90° and collimator 0°, and (b) the same bank moved from couch to gantry side horizontally at gantry 90° and collimator 90°.

Fig. 5 shows the speed variation of both maximum and minimum speed leaves of X2 bank during the traveling period. Fig. 5(a) shows the curve of X2 bank moving upward against gravity force vertically at collimator 0°, and Fig. 5(b) shows the same bank moving from couch to gantry side horizontally at collimator 90°.

4. Discussion

The use of MLC in radiotherapy has been shown to have the potential to deliver highly conformal dose distributions. The leaf was usually required to move at the maximum physical speed to minimize the treatment time and transmission dose. MLCs produced by different manufacturers employed different mechanisms for moving the leaves accurately to deliver the prescribed dose. Depending on the design, the speed of the leaves varied between 0.2 and 50 mm/s. In most cases, the leaves moved at a speed of 1–2 cm/s [20]. Our measured data were found within that range. It was essential to define upper speed limited in terms of actual clinical requirements. Through the production of digital-video imaging procedures, quantitative verification of dynamic MLC leaves speed was precise to 1 mm/s. Leaves speed had to be measured to achieve a safe and reliable dose delivery controlled by DCRT and IMRT. A study was conducted to determine the required leaves speed to shape various target volume configurations during complete rotation (at 1 RPM). It showed that a leaves speed of at least 1.5 cm/s at isocenter was needed for the dynamic conformal treatment [17].

The sole purpose of this verification system was to document the evidence that leaves could travel successfully. For the initial commission and performance assessment of a new piece of equipment or for routine QA measurements, more information about the actual trajectories of each MLC leaf was desirable. Also, if prescriptions failed to deliver correctly, it would be useful to know what caused that failure. Knowledge of the actual leaves speed might answer this problem. For routine quality assurance checks, it was desirable to have a simple and quick method to give an overall assessment of the mechanical accuracy of all leaf pairs. The features of this method were that one might be able to assess the results by visual inspection and examine all pairs simultaneously. The method proposed in this paper intends to get the mechanical MLC leaves motion digital-video images for the worst cases at a gantry angle of 90°. This method is possibly the simplest way of ensuring that a beam could deliver the intended fluencies distribution from the planning system under a stable output dose rate.

Leaves that lag behind might be an indicator of a problem, which leads to failure of the MLC and should be addressed as soon as possible. Gravity could potentially cause the leaves to sink onto the lead screws and cause an asymmetric field when leaves are aligned with the direction of gravity. The effect of gravity on the speed of the MLC leaves would be significant, due to wear and tear of the lead screws or the ball bearing with mounted carriages. The leaves were worn significantly under leaves perpendicular to the direction of gravity. In case of the inaccuracy was occurred between velocity and direction of leaves [19]. This could lead to large discrepancies in carriage positioning at gantry angles of 90° and 270° due to backlash.

The gravitational effect could be monitored and compared easily by taking leaves motion video image mentioned in this paper. The camera was easy to set up and it focused well on the leaves banks shadow, which was projected on the MLC check tray. Time taken on the linac was kept to a minimum while video images could be recorded. The entire test procedures including camera set-up, leaves motion, process and evaluation could be completed in about 10 min. These routine checks could be performed by a therapist every day or only on the days when DMLC was to be used and to provide useful data to convince a service engineer to check and adjust potentiometer resistance to set leaves speeds back to factory default settings.

5. Conclusion

Leaves speeds should be measured to achieve safe and reliable dynamic dose delivery control. The maximum speed of leaves motion should be verified and the individual leaf should move in a continuous smooth motion over their range of travel. It is essential to define the upper speed limits in terms of actual clinical requirements. Visual inspection and confirmation of the MLC leaves speed have been found effective. The procedure outlined here was applicable when the MLC was used in dynamic mode.

This technique has been produced by these groups as a part of their evaluations and commissioning work of routine conformal radiotherapy and intensity-modulation techniques.

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