International Journal of Core Engineering & Management
Volume-6, Issue-12, 2021 ISSN No: 2348-9510

COMMISSIONING AND VALIDATION OF VARIAN TRUEBEAM LINEAR ACCELERATOR FOR HIGH-PRECISION RADIOTHERAPY

Priya Jacob
priyajacobjp@gmail.com

Alex Antony
alexantony99@gmail.com

Abstract

This study aims to commission and validate the Varian TrueBeam linear accelerator for high precision radiotherapy, focusing on the dosimetric characteristics of photon and electron beams, including flattening filter-free (FFF) beams, and comparing them with traditional methods. The TrueBeam system, installed in November 2021, was commissioned for five photon energies (6 MV, 10 MV, 15 MV, 6 MV FFF, 10 MV FFF) and four electron energies (6 MeV, 9 MeV, 12 MeV, 15 MeV, 18 MeV, 6 MeV HDTSE). Dosimetry measurements included Percentage Depth Dose (PDD), beam profiles, and output factors using various detectors such as PTW Pin Point chamber, Semiflex 3D CC125, and diode detectors. Data were processed and imported into the Eclipse Treatment Planning System (TPS) for beam modeling using the Anisotropic Analytical Algorithm (AAA) and AcurosXB. The beam analysis criteria of 2 mm at 50% dose were achieved for all fields except the 40x40 cm field, which was within a 3% deviation. Depth difference at maximum dose (Dmax) was within 1 mm, and dose difference at 100 mm and 200 mm depths was less than 1% for all fields. FFF beams exhibited a steeper gradient and lower mean energy compared to conventional beams. The TrueBeam system demonstrated excellent performance and consistency with Varian Representative Beam Data. The integration of FFF beams into a comprehensive quality assurance program is crucial for enhancing treatment precision and patient outcomes. External audits are recommended to verify the correct application of new techniques in clinical settings.

Keywords: Varian TrueBeam Linear Accelerator, High-Precision Radiotherapy, Commissioning, Dosimetry, Flattening Filter Free, Multi-Leaf Collimator , Intensity-Modulated Radiation Therapy, IMRT, Volumetric Modulated Arc Therapy, VMAT, Quality Assurance, Anisotropic Analytical Algorithm.

I. INTRODUCTION

All Linear accelerators, a new type of radiation machine, have made significant progress by introducing new energy techniques in recent years. They can now produce different kinds of radiation beams, some of which don’t require a flattening filter. This innovation has generated significant interest in highlighting their dosimetry characteristics—how they measure radiation doses—and exploring their advantages over traditional methods. Both types of systems use the same basic method to generate radiation beams, but the key difference in the newer technology is that the flattening filter is removed. Traditionally, flat photon beams were used to make monitor unit (MU) calculations easier. However, with the development of Intensity-Modulated Radiation Therapy (IMRT), this flattening process is no longer necessary.In November 2021, the clinic installed a TrueBeam accelerator. This system offers photon energies of 6 MV, 10 MV, 15 MV, 6 MV FFF (Flattening Filter Free), and 10 MV FFF. For electron energies, it provides 6 MeV, 9 MeV, 12 MeV, 15 MeV, 18 MeV, and 6 MeV HDTSE (High Dose Total Skin Electron).

II. METHODS AND MATERIALS

Following acceptance testing, the TrueBeam system was commissioned to operate with five photon energies and four electron energies. The dose rates for 6 MV and 10 MV photon beams ranged from 5 to 600 MU/min, while the 15 MV beams delivered dose rates between 20 and 600 MU/min. The 6 MV FFF beam provided dose rates from 400 to 1,400 MU/min, and the 10 MV FFF beam offered dose rates from 400 to 2,400 MU/min. The system was equipped with the HD120 Multi-Leaf Collimator (MLC).

III. DOSIMETRY MEASUREMENTS

Each photon beam was calibrated to deliver 1 cGy/MU at the depth of maximum dose (dmax), using a standard field size of 10x10 cm^2 and a source-to-skin distance (SSD) of 100 cm. Percentage Depth Dose (PDD) and beam profile data were collected at 100 cm SSD using various detectors, including the PTW Pin Point chamber, Semiflex 3D CC125, and diode detectors within the PTW BeamScan Radiation Field Analyzer. Field sizes measured ranged from 2x2 cm^2 to 40x40 cm^2, including intermediate sizes such as 3x3 cm^2, 4x4 cm^2, 6x6 cm^2, 8x8 cm^2, 12x12 cm^2, 15x15 cm^2, 20x20 cm^2, 25x25 cm^2, 30x30 cm^2, and 35x35 cm^2. For smaller fields (1x1 cm^2 to 5x5 cm^2), pinpoint chambers and diodes were utilized.

We analysed data from all detectors, comparing flat and flattening filter-free beams. Despite the higher resolution of diode measurements, we opted to use data from the Semiflex 3D ionization chamber in our Treatment Planning System (TPS), following Varian's recommendation to use consistent detector types. As field size and depth increased, the PDD measured with pinpoint chambers was approximately 2% lower than those measured with the PTW Semiflex 3D.

TABLE 1.

Energy [MV]	R100 [mm]	R80 [mm]	R50 [mm]	Rx [mm]	Ds [%]	D100 [%]	D200 [%]	Dx [%]	Qi
6.0 MV	14.8	61.06	140.14	49.78	58.86	63.76	34.57	46.94	0.6269
10.0 MV FFF	22.2	76.25	169.67	63.41	42.83	71.11	42.92	55.26	0.7047
10.0 MV	23.4	82.17	184.5	68.25	35.06	73.79	46.6	58.69	0.7401
15.0 MV	30.2	91.14	200.09	76.4	31.72	77.21	50.02	62.17	0.7607
6.0 MV FFF	14.1	64.05	150.57	51.88	54.05	66.09	37.88	50.16	0.6662

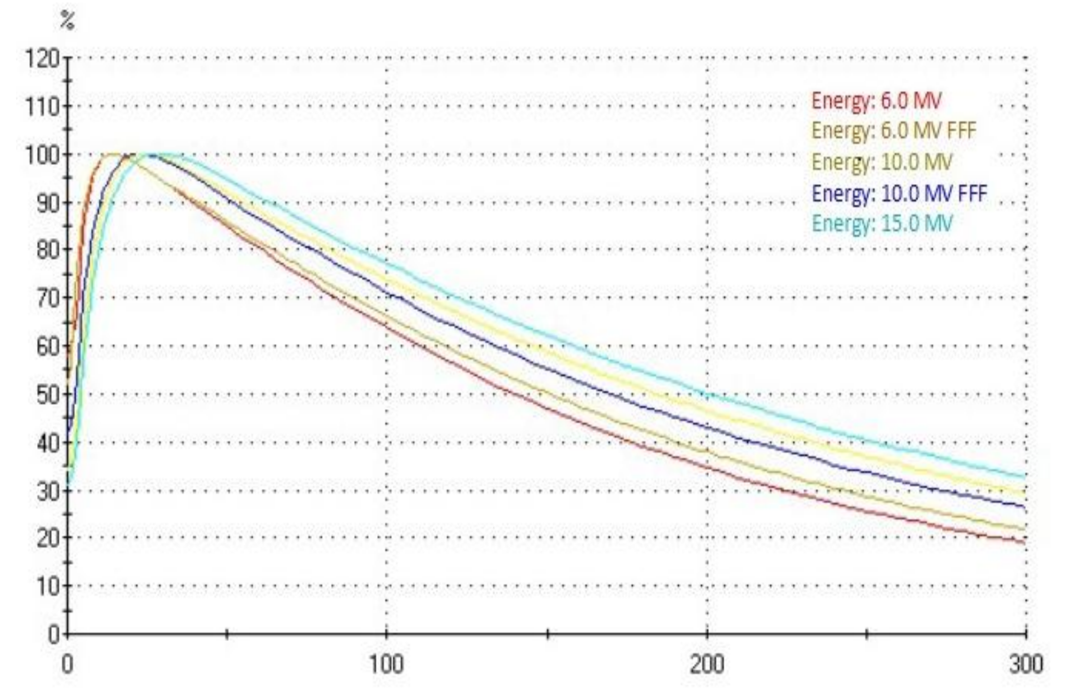

FIG 1. PDD of a 10x10 cm2 field for 6 MV and 6 MV FFF,10 MV,10 MV FFF &15MV (b) profiles measured with different detectors

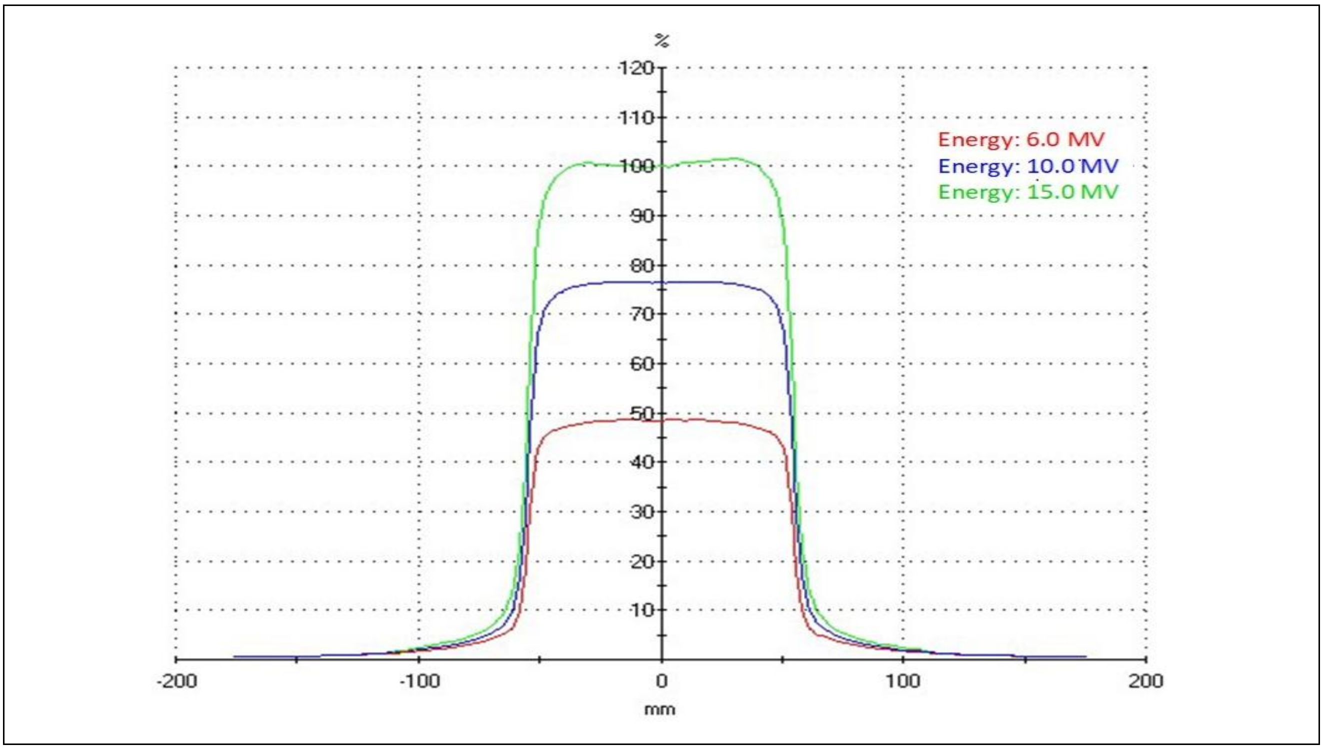

FIG 2. profiles measured semiflex 3D detector-6MV,10MV&15MV

TABLE 2.

Energy [MV]	CAX DV. [mm]	Field Size [cm]	Pen.Left [mm]	Dmax [%]	Dmin [%]	Flatness [%]	Symmetry [%]	Filed Size at SID [cm]
6	-0.01	10.995	6.33	100.32	95.59	104.95	0.02	9.995
10	0.08	10.987	6.95	100.28	96.34	104.09	0.05	9.988
15	0.05	10.997	7.1	101.49	97.24	104.37	0.3	9.998

The PDD curves FFF beams exhibit a steeper gradient compared to conventional beams, and their mean energy is lower due to the absence of the flattening filter. As energy increases, the depth of maximum dose (Dmax) shifts deeper, but for 6 MV FFF beams, Dmax is lower than for standard 6 MV beams. Beam profiles were measured in the inline, crossline, and diagonal directions at various depths, including Dmax, 5 cm, 10 cm, 20 cm, and 30 cm. Output factors for FFF beams increase less with field size due to reduced secondary radiation reaching the jaws, resulting in lower electron contamination. Measurements were conducted using PTW Semiflex 3D ionization chambers, PinPoint chambers, and Microsilicon diode detectors, with all values compared to ensure accuracy and consistency

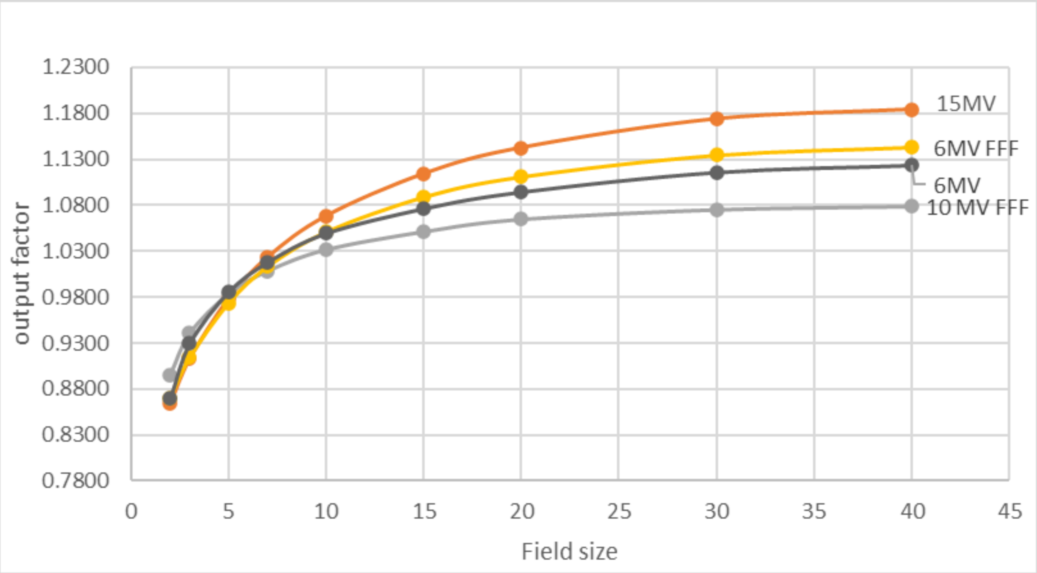

FIG 3. Output factors for energies 6MV, 6MV FFF, 10 MV FFF and 15MV

The transmission factors for the MLC HD 120-STD were measured using a Farmer chamber in a water phantom with an isocentric setup at a depth of 10 cm. The MLC transmission factor and dosimetric leaf gap were found to be lower for FFF beams compared to the flattened beams of the same energy, as the mean energy is lower in FFF beams. Dynamic wedge factors were also measured for QA purposes, although this data is not needed for the Eclipse TPS.

TABLE 3. MLC transmission factor and dosimetry leaf gap

Energy	6X	10X	15X	6X FFF	10X FFF
MLC TF	0.013	0.016	0.015	0.008	0.012
DLG (mm)	0.3122	0.3868	0.4093	0.2907	0.2768

IV. BEAM MODELING AND EVALUATION OF THE MODEL

All the collected data, including percentage depth dose (PDD) curves, profiles, diagonal profiles, and output factors, were processed, smoothed, and thoroughly evaluated before being imported into the Eclipse Treatment Planning System (TPS). This same data set was utilized for both the Anisotropic Analytical Algorithm (AAA) version 16.1 and the AcurosXB dose calculation algorithm.

The beam modeling process for all energies was executed accurately. Notably, for FFF fields, a lower gamma error was observed. This is due to the fact that the virtual source model, which accounts for secondary radiation in flattened beams, is not a factor in FFF beams due to the absence of the flattening filter.

Beam analysis criteria, including a 2 mm tolerance at the 50% dose level, were met for all field sizes except for the 40x40 cm field, which was within a 3% deviation. The depth difference at the point of maximum dose (Dmax) was within 1 mm across all fields, and the dose difference at depths of 100 mm and 200 mm was found to be less than 1% for all fields.

The average gamma error in the depth dose curves, both before and after Dmax, within the field penumbra, and outside the field, was consistently less than 1. Additionally, the gamma value was always below 2, confirming compliance with the 3 mm/3% acceptance criteria.

The success of beam modeling is influenced by several factors, including the quality of the imported beam data, the algorithm being used for modeling, and the virtual source size. Overall, the acceptance criteria for compatibility between measured and calculated data were achieved.

V. VERIFICATION

To ensure the TPS performs accurate calculations, various tests were conducted. These included basic verifications of PDD and profiles, along with dose calculations for dynamic fields such as IMRT (Intensity-Modulated Radiation Therapy) and VMAT (Volumetric Modulated Arc Therapy). The verification process involved comparing the TPS-calculated dose values with actual measured doses.

A key aspect of validating the algorithms was their ability to accurately calculate PDDs for open fields, a test that was performed for different field sizes. Additionally, isodose distributions in both the inline and crossline directions for open fields were evaluated, with differences found to be less than 1%. Output factors, critical for Monitor Unit (MU) calculations, were also compared, showing results consistently within a 1% margin.

For IMRT and VMAT, where treatment delivery involves continuous MLC movements, specialized MLC tests were verified using Varian's test package. This included tests for MLC velocity, transmission factors, and positioning accuracy. The velocity test ensures that the MLC controllers are functioning correctly, as each MLC pair moves at different speeds, creating a stripe-shaped distribution. The comparison between these movements and real measurements provided additional validation for the IMRT system.

The "picket fence" test, named after the stripe-like pattern of the isodoses, was conducted at various gantry angles to assess MLC positioning during IMRT treatments. The "chair shape" test was used to evaluate the MLC transmission factor and dosimetric leaf gap (DLG). Before treating the first patients, an end-to-end test was completed after commissioning the TPS. Plans with different field setups, energies, and techniques—including IMRT and VMAT—were measured using portal dosimetry and the Mobius 3D software.

Daily quality assurance (QA) checks for the output, beam geometry, MLC positioning, and reproducibility are performed using the Isocal Phantom with the Machine Performance Check (MPC) module and also with Sun Nuclear Daily QA™ 3 phantom Our TrueBeam system has proven to be very stable, with output trends remaining consistently linear

VI. CONCLUSIONS

Commissioning is a highly intricate process that demands skilled and well-trained resources. The commissioning and validation of the Varian TrueBeam linear accelerator have confirmed its outstanding performance and reliability for high-precision radiotherapy. The system's capability to deliver accurate and consistent dosimetric data across various photon and electron energies, including FFF beams, highlights its versatility and effectiveness in clinical applications. The integration of FFF beams, which provide higher dose rates and improved treatment efficiency, is particularly significant for enhancing patient throughput and reducing treatment times.

The successful deployment of the TrueBeam system facilitates the adoption of advanced radiotherapy techniques such as Intensity-Modulated Radiation Therapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT). These techniques benefit from the system's precise dose delivery, leading to better tumor targeting and sparing of healthy tissues.

To ensure the highest standards of patient care, continuous quality assurance and regular external audits are recommended. These practices will help verify the correct implementation of new techniques and maintain the accuracy and safety of radiotherapy treatments. Overall, the TrueBeam system represents a major advancement in radiotherapy technology, offering enhanced treatment precision and improved patient outcomes

REFERENCES

1. P. J. Biggs, "AAPM's TG-51 protocol for clinical reference dosimetry of high-energy photon and electron beams," *Med. Phys.*, vol. 26, no. 10, pp. 1847-1870, Oct. 1999.

2. F. M. Khan and J. P. Gibbons, *The Physics of Radiation Therapy*, 5th ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2014.

3. IAEA, "Absorbed Dose Determination in External Beam Radiotherapy: An International Code of Practice for Dosimetry Based on Standards of Absorbed Dose to Water," IAEA, Vienna, Austria, Tech. Rep. Series No. 398, 2000.

4. AAPM Task Group 106, "Accelerator beam data commissioning equipment and procedures," *Med. Phys.*, vol. 35, no. 9, pp. 4186-4215, Sep. 2008.

5. J. V. Dyk, *The Modern Technology of Radiation Oncology: A Compendium for Medical Physicists and Radiation Oncologists*, vol. 2. Madison, WI: Medical Physics Publishing, 2005.

6. D. W. O. Rogers, B. A. Faddegon, G. X. Ding, C. M. Ma, J. We, and T. R. Mackie, "BEAM: A Monte Carlo code to simulate radiotherapy treatment units," *Med. Phys.*, vol. 22, no. 5, pp. 503-524, May 1995.

7. A. E. Nahum and J. L. Orton, "The quality of high-energy photon beams," *Phys. Med. Biol.*, vol. 24, no. 2, pp. 225-246, Mar. 1979.

8. J. P. Gibbons, "Monitor unit calculations for external photon and electron beams," in *The Modern Technology of Radiation Oncology*, J. V. Dyk, Ed. Madison, WI: Medical Physics Publishing, 1999, pp. 353-394.

9. A. Brahme, "Dosimetric precision requirements in radiation therapy," *Acta Radiol. Oncol.*, vol. 23, no. 5, pp. 379-391, Sep. 1984.

10. M. J. Murphy, "The importance of dosimetric accuracy in stereotactic radiosurgery," *Med. Phys.*, vol. 29, no. 10, pp. 2359-2370, Oct. 2002.

11. J. M. Moran, M. J. Radawski, and J. F. Fraass, "A dose-volume histogram analysis tool for radiation therapy treatment planning," *Int. J. Radiat. Oncol. Biol. Phys.*, vol. 41, no. 2, pp. 409-417, Jan. 1998.

12. M. L. Kessler, "Image registration and data fusion in radiation therapy," *Br. J. Radiol.*, vol. 79, Spec. No. 1, pp. S99-S108, Jan. 2006.