STANDARD AND MICROBEAM LINATRONS BY VAREX IMAGING CORPORATION

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Abstract

At Varex Imaging Corporation, High Energy Systems (HES) Department staff with help and support of our Production and Imaging groups continue adding new features to our LINATRON™ linear accelerator (LINAC) systems and transitioning new developments to our products. HES is at the final stages of productizing our usual LINATRONs, equipped with our new, in-house developed and built Accelerator Beam Centerlines (ABC). The products we offer today match or exceed the older products specifications, which were offered before we established our own ABC development and production line. In addition, we are making good progress on our new Microbeam LINATRON™ (MBL) systems, and we present the latest results on our MBL production prototypes. Our 6 MeV MBL6 prototype has been packaged, and it is under extensive testing and qualification process, getting ready for demonstration to our customers and for delivery. The similar packaging of our 3 MeV LINATRON systems offers option of Ultra Low Leakage (ULL) shielding and an option of integrated X-Ray Head packaging for both 3 MeV and 9 MeV, for our security LINACs and for NDT LINACs under development.

VAREX LINATRON™ FAMILY

Introduction

Our standard line of products, which includes LINATRON™ systems for NDT and security screening is well-known in the industry [1]. All the systems installed worldwide are operating in energy range from 1 MeV to 9 MeV (many more than 1000 units) and use the predecessor Beam Centerlines (BCL), which were equipped and operated exclusively with a diode electron gun. Compared to a triode electron gun, a diode version has its advantages and disadvantages, and the industry mostly prefer triode e-gun configuration for a better control of such e-gun and LINAC performance. In addition, the BCL operates at high electron gun voltage at approximately 30 kV while a proprietary electron gun design is used. Hence, designing and building Accelerator Beam Centerline (ABC) drop-in replacements for such BCLs presented a special challenge for High Energy System team. It was important to ensure that we have ABC for field replacements with a different, commercially available and lower voltage electron gun and having a newly developed to Varex ABC RF structure design, which meets or exceeds the parameters of the predecessor units. We selected a commercially available triode electron gun operating at less than 15 kV and modified its design to a diode configuration with intent of using both versions - a diode version for the drop-in replacements and a triode version for most of the new LINACs, which may provide the new models with many new capabilities [2].

Traditional LINATRON Linear Accelerators

Figure 1: “Standard” LINATRON packaging for NDT and Security, used with separate blocks - modulator and chiller, BCL equipped with diode e-gun.

Figure 2: LINATRON ”Tower” packaging with Solid State Modulator (SSM) used on a 6 MeV Mi6SSM (diode e-gun), but now the similar packaging is used for Mi6SSM-T (triode e-gun), both are subsystems for security screening systems.

Before we introduced new designs, two primary configurations were used in Varex LINATRONS. A “standard” classic configuration of the X-ray head shown in Fig. 1 operated with a line modulator block, chiller block, and control console. The other, newer “tower” design (Fig. 2) utilized a Solid-State Modulator (SSM) incorporated in the tower, but it still used BCL with a diode electron gun, for which a diode electron gun driver (DEGD) was used, also built in the tower.

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ABC designed for both field "drop-in" replacements and for new products

As reported earlier, at Varex, we have now established an ABC design and production line [2]. We have designed and built, tested several new models, suitable for drop-in replacements to cover for the installed LINATRON base. For example, our 6 MeV model (Fig. 3) is fully productized at Varex and exceeds the predecessor performance specifications, while it can operate in both "drop-in" diode configuration and with a triode e-gun, too.

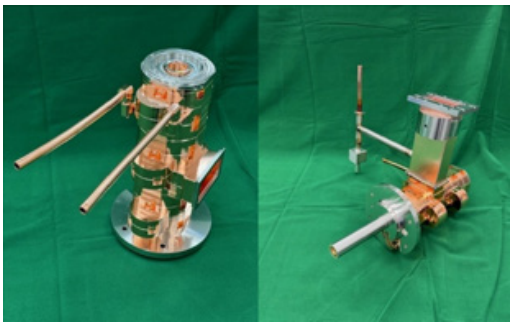

Figure 3: Universal 6 MeV ABC designed to operate with either diode or triode e-gun.

Our new energy regulated (ER) version of the 9 MeV ABC-9-S-M-X-D-ER just passed Verification and entered the Validation process, and one from three ABCs used for Verification process has been already evaluated in field deployment environments, receiving very positive feedback [3]. A triode version of such 9 MeV represents a "minor variant" and is under certification as well, both are currently in validation for production deployment. We are continuing our work on a 3 MeV energy regulated version, and while we produced several prototypes and obtained some impressive results, we continue to improve overall performance of this most challenging ABC to a very high demand. We are driving this last model to certified production. Overall status of our work to have drop-in diode e-gun designs capable of performing with a triode electron gun are progressing very well and development is ongoing with continued performance optimization.

New MicroBeam Products - Addition to LINATRON Family

We have diligently reported on any progress in designing and testing of our Submillimeter ABCs and on MicroBeam LINATRON™ (MBL) new line of products [2, 4-6]. Most of the previously published results were focused on bench testing of the Submillimeter ABC. Now we present the first fully packaged X-ray Head assembly, integrated with Solid State Modulator (SSM) and Triode Electron Gun Driver (TEGD), developed at Varex, in one single package. Therefore, MicroBeam LINATRON (MBL6) is the first 6 MeV X-ray source with a submillimeter electron beam focal spot on a target, equipped with a triode electron gun and integrated with SSM and TEGD (Fig. 4). It features a unique accelerator design which ensures exceptionally small (with Full Width at Half Maximum or FWHM 0.4 mm ± 0.1 mm), providing customers with high-resolution imaging capability relative to current commercial systems, based on current resolution standards and published results, making the invisible visible. The system controls are delegated to a distributed on-board system controlled using a PC. The completed assembly requires external temperature-regulated chiller to operate.

Figure 4: MBL6 represents a combination of "standard" LINATRON package and reconfigured Mi6SSM-T design, utilizing SSM and TEGD. The ULL adds to MicroBeam advantage for better imaging.

MBL Testing and Customer Demonstration

The first unit has been assembled and tested at our Varex Las Vegas location. Before demonstrating the prototype to our customers, we performed all necessary actions to ensure it is certifiable as our standard LINATRON systems (Fig. 1, Fig. 2). Many tests have been performed, but the essential high-level results are enclosed in Table 1. The spot range was estimated in 0.3 mm to 0.5 mm, while we believe we have detected 0.2 mm focal spot size as well. In Table 2, we compare our standard 6 MeV unit performance and its Submillimeter Spot version.

Table 1: E-Beam Generated Bremsstrahlung, High Level Data

Mode	Energy, MeV	Flatness, %, ± 7.5°	Max. Dose Rate, Rad/min@1m
High Dose	6.0	>59.7	300
Smallest Spot	6.0	>59.7	100
High PRF	6.0	>59.7	200

Table 2: E-Beam Generated Bremsstrahlung Comparison

ABC Type	Max Dose Rate, Rad\/min@1m	Max Spot Size, mm	Dose Rate, Rad/min@1m	Min Spot Size, mm
Standard	1000	1.5	800	0.8
MicroBeam	420	0.5	100	0.3

The MBL6 went through thorough assessment and rigorous tests with participation of a team from Los Alamos National Laboratory (LANL). For qualification of the image, a tool loaned by LANL team is shown in Fig. 5, and resolution of 125 μm has been confirmed [7].

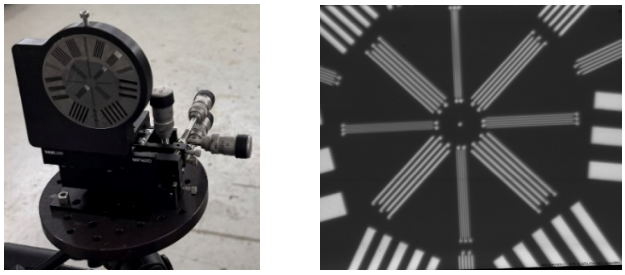

Figure 5: Resolution measuring tool and full calibration image created by MBL6*.

CT imaging using MBL6

At Varex location in Franklin Park, our experts in CT conducted series of tests using MBL6. The traditional Full Width Measured at Half Maximum (FWHM) measurement of the spot resulted in 430 µm, and Integrated Line Profile (ILP) was 610 µm, which represents a significant improvement compared to typical commercial LINAC performance and has never been seen before in commercial LINACs. With this spot, one can achieve about 185 µm resolution using Varex flat panel detector, which no practical accelerator has done before.

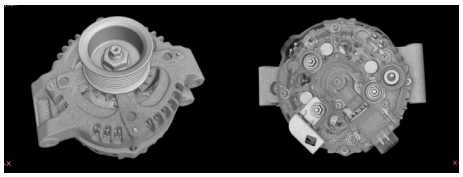

Figure 6: Sample CT images of Alternator 150 µm reconstruction, volume rendering top down and bottom up.

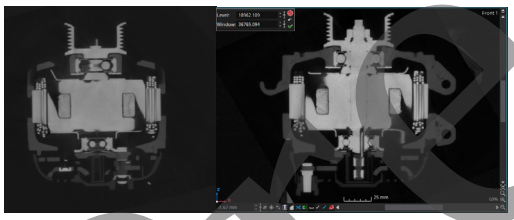

Figure 7: Both orthogonal views are clean and crisp and present excellent material separation.

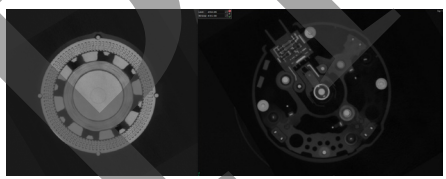

Figure 8: Vertical Z-slice examples present electronics, sharp and visible with individual wire separation.

These scans shown in Fig. 6, Fig. 7, and Fig. 8 were run with high output, and the system stability was excellent, no dark frames noticed, which was an improvement.

In Fig. 9, we present calculated system resolution based on measured ILP spot size of 610 mm (FWHM 430 mm) for MBL6, which does not use solenoid for focusing the electron beam, while using detector resolution of 220 mm. For the M9A, which uses a solenoid, in "low mode" operation the corresponding spot size ILP and FWHM characteristics were 1,050 mm and 595 mm, correspondingly.

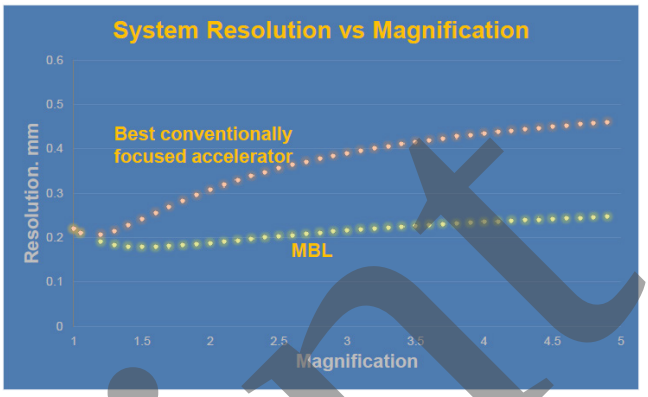

Figure 9: Starting at relatively low magnification and in broad range, MBL results present significantly better resolution compared to conventional spot M6A and M9A.

CONCLUSION

We are continuing to expand Varex product line, meeting or exceeding the common specifications, ensuring that the legacy systems have ABC models to replace the predecessor BCL models in the field. Based on MBL6 performance and test results, the created system now qualifies for mass production. According to the external experts and Varex team joint assessment, MBL takes imaging to a new level and now raises serious interest with the customers in the fields of NDT, Security Screening, and Radiation Therapy.

REFERENCES

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[6] Andrey V. Mishin, Progress on MicroBeam Linatron™ (MBL) Linear Accelerators at Varex Imaging, *ASNT2025, Orlando, Florida, 6-9 October 2025.*

[7] S. Watson and LANL, Private communication, 2026.

* The tool was loaned by visiting LANL team, images made together with Varex team in our Las Vegas building.