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STATUS OF MICROBEAM LINATRON™ (MBL) PRODUCT LINE DEVELOPMENT AT VAREX IMAGING CORPORATION

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Abstract

The High Energy Systems (HES) group at Varex Imaging Corporation (Varex) introduced a new concept and design for Accelerator Beam Centerline (ABC) (patent pending), which can be used on compact commercial electron linear accelerators in the 1-20 MeV energy range, delivering substantially reduced focal spot, for example, less than 0.5 mm focal spot on a beam stopping target, thus improving imaging qualities with the produced Bremsstrahlung. The first 6 MeV prototype tests have been completed successfully, and the work continues to build and test a 3 MeV and 9 MeV ABC prototypes. These linac systems will be marketed under the brand name MicroBeam LINATRON™ (MBL) series. The design and experimental data obtained to date are presented.

INTRODUCTION

Varex Imaging Corporation (Varex), based in Salt Lake City, Utah, is a leading innovator, developer, and manufacturer of X-ray imaging component solutions. Varex's Security and Industrial Products (SIP) business manufactures high-energy linear accelerators (LINACs) and has created a design and production line for independently developed ABCs, which are now produced in Salt Lake City. The HES group in Salt Lake City and Las Vegas has been leading the development and has been instrumental in advancing this technology. Varex is now shipping prototypes of most of the models and in the process of moving models to production [1]. Along with replacing the previous linac models, new ABCs and LINACs are under development [2, 3]. As a part of this innovation, we developed a new design and tuning method (patent pending) that can reliably produce small, true Gaussian focal spots with Full Width Half Max (FWHM) of less than 600 μm without any external magnetics. The newly obtained small focal spots have the potential to provide a better image than the focal spots obtained in most standard structures. In addition, the spots are normally measured by FWHM parameter, a true spot size measured at the base of its profile for non-Gaussian profile is much larger than that for a Gaussian spot. We found only a few publications with enough details, where a 950 keV linac with a small spot under 0.6 mm was described, however, it seemed to utilize a magnetic system, perhaps quadrupoles. Some other information we found which would not offer any substantial details when submillimeter (SUBMM) spots were referenced [4, 5].

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NEW ABC DESIGN

The idea has been nurtured by the presenting author for quite a long time, and it required a different approach to designing and tuning of the RF structure, and to the beam optics design. In previous publications, we enclosed graphs, which present design data for the three linacs at our classic ABC and LINAC parameters – at 3, 6, and 9 MeV, correspondingly [2]. The outside envelope of the 6 MeV submillimeter design is the same as the standard 6 MeV design, either triode (TEG) or diode (DEG) electron gun version, and can replace the standard ABC in any of our systems.

PROTOTYPES AND TEST RESULTS

We selected the first prototype of the submillimeter ABC to operate at 6 MeV, because it is the most popular unit we build, representing over 90% of the standard ABCs at this energy. The first 6 MeV ABC prototype was built and tested at the end of CY2024; it went through extensive testing and demonstrated favourable results. The presenting author mentioned the first results in his monography published in American Journal of Modern Physics in February 2025 year [1].

First MBL Prototype at 6 MeV

It is important to mention, that the standard ABC delivers the best focal spot of 1.0±0.2 mm, while similar third party linacs or their predecessors normally would deliver spots with FWHM of 1.5 mm in diameter. Designing a SUBMM prototype was our next step in spot reduction, following our continuous improvement policy. We have designed, built and high-power tested two 6 MeV submillimeter units for the new MBL product line, both of which delivered less than 600 μm spot size (estimated 350±150 μm in various versions and while operating in a range of parameters). In the first unit, we observed only 12.5% maximum dose rate reduction (700 R/min@1m) sited in a 6 MeV ABC, compared to a standard 6 MeV unit (800 R/min@1m) while operating with 500 μm. The second unit was designed to minimize the spot size, which, in turn reduced the maximum dose to 250 R/min@1m, and for the smallest spot sizes it operated at approximately 50 R/min@1m. This second unit was selected for further testing. During our initial tests, we have completed measurement of the linac key parameters including electron beam energy, the corresponding dose rates, and the spot sizes at these measured parameters. Note the units were equipped with the triode electron guns giving us a couple of options for some parameters adjustments. In addition, the design

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permitted regulating the electron gun voltage in a minimum range from 8 kV to 14 kV and the injected electron beam current by regulating the grid voltage. More detailed results have been presented in our previous publications. In Fig. 1, (a) and (b), we present the images of the focal spot on a stopping target, measured by using a planar camera in high and low dose, correspondingly, and in Fig. 2, (a) and (b), the similar spot sizes measured by a grid camera at 6 MeV. In Fig. 3, we present one of the scans of the beam spot, which shows the spot profile nearly 100% repeating the classic Gaussian profile. It is very important that there are no "tails" observed at the edges of the Gaussian, which can lead to deterioration of the image quality.

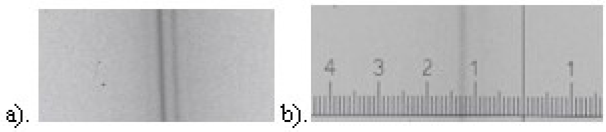

Figure 1: Planar Camera (with 230 µm period) overexposed image of the submm spot ("a", left), 4 lines 3 gaps are visible, which would suggest possible maximum size of the spot of 500 µm FWHM and record small spot image, on the order of 200 µm ("b", right).

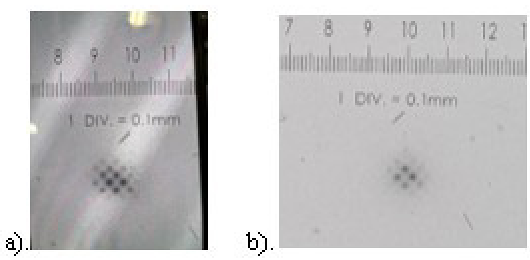

Figure 2: The measured spot size with high output (240 Rad/min@1m) estimated FWHM 400 µm, ("a", left), and with a reduced output (50 Rad/min@1m), the spot would only get smaller, showing results closer to 200 µm ("b", right).

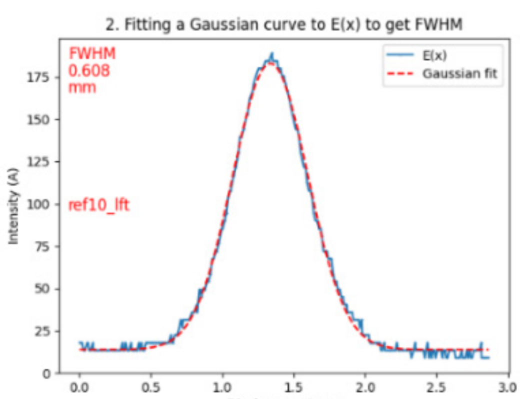

Figure 3: Spot scan obtained during the initial testing. Note the exact match between the spot profile and Gaussian distribution.

After completion of the preliminary "bench-testing", we packaged the new SUBMM ABC in the standard LINATRON X-Ray head, shown in Fig. 4, and shipped to the Varex Franklin Park facility near Chicago to perform the imaging tests. The obtained image is shown in Fig. 5.

Figure 4: The 6 MeV SUBMM ABC fits in the standard LINATRON X-ray head package (with covers removed).

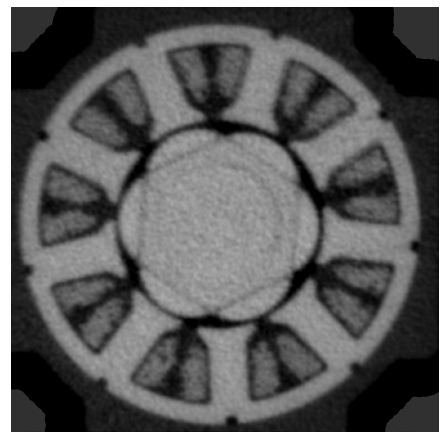

Figure 5: Image obtained using MBL6 at its worst spot was better than that obtained using the best possible spot size using LINATRON™ 9A operating at 6 MeV.

3 MeV Prototype

The 3 MeV standard spot unit was built using the new "short" guide design that we have just created and tested. The standard unit has demonstrated excellent performance in energy range 1-3 MeV. We have also completed the submillimeter version of such standard linac, shown in Fig. 6.

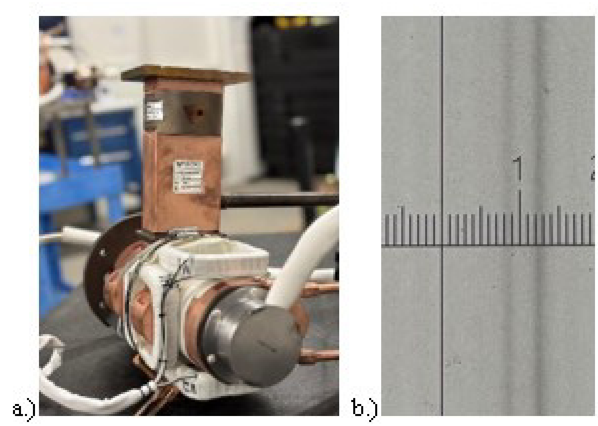

Figure 6: The 3 MeV SUBMM ABC model for MBL3 ("a", left), and spot of 300 □m obtained in "Low Dose" mode ("b", right).

The first test results are enclosed in Table 1. We varied e-gun voltage in a range of 12-14 kV and grid voltage, changing the injected current.

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Table 1: Test Results for SUBMM ABC Model for MBL3

Electron Energy [MeV]	Maximum Dose Rate [R/min@1m]	Est. Spot Size [μm]	Magnetron Peak Power [MW]
3.6	90	300	1.7
3.5	192	500	1.9
3.5	174	500	1.8
2.4	126	500	1.7

The measured values give us an idea that the ABC works well. The “Low Dose” ran at 1.7 MW, 90 R/min@1m produced spot with FWHM estimated in 300 μm (marked in yellow), “High Dose” spots were all estimated in 500-600 μm. The results at 3 MeV are very similar to that at 6 MeV. The experimental load lines can be seen below in Fig. 7.

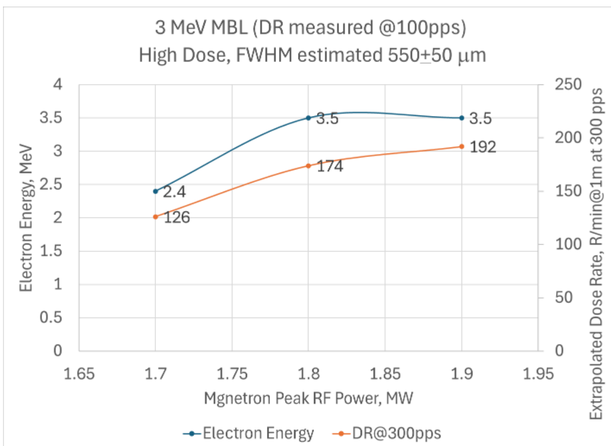

Figure 7: MBL3 output at various magnetron input peak power values, dose rate maximized by varying e-gun high voltage.

9 MeV Prototype

The first manufactured MBL9 prototype can be seen in Fig. 8. The first preliminary test results for MBL9 were obtained quickly by HES team to be presented at this conference, enclosed in Table 2 and shown in Fig. 9.

Figure 8: Full ABC stack for MBL 9 has been brazed, pretest results follow, HES team have done a great job.

Table 2: Test Results for SUBMM ABC Model for MBL9

Electron Energy [MeV]	Maximum Dose Rate [R/min@1m]	Est. Spot Size [μm]	Magnetron Peak Power [MW]
7.1	317	500	1.4
9.5	780	500	2.3

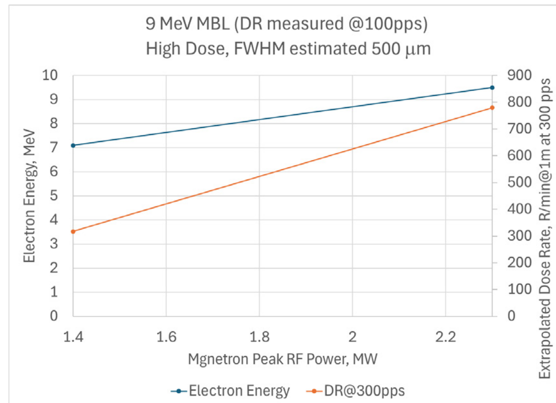

Figure 9: MBL9 output at various magnetron input peak power values (two key points only measured), dose rate maximized by varying e-gun high voltage.

CONCLUSION

The new design for the MicroBeam LINATRON™ (MBL) represents a significant industry advancement, enabling Varex to develop a unique product line across a broad energy range with spot sizes that are reliably under 600 μm.

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