ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB412

NEW 3 MeV AND 7 MeV ACCELERATORS FOR CARGO SCREENING AND NDT

S. Proskin†, A. V. Mishin, D. Fischer
Varex Imaging Corporation, Salt Lake City, United States

Abstract

For decades, high energy systems based on electron beam linear accelerators (linacs) have been used for cargo security screening and non-destructive testing (NDT). The customers require better image quality, reliability, and functionality. At Varex [1], we have been developing a set of new accelerator products with improved parameters, produced in Salt Lake City, UT in order to replace Varian Medical [2] as a supplier, replace existing outdated systems and increase our share in existing and new, emerging markets [3]. New S-band, energy regulated 3 MeV and 7 MeV linear accelerators have been designed and high-power tested at Varex Imaging and their customer sites. The new linacs demonstrated increased output, reduced beam spot, longer life span, better reliability, and functionality. In this paper, authors present recent progress and test results for these two latter models.

MODERN TRENDS AND HISTORY OF DEVELOPMENT

This paper presents results of our research and development of two accelerator beam centerlines (ABCs): one as a replacement for an existing guide and the second one – a new development for future Varex products.

NEW LINACS FOR INDUSTRY

Energy Regulated Beam Centerline ABC-3-S-X

We have found that in some cases, customers use much more extensive cycling of the targets, running linacs with shorter pulse, higher pulse repetition frequency. This approach restrains life of X-ray targets substantially. Broad regulation of energies and smaller X-ray focal spots are also among the main points of interest from customers.

While working on our new guide ABC-3-S-X, we addressed most of all of the requirements mentioned above.

A different target design with additional cooling has resulted in extended life. The prototype ABC has been run continuously at our customer site, for more than 3000 hours up to date without any issues.

In a relatively short beam centerline designed to operate at peak beam currents up to 500 mA where fields are high enough, a so-called beam backstreaming issue is one of the output main limitation factors. By utilizing a powerful beam tracking software Opera [4], we have been able to improve the electron gun beam optics and, at the same time, restrain beam from striking the electron gun cathode. As a result, we have achieved X-ray dose rate of up to 500 R/min at 1 m from the target.

The triode gun helps in a continuous regulation between 2 and 4 MeV while regulating input RF power.

† email: stanislav.proskin@vareximaging.com
LinkedIn: stanislav-proskin

Some of the main features of the new ABC are shown in Table 1. Figure 1 presents a prototype manufactured, tuned, and sealed under ultra-high vacuum (10^{-10} Torr). Figure 2 shows an example of theoretical and experimental performance of ABC during high power test. The chart highlights a series of ABC-3-S-X solid load lines (energy versus beam current at the exit of the accelerating structure) for one of the prototypes manufactured and tested at high power. Corresponding dose rates versus beam currents (dashed lines) have been evaluated using a well-known Haimson equation [5]. It could be seen, that, first of all, experimental results match with theoretical ones within a reasonable margin (for both simplified evaluation as seen on red lines, and the results obtained with a beam-tracking software Parmela [6] as seen on blue lines). Secondly, one can see ABC performance at different peak RF power levels.

All the above-mentioned improvements will make linac system better, more reliable, and deliver better functionality to our customers.

Figure 1: ABC-3-S-X IN004 prototype fully tuned and sealed under ultra-high vacuum.

ABC-7-S-X Beam Centerline with Broad Energy Regulation

We have also designed and built an ABC that achieved broad energy regulation, had a relatively small X-ray focal spot, and produced 1000+ R/min to be utilized in security and NDT applications.

To achieve the above requirements, the team has worked on scaling an existing X-band structure to S-band, while maintaining our manufacturing technology. The resulting ABC has been designed to be less than 25 in long including an electron gun and a target. While an accelerating structure itself is about 17 in long. An improved electron gun anode shape has been used for ABC-7ER-S-X based on ABC-3-S-X success.

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB412

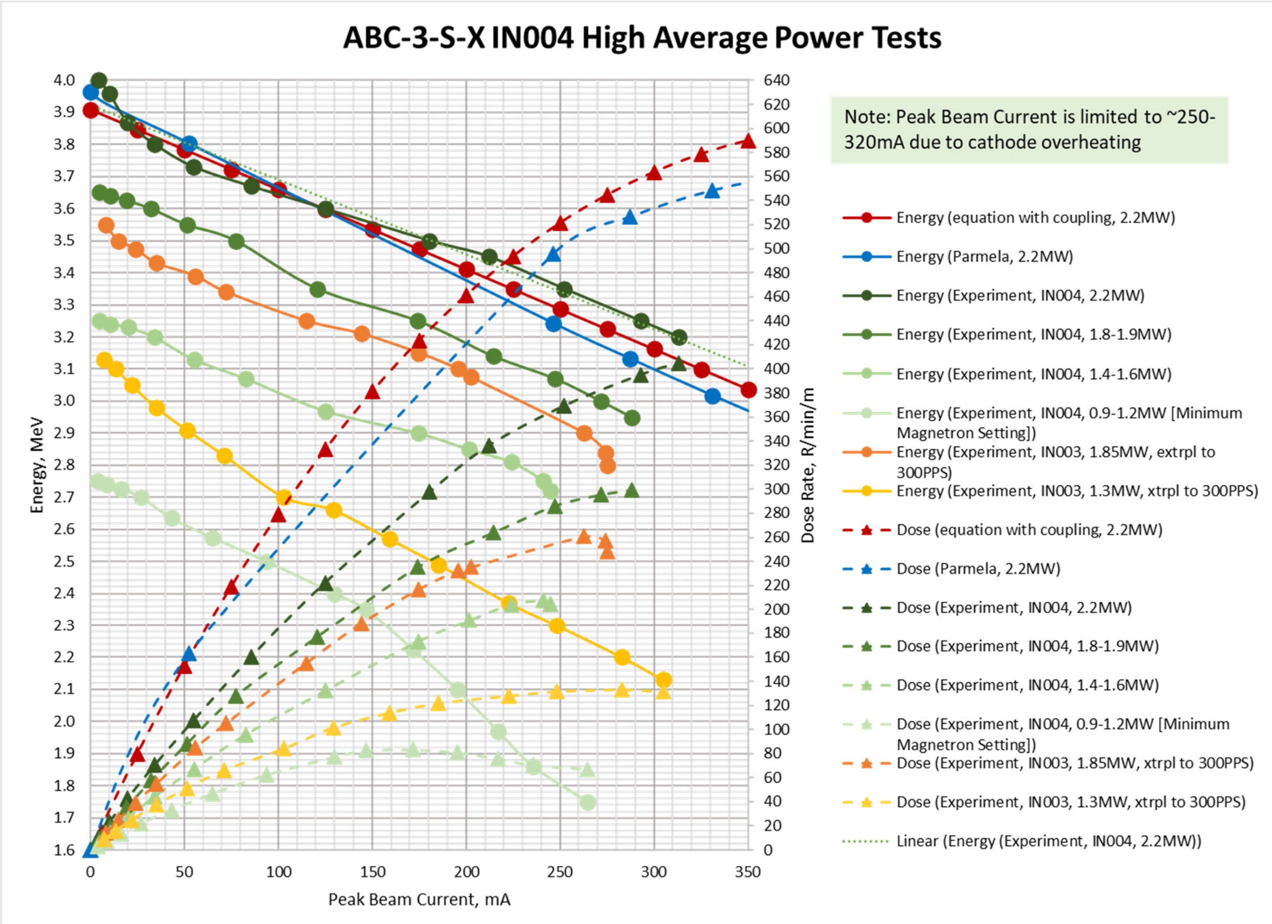

Figure 2: An example of ABC-3-S-X performance during a high-power test.

Two versions of ABC-7-S-X have been built – an electron accelerator with a tungsten foil at the output, and one with an X-ray target. Both have shown outstanding results during high-power testing. Although indirectly measured (with a custom-made Faraday cup in electron case, and via half value level measurement technique in case of X-rays) energy and beam current measurements matched within reasonable margins. ABC-7-S-X has produced up to 1300 R/min maximum dose rate at 6.5 MeV energy. As in the case of ABC-3-S-X, it was measured at 1 m from the target with the 10 x 10 collimator and the ion chamber installed. A triode electron gun helped in smooth energy regulation from 3 to 8 MeV. Fig. 3 illustrates a model of ABC-7-S-X beam centerline and Fig. 4 and 5 highlight some of ABC high-power testing results.

Electron beam spot has been measured by exposing a tape and measuring discoloration of the tape at full width, half maximum (FWHM) of beam distribution. X-ray focal spot has been measured via a pinhole camera method in which one should take magnification of an X-ray image into account. All the obtained beam spot pictures have been analysed with Varex developed image evaluation software. For both electron beam spot and X-ray focal spot FWHM measurement results appeared to be satisfactory within the whole range of energies.

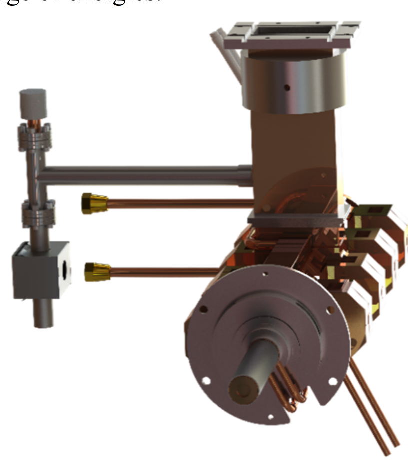

Figure 3: ABC-7-S-X Model.

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB412

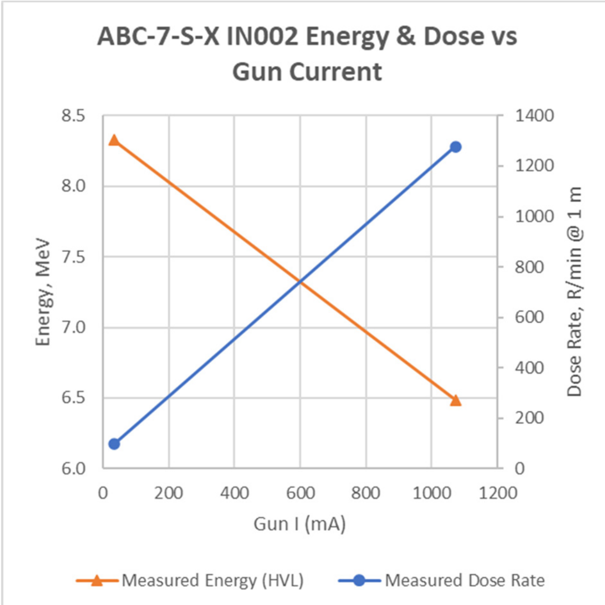

Figure 4: ABC-7-S-X IN002 Measured Energy and Dose Rate versus Gun Current.

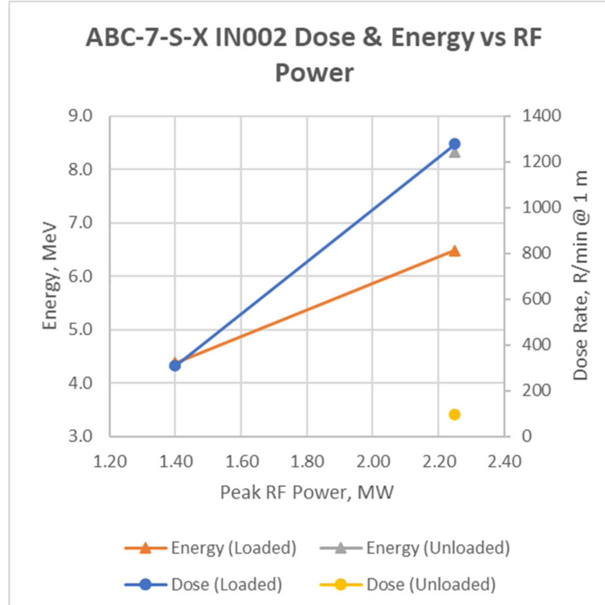

Figure 5: ABC-7-S-X IN002 Measured Energy and Dose Rate versus Gun Current.

Table 1: Highlights of ABC With a Nominal Energy of 3 MeV

Product	Energy, MeV	Maximum Dose Rate, R/min	X-ray Focal Beam Spot, mm	Life of Target
Current	1, 2, 3	300	< 2.0	Standard
New Development	2.0-4.0	500	< 1.5	Improved

Table 2: New ABC With a Nominal Energy of 7 MeV

Energy, MeV	Peak Beam Current, mA	Maximum Dose Rate, R/min	X-ray Focal Beam Spot, mm	Status
3-8	Up to 200	1300	< 2.0	Improved beam spot version is under development

CONCLUSION

Varex Imaging Linear Accelerators Group developed and built ABC-3-S-X and ABC-7-S-X accelerator beam centerlines for applications in security and inspection. The accelerators showed outstanding performance with improvement in beam parameters, X-ray output, and life of targets.

ACKNOWLEDGEMENTS

This work would have not been successful without outstanding contribution of Devon Fischer, Loren Young, John Roylance, Matthew Denney, Corey Molter, and the whole Security and Inspection Products division of Varex Imaging. We would also like to express our gratitude to established partnerships with our customers and vendors. Special "thank you" is to my mentors Igor Shchedrin and Andrey Mishin for their invaluable contributions. And unlimited gratefulness to my family for continuous support in my accelerator journey.

REFERENCES

[1] Varex Imaging Corporation, https://www.varex imaging.com

[2] Varian Medical Systems, https://www.varian.com

[3] A.V. Mishin, "New accelerator beam centerline (ABC) production line at Varex Imaging Corporation", presented at the 12th Int. Particle Accelerator Conf. (IPAC'21), Virtual Edition, paper MOPAB349, this conference.

[4] Opera, electromagnetic and electromechanical simulation, https://www.3ds.com/products-services/simulia/products/opera/

[5] J. Haimson, "Some aspects of electron beam optics and X-ray production with the linear accelerator", IRE Transactions on Nuclear Science, vol. 9, issue 2, p. 35, Apr. 1962. doi:10.1100/TNS2.1962.4315948

[6] Parmela, https://laacg.lanl.gov/laacg/services/serv_codes.phtml