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MAXIMIZING OUTPUT OF 3 MeV S-BAND INDUSTRIAL ACCELERATOR

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Abstract

Earlier, we have reported on a record-breaking 3 MeV Accelerator Beam Centerline (ABC) built in 2017-2018. An upgraded version of this 3 MeV S-band ABC has been developed at Varex Imaging as a key component for one of the most popular X-ray industrial linear accelerator systems, commonly used for security and non-destructive testing (NDT) applications. Being significantly strained by excessive backstreaming, increasing of the ABC output is a challenging task. We describe these challenges and highlight high power test results. The triode gun and structure design improvements allowed us to raise stable output up to 530 Rad/min/1m at 3 MeV and up to 220 Rad/min/1m at 4.5 MeV with a widely available 2.5 MW/2.7 kW magnetron, while maintaining the spot size at 2 mm.

CHALLENGES

In the last year we worked to improve upon the previous prototype of the S-band 3MeV ABC (ABC-3-S) [1, 2]. See Fig. 1 for a model of the upgrade. One of our main areas of focus was the spot size. Industry is used to seeing and using spot sizes of less than 2 mm. The spot size is a very important parameter for clarity of image and precision. While multiple aspects, like distance to the object being tested contribute to how clear the image is or geometric unsharpness, smaller spot sizes helps limit unsharpness, especially for thicker objects.

To enhance the image, we worked to reduce the spot size. We did this by redesigning aspects of the internal RF structure and simulating the results.

It is also highly beneficial to maximize dose rate output of an industrial accelerator. The feature improves throughput of objects being scanned. With such a short accelerator and utilization of a high power magnetron, fields in the accelerating structure are high enough for excessive backstreaming; which in turn becomes a large issue. When there is a lot of backstreaming, the electron gun (e-gun) cathode is overheated, and emission current becomes unstable. The latter leads to e-gun failure and decreases the longevity of the accelerating structure. In addition to unstable accelerator operation, at a certain average current value the e-gun high voltage is shut off due to e-gun driver safety electrical circuits. We were able to raise limits of average accelerator characteristics by simulating an improved e-gun anode shape and corresponding adjustments in the buncher of the accelerating structure. See Fig. 1 for a model of the upgraded accelerator.

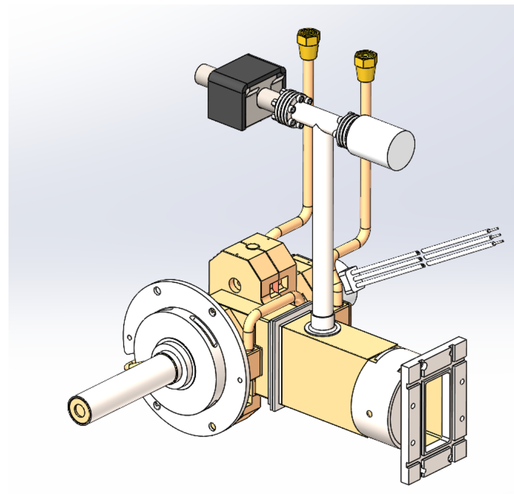

Figure 1: Model of the new accelerator, ABC-3-S-X-RS.

ACCOMPLISHMENTS

After adjusting the structure to reduce the spot size and building it, we used an exposed tape and measured the discoloration at FWHM for the e-beam distribution. Using Varex proprietary spot grid camera and radiographic film, we obtained images which we analyzed and found that our spot size reduced to 2.1 x 2.0 mm FWHM at 3 MeV. In addition to the grid camera and the radio graphic film method, the spot was also verified with two measurement techniques involving X-ray detector – a thin slit penumbra evaluation and duplex wire imaging.

When we redesigned the accelerating structure, we also increased dose rate output. In the design phase we concentrated on reducing the spot size and saw that our dose rate also increased in the simulations. We saw good agreement between simulations and testing. Where we saw a decrease in simulation spot size, we saw a similar decrease in testing. This held true for dose rate as well.

Another aspect that helped increase the dose rate was decreasing backstreaming. When we redesigned the first cavity, we also created optimum bunching which increased the dose rate. Overall, the dose rate increased to 530 Rad/min at 1 m from the target.

In researching the backstreaming effect we found a new feature to be useful in general linear accelerator system operation. The new configuration of the accelerating structure and anode design gave us an opportunity to lower e-gun high voltage required for stable accelerator performance. By keeping all parameters in specification at lower high voltage, one may possibly improve cathode lifespan, make it less demanding for e-gun control electrical circuit requirements, and achieve a safer operation.

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Table 1: Summary and Comparison of 3 MeV Accelerators

	ABC-3-S-X-RS Upgrade (2022)	**ABC-3-X-X (2018)**	**ABC-3-X-X-DI (2021)**
Product type	New Product	New Product	New Product
Energy (nominal) MeV	3	2.5	2.5
Energy Range	2.6-5.0		
E-Gun	Triode	Triode	Triode
Frequency Band	S	X	X
Maximum Magnetron RF Power, MW/kW	2.5/3.0	0.75/0.75	0.75/0.75
Appx, RF length, cm	16	19	19
Maximum Stable Dose Rate, R/min@1m	530	50	50
FWHM Spot Size, mm	1.7±0.5	1.5±0.5	1.5±0.5
Features	Improved dose rate improved target life span, improved spot, <10kV e-gun	Small envelope	Small envelope, no circulator is needed
Applications	NDT, Radiation Therapy	Cargo Screening	Cargo Screening
Production	Being certified	In production	Being tested

CONCLUSIONS

Our work on the ABC-3-S line of accelerators improved upon the prototype from 2021 (see Table 1). We successfully designed a spot size to 2.0 mm FWHM, increased the dose rate output while still using the same magnetron and accelerating structure length, to 530 R/min at 1 m from the target, and increased target life span. Additionally, we kept the same very short envelope from the prototype. We plan to continue work on reducing the spot size and increasing dose rate in further development.

AKNOWLEDGMENTS

This work would not have been successful without outstanding contribution of the whole Varex Imaging High Energy Sources R&D Group located in Las Vegas and Salt Lake City [3].

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