A PROTOTYPE 1 MEV X-BAND LINAC FOR AVIATION CARGO INSPECTION

M. Jenkins*, G. Burt, B. Hall, Lancaster University Cockcroft Institute, UK
P.K. Ambattu, BITS Pilani, India
P. Corlett, P. Goudket, A. Goulden, P McIntosh, K. Middleman,
Y. Saveliev, R. Smith, A. Wheelhouse, ASTeC, Daresbury Laboratory, UK
P. Hindley, C. Hill, N. Templeton, T. Hartnett, S. Griffiths,
B. Martlew, M. Hancock, Daresbury Laboratory, UK
S. Andrews, T. Cross, C. Weatherup, e2v, UK

Abstract

Aviation cargo Unit Load Device (ULD) containers are typically much smaller than standard shipping containers, with a volume of around 1 m^3. Standard 3 to 6 MeV X-ray screening linacs have too much energy to obtain sufficient contrast when inspecting ULD's, hence a lower 1 MeV linac is required. In order to obtain a small physical footprint, which can be adapted to mobile platform applications a compact design is required, hence X-band technology is the ideal solution. A prototype 1 MeV linac cavity has been designed by Lancaster University, manufactured by Comeb (Italy) and tested at STFC Daresbury Laboratory using an e2v magnetron, modulator and electron gun. The cavity is a bi-periodic $\pi/2$ structure, with beam-pipe aperture coupling to simplify the manufacture at the expense of shunt impedance. The design, manufacture and testing of this linac structure is presented.

INTRODUCTION

Inspection of aviation cargo Unit Load Device (ULD) containers is increasing in frequency due to security concerns. Due to the size of a ULD, typically 1 m^3, existing cargo scanning linacs are unable to be used due to the energy of the X-rays produced. Current X-ray screening linacs were designed to scan shipping containers which are constructed from steel and have a volume of at least 33 m^3 which means that high energy X-rays are required to traverse the container. ULD's are normally constructed from aluminium which combined with the much smaller volume of the container means that a 1 MeV linac is required. As a mobile scanner is desired a compact design is necessary which means that X-band technology is ideal.

Prototyping of an X-band 1 MeV linac is underway. The linac has been designed by Lancaster University and STFC Daresbury Laboratory. The RF design was done at Lancaster University which was then passed to STFC Daresbury Laboratory who completed the mechanical design. This structure was then manufactured by Comeb and initial RF testing was conducted at the Cockcroft Institute. The linac is now being installed on a beam line at Daresbury Laboratory to be test using an e2v magnetron, modulator and electron gun.

* michael.jenkins@cockcroft.ac.uk

CAVITY DESIGN

The cavity was designed as an X-band $\pi/2$ bi-periodic structure in order to meet the requirements of industry who would produce commercial systems for scanning ULD containers. X-band technology was chosen to produce a physically small linac which not only ensures the linac is compact but the shielding is also compact. In order to increase the cavity stability a $\pi/2$ standing wave mode was selected, as this mode has the largest frequency separation to the next nearest mode which minimises the affect of perturbations. $\pi/2$ mode structures have every 2nd cell unfilled resulting in a much lower accelerating gradient. In order to increase the accelerating gradient, which reduces the cavity length, a bi-periodic cell design was chosen for this project (see Fig. 1).

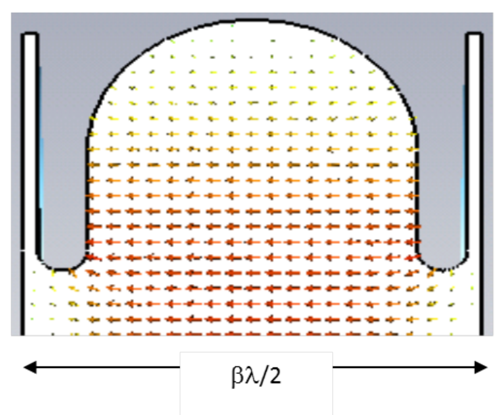

Figure 1: A single cell in a bi-periodic standing wave cavity.

The energy of the electron beam adds extra complication to the RF design. The electron gun which is connected to one end of the cavity produces 17 keV electrons which are non relativistic. This means that the relativistic β of the electron beam changes along the length of the linac. The rate of change in β depends on the accelerating gradient, the electric field amplitude must be chosen before optimising the cavity design. For this application an accelerating gradient of 30 MV/m was chosen which resulted on a structure with 8 accelerating cells. The length of these cells were then optimised by tracking the electron beam in ASTRA [1].

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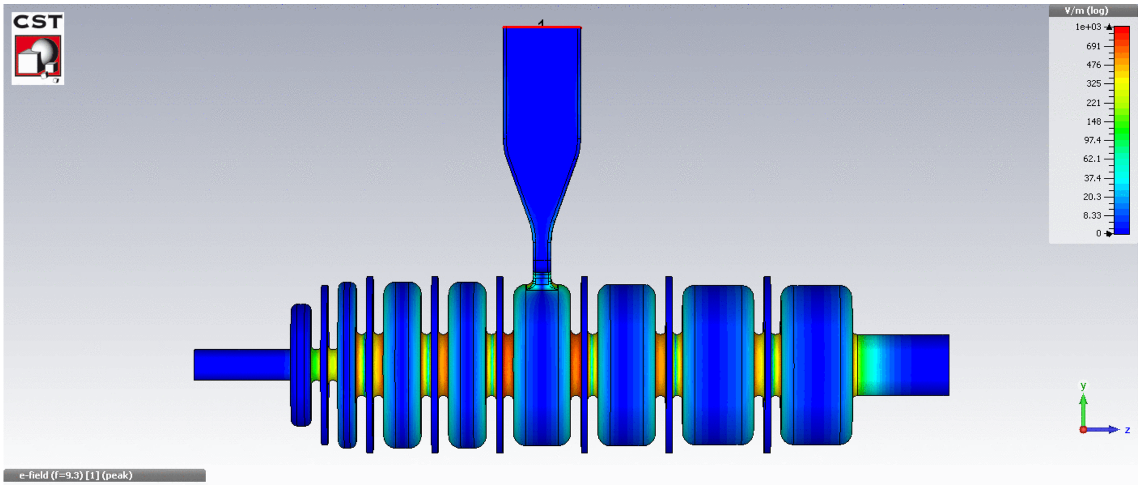

Figure 2: Final RF design of x band linac simulated in CST Microwave Studio. Image is of the electric field distribution in the final cavity.

This is the second cavity designed by Lancaster University for security scanning ULDs [3]. The first cavity was designed using the same techniques described here however the waveguide coupler was connected to the last cell in the linac. The decision to position the coupler on the final cell combined with manufacturing errors meant that the field flatness was poor and the linac was only able to produce an electron beam with a maximum energy of 750 keV. To mitigate the problems experienced with the first prototype the coupler was positioned on the central cell and the aperature radius was increased. This improves the cell to cell coupling and the field flatness. In addition the first cell has been made re-entrant so that it is easier to tune as having a small gap made the cell very mechanically stiff. The final RF design was completed using CST Microwave Studio [2] to optimise the structure in terms of peak surface fields, account for ohmic losses in the cavity walls and to design the coupler and is shown in Fig. 2.

After the RF design was finalised it was sent to the technology department at Daresbury Laboratory who did the mechanical design. Once the mechanical design was finalised thermal modelling of the cavity was done using ANSYS to determine what cooling was required to ensure that the temperature in the cavity remains stable. With this completed the mechanical design was finalised and sent to Comeb who manufactured the linac.

CAVITY TESTING

When the cavity was received from Comeb it was measured using a bead pull system. The bead pull was done using a non-resonant method [4] as only S11 could be measured. The initial measurement made upon receiving the cavity was to measure S11 and compare with the S11 measurements provided by Comeb as well as the expected S11 from simulations of the cavity. Figure 3 shows the results of the S11 measurements performed.

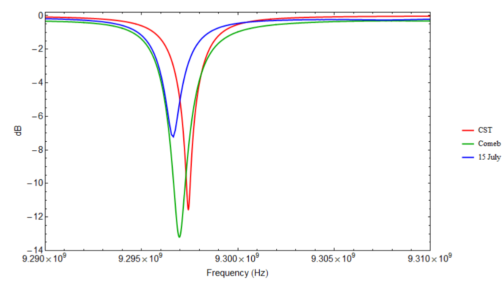

Figure 3: Magnitude of S11 for the x band cavity. The expected S11 measurement calculated in CST is shown in red, the S11 measurement performed by the manufacturer is shown in green and the S11 measurement performed on receipt of the cavity is shown in blue.

The S11 match at the operating mode does not agree between the measurements performed at Comeb and at the Cockcroft Institute. This suggests that the cavity underwent detuning whilst being transported from Italy to the UK. Table 1 compares the frequency and match of the operating mode measurements with the expected values from CST.

Table 1: S11 measurement of the operating mode.

	Units	CST	Comeb	Measured
Frequency	GHz	9.29743	9.29696	9.29665
Match	dB	-11.5539	-13.1971	-7.2201

Figure 4 shows the initial bead pull result compared with the predicted field flatness for the cavity calculated using CST. The data has been normalised so that the peak electric field is set to 1. The measured data agrees very well with the predicted data except in the first two accelerating cells. There are three peaks in the measured data where we would only expect two peaks. This could mean that there is electric field in the first coupling cell which means that the phase change between the first two accelerating cells and the first coupling cell could be π, $\pi/2$ or 0. If the phase change between the cells is not $\pi/2$ this has implications for the quality of the electron beam.

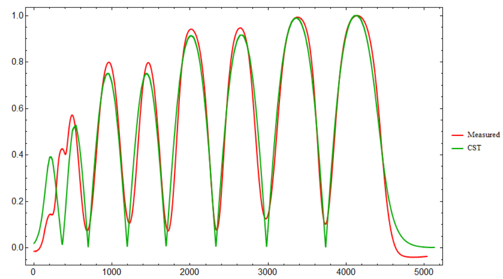

Figure 4: Field flatness plot showing how the electric field varies along the axis of the cavity. The red line shows the measured field flatness and the green line the expected field flatness.

To attempt to correct the field in the first two accelerating cells a tuning procedure was started based on simulations which contained errors to attempt to replicate the measured field flatness. The tuning methodology used was a modified version of the tuning method developed for the SPARC RF deflector [5]. The method had to be modified as the deflector was tuned using the H field whilst for the compact linac we tuned using the E field. The simulations predicted that the largest error was in the first accelerating cell so this was tuned first. The results from this initial tuning are shown in Fig. 5.

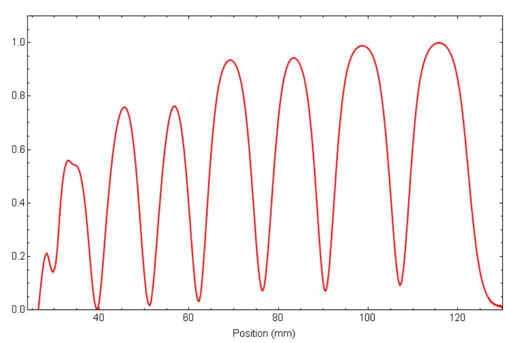

Figure 5: Field flatness plot showing how the electric field varies along the axis of the cavity after initial tuning.

The tuning resulted in an unexpected change in the field flatness. It was expected that the peak in between the peaks corresponding to the first two accelerating cells would reduce. Instead it has increased to a point where it is level with the field in the second accelerating cell. As a result tuning of the structure has halted whilst more work is done on interpreting the results and developing a more reliable tuning routine. Whilst this work is on going beam dynamics simulations using the field profile shown in Fig. 5 have been conducted.

BEAM DYNAMICS

The beam dynamics simulations were conducted using ASTRA. The main aim of these simulations was to attempt to determine if the field in the cavity as shown in Fig. 5 would provide a useable beam. To determine this simulations were also done using fields from the ideal structure simulated using CST. As this linac is being used for security scanning apllications the main beam parameters that are important are the beam energy and the spot size. Figure 6 shows the RMS beam spot size along the linac.

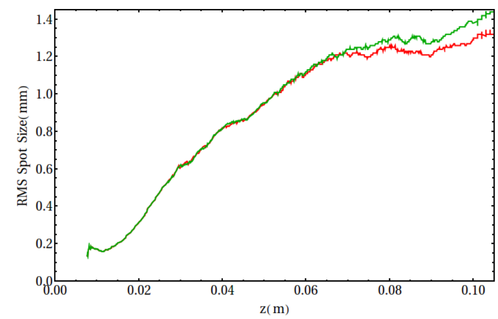

Figure 6: Plot showing the RMS spot size of the electron beam along the compact linac calculated using ASTRA. The red line shows the spot size for the ideal cavity and the green line shows the spot size for the actual cavity.

The beam spot size at the end of the linac is similar in both cases. The RMS spot size is 0.16355 mm for the measured field profile shown in Fig. 5 compared with 0.14648 mm. This is a 11.65 % increase but should still be acceptable for the to be used as the prototype structure for the security scanning experiment at Daresbury Laboratory.

CONCLUSION

A bi-periodic $\pi/2$ mode structure has been developed at Lancaster University, Daresbury Laboratory and the Cockcroft Institute for use in security scanning applications. The cavity has been recently received from the manufactures and after initial testing and tuning of the structure it is currently being installed on a beam line. The electron beam produced by the cavity will be characterised before begin used to produce X-rays for security scanning.

REFERENCES

[1] ASTRA, DESY, `http://www.desy.de/~mpyflo/`

[2] CST Microwave Studio, CST GmbH, Germany, `http://www.cst.com/`

[3] G. Burt et al., "Design and Operation of a Compact 1 MeV X-band Linac", MOPB004, Proceedings of LINAC12, Tel-Aviv, Isreal (2012).

[4] A. Mostacci et al., "About Non Resonant Perturbation Field Measurment in Standing Wave Cavities", TH5PFP086, Proceedings of PAC09, Vancouver, BC, Canada (2009).

[5] L. Ficcadenti et al., "RF Measurements Results of the Final Brazed SPARC RF Deflector", FRPMN030, Proceedings of PAC07, Albuquerque, New Mexico, USA (2007).

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