ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-MOPOJO10

THE LINAC TEST FACILITY AT DARESBURY LABORATORY

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Abstract

The LINAC Test Facility (LTF) based at Daresbury Laboratory supports research and development of applications in medical, security, and environmental technologies through the operation of a Compact LINAC. This facility has been operated and upgraded over several years and this work has been performed in a collaboration between STFC and Teledyne e2v, enabling the facility to deliver an increased accelerating gradient of 6 MeV, which has broadened the capability to provide testing of radiotherapy and security scanning technologies. This paper describes the developments undertaken, the benefits gained by both parties, and future planned improvements.

INTRODUCTION

For decades the Accelerator Science and Technology Centre (ASTeC) at STFC Daresbury Laboratory has been home to advanced particle accelerator research. Working on a wide range of projects, carrying out research, developing and building the next generation of accelerators, one aim is to support industrial applications of particle accelerator technology. The LINAC Test Facility (LTF) is dedicated to facilitating research and development of applications in medical, security, and environmental technologies through the operation of a Compact LINAC. To advance the world's next generation of particle accelerator technologies and attract exciting new opportunities for UK industry, STFC and Teledyne e2v established a collaboration and strategic relationship in 2018 and share a positive, impactful relationship continuing through to 2022 and beyond. Teledyne e2v [1] is a leading supplier of RF technologies and components in many industries, including radiotherapy, security, and high-energy physics. The company required access to an accelerator and radiation test facility. Gaining access to STFC's unique facilities allowed Teledyne e2v to assist with the development of their integrated RF sub-systems.

An important part of the collaboration between STFC and Teledyne e2v is the Compact LINAC, an innovative and highly compact electron beam accelerator, used by both industry and the research community for testing x-ray and electron beam technologies. The Compact LINAC has undergone important upgrades enabling the facility to deliver an increased accelerating gradient and beam energy of 6 MeV [2].

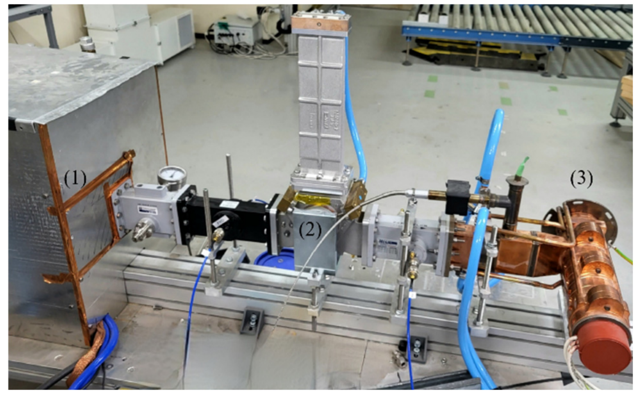

Figure 1: The Compact LINAC in the LTF. The main components are (1) 3.1 MW S-Band Magnetron, (2) 3-Port Circulator and (3) the 6 MeV Linear Accelerator.

The Compact LINAC uses a commercially available 6 MeV linear particle accelerator manufactured by AcceleRAD Technologies, Belmont, USA. The S-Band LINAC produces electrons and X-rays and is powered by a tuneable S-Band Magnetron, see Figure 1. The pulsed RF frequency is 2.998 GHz, and the peak output power is 3.1 MW. The Compact LINAC's RF repetition rate is from a single pulse up to 400 Hz with a pulse width from 0.5 to 4 μs [3].

In this paper, the Compact LINAC system is described, and operating conditions specified. Further, a few examples of work are listed to show the wide range of application possibilities with the system.

OPERATING CONDITIONS

The system comprises a Teledyne e2v AMM1 modulator [4] and MG7095 magnetron [5] paired with a Teledyne e2v electromagnet* an AFT three-port circulator, AcceleRAD 6 MeV LINAC, and bespoke Electron gun driver. The combination of the AMM1 modulator and magnetron with electromagnet allows for a wide range of operating points, see Table 1 and Figure 2. The pulse width and repetition frequency can be changed quickly and easily allowing for the output dose rate to be controlled.

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Table 1: Typical Operating Conditions

Operation parameters	Value
RF Repetition Rate	50 Hz - 400 Hz
LINAC Forward Power	1.3 MW - 2.2 MW
Pulse Width	0.5 µs - 4 µs
Peak Pulse Beam Current	35 mA - 240 mA

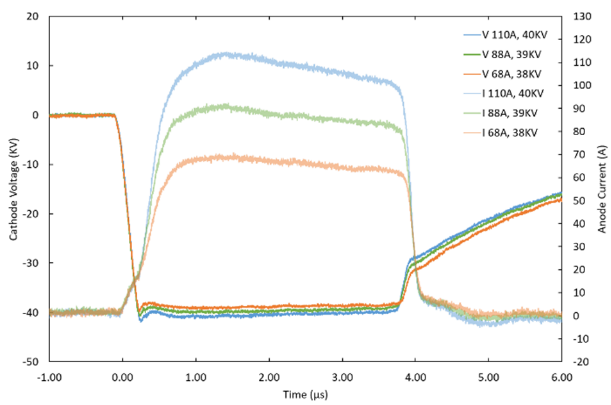

Figure 2: Cathode voltage and anode current measured on the magnetron in the Compact LINAC system.

WORK CONDUCTED

A few examples of research and development specifically geared towards testing the next generation of environmental and security technologies are outlined in this section. These collaborative works were conducted by STFC and their end-customers and users.

The efficient and secure movement of goods is important for national security and economic prosperity. Rapiscan Systems was interested in generating three-dimensional X-ray images for more comprehensive cargo screening to improve the detection of contraband and illicit material hidden within dense metal objects. STFC's Daresbury Laboratory provided Rapiscan Systems with the ideal environment to perform the proof-of-principle and proof-of-concept experiments. The LTF enabled the team to test the technology at high energy levels of up to 6 MeV and allowed for scattering X-ray photons off a variety of materials. Its novel detectors provided valuable information to the scientists at Rapiscan Systems as they aimed to reduce the amount of scatter. These experiments are designed to examine the time of flight of the photons between the source of the X-ray photon and an object, allowing algorithms to approximate the position of an object. This type of photon counting can be done only at Daresbury Laboratory due to its high-precision equipment and controlled conditions. Rapiscan Systems has been able to test, validate, and improve products and processes with the assistance provided by STFC more effectively [6].

As the global population increases, securing enough supplies of clean, safe freshwater is a critical priority and using our current resources more efficiently needs to be part of this. Since farming is one of the largest consumers of freshwater, reusing wastewater within agriculture could have a significant impact, however existing techniques are limited and difficult to apply at scale. The main issue with using wastewater from industrial sources within agriculture is the presence of contaminants which can then accumulate in plants and seeds. Researchers from the University of Surrey supported by the STFC 'Food Network+' approached treating wastewater with pulses of electrons that will react with organic compounds and instantly degrade them. Using electron beams produced by the Compact LINAC system in the LTF could purify wastewater to a very high standard within minutes. To assess whether this water could safely be used for agricultural purposes, the team have been testing the purified water on plants (such as lettuce and beans) grown in petri dishes. Reassuringly, the results showed little difference between tap water and the purified wastewater, with the seedlings appearing completely healthy with no growth defects [7].

Teledyne e2v characterised the system performance, looking at how the system responded to changes in magnetron output, see Figure 3. The amplitude and phase of the forward and reflected power were studied.

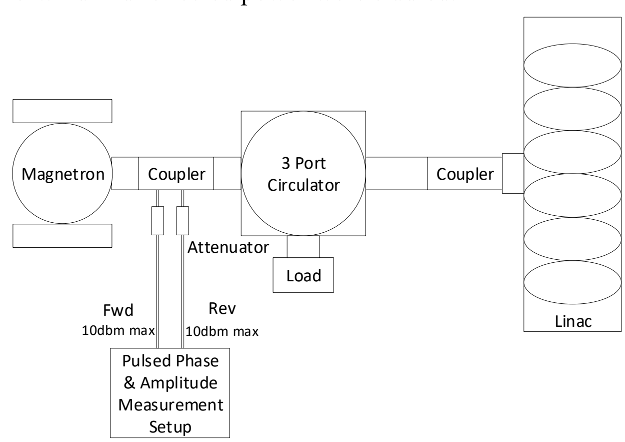

Figure 3: Set-up of measurement apparatus for characterisation of the Compact LINAC.

The phase and amplitude of the reflected power to the magnetron was measured during pulsed operation to allow characterisation of the frequency pulling* phenomenon. Phase is measured with respect to the forward power signal, at fast speed (nanoseconds scale) and sub-degree resolution. RF amplitude is measured and calibrated to sub-percent resolution, see Figure 4.

The phase and amplitude information gathered, gives understanding of the RF behaviour of the circulator and LINAC combination under different operating conditions such as: peak power, duty cycle, electron beam loading and coolant temperature. This knowledge is particularly useful in a LINAC system during development and commissioning phases to optimise RF performance. The information gathered will inform Teledyne e2v in subsystem building, allowing for improved integration of components in the RF subsystem offering.

* Frequency Pulling is when the source output frequency is changed due to the reflected power from the load.

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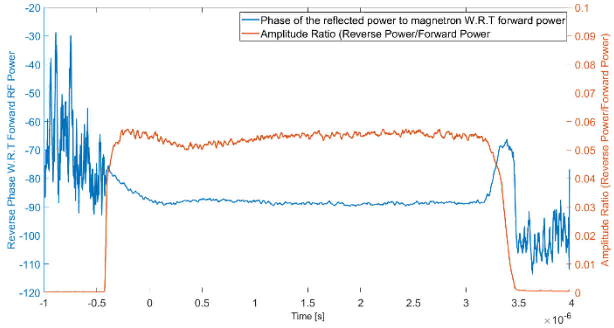

Figure 4: S11 phase and amplitude response of the Compact LINAC RF chain (at LINAC resonant frequency) averaged over 50 magnetron pulses.

SUMMARY AND OUTLOOK

The collaboration between STFC Daresbury Laboratories and Teledyne e2v has been very positive with progress being made in research and development across sectors using the upgraded Compact LINAC. This collaboration has also provided a valuable opportunity for Teledyne e2v to explore the use and limits of components in beam-producing systems, enabling this knowledge to be used for future developments.

Possible future upgrades and product support for the Compact LINAC will include Teledyne e2v's next generation of magnetrons and modulators; providing better life, monitoring and stability.

This collaboration and the work on the Compact LINAC will be carrying on into the future, facilitating users to have access to a reliable world-class system for x-ray and electron beam research.

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