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THE SOUTHERN HEMISPHERE'S FIRST X-BAND RADIO-FREQUENCY TEST FACILITY AT THE UNIVERSITY OF MELBOURNE

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Abstract

The first Southern Hemisphere X-band Laboratory for Accelerators and Beams (X-LAB) is under construction at the University of Melbourne (UoM), and it will operate CERN X-band test stand containing two 12 GHz 6 MW klystron amplifiers. By power combination through hybrid couplers and the use of pulse compressors, up to 50 MW of peak power can be sent to any of 2 test slots at pulse repetition rates up to 400 Hz. The test stand is dedicated to RF conditioning and testing CLIC's high gradient accelerating structures beyond 100 MV/m. It will also form the basis for developing a compact accelerator for medical applications, such as radiotherapy and compact light sources. Australian researchers working as part of a collaboration between the University of Melbourne, international universities, national industries, the Australian Synchrotron -ANSTO, Canadian Light Source and the CERN believe that creating a laboratory for novel accelerator research in Australia could drive technological and medical innovation.

INTRODUCTION

The bunker in the basement of the UoM School of Physics - previously used to house a 35 MeV electron accelerator (betatron [1]) until the late 1980s - has been identified as the ideal location for the new accelerator laboratory called X-Lab (Fig. 1). With some modest refurbishment, this space will become the first high-power, high-frequency accelerator laboratory in Australia and one of only a few in the world. At the heart of the project is the technology transfer from the Partner Organisation CERN in the form of the multimillion dollar compact X-band accelerator radio frequency (RF) system known as XBOX3 [2, 3]. XBOX1 and XBOX2 use similar technologies to the original klystron-based test facilities in Japan and the US. These use costly, high peak power, 50 MW klystrons which require modulators capable of producing up to 450 kV. However, XBOX3 uses twin low peak power, 6 MW Toshiba E37113 klystrons and ScandiNova K1 modulators . The use of half XBOX3 (Fig. 2), renamed Mel-BOX , in this project will give the Australian research community a powerful boost into the latest developments in future accelerators. The project will provide a unique test facility for initial testing of accelerating structures for the CLIC [4] future collider programme. Without the electron source, X-LAB is limited to testing RF components only. The integration of an electron source, scheduled for phase two, will provide a unique test facility for initial light source developments.

Figure 1: X-Lab pictures, after unloading the container.

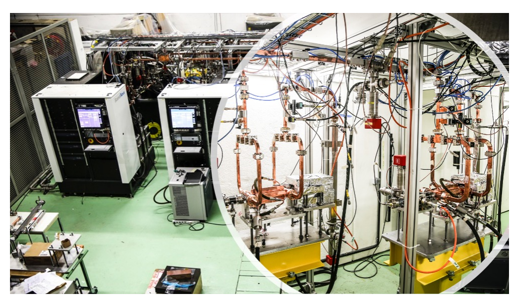

Figure 2: CERN X-Band facility view.

STRUCTURE CONDITIONING

Mel-BOX is the the core of the X-Lab, it consists of half XBOX3, two twin low peak power, 6 MW klystrons. High peak powers are achieved by combining the output power of these klystrons and using pulse compression. This process allows the production of about 50 MW for a 200 ns pulses at much higher repetition rates than would be possible with the single, 50 MW klystrons used in previous high frequency test stand facilities. CLIC prototype structures require 40-50 MW of RF power to reach a unloaded gradient of 100 MV/m. High-gradient accelerating structures take several hundred millions pulses to condition to nominal operating conditions [2]. It is therefore advantageous to make

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testing facilities that can pulse at high repetition rates, in order to reduce the time needed to condition structures.

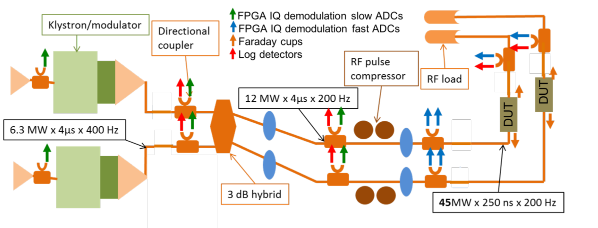

Figure 3: Schematic of the high power RF network of the X-Lab facility.

Depicted in Fig. 3 is the layout of the Mel-BOX waveguide network. To achieve the peak power necessary, two klystrons are combined through a hybrid and subsequently compressed using a SLED-I pulse compressor [5]. By changing the phase difference between the two klystrons, the power can be split in any ratio to either of the hybrid outputs. Under normal operating conditions the power is sent to each slot in an alternating fashion. The pulse repetition rate of each klystron can be increased up to 400 Hz, consequently each test stand can operate up to 200 Hz. An in-house built RF frontend and a FPGA bases NI PXI system for high speed digital data processing form the Low Level RF system. The RF drive signals are produced using NI 5793 IQ generators at 2.4 GHz. The arbitrary IQ signals are externally up converted to 12 GHz. NI-5793 RF Adapter Modules provide bidirectional computerised I/O lines steered from the FPGA to empower advanced device under test control and straightforward advanced conventions including phase modulation for pulse shaping of the SLED-I and pulse by pulse changes.

After the hybrid combination each line has a PC, test slot for the device under test and an RF stainless steel load to terminate the waveguide network. Directional couplers are placed at critical locations in the network for monitoring purposes. There are several control loops controlling the stability of the RF power distributed to the waveguide network. Pulse- by-pulse changes can be made to the drive signal which allows the two test slots to operate independently. The waveguide network is kept under UHV supported by several Ion pumps and all water cooled for thermal stability and personal safety. The new waveguide layout for X-Lab could also be shortened to reduce the transmission losses of 0.1 dB/m@12 GHz while benefiting in more available RF power.

Figure 4 shows the layout of the Mel-BOX test stand facility inside the underground 70m^2 X-Lab bunker. The modulators are seated in the controlled radiation areas, the structure test stands will be placed in the radiation area secured by a chicane and interlock gate.

In industrial and commercial use facilities need to be able to predict breakdown as a function of gradient and pulse width to ensure reliability of operation while in collider applications the large number of RF structures also require reduced likelihood of breakdown [6].

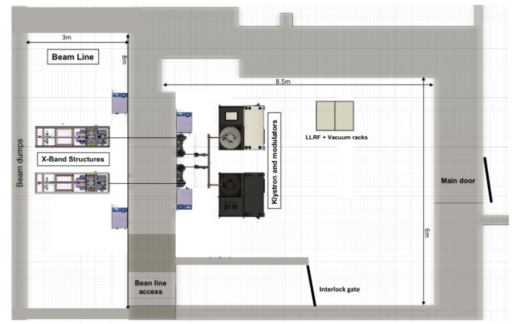

Figure 4: Layout of the Mel-Box at the X-Lab bunker.

Each RF breakdown causes a destructive sideways kick to the particle bunches, leading to loss of beam transmission. It can also destroy the accelerator by reflecting power back towards the RF driver, damaging accelerating structures and klystrons and creating unwanted radiation. Breakdowns can affect operation of testing facilities, like the X-band test stand this project relies on. This is why accelerating structures are conditioned before operation, ensuring operation all the way up to their full operating power level. The process of conditioning requires a time-based variation of input pulses done in a reliable and repeatable fashion for the accelerator to attain the lowest possible breakdown rate. Despite many years of study, the exact time when a structure will experience breakdown and the best way to prepare a structure to avoid this is not known at any frequency, let alone at X-band. Variables in conditioning include pulse width, pulse shape, pulse rise time, power level, overall conditioning time among others and the present conditioning process is governed based on experimental experience but is not optimal. A typical conditioning plot is shown in Fig. 5. Two high gradient CLIC prototype structures (TD24BO and TD24UBO) have been tested at CERN before been shipped to Melbourne, they already reached a gradient of about 100 MV/m. More tests will be done at the X-Lab.

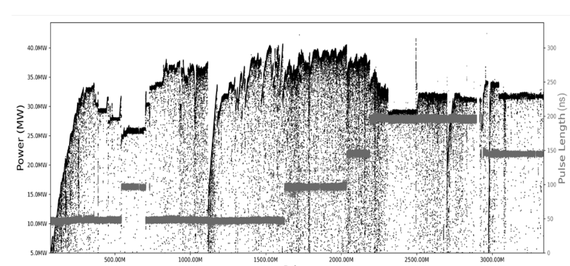

Figure 5: Conditioning history plot of one of the two TD24 structures tested at CERN. This structure so far reached 40.45 MW which is correspond to a gradient of 97.9 MV/m

Around 20 prototype structures have now achieved an accelerating gradients of 100 MV/m, an order of magnitude higher than existing S-band technology (Fig. 6). If this breakthrough technology could be used in applications, accelerators could be 5-10 times smaller than existing devices,

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with the potential for cost reduction and new applications as a result.

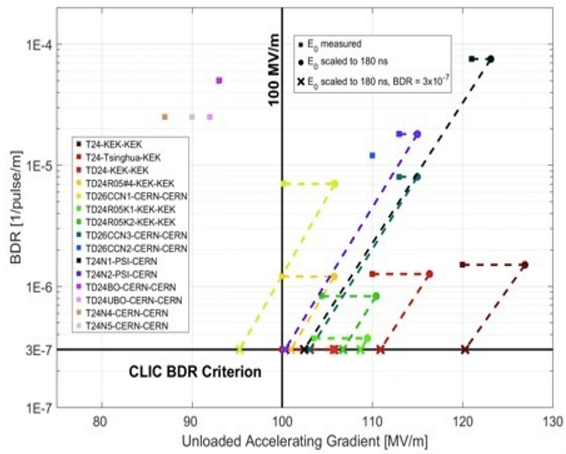

Figure 6: Conditioning summary plot of CLIC prototipe structures rescaled to the CLIC breakdown rate ($3x10^{-7}$) and to the CLIC pulse width (180ns). T24N4 and T24N5 conditioning underway, TD24BO and TD24UB will be re-conditioned in Melbourne.

A COMPACT ACCELERATOR

The X-LAB beamline upgrade focuses on achieving two time-critical major goals for the research community development of novel particle accelerator technology and flexible electron beams for end-user research. The development of small, lightweight, 12 GHz electron accelerators alongside their future applications will create both near-term and long-term impact. In this project we will be taking the technology from test to application. With collaborators, willing to provide an electron gun, we will accelerate electrons using high gradient X-band structures. This project is seen as the first of perhaps many future collaborative ventures, integrating an electron source, adding a diagnostic beamline to measure accelerated electron beams and creating an end-user station. The layout of the beam line is shown in Fig. 7. This upgrade will enable the first high-frequency high-gradient compact electron accelerator in the Southern Hemisphere that will lead to new knowledge in accelerator physics and technology.

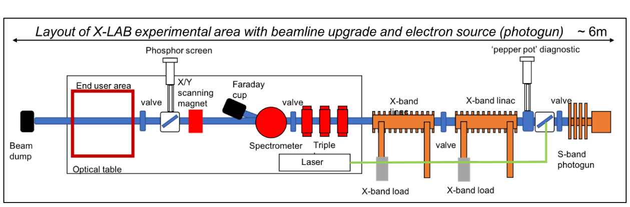

Figure 7: Preliminary layout of X-LAB experimental area with beamline upgrade and electron source (photogun).

After capture and acceleration, preliminary simulations show the system will be able to provide: electron beams with available energies up to 40 MeV, a 125 keV energy spread, emittance of 1 π.mm.mrad and pulse length of 150 µm. The beamline will consist of 1.5 cell clamped S-band RF photogun, two X-band accelerating structures operating at an average accelerating gradient of 70 MV/m, a magnetic quadrupole triplet used for focusing the beam, the end user facilities and a beam dump. The pulse rate will be 3 Hz based on the S-band gun but could be upgraded in future. Charge per bunch is 0.1 nC and dose rate is 12 mJ/sec. All parameters are tunable, these represent the optimum set. We next aim to add a down-stream beamline to characterise the accelerated electron beam including a magnetic spectrometer (energy measurement), emittance measurement system (beam quality) and faraday cup (beam current). This is essential in order to measure beam properties of the electron gun and commissioning of acceleration. An overview of the bunker with the photogun, X-band structures , modulators and beam diagnostic is shown in Fig. 8.

The upgraded X-LAB facility with its strong accelerator physics underpinning also has capacity to transform accelerator applications identified in discussions with industry, who need small portable accelerators for use in the field for minerals exploration, security scanning and radiotherapy in remote areas. Accelerators are already a key technology in cancer treatment, new therapy ideas based on novel accelerator technology are constantly emerging, from microbeam radiation therapy to the exciting potential of 'FLASH' [7] high dose-rate radiotherapy using Very High Energy Electrons (VHEE). Of particular focus is a 150-250 MeV X-band electron accelerator for VHEE [8].

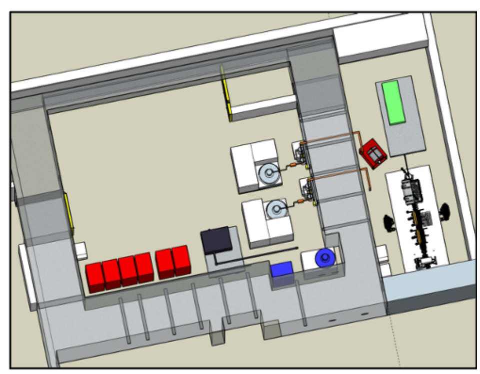

Figure 8: Preliminary layout of X-Lab bunker with the beamline.

CONCLUSION

As a result of a decade collaboration between UoM, The Australian Synchrotron and CERN, a multi-million-dollar package of X-band equipment has been sent to Melbourne to serve as the central infrastructure for further development in the new X-Lab. The project will provide training and research opportunities for the next generation accelerator physicists for Australian science, medicine and industry. Refurbishing of the Melbourne University basement is going on, the first high power X-band pulses are planned for the end of 2021.

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