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OPERATIONAL EXPERIENCE WITH A SLED AND MULTIBUNCH INJECTION AT THE AUSTRALIAN SYNCHROTRON

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Abstract

The Australian Synchrotron Light Source has been using multibunch injection successfully with a Stanford Linear Energy Doubler (SLED) powered LINAC since 2017, considerable experience has been gained since then. The SLED has proven to be stable beyond expectations and has greatly simplified LINAC tuning by providing a single high power Radio Frequency (RF) source. Despite the energy variation over the 140ns injection period it was possible to capture the entire bunch train.

INTRODUCTION

The Australian Synchrotron uses an S band Linear Accelerator (LINAC) comprising of 2 main accelerating structures each supplied by a Thales TH2100 37MW pulsed klystron, to achieve 100MeV total acceleration. Over time the LINAC was tuned to require 14.5 MW RF power per structure. Single point of failure reduction imperatives led to an investigation into operating on one klystron leaving the other klystron as a redundant spare. Testing with a single klystron failed [1] to achieve the required power levels due to klystron arcing at higher power levels. So a SLED was settled on as a means to achieve that end. The facility injects a 140ns bunch train requiring the accelerating RF to be fairly constant for that period to enable capture of the entire bunch train by the booster. A SLED with a lower Beta of 3.5 was specified [2] to reduce the decay of the enhanced pulse and limit peak power to 45 MW while being compensated by a longer >5 µs klystron pulse width. As part of the SLED installation a high speed I/Q based phase and amplitude waveform detection system was installed [3] to replace the sample and hold based system.

SLED COMMISSIONING

To select a suitable injection time the charge time constants for the accelerating structure and the decay time constant of the SLED were modelled as switched RC circuits with circuit simulation software (SPICE) giving a phase flip time within 50ns of the final value and this has not been changed since. The RF pulse was lengthened to 5.5µs thereby including some of the High Voltage (HV) pulse before and after the flat top, no problems were observed. Injection point was timed to occur before the phase rotation due to the falling High Voltage (HV) pulse begins, we do not care what happens to the klystron phase after the electrons are injected so long as it does not result in excessive reflected power. The power balance of the structures was optimised in normal pulsed mode and this balance was retained for the SLED mode. Peak power was set using the data from the SPICE simulation. It was not possible to compare the RF phase in the structures pre and post installation requiring 6 hours of tuning to get capture in the booster Tuning the LINAC for optimum booster capture was relatively simple using a fast current transformer (FCT) to monitor the captured charge, if the energy was too low the bucket train was rounded if was too high the bucket train had a dip in the middle. The optimum energy point is in the middle of the bunch train giving this the highest energy.

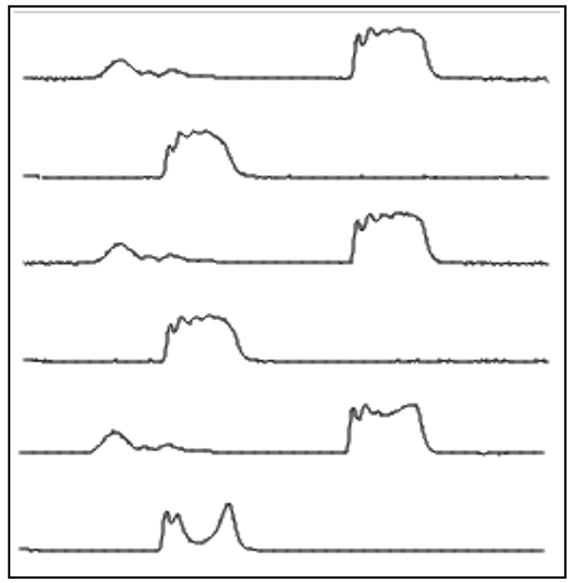

Figure 1: Capture vs energy.

Figure 1 represents three sets of bunch trains being captured at the under energy, optimum energy and over energy conditions top to bottom respectively The energy peak occurring in the centre of the bunch train can clearly be seen in the bottom pair of traces. The bump before the injected bunch train is an artefact of the injection kicker.

SLED OPERATION

Various phase flip techniques have been tested including:

- Switched transmission lines using mincircuits ZFSWA2-63DR connectorised switches and coaxial achieving a phase flip in 50ns
- Fast switched microstrip transmission lines using Hittite microwave HMC221 switches achieving a phase flip at the switch of 2ns (Fig. 2)
- Vector modulation with an I/Q modulator and linear ramp flip in 40ns (Fig. 3).

All techniques could accelerate the entire 140ns bunch train to 100MeV with the vector technique giving the best overall result. Currently we use the fast microstrip based

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phase flip with plans to convert to a profiled vector phase flip sometime in the future.

Our SLED cavity is a Q 100000 device from Research Instruments (RI) patterned off a MAX IV SLED with the Beta changed from 6 to 3.5. Initial calculations based on the thermal expansion coefficient and Q [4] suggested that is might be fairly temperature sensitive requiring temperature control of +/- 0.05 degrees. It turned out to operate fine with +/- 0.2 degrees temperature control.

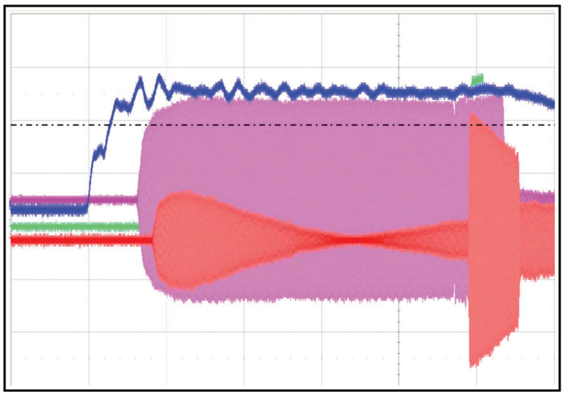

Figure 2: Fast phase flip.

Figure 3: Vector phase flip.

The SLED cavity pair includes two separate motors for fine-tuning each cavity to resonance within a limited elastic deformation range. The following picture shows the SLED before tuning and the two peaks of the cavity pair (Fig. 4).

Fine tuning was carried out before installation in the lab with a network analyser at 40 ºC and 1 mBar. Pre-tuning was almost spot on as later shown during commissioning. The mechanical design and limited elastic range on the other hand restrict the motors for ongoing tuning. Detuning is therefore achieved by changing the operating temperature from 40 ºC to 20 ºC within a couple of minutes and useful to bypass the SLED to switch back to LINAC operation with two klystrons.

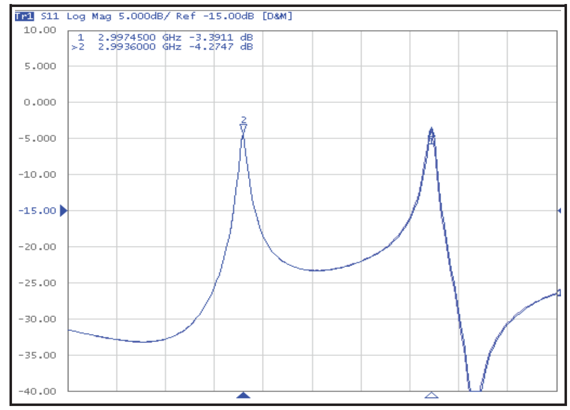

Figure 4: Detuned cavity pairs.

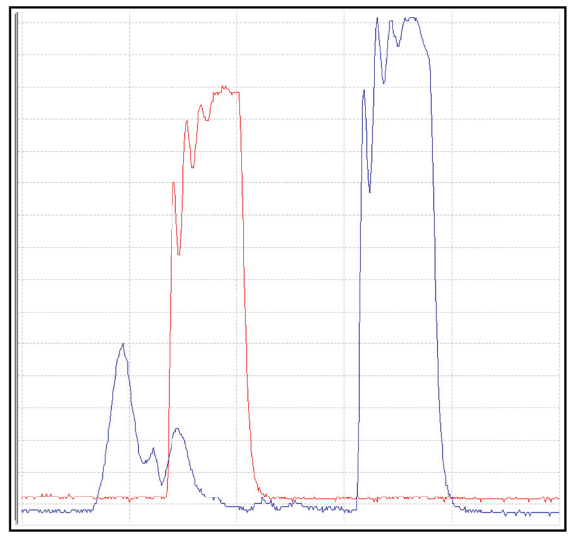

Figure 5: Capture.

Figure 5 shows the bunch train at the source in red and captured by the booster in blue indicating that the entire 140ns bunch train was able to be accelerated.

We are monitoring the phase and amplitude of all accelerating structures using hardware from EICSys Gmbh. The phase measurements from this system are stable and repeatable making it possible to set up most of the LINAC using these measurements with only minor power tuning required to optimise the output.

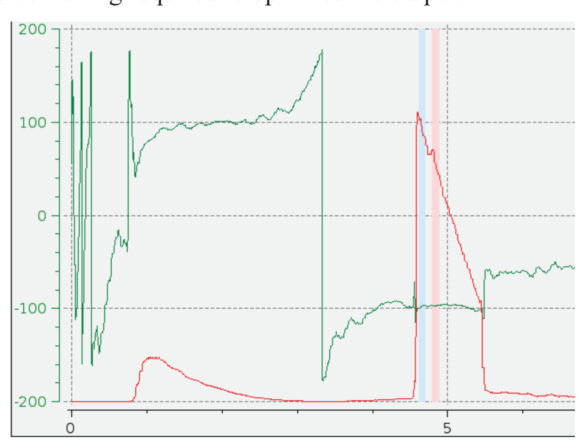

Figure 6: Phase monitor.

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Figure 6 represents the phase of the SLED output in green and the amplitude in red with the blue band representing sample point one and the red band sample point two (injection). These sample points are used to adjust the phase and power of the system to a known working condition. The phase setpoints are repeatable enough not to require any subsequent adjustment while the readback is more to diagnose any anomalous conditions. On the other hand there is significant power variation primarily from the klystron driver amplifier which needs to be corrected from time to time

CONCLUSION

Operationally the SLED has been successful, it has not required any adjustments in 2 years of operation furthermore it has reduced the phase sensitivity full width half maximum (FWHM) of the LINAC from +/- 2 degrees when RF power is supplied by 2 klystrons to +/- 10 degrees with a single SLED RF source. Removing the 2nd Klystron with it's inherent voltage dependent phase shift has made the linac "set and forget", it can be brought to operation by loading setpoints or tuning to prior phase and power readbacks. There is some power drift due to the temperature sensitivity of the existing driver amplifiers. Plans are under way to replace the driver amplifiers with temperature stabilised units optimised for low duty cycle operation

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