REPORT ON SUPERCONDUCTING RF ACTIVITIES AT ANU

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Abstract

This paper describes the commissioning of a new RF Control System that was funded by a LIEF Grant Project* that included RF control modules from the Bhabha Atomic Research Centre (BARC) India, computer Interface Modules from Group3, Auckland New Zealand and power amplifiers from Dressler, Germany. The hardware to operate stepping motors and implementation of Computer Control System was undertaken at ANU. The system was implemented in February- May 2005 when it was used to accelerate LINAC beams of $^{16}O^{+5}$ and $^{58}Ni^{+22}$ injected from the14UD. The system demonstrated very high stability, simplicity of operation and high reliability allowing sustained operation of the LINAC facility. Efforts are now devoted to the development of the low velocity two-stub resonator.

RESONATOR RF CONTROL SYSTEM

The resonator controller modules are housed in a NIM style crate that contains modules to operate up to four resonators as shown in figure 1. The modules are: (1) 4 Resonator controllers; (2) 1 Resonator Controller Support Electronics; (3) 1 Input Module; (4) 1 Reference Phase Shifter Module.

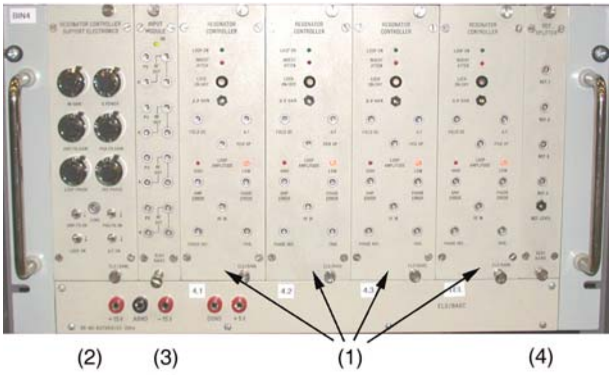

Figure 1: RF Control NIM bin at ANU: (1) Resonator controller, (2) Resonator Controller Support Electronics, (3) Input Module and (4) Reference Phase Shifter Module.

The main features of the RF Control System are: frequency range: 105 to 175 MHz; range of input gain: 40 dB; input range for amplitude and phase locking: -10 dBm to +20 dBm; Quiescent Output: +10 dBm; Quiescent Output Control Range: 20 dB. Each resonator operates as a self-excited loop, which is formed by a feedback signal from the resonator, the RF control module and the power amplifier. The reference Splitter module receives the reference clock signal as input and splits it into four outputs with the nominal level + 10 dBm for an input signal range from – 10 to + 10 dBm.

The Resonator Controller includes the loop phase shifter and the limiter. For phase locking, a suitable phase reference is derived from the output of the Reference Splitter Module. The amplitude reference is generated in the Resonator Controller Module by setting the input gain attenuator. The resonator Controller performs low-level signal processing and generates the drive signal for the amplifier to maintain phase and amplitude stability. Its operation is based on supplying quadrature power as the resonator center frequency varies. The product of the peak frequency excursion and energy content of the resonator determines the incident power required. This control strategy has been found adequate for the ANU QWRs and SLRs in spite of the fact that the SLRs have quite poor mechanical stability with a field derived frequency shift up to $-100E_{acc}^{2}$. The RF power requirement for an SLR is 100-120 W at an operating field of 3-3.5 MV/m.

COMPUTER CONTROL SYSTEMS

A VME crate, with a RT Vax Crate controller, controls a Group3 module, which communicates over fiber optics at 1 Mbaud to distributed device interfaces (DI) on two independent loops. Each loop has seven DI’s (maximum 16) each of which contains 3 interface cards and a Group3 control computer. The DI’s are configured with DAC, ADC, DI0 and stepper motor cards, figure 2.

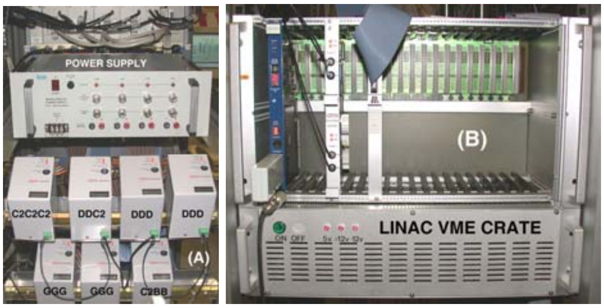

Figure 2: (A) A combination of 7 Group3 DIs services 8 RF Controllers and 16 stepping motors - *C2*: 8 ADC inputs -*D*: 8 analogue outputs - *G*: Logic drivers control up to 4 stepper motor; *B*: 24 digital channels, input and output. (B). Loops of DIs are controlled from a VME crate.

A diagnostic port allows local configuration and control of modules independently of the loop controller - a useful feature for testing the system. The VME crate is a part of a distributed accelerator control system that has been in

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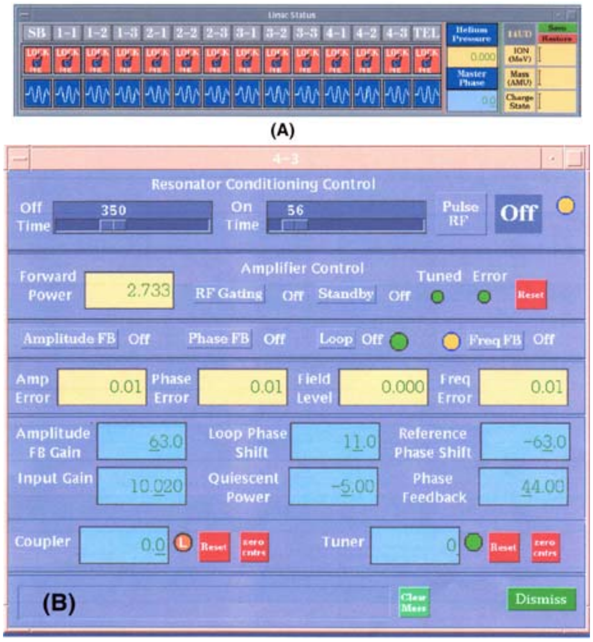
operation for 10 years. A VAX 4000 computer is linked via Ethernet to 5 VME crates. Each crate controls of variety of I/O modules some of which are GROUP3 loop controllers. The VAX computer issues control messages and performs some high-level functions, while VME crate computers control the devices modules. A central database contains all device control and monitoring parameters. Separate graphical interface processes allow the operator to interact with the control process, communicating through shared memory. Many graphics processes can be active simultaneously, displaying either on a single or on multiple terminals [1].

Figure 3 displays the features of the LINAC status (A) and resonator control (B) panels. The resonator Control Panel, figure 4(B) operates resonator selected. For controlling an individual resonator, different modes of operation ON, OFF and PULSE can be set. The duty cycle in the PULSE Mode can be controlled with independent selection of the ON and OFF periods. The system also allows setting parameters for all resonators simultaneously: turning loops and feedbacks ON and OFF and shifting a Phase Reference.



Helium Pressure 0.000
Master Phase 0.0
Off Time 350
On Time 56
Forward Power 2.733
RF Gating Off
Standby Off
Amplitude FB Off
Phase FB Off
Loop Off
Freq FB Off
Amp Error 0.01
Phase Error 0.01
Field Level 0.000
Freq Error 0.01
Amplitude FB Gain 63.0
Loop Phase Shift 11.0
Reference Phase Shift -63.0
Input Gain 10.020
Quiescent Power -5.00
Phase Feedback 44.00
Coupler 0.0
Tuner 0

Figure 3: (A) Graphical virtual LINAC status and (B) resonator control panels.

The LINAC panel displays status of all resonators, amplifiers and the helium gas pressure in the cryostats. It also displays and controls the phase reference across entire LINAC (Master Phase). The system selects and, using the buttons, activates the resonator control panel. All control parameters can be saved and restored at later stage.

COMMISSIONING RF AND COMPUTER CONTROL SYSTEMS

The commissioning included initial tests of the RF electronics, stepping motor controller and computer control system, low- and high-power conditioning, tuning, phase locking, operation of each cavity and the entire LINAC and finally delivering 343 MeV ^{58}Ni beam for Nuclear Physics experiments.

The cross talk tests of the RF Control System failed to detect any interference between different sections of RF Control System.

Pulse Conditioning – High Power Processing

It was during commissioning that a peak power up to 500 W was, for the first time, readily available for each SLR. Due to a tight schedule, the high power processing (HPP) time was limited to 30 minutes per cavity during which time the performance of the SLRs improved by 10-20%. The improvement was stable after HPP during the several weeks of Linac operation including an accidental warming up of the LINAC from 4.2K to ~20K. A longer HPP time combined with He processing should lead even to higher accelerating filed in the SLRs.

Final Performance Test

Q values were determined, after conditioning, by measuring the exponential fall of the stored energy immediately after the input power was switched off. During Q measurement, the loop pulsed period was 500 ms ON and 500 ms OFF. The best resonator achieved 3.7 MV/m at 6 Watts as inferred from the energy gain of a ^{58}Ni^{+22} beam. The *Q* and X-ray intensity versus E_{acc} curves of the resonator 3.1 obtained during commissioning are shown in figure 4.

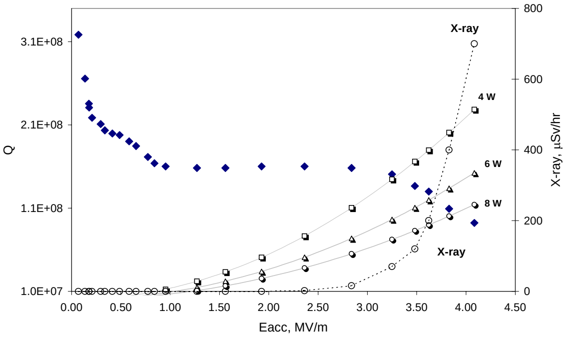


Figure 4: *Q* and X-ray flux versus E_{acc} curve of the resonator 3.1. Lines for absorbed power versus E_{acc} at 4, 6 and 8 W are shown.

Typically, in the ANU SLRs, *Q* fell sharply at very low field presumably due to losses in the RF gaskets. The second fall was observed at $E_{acc} > 3$ MV/m as a result of field emission.

Resonators Set-Up for Acceleration

The overall layout of the ANU Booster is shown in figure 5 [2].

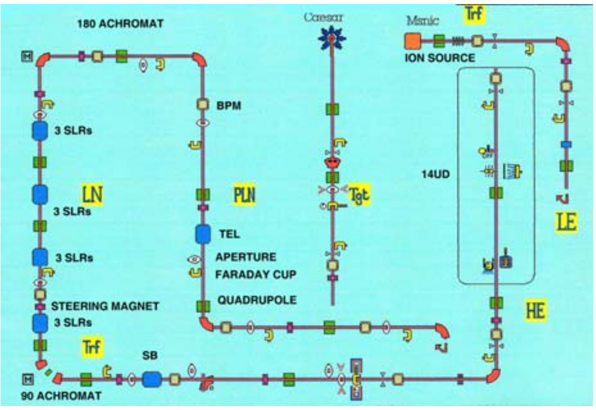


Figure 5: ANU superconducting booster.

During commissioning, two species of ions $^{16}O^{+5}$ and $^{58}Ni^{+22}$ were accelerated with the Ni beam used for a physics experiment. A $^{58}Ni^{+22}$ beam was produced using a 4 μg/cm^2 carbon foil in the terminal of the 14UD and an external LINAC stripper foil 8 μg/cm^2 thick. All cavities were tuned and locked at nominal incident power and coupling strength to establish the RF power level that the LHe plant and cryogen distribution system could sustain. Then the cavities were turned off by switching the RF amplifiers to Standby. The DC and pulsed beams were then tuned through the LINAC. Finally, the cavities were turned on and locked, one by one, without changing any settings in the RF control loops.

The determination of the bunching and acceleration phase of the QWRs and SLRs was done by interpreting the BPM trace in the middle of 180 degrees achromat. The energy dispersion at this location, allowed observation of the energy of the beam as it was affected by each successive resonator. The crossover phase and its type, 0 or 180 degrees, was inferred by variation of the resonator phase from 0 to 360 degrees. The acceleration phase was set at –18 degrees with respect to the maximum acceleration phase for phase stability. An unwelcome by-product was over-bunching which was evidenced by a wide BPM trace equivalent to a wide energy spread. To counteract this, the acceleration phase was set to +18 degrees when this lead to an improvement in beam profile. Typically this was necessary in 2-3 cavities across the LINAC.

The accelerating field E_{acc} achieved in each SLR operating on-line is shown in figure 6.

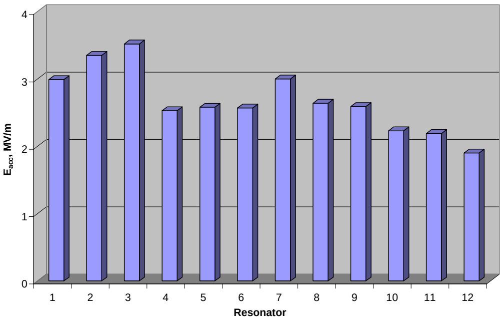


Figure 6: Accelerating field E_{acc} in twelve SLRs operating on-line.

The energy gain of the accelerated beam was determined by scaling the magnetic field in the first dipole of the 180-degree achromat. The energy of $^{58}Ni^{+22}$ beam was boosted from 210 MeV to 342.5 MeV. The performance reflects the evolution of the plating process at ANU. The worst resonators, numbers 10 to 12, were plated earlier with the Solderon MSA bath. The SLRs 4 to 9 were plated later with the Schloetter bath as were resonators 1 to 3 but with an improved technique.

Long-term Stability Test

During the physics experiment with $^{58}Ni^{+22}$ beam, the RF Control System demonstrated remarkable long-term stability. Figure 7 displays phase error signals of randomly selected SLRs running in four module cryostats recorded continuously during 72 hours.

The long-term phase stability across entire LINAC was within ±0.05°. Cavities 1.2 and 3.3 exhibited extremely slow oscillations of phase error signal but still maintained acceptable phase stability. This phenomenon has to be evaluated.

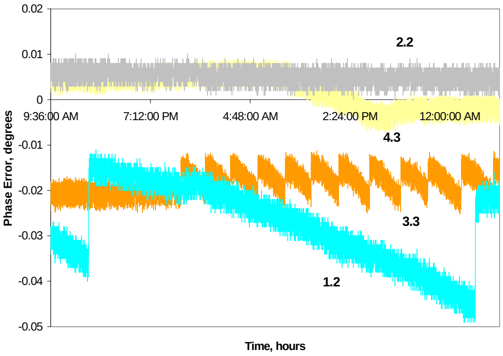


Figure 7: Long term stability of RF Control System. Recorded parameters are phase error of locked SLRs.

CONCLUSION

The control system for the ANU LINAC was successfully commissioned in May 2005 The new technology Resonator Control Cards (BARC), upgraded RF amplifiers and computer control demonstrated superior short and long-term stability and ease of set-up and control, sufficient to eliminate the need for a full-time dedicated technical operator. This represents a major improvement allowing uninterrupted user operation of the complete accelerator system, a mode not possible before.

REFERENCES

[1] P. Davidson and G. Foote, *Nucl.Instrum and Meth. in Phys. Res* A 382 (1996) 178-181.

[2] N.R.Lobanov and D.C.Weisser, *Low Velocity, Two-Stub Superconducting Resonator for Heavy Ion Accelerators*, Australian Institute of Physics, 16th Biennial Congress (2005)