RF CONTROL SYSTEM FOR ISAC II SUPERCONDUCTING CAVITIES

K. Fong, M. Laverty, S. Fang, TRIUMF, Vancouver

Abstract

The first phase of the ISAC II project consists of the acceleration of radioactive ions by 20 superconducting DTL's with a total effective voltage of ~20MV. Each of these cavities will be powered at a frequency of 106.08 MHz to a maximum field gradient of 6 MV/m. With unloaded cavity Q's of ~10^9, the RF control system for these superconducting cavities is based on a self-excited feedback loop. The self-excited frequency is stabilized by an internal analogue Phase-Locked Loop. A digital phase/frequency discriminator and a quadrature combiner are used to provide phase locking to an external frequency reference to allow all the cavities to run synchronously. The demodulated amplitude, phase, and frequency are feedback regulated with digital signal processors. This paper describes the RF control system and the experience gained in operating this system with a single test cavity.

1 INTRODUCTION

The control system used for the superconducting cavity test stand shares some elements with systems employed for the normal conducting cavities of the ISAC accelerator. The latter system has been documented in earlier papers [1], [2]. As previously mentioned, the very high Q of the superconducting cavities required a somewhat different approach. The design chosen was a self-excited system, with the cavity initially controlling the operating frequency. Once amplitude stability is achieved, the control system is used to achieve frequency and phase coherence between the cavities. The details of this design and some initial test results with a prototype cavity are outlined in the sections following. For further information on the ISAC and ISAC-II accelerators, several other papers will be presented at this conference [3],[4],[5],[6].

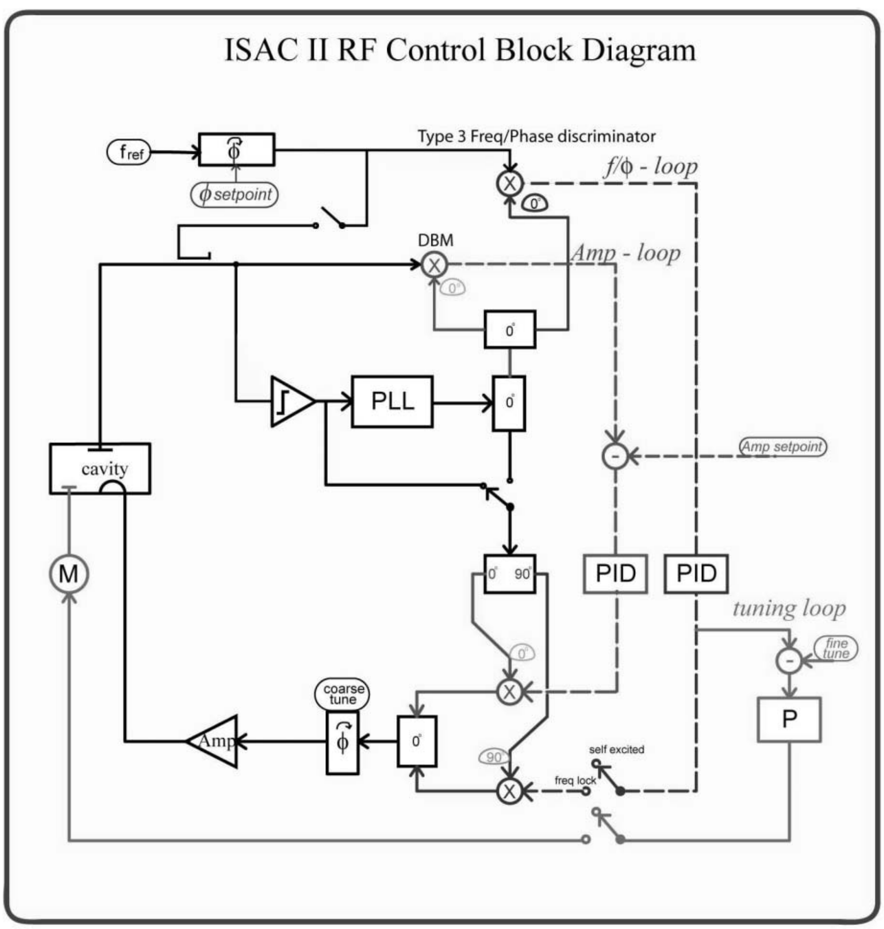

Figure 1 – System Block Diagram

2 RF CONTROL SYSTEM

A block diagram of the control system is presented in Figure 1. The system consists of a desktop PC, a VXI slot zero control module, and two custom modules housed in a VXI mainframe. The basic design is similar to that used for ISAC I, except for one important difference - instead of operating in driven mode, the system now operates in self-excited mode. The self-excited frequency is locked to an external reference by regulating the phase shift within the self-excited loop. Other diagnostic equipment not shown in the figure includes forward and reverse power meters, a frequency counter and oscilloscopes. These instruments are used to measure the accelerating field and Q of the cavity.

2.1 System Hardware

As seen in Figure 1, the amplitude detector is a synchronous demodulator, in which an internal Phase-Locked Loop supplies an amplitude-stabilized reference to be multiplied with the RF input. The detected signal is filtered, sampled and digitized at 3 k samples/sec and fed into a Motorola DSP56002 Digital Signal Processor. A lower than normal sampling rate is used because of the long time constant of the cavity when it is superconducting. The DSP is configured as a Proportional-Integral controller, providing amplitude regulation. The internal PLL output is also compared with an external master frequency source using a phase/frequency discriminator. The difference in phase is filtered by another DSP PI controller, whose output is used to control the quadrature part of the amplifier output. Because of this quadrature component, the self-excited frequency changes to a new value such that the phase shift due to the cavity exactly cancels the phase shift introduced by the quadrature circuit. The PI controller plus the integration provided by the phase discriminator enables zero steady-state phase and frequency error.

Supervisory tasks, which require low signal bandwidth but relatively complex decision logic, are performed with the desktop PC. Communication between the PC and the VXI mainframe is done via a FireWire (IEEE 1394) interface. Communication between the PC and the central control system is done via 100BaseT Ethernet. The same PC is also used for data acquisition, and communicates with instruments such as frequency synthesizer, frequency counter and power meters via GPIB.

2.2 System Software

There are two main functions of the system software:

- Control of the superconducting cavity.
- Data acquisition and calculation.

For controlling the cavity, the low level feedback control firmware for the DSP performs open and closed loop regulation, output limiting, as well as exchanges of status information with the supervisory processor. This software is hand coded in assembler. The supervisory processor performs the tasks of setting feedback loop parameters, local status display, and communication with the EPICS-based master control system. This and other Inter-task communication is performed using TCP/IP and UDP/IP packets. These high level controls are written using 32 bit C++ with Windows API's. In an effort to encapsulate and reuse the software as much as possible, most modules are compartmentalized into Component Object Modules. Figure 2 shows the deployment diagram of the system software using UML.

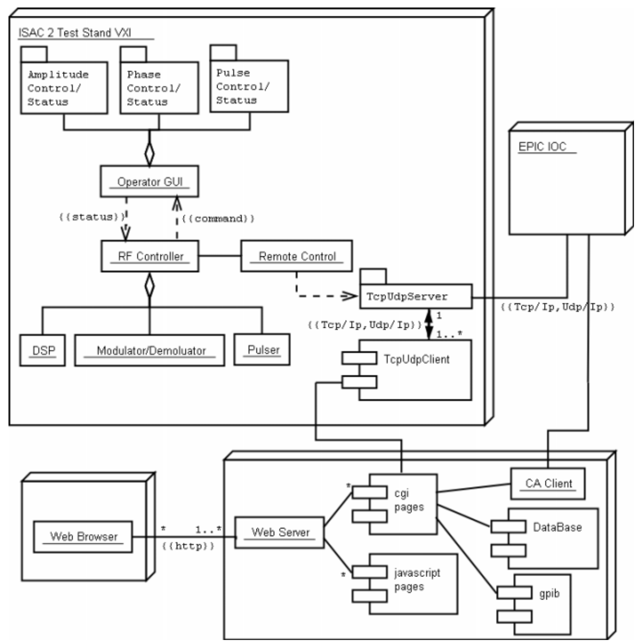

Figure 2 - Deployment Diagram of ISAC 2 Control System

For data acquisition, an Apache httpd server communicates with the control processor and GPIB instruments using Common-Gateway Interface. The same or another computer running a http browser can access the server and request data from the control processor and any other connected instruments. This enables data acquisition requests to be initiated in any computer. Data can be manipulated on-line, stored and retrieved using a relational database as indicated in Figure 2.

3 PROTOTYPE TEST RESULTS

The cavity was first tested on April 14, 2002. To initially power up the cavity, the coupling loop was moved inward to achieve over-coupling and reduce the loaded Q. An external signal generator, tuned to the estimated resonance frequency of the cavity, was injected through a directional coupler into the feedback input. This enabled setting the frequency of the system when the feedback signal level was too low for the self-excited loop to work properly. Once the self-excited oscillation starts, its feedback overrides the injected signal at the input of the internal PLL, and this injection source can be removed.

3.1 Multipactoring

Before full voltage operation can be achieved, the cavity has to be conditioned. Without conditioning, the cavity voltage rises until the multipactoring level is reached, and can go no higher. Getting the prototype cavity power above the multipactoring threshold proved to be quite difficult, at least until the cavity characteristics were understood. Once multipactoring is initiated, the cavity requires a minimum of 35 ms with RF power removed to recover. If the cavity does punch through multipactoring, however, to maintain the RF level above multipactoring threshold there must be no more than 6 msec between pulses. Otherwise the voltage will fall below the multipactoring level and may not recover in the next pulse. This is done at present by manually switching off the RF pulses when multipactoring is present. In the future this switching will done by an automatic voltage detector. Once the cavity voltage is above the multipactoring threshold the control system can switch to cw, the injected signal can be removed, and the system goes into self-excited oscillation. Then the coupling loop can be retracted and the loop phase adjusted in order to reduce the reflected power.

3.2 Amplitude and Phase Regulation

After the above adjustments, the amplitude-regulating loop can be closed. The amplitude regulation demonstrated by the prototype system is better than 0.25%. Since the system operates in self-excited mode, the self-excited frequency is locked to the external frequency reference by varying the phase shift of the loop. Figure 3 shows this phase correction due to frequency changes in the external source. In this measurement, the cavity is slightly over-coupled to increase the bandwidth of the cavity.

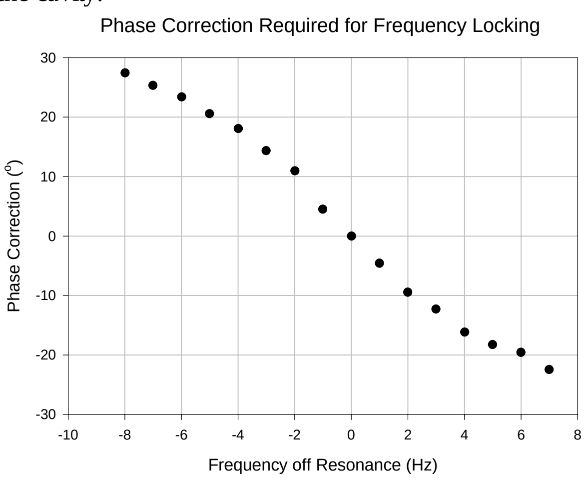

Figure 3 - Phase Correction Required for Frequency Locking

3.3 Helium Conditioning

In order to reduce electron loading at high electric field due to field emission, helium conditioning was performed on the cavity. Evaporated helium from the cryostat was fed into the cavity vacuum through a calibrated leak to a pressure of 10^{-5} torr. Figure 4 shows the original Q vs. E_a curve as well as the results after helium conditioning. The second curve was measured after conditioning the cavity at cw for 15 minutes at 200W. The third curve was obtained after 1 hour of conditioning at the same power. Before Helium conditioning, field emission began at 4 MV/m. After 1 hour of conditioning, the onset of field emission was increased to 5 MV/m.

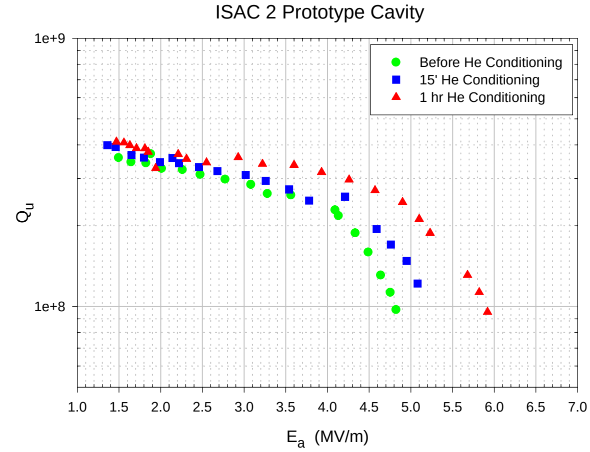

Figure 4 - Improvement in Q by Helium conditioning

4 CONCLUSION

This self-excited mode control system has been successfully tested with the ISAC 2 prototype cavity. It has demonstrated satisfactory operation during startup as well as good regulation of the cavity, both in self-excited and frequency-locked modes. The use of Helium conditioning on the cavity increased the threshold of field emission from 4 MV/m to 5 MV/m.

5 REFERENCES

[1] K. Fong, M. Laverty, S. Fang, “RF Control Systems for the TRIUMF ISAC RF Structures,” Proceedings of the 2001 Particle Accelerator Conference, Chicago, June 2001, pp. 948-50.

[2] M. Laverty, K. Fong, S. Fang, “Design and Testing of the ISAC RFQ Control System”, Proceedings of the 1999 Particle Accelerator Conference, New York, March 1999, pp. 890-2.

[3] R. Laxdal, Z.T. Ang, I.V. Bylinsky, G. Dutto, M. Pasini, R.L. Poirier, “Beam Commissioning and Operation of the ISAC Post Accelerator at TRIUMF”, this proceeding.

[4] M. Pasini, R. Laxdal, “Beam Dynamics Studies on the ISAC-II Post-Accelerator at TRIUMF”, this proceeding.

[5] M. Pasini, R. Laxdal, “An Isopath Achromatic Bending Section for Multi-Charge Ion Beam Transport at ISAC-II”, this proceeding.

[6] A.K. Mitra, Z.T. Ang, I.V. Bylinsky, P. Harmer, J. Lu, R.L. Poirier, B. Waraich, “RF Test and Commissioning of the Low and High Beta Bunchers for the TRIUMF ISAC Facility”, this proceeding.