

RF Control System for TRIUMF Booster Cavity

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Abstract

The 160 kV, 92 MHz booster cavity is amplitude and phase regulated by a VME/PC-AT based control system. The control system is partitioned into three subsystems: digital, analog, and rf, each with its own separate power supply and ground. Each subsystem is composed of field replaceable modules with different functions. The software of the system is also partitioned into modules, and Object Oriented Programming is used throughout. This modular design has significantly improved the ease of maintenance and it can be easily upgraded. The digitally programmable loop gain and frequency response of the feedback system achieved an amplitude regulation of better than 0.5% and a phase regulation of 1 degree. The control system also includes automatic power-up sequencing, cavity conditioning and tuning functions. These and other control parameters can be controlled locally through soft buttons and soft knobs in conjunction with a plasma discharge display, and remotely through Ethernet.

1. INTRODUCTION

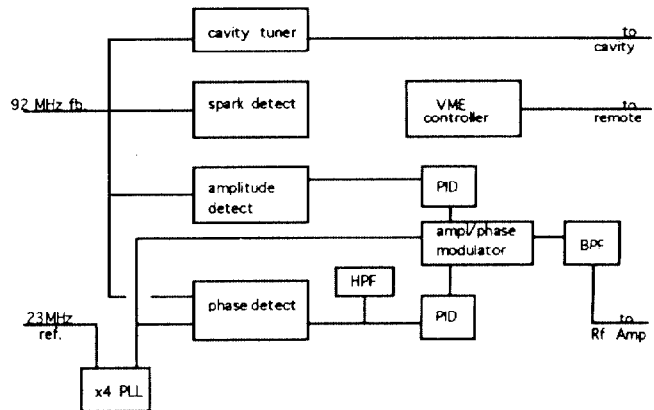
The TRIUMF booster cavity is located within the cyclotron vacuum tank. It operates at the fourth harmonic of the main cyclotron rf and provides two additional accelerating gaps which serve to approximately double the energy gain per turn for the outer turns of the cyclotron beam. In its present application, it functions mainly to reduce acceleration time and beam losses [1].

The booster control system described in this paper is an outgrowth of earlier work on the control of a beamline rf separator [2]. Like its predecessor, this system uses an analog control loop for speed of response and accuracy, and a PC-based controller and operator interface. The PC provides sequencing logic and control of the critical loop parameters.

In its present version, the control software takes advantage of the object oriented constructs of the C++ language to improve readability and reduce support requirements. The functionality of the system has also been expanded so that it now provides basically turnkey operation from the control room.

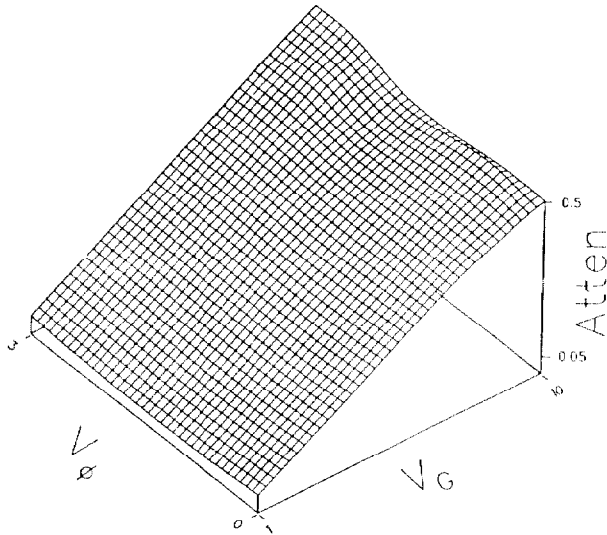
2. SYSTEM BLOCK DIAGRAM

A simplified block diagram of the system is shown in Figure 1.

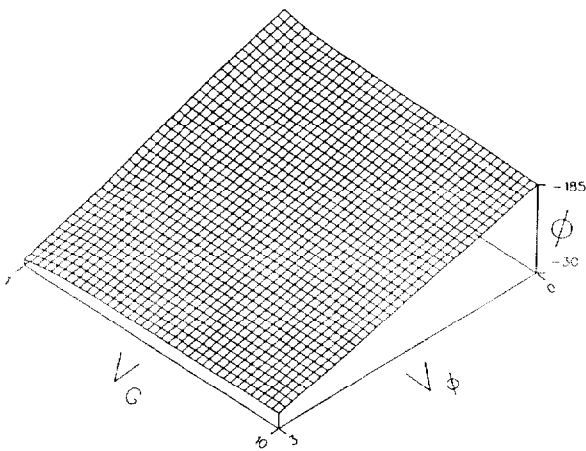


Booster Control System Block Diagram
 Figure 1

A 23 MHz phase reference signal derived from the main rf is fed to an intelligent Phase-Locked-Loop, which multiplies the incoming frequency by four. Some features of this loop are detailed in the next section. The 92 MHz signal from the PLL then goes to the phase detector and the amplitude/phase modulator. The phase detector consists of three limiting stages followed by a balanced modulator and low-pass filter. The amplitude/phase modulator is a vector modulator similar to that described in [3]. It uses a 90 degree hybrid followed by two wideband analog multipliers, a combiner, and a bandpass filter. Precision function generators provide the necessary sinusoidal conversion for linear amplitude and phase modulation functions. This approach provides the required modulation with minimal group delay through the modulator. The amplitude response of the modulator is shown in Figure 2 and the phase response in Figure 3.



Modulator Amplitude Response
Figure 2



Modulator Phase Response
Figure 3

The amplitude detector employs a synchronous detector. The incoming signal is split into two equal components. One component is fed through three stages of limiting, while the other goes through a delay line which matches the group delay of the limiters. Both components are then combined in a balanced modulator and low pass filtered. The resulting signal is free of the usual nonlinearities and temperature sensitivity common to diode detectors, and has a dynamic range of 40 dB.

The PID controllers use multiplying DACs to achieve computer control over their operating coefficients. These coefficients are sent by the PC system controller via the VME bus. Operating and limiting setpoints for amplitude and phase may be programmed. Provision has also been made to read back the error and drive levels for display on the system operator interface.

The spark detector employs a logarithmic amplifier followed by a video detector, a differentiator, and a comparator. For an rf level of V , this results in an output signal as follows:

$$\text{spark} = 1 \text{ if } (1/V) * (dV/dt) \geq \text{threshold level} \quad (1)$$

The threshold is set close to the level corresponding to the resonant decay time of the cavity. The log amplifier makes the spark detector independent of the drive level.

For startup cavity conditioning, a method for detecting multipactoring is required. This is provided by the high pass filter on the output of the phase detector which detects the amplitude modulation sidebands characteristic of multipactoring operation.

The tuner control detects the VSWR in the drive line to the cavity and uses a proportional with deadband controller to control the mechanical cavity tuning system.

The VME controller provides control and monitoring of all modules as well as control of the local operator interface, and communications with the remote host operator.

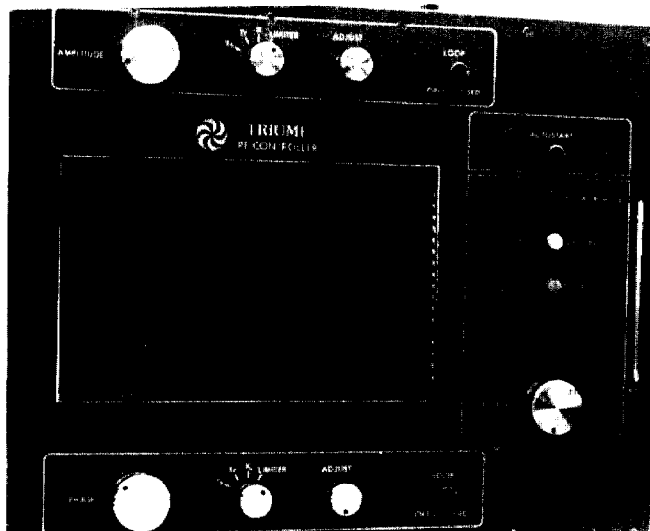
3. PHASE LOCKED LOOP OPERATION

Under normal conditions this block functions as a conventional analog PLL, providing accurate tracking of the reference. The oscillator control voltage is continuously sampled, digitized, and stored. When the system detects a loss of the reference frequency (perhaps due to sparking and/or shutdown of the main rf) the loop is immediately disabled, and the control voltage held at its last value. When the main rf returns, it will likely be at a different frequency from the original (self excitation is normally employed for startup in the cyclotron). The loop will then gradually ramp the booster frequency (at a rate the mechanical cavity tuning system is able to follow) until the drive frequency falls within a cavity bandwidth of the correct value. At that point the loop returns to normal operation. This scheme prevents the booster from shutting down along with the main rf, and then having to go through a lengthy power-up sequence on both systems.

For cavity conditioning purposes, the loop also provides the capability of adjusting the booster frequency via the VME controller. On startup, the drive level is increased until about 2 kW of reflected power is sensed. This is a level which the booster power amplifier can safely tolerate for an extended time. If this level does not decrease within about 60 seconds, the presence of multipactoring is indicated. The PLL is then used to slowly sweep the booster frequency over the operating range until the multipactoring/sparking are maximized. This frequency is then held until multipactoring and sparking stop. The sweep will then resume until another multipactoring peak is detected. This continues until conditioning is complete and the cavity tuner has brought the VSWR down to an acceptable level. The frequency is then brought to its correct value and the phase lock loop enabled.

4. OPERATOR INTERFACE

A photo of the local operator interface is shown in Figure 4.



Booster Control Operator Interface
Figure 4

Hardware features of this interface include a flat panel plasma display. This overcame the problems associated with high magnetic fields in the vicinity of the cyclotron and the resulting distortion of cathode ray tube displays. Another feature is the extensive use of soft pots for setting operating points, limiting values, etc.. Together with the bar graph visual displays, these permit setting digital values with the ease and speed of adjusting the volume on a radio.

The display provides a graphical presentation of the operation of the two main control loops, amplitude and phase. These both use similar control hardware and, for this reason, share a common operator interface. The loop setpoints and digitized readback levels use bar graphs. The numerical values giving gap voltage in kV and phase values in approximate degrees are displayed as well. These are shown connected to difference blocks, and then to gain blocks. A selector switch and soft pot are used to set the limit values as well as proportional, integral, and derivative gains for the controller.

They are then connected to another bar graph which provides a visual display of the actual error signal after amplification. These drive level bar graphs also incorporate pointers to display the current level of the limiting circuits. These are hardware clamp limits imposed on the drive levels to prevent overdriving the booster power amplifier. They help prevent nuisance tripping of protection systems under fault conditions. The final element in the control loop display is a block representing the amplitude/phase modulator.

To the right of the display, an array of 'button boxes', corresponding to the five pushbuttons, provides system status information. The functions of these are more or less self-explanatory. Autostart permits the controller to go through its power up sequence without operator intervention. Disabling this feature permits manual startup, if desired. The next switch selects local or remote operation. The third box indicates the phase lock loop status. The third switch activates a pop-up window which permits adjustment of some of the start-up timing parameters. Pop-up windows are also used to indicate fault conditions such as sparking. The fourth switch selects the desired mode of cavity conditioning and permits adjustment of the duty cycle for pulse mode (CW mode is primarily used at present). The last switch turns the rf drive on or off. It initiates the start-up sequence if the autostart feature is enabled. It can also function as a 'kill button' in the event of problems.

5. CONCLUSION

The booster rf system recently underwent a full week of successful operational testing at 140 kV. Full power testing at 150-160 kV is expected within the next few weeks, with full commissioning following soon after this.

The Ethernet link between the operators VAX-based system and the booster controller is planned, but has not yet been implemented. In the interim, an existing CAMAC link is being utilized. This currently provides basic 'two knob' functionality from the operators console.

6. REFERENCES

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