CA9700244

SCRUNCHER PHASE & AMPLITUDE CONTROL

R. A. DeHaven, C.L. Morris, R. Johnson, J. Davis, J. M. O'Donnell
Los Alamos National Laboratory
P.O. Box 1663 MS-H826
Los Alamos, New Mexico 87545

Abstract

The analog controller for phase and amplitude control of a 402.5 MHz super conducting cavity is described in this paper. The cavity is a single cell with niobium explosively bonded to a copper cavity. It is used as an energy compressor for pions at the Clinton P. Anderson Meson Physics Facility (LAMPF). The controller maintains cavity frequency to within 4 degrees in phase of the LAMPF beam frequency. Field amplitude is maintained to within 2 percent. This control is accomplished at critical coupling (Q loaded of 1 x 10^9) with the use of only a 30 watt rf amplifier for accelerating fields of 6 MV/m. The design includes the use of piezoelectric crystals for fast resonance control. Three types of control, self excited, VCO, and a reference frequency driven, were tried on this cavity and we present a comparison of their performance.

INTRODUCTION

The SCRUNCHER[1] is a single cell superconducting cavity operating at 402.5 MHz. It is constructed from a 3 mm thick copper shell with a 3 mm explosively bonded niobium layer. Liquid helium flowing in copper pipes attached to the outer copper surface cools the cavity with the boiled-off cold gas used to cool the heat shields surrounding the cavity. A 60 liter liquid helium storage dewar is installed at the top of the cavity and is used as a reservoir for the cooling pipe system. Coupling to the cavity is by a 3-in. coaxial line with a movable center conductor that allows operation at loaded Q's of 1 x 10^7 to 3.6 x 10^9. Three mechanical lead screws, each in line with a piezoelectric crystal, are mounted between one end of the cryostat and one of the beam tubes attached to the cavity. Cavity tuning is accomplished by compressing the cavity with these actuators. External mounting of the piezoelectric crystals eliminates the high voltage breakdown problem experienced in a helium atmosphere. The range of the tuner is 1.6 MHz while the piezoelectric crystals generate a tuning range of 12 kHz. Since the cavity is used to manipulate the phase space of the secondary pion beam at LAMPF, the cavity frequency must be phase locked to the beam bunching frequency of 201.25 MHz as set by the accelerator. The Pion beam represents a minuscule loading effect on the cavity allowing the operation of the cavity at high loaded-Q with a low power solid state rf amplifier. Use of the piezoelectric crystal fast tuning in concert with the high frequency mechanical resonance's, resulting from the stiff large mass copper-niobium-cavity, allow frequency control to within 4 degrees of phase at operating Q's of 1 x 10^9.

ANALOG CONTROL

A. Amplitude Control

Amplitude control for the cavity is typical. A sample of power from the cavity-transmitted-pickup-probe is detected

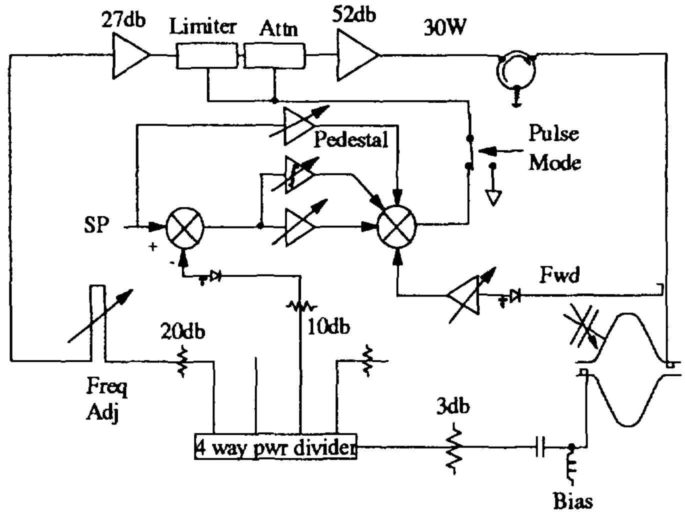

Fig 1. Amplitude Controller for Cell.

and compared to a reference voltage level (see Fig. 1). This error signal is amplified using a Proportional-Differential-Integral (PDI) controller that biases the diodes on double balanced mixers used as attenuators. These adjustable attenuators are in series with the rf drive for the final cavity amplifier. A sample of the amplifier forward output power is used for the differential state variable in the amplitude control loop. Operationally the differential input has very little effect and is not used. The pedestal is a steering signal and can be used for open loop operation of the system. Q is measured by clamping the control output to pulse the rf.

B. VCO Mode

A Voltage Controlled Oscillator (VCO) was incorporated for use in making Q measurements on the cavity. A crystal VCO operating at 201.25 MHz with frequency doublers was used because of signal to noise concerns when working with high Q. This type of oscillator has a narrow frequency range, but has the lowest noise sidebands available and worked quite well in this application. The control loop for this system was again typical. We used a phase bridge between the oscillator output and the cavity transmitted pickup probe with a proportional controller. No attempt was made to control the absolute frequency of the cavity in this mode of operation.

C. Driven Mode

Phase Controller

This is the mode that we originally intended to operate in. A 5 kW amplifier was procured and the coupler was designed to operate the cavity overcoupled for broader bandwidth. The source of rf for the cavity amplifiers is derived by frequency doubling the 201.25 MHz from the accelerator master reference oscillator in passive doublers. The rf from the cavity transmitted pickup probe is mixed with a sample of the 402.5 MHz reference in a double balanced mixer designed to operate as a phase detector. The phase error is amplified using a PDI controller and operates a phase shifter in series with the rf supplying the cavity amplifiers (see Fig. 2). Two

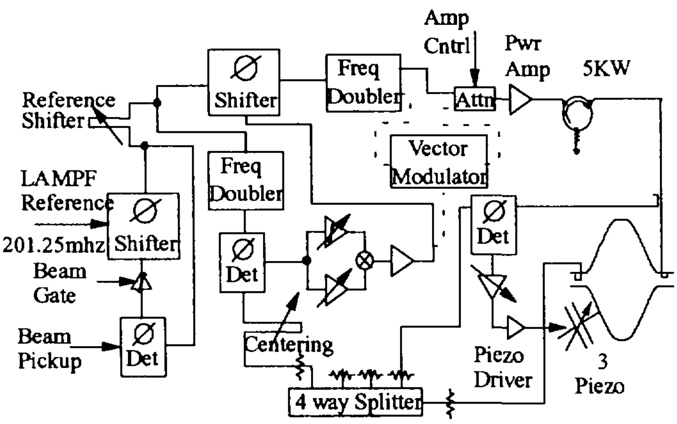

Fig 2. Control with drive from frequency reference.

different types of electronic phase shifters were tried in the controller. One was a Vector Modulator operating at 402.5 MHz. This unit has 3 dB amplitude modulation of the proper sign for amplitude control of the cavity in conjunction with 180^{0} of phase shift. The second shifter is a LAMPF designed shifter operating at 201.25 MHz. This analog shifter has 200 degrees of ultra-linear phase shift and less than one dB of amplitude change over the phase shift range. Comparisons of system performance between the two shifters showed the minimum phase error of 4 degrees and amplitude error of less than 2 percent achievable before loop instability were the same. As it turned out this mode was abandoned and neither of the shifters is used in the final operation.

Resonance Control

A phase comparison was made between the forward power from the final amplifier and the rf from the cavity-transmitted-pickup-probe to generate an error signal for resonance control of the cavity. This error signal was fed back by a proportional controller with a 60 Hz pole to the piezoelectric crystal drivers (see Fig. 2). The driver piezoelectric crystal combination has a pole at 140 Hz. This controller was intended to be a slow resonance controller and the mechanical lead screw tuners were to be used only to get the cavity within range of the crystals. The helium boil-off in the reservoir for the cavity causes a constant changing pressure on the cavity that results in a steady frequency change about a 100 Hz per minute. Depending on how well the refill system from the helium dewar is set, more than the entire 12 kHz range of the piezoelectric crystals is often used to keep the cavity on frequency. The piezoelectric frequency adjusters are necessary to operate the cavity, as the 5 kW amplifier could not drive the cavity when it is several kHz off resonance, even in the overcoupled condition.

D. Self Excited Mode

This mode was originally intended only for starting and conditioning the cavity. It consists of feeding the cavity transmitted pickup probe directly back to the amplifiers with phase adjustment and 30 dB of inter-loop rf gain, so the

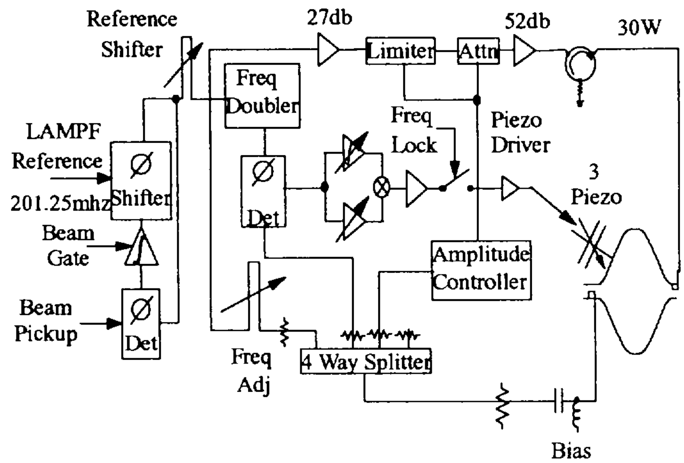

Fig 3. Control for the self oscillating mode.

system will self oscillate (see Fig. 3). It was included because of perceived ease of operation and was finally selected as the operating mode for the cavity for that reason. The frequency locking of the of cavity to the LAMPF beam is accomplished by using the piezoelectric crystals in a fast tuning loop with a Proportional-Integral controller. A phase lock to the beam frequency is also included. It consists of a phase comparison between a beam pickup and the cavity operating frequency that drives an electronic phase shifter in series with the reference phase shifter (see Fig. 3). This loop is to compensate for the reference 201.25 MHz timing signal phase drift due to several hundred feet of air dielectric cable that is not temperature controlled. This loop incorporates a sample and hold circuit for the error signal as the beam is pulsed. We use an Integral controller for this loop.

RESULTS

Operation of the system in its various modes and controller setups gave the same close loop response when operating at high loaded Q's (1×10^{9}). Due to the stiffness and mass of the cavity construction, microphonics have not been much of a problem. The cavity is shock mounted on a stand attached to an isolated floor to reduce driving frequencies. The first mechanical resonance appears at 78 Hz and a thermo-acoustic resonance at 87 Hz is severe but intermittent. It may be related to the level of the helium in the reservoir. The driven mode was extremely difficult to operate. The slow response of the cavity when operating at high Q made aligning the cavity resonance to the operating frequency and locking the resonance control loop extremely difficult. It was necessary to use a spectrum analyzer with a noise floor of -120 dBm to find resonance. One tended to scan right through the resonance point before the cavity began to respond. With 1.6 MHz of tuning range to search, scanning slowly takes a prohibitively long time. One can adjust the trombones in the self excited loop and when the feedback is positive the cavity will start. The resonance can easily be set by observing reflected power from the cavity and is quite stable. By viewing the difference frequency from the phase control bridge, one can easily set the cavity to the null frequency with the mechanical tuner. A switch can close the control loop, locking the cavity to the reference frequency. The system has been operated in the LAMPF accelerator for two run cycles. The experimenters using the device have operated the system. Loop gains are set at the beginning of the cycle and have not required any service during the run. Coupling is set for critical coupling at the operating field level. We found that the cavity could be controlled at the high loaded-Q levels when we first turned on the system and the 5 kW amplifier has never been hooked up to the cavity. We operate with the 30 watt solid state pre-driver that will supply 6 MV/M accelerating fields at loaded-Q of 1×10^9. Operating with the low power amplifier limits the possible accidental X-ray level that could be generated, simplifying worst case accident scenarios. After the first run period, we increased loop rf gain to 30 dB from a few dB, to increase the turnon speed of the cavity. This was to eliminate switching back to the VCO mode to measure the cavity Q that required disconnecting and reconnecting some cables. With proper padding and the use of two control elements, the turnon overshoot was reduced but we could never eliminate it at the higher loop gains. Cables and couplers were calibrated and the experimental computer is used to take data on the forward and reflected power levels to calculate the Q with the overshoot occurring.

The system is extremely sensitive to noise introduced through the electronics. When closing the control loops, we were introducing 60 Hz noise into the system. Separating the dc power supply wires from the signal wires in the cable dressing for the bin helped this problem. We also found it necessary to move the power supply out of the bin because of magnetic pickup from its transformer. We still experience some performance degradation from 60 Hz pickup.

MICROPHONICS

We made a few measurements on the microphonics associated with the cavity using a digital scope with a fast Fourier transform. The scope could not contend with the frequency drift due to the helium boil off. I had to lightly lock the phase loop with the integral gain control to keep the cavity close to frequency during the time it took for the scope to accumulate enough data to generate an averaged spectrum. I measured the output of the phase detector comparing the cavity frequency with the LAMPF reference. Applying an inverse sign function to the ratio of bridge full output to measured spectrum gives the data reported in Fig. 4. The

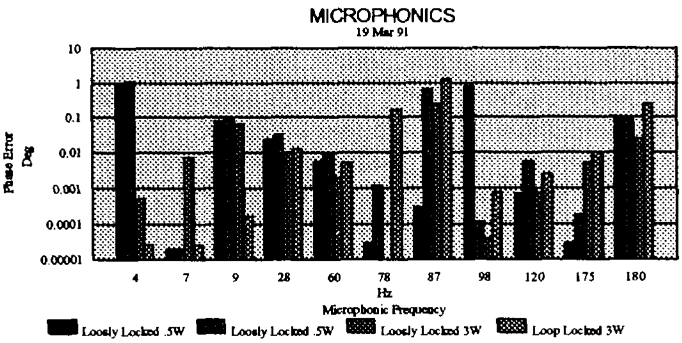

Fig 4. Phase Error due to Microphonic Vibrations.

loop is able to suppress the first three or four low frequency modes when it is tightened. Note that the 60 Hz components increase when the loop is tightened indicating that the 60 Hz is being introduced by the controller. The mechanical resonance at 78 Hz is spurious. The thermo-acoustic oscillations at 87 Hz occurred during part of the data taking for the Locked Loop spectrum. The loop does maintain lock when this oscillation occurs and may suppress it somewhat. The error due to this oscillation effects data being taken on the experiment although the original specification for control was 5 degrees in phase and 5 percent in amplitude. The experimenters correct for the pion beam energy shifts due to the phase changes by reading the loop phase error with the experiment computer.

REFERENCES

[1] J. M. O'Donnell, J. Davis, R. A. DeHaven, E. Gray, R. J. Johnson, R. E. Lomax et al., A Superconducting Radio Frequency Cavity for Manipulating the Phase Space of Pion Beams at LAMPF, Nuclear Instruments and Methods in Physics Research A317, July 1992, p. 445