LOW LEVEL RF CONTROL SYSTEM FOR CYCLOTRON 10MEV*

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Abstract

The low level RF control system consists of a 101 MHz signal generator, three feedback loops, an interlock and a protection system. The stability of control system is one of the most important indicators in the cyclotron design, especially when the whole system has a high current. Due to the hugeness of the RF system and the complexity of control objects, the low level RF control system must combine the basic theory with the electronic circuit to optimize the whole system. The major obstacles in the research, which rarely exist in other control systems, lay in the coupling of beam and resonant cavity, requiring to be described by the transfer function between beam and cavity, the complex coupling between microwave devices and the interference signals of all loops. By introducing the three feedback loops (tuning loop, amplitude loop and phase loop) and test results from some parts of electric circuits, this paper unfolds the performance index and design of low level RF control system, which may contribute to the design of cyclotron with a high and reliable performance.

INTRODUCTION

The low level RF control system is an essential part of the RF system for CYCHU-10. The RF system should provide 12kW power to CYCHU-10 and the Frequency is 101MHz. The Specifications related to RF system are listed in Table 1.

Table 1: Main Specifications Related to RF System

Parameter	Value
Rated Power Output	12kW
Frequency Range	100.5~101.5MHz
Frequency Stability	20ppm
Output Impedance	50ohms

In the R&D of the CYCHU-10, a high power RF system has been established, which contains a klystron and its power supply and low level RF control system [1].

The low level RF control system consists of a 101MHz signal generator, three feedback loops, an interlock and a protection system. The design is basically similar to those of others electron storage rings in the world and is based on the use of conventional, stability and well-proven equipments. The scheme of low level control system is shown in Figure 1.

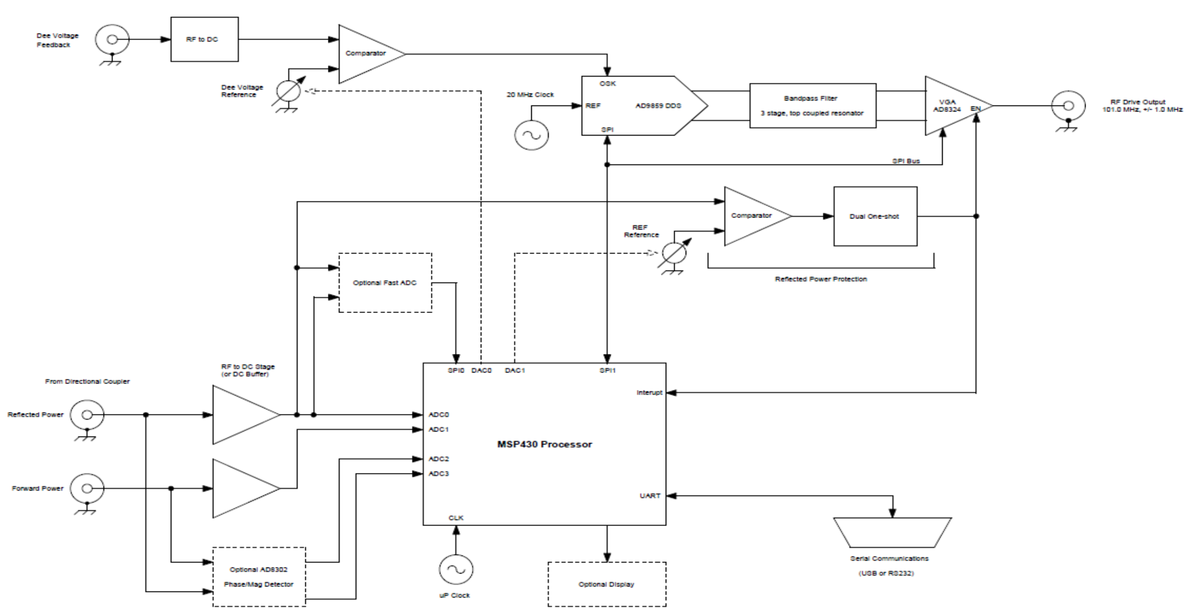

Figure 1:The scheme of low level control system.

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FEEDBACK LOOPS

In the low level control system, the reference RF signal is generated by a DDS signal generator (AD9859). AD9859 is a great chip for synthesizing RF signal, which integrations a 10-bit DAC and provides 32-bit frequency tuning word. The chip also has great frequency resolution which can be 0.093Hz when system clock is 400MHz [2]. The output signal f_o is decided by system clock frequency f_s and frequency tuning word (FTW), the relationship is presented in the equation (1).

$$\begin{cases} f_o = (\mathrm{FTW})(f_s)/2^{32} \\ f_o = f_s \times (1-(\mathrm{FTW}/2^{32})) \end{cases} \quad (1)$$

In addition, the amplitude of the RF system can be achieved by adjusting the external connection resistor's value. This resistor value (R_{SET}) sets the internal DAC ful-scale output current (I_{OUT}). The relationship is presented in equation (2).

$$R_{SET} = 39.19 / I_{OUT} \quad (2)$$

In the above expression, the current is in A and the resistor is in Ω.

Tuning Loop

The tuning scheme is shown in the Figure 1. First, make the loop open and search the tuner position by changing the DDS's FTW. Secondly, make the loop close and compare the Reflect power and Forward power signal by phase/mag detector, then give the results to the controller. And at last, the controller set up DDS's FTW by the serial communication port, we use RS-485 in this system. The bandwidth of this loop is set up around 1 Hz. This tuning loop controls the DDS, which changes the frequency along with the cavity frequency [3].

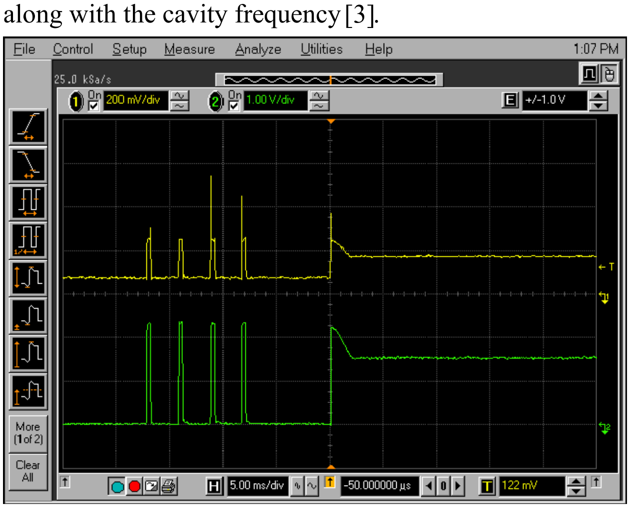

Figure 2: The waveform of forward and reflect power.

In addition, a RF switch is set up to the end of drive amplifier, which has great effect to solve the multipactor effect. During frequency search the reflected power port can be monitored to watch the progression of reflected power level versus frequency. The waveform of forward and reflect power is shown in Figure 2. Each pulse is likely to have large spikes at turn-on and turn-off, that's because rapid change in the RF envelope spreads energy far away from the cyclotron resonance. As the frequency nears resonance and SWR becomes low enough, the controller shifts into Operate mode and applies drive continuously.

Amplitude Loop

RF signals picked up from the Dee Voltage pickup at the cyclotron, and compared with the Dee Voltage reference. Then the compared signal sent to the AD9859's OSK port, which can achieve close-cycle control of the amplitude. The protection reference value of the Dee Voltage and reflected power is setting up by the control program. Main Specifications of RF control system is shown in Table 2.

Table 2: Main Specifications of RF Control System

Parameter	Value
Power Requirement	+24VVDC, ~120mA
Forward Power Feedback Input	+10.8dBm (12 kW)
Reflected Power Feedback Input	+10.8dBm (12 kW)
Dee Voltage Feedback Input	+17dBm maximum
Forward Power Monitor Output	0-1.85VDC for 0-12kW
Reflected Power Monitor Output	0-1.85VDC for 0-12kW
Dee Voltage Monitor Output	0-2.5VDC for 0-40kV

Phase Loop

This loop is to keep phase of the fields in the cavity locked with the signal generator. RF signals picked from the direct coupler which in the front of the cavity, then sent to MSP430 processer to control DDS. The phase loop will also compensate the phase change with the RF power variance, due to the power amplifier, the circulator, the klystron, the driving electronics and so on. The components of the driving electronics are designed to have a small phase variation over a wide operating range.

The Phase Detector (PD) is the key component. The PD is a device with rather constant sensitivity against large power variations. This will prevent the effect of amplitude modulations on the operation of the loop.

SYSTEM TEST

The low level RF control system consists of a 101MHz signal generator, three feedback loops, an interlock and a protection system. It connects with the cyclotron control system by serial communication port (RS485). The RF control system is shown in Figure 3.

Monitor ports for forward power, reflected power and Dee voltage RF feedbacks are available on the front panel. These outputs, from the respective RF-to-DC converter stages, are unity-gain buffered and can drive an oscilloscope or other >1kΩ load. No filtering is applied to the monitor outputs so response time is equal to the RF detector response. The level at the forward and reflected ports corresponding to 12 kW is approximately 1.85 VDC. The picture of control system is shown in Figure 3.

Figure 3: The picture of control system.

To prove the function of the control system, we do bench-top testing. It is possible to simulate the cyclotron load and demonstrate the controller operation using a resonant cavity. The Bird Electronics Model 211-29-05 shown Figure 4 can be adjusted to give the desired SWR, resonant frequency and feedback port attenuation for bench-top testing.

Figure 4: The picture of resonant cavity.

For bench testing an outboard amplifier is used to boost signal levels high enough for sampling by a directional coupler. The controller output drives the input of the amplifier and the controller forward and reflected inputs receive feedback from directional coupler. The picture of amplifier and directional coupler is shown in Figure 5.

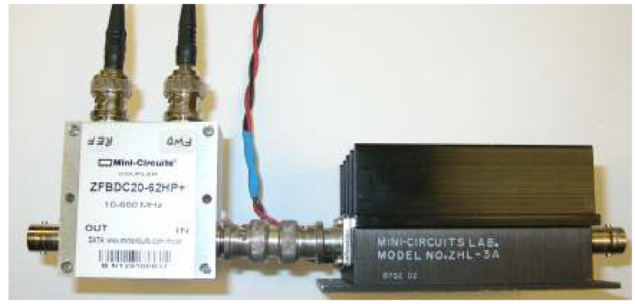

Figure 5: The picture of amplifier and directional coupler.

A LabView utility program is used to set up and operate the controller. This program has a Monitor tab, shown in Figure 6, with easy-to-use command inputs and feedback of important parameters.

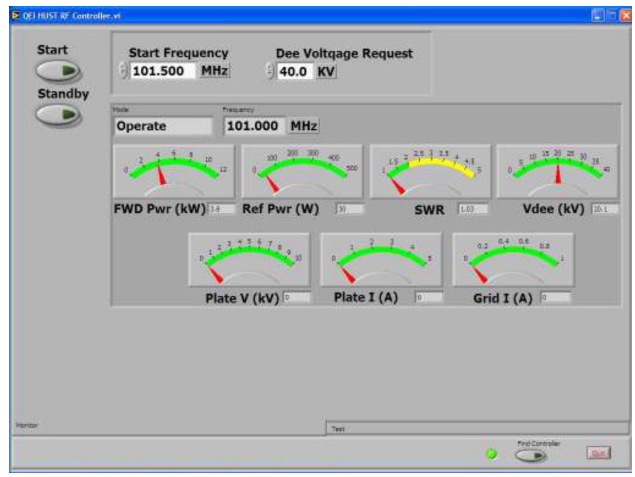

Figure 6: LabView Control Program – Monitor Tab.

The scope should show strings of four tuning pulses for each frequency step in the search. As the frequency approaches 101.00 MHz the height of the reflected pulses will become smaller and the SWR value will eventually fall below the Operate Mode threshold. At this point the controller output switches to steady-state. The process of searching resonance frequency is shown in Figure 7.

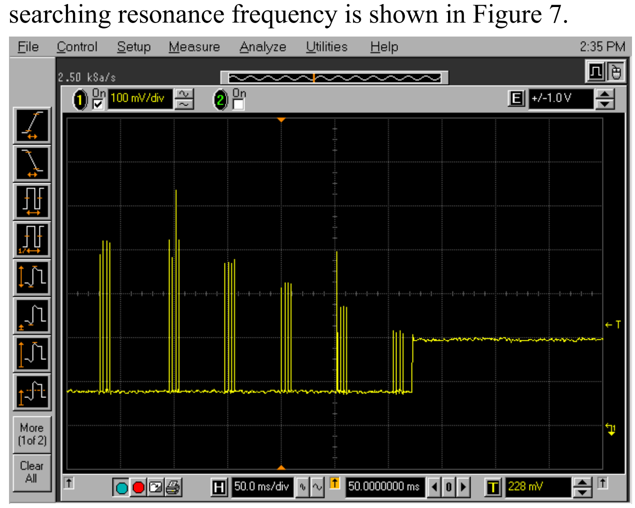

Figure 7: The process of searching resonance frequency.

CONCLUSIONS

The low level RF control system for CYCHU-10 has feedback loops which monitor Dee Voltage, Forward Power and Reflected Power. This allows the system to seek and follow the resonant frequency of the cyclotron cavity and maintain a constant Dee Voltage. The controller operating parameters are communicated via an RS485 serial interface. The system communicates using a message packet that carries commands to the system and feedback from the controller regarding its status.

The bench-top testing results of control system show that the system can achieve the designed functions. The further debugging with the whole RF system for CYCHU-10 will be carried out.

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