PRELIMINARY DESIGN OF A RF SYSTEM FOR THE 100 MEV CYCLOTRON

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Abstract

This paper describes the recent status of a RF System for the 100 MeV Cyclotron including the structure and numerical calculation results of cavities, RF power generator, frequency, phase and Dee voltage stabilization control loops, etc. The 100 MeV Cyclotron as a compact machine requires all RF cavities locate in the magnet valleys. The fixed RF frequency feature needs a fine-tuning system to keep cavity resonance circuit to operate at satisfied conditions. The main specifications of RF system and possible problems to be encountered are also given.

INTRODUCTION

Two triangles, half wave-length cavities are installed into the valleys of the magnet. They are connected at the central region of the machine. The RF power via coaxial transmission line is coupled into the cavities capacitively. This RF system consists of copper quarter wave resonant cavities, RF power generator and low level control circuit. The block diagrams of the RF system are illustrated in Figure 1. Its main specifications are given in Table 1.

Table 1: main specifications of the RF system

Operating Frequency	42—46 MHz
RF Output Power	0—120 kW
RF Frequency Stability	$\pm 5\times 10^{-8}$
Dee Voltage Stability	$\pm 5\times 10^{-4}$
Phase Stability	$\pm 0.3^{o}$

The capacitive coupling between the RF power source and the resonant cavity is selected. The two-stem structure will be used in the Dee resonant cavity design to meet the requirements of the Dee voltage distribution along radius of accelerating gap, which should be range about from 60kV at the centre area to 120 kV at the large radius area.

RF POWER AMPLIFIER

The RF power amplifier chain includes RF synthesizer, amplitude modulator, 150 W solid state amplifier, 6 kW intermediate driver power amplifier (IDPA), and 120 kW final power amplifier (FPA). RF synthesizer with phase-

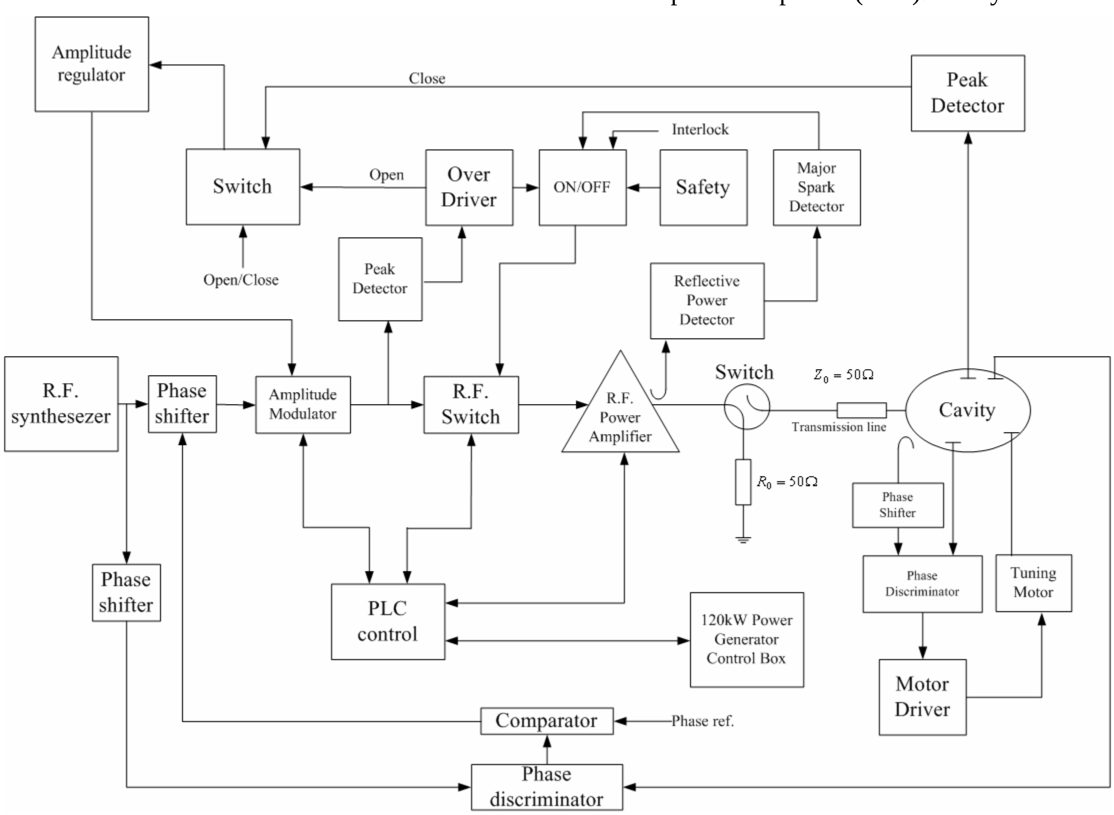

Figure 1: The block diagrams of the R.F. system.

lock loop takes temperature compensation crystal oscillator as the source of the reference signal. The output signal of the voltage control oscillator will be discriminated with the reference signal. The resulting voltage signal is used to control frequency of the output signal of the voltage control oscillator to ensure that it meets the requirements of frequency stability. By changing the ratio of frequency dividing, it is convenient to switch the operating frequency between 42MHz and 46MHz. The frequency stability is superior to $\pm 5*10^{-8}$ and the frequency can be changed in step of 5kHz. The frequency spectrum of the oscillating signal is fairly pure and there is very little interference from harmonics. The output signal voltage is approximately 1Vpp.

The main function of the amplitude modulator is to meet the requirements of Dee voltage stability. The pick-up Dee voltage signal and preset reference signal are compared here and output a differential signal to keep Dee voltage constant. RVA2500 voltage control adjustable attenuator produced by American Mini-circuits Company is chosen for the amplitude modulator. Its linearity is good and the deviation of the accessory phase is relatively small.

The 150 W transistor amplifier involves a 7 W amplifier and a 150 W MOSFET amplifier. The 7 W amplifier is a product from Japan with high gains and good stability. The 150 W MOSFET amplifier comes from Philips Company with good linearity and small additional phase deviation. This stage is an air-cooled solid-state amplifier and its 150 W output drives the 6 kW drive amplifier. A over heat temperature switch is applied here as a safety interlock.

Because a 120 kW final power amplifier needs 5 kW driving power in normal operation, a 6 kW driver amplifier is used here to increase the stability and reliability of RF system. It is driven by the 150 W solid-state amplifier. The amplifier tube will be chosen from 4CX5000A produced by Eimac or TH541 produced by Thales. The amplifier has local control for adjustment and maintenance, remote control, and meters displaying reflected power, forward power, currents and voltages. This stage is protected on the load side against over-current and short circuits.

The final power amplifier applies 4CW100,000E produced by American Eimac Company or TH581 produced by French Thales Company. Its maximum output power is 120 kW. To meet the requirements of maintenance, testing and debugging, a testing loading is applied and controlled by the switch. The output power feeds to the resonant cavity through a RF coaxial feeding tube. There are four power supplies connected to the final power amplifier:

- The filament circuit transformer
- The grid power supply
- The screen power supply
- The anode (plate) power supply

A set of relays allows the system to start the filament heating smoothly according to the tube manufacturer. The relays switch the transformer tap to 25%, 50%, or 100% of the specified filament voltage.

LOW LEVEL CONTROL CIRCUIT

The purpose of the low level control circuit is to keep the RF system stable and reliable in operation. It mainly includes voltage stability, phase stability, frequency stability, and load match adjusting circuit.

Voltage Stability Loop

In order to meet the requirements of the Dee voltage stability, considering detuning, sparking and Multipactor effect during RF field establishing process in cavity, the RF system is equipped with a Dee voltage stability loop with pulser and continuous auto switching modes to ensure equipment safety . In case of detuning or sparking, it can turn to pulse operating mode, quickly tuning and then resume the continuous mode. In order to increase the Dee voltage smoothly during starting process, a ramp signal generator is used. The output signal of the amplitude modulator will first go through the peak detector and the overdrive detector, and then it will be compared with the reference voltage (Vref) at the amplitude regulation board. Output signal of the amplitude regulation board controls the modulator to change the RF output of the modulator. This process continues until the RF field amplitude in the RF cavity has reached the preset value. There is a forward and reflected power detector at the output of the final power amplifier. If the reflected power signal exceeds the permitted value, the output of the amplitude modulator will be cut off swiftly.

Automatic Frequency Tuning Loop

The purpose of automatic frequency tuning loop is to maintain the impedance matching between RF power source and resonant cavity. To prevent the dismatching due to the variation in temperature, beam loading and the vacuum, a tuning capacitor made up of copper plates is applied. The cavity pick-up detector signal and the transmission line detector signal through phase shifter will go into the phase discriminator. When the phase difference is smaller than 90^o or larger than 90^o, the output signal of the phase discriminator will be positive or negative. After being compared with the output signal of automatic search circuit, its output signal will directly go into the DC power amplifier circuit through proportional integrator (P.I.) to control the rotation of the tuning motor.

Phase Stability Loop

In order to keep output phase of the amplifier chain constant and adjust beam injection phase we use a phase lock loop to lock it to the phase of master oscillator via a phase shifter. Two input signals of the phase discriminator come from the directional coupler of the cavity and master oscillator via the phase shifter.

Load Matching Adjustment

The output power of RF power source will pass through the coaxial line to the Dee cavity via the coupling capacitor. When we change coupling capacitance the automatic frequency tuning loop of cavity will automatically follow the change of coupling capacitance [1][2]. Then through monitoring the magnitude of reflected power we can make resonant cavity and RF power source to achieve the match. In case of heavy beam loading, we can consider adjusting coupling capacitor to make the resonant cavity and RF power source match at a half of maximum beam loading. The coupling capacitor is adjusted using open loop control. Because the reactive part of the input impedance is insensitive to beam loading, we can adjust transmission line length to about one-fourth wave length to make the load of final power amplifier look like pure real by using phase difference signal between input and output of it.

CAVITY DESIGN

operating frequency of the resonant cavity is 44 MHz. It works in 4th harmonics and is located in the valleys of the cyclotron. The cyclotron beam dynamics design expects that the voltage at the central region should be about 60 kV and at the large radius area 120 kV. The preliminary From the physical design of the 100MeV cyclotron, the consideration is to adopt the two-stem structure [3][4] to control the voltage distribution well and adjust the frequency by changing the inductance of cavity, the capacity of cavity, and the position and diameter of the stems. Our purpose is to minimize the dissipated power of the cavity to obtain a correct Dee voltage distribution, high unloaded quality factor, and good mechanical stability. The designed structures of the cavity for two stems are illustrated in figure 2. The calculation results show that the resonant frequency can be adjusted by the cavity height, the tuning capacity, and the diameter of stems. Also we can adjust the resonant frequency in a simple way by changing the position of the external stems in the real cavity. The distribution of the Dee voltage along radius of accelerating gap is reported in Figure 3.

The principal results obtained by the computer are as follows:

Resonant Frequency 44.66 MHz
Unloaded Quality Factor 10610
Maximum Accelerating Voltage 120 kV
Total RF Power Dissipated 73 kW.

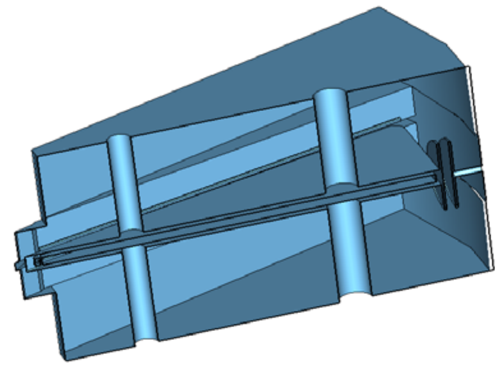

Figure 2. The designed structures of the cavity

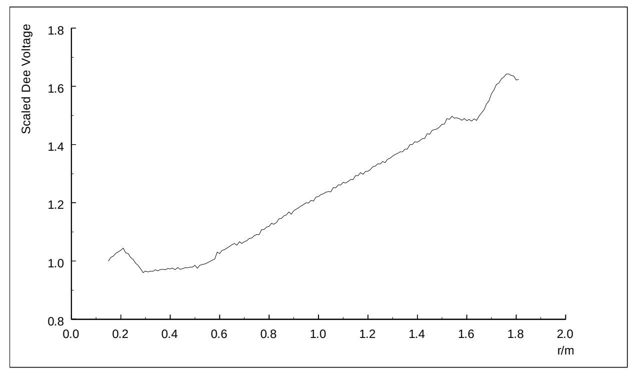

Figure 3. The distribution of the Dee voltage along gap

SUMMARY

The preliminary design of the RF system including the RF power amplifier, low level RF control circuit, and resonant cavity has been obtained. The main parameters of the RF system were analyzed and calculation by using Microwave Studio 3D code. As shown in Figure 3, the Dee Voltage distribution (74-120kV) needs improving. The beam loading effects and optimum of cavity structure still require further work.

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