RF SYSTEM FOR THE RCNP CYCLOTRON

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Abstract

The outline of the RF system for the RCNP cyclotron is described together with the latest developments.

With the double pick up detectors, the dee voltage is stabilized within 10^{-4}(P-P)/P on beam loading condition. To ensure the rapid and easy tuning flexibility of MOPA system, an automatic pretuning system has been developed and works satisfactorily. For the tube protection, a fast crowbar is installed in the anode power supply.

Introduction

The RCNP AVF cyclotron has been in operation since 1974 and every design goal has been achieved. The RF system operates 5.5-19.5 MHz and is able to deliver 200kW RF power. A MOPA system is developed for the RF system of the RCNP AVF cyclotron. The time in operation of the RF system is more than 9000 h. The RF system operates without serious trouble.

Resonator

A ¼λ mode coaxial resonator, 2.5 m in diameter and 4 m in length, with a single 180° dee and a sliding short is used. The resonance frequency is variable from 5.5 MHz to 19.5 MHz. The sliding short is moved by an electro-hydraulic pulse motor. For fine tuning, two capacitive trimmers (60x8cm^2) are provided, one on either side of the dee. The trimmers are driven by stepping motors through hydraulic systems. The stroke and the increment of the trimmers are 20mm and 5μm/pulse, respectively. The fractional change of the resonance frequency is 5x10^{-7} /pulse.

MOPA system

A MOPA system is developed for the RF system of the cyclotron. The schematic diagram is shown in fig.1.

The system is divided into five major components: a frequency synthesizer, a modulator, a wide band driver amplifier, a final amplifier and the resonator. The final amplifier (RCA 4648 tetrode) is able to deliver 200kW RF power to the resonator. For amplitude modulation of dee voltage stabilizer, a double balanced mixer is used. The band pass filter (pass band: 5-20 MHz) is used to suppress the harmonic distortion of balanced mixer output, and low frequency parasitic oscillation.

The output of the final amplifier is fed to the resonator through a 2000pF vacuum capacitor, a feeder line 2m in length and a capacitive coupling. The space between the coupling electrode and the dee electrode can be varied so as to change the coupling capacitance and the anode load impedance of the 4648.

The measured Q values and load impedances are shown in fig.2. The load impedance is adjusted to about 250Ω for the frequency range from 8 MHz to 19.5 MHz. For low frequency with weak coupling condition,

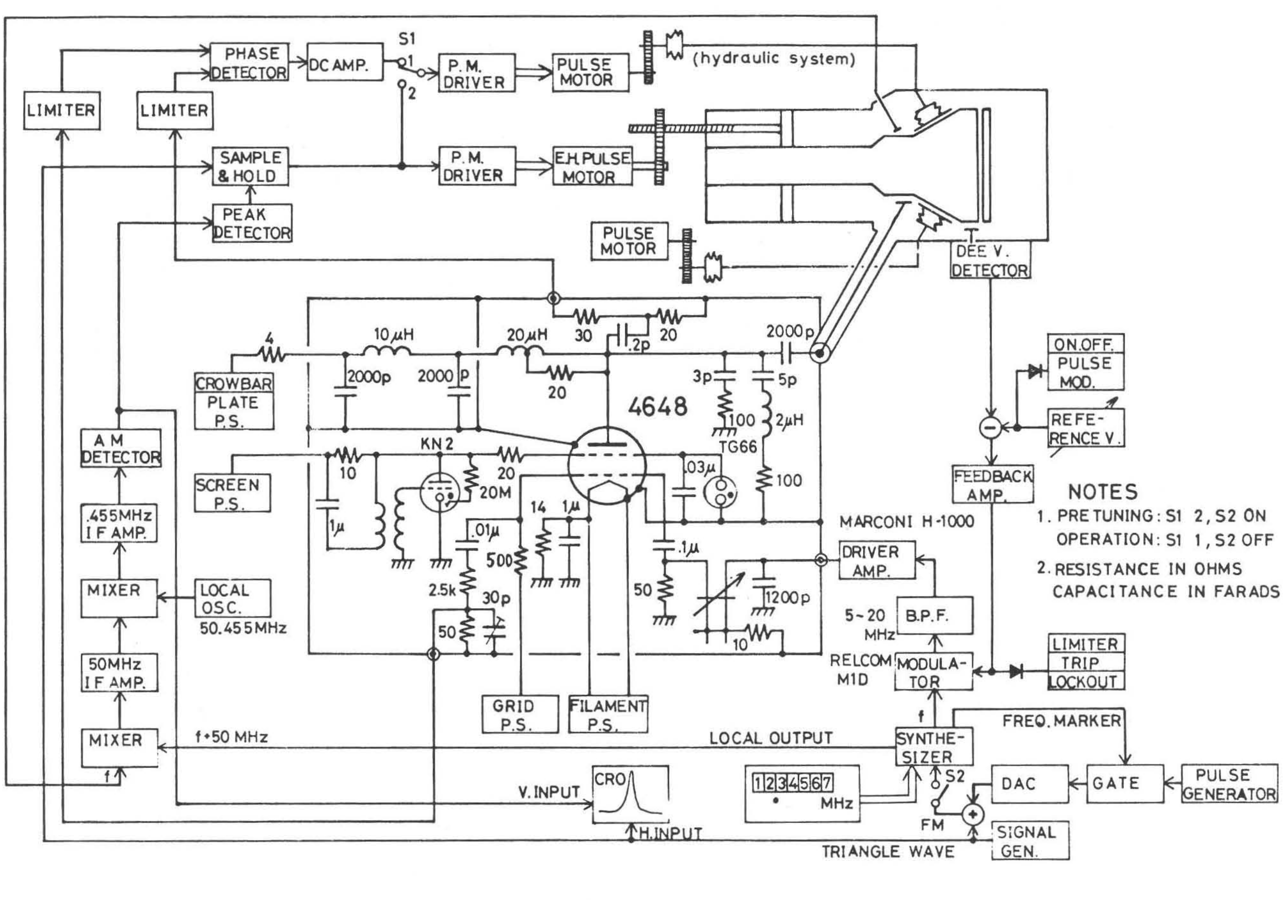

Fig.1 Schematic diagram of the MOPA system.

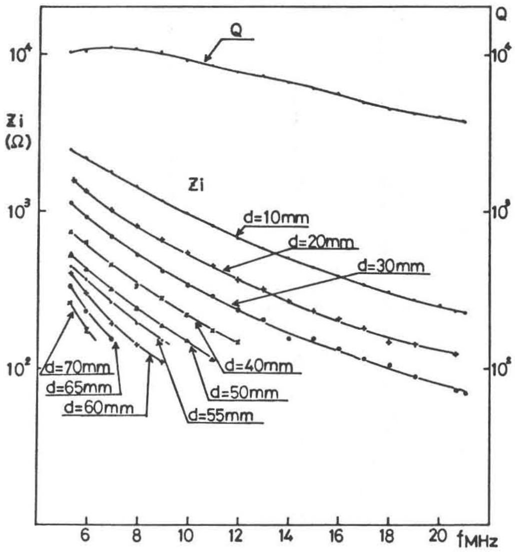

Fig.2 Measured Q values and load impedances versus resonance frequencies for several coupling conditions. "d" is the space between the coupling electrode and the dee electrode.

the magnitude of the impedance has a maximum value at the point where its phase is less than 0°, as shown in fig.3. Rather high impedance and strong coupling conditions are chosen to get a wide dynamic range to use the automatic tuning mode for low frequency.

Power supply

The anode power supply for the final amplifier is rated at 15kV, 30A. The primary voltage is adjusted and stabilized by induction regulator through an automatic voltage regulator.

A crowbar circuit on the output is able to remove the output voltage within 1μs in the event of abnormal operation, as shown in fig.9. A current limiting reactor is located between the induction regulator and rectifying transformer to limit the short circuit current and to reduce mechanical shock in the induction regulator, when the crowbar fires. The short circuit produced by crowbar operation causes about 2% line drop in the 6.6kV ac line. The circuit breaker needs about 5.5 cycles of 60Hz to break the 6.6kV ac input after the crowbar is triggered.

An all solid-state power supply, 1.5kV, 1.5A, 0.01% regulated, is used as a screen power supply. A circuit diagram of the anode power supply and crowbar is shown in fig.4.

Dee voltage stabilizer

A new dee voltage detector is developed. This detector has two pick up electrodes. Both have same capacitance between electrode and dee. A large electrode is far from the dee and generates a positive dc output. The small one is close to the dee and generates negative dc output. The outputs are summed with proper ratios, in order to get both an insensitive output and a sensitive output to the dee motion. A preliminary test shows that the effect of thermal expansion of the dee width is very large. The effect per day is about 2×10^{-3}, and can be reduced to less than 10^{-4} with this double pick up dee voltage detector.

Together with the highly stabilized power supplies for the final amplifier, the dc stability and the noise levels of the dee voltage are 10^{-4}(P-P)/P each, on beam loading conditions, as shown in fig.10. The circuit diagrams of dee voltage detector and feedback amplifier are shown in figs.5 and 6.

Automatic tuning system

An automatic tuning system is necessary to ensure the dc stability. The tuning error detector, shown in fig.8, detects the phase difference between the signals from control grid and anode of the 4648. The tuning error detector drives the capacitive trimmer, to make the phase difference zero.

An automatic pretuning system is developed for fast and easy tuning in variable energy experiments. As the resonator tunes precisely before appyling RF power, the multipactoring is overcome easily. The schematic diagram of the automatic pretuning system is also shown in fig.1. A circuit diagram of the tuning error detector is shown in fig.7.

On the pretuning mode, the anode and screen voltages are not applied. The synthesizer is used on a sweep oscillator mode. The resonator system is excited very weakly with an FM signal (Δf=500kHz and 50kHz), through capacity between the control grid and the anode of the 4648. The center frequency of FM signal is automatically adjusted to desired frequency with the frequency marker signal from the synthesizer. A small resonance signal is picked up and amplified by the superheterodyne method.

The tuning error detector consists of a sample hold circuit and a peak detector. The sample hold circuit measures dc voltage of the sweep signal, which is proportional to the deviation from the desired frequency, just on resonance peak. The tuning error detector initially drives the sliding short of the resonator within a limit of 500kHz deviation of FM signal, and a capacitive trimmer finally within a 50kHz frequency deviation of that. By pushing "tuning" button on the console, all processes above mentioned automatically proceed.

The frequency change procedure is as follows.

1. Turn off the RF excitation.
2. Turn off the anode and screen power supplies.
3. Set a frequency at seven thumbwheel switches on the console.
4. Set the position a. sliding short.
   b. grid tuning short.
   c. capacitive coupling.
   according to the tables.
5. Push "tuning" button and wait for a few minutes till ready lamp lights.
6. Turn on the anode and screen power supplies.
7. Turn on the RF excitation.

A frequency change needs 5 to 15 minutes.

References

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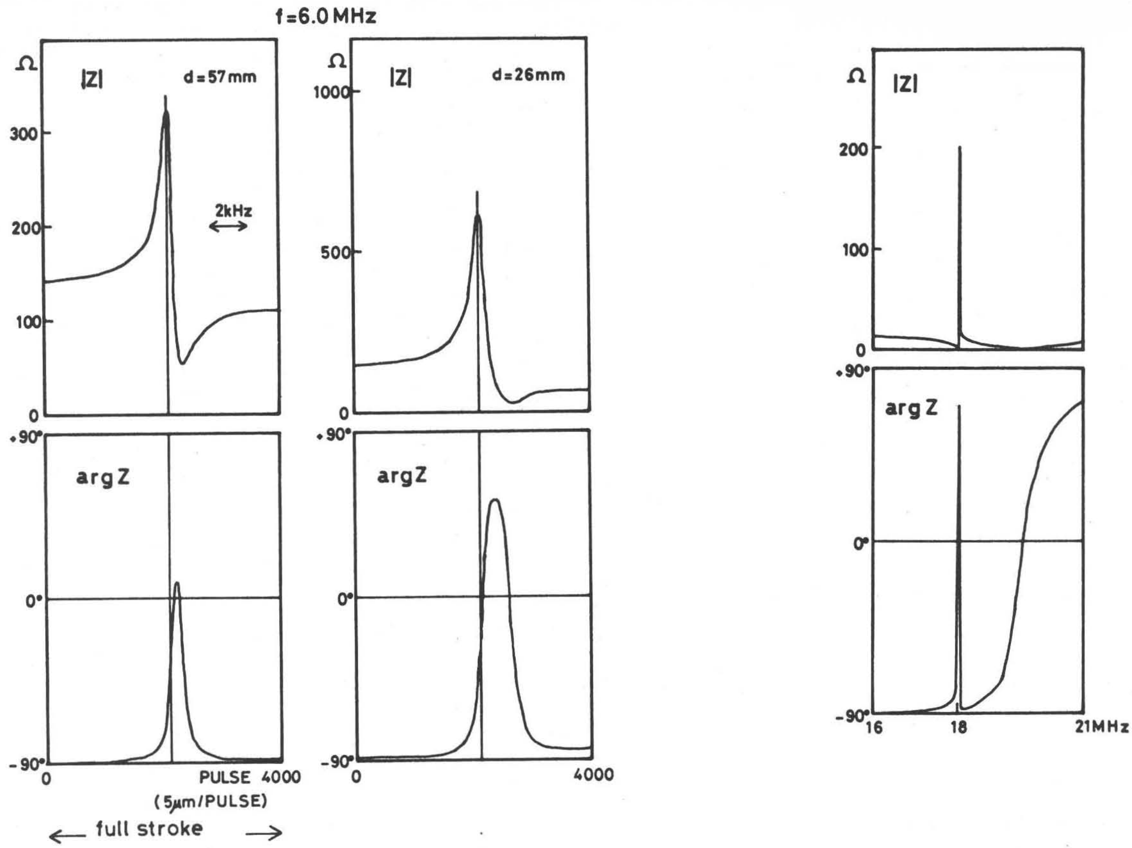

(a) (b)

Fig.3 The resonance characteristics of resonator at 6.0MHz and 18.0MHz, measured with RF vector impedance meter.

(a) The anode load impedance versus position of the capacitive trimmer for two different coupling conditions. The frequency is fixed at 6.0MHz.

(b) The anode load impedance versus frequency. The resonator tuned to 18.0 MHz.

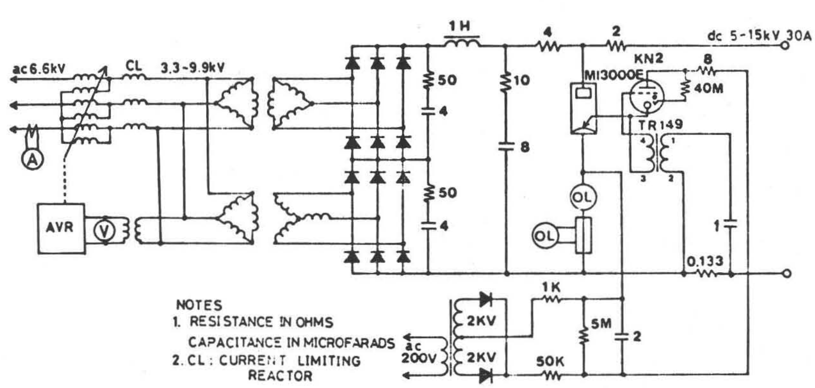

Fig.4 Circuit diagram of anode power supply and crowbar.

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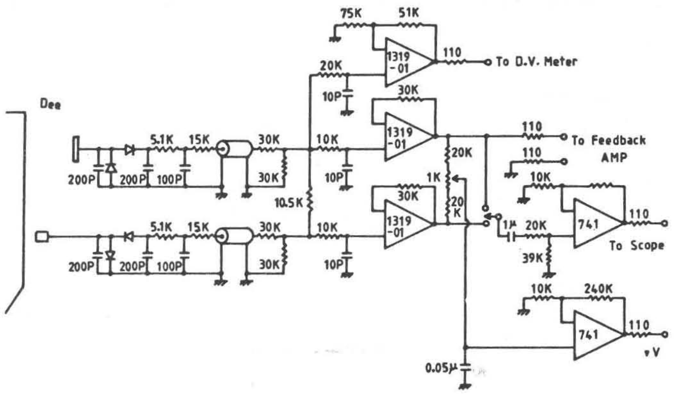

Fig.5 Circuit diagram of dee voltage detector.

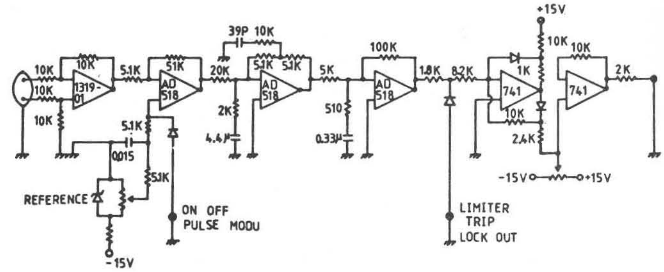

Fig.6 Circuit diagram of the dee voltage feedback amplifier.

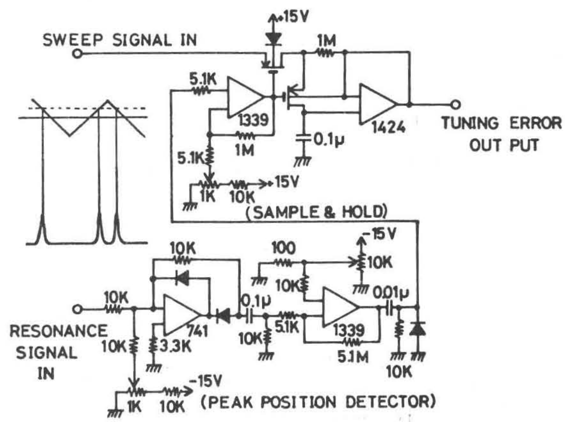

Fig.7 Circuit diagram of tuning error detector.
(for pretuning mode)

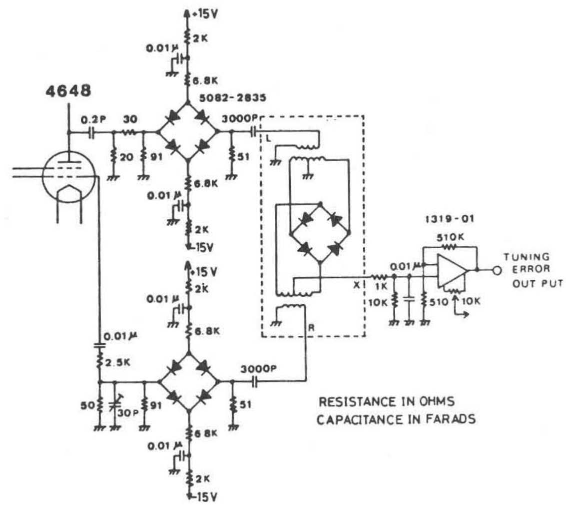

Fig.8 Circuit diagram of tuning and phase error detector.
(for normal operation mode)

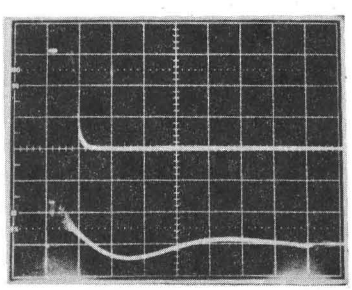

Fig.9 A typical wave form of crowbar circuit.
(Horizontal: 1μs/div.)
Upper: Output voltage of power supply. (800V/div.)
Lower: Crowbar firing signal. (50V/div.)

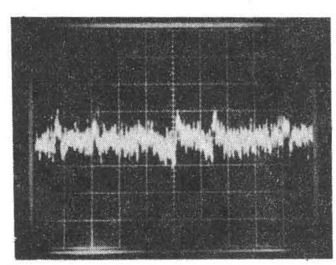

Fig.10 Ripple and noise voltage of dee voltage envelope at 60kV, 11.85MHz, on beam loading condition.
(E(α)=120MeV)
Horizontal: 2ms/div.
Vertical: 3V/div.