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Development of a Magnetron Resonance Frequency Auto Tuning System for Medical X-band [9300 MHz] RF Linear Accelerator

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1. Introduction

The Radiation Equipment Research Division of the Korea Atomic Energy Research Institute has been developing and upgrading a medical X-band linear electron accelerator. The total components of the accelerator are the magnetron, electron gun, accelerating structure, a set of solenoid magnets, four sets of steering coils, a modulator, and a circulator [1-6]. One of the accelerator components of the accelerating structure is made of oxygen-free high-conductivity copper (OFHC), and its volume is changed according to the ambient temperature [7-8]. As the volume changes, the resonant frequency of the accelerating structure is changed. Accordingly, the resonance frequency is mismatched between the source of the magnetron and the accelerating structure. Therefore, it can-not obtain a high beam energy and an unstable accelerator operation continues. An automatic frequency tuning system is automatically matched with the resonant frequency of the magnetron and accelerating structure, which allows a high output power and reliable accelerator operation. An automatic frequency tuning system is composed of a step motor control part for correcting the frequency of the source and power measuring parts, i.e., the forward and reflected power between the magnetron and accelerating structure. In this paper, the design, fabrication, and RF power test of the automatic frequency tuning system for the X-band linac are presented.

2. Design and Specifications

In this section, some of the techniques regarding the background knowledge, a phase-locked loop, and system specifications required for system development are described.

2.1 Pillbox Cavity Model

$$\omega^2 / c^2 = k^2{}_{mn} + k^2{}_z \qquad (1)$$

where $k_{mm} = x_{mm} / R_c$ and $k_z = 2\pi / \lambda_{guide} = p\pi / l$, $p = 0,1,2...$ The relationship of the TM_{010} mode between the resonant frequency versus the radius size is shown in Eq. (1-2) and Fig. 1. If the radius of the accelerating structure changes, the resonant frequency is changed. Therefore, the reflection is increased and a stable operation is difficult. For the frequency of the TM_{010} mode of the accelerating structure, a higher frequency indicates a smaller radius.

$$\omega_{010} = \frac{2.405C}{R_c} \qquad (2)$$

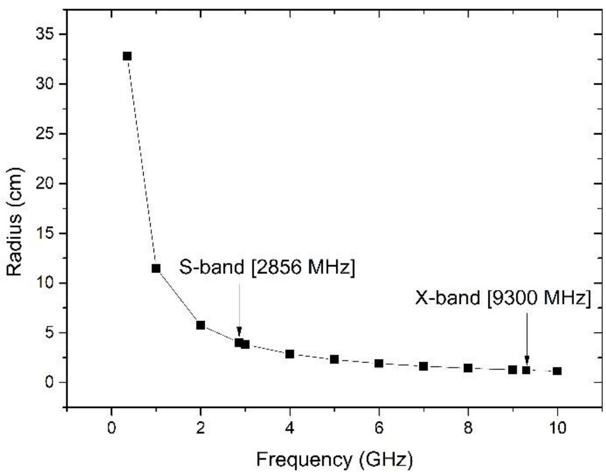

Fig. 1. Frequency dependence of the pillbox cavity radius.

2.2 PLL Model

A phase-locked loop, as shown in Fig. 2, is a non-linear element that reduces the phase difference between the input and output signals using negative feedback. The phase difference detected by the phase comparator is converted into a low-frequency voltage through the LPF, which is input to the voltage-controlled oscillator (VCO). In the oscillation circuit including the VCO Varactor, when the phase difference corresponding to the low-frequency voltage is input, the capacitance of the capacitor of the Varactor changed, causing the oscillation frequency changes owing to the LC resonance circuit, and thus generating an output frequency that is fixed to the phase of the input reference frequency.

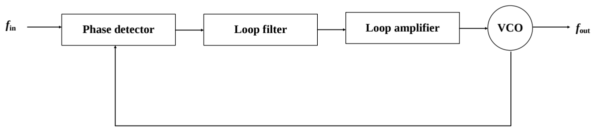

Fig. 2. Phase-locked loop model.

2.3 Specifications

The detailed specifications are shown in Table 1. The frequency tuning range of the magnetron is 9300 ± 25 MHz, 10 kHz per pulse to be tuned. The signal input and output terminals are minimized to minimize the radiation exposure.

Table 1: Specifications of the system

Parameters	Values	Unit
Frequency control range	9300 ± 25	MHz
Trigger input	0 - 5	V
Input signal form (pulse width)	4 - 13	μs
RF pulse repetition rate	1 - 300	Hz
Power supply	+24	VDC
Forward, Reflected, Trigger input	SMA Female Feed-thru	-
Stepping motor control	MS3112A 10-6SN	-
Remote control	RJ45	-

3. Test Results

The X-band frequency wavelength is short. Therefore, it is not easy to calculate and process. Using a step motor, a more compact and convenient frequency control device was developed. The frequency tuning system included the intermediate frequency (IF) and then a down-conversion. The RF is converted into a 70 MHz IF band using a local oscillator (LO) and mixer. Therefore, an easy frequency calculation and small requirement of the Q values of band pass filter (BPF) can be achieved.

3.1 Block Diagram for RF Test

The whole system configuration is shown in Fig. 3. The forward and reflected power is received from the 70 dB coupler and tuning the motor, and thus the reflected power is minimized. Automatic, manual tuning mode, and a magnetron resonance frequency display are possible.

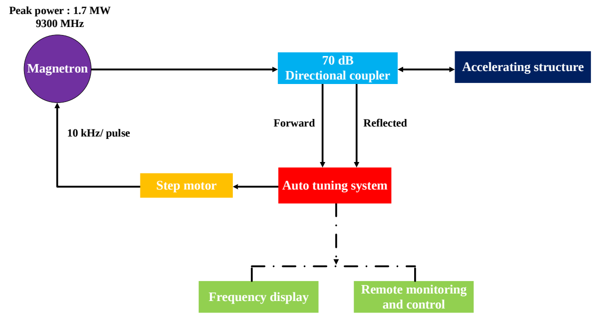

Fig. 3. Overall system configuration.

3.2 Measurement

Figure 4 shows the results of measuring the actual accelerator operation. After the frequency tuning, the frequency instability is minimized and a stable power supply is available.

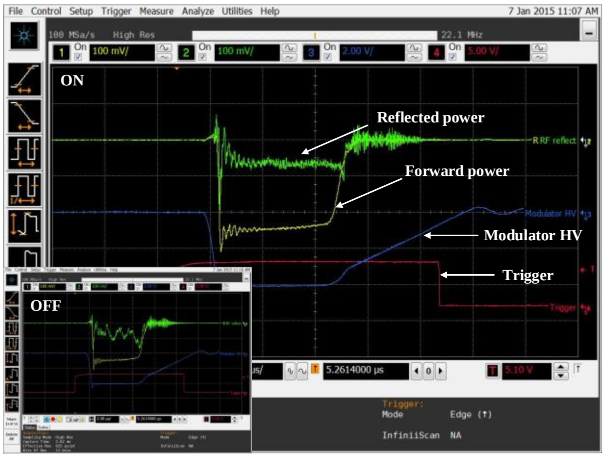

Fig. 4. Power pick up.

4. Conclusions

A frequency tuning system was developed to overcome an unstable accelerator operation owing to the frequency mismatch between the magnetron and accelerating structure. The frequency measurement accuracy is 100 kHz and 0.72 degree per pulse. The tuning shaft of the magnetron is tuned 5 MHz per turn. Consequently, frequency matching is possible and the reflected power reduced.

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