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Control of the RF System for the Helium RFQ

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1. Introduction

A radio frequency quadrupole (RFQ) is considered as a main accelerator for the helium beam irradiation system of the semiconductor [1][2]. The specification of the RFQ is shown in Table 1. A RFQ is a kind of accelerating cavity which has a high quality-factor. Therefore the RF parameters of the RFQ are very sensitive to the circumstance such as an ambient temperature. Generally, the resonant frequency of the high quality factor cavities should be fixed to design frequency when many cavities are used for higher energy beam acceleration. The resonance frequency should be controlled by using movable tuners or cooling water temperature control. But those methods make the system complex. In the helium RFQ system, we use a single cavity which means that it is not necessary to fix the cavity resonance frequency but it is enough to track the resonance frequency of the cavity by changing the driving frequency of the RF system which makes the system simple. In this paper, the control method of the RF system for the helium RFQ is presented and the operating conditions of the system are discussed.

Table 1. RFQ design parameters

Parameter	Value
Particle	$^{4}He^{2+}$
Input beam energy	100 keV
Output beam energy	4 MeV
Peak beam current	10 mA
Emittance (nor. Rms)	0.2 π mm mrad
Type	Four vane
RF frequency	200 MHz
RF power	130 kW
Maximum electric field	1.6 Kilpatrick
ρ/r_0	0.87
Length	328 cm
Transmission	95.3 %

2. Control Schemes

2.1 Control Margin

The sensitivity of the resonant frequency was calculated by using SUPERFISH code as shown in Fig. 1. The helium RFQ is 4-vane structure without windows and has octagonal cross section. The cross section was designed with the target frequency of 198.95 MHz. The unloaded quality-factor was 13,400 and the width between inner walls was 300 mm. The vane tip sensitivity due to displacement was 6.2 MHz/mm and the wall sensitivity was 0.8 MHz/mm, which corresponds to the temperature sensitivity of 4 kHz/°C.

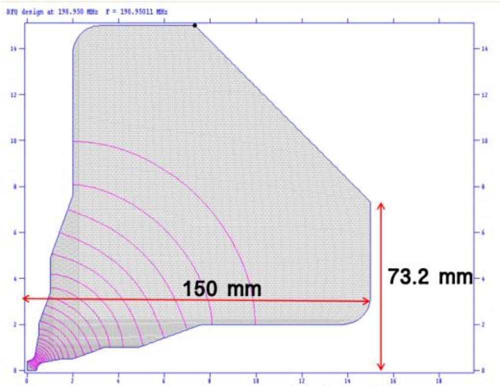

Fig. 1. RFQ cross section

The RF power distribution of the RFQ is such that power at the cavity wall is 120 kW in consideration of the quality factor degradation, beam power is 20 kW, loss at the transmission line is 20 kW and control margin is 40 kW. The required total power is 200 kW and 20 % of the total power is allocated to the control margin. The allowable cooling water temperature range was calculated to set the chiller specification and the result is shown in Fig. 2. Fig. 2 shows the normalized RF amplitude and power depending on the frequency difference between cavity and RF driver. If we consider 20% margin of the RF power, possible frequency difference is 10 kHz which corresponds to ± 2.5 °C cooling water temperature control range. Generally, the temperature control requirement of the cooling system for resonance frequency control purpose is ± 0.01 °C ~ ± 0.1 °C, which need very complicated system. But in this case, the cooling system can be very simple and we can get it from the commercial product.

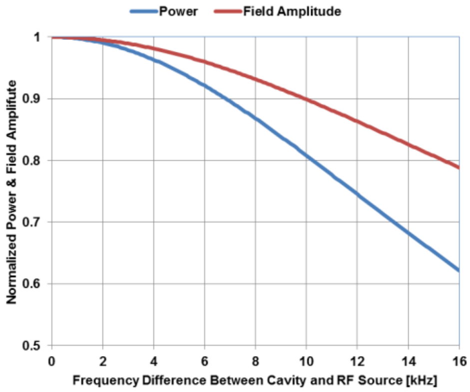

Fig. 2. RF parameters depending on the frequency

2.2 RF Control Scheme

The RF frequency and amplitude are controlled through low level rf (LLRF) control system. The LLRF system is developed by using FPGA based digital control technology. The block diagram of the LLRF control system is shown in Fig. 3. The local oscillator (LO) signal to down convert the RF frequency to intermediate frequency (IF) signal or up convert the IF to RF signal is not necessary because the digital board can sample or synthesize the 200 MHz RF frequency directly. The control loop is divided into two parts, one is for the fast amplitude control loop and the other is for the slow DDS control loop. The amplitude control logic is implemented in the FPGA itself and controls the RF amplitude within a pulse with the latency of a few micro second. The frequency error calculation logic is implemented in the CPU of the carrier board and delivers the DDS input signals in every pulse. Therefore, the DDS output maintains constant value during a pulse and is updated for the next pulse at the end of the pulse. We are going to install the low pass filters in the frequency control loop and make the response time of a few second. The PI control logics are implemented to control both the RF amplitude and frequency respectively.

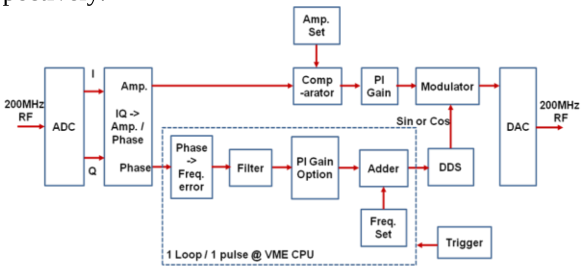

Fig. 3. Schematic diagram of LLRF control system

3. Conclusions

A RF control system for the RFQ was proposed. A resonance frequency tracking method is planned to be used in order to simplify the overall system. A 20 % RF power margin makes it possible to use a commercially available cooling system. And the algorithm to change the driver frequency following the cavity resonance frequency is proposed. The helium RFQ system will be installed by the end of 2015.

ACKNOWLEDGEMENT

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