DESIGN OF MONITORING AND TUNING SYSTEM OF RESONANT FREQUENCY FOR RFQ

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Abstract

A 37.8 MHz, 3.4 m long, four rod type RFQ Linac has been commissioned for the RIB facility project at VECC, Kolkata. The RFQ consists of a loop type tuner. The tuner is used to tune the RFQ resonant frequency whenever there is a change in its resonant frequency during beam operation. This paper describes the design and development of the control system for monitoring as well as restoring the resonant frequency by movement of the tuner of the RFQ. The system has been tested using the half scale cold model of RFQ.

INTRODUCTION

The RFQ is a 3.4 m long extended rod type structure and operates at a frequency of 37.83 MHz. The RFQ is operational at present and the beam energy of the RFQ is 99 keV/u [1, 2]. The rf structure of the RFQ cavity consists of a base plate, a number of pair of right-wound and left-wound arms called posts and 4-rod quadrupole electrodes called vanes. The rf power is fed to RFQ cavity from a high power rf transmitter through a 3-1/8", 50 Ω coaxial transmission line. A water-cooled loop coupler for rf power feeding inside the RFQ cavity and an inductive tuner (loop type) are used for frequency tuning. The loop coupler and the frequency tuner have been indigenously designed and built [3].

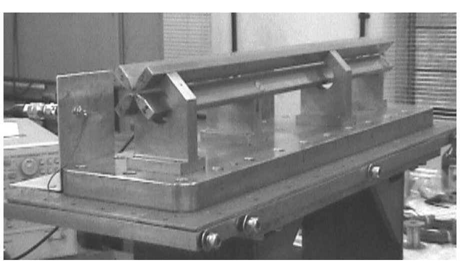


Figure 1: The 1.7 m RFQ.

RFQ resonator needs to be operated at resonant frequency for the efficient utilization of rf power in obtaining a large electric field between the vanes. However, the resonant frequency of the RFQ cavity varies due to changes in temperature (when power is fed into the cavity) and beam loading. It is thus necessary to keep the RFQ stay tuned to the initial input resonant frequency during a long beam run. A control system has been built for monitoring the resonant frequency and tuning the RFQ cavity to its resonant frequency. This control system has been tested on the half scale cold model (72.07 MHz) of the RFQ. Figure 1 shows the rf structure of cold model of RFQ.

SYSTEM DESCRIPTION

The information of shift in resonant frequency of the cavity is required for design and operation of control system. The phase difference between the forward power and the transmitted power gives a measure of the shift in resonant frequency of the cavity [4]. Based on this information, a system is being built for the monitoring as well as tuning of the resonant frequency of the RFQ. Figure 2 shows the schematic diagram of the control system. The dual directional coupler (DDC) is used to monitor the forward and reflected power whereas the transmitted is obtained from the pick-up port of the RFQ cavity. A phase detector is used for monitoring the phase difference between the forward and the transmitted signals.

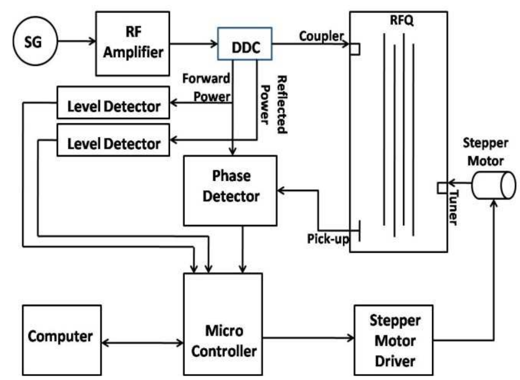


Figure 2: The schematic diagram of the system.

The output of the phase detector is amplified to a suitable level and fed to an ADC. Based on the output of the ADC, a microcontroller is programmed to drive the stepper motor of the tuner which restores the resonant frequency of the RFQ to its original value.

Optimisation of Tuner

Tuning of resonant frequency is done by inserting a loop tuner in the RFQ cavity, which utilises the maximum available magnetic flux near the post. For the calculation of the tuning range of the tuner and optimisation of its size and position, a lumped parameter model has been used. The change in frequency (Δf) due to the loop tuner is given by:

$$\Delta f = f - f_o = \pi . M^2 . f_o^2 . Q_o / (L_t . R) \quad (1)$$

Where,

$$M = (a.\mu_o / 6\pi)*\ln (c/d), \text{ where } c=d+b \quad (2)$$

$$L_t = (\mu_o /\pi). \{a. \ln (2.a.b/ (g.(a+ \sqrt{(a^2+b^2)})) + b. \ln (2.a.b/ (g. (b+ \sqrt{(a^2+b^2)})) - (a+b) + 2. (\sqrt{(a^2+b^2)} +g)\} \quad (3)$$

g is the cross section of the loop conductor.

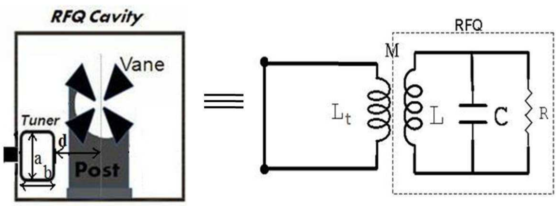


Figure 3: RFQ resonating structure with coupler and its lumped equivalent.

The loop size in our case is 65 mm x 80 mm and the distance from the centre of the post is 80 mm. This gives us a maximum frequency shift of 70 kHz. The tuner is rotated using a stepper motor. The dimension and position of the tuner is adjusted in such a way that the desired change in resonant frequency of the RFQ is obtained. For 90^o movement of tuner, the stepper motor requires 100 steps of rotation. Figure 4 shows the measured frequency shift vs steps of rotation for given loop size and position of tuner.

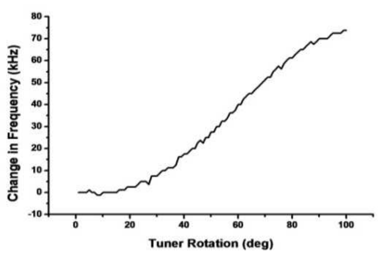
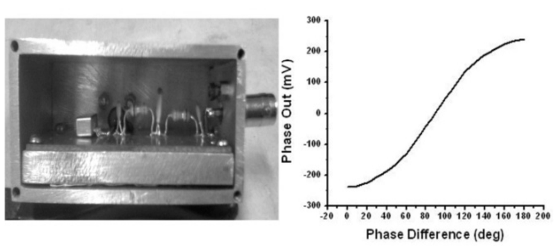


Figure 4: Measured change in frequency for 90^o rotation of tuner.

Phase Detector

A phase detector is required for detecting the phase difference between the forward power and transmitted power (pick-up power). The phase detector has been designed and developed using a mixer TUF-1SM+ [5] followed by a low pass filter and amplifier as shown in figure 5(a).



(a) (b)

Figure 5: (a) phase detector (b) Output.

The output of the mixer is a dc voltage along with other higher order terms. The LPF is designed as a Butterworth LPF with a cut-off frequency of 20 MHz. The output of LPF is dc voltage proportional to the phase difference (0^o to $\pm 180^o$) between two inputs. Figure 5(b) shows the measured output voltage for 0^o to 180^o phase difference between the inputs.

Microcontroller System

The control system for tuning and monitoring of resonant frequency is based on microcontroller 8051 for which Analog Devices ADuC841 card has been used [6]. Initially, the RFQ cavity is tuned to operating frequency for minimum reflection (i.e. matched coupling condition). In this condition, the phase difference between forward and transmitted power is the reference value for the microcontroller program. The dc output from phase detector is acquired by the microcontroller and used for comparison with reference value. The number of steps and the direction of rotation of the stepper motor for the tuner is decided by the microcontroller on the basis of feedback data.

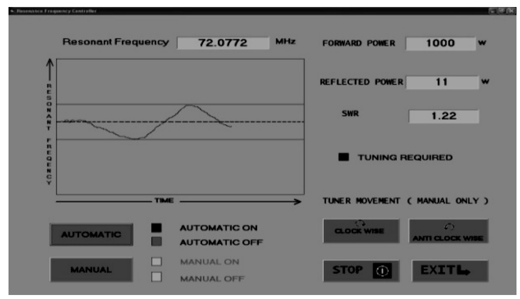


Figure 6: Screenshot of the Computer interface.

The microcontroller communicates with a computer by transmitting status signals and receiving commands. Manual control of the stepper motor is also provided. A GUI based software program for acquisition, processing, logging, storing and on line monitoring of data has been developed in Visual Basic. A screenshot of the computer interface is shown in figure 6.

CONCLUSION

The optimisation of tuner and development of the phase detector has been completed and tested. The microcontroller and front end programming has been done. The whole system is currently under test using the 72.07 MHz, 1.7 m cold model of the RFQ. Further tests have to be done for the main RFQ cavity (37.8 MHz, 3.4m) to assess the thresholds over which control action has to be initiated.

ACKNOWLEDGEMENTS

Authors would like to thank Shri Sumit Som for his valuable suggestions. Authors are also grateful to Aparnita Das for her support in developing the computer interface programming.

REFERENCES

[1] Alok Chakrabarti et al., NIM A 535 (2004) 599.
[2] S. Dechoudhury et al., RSI, 81, 023301 (2010).
[3] H. K. Pandey et al., IEEE-AEMC (2007).
[4] M. T. Lynch et al, PAC -1987, 775.
[5] TUF-1SM+ Datasheet, Mini-Circuits.
[6] ADuC841 Datasheet, Analog Devices.