ADVANCED CLOSED-LOOP TRIMMER CONTROL SYSTEM FOR FINE TUNING THE RF CAVITY OF K500 SUPERCONDUCTING CYCLOTRON

Aditya Mandal, Surajit Ghosh, Sudeshna Seth, Sumit Som, S Paul, P R Raj, S Roy, S Saha, R K Bhandari and RF Group
Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata 700064

Abstract

The RF system of superconducting cyclotron operates between 9 – 27MHz. The RF cavities are consisting of three numbers of half wave (λ/2) coaxial sections. RF power from the tuned RF amplifier is capacitively coupled to the dee (accelerating electrode) of the main resonant cavity through Coupler (Coupling capacitor). The coupler is used to match the high shunt impedance of the main resonant cavity to the 50 Ohm output impedance of final RF power amplifier. Owing to RF thermal instability the volume inside the cavity changes as results there is a shift in frequency of resonance, consequently sharp fall in Dee voltages. Hydraulic drive based Trimmer capacitor operates in closed loop for the adjustment of a small variation in tuned frequency due to thermal effect and beam loading of the cavity. The impedance matching during the close loop operation is maintained by trimmer movement system. The precise movement of trimmer is necessary to compensate the change in volume of the cavity due to thermal expansion and maintain impedance matching between RF amplifier and RF cavity. Phase detector is used to detect the cavity de-tuning angle by comparing the phase difference between the cavity pickup (Dee pick-up) signal and cavity driven signal. This signal is fed to the PLC based digital P. I. controller to control the movement of trimmer capacitor. The control system has been modelled, analyzed, optimized and is operating round-the-clock with the K-500 SC Cyclotron system successfully

INTRODUCTION

The RF system of K500 superconducting cyclotron consists of three half wave (λ/2) coaxial cavities[1]. In the vicinity of resonance a RF cavity can be modelled as parallel RLC circuit [2]. The resonant frequency of the cavity depends on L and C i.e. $\omega_n = \frac{1}{\sqrt{LC}}$. For tuning the cavity, two conditions have to be satisfied i) Resonant frequency of the cavity should be equal to generator frequency $\omega_g = \omega_n = \frac{1}{\sqrt{LC}}$ ii) The input impedance of the cavity seen from RF amplifier(RF source) is 50+j0 Ω which ensures minimum VSWR at coupler port. And to attain these two criteria we have three controls i) Sliding Short (changes the length of the cavity) ii) Variable Coupling capacitor, iii) Variable Trimmer Capacitor [3]. The schematic block diagram of the system is shown in figure 1.

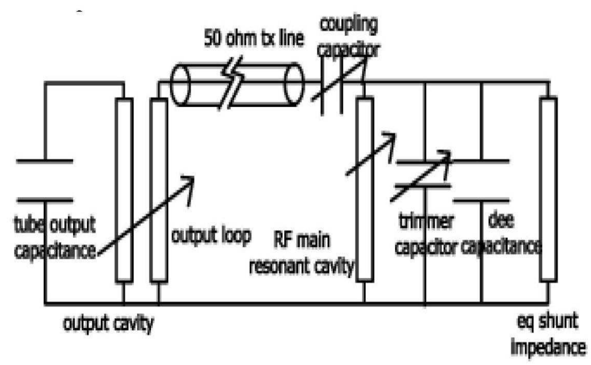

Figure 1: Block Diagram of RF system

The phase angle between Dee-in voltage (signal taken from input to cavity) and Dee pick-up is monitored to ensure tuning requirements. In tuned condition Dee-in signal and Dee pick-up signal are in phase quadrature. During operation, due to heat dissipation the cavity dimension gets changed resulting a frequency detuning. Due to this change, the phase between Dee-in and Dee pick-up signal changes. The trimmer control system which primarily operates on this phase error, acts on the movement of trimmer capacitor to restore the frequency of the cavity.

SYSTEM MODEL

The system consists of a PLC based PID controller, Hydraulic Valve Actuator, Trimmer capacitor, RF cavity, Phase detector and Reflected power meter. The control system block diagram is shown in Figure 2. Due to the very high Q of the cavity, Dee voltage amplitude and phase is very sensitive to the movement of trimmer. Both phase error and reflected power are measure of frequency detuning and ideally both are zero when the cavity is properly tuned. Primarily the control system operates on the phase error between Dee-in and Dee pick-up signals. But due to measurement noise, non-linearity, delay in loop, the system lead to oscillations. Lowering of proportional gain of PID control loop will reduce the oscillations but settling time will be increased as well. So a variable gain system is proposed which comprises of phase error (Φ) and reflected power (R). The basic idea behind the variable-gain control design is that, firstly, when the error is small a low-gain design should be in effect to ensure low sensitivity to high-frequency measurement noise and, secondly, when the error becomes large due to low-frequency thermal events a high-gain design should be active to ensure a high level of low-frequency tracking performance. Reflected power does not provide the direction of detuning (i.e. whether positive or negative), it gives

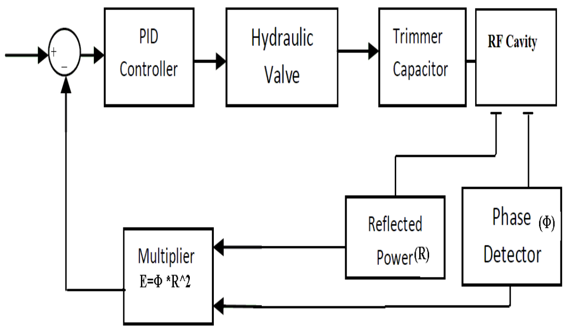

Figure 2: Trimmer Control System block diagram

only the magnitude of detuning. Feedback signal is made of phase error (Φ) times the square of reflected power (R) to have non-linear gain. The error signal vs frequency drift is shown in Figure 3. Moreover, multiplication of reflected power improves the

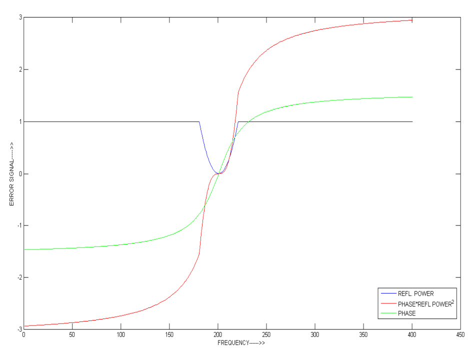

Figure 3: Error Signal Vs Normalized frequency

system performance by averaging the two signals when minima of phase and reflected power differs.

CONTROL SYSTEM ANALYSIS

The equivalent system is modelled in MATLAB and responses are examined. The control system has to take care of time delay in feedback chain, non-linearity of the valve, dead-band, inertia, jittering etc. The PID controller is tuned using Ziegler–Nichols criterion [4] for phase only feedback system. But due to noise in measuring system, jittering etc. the system remains oscillating. Further improvement is done by making variable gain i.e. making error signal nonlinear ($E=\Phi *R^2$). The responses are plotted in Fig.4. Popov stability criterion is examined and both the signals are scaled accordingly.

It is observed that the system takes good care of measurement noise and both rise time and settling time is improved. Similar response is also observed in practice.

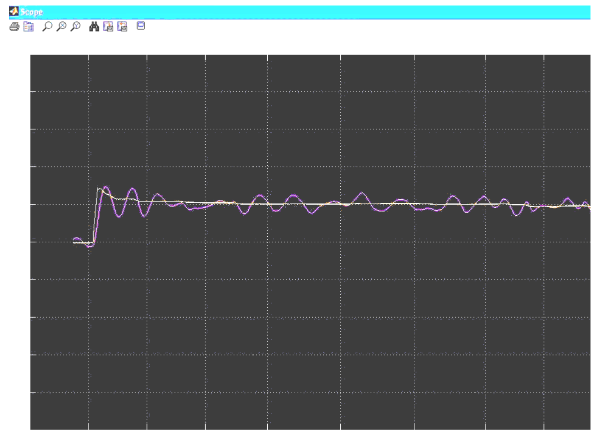

Figure 4: Step response of the system

CONCLUSIONS

Proper adjustment of trimmer capacitor ensures minimum RF power requirement and minimum reflected power to the RF power source. Less oscillation of control loop results in better Dee voltage amplitude loop stability and phase loop stability.

REFERENCES

[1] "An overview of the RF system of k500 Superconducting Cyclotron at VECC", S. Som et. All, InPac-2005,C-139.

[2] "Modelling and Analysis of Radio frequency Structures using an Equivalent Circuit Methodology with Application to Charged Particle Accelerator RF resonators", John J Vincent

[3] "Closed loop RF tuning for super conducting cyclotron at VECC", Proceedings of CYCLOTRONS 2010, Lanzhou, China, Aditya Mandal.

[4] "Revisiting the Ziegler–Nichols step response method for PID control", K.J. Astrom, Journal of Process Control 14 (2004) 635–650.