

Self-Tuning Low Level RF Control System for the Linac Cavity

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Abstract

This paper presents the Matlab programming work and results for the Inphase Quadrature (IQ) based Low Level Radio Frequency (LLRF) self-tune control of RF cavity voltage. The RF cavity chosen here is the Radio Frequency Quadrupole (RFQ) cavity in our RIB project. All the subsystems in the IQ based RF control were modeled using MATLAB programming. The envelope program was carried out using the IQ model of RF cavity. The PID controller was tuned to the help of the RFQ cavity parameter like Q-value and cavity resonating frequency (ω_0) for achieve good control performance in time. The plot showing the time evolution of the RF cavity voltage with a step change of the input reference signal is presented. The bode plot showing of the control loop gain and phase margin values obtained from them are presented, which are good enough for stability considerations.

Introduction

One of the challenges for a control system design engineer working in a particle accelerator facility is to minimize particle-loss in the LINAC. As we know the cavity heats up during the operation of the LINAC which results in physical changes to the cavity like widening, elongation etc. of the tube which in turn takes toll on the cavity parameters like Q Factor and Resonating frequency.

Hence there is an obvious mismatch between the RF applied and the particle beam, magnifying the chances of particle loss which is undesirable and hence this mismatch has to be reduced or eliminated by some engineering techniques.

At present the RF cavity voltage are controlled by analog/digital IQ method. The IQ LLRF control method is based on the principle

that we can control the amplitude (A) and phase (ϕ) of a RF voltage.

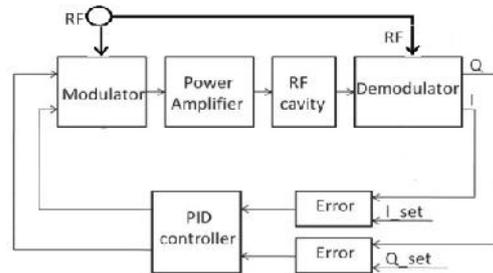


Fig. 1 Schematic Diagram of IQ LLRF control.

Our aim is to design a self-tuning PID controller which would decrease the response time of the system thereby stabilizing IQ of the RF. We started off by finding the Transfer function of the cavity in terms of Q- factor and ω_0 i.e. the cavity resonating frequency. Then we designed the PID controller in such a way that if the cavity parameters change the tuning parameters will also change accordingly. The response of the system is plotted on Matlab and examined.

Transfer Function of the Cavity

The conventional electrical model of an RF cavity (RFQ) is a shunt RLC circuit supplied by a current source. Although, this is a lumped model and the transfer function of the RFQ is

$$G(S) = \frac{\left(\sqrt{\frac{1}{LC}}\right)^2}{S^2 + \left(\frac{2S}{2R}\left(\frac{1}{\sqrt{LC}}\right)\sqrt{\frac{L}{C}}\right) + \left(\sqrt{\frac{1}{LC}}\right)^2}$$

Where, R, L and C are the lumped cavity parameter.

$$\text{So, } \omega_n = \sqrt{\frac{1}{LC}} \text{ and } \xi = \frac{1}{2R} \sqrt{\frac{1}{LC}}$$

Hence,

$$G(S) = \frac{\omega_n^2}{S^2 + 2S\omega\xi + \omega_n^2}$$

These L, R and C parameters are directly related to the Q-factor and resonating frequency ω_0 of the Cavity.

$$L = \frac{R}{\omega_0 Q} \text{ and } C = \frac{Q}{R\omega_0}$$

So the transfer function of the cavity is in the form of the cavity parameter

$$G(S) = \frac{\omega_0^2}{S^2 + \left(\frac{\omega_0}{Q}\right)S + \omega_0^2} \quad (1)$$

Tune the PID Controller Parameter

The transfer function of the PID controller is given by:

$$C(S) = K_p \left(1 + \left(\frac{T_i}{S}\right) + T_d S \right) \quad (2)$$

So the open loop TF (OLTF) of the system with PID is G(s)C(s). Now if we tune the parameters Kp, Ti and Td in such a way so that the closed loop TF (CLTF) becomes of first order type. By comparing the CLTF to the first order system transfer function which time constant is τ . We can find that the values of PID parameters that make the CLTF of first order type are: -

Block diagram

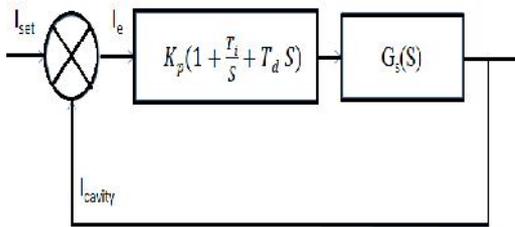


Fig. 2 Feedback Control Loop of system.

Transfer function of this feedback control system is

Closed Loop Transfer function

$$\frac{C(S)G(S)}{1+C(S)G(S)} \quad (3)$$

Equation (3) is compare with the first order system, which time constant is τ .

That means,

$$\frac{1}{S\tau + 1} = \frac{C(S)G(S)}{1+C(S)G(S)}$$

Or,
$$C(S) = \frac{1}{G(S)S\tau}$$

Now,

$$K_p \left(1 + \left(\frac{T_i}{S}\right) + T_d S \right) = \frac{1}{G(S)S\tau}$$

From equation (1)

$$K_p \left(1 + \left(\frac{T_i}{S}\right) + T_d S \right) = \frac{S^2 + \left(\frac{\omega_0}{Q}\right)S + \omega_0^2}{\omega_0^2 S \tau} = \left(\frac{1}{\omega_0 \tau Q}\right) \left(1 + \left(\frac{\omega_0 Q}{S}\right) + \left(\frac{Q}{\omega_0} S\right) \right)$$

Comparing the both side,

Hence,

$$K_p = \left(\frac{1}{\omega_0 \tau Q}\right); \quad (4)$$

$$T_i = \omega_0 Q; \quad (5)$$

$$T_d = \frac{Q}{\omega_0}; \quad (6)$$

So, Q-value, resonating frequency (ω_0) and the time constant τ of the first order system will give the controlling parameter of the controller. These Kp, Ti and Td values provide fast response to the system.

MATLAB Analysis

For the given value Q-value and resonating frequency ω_0 of the RFQ cavity and take the time