Title: Analysis of the SNS Superconducting RF Control System

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ANALYSIS OF THE SNS SUPERCONDUCTING RF CONTROL SYSTEM

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Abstract

The RF system for the SNS superconducting linac consists of a superconducting cavity, a klystron, and a low-level RF (LLRF) control system. For a proton linac like SNS, the field in each individual cavity needs to be controlled to meet an overall system requirements. The purpose of the LLRF control system is to maintain the RF cavity field to a desired magnitude and phase by controlling the klystron driver signal. The Lorentz force detuning causes the shift of the resonant frequency during the normal operation in the order of a few hundreds hertz. In order to compensate the Lorentz force detuning effects, the cavity is pretuned into the middle of the expected frequency shift caused by the Lorentz force detuning. Meanwhile, to reduce the overshoot in the transient response, an error feedforward algorithm is proposed to get away a repetitive noised caused by the pulsed operation.

1 INTRODUCTION

To analyse the performance of the RF control system for the SNS superconducting linac, a MATLAB model is created for each functional blocks, which includes the superconducting cavity model, klystron model, PID feedback controller, and an error feedforward controller[1]. An equivalent resonant circuit couple with a coupling tranformer is used for the superconduncting cavity model in which the Lorentz force detuning of the cavity resonance frequency is included. The klystron is modeled as a cascation of a pass filter, determined by the bandwidth of the klystron, and a phase-magnitude saturation curve, which represents the saturation characteristics of the klystron. The phase-magnitude aturation curve is obtained from the measurement and is further analysed using the curve fitting to generate the final model. The main feedback controller is a PID controller for an easy implementation and robustness concern. In order to implement the RF control system in a full digital control system, the latency analysis is needed to satisfy the performance requirement of the system. Finally, with the results obtained from the numerical simulation and the performance requirements, a full digital control system for the LLRF system is proposed. In this system, a combined CPLD and DSP technology is used to cope with different requirements. The CPLD is applied to the critical path in which the time delay need to be minimized. While the DSP is used to perform the complex error feedforward which required the computation power but need only be feed to the control signal in the next pulse.

2 LORENTZ FORCE DETUNING

The Lorentz force detuning is represented by a tate equation.

$$\dot{\Delta}\omega_L = -\frac{1}{\tau_m}\Delta\omega_L - \frac{2\pi}{\tau_m}KE_{acc}^2.$$

Where, Eacc is the actual electric field intensity of the cavity[MV/M], τ is the mechanical time constant of the cavity[second], K is the Lorentz force detuning constant[Hz/(MV/m)]. The relationship among the gap voltage Vacc, the In-phase conponent Vi and the Quadrature component Vq of the cavity voltage is given by:

$$V_{acc} = \xi\sqrt{V_I^2 + V_Q^2},$$

$$E_{acc} = \frac{E_0}{V_{gap}}V_{acc}$$

Hence, we can write the Lorentz force detuning as

$$\dot{\Delta}\omega_L = -\frac{1}{\tau_m}\Delta\omega_L - \frac{2\pi}{\tau_m}K\left[\xi\frac{E_0}{V_{gap}}\right]^2\left(V_I^2 + V_Q^2\right)$$

Where, E is the electric filed and Vgap is the gap voltage of the designed cavity voltage. Define

$$\overline{K} = K\left[\xi\frac{E_0}{V_{gap}}\right]^2$$

Then, the Loretz force detuning is represented as

$$\dot{\Delta}\omega_L = -\frac{1}{\tau_m}\Delta\omega_L - \frac{2\pi}{\tau_m}\overline{K}V_I^2 - \frac{2\pi}{\tau_m}\overline{K}V_Q^2$$

The effect of the Lorentz force detuning is in[1].

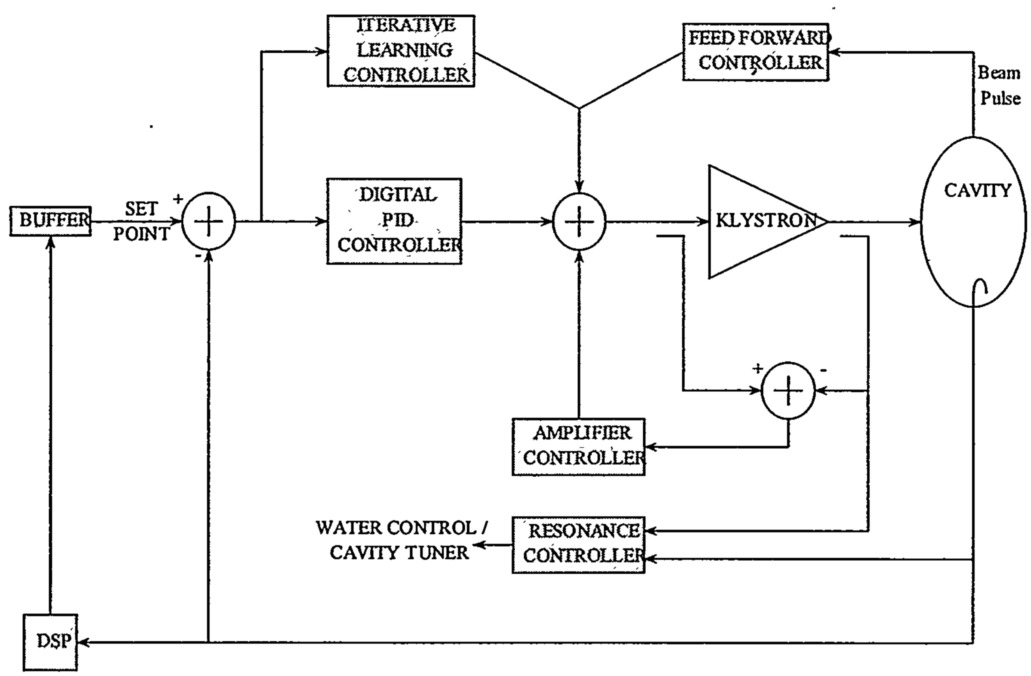

Figure 1: Functional block diagram of the RF system for SNS

3 RESULTS AND CONCLUSION

Figure 1 is the block diagram of the RF control system. As we can see that the fast signal path is the implemented using the CPLD while the error feedforward is implemented using the DSP. The total frequency response of the system is given is Figure 2.

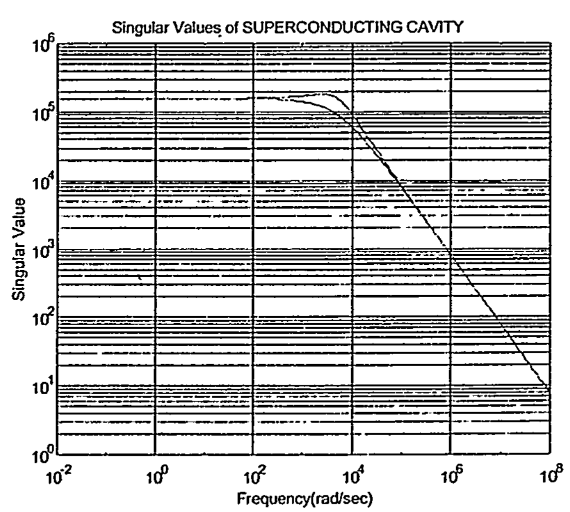

Figure 2. Singular Value of the Open Loop System

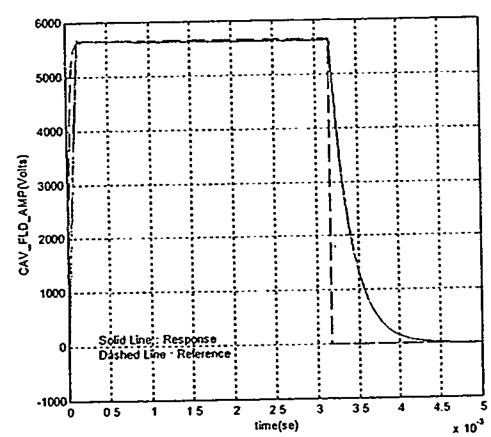

Figure 3. Closed Loop System Response: Cavity field Amplitude of the Transformed Cavity Equivalent Circuit.

The system performance is given in Figure 3 in which the steady state value is within the error limit. In Figure 4, the performance of the feed-forward control is represented in a way so that the reduction of the repetitive noise due to the beam pulse can be observed. Here, the feedback controller is a PI controller and the feed forward controller implemented is an iterative learning controller.

From the analysis and the simulation results obtained from our modelling, it is obviously that the performance requirements have been achieved with a full digital control system in which the latency of the digital system has been take into account in the modelling. However, in the real operation, other problems may arise, such as the effect of the microphonics. The performance of the proposed RF control system in the real operation will be reported when the data is available.

REFERENCES

[1] S.I. Kwon, Y.M. Wang, and A.H. Regan, "SNS Superconductin cavity modelling and linear parameter varying gain scheduling controller(LPV GSC) and PI controller syntheses, Technical Report, LANL, June, 2000.

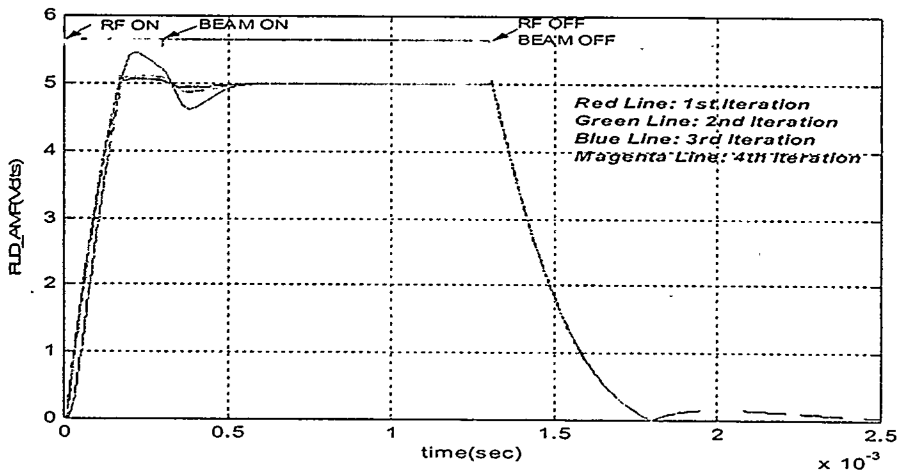

Figure 4. Field amplitude with the feedforward controller.