Stability analysis using EMTP for JHF systems

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Abstract

The Stability analysis for JHF (Japan Hadron Facility) synchrotron has been performed by using a code for the stability analysis, EMTP(Electronic Magnetic Transient Program). We have examined two cases; a MA (Magnetic Alloy) loaded cavity and ordinary ferrite one. The MA loaded cavity has low Q value and does not require the tuning system for a frequency sweep. The result shows that the MA loaded cavity has larger stable area than the ordinary ferrite loaded cavity. The JHF RF system using the MA loaded cavity can be operated stably. Another simulation has been performed with a code, MC(Micro Cap). The results were consistent with the EMTP analysis.

1 INTRODUCTION

On the JHF proton synchrotrons, the circulating beam current goes up even 7A. Therefore, the heavy beam loading problem is one of the most severe problems for the JHF synchrotrons. When there are a few feed backs under the strong beam loading, the condition of stability of an RF system can be calculated analytically [1]. However, when the RF control system of the proton synchrotron has some feedbacks such as ALC (Automatic Level Controller), Tuning, Phase and ΔR, the instability of the RF system can not be calculated analytically. In addition, each feedback loop has the bandwidth and these feedback loops interfere each other under the beam loading. According to a preceding analysis [2], the condition to operate RF system stably is that relative loading Y should be less than 1.

On the proton synchrotron, the particle's velocity at the injection differs from the one at the ejection. Therefore, in the ordinary RF system the tuning loop is necessary. However, the MA loaded cavity does not require the tuning loop, because it has a large impedance which cover the required frequency for acceleration. Because the voltage variation between the resonant frequency and the acceleration frequency is small, the ALC can compensate the voltage variation. This characteristic allows a simple RF system without tuning loop.

2 PRINCIPLE OF THE SIMULATION

The bandwidth of each loop was chosen from the realistic values and it was stable under the no-beam condition. Figure 1(a) shows the block diagrams for ALC and phase, and figure 1(b) shows each stepping response for ALC and phase controller. The boxes of figure 1(a) represent the transfer function of each element. Because the controlled loops interfere each other under heavy loading[3], the analysis for a total system is necessary. This block diagram of the control system is shown in Figure 2. In order to analyze the stability of this system, we used the code, EMTP, which calculated the transient phenomena by resolving differential equations corresponding to the transfer functions. The stability analysis for JHF main ring has been performed as follows. The block diagram of the total RF system is shown in Fig.2. A step input signal was input at ΔR reference, if the ΔR response converged, this system is stable.

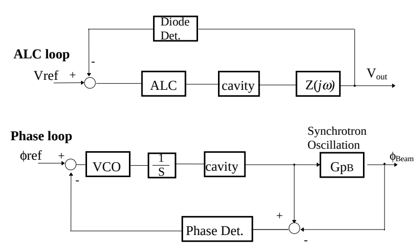

Figure 1(a): The control system for ALC and phase.

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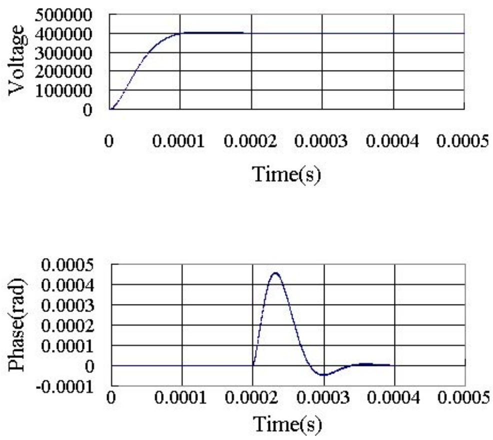

Figure 1(b): The stepping response for ALC and Phase.

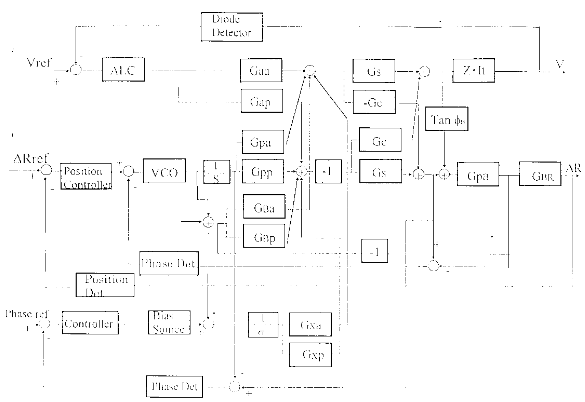

Figure 2: The block diagram of the control system under the heavy beam loading.

3 STABILITY ANALYSIS WITH EMTP

We performed a stability analysis with the code, EMTP for the two different systems. One is the ordinary ferrite-loaded cavity which has the Q value of 100 with the tuning loop. Another is for the MA loaded cavity without the tuning loop. The MA loaded cavity has the Q value of 1. Figure 3 shows a stability limitation as a function of loading angle. The result is that the MA loaded cavity has larger stability region than the ferrite-loaded cavity. The reasons are as follows. The cavity has a small phase lag because of the low Q values of the cavity. The order of the characteristic equation for the MA loaded cavity system is lower than that of the high Q cavity system. A system generally becomes more complicated and unstable when the order of the characteristic equation increases. The minimum stable value of relative loading $Y(=I_B/I_0)$ for MA loaded cavity is 1.5. The system that used MA cavity for JHF can operate stably for all loading angle ϕ_L, because it keeps relative loading Y less than 1. When the beam is positioned in the stabile region, the oscillation is damping as shown in figure 4(a). On the other hand, the beam oscillation grows up in the unstable region, then it is diverging as shown in Fig. 4(b).

4 SIMULATION BY MC(MICRO CAP)

Another simulation for the time domain of the RF control system with MA loaded cavity was performed by using the code, MC. Figure 5 indicates the block diagram of this simulation circuit. The Q value, the shunt impedance, and the accelerating voltage are 1, 4kΩ, and 40kV respectively. Figure 6 shows the result when the ALC and phase feedback were turned on. On the other hand, Fig. 7 shows the result when the phase feedback was turned off. The phase difference between the fundamental component of the beam current and the accelerating voltage became proper position (90^O) for accumulation. The result shows that the generating current was controlled to achieve the target point. When the phase loop was turned on, the response time at this condition was 30kHz for ALC and 30kHz for phase respectively. The result was consisted with the step response of controller designed with EMTP. We used more severe parameter for the MC analysis then the designed value. We should note High Gradient cavity [4] will reduce the relative loading significantly.

5 CONCLUSION

We conclude that MA loaded cavity without a tuning loop can have a larger stable region than the ferrite-loaded cavity. Another analysis using the code MC was consistent with the code EMTP.

6 REFERENCES

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[2] D.Bussards CERN 92-03

[3] K.W. Robinson, CEA, Report No.CEAL-1010 Feb. 1964

[4] JHF accelerator design study report Sep. 1997

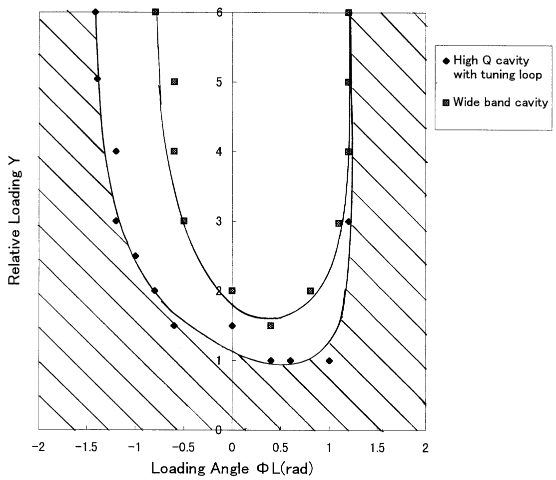

Figure 3: The stability limitation of the ordinary ferrite loaded cavity and MA loaded cavity.

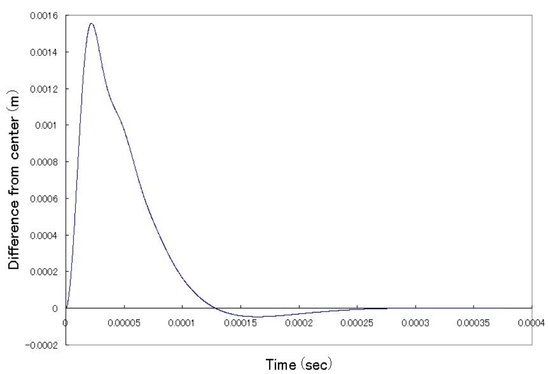

Figure 4(a): The ΔR response is damping.

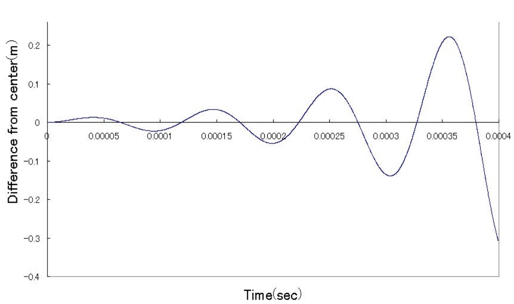

Figure 4(b): The ΔR response is diverging.

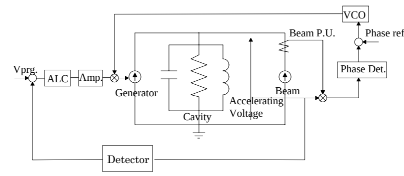

Figure 5: The block diagram of the simulation using the code, MC.

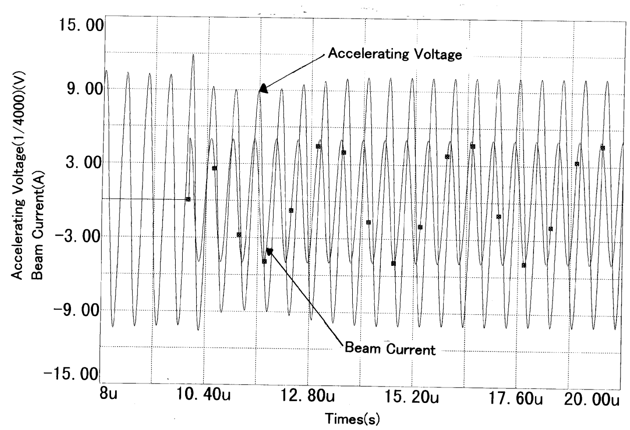

Figure 6: The accelerating voltage and the fundamental component of the beam current when the ALC and phase feedbacks were on.

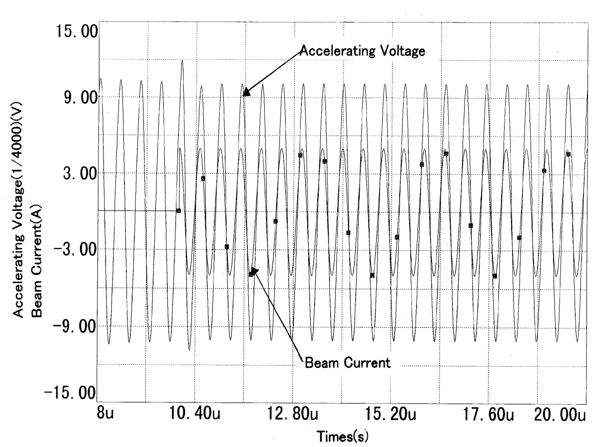

Figure 7: The accelerating voltage and the fundamental component of the beam current when the phase feedback was off.