

## Analysis of the Servo-Spill Control for Slow Beam Extraction

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### Abstract

This report describes an analysis of servo-spill control system for the slow beam extraction from the KEK PS. Transfer function of extraction process is derived from measurement of the closed-loop characteristic using measured frequency response of each equipment. Result indicates the restriction of the present servo-spill control and give a guide line for the improvement.

### I. INTRODUCTION

In order to utilize a full intensity extracted beam, a slow extraction system was upgraded to extend the spill time by a factor of four [1] and the second beam extraction line was constructed.[2] Deterioration of spill fluctuation ratio was expected by the extension of extraction period, since the spill fluctuation is roughly proportional to  $dv_H/dt$  from the ripple of lattice focusing quadrupoles for low frequency region. Extracted beam spill fluctuation is also produced by the re-bunch phenomena or coasting beam instability induced by the impedance of RF cavities. Then, the efforts to reduce the spill fluctuation has been going on, that is, the servo-spill control system has been upgraded by adding feed forward signal to feedback signal and the wake field in the RF cavity has been cancelled by the beam bunch signal to reduce the re-bunch effect during extraction period.[3]

The servo-spill control system aims to reduce the low frequency spill fluctuation less than a few KHz, however it works well in lower than only a few hundreds hertz. When one increase the loop gain to reduce the fluctuation, closed system becomes unstable. Then, an analysis of characteristic of the servo-spill controller has been wanted to know a restriction for the present servo-spill control are described.

### II. SIMULATION MODEL OF THE PRESENT EXTRACTION SYSTEM

If all system is made by only linear components, the

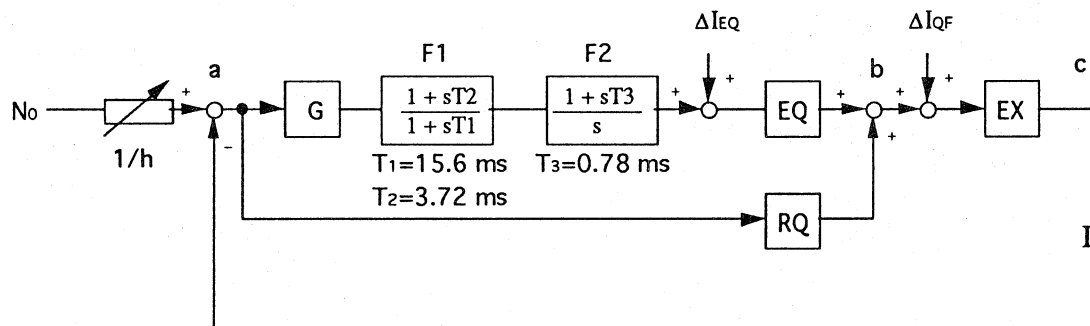


Fig.2 Schematic diagram of a feedback control system for the slow extraction.

model of simplified extraction system is shown in Fig.1.

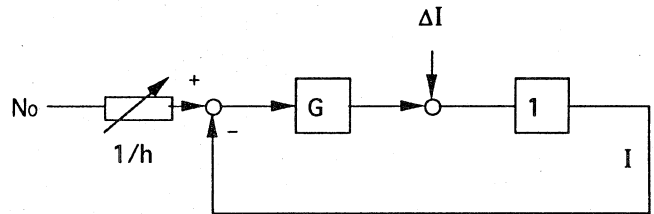


Fig.1 Simplified closed-loop extraction feedback system

Then,

$$I = \frac{N_0 G}{h(G+1)} + \Delta I \frac{1}{G+1}$$

Where  $N_0$  is the DC reference input made by sample-hold of circulating beam intensity,  $h$  is the parameter for spill height control,  $G$  is the loop gain,  $\Delta I$  is the external disturbance or noise and  $I$  is the extracted beam spill intensity. As a general effect of feedback, this indicates that  $I$  is almost equal with  $N_0/h$  and the effect of external disturbance decreases as increasing  $G$ . Of course, in a practical control system,  $G$  is a function of frequency, so the magnitude of  $G+1$  is different in frequency range. As external disturbance, there are current ripple of focusing quadrupole magnets and so on.

Schematic of feedback system for the slow extraction can be shown in Fig.2. The transfer functions of F1 and F2 are phase-lag controller and integrator, respectively. EQ, RQ and EX are the transfer functions of extraction quadrupole, ripple quadrupole and extraction process [including spill monitor (SEC, secondary emission chamber) and beam duct], respectively. Then, the transfer function of the closed-loop is

$$I = \frac{N_0(G \cdot F1 \cdot F2 \cdot EQ \cdot EX + RQ \cdot EX)}{h(G \cdot F1 \cdot F2 \cdot EQ \cdot EX + RQ \cdot EX + 1)} + \Delta I_{EQ} \frac{EQ \cdot EX}{h} + \Delta I_{QF} \frac{EX}{h}$$

Where,  $\Delta I_{EQ}$  is the external disturbance or noise into the EQ magnet and  $\Delta I_{Qf}$  is ripple of the focusing quadrupole magnet. The characteristic of EQ and RQ are modeled from measurement result of frequency response. Ripple quadrupole magnets are made by air core magnet, then frequency response is good enough within a considered frequency region.[4]

Rapid phase lag of EQ over several hundred hertz [5], which is shown in Fig.3, is an effectual determinant in the dynamic range and stability of servo-spill control as described later.

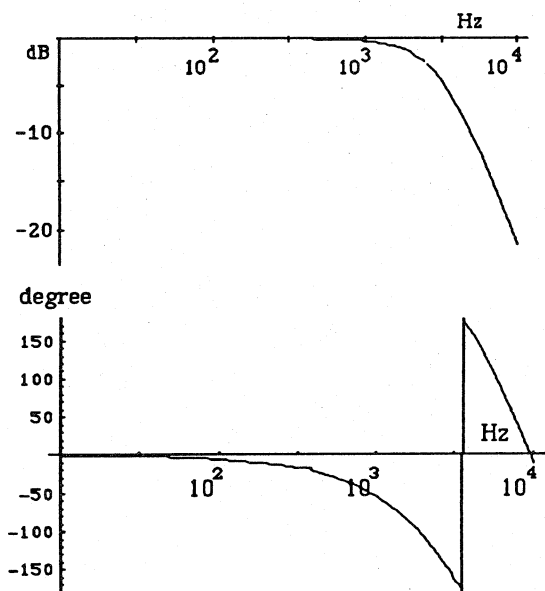


Fig.3 Frequency response of the extraction quadrupole.

Modeled transfer function of extraction process (EX), can be derived from the measurement of open-loop function since each of other component's transfer functions are already known, is shown in Fig.4. This means the extraction process is differential function in deed lower than 70 Hz, and the gain decreases by 20dB/decade greater than 70Hz.[6]

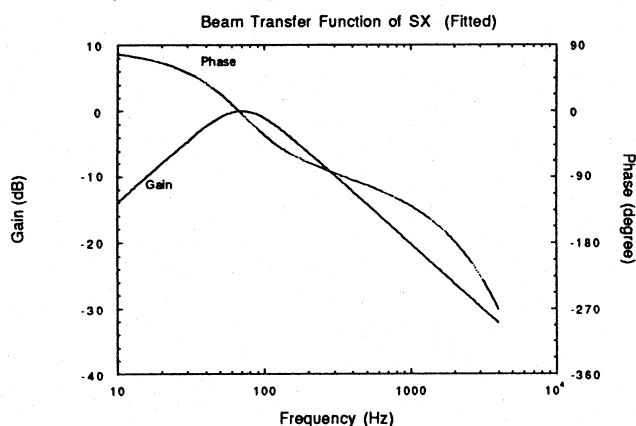


Fig.4. Frequency response of the slow extraction process.

### III. ANALYSIS OF THE SERVO-SPILL CONTROL

#### A. Analysis of the present system

Transfer function, F, from a to c in Fig.2 without RQ, is shown in Fig.5. This indicates that the phase lag is exceeds 180 degrees at 1 KHz and the gain margin at this point determines the closed-loop response. Closed-loop dynamics and elimination of the disturbance effects are shown in Fig.6 and 7, respectively. These results indicate that increasing of loop gain G make a resonance frequency at about 300 Hz and then closed-loop response is to be unstable, even if elimination of the external disturbance becomes larger. In order to make a stable condition, decreasing G causes large steady state error. This is caused by a poor phase margin of open-loop characteristic due to the phase lag of the transfer function of EQ together with EX .

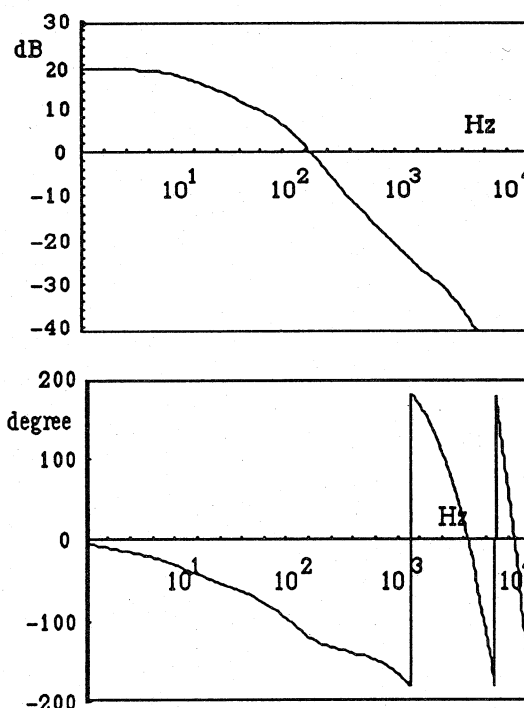


Fig.5 Frequency response of transfer function F from a to c in Fig.2 without ripple quadrupole magnet.

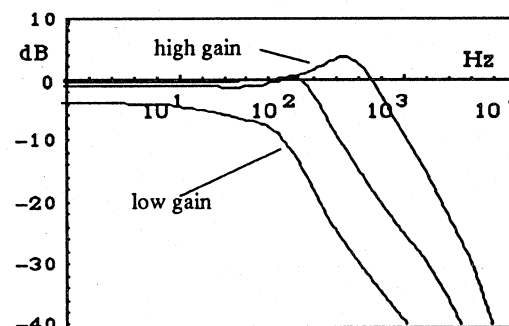


Fig.6 Closed loop dynamics of the present extraction feedback control system.

Transfer function F, when RQ works, is shown in Fig.8. This indicates that loop gain increases and phase lag is improved near 1KHz, but there is narrow dip at a few hundred hertz. That is, RQ works to reduce a fluctuation near

1KHz and compensates a phase lag of open loop.

Elimination of the external disturbance effect is about -10dB near 100Hz by EQ and RQ reduces only a few decibel up to 1KHz. This means that the external disturbance between a few hundred hertz and KHz is expected to reduce only 1/2-1/3. When an extraction will be operated at low energy, the ripple increases relatively, then, spill fluctuation will be so wrong and it did in an actual state.[7]

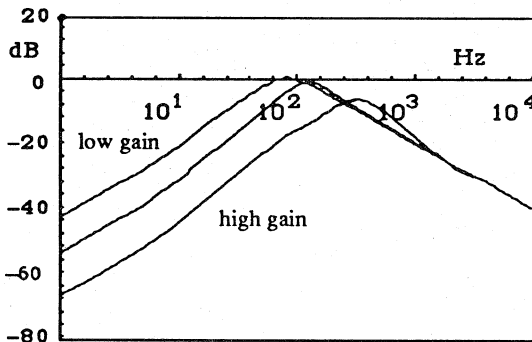


Fig.7 Elimination effect of the disturbance of the present extraction feedback control system.

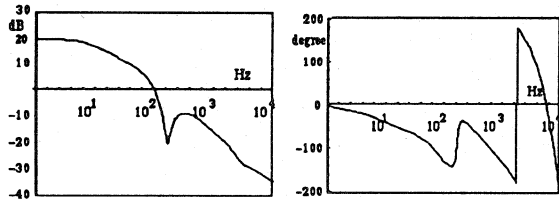


Fig.8 Frequency response of the transfer function F from a to c in Fig.2 when the ripple quadrupole magnets work.

### B. Guide line to improve

Improvement of the loop characteristic will be expected by tuning a function of F1 and F2. In order to suppress the parasitic oscillation near 300Hz and to increase the loop gain at low frequency region, T2 and T3 were varied to 1.86ms and 15.6ms, respectively. This variation means the gain at low frequency region of F1 still remains, however the loop characteristic is improved up to higher frequency region. Resonance frequency moves to about 1KHz. Figures 9 and 10 show the closed-loop dynamics and elimination of the disturbance effects under these parameters using a higher gain as shown in Figures 6 and 7.

### IV. CONCLUSION

Numerical calculations described above indicate followings. Increasing of low frequency gain by tuning a parameter of F1 derived the improvement of steady state error for spill height. To improve the response for an external disturbance, increasing the time constant of F2. Servo-spill controller needs easy tunable parameters for F1 and F2 in order to tune the various flat top energy. Temporal experiment supports the above-mentioned result.[7] When characteristic of EQ will be improved to rather high frequency region, servo-spill control will work up to more high frequency region (expected up to 1-2KHz). Loop gain G is

depend on the extraction process so it is necessary for further investigation to clear the transfer function of extraction process and to find an optimized parameter of servo-spill controller.

### V. ACKNOWLEDGMENT

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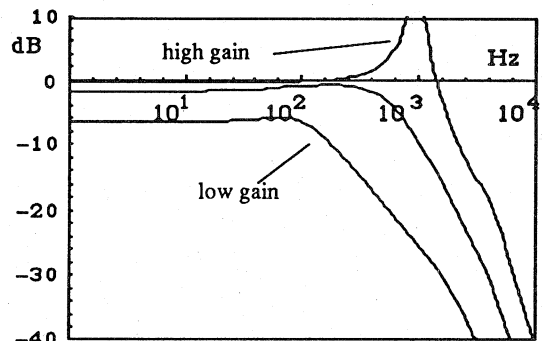


Fig.9 Closed loop dynamics of the revised extraction feedback control system at the higher gain in Fig.6.

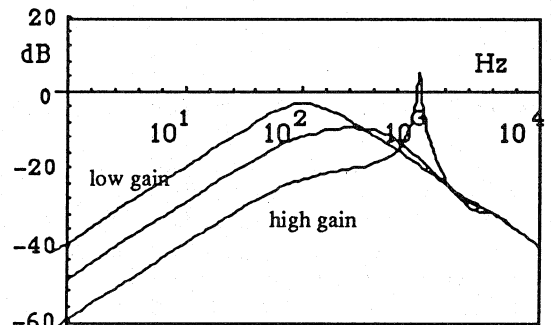


Fig.10 Elimination of the disturbance effects of the revised extraction feedback control system at the higher gain in Fig.6.

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