LONGITUDINAL BUNCH POSITION CONTROL FOR THE SUPER-B ACCELERATOR[*]

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Abstract

The use of normal conducting cavities and an ion-clearing gap will cause a significant RF accelerating voltage gap transient and longitudinal phase shift of the individual bunches along the bunch train in both rings of the SuperB accelerator. Small relative centroid position shifts between bunches of the colliding beams will have a large adverse impact on the luminosity due to the small β_y* at the interaction point (IP). We investigate the possibility of minimizing the relative longitudinal position shift between bunches by reducing the gap transient in each ring and matching the longitudinal bunch positions of the two rings at the IP using feedback/feedforward techniques in the LLRF. The analysis is conducted assuming maximum use of the klystron power installed in the system.

INTRODUCTION

The SuperB accelerator requires a short gap in the bunch train to clear ions from the beam. The cavity voltages and phases change during this ion-clearing gap and then return nearly to steady state during the remainder of the bunch train. The cavity voltage variation causes bunches to move to a new synchronous phase, which adds to the cavity phase shift to result in a variation of absolute bunch phase (hence longitudinal position) along the bunch train. These shifts will in general be different in the high-energy beam (HEB) and low-energy beam (LEB).

The IP of the SuperB has a β_y* which is significantly smaller than the bunch length. The LEB and HEB bunches must overlap at this z-location or the luminosity will suffer. A shift in z of 20% of the 6 mm bunch length will cause about a 1% drop in luminosity. The bunch locations of the LEB and HEB must match to better than 1.2 mm, hence, the phase transients must match to better than 0.6 degrees.

For PEP-II rings, the gap voltage induced a phase difference of about 4 degrees (about 8 mm) between the LEB and the HEB. Part of the phase difference is due to the asymmetry between the RF systems for the low-energy and high-energy rings. The SuperB design is more demanding with respect to the phase difference between colliding bunches from the LEB and the HEB, but in comparison to PEP-II the operation of both rings is better matched. This better matching results from the cavities in LEB and HEB operating at more similar beam loading and similar synchronous phase. This causes the cavity voltage and phase shifts to vary in a similar way along the

bunch train. Table 1 summarizes the nominal parameters of the LEB and HEB rings for the proposed SuperB facility.

Table 1: Nominal SuperB Parameters

Parameter	HEB	LEB
Beam Energy	7 GeV	4 GeV
Beam Current	2 A	2 A
Gap Voltage	8 MV	6 MV
Energy Loss	1.95 MV	1.13 MV
# Cavities	12	10

GAP VOLTAGE VARIATION

The ion-clearing gap defines a beam pattern with a strong amplitude modulation (AM) that interacts with the RF impedance and induces a periodic gap voltage variation and a resultant bunch phase modulation. A number of different approaches have been proposed and implemented to deal with this effect.

Modulation of Klystron Power

In machines with heavy beam loading such as PEP-II or SuperB, the active RF stations include feedback loops to minimize the overall impedance and reduce the beam-RF station interaction. In this topology, the voltage perturbation in the RF cavity induced by the beam AM modulation is eliminated by a direct feedback loop at the expense of a large swing of the klystron power. This approach results in poor utilization of the installed klystron power due to the power headroom required to reject the beam current perturbation.

Modulation of Klystron Phase

Another approach to reject the beam perturbation is to detune the cavity such that the klystron, operating at almost constant power, rejects the perturbation by changing the phase of the forward power delivered to the cavity. In this case, the klystron forward power remains nearly constant and lower than the peak power demanded in previous scheme, at the expense of delivering part of the reactive energy to the cavity when the beam is loading the cavity.

Gap Feed-Forward

In the PEP-II B-Factory a different approach was used to handle the perturbation induced by the beam AM. A feed-forward signal was injected to keep the klystron power nearly constant, disabling its reaction to the beam perturbation. In this case, the klystron forward power is efficiently used to transfer energy to the beam and minimize the RF station impedance presented to the beam. The AM beam perturbation at the revolution

harmonics is only partially rejected by the energy stored in the cavities, giving rise to a periodic gap voltage.

An equalization scheme has been proposed to match the closed loop impedance of the RF systems for both rings, allowing the gap voltage variations of the two rings to be equal [1]. This "magic detuning" was investigated for PEP-II but was never effectively implemented.

Other Techniques

Other schemes have been proposed to deal with the ion-clearing gap transient in LHC. One of them is similar to the one used in PEP-II; another de-tunes the cavity away from the optimal de-tuning to reject the beam AM perturbation.

SIMULATIONS

The RF system for SuperB rings will include state of the art controlled impedance feedback, similar to the systems in used in the PEP-II and LHC RF stations, to minimize the instability induced by the fundamental cavity impedance. Wideband feedbacks around the RF station to minimize the normal-conducting cavity impedance in combination with longitudinal dampers are planned to stabilize the low-order mode beam dynamics.

Gap Feed-Forward

As mentioned above, klystrons driven by fast feedback systems will react to the beam perturbation, requiring overdesign of the installed klystron power to handle the required headroom. To avoid this we can consider a control strategy for the gap transient similar to the one used in PEP-II [2,3]. In this case, the LLRF system includes a feedback loop that injects a feed-forward signal such that the klystron power is almost constant at the revolution frequencies and its harmonics.

Based on this feed-forward configuration, it is possible to analyze the bunch phase variations for different operational strategies. A simple model for the RF station in combination with the feed-forward technique assumes that the effect of the feedback system at the revolution harmonic frequencies is null and the klystron forward power is constant. Using nominal SuperB parameters with an ion-clearing gap of 50 RF buckets and a ring of 3200 buckets (Gap ~ 1.5-2%), the simulation results are shown in Fig. 1. This plot shows a maximum phase transient for each ring of about 6 degrees of RF phase. Because the operational conditions in both rings are similar, the phase difference of colliding bunches is less than 0.5 degrees, within our specification.
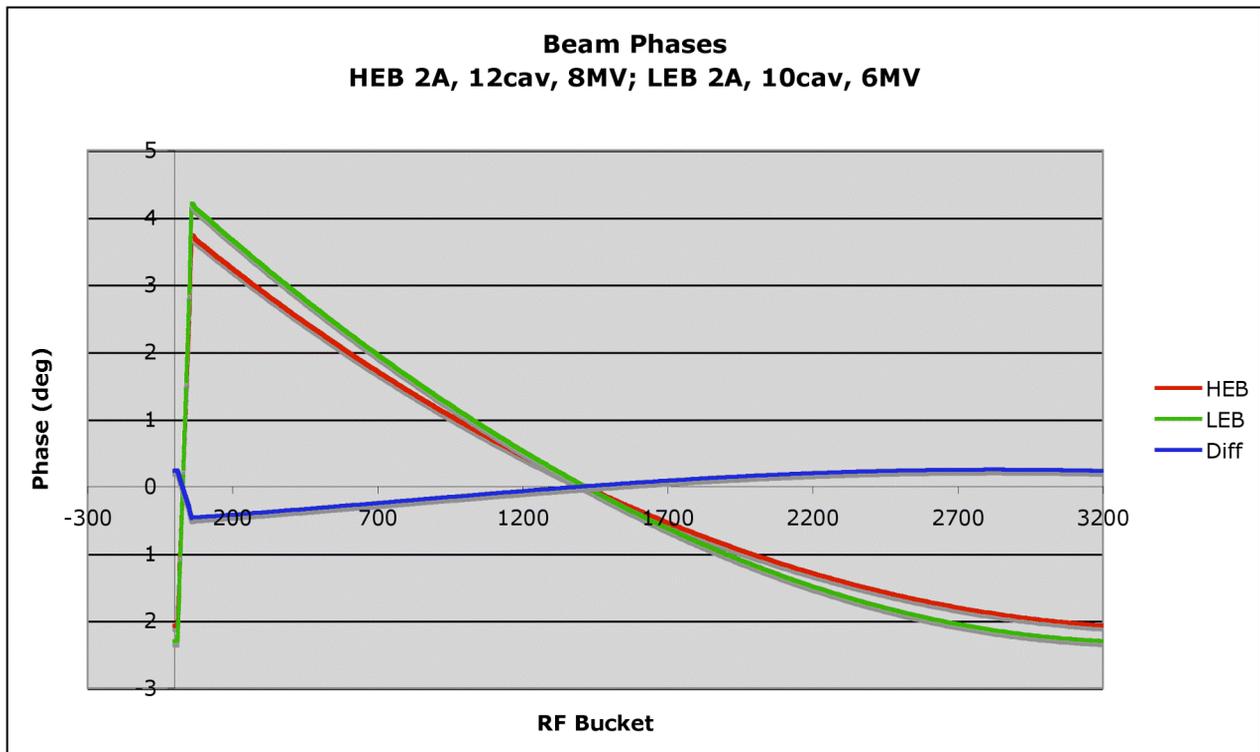

Figure 1: SuperB phase transients and phase difference, from simulations.

A shift in gap voltage of about 10% (either 10% lower for the HEB or 10% higher for the LEB) matches the phase transients almost perfectly, to about 0.1 degree. The resultant quasi-sinusoidal variation in beam phase difference could be reduced even further, if desired, by varying the klystron phase in a quasi-sinusoidal fashion along the bunch train.

This study is idealized in the sense that all the cavities are operating in similar conditions and the beam profile is constant along the filled buckets. Un-matching the cavities' operational conditions or varying the charge per bunch can increase the phase error between colliding bunches. It is likely that unforeseen problems will necessitate changing the operational parameters from time

to time. The resultant mismatch in bunch positions will adversely impact the luminosity.

Preliminary simulations suggest that the technique of modulating the klystron phase, described above, can reduce the phase transient in SuperB. However, this phase modulation seems to require a significant increase in peak klystron power (on the order of 50%). This produces a more constant bunch phase over most of the bunch train, but the beginning of the bunch train retains a large, uncorrectable phase shift. Investigations into feedback techniques are ongoing.

SUMMARY AND CONCLUSIONS

The SuperB accelerator can tolerate only a very small longitudinal shift in bunch positions at the IP before luminosity begins to suffer. The RF phases of bunches in the two rings must match to within about 0.6 degrees. This is a concern, because the ion-clearing gap in the bunch train causes phase variations along the bunch train of about 10x this amount (6 degrees).

The nominal beam parameters should match the phase variations of the two rings to about 0.5 degrees, which is within spec. Small shifts in operating parameters (e.g. gap voltage) can help to equalize the phase variations. Feedback techniques may also be able to equalize the phase variations; these investigations are ongoing.

REFERENCES

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