BEAM-BEAM INTERACTION UNDER EXTERNAL FORCE OSCILLATION

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Abstract

Beam-beam interaction is strongly nonlinear. Response for external oscillation applied to beam shows characteristic feature. Simulations for external frequency scan become feasible for the recent computer power. We show the frequency response for beam-beam system in KEKB.

INTRODUCTION

KEKB targeted a very high beam-beam parameter over 0.1-0.15. However achieved vertical beam-beam parameter is around 0.09. (Horizontal parameter is higher, but does not contribute luminosity. We say the beam-beam parameter is smallest value, which limits luminosity: that is, the vertical tune shift of the positron beam.) External noise is one of the possibilities to degrade the luminosity. The vertical beam size is very small, and is sensitive for fast turn-by-turn noise of collision offset. Electrons and positrons experience turn-by turn fluctuation due to synchrotron radiation. The fluctuation amplitude is $(2\tau/T_0)^{1/2}\sigma_y\sim 0.02\sigma_y$, where τ/T_0 is damping time in unit of turn. The random noise smaller than the radiation fluctuation is invisible for electron-positron collider. Proton colliders are more sensitive in this point of view. The vertical beam size is very small in e-e+ collider, especially in super B factories.

The beam-beam system has two eigen-modes in each motion of the horizontal and vertical. When the tunes are the same, the two modes are π and σ modes, which are two betatron phases are out-phase and in-phase, respectively. When not the same tunes, two modes are approximately positron and electron modes. Since the beam-beam interaction is strongly nonlinear, it has characteristic features for response on external noises. The amplitude response for sinusoidal noise had studies by T. Ieiri and K. Hirata [1] in TRISTAN. Recently response for horizontal noise has studied using crab cavity phase modulation in KEKB [2]. In KEKB, the horizontal tunes (fractional part) are almost same in positron (ν_{x+}=44.507) and electron beam (ν_{x-}=45.512). The vertical tune is separated somewhat, ν_{y+}=43.56 and ν_{y-}=41.62. Therefore the vertical response shows different behavior from the horizontal one. Response for white noise is another interesting subject. A series of beam experiments were done for external noise response of sinusoidal and white noise applied into the positron beam in vertical in KEKB. We discuss the phenomena from experimental and theoretical (simulation) approaches.

BEAM-BEAM MODE

The two beam-beam modes are given by solving eigenvalues of the revolution matrix containing the linear beam-beam force.

$$M = \begin{pmatrix} \cos\mu_+ & \sin\mu_+ & 0 & 0 \\ -\sin\mu_+ & \cos\mu_+ & 0 & 0 \\ 0 & 0 & \cos\mu_- & \sin\mu_- \\ 0 & 0 & -\sin\mu_- & \cos\mu_- \end{pmatrix}$$

$$K = \begin{pmatrix} 1 & 0 & 0 & 0 \\ -4\pi\xi_+ & 1 & 4\pi\xi_+ & 0 \\ 0 & 0 & 1 & 0 \\ 4\pi\xi_- & 0 & -4\pi\xi_- & 1 \end{pmatrix}$$

The vertical emittance is assumed 0.12 nm for both beams. Since the horizontal emittances are 24nm(e-) and 18nm(e+) , emittance coupling is less than 1%. The small coupling is indicated by high specific luminosity at low current. Direct measurement of the beam size shows 0.7~1% coupling. The bunch populations are 4×10^{10} (e-) and 5.8×10^{10} (e+) in the experiment and simulation. The vertical beam-beam parameters calculated by the parameters and beta functions at IP (β_{xy}=1.2m & 5.9mm) are ξ_+=0.099 and ξ_-=0.077. The tunes of the two eigen-modes are ν_{y1}= 43.587, ν_{y2}= 41.718 for positron and electron modes, respectively. Actually the vertical beam sizes are larger than the nominal ones due to the beam-beam interaction. Therefore true mode tunes are difficult to estimate. The mode tunes also depend on the collision condition; for example one beam may be strongly enlarged than the other.

RESPONSE FOR SINUSOIDAL EXCITATION

The vertical noise is applied to the positron beam using bunch-by-bunch feed back kicker. The kicker is excited by sinusoidal or white noise signal. We first discuss sinusoidal excitation. The frequency is scanned 0.55 to 0.75 in tune unit with various kicker voltages. Figure 1 shows the luminosity response for each kicker excitation. The data between 0.60-0.65 is missing for the highest voltage 0.4V, because of too strong beam loss. Strong luminosity degradation around 0.62 is seen in every exciting voltage. The frequency is the same as the electron tune. Figure 2 shows the amplitude of excited oscillation in the frequency scan. The amplitude has peak near 0.60 or 0.62 similar behaviour with the luminosity loss. Increasing excitation strength lower frequency component near positron tune 0.56 responds.

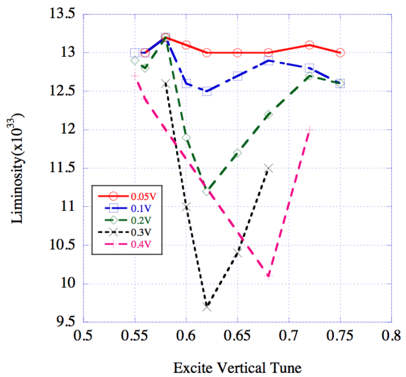

Figure 1: Luminosity response for frequency scan in various voltages. The data 0.60-0.65 at 0.4V is missing because of too strong luminosity loss.

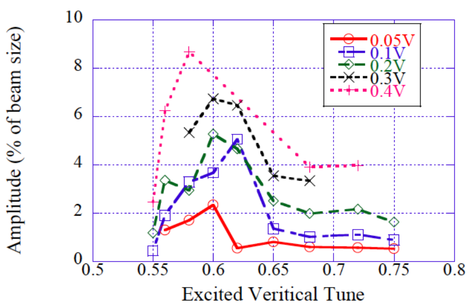

Figure 2: Amplitude of excited oscillation at IP. The data 0.60-0.65 at 0.4V is missing.

Beam-beam simulation based on the 3D strong-strong model [3] has been executed to study the frequency response. Relation between the luminosity degradation and excited amplitude has been discussed in our previous paper [4]. The fluctuation of 0.05 σ_y gives 5-30% luminosity degradation depending on the frequency in both of measurement and simulation. We focus the frequency response in this paper. Horizontal response has been studied using crab cavity phase modulation [2]. The horizontal tunes are similar values for e+ and e-, thus clear frequency response phenomena related to π/σ mode have been seen. Vertical tunes of e- and e+ beams are separated, therefore the response is more complex.

Figure 3 shows the luminosity response for frequency scan given by the simulation. Sinusoidal excitations, whose amplitude and frequency are seen in the figure, are applied to the positron beam. Clear luminosity degradation is seen around the tune of positron beam 0.57. The degradation near electron tune (0.62-) is seen though it is not remarkable. Figure 4 shows the excited oscillation amplitude of positron and electron beam. e+ beam is strongly excited at its tune or a bit higher 0.56-0.57. Asymmetric response for the frequency indicates nonlinear beam-beam force. e- beam is excited at 0.57 and 0.63 where a bit high of e+ and e- tune, respectively. The peaks approach the bare tunes for large amplitudes. The peak of luminosity degradation and amplitude response is 0.59 for weak excitations (20% luminosity loss and 10% excitation amplitude, see Figure 4 top right), which is similar tune as the experiment. The experiment in Figure 1 and 2 shows strong response around 0.62 in luminosity and excited amplitude. The frequency 0.62 is e- tune, and is also close to e+ tune shifted by the beam-beam force.

Figure 5 shows the vertical betatron phase difference between two beams. For larger excitation, it is out-phase near the bare tunes of e- beam (0.62). For large excitation >0.1um, it is in-phase near e+ tune. This behaviour is similar as horizontal case. The luminosity loss near e+ tune is caused by large e+ beam oscillation mainly; this is trivial case.

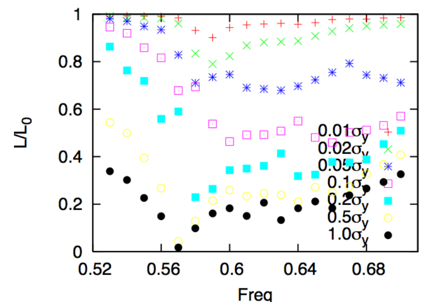

Figure 3: Luminosity response for frequency scan given by the simulation.

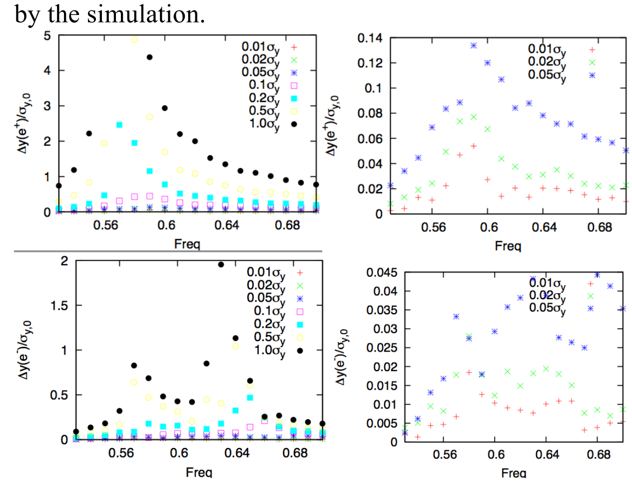

Figure 4: Amplitude of excited oscillation at IP given by the simulation. Top and bottom are positron and electron amplitudes, respectively. Rights are plotted with fine vertical scale. Positron beam is excited by an external sinusoidal noise.

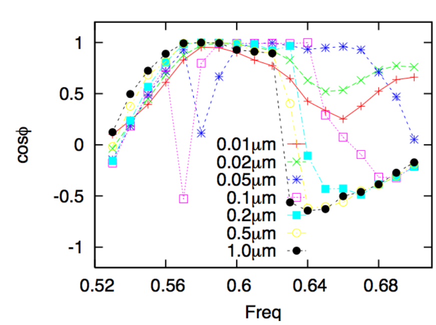

Figure 5: Vertical betatron phase difference between two beams in the simulation.

RESPONSE FOR WHITE NOISE

The feedback kicker is also excited by white noise in the experiment. Figure 6 shows luminosity degradation and oscillation amplitude each frequency component. Positron mode (0.56) exists independent of excitation, while modes with 0.58 and 0.60 are enhanced for larger noise strength. The luminosity degrades 20%, when the three modes grow around 0.012 σ_y.

Figure 7 shows luminosity degradation for excited vertical amplitude in the simulation. Amplitude excitation 7-8 % induces the luminosity loss 20%. The amplitude in experiment is around 5% to take summation of every modes. The luminosity degradation agrees with the experiment.

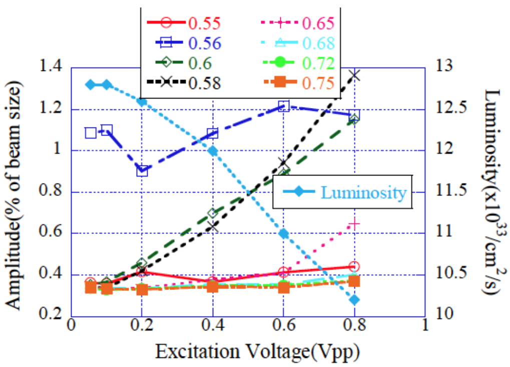

Figure 6: Luminosity degradation and vertical oscillation amplitude for each frequency component excited by white noise.

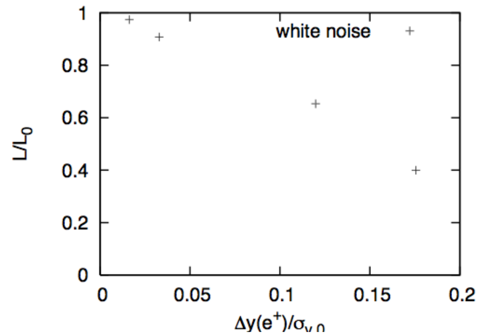

Figure 7: Luminosity degradation and vertical amplitude due to white noise excitation in the simulation.

SUMMARY

Luminosity degradation due to vertical noise has been studied by exciting feed-back kicker using sinusoidal and white noises. The noise induces coherent beam-beam modes. The vertical tunes are separated to 0.56 and 0.62 for positron and electron beams in KEKB. Response for the beam-beam modes is complex than the equal tune case. The experiment and simulation showed characteristic behaviors of the nonlinear beam-beam interaction.

REFERENCES

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