BEAM-BEAM STUDY IN BEPC MINI- β SCHEME*

Sheng Wang#, Shouxian Fang, Chuang Zhang
Institute of High Energy Physics, Beijing 100039

Abstract

For performing mini-β colliding on Beijing Electron Positron Collider(BEPC), high RF voltage is supplied for shortening the bunch length, but beam experiments show that high RF voltage results in the luminosity decrease. The conclusions of detailed study are that , for BEPC, the averaging over the betatron phase during the collision has occurred. The ratio of bunch length over beta function at interaction point is too small , and the mitigating of averaging over the betatron phase causes the luminosity decreases.

1 INTRODUCTON

Mini-β scheme is one of the most important way of Beijing Electron Positron Collider(BEPC) luminosity upgrades. For performing Mini-β scheme on BEPC, high RF voltage is supplied for shortening the bunch length. But the abnormal phenomenon was observed during machine study [1]. For 2.015GeV colliding mode, the vertical beam size σ_y increases with the RF voltage increasing and result in the luminosity decrease. Learned from the machine study that the increase of σ_y is correlated with the beam-beam interactions, but we did not know why and how to overcome it. This abnormal phenomenon seriously influenced on the performance of the Mini-β scheme. Here, authors are aiming to explain the abnormal phenomenon and overcome it.

The higher RF voltage not only shorten the bunch length, but also increase the synchrotron frequency. Here , our study are concentrated on the effects of bunch length, and for the change of the synchrotron frequency induced by the RF voltage, as shown in the later simulation and machine study, do not influence on the vertical beam size and luminosity obviously. We also can know from the beam experiments that the synchrotron betatron resonance is not the reason of the abnormal phenomenon.

The "hourglass" effect lets the luminosity increase with the increasing of the ratio β_y^*/σ_s , where β_y^* is the vertical β function at the interaction point, and σ_s is the bunch length. On the other hand, there is another bunch length effect on beam-beam interaction, i.e. effect of averaging over the betatron phase. In BEPC, this effect occurred.

For the finite bunch length, the beam-beam force experienced by a particle does not act on a betatron phase point, but a phase interval. The total beam-beam force is "averaged" by the phase interval. For the resonance

$$p\nu_y = m \qquad p , m \text{ integer,} \tag{1}$$

in which ν_y is the betatron tune, the effect of averaging decreases the resonance strength. Roughly speaking, the effect is proptional to the size of the interval . The size of phase interval is

$$\Delta\varphi = \int_{-\sigma_s}^{\sigma_s} \frac{1}{\beta(s)} ds \approx \frac{2\sigma_s}{\beta *} \tag{2}$$

one can obtain that the smaller β_y^*/σ_s contributed more to increase the effect of the averaging over betatron phase as well as to decrease of the resonance strength. This agrees to the result of theoretic derivation [2].

In BEPC machine study, we found that for 2.015GeV mini-β mode, when the nominal value of β_y^* is 5cm, the measurement value is about 8.7cm, and β_y^*/σ_s >1.5. Just under this condition , the special phenomenon that the σ_y increase with increasing of RF voltage, resulting in the decrease of the luminosity. So we infer that the increase of the vertical beam size resulting from high RF voltage is related to the decrease of the effect of averaging over betatron phase resulting from the compression of the bunch length. This reference is supported by the later simulation and results of machine study.

2 SIMULATION

The code BBC(Beam Beam with Crossing angle) [4], with little modification, was used in beam-beam interaction simulations. The bunch length used in simulation is calculated by the following scaling law,

$$\sigma_s(\text{cm}) = 0.651 * \left(\frac{I_b(\text{mA})\alpha_p}{E(\text{GeV})\nu_s^2}\right)^{\frac{1}{3.49}} \tag{3}$$

which is given by the bunch length measurement with stream camera, and α_p is momentum compaction factor.

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# E-mail: wangs@bepc5.ihep.ac.cn

2.1 Simulation results of 2.015GeV

In the first two figures give simulation results of total 6 different working point, ν_x=5.81, ν_y is from 6.75 to 6.80, with step 0.01, and under the different RF voltage, compare the luminosity.

Fig.1 shows the simulation results with parameters of E=2.015GeV, β_y^*=8.7cm, bunch intensity I_b=35mA. One can obtain from Fig.1 that the luminosity with RF voltage 0.9MV is higher than the one with RF voltage 1.5MV, except one working point. So when β_y^* is larger than nominal value, luminosity decrease with RF voltage increase. Then if we set β_y^*=5cm(nominal value), how about the results?

Fig.2 shows the simulation results with same parameter as Fig.1, except β_y^*=5cm. One can learn from Fig.2 that luminosity increase with RF voltage increase, totally contrary to the Fig.1.

In Fig.1 and Fig.2, all the parameters except β_y^* are same, but the results are totally different. From this we also can draw another conclusion that the synchrotron frequency changed with RF voltage do not influence the luminosity obviously.

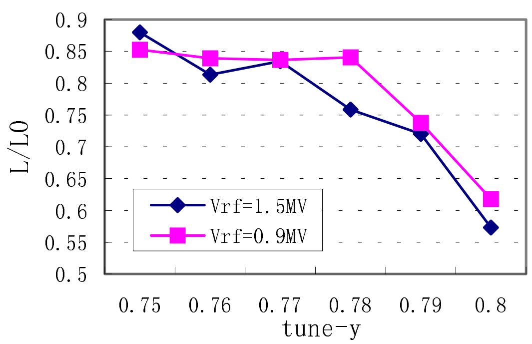

Fig.1 Luminosity vs. RF voltage with E=2.0GeV, β_y^*=8.7cm

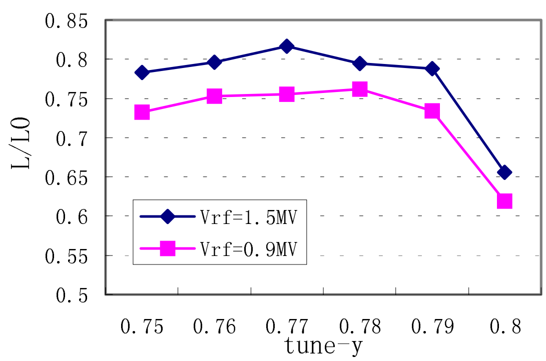

Fig.2 Luminosity vs. RF voltage with E=2.0GeV, β_y^*=5cm

2.2 Simulation results of 1.548 GeV mode

The simulation results of 2.0GeV colliding mode are given in the above section. We are more interesting in the 1.548GeV mini-β colliding mode, because now BEPC is running on J/ψ (1.548Gev) energy region, and the later machine study are also at 1.548GeV colliding mode. So we can compare the machine study results with the simulation here directly.

Fig.3 shows the simulation results with E=1.548GeV, β_y^*=5cm, bunch intensity I_b=15mA, and gives simulation results of total 6 different working point, ν_x=5.81, ν_y is from 6.73 to 6.78, with step 0.01. One can obtain that the luminosity with RF voltage 0.85MV is higher than the one with RF voltage 0.30 MV, except one working point (5.81,6.71), which close to resonance $3\nu_x+2\nu_y+2\nu_s=4$.

Fig.4 gives the simulation results with β_y^*=8.5cm, same energy and bunch intensity as Fig.3. Totally 10 working points, ν_x=5.81, ν_y is from 6.67 to 6.76, with step 0.01, are involved in the simulation. The figure tell us that the result here is not only different from Fig.3, but also different from Fig.2. The luminosity do not vary with RF voltage regularly. From Fig.5 in the later section, we can get the answer: under this condition, β_y^*/σ_s is too large to observe varying of luminosity with different RF voltage.

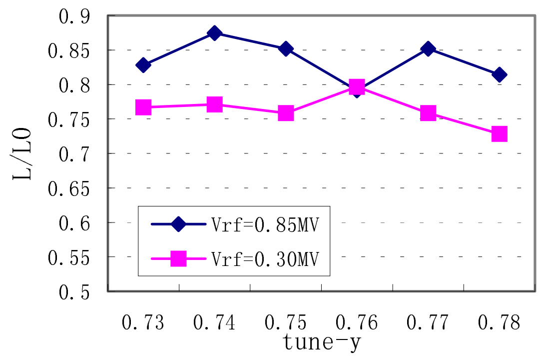

Fig.3 Luminosity vs. RF voltage, E=1.5GeV, β_y^*=5cm

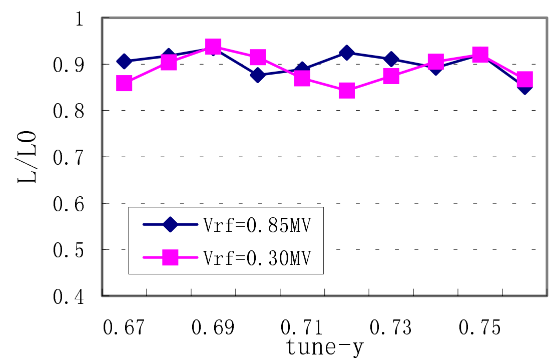

Fig.4 Luminosity vs. RF voltage, E=1.5GeV, β_y^*=8.5cm

2.3 Simulation study on the relation between luminosity and σ_s/β_y^* in BEPC

In the above simulation study, our purpose is to observe how the luminosity change with higher and lower RF voltage, and so only two RF voltage value(bunch length) were simulated. According to the theoretic analysis, for the existing of "hourglass" effect and averaging over betatron phase, how will the luminosity vary with σ_s/β_y^* continuously? For BEPC, is there the most optimal σ_s/β_y^* which give highest luminosity? If there is, what its value is? To answer these questions, a group of simulations were done. Different from the above simulations, here synchrotron frequency ν_s do not change with RF voltage.

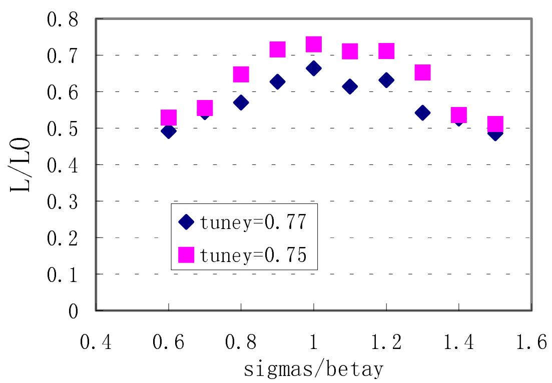

Fig.5 Relations between luminosity and σ_s/β_y^* in BEPC

Fig.5 shows the simulation results of two working points (5.81,6.75) and (5.81,6.77). We can obtain that the most optimal value of σ_s/β_y^* is about 0.9~1.1 .

3 MACHINE STUDY

Machine study is done at 1.548GeV mode. Under the condition of β_y^*=8.5cm and β_y^*=5cm, change RF voltage, and oberserve the change of luminosity. RF voltage was changed from 0.3MV to 0.85MV. For each given RF voltage, five luminosity readings are recorded to reduce the measurement error of luminosity. The bunch intensity should decrease during the changing of the RF voltage, and this change are corrected by $L \propto I_b^2$ when process data. In the following figures the line indicates the average value.

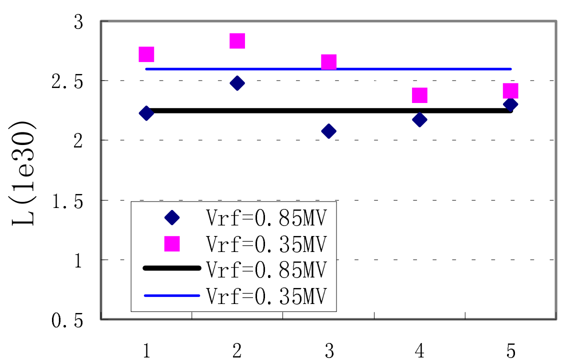

Fig.6 Machine study results, E=1.548GeV, β_y^*=8.5cm

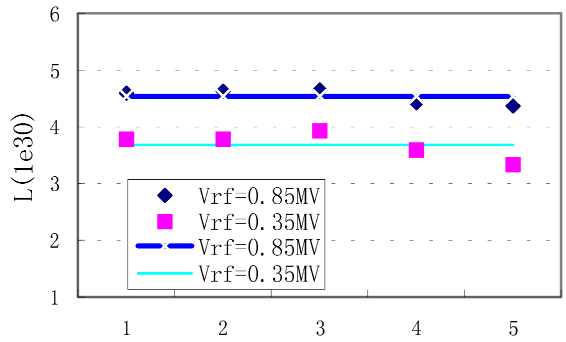

Fig.7 Machine study results, E=1.548GeV, β_y=5cm

The machine study results of β_y^*=8.5cm mode are shown in Fig.6, in which the luminosity decrease with the increase of RF voltage. Fig.7 shows the results of β_y^*=5cm, the luminosity increase with the increase of RF voltage, as predicted by theoretic analysis and simulations.

4 CONCLUSIONS

The study on problem of the beam-beam effects which come from mini-β scheme BEPC luminosity upgrades draws the following conclusions:

For BEPC, the bunch length σ_s influences the beam-beam interaction mainly through the "hourglass" effect and averaging over the betatron phase during the collision, and these two contrary effects make the luminosity be maximum only when σ_s/β_y^* is near the optimal value. If σ_s/β_y^* is more than the optimal value, the luminosity decreases resulting from the hourglass effect, and if the σ_s/β_y^* is less than the optimal value, the luminosity decreases resulting from mitigating of averaging over the betatron phase as well as the increasing of resonance strength. The most optimal value of σ_s/β_y^* for BEPC given by the simulation is about 0.9~1.1. All the recorded machine study results about bunch length influencing on luminosity agree to the theoretic analysis and simulations. At the suitable range of σ_s/β_y^* ,the luminosity can be increased by shortening the bunch length, for BEPC, as well as increasing of RF voltage.

5 REFERENCES

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