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Studies on the Beam Orbit and Energy Instabilities at the BEPCⅡ Linac*

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Abstract During the commissioning and early operation of the upgraded BEPCⅡ injector linac, some beam instabilities were appeared, and have been studied by both experimental and analytical ways. This paper describes the observed beam orbit instabilities, beam energy jitter, and the beam emittance jitter. The ways to cure these instabilities are also presented.

Key words beam orbit, beam energy, stability

1 Introduction

The upgrade project of the Beijing Electron Positron Collider (BEPCⅡ) and its injector linac are going well. The upgrade goal of the linac aims at a higher energy (1.89GeV) e^- and e^+ beams for on energy injection into the rings, and with a high e^+ beam injection rate of 50mA/min, which is about ten times the previous injection rate. To meet with these goals the high current beam with low emittance and small energy spread from the injector linac are demanded, as listed in Table 1[1].

Table 1. Beam parameters of the BEPCⅡ-Linac.

	unit	e^+	e^-
beam energy	GeV	1.89	1.89
beam current	mA	37	300
emittance(1σ)	πmm·mrad	0.40	0.10
energy spread	%	±0.50	±0.50
injection rate	mA/min	50	200
pulse repet. rate	Hz	50	50
beam pulse length	ns(FWHM)	1.0	1.0

To reach these specifications, a new electron gun with high current and low emittance, a new positron source with a flux concentrator, a new RF high power system with its phasing loops and a new beam tuning system with orbit correction devices have been designed, fabricated and installed in their final positions in 2004. In addition, the beam instrumentation system, the control system, the RF transmission system and the vacuum system have been also greatly upgraded. In 2005 and 2006, the linac has been commissioned part-timely since it has to be used as an operational injector for the synchrotron radiation experiments with original BEPC and upgraded BEPCⅡ storage rings. In June and July 2006, the most linac parameters were measured and checked by an expert team organized by the BEPCⅡ project managers. The measured beam energy, current, transmission efficiencies and emittance both for the e^- and e^+ beams and the energy spread of e^- beam reached their design goals, except e^+ beam energy spread that will be measured soon later. During the commissioning and early operation of the upgraded BEPCⅡ injector linac before July of 2006, some beam instabilities, such as orbit instability and energy instability, were appeared. The linac group has paid much effort to look for the sources of these instabilities and to study the measures to cure these instabilities. Up to now, the linac is well operated to deliver the principally

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stable e$^-$ and e$^+$ beams for the commissioning of the upgrade BEPCⅡ e$^-$ and e$^+$ new rings. The further improvement on the linac beam instabilities is being studied.

2 The beam orbit instability

In the BEPCⅡ linac, totally 19BPMs are distributed along the linac used for the orbit measurement and correction. In the early operation, we found the beam orbit oscillated periodically with time seen by the BPMs, and the oscillation periods were changed frequently, say from a few seconds to a few hundreds seconds in some hours. To find the sources of this oscillation, we have firstly checked many components operation parameters, such as the rf phases and amplitudes of the pre-buncher, buncher and each RF power units; the drive currents of solenoids and magnets; the cooling water temperatures and so on. However we have not found any obviously periodic changes of these operation parameters.

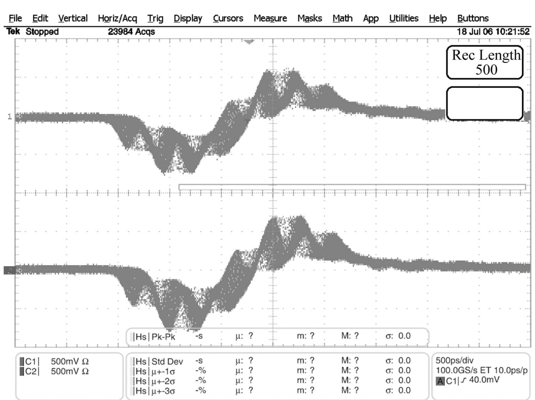

Fig. 1. Bunch distribution oscillations at BPM14.

During the Mini-workshop on the BEPCⅡ linac in June 2006, the working group consists of BEPC and KEKB linac experts has firstly checked the asynchronous effect of the power-line on the orbit oscillation by changing gun trigger pulser from 50.0Hz to 50.1Hz, and did not find any spurious beam fluctuation changes, it indicated that the power-line nonsynchronization was not a major source of the beam fluctuation. Later on the working group has found the fluctuation of beam intensities at the 2nd beam current monitor (BCM) and the bunch distribution oscillations at BPM14 seen by a oscilloscope, as shown in Fig. 1, caused by the electron gun trigger jitter (say about 27ps rms, that is not too bad for timing itself).

Since the electron gun works at 50 Hz repetition rate with pulse length of about 1.0ns of FWHM and 1.6ns in bottom. The pre-buncher and buncher work at the same frequency of the main linac (2856MHz, corresponding time period of about 350ps), so that there are about 5 bunchs in each beam pulse down stream the bunching system. The simulated value of each bunch charge relative to the middle one is about 0.17, 0.83, 1.0, 0.65, and 0.06, respectively, without gun trigger jitter. However the gun trigger jitter may produce these bunch charge changes frequently, and leading to a fluctuation of beam intensity, and further leading to a beam pulse orbit oscillation due to the accelerating structure misalignment effects (via wakefield effect) and the initial beam offset effects (via dispersive effects in magnet and wakefield effect in accelerating structures). It was observed that the higher the current from the gun, the stronger the oscillation amplitude in the beam orbit. If the beam position monitor works at 2.0Hz of sampling frequency, and bunch charge changes at frequency of 2.2Hz, then the beat frequency is 0.2Hz, that corresponds the bunch orbit oscillation period of 5 seconds.

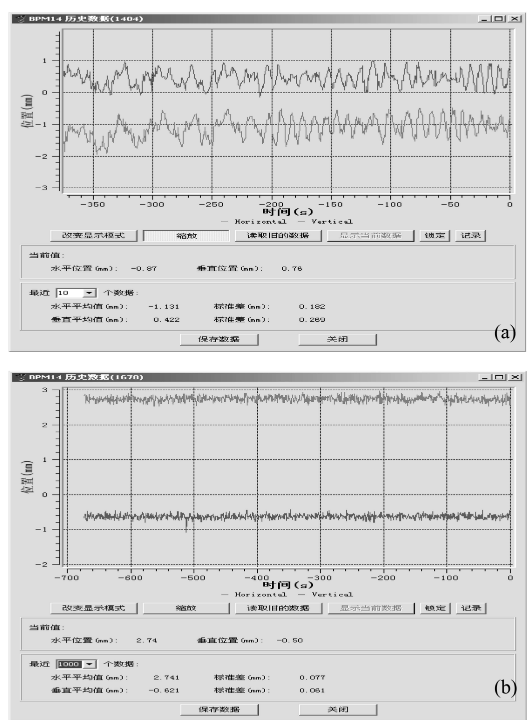

Fig. 2. Measured orbit at BPM14 with time, before (a) and after(b) curing the oscillation.

To cure this beam intensity fluctuation caused by the gun trigger jitter, an effective way is to synchronize the gun trigger and 2856MHz master oscillator, which was realized by connecting two master oscillators of 2856MHz and 499.8MHz (ring rf frequency) at linac control room (and by reducing the gun trigger by a factor of 4×7=17.85MHz). The beam orbit seen by the first 6BPMs became much stable, and their fluctuation was suppressed down to about 1/5 of the original ones, say about a few tenths of millimeters. However the beam orbit fluctuations in the remained downstream BPMs were still large, which was amplified mainly by the multi-bunch transverse wakefield effect due to the beam transverse offset. By beam orbit correction, these fluctuations are also significantly cured, and the remained oscillation was less than ±0.1mm (rms), as shown in Fig. 2.

3 The beam energy instability

At the end of the linac, there is an energy spectrum meter (AM3), followed by a BPM (AM3-BPM). By applying the synchronization between gun trigger and 2856MHz oscillator, the beam orbit correction and the RF phasing system for each RF power unit, we have found that the orbit jitter on the AM3-BPM was suppressed to about ±1.0mm. This jitter includes the beam energy jitter and the beam orbit jitter. The measured beam orbit position jitter is about ±0.16mm and the estimated orbit angle jitter is about ±0.015mrad at the linac end. By applying the beam transport optics from the linac-end to the AM3-BPM, we found that above beam orbit position and angle jitters may produce an orbit jitter of about ±0.33mm at AM3-BPM. Thus the orbit jitter at AM3-BPM caused by the beam energy jitter is about

$$\sqrt{(\pm0.10\text{mm})^2-(\pm0.33\text{mm})^2}=\pm0.94\text{mm} .$$

Considering the dispersion function 0.63m at AM3, then the related beam energy jitter is about ±0.15%.

4 The beam emittance jitter

The e^- and e^+ beams emittance at the linac end have been measured many times, and all measured results are repeatable. A method by multi-changing the quadrupole focusing strength is employed in the emittance measurement[2], in which fast taking each beam profile dimension on the profile monitor for each focusing strength likes a “transient” behaviour. Hence the measured emittance is a “transient” one, and may be changed time-by-time due to the random orbit jitter, leading to an effective (or a long-turn) emittance that may be larger than the measured “transient” one.

As an example, the measured “transient” emittance parameters are $\varepsilon_x=0.39$mm·mrad, $\beta_x=14.4$m, and $\alpha_x=-0.286$/m for 1.89GeV and 40mA e^+ beam, and the measured beam orbit jitter of ±0.2mm at the linac end. Then the related beam envelope is

$$x=\sqrt{\varepsilon_x\beta_x}=2.37\text{mm} .$$

We can image that an orbit jitter leads to a growth of the beam profile (envelope) and hence a growth of the beam emittance. Since $x^2=\varepsilon_x\beta_x$, $x'^2=\varepsilon_x\gamma_x$, where

$$\gamma_x=\frac{1+\alpha_x^2}{\beta_x},$$

then

$$\frac{\Delta\varepsilon_x}{\varepsilon_x}=2\frac{\Delta x}{x}=2\times\frac{(\pm0.2\text{mm})}{2.37\text{mm}}=\pm17\% .$$

Assuming that the ratio of the orbit angle jitter to the measured orbit angle is the same as the ratio of the orbit position jitter to the measured orbit position, so that

$$\frac{\Delta\varepsilon_x}{\varepsilon_x}=2\frac{\Delta x'}{x'}=\pm17\% ,$$

and the total emittance growth is about

$$\frac{\Delta\varepsilon_x}{\varepsilon_x}=\sqrt{2}\times17\%=24\% .$$

This result is very similar with the beam modelling for the beam injection into the ring1).

5 Summary

The orbit and energy instabilities at BEPCⅡ linac have been significantly suppressed by a long-term great effort paid by the BEPCⅡ linac group. Thanks to the KEKB linac experts S. Ohsawa, K.

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Furukawa and T. Suwada for their great help on curing the orbit instability. The further improvements to cure the remained jitters are under the way. These are 1) using a sub-harmonic bunching system instead of the present one, to form a single bunch in a beam pulse to cancel the multi-bunch beam instability; 2) applying the beam energy feedback system to keep the beam energy further stable; 3) using the beam based alignment (BBA) and other measures to further suppress the beam instabilities.

References

1 PEI G X et al. Design Report of the BEPCⅡ Injector Linac, IHEP-BEPCⅡSB-03-02. November 2003

2 WANG S H et al. HEP & NP, 2002, **26**(11): 1184 (in Chinese)
(王书鸿等. 高能物理与核物理, 2002, **26**(11): 1184)

BEPCⅡ直线加速器中的束流轨道和能量稳定性的研究*

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摘要 在BEPCⅡ直线加速器的调试和初期运行中, 观察到束流轨道和能量的不稳定性. 本文通过实验测量和分析研究, 说明了这些不稳定性的原因, 并叙述了解决这些不稳定性的方法和改进结果.

关键词 束流轨道 束流能量 稳定性

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∗ BEPCⅡ重大改造工程项目

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