ENERGY-SPREAD FEEDBACK SYSTEM FOR THE KEKB INJECTOR LINAC

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Abstract

Some feedback loops are needed to perform the stable beam operation in the long term. The beam orbit and energy feedback loops are widely used for the linac beam operations of many facilities. In addition, the beam energy spread control is also effective for the stable beam operation. In order to realize the energy-spread feedback, the non-destructive beam-energy-spread monitor (ESM) has been developed for the KEKB injector linac. This monitor is an ordinary strip-line type beam monitor with eight electrodes instead of four electrodes. Three EMSs have been installed in the KEKB injector linac for a regular energy-spread measurement. One of them is used for the energy-spread feedback operation. This system works well. In this paper, we will present the energy-spread feedback system for the KEKB injector linac in detail.

INTRODUCTION

The KEKB linac is the 600-m long linear accelerator, which has the 8-GeV electron and 3.5-GeV positron acceleration performance. It is used as the injector for the four rings; KEKB-HER 8-GeV electron, KEKB-LER 3.5-GeV positron, PF 2.5-GeV electron and PF-AR 6.5-GeV electron storage rings. For all rings except the PF-AR, the full energy injection operations are carried out, and the linac beam operation is devoted to the continuous injection of the KEKB rings in most time.

In the current linac beam operation, the beam orbit and energy feedback loops are used for the daily operation, and they help the stable beam operation to keep a beam quality high. For the future Super-KEKB project and the PF Top-up operation, the beam quality of the injector linac should be improved to keep the beam injection rate high and to reduce the noise signal during the beam injection. For such purpose, a beam energy-spread feedback system using a non-destructive beam monitor is strongly required.

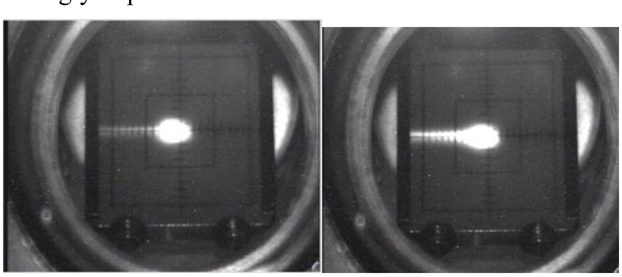

Figure 1: Energy spread measurement using the fluorescent screen monitor in the case of a small energy-spread (left) and a large energy-spread (right) condition.

In the KEKB linac, the ordinary fluorescent screen monitor has been used for the energy-spread measurement and adjustment. Using the screen monitor installed in the beam line with a large dispersion and a small beta function, the energy-spread can detect by the variation of the beam profile (Fig.1). The screen monitor is not useful very much for the energy-spread feedback since it is a kind of a destructive beam monitor. The beam energy-spread feedback system requires the non-destructive beam monitor, which can measure the energy-spread quantitatively.

SYSTEM DESCRIPTION

Beam Energy-Spread Monitor

In the KEKB linac, about ninety strip-line-type beam-position-monitors (BPMs) with four electrodes have been already installed and used for a beam-position measurement. Some BPMs have been used for the beam orbit and energy feedbacks. In order to measure the beam energy-spread, a beam monitor should be installed in a large dispersion location like an arc section. Using an ordinary BPM with four electrodes, it should be installed with a 45-degree rotation to avoid the SR hitting the electrodes because it may cause the abnormal large signal to the DAQ system. In such case, however, the quadrupole moment term will be vanished. For these reasons, three BPMs with eight electrodes are used as the energy-spread monitors [1, 2]. Figure 2 shows the photograph of the energy-spread monitor installed in the arc section of the KEKB injector linac. Two other monitors have been installed in the KEKB electron and positron BT lines.

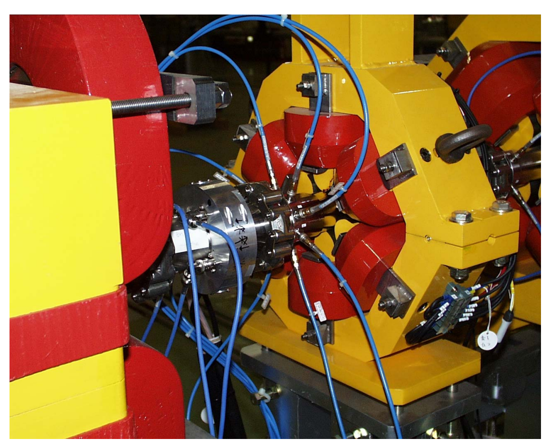

Figure 2: Photograph of the beam energy-spread monitor with eight electrodes.

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DAQ System

The performance of the DAQ system is one of the most important parts for the beam energy-spread feedback measurement and feedback system. In order to enhance the control accuracy of the energy-spread, the fast DAQ rate is needed up to 50-Hz, which is the maximum beam repetition rate in the KEKB linac. Nineteen DAQ systems have been used for the ordinary BPMs, and each of them consists of a VME computer and a digital oscilloscope [3]. The data taking speed of the oscilloscope in the ordinary system is not very high since the oscilloscope performance limits the DAQ rate around 1-Hz.

Figure 3 shows the schematic drawing of the DAQ system for the energy-spread monitor. It consists of a PC/Linux-based and a fast digital oscilloscope (LeCroy wavepro-950). Such simple system setup can enhance the system reliance very much. The eight signals of the monitor are divided by two signal groups alternately (2x4 signals). The four signals of each signal group are sent directly to a signal combiner through the coaxial cables with suitable delay lines, which are required to avoid a superposition of the analog signals. The two combined signals out of the signal combiners are directly connected to the digital oscilloscope. Trigger pulses synchronized with the beam are provided to the oscilloscope at a maximum rate of 50-Hz cycle. This rate is applicable for communication between the computer and the oscilloscope through an ethernet. The computer receives digitized data from the oscilloscope, extracts the eight-pickup voltages, and calculates the beam positions, charge and the multipole moments pulse-by-pulse in 50-Hz via linac control network.

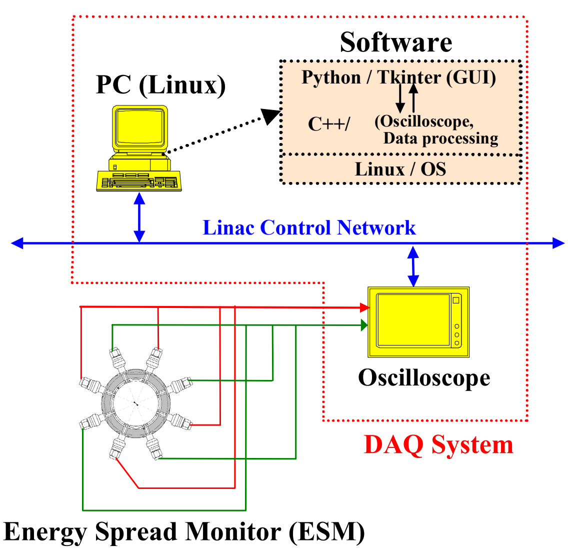

Figure 3: Schematic drawing of the beam energy-spread monitor system.

Software

The control software structure is also shown in Fig. 3. It should work stably in a high data taking repetition. In addition, the easy modification and extension of the software are strongly needed. The software was developed under PC/Linux-based. The C++ language was used for the main layer to control an oscilloscope, transfer the data to PC and process the obtained data. The C++ language has a high execution speed (compiler language), high reusability (Object-Oriented language). In addition, the template like the standard template library (STL) can accelerate the development of software.

Figure 4 shows the GUI of the trend plot and the alarm panel software. The Python language is used [4], and it is an object oriented script language and can use a wealth Tk GUI interface via Tkinter module. In addition, Python-Mega-Widget (PMW) [5] and Tk-Interface-eXtension) [6] can be also used for an easy GUI development. Moreover, the numerical calculation package is also available for an easy data processing [7].

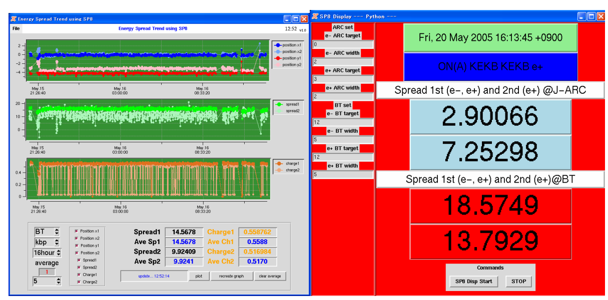

Figure 4: GUI of the energy-spread trend plot (left) and the alarm panel (right).

FEEDBACK SYSTEM

For a high quality beam control, the beam energy-spread feedback system was developed for the KEKB injector linac. The feedback was carried out with the energy-spread monitor installed in the middle of the arc section. The block diagram of the feedback loop is shown in Fig. 5. The simple PID was adopted as the feedback algorithm in our system. The phase shifter of the sub-booster klystron was used as an actuator of the feedback.

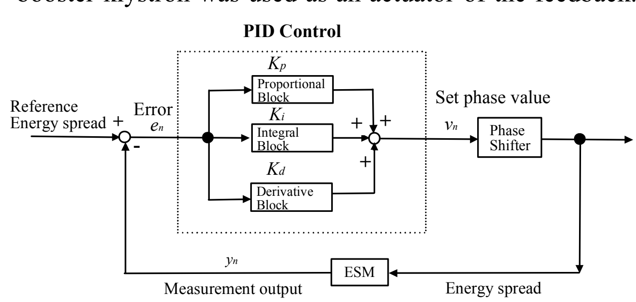

Figure 5: Block diagram of the energy-spread feedback loop.

In the feedback operation, the difference of the setting value difference between the n-th and (n-1)-th operation can be written by

$$\Delta V_n = K_p(e_n - e_{n-1}) + K_i e_n + K_d\{(e_n - e_{n-1}) - (e_{n-1} - e_{n-2})\}, \quad (1)$$

where the subscript "n" means n-th feedback step, the e_n term presents a deviation between the target and measured value in the n-th operation. The K_p, K_i and K_d term stand for the coefficient of proportional, integral and derivative term, respectively in Eq. (1). In the present feedback operation, the K_d term is set to zero since it is sufficient for the feedback performance.

Figure 6 shows the GUI of feedback software. It was also developed by the Python language. In this GUI, the left side part is used for setting the target value. The upper and lower limit of the sub-booster klystron can be also set to avoid the disorder of a feedback operation. In the right hand side, the energy-spread and the phase control trend plots are shown. From Fig. 6, it can be seen that the measured energy-spread (upper) is almost

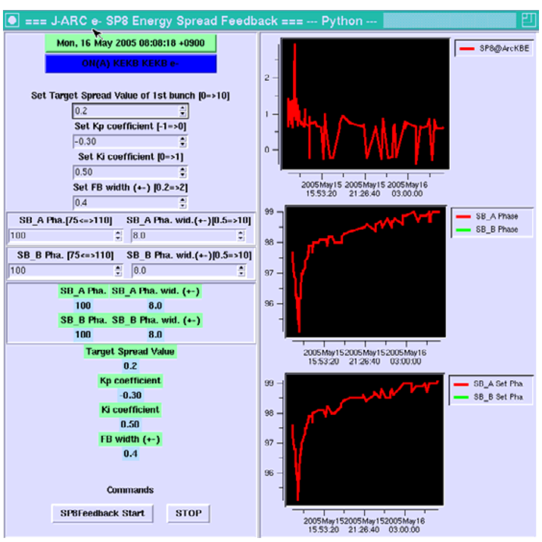

Figure 6: GUI of the energy-spread feedback software.

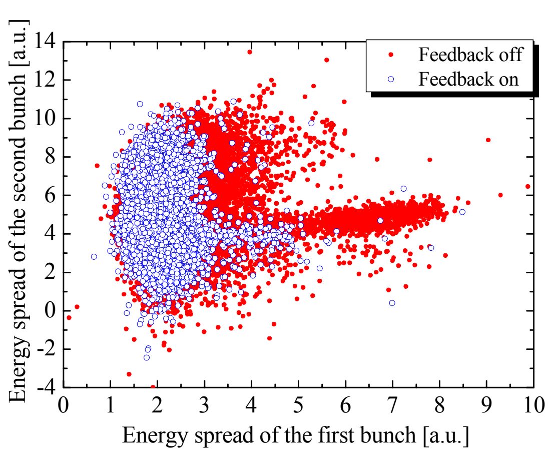

Figure 7: Result of the energy-spread feedback.

constant. However, the set (lower) and read-back (middle) value of the sub-booster klystron phase increase gradually. It can be considered that our feedback system can keep the energy-spread around a feedback target by suppressing the some perturbation that may be caused by the variation of the cooling water temperature.

Figure 7 shows the second bunch versus the first bunch energy spread with and without the feedback operation. In this figure, the red filled circle and the blue opened circle mean the result without and with the feedback operation, respectively. From this figure, the feedback system can much reduce the energy-spread fluctuation of the first bunch. However, that of the second bunch is almost same since the feedback target is a first bunch energy-spread in this feedback loop.

SUMMARY AND FUTURE PLAN

In order to control the energy spread, the energy-spread system was developed for the KEKB injector linac. This system consists of the non-destructive energy-spread monitor with eight strip-line type electrodes and the fast DAQ system. The simple DAQ system consists of the fast digital oscilloscope and the PC/Linux-based, and it works in a high reliability. In addition, its fast DAQ performance realize the two-bunch simultaneous measurement up to 50-Hz, which is the maximum beam repitition for the KEKB linac. The energy-spread feedback sytem of the arc section started to be used for the daily operation, and its performance was satisfied for our purpose. An energy-spread feedback in the KEKB-BT line will be tested soon, and it will be used for the regular operation in the near future. Its result will be presented elsewhere.

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