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Recording System of the Beam-Energy Stability for the KEKB Injector Linac

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Abstract

A new recording system of the beam-energy stability based on a software filtering algorithm was developed for electron and positron beams of the KEKB injector linac. This diagnostics software is useful for monitoring any beam instability during beam injection. It also allows software operators to know of any sudden beam instabilities by using several graphical plots when and where these are generated along the linac. This report describes in detail the method and the availability for this recording system based on beam tests.

1. Introduction

The KEKB injector linac[1] is required to supply certain amounts of single-bunch electron beams (8×10^9 e^-/bunch) and positron beams (4×10^9 e^+/bunch) for the KEKB high-energy (electron) and low-energy (positron) rings[2], respectively. High-current primary electron beams ($6\times10^{10} e^-$/bunch) are also required to produce certain amounts of positron beams. Since the KEKB is a factory machine, well-controlled operation of its injector linac is required for keeping the injection rate as high as possible and for maintaining a stable operation. For this purpose, beam diagnostic and monitoring tools are essentially important. Of those tools, the beam-position monitors (BPMs) are important to keep the orbits of the beams stable; especially, the beam positions and charges of the primary high-current electron beams must be well controlled in order to suppress any beam blowup generated by large transverse wake-fields. Although the beam orbits are automatically controlled by the beam-position feedback system of the linac[3] in daily operations, sudden position and charge changes have often been observed by the BPMs at energy-analyzing sections. Such instabilities are frequently accompanied by unexpected beam instabilities. The linac operators worry about such sudden instabilities because they can not know where the beam instabilities are generated along the linac, except for clear phenomena, for example, tripped-off of the high-power klystrons. Of course, data-logging system for any devices works during linac operation; for example, the RF monitor system records any fluctuation of the phase and amplitude of the high-power klystrons. However, such a logging system can not observe fast changes caused by pulse-to-pulse fluctuations, because the nominal loggings are performed on the order of minutes. The BPMs are only useful tools for fast logging on the order of a second. New software has been developed to monitor the beam-energy stabilities at the energy-analyzing sections by using the BPM data for operation diagnostics. In this report, some experimental examples are given regarding the logging-system structure.

2. Beam-energy monitoring system

2.1 Beam-position monitor system

The hardware and software systems of the BPMs have already been reported elsewhere[4]. Here, only the data-taking system is briefly described. Ninty BPMs installed along the linac are controlled by eighteen monitor stations, each of which comprises a front-end computer (VME/OS-9 with a 68060 microprocessor at 50MHz), a signal-digitizing system (an oscilloscope with a sampling rate of 5GHz and a bandwidth of 1 GHz) are located on the linac klystron gallery at a nearly equal interval along the beam line. Each monitor station can control twelve BPMs at maximum. Trigger-pluses synchronized with the linac beam are provided to all of the oscilloscopes at a 0.67 Hz cycle. This rate is limited by the communication throughput between a front-end computer and an oscilloscope through a GPIB line. Unix workstations and the front-end computers communicate with each other through the network system of the linac, and receive the beam positions and charges from the eighteen front-end computers and store ten recent data for each front-end on shared-memory regions. The data servers for BPMs use the data on the shared-memory.

2.2 Recording software of the BPM data

The beam energies are observed at two energy analizing sections (the center of the 180-degree arc and the beam switch yard) where large horizontal dispersions are made. An application software was coded by using the interpreter software “SAD”[5]. This software gets all of the BPM data synchronized by the beam trigger within several seconds. The selected target BPMs are located at the energy-analyzing sections. If sudden changes of the beam positions or charge at the target BPM occur, an event flag for the BPM is stored in memory. The events are judged as a sudden change separated from fluctuations of noise by using a software filter algorithm. Such events are succeedingly searched one-by-one for upstream BPMs, and judged by the same filter algorithm. If any step changes are not observed at the most upstream

BPM, we can speculate that the step change was generated just after the BPM, and we can search for device failures within this region. Unfortunatelly, we can not determine what kinds of devices are not properly working, because all of the logging and monitoring system including the beam and device parameters are not mutually connected with sufficient efficiently in the present linac control system. If the function is formed to work completely, this system will be extended as a more reliable trouble-diagnostics system.

2.3 Software filtering algorithm

The beam positions and charges detected by the BPMs normally fluctuate in time series because of the electrical and environmental noise for signal detections. A software filtering algorithm was developed in order to separate any beam signals with a sudden (step) change from those with nominal fluctuations. An ε-separating nonlinear digital filter (ε-filters)[6] is a useful software algorithm for this purpose, that is, for a function of rejecting high-frequency noise with small amplitudes and of keeping sudden changes of the signals. A block diagram of the ε-filter function is shown in Fig.1.

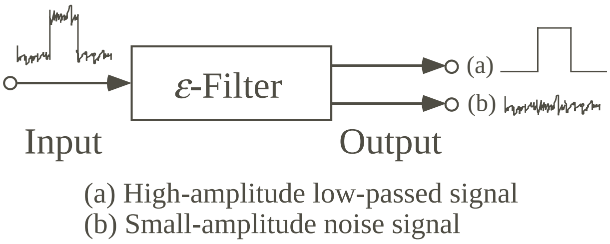

Fig.1. Block diagram of the ε-filter function.

The mathematical formulation is described in ref.6 in detail; here, only the principle and function are briefly described. The ε-filter comprises a digital linear low-pass filter (LPF) and a non-linear filter (NLF). A general manipulation for time-series data, like averaging, is a typical well-known LPF, and such a manipulation can reject high-frequency components of signals with small amplitude. However, it also smooths any sudden changes of the signals with a large amplitude at the same time. An added function by the NLF, here the ε-filter, does not smooth such a high-amplitude sudden change of the signal greater than the threshold level, defined by $\pm\varepsilon$. The threshold level (ε) should be experimentally determined by the relation of the noise level to the amplitude of the step change. An example is shown in fig.2 for the ε-filter function. Three examples for data in time series were simulated by using (a) a step change, (b) a gradually slanted change and (c) two succesive sudden change signals superimposed on Gaussian random signals. One can clearly see that a typical somoothing function on the base of the LPF does not work well compared with the ε-filter; especially, the LPF smoothing shows poor separation of a signal comprising two succesive impulse-like changes (see example (c)).

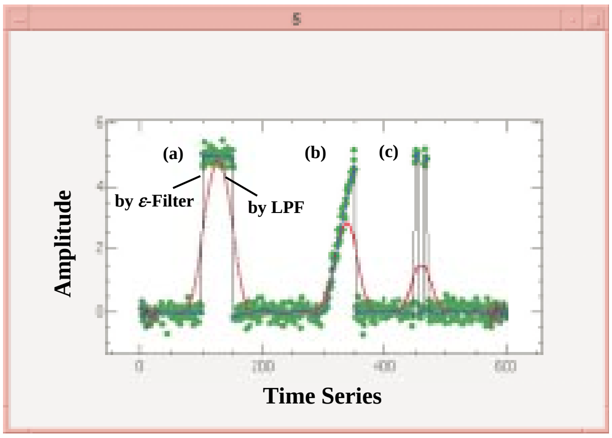

Fig.2. Three examples of software-filtered signals when using the use of the ε-filter and LPF.

3. Beam experiment and its results

A beam-stability experiment has been performed using high-current single-bunch electron beams of about 10 nC in the beam line up to the 180-degree arc, where the beam energy was fixed by 1.7 GeV. These beams were nominal-injection beams to the KEKB ring under a typical operation condition. Under the operating condition, several feedback system worked almost stably. Figure 3 shows typical recorded BPM data measured at the center of the 180-degree arc (SPR032), which was called a target BPM. The recorded time was about forty hours. A couple of zero charge data were taken just after the end of the injection in order to indicate the injection time;thus, the beam positions were incorrect because of the signal detections for noise events. One can clearly see some sudden changes ((a),(b) and (c) in fig.3) for time series of the beam charge detected at the target BPM. Three examples ((a), (b) and (c)) show a spike-like change, a step change with relatively long interval instabilities and a step change with short interval instabilities, respectively, which were clearly separated by using the ε-filters from the noise fluctuations. After the step detections at the target BPM, the software algorithm continuously searched for such beam instabilities generated at the same detection time along the upream BPMs until no change was found. In these examples, the seed of the 1st instability of the example (a) started at the BPM (SPA1B8) just after the buncher. On the other hand, the 2nd instability was generated at the BPM (SPA1C5) just before the first accerelation structure. It is understood that for fhe 3rd instability the seed was generated at the BPM at the end of sector B (no figure). The seeds for step instabilities (b) and (c) were also detected at the BPM (SPA1B8). Especially, in example (b) the time trend for the vertical beam position gradually retraces the nominal level after the step change. The same gradual recovery of the beam charge at the target BPM was also clearly seen according to the recovery of the vertical position detected for the BPM(SPA1C5). Figure 6 shows an accumulation plot for all step changes caused by the beam instabilities, which were analyzed in real time. The counts of all the step changes (caused by positions and charge) for all the upstream BPMs are accumulated in a plot for only a step change on the charge simultaneously detected at the target BPM. This plot shows that the step changes on the charge are generated at almost same the counting rate at any BPM location;on the other hand, those on the positions are generated by a betatron-motion-like shape.

4. Conclusions

A new software low-pass filtering algorithm based on the ε-filter was developed for detecting the beam-energy instabilites. The performance and availavility of this algorithm were tested by beam experiments. This method could effectively separate sudden step changes by the beam instabilities with large amplitudes from noise fluctuations. Its real-time processing also worked well during daily operations. This system will be extended as a more reliable trouble-diagnostics system by connecting with other logging and monitoring systems including the linac device parameters.

References

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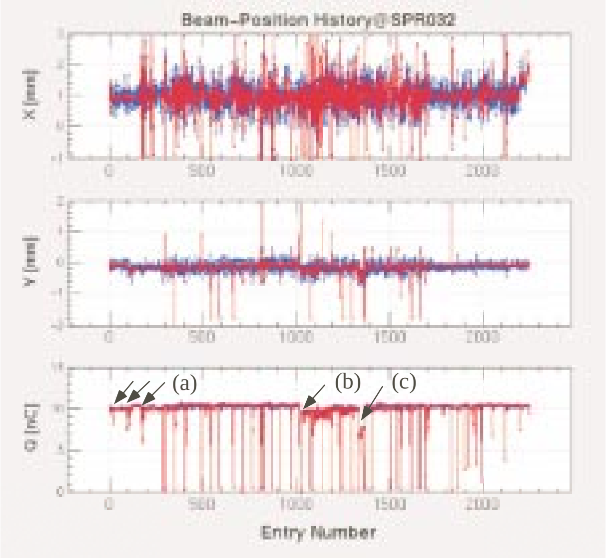

Fig.3. Recorded BPM data at the center of the 180-degree arc under a typical operating condition of hich-current single-bunch electron beams.

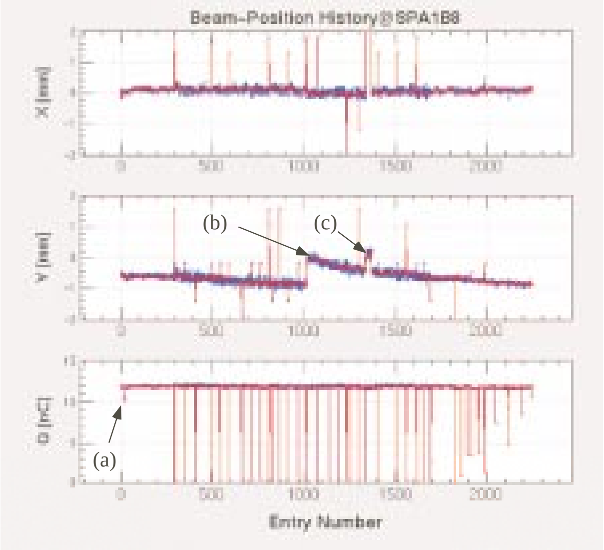

Fig.4. Recorded data at the BPM /SPA1B8 location.

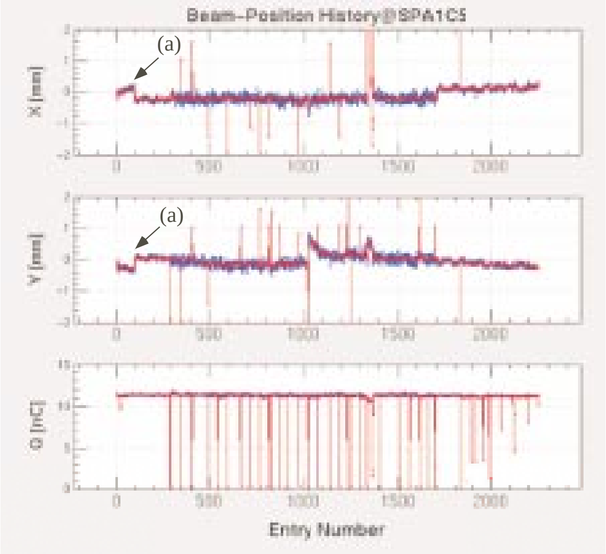

Fig.5. Recorded data at the BPM /SPA1C5 location.

Fig.6. Accumulation plot detected by all upstream BPMs for any step changes in the beam positions and charge.