ENERGY FEEDBACK SYSTEMS AT THE KEKB INJECTOR LINAC

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Abstract

While commissioning the KEKB e^- 8-GeV / e^+ 3.5-GeV linac the beam handling system was greatly improved since stable operation of the linac is required to achieve a higher luminosity. One of the newly installed sub-systems is an energy feedback system.

The feedback system comprises an energy monitor and a tuner. The monitor measures the linac beam energy using beam position monitors installed at a location with a large dispersion. Noise to the measurement caused by beam-orbit fluctuation is eliminated by a simple beam optics calculation around the monitor locations.

The tuner changes the beam energy using microwave phase shifters at two adjacent klystron stations simultaneously to maintain the energy distribution in a beam bunch.

A generalized graphical operator interface to the system is also developed employing script languages in order to manipulate and monitor the feedback parameters in real-time.

This type of feedback system is installed at six locations along the linac and is used for four beam operation modes. The same software is applied to beam-orbit feedback and accelerator equipment feedback loops. They have also greatly improved the stability of linac operation. This report describes the current status of linac feedback systems with emphasis on the beam-energy stabilization.

1 INTRODUCTION

The KEK e^- / e^+ linac has been reinforced to inject full-energy beams to the KEKB asymmetric B-factory with 8-GeV e^- and 3.5-GeV e^+.

Operation of the KEKB electron linac became much more different from that in the previous project, TRISTAN. The main reason is that the required electron and positron beams are of higher quality in terms of energy, charge per bunch, emittance and stability. The energy and beam charge are also quite different between four beam operation modes, namely the KEKB e^-, e^+, PF e^- and AR-PF e^-[1].

Each component of the linac was designed to achieve the required quality. However, it was found that the stability of the linac sometimes did not satisfy the requirements. This was partially caused by the synchronized temperature or electric-power variation over the linac, or interim hardware failures. Not all sources have been identified.

Because of these reasons, several software feedback loops were installed during the commissioning. Some of these were installed after some instabilities and their sources were identified.

However, in most cases the source of a variation could not be found, although we made every effort to find source by employing a statistical method and singular value decomposition (SVD)[1]. Also in some cases, the source was assumed to be at the linac injection part, where many kinds of equipment were installed with many parameters. Even so, certain parameters were chosen to tune a monitor value and to form a feedback loop.

Instead of simple feedback, more sophisticated methods like downhill simplex[1] or a global orbit correction were studied and gave promising results. However, since these methods are multi-parameter to multi-parameter corrections and interpretation of results is often difficult, they may hide important issues in the linac, which should be corrected or improved. Therefore they are not routinely used.

2 LINAC BEAM PARAMETERS

It was realized that keeping the beam parameters stable is quite difficult because four beam modes had to be switched frequently. Since some beam parameters, such as charge per bunch, are more than ten-times different between the beam modes the operation point of each piece of equipment must be adjusted to meet the beam-acceleration scheme. Although each variation is within the design value, the accumulated variation sometimes exceeds the expected value.

For example, about 60 high-power microwave generators (klystron) are installed in the linac, and the cumulative variation of many parameters, such as microwave phases and SLED (SLAC energy doubler) phase flip timing at each klystron station, affects the beam energy.

Other equipment parameters may affect the beam parameters like the orbit, emittance or energy spread. These beam parameters are predefined at the injection lines to the rings. If they exceed predefined values, KEKB luminosity may be degraded or some equipment may be even damaged.

3 BEAM MONITORS AND TUNERS

Since the reinforcement for KEKB, the linac has been equipped with several computer-readable beam monitors, which were not available in the previous project.

In order to diagnose the beam parameters, various types of beam instrumentation and their readout systems were developed or are being developed: strip-line beam position monitors (BPM)[2, 3], streak cameras as beam bunch monitors[4, 5], and wire scanners as beam profile monitors[6].

These monitors are utilized in routine operations as well as accelerator studies. Currently, most beam feedback loops employ BPM's because of their straightforward interpretation as described below.

3.1 Linac Energy Monitor

The linac energy can be determined by measuring the beam position displacement at a location with a large dispersion. This value is linear with the beam energy and is intuitive to the operator. We also tried to find the Linac energy at the straight section by measuring the betatron wavelength, however, the result was not reliable enough.

Information of beam energy derived from the beam positions may include noise, a part of which is caused by electric noise induced by high-power klystrons; another from beam-orbit fluctuation.

The former can be reduced by integration. Using a BPM resolution of about 100 micrometers, a data acquisition frequency of 1 or 5 Hz and the dispersion function we may determine the integration constant depending on the required stability.

For the latter the betatron orbit can be isolated by measuring the beam-orbit displacement at the previous straight section of the linac, which is then subtracted.

Along the linac there exist six locations where the dispersion is designed to be large. At all of these locations feedback loops are installed. For some locations the beam charge or the beam energy varies depending on the beam operation modes.

3.2 Linac Energy Tuner

The beam energy can be tuned by modulating the upstream microwave system. Normally, we vary the microwave phases at the klystron stations, since both the amplitude and the phase vary if we change the klystron voltage.

If the phase value at only one klystron station is changed, the energy spread becomes large, which is critical for the KEKB ring injection. We thus change the microwave phases at two adjacent klystron stations simultaneously in opposite directions relative to the phase crests, as shown in Fig. 1. Actually, the energy tuners are packaged in what is called energy knobs, which are sometimes used independently.

4 SOFTWARE

A feedback loop was implemented as a client to the linac control system[7]. It was written in the Tcl script language in order to maximize the flexibility[4]. The software is actually modified several times a week, as the commissioning advances. The graphical user interface (GUI) was designed with Tk widgets and the operator can change the parameters in real-time.

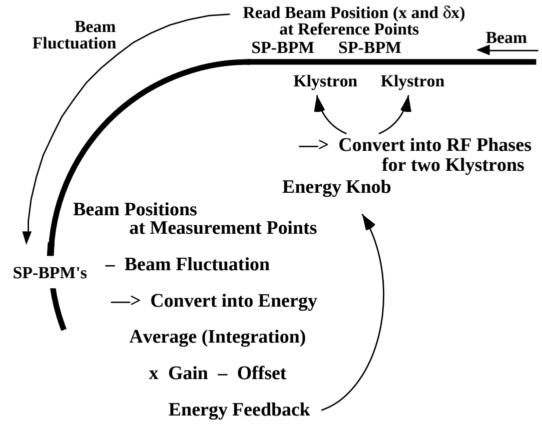

Figure 1: Process flow for beam-energy feedback.

4.1 Structure

The software has five parts. The first part tests conditions, such as the beam operation mode and the beam charge limit.

The second part determines the monitor value. It reads information through a direct Tcl interface to the control system or a shell command, where Tcl post-processing can be specified. Time-weighed averaging and windowing are applied before it is passed to the next step. Optionally, beam-orbit fluctuation is isolated for energy feedback.

The third part calculates the feedback value, where the conversion factor from the monitor to the tuner and the feedback gain are multiplied, and the frequency can be specified. If the result exceeds a minimum feedback value, a dead-band, it is sent to the next part.

In the fourth part the value is applied to the tuner through the control system, where Tcl pre-processing can be specified, if it goes in between the lower and upper limits.

The last part controls the information flow, monitors processing errors, draws graphs and logs the feedback information. It accepts controls from other applications, such as a global orbit correction and a feedback status viewer, through interprocess communication.

Almost all parameters and Tcl pre/port-processing codes can be specified through GUI at any time, as shown in Fig. 2. These codes are structured into hierarchical orders: a general package; energy, orbit and device feedback packages; and applications.

5 OTHER FEEDBACK LOOPS

For a beam-orbit correction, the response from a steering magnet to BPM's in one betatron wavelength is measured beforehand. The weighed average over the BPM's is used as a monitor and it is fed back to the steering magnet. Currently, two steering magnets in a section with a 90-degree phase advance are chosen to make a loop.

This adaptive feedback is effective, since the wake field generated by a high-current beam is difficult to predict under the present circumstances. If the global orbit correction

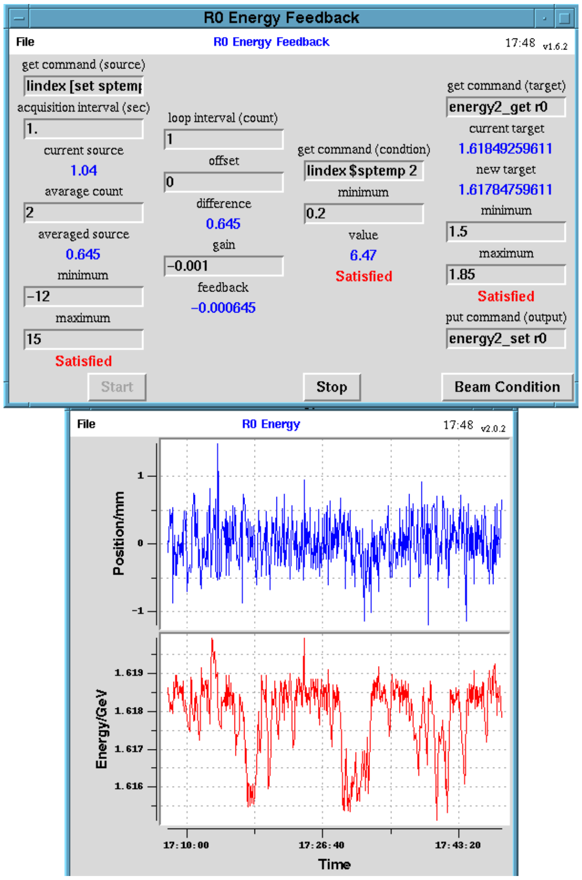

Figure 2: Graphical user interface to the feedback system built using Tcl language and Tk widgets. This is an interface for energy feedback at the R0 section.

becomes sufficiently robust to be repeated continuously, it may replace feedback loops.

After the commissioning began, some parameters of the accelerator equipment were found to fluctuate over predefined ranges. Although the hardware or local-controller feedback was planned to be installed, as a quick fix, software feedback loops were installed. They cover the voltages of electron guns, amplitudes and phases of sub-harmonic bunchers (SHB).

6 DISCUSSIONS

It should be noted that the graphical user interface (GUI) should be improved so as to avoid human mistakes.

Although the beam repetition of the linac is normally 50Hz, the current data acquisition system is limited to 1Hz[2]. Thus, beam feedback loops cover the frequency domain below 0.1–0.5Hz. Currently with 0.5Hz, our energy feedback systems suppress the energy fluctuation by one half or one third, which is just below the predefined constraint. The sum of the energy variation and energy spread sometimes exceeds the imposed limit.

We observed a fluctuation of the linac beam energy using an experimental BPM readout system at 50Hz and found that the amplitude spreads over a wide range in frequency domain. We thus plan to install a faster readout system, at least for important locations. Since the feedback is slightly affected by fast electric noise, even a 50-Hz average with a slow feedback may help.

Betatron orbit isolation is not yet sufficiently mature, more studies on wake fields are required.

The above-mentioned feedback loops are all linear. However, there are many accelerator parameters which should be optimized, but have quadratic behavior. We optimize those parameters, such as the microwave timings and phases, when we start the accelerator operation using correlation plots. However, some parameters are often found to be shifted off the optimum.

The beam energy spread is one of the most crucial parameters. If the energy spread becomes large, energy feedback is useless. In order to suppress it, a wire scanner, which is being installed[6], can be utilized. Upstream microwave systems may be tuned so as to optimize the value.

7 CONCLUSIONS

Linac energy feedback systems are installed at six locations along the linac and are utilized routinely to stabilize injection. They will be improved with a reinforcement of the beam instrumentation. Twelve orbit feedback systems and six equipment feedback systems are installed as well. They could all installed or modified quickly because of the script language, thus have greatly helped the linac commissioning.

8 REFERENCES

[1] Y. Ogawa and LCG, “Commissioning Status of the KEKB Linac”, Proc. PAC’99, New York, U.S.A., 1999.

[2] N. Kamikubota, T. Obata, K. Furukawa and T. Suwada, “Data Acquisition of Beam-Position Monitors for the KEKB Injector-Linac”, in these proceedings.

[3] T. Suwada, N. Kamikubota, K. Furukawa and H. Kobayashi, “New Data-Acquisition System of Beam-Position and Wall-Current Monitors for the KEKB”, Proc. APAC’98, Tsukuba, Japan, 1998.

[4] K. Furukawa, A. Enomoto, Y. Ogawa, S. Ohsawa and T. Kamitani, “Control System for a Bunch/Profile Monitor at the KEK e^+/e^- Linac”, Proc. Linac’94, Tsukuba, Japan, 1994.

[5] Y. Ogawa, K. Furukawa, T. Kamitani, S. Ohsawa, A. Enomoto, T. Suzuki, S. Abe and K. Iwazaki, “New Streak-Camera System for the KEKB Linac”, Proc. APAC’98, Tsukuba, Japan, 1998.

[6] Y. Funakoshi, N. Iida, T. Suwada, T. Kawamoto and M. Kikuchi, “Beam Tests of a Wire Scanner for the KEKB Injector Linac and Beam Transport Line”, Proc. APAC’98, Tsukuba, Japan, 1998.

[7] K. Furukawa, N. Kamikubota, K. Nakahara and I. Abe, “Upgrade Plan for the Control System of the KEK e^-/e^+ Linac”, Proc. ICALEPCS’91, Tsukuba, Japan, 1991, p. 89.