BEAM PROPERTY MANAGEMENT AT KEK ELECTRON / POSITRON 7-GeV INJECTOR LINAC

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Abstract

The electron / positron injector linac at KEK has injected a variety of beams into the electron accelerator complex of an asymmetric collider and light sources for particle physics and photon science experiments for more than 30 years. The beam property of electrons and positrons varies in energy from 2.5 GeV to 7 GeV and in bunch charge from 0.2 nC to 10 nC, and their beam emittance and stability requirements are challenging dependent on the injected storage rings. They have to be switched by pulse-to-pulse modulation at 50 Hz. The emittance control is especially crucial to achieve the goal at SuperKEKB and is under development. The beam energy management becomes more important as it affects all of the beam properties. Beam acceleration provided by 60 high-power microwave stations should be properly arranged considering redundancy and stability. Thus, the equipment controls are also restructured in order to enable the precise control of the beam properties, based on the synchronized event control system and EPICS control system. The strategy and status of the upgrade is discussed from the practical aspects of device controls, online simulation and operation.

INTRODUCTION

At High Energy Accelerator Research Organization (KEK), SuperKEKB, the electron-positron asymmetric collider, is under construction [1]. This project is expected to be able to elucidate the flavor physics of elementary particles with 40-fold improved luminosity compared with the initial KEKB, by doubling the stored beam current, and also by the nano-beam scheme to shrink the beam size down to a twentieth at the interaction point. SuperKEKB is composed of the electron-positron injector, high-energy electron ring (HER), low-energy positron ring (LER), and a positron damping ring (DR).

The Electron-positron injector will perform the first injection to SuperKEKB in Japanese fiscal year 2015. It will fill the dual rings of SuperKEKB as well as two light source rings in top-up mode in 2017 with significantly different beam properties while switching beams at 50 Hz as shown in Fig. 1. The beam energies are 2.5 GeV for Photon Factory (PF), 6.5 GeV for PF Advanced Ring (PF-AR), 4.0 GeV positron for LER and 7.0 GeV electron for HER, respectively [2].

Especially, it is a major challenge to inject beams to SuperKEKB with a small emittance of 20 mm·mrad and an energy-spread of 0.1% under the large beam current of 5 nC per bunch. In order to achieve such a high quality beam, a new RF gun for high-current and low-emittance electron

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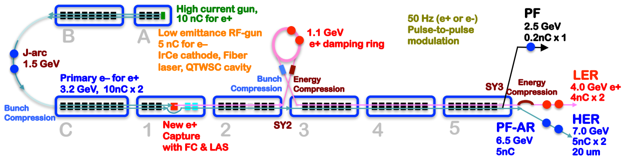

Figure 1: Layout of injector linac and its beam delivery to multiple experimental facilities.

beam and a flux concentrator for high-current positron capture are introduced. It is crucial for the injection operation with higher stability and accuracy to achieve lateral equipment alignment less than 0.3 mm over 600 m linac, and less than 0.1 mm in a short segment. The designed beam should be delivered with iterative corrections understanding the static and dynamic properties of the accelerator equipment and evaluating the beam properties in every conceivable way.

These beam operation management processes need to be improved for SuperKEKB on the basis of the techniques achieved in KEKB.

ACCELERATOR EQUIPMENT

The injector linac is operated with the EPICS control framework at the lower and middle layer [3], the event-based control system (MRF) at the lowest layer, and the script languages including SADscript for online accelerator design. This combination was quite successful at the both KEKB injector and collider rings, and is maintained for SuperKEKB as well, with many improvements such as embedded EPICS systems [4,5]. This environment is supported by the carefully-managed control databases.

Example of static database of accelerator equipment for beam-property management is shown in Fig. 2.

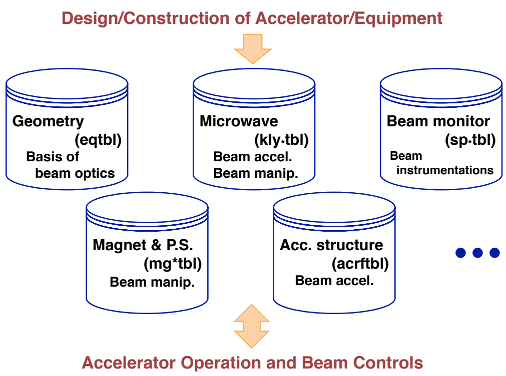

Figure 2: Construction of static database and its contribution to linac beam operation.

Geometrical arrangement

Each device comes with a name that is up to six characters, the two-character device type name, a sector name that represents the installation location (A, B, R, C, 1, 2, 3, 4, 5, 6, etc.), an unit number (1-8, etc.), an accelerating structure or magnet number (0-6), and a sequence number. Each equipment database is a table that has the device name as the key.

As basic information, the equipment database (eqtbl) contains the group name of each device, the distance from the electron gun, the mechanical length, the effective length, and so on. Presently, such geometrical information and the CAD drawings are not automatically reflected each other. A certain mechanism to directly exchange information is being developed.

Accelerator devices

For the beam transport, the magnet and its power supply information, conversion factors to/from control value, electric current and magnetic field as well as optics correction factors based on beam measurement are maintained in several databases (mgtbl, mgbtbl, mgbftbl). The convention how to define those factors varies between facility to facility, and reasonable one was redefined for the KEKB project, and utilized so far to manage the beam optics.

For beam acceleration, the microwave modulation information (klytbl) and beam acceleration gain information (acrftbl) are prepared and refined using beam measurement, and it is employed to calculate the beam energy and other beam properties along the linac.

There are many other databases for accelerator equipment, beam instrumentations, vacuum system, utilities, and so on. The database for beam instrumentation such as beam position monitors (sp*tbl) has a large number of parameters per a device.

CONFIGURATION OF THE INJECTOR

The injector in SuperKEKB project as in Fig. 1 has eight sectors (A~C, 1~5) of 80-m length each with the exception of the sector A of about 40 m. Each sector has typically eight 10-m long accelerating units, with a high-power RF modulator and four 2-m long accelerating structure (cavity).

Entire 600-m injector is divided into four sections from the viewpoint of beam operation. In each section, one or two units are designed to be redundant for a margin in energy gain. At the end of each section an energy knob is assigned to a pair of units to define the beam energy. Energy knobs and many other units are equipped with fast RF phase shifters, to enable the energy change at 50 Hz through the event control mechanism [6]. Each unit in an energy knob shifts RF phase to the opposite direction to suppress the energy spread as shown in Fig. 3.

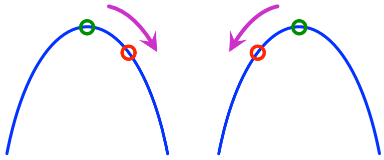

Figure 3: Energy knob to adjust beam energy from crest phases (green) to operation phases (red) compensating energy spread.

BEAM ENERGY MANAGEMENT

It is necessary to manage the beam energy at each injector location by estimating the energy gain at each unit, in order to enable the beam optics calculation.

Adjustment of the microwave source

At first, RF conditions for the maximum energy gain at each unit would be stored into EPICS online database. While there is a method to determine the proper RF phase measuring the beam-induced field, the precision is not enough under our circumstances. Therefore, the beam position measurement at large dispersion function is employed to determine the crest RF phase as well as pulse timing for the maximum acceleration.

Based on the above condition, it is necessary to shift the RF phase off the crest in order to suppress the energy spread due to the longitudinal wake field depending on the beam current. Furthermore, the pulse timing should be adjusted at the both shoulders of the RF pulse in order to accelerate two bunches in a pulse 96-ns apart with the same energy.

Determination of the beam energy

By using the RF and acceleration database, the corrected energy gain at each unit is calculated and the accumulated energy is stored into the online database. In order to increase the overall reliability, the energy gains are regulated and optimized every week observing the high-voltage discharge rate, the field emission condition, the stability of the power supply, and so on. Otherwise, the related interlocks for equipment protection may disturb the beam injection. This process is important since the beam energy at each location directly affects the accuracy of the beam optics calculation [7].

Energy stabilization

Depending on the injected ring among HER, LER, PF and PF-AR, the compensating off-crest phases and longitudinal wakefield as well as the beam energies are different because the beam currents are different. Thus, the operating points of energy knobs to secure the energy are also different. Therefore, it turns out that a single injector linac behaves as one of four separate virtual accelerators that are switched one another every 20 ms by the event control mechanism. Actually, operating points of more than 200 devices are changed between those virtual accelerators, and each virtual accelerator must be treated in different manner [5].

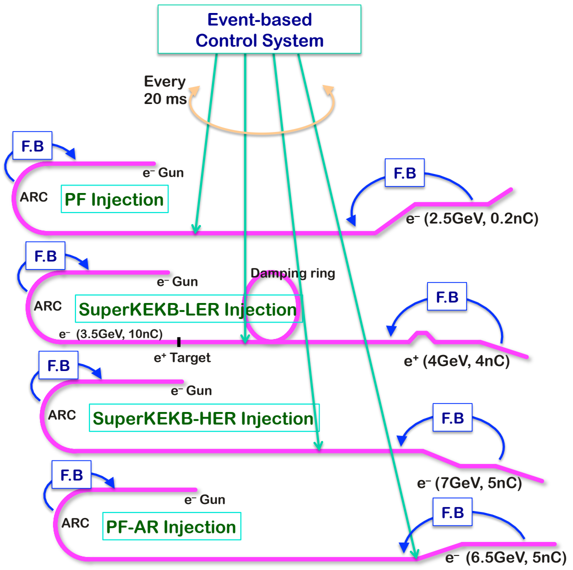

Figure 4: Each virtual accelerator (VA) would be associated with several beam feedback loops, independent of loops in other VAs.

For the end of each section of those virtual accelerators, independent energy stabilizing feedback loops need to be installed as shown in Fig. 4. Similarly, the energy equalizing feedback loops for two bunches within a pulse are required by adjusting the pulse timings. These will be operated with energy knobs and timing adjustments by the beam position measurements at locations of large dispersion functions [8].

BEAM ORBIT AND EMITTANCE MANAGEMENT

During KEKB operation, a large number of orbit stabilization feedback loops were required because of poor air conditioning stability and alignment accuracy, and an attention was paid to maintain the beam orbit not to loose the beam [9].

Towards SuperKEKB, it is necessary to have more accurate orbit controls in order to suppress emittance blow-up. According to a simulation, including the random alignment errors of the accelerating structures and the quad magnets, the beam may have 100-times large emittance easily. The simulation suggests it is possible to deliver a required beam only if their alignment is less than 0.3 mm (rms) for overall 600-m injector and 0.1 mm (rms) for a short segment as shown in Fig. 5. In the method the choice of an orbit can cancel the longitudinal bunch deformation. To that end, the angular accuracy of the steering coil needs to be less than 1 μrad [10, 11]. The beam position read-out system of precision less than 10 μm is also developed to support the method [12, 13].

If it is possible to maintain the orbit, the emittance can be preserved. For example, several orbit stabilization feedback loops may be installed so as to fix the beam angle and position at several locations along the injector. For

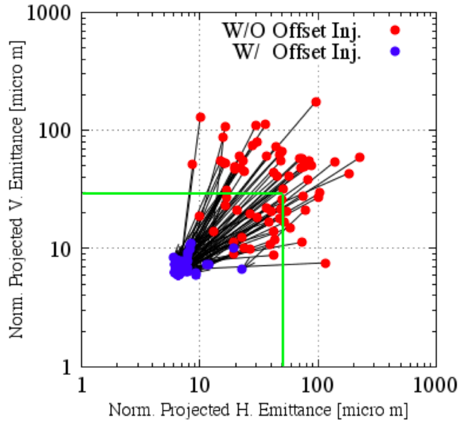

Figure 5: Controlled recoveries (blue) of blew-up emittances (red) with adjusted initial beam positions and angles for 100 random initial simulation orbits.

SuperKEKB multiple feedback loops are necessary with respect to the both HER and LER injection virtual accelerators independently. In order to operate the mechanism flexibly and reliably it is required to refine the quality of the machine database and to maintain the advanced beam optics model.

However, as it has been found in the measurement of long-term floor joint movement that each part of the building move up to a millimeter yearly. More precise and continuous measurements will be performed and absorption or correction mechanism including a mover girder will be installed in order to cure the issue. We need to design the corresponding operational software for emittance preservation.

In addition, not only the transverse beam emittance, but also the beam energy spread or longitudinal beam emittance should be controlled by bunch shape measurement in accordance with integrity of beam generation and bunch compression [14].

DATABASE IMPLEMENTATION

Presently, each control database is configured as a text file of a table in a predetermined format, in which each row corresponds to a device name as a key, and each column represents a device property. Further comments can be written at any row, such as the device history.

Procedures to deal with databases are available in several programming languages. For C/C++ language the database is converted into a hash database in memory, and it can be utilized efficiently [15]. For scripting languages it is converted into a associative array. Also, a set of programs is prepared for the database integrity check and management.

Because a database management system (PostgreSQL) is already used for multiple purposes in the operation, it seems to be natural to manage those accelerator property databases in PostgreSQL, and it is implemented as a test for the next phase of the beam commissioning. At the same time, more and more database elements are put into the EPICS database, and conversion procedures are prepared.

On performing beam optics calculation, a part of the information is taken from database and other information is directly taken from EPICS online process variables through the channel access protocol. For such purposes, SAD / SADscript environment for the beam control is quite flexible and is used extensively [16, 17]. Many of such operation programs are designed to refine databases scanning device and beam parameters.

CONCLUSION AND FUTURE

The management of beam properties in the KEK electron positron injector linac was considered based on the controls and databases. Especially for the realization of SuperKEKB, a reliable operation management is required for advanced beam quality and complex virtual accelerators (beam operation modes) with robust databases, calibrations based on beam measurements, iterative refinements of beam optics model in each virtual accelerators, and preservation of fine beam emittance and energy. Based on the experiences in KEKB project the controls and management of beam properties should be further improved during SuperKEKB beam commissioning phases.

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