LLRF controls in SuperKEKB Phase-1 commissioning

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Abstract (Summary)

Phase-1 beam commissioning of SuperKEKB was successfully accomplished. Desired beam current in the two rings was achieved and sufficient vacuum scrubbing was progressed. Phase-2 is scheduled in the last quarter of JFY 2017. Newly developed digital LLRF control systems are applied to 9 stations at OHO section, and successfully worked in Phase-1. For Phase-2, some improvements against heavy beam loading will be implemented in the new LLRF control system. The \( \mu \)-1 mode damper is applied to HER, and the coupled bunch instability due to detuned cavities is suppressed successfully. The \( \mu \)-1 and -3 mode damper system is now under development for Phase-2.

Phase modulation due to the bunch gap transient was clearly observed by the new LLRF control system, and validity of the new simulation code for the evaluation of bunch gap transient effect was confirmed. Accordingly, the proposed measures to cancel the bunch gap transient effect are expected to be effective.

Overview of LLRF control systems

All systems worked successfully without serious problem!

Operation status of Phase-1 commissioning

Phase-1 had started from 1st February 2016 and continued for five months. After the tuning of the injection-inac and beam transport line optics, on 10th February the first revolution beam was successfully operated in LER as accelerating cavities powered and the RF phases were adjusted. Subsequently, the RF commissioning was performed smoothly. Target beam current of \(-1\)A for Phase-1 was successfully achieved in both ring and vacuum scrubbing has been progressed as expected. All new and old RF systems including RF reference distribution system worked well without serious trouble and provided sufficient accelerating voltage during Phase-1. Some software bugs in LLRF controls found during the operation were fixed.

The cavity voltage operated in Phase-1 was 80-90\% of the nominal voltage. Mutual phases between RF stations are optimized to obtain higher synchrotron frequency and to make the bunch loading of each cavity balanced.

Bunch gap transient (BGT) effect on beam phase

In general, for a high-current multi-bunch storage ring, a bunch train has a gap of empty buckets in order to allow for the rise time of a beam abort kicker. The empty gap is also effective in clearing ions in electron storage rings. However, the gap modulates the amplitude and phase of the accelerating field. Consequently, the longitudinal synchronous position is modulated by the cavity field modulation. The bunch gap transient effect is expected to be effective.

Concerned issues for Phase-2

We have still some concerned issues for the future operation, because the desired beam current for SuperKEKB will be much higher than achieved in KEKB.

One of the issues is the cavity detuning. At the design beam current, the accelerating cavity detuning of ARES will be about 270 kHz for the optimum tuning. This detuning corresponds to 70-degree phase shift in the cavity transmission (in the KEKB operation, maximum detuning is 170 kHz). Such large phase shift may deteriorate the stability in the cavity-field FB control by IQC components. In order to mitigate the issue, implementation of additional function in the FB control is under consideration now.

Another issue is coupled bunch instability. The \( \pm 2 \) mode instability, which was negligible in KEKB, is predicted to be excited at the design current. Therefore, the \( \pm 2 \) mode damper system is additionally required for SuperKEKB. New damper system with new digital filters was developed for Phase-2. It will be available for \( \pm 1 \), \( \pm 2 \), and \( \pm 3 \) modes in parallel.