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LLRF controls in SuperKEKB Phase-1 commissioning

P-60

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Related to O-21 K. Hirosawa, et al., "A New Damper for Coupled-Bunch Instabilities caused by the accelerating mode at SuperKEKB"

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 μ=-1 mode damper is applied to HER, and the coupled bunch instability due to detuned cavities is suppressed successfully. The μ=-2 and -3 mode damper system is now under development for Phase-2.

The 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 large bunch gap transient effect are expected to be effective.

SuperKEKB is Upgrade from KEKB

RF systems have been reinforced, & New LLRF control systems have been developed.

Luminosity : x 40 !

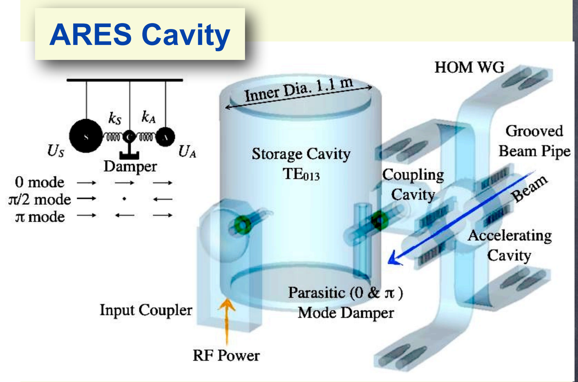
Beam Current: x 2

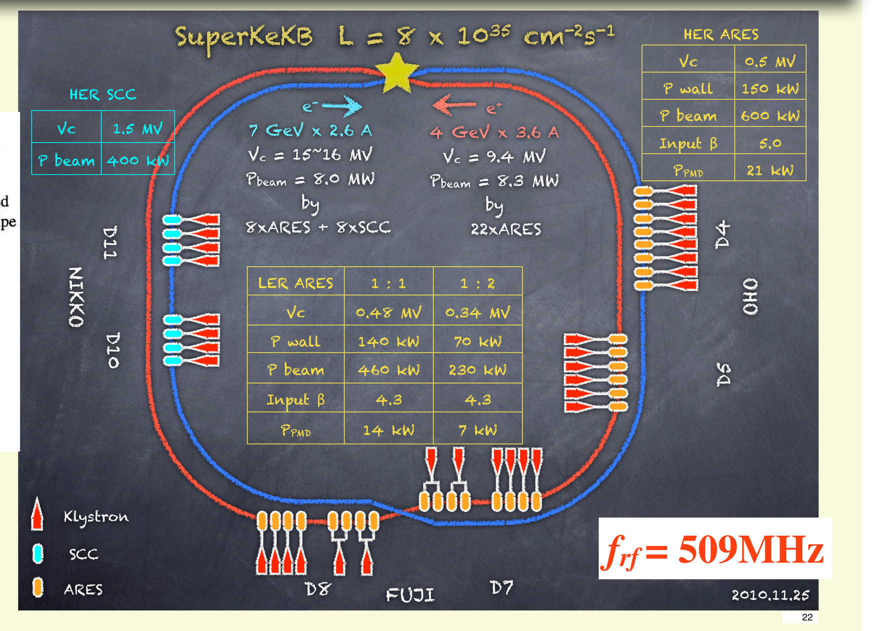
β_y@IP: x 20 (Emittance: 1/5)

Phase-1 commissioning (Feb.~ May 2016) was successfully accomplished !

RF Parameters (Required Power)

ARES Cavity





Illustrated by T. Kageyama

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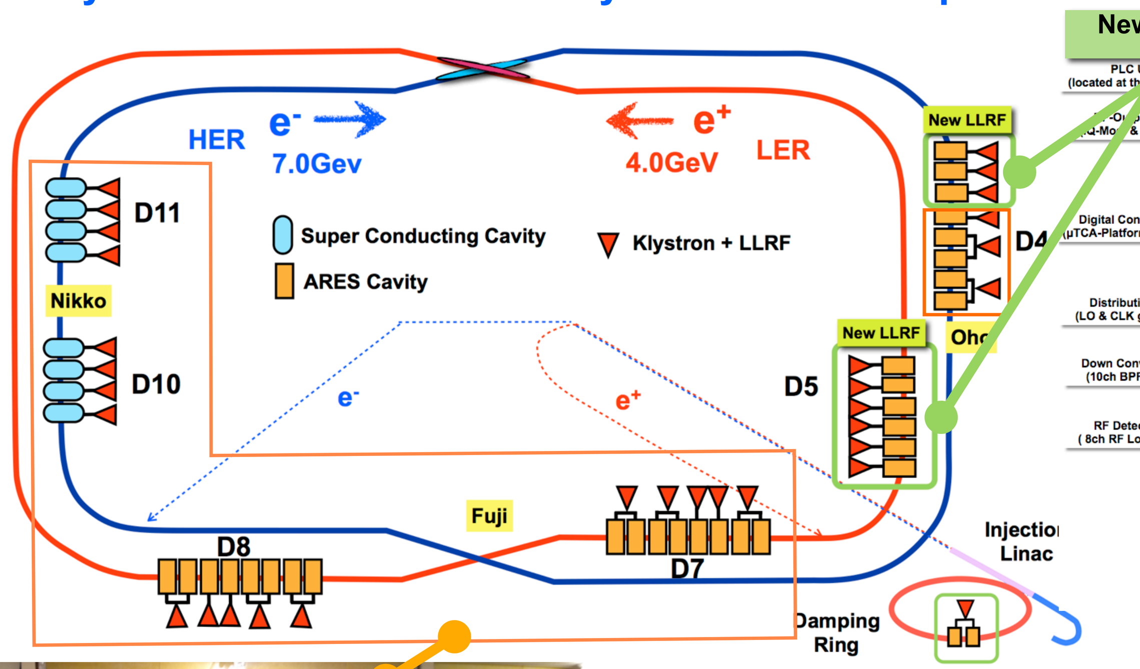
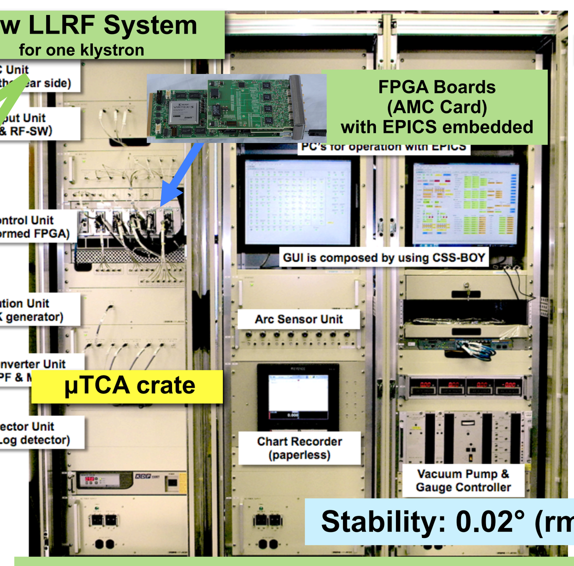
Overview of LLRF control systems

All systems worked successfully without serious problem !



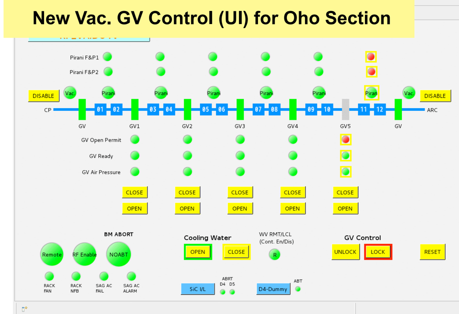


Stability: 0.02° (rms)

- consists of μTCA-FPGA, PLC.
- controls I/Q-components.
- embeds EPICS in μTCA & PLC

@Oho Section
Vacuum Gate Valve Control System was also updated.

New Vac. GV Control (UI) for Oho Section

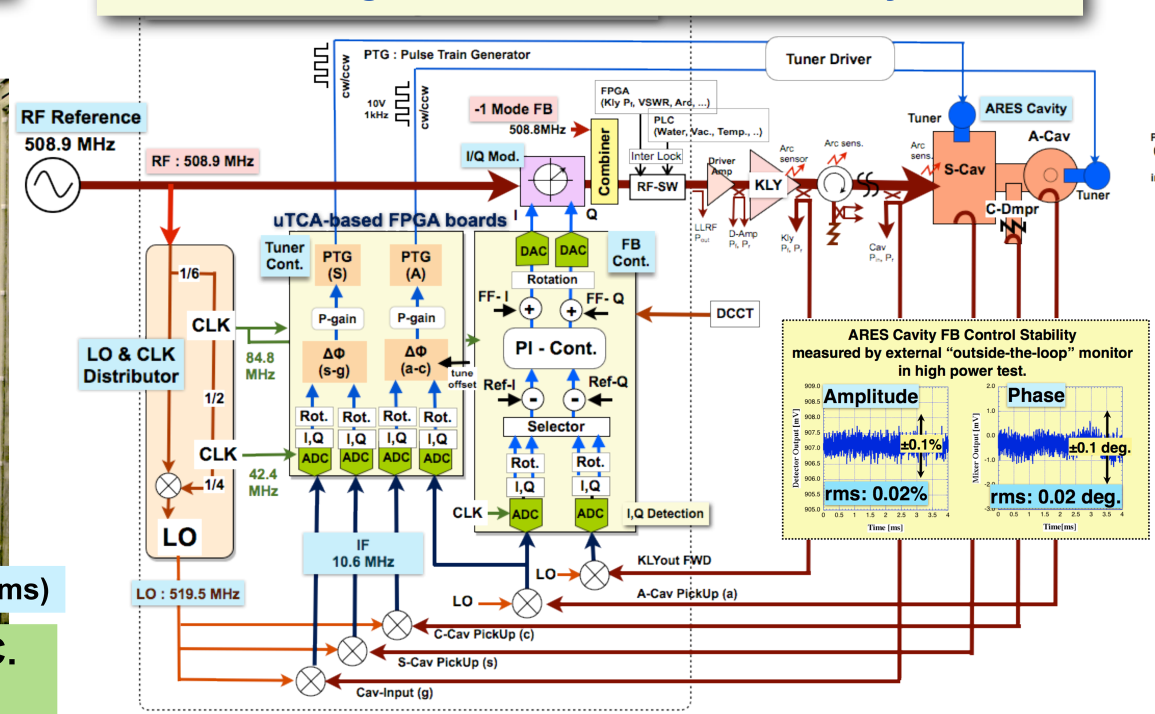


f_{rf} = 509MHz

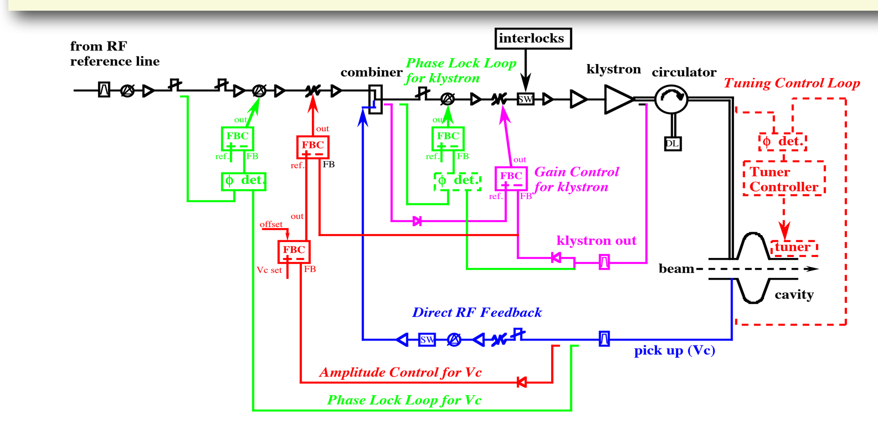
- consists of NIM modules.
- controls amplitude & phase.
- remotely controlled via CAMAC system with IOC(VME)

Many defective modules were replaced with the spares in maintenance works before Phase-1.

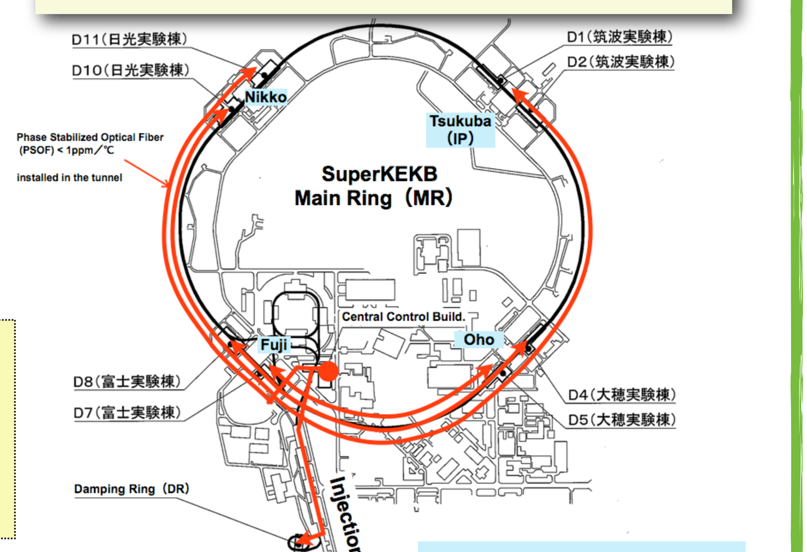
Block diagram of new LLRF control system



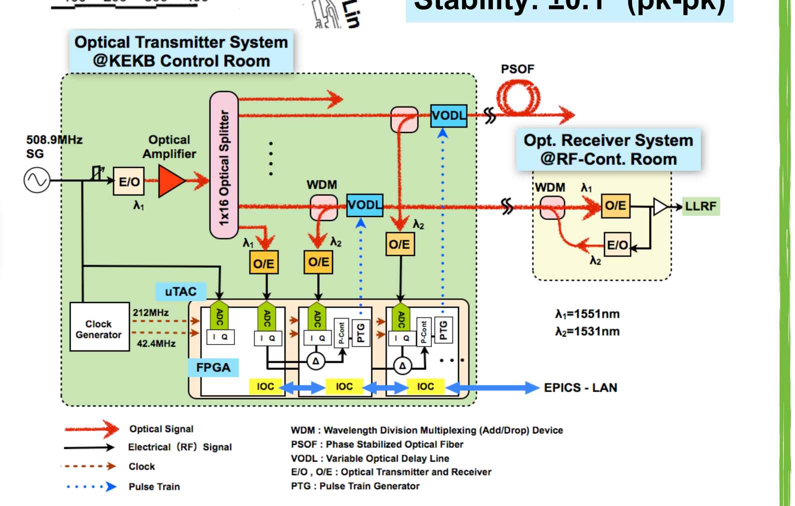
Block diagram of old LLRF control (example for SCC)



RF reference distribution system

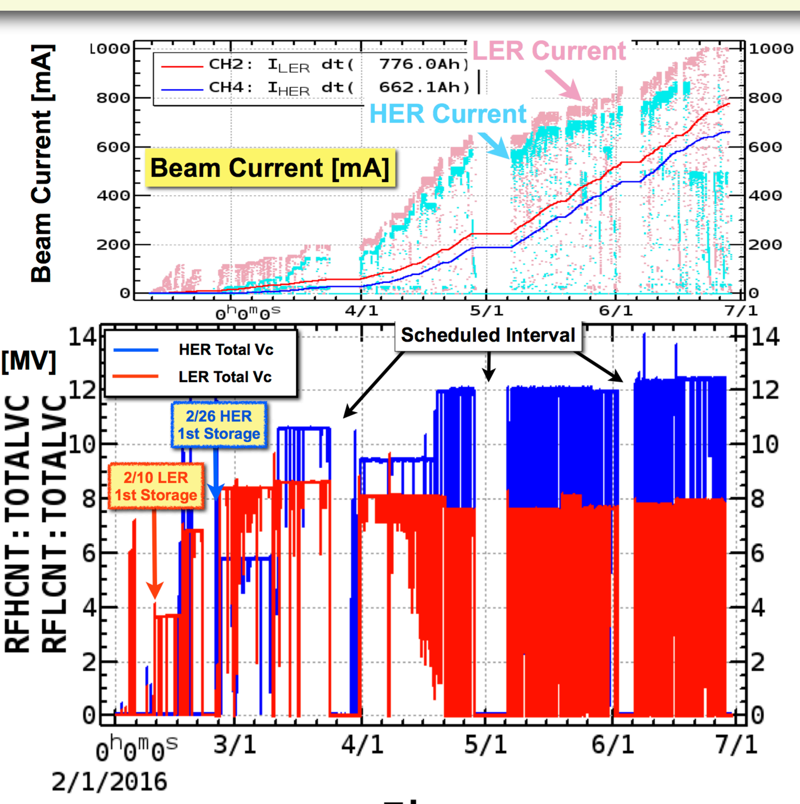


Stability: ±0.1° (pk-pk)



RF reference distribution system was also upgraded for SuperKEKB. RF reference signal is optically distributed into all RF sections by means of "Star" topology configuration from the central control room (CCR)."Phase Stabilized Optical Fiber", which has quite small thermal coefficient, is adapted. For the thermal phase drift compensation, optical delay line is controlled digitally at CCR for all transfer lines.

Operation status of Phase-1 commissioning



history of the stored beam current with beam dose (upper side) and the total acceleration voltage called total-Vc (lower side) for the both ring during Phase-1.

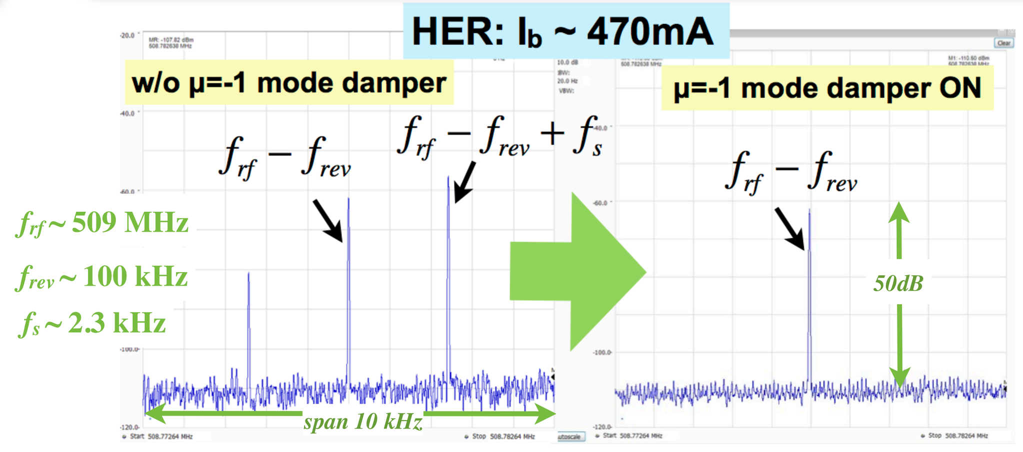
Phase-1 had started from 1st February 2016 and continued for five months. After the tuning of the injection-linac and beam transport line optics, on 10th February the first revolution beam was successfully observed in LER as accelerating cavities powered and the RF phases were adjusted. Subsequently the MR commissioning was performed smoothly. Target beam current of ~1A for Phase-1 was successfully achieved in both ring and vacuum scrubbing has been progressed as expected.

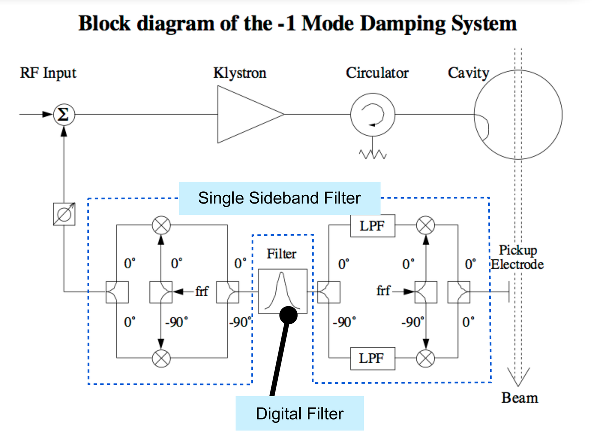
All new and old RF systems including RF reference distribution system worked well without serious trouble and provided sufficient accelerating voltage during Phase-1. Some software bugs in LLRF controls found during the operation were fixed.

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 beam loading of each cavity balanced.

Coupled bunch Instability & the damper

HER: I_b ~ 470mA





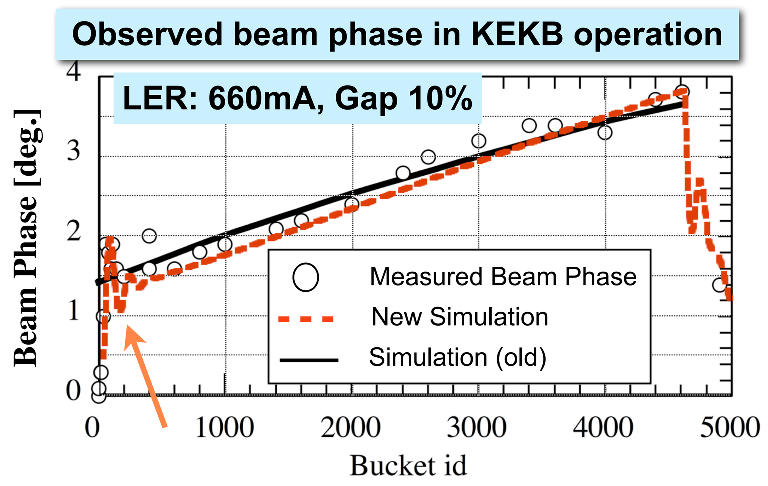
In HER, the =-1 mode instability due to the detuned cavities (parked with some reasons) was excited since the stored beam current became over 400-mA. Consequently, the =-1 mode damper system, which had been used in KEKB operation, was applied to the D4 station. It worked well to suppress the =-1 mode successfully, and the beam current could be increased. The threshold current of the =-1 is about 1.7 A for LER and 1.2 A for HER. In Phase-1, at an earlier stage than expected, the =-1 mode damper became needed due to the parked cavities with detuning, the stations of which had some troubles in the RF system.

Refer to "O-21" in this workshop for coupled bunch instability

Bunch gap transient (BGT) effect on beam phase

In generally, 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 cavity field. Consequently, the longitudinal synchronous position is shifted bunch-by-bunch along the train, which shifts the collision point of each bunch.

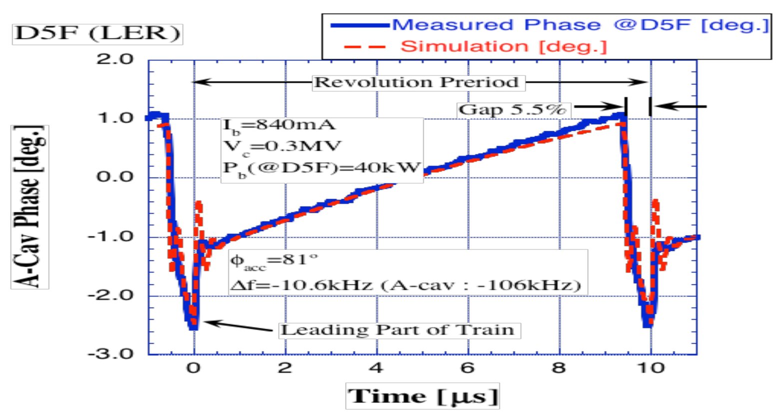
Observed beam phase in KEKB operation



The observed phase-shift due to the bunch gap effect in KEKB operation, agreed well with a simulation and a simple analytical formula in most part of the train. However, a rapid phase change was also observed at the leading part of the train, which was not predicted by the simulation or by the analytical form.

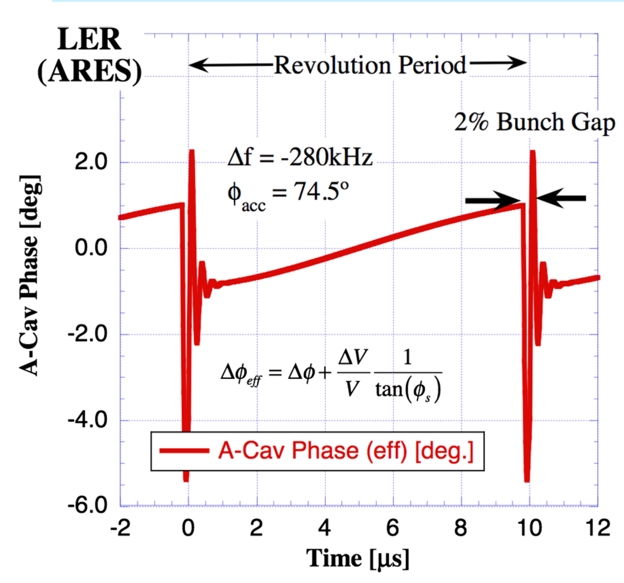
In order to understand the cause of this observation, we have developed an advanced simulation, which treats the transient loading in each of the three cavities of ARES. The new simulation can reproduce well the observed rapid phase change. Accordingly, it was clarified that the rapid phase change at the leading part of the train is caused by a transient loading in the three-cavity system of ARES: the rapid phase change is attributed to the parasitic (0&π) modes of ARES.

RF phase modulation of cavity field measure by new LLRF system.



RF-phase transient of the accelerating cavity of ARES is shown. It was measured by the new digital LLRF control system in the Phase-1 commissioning. The time interval of 10 microseconds is the revolution period. As shown in the figure, the phase modulation due to the bunch gap transient effect was clearly observed by the new LLRF system, and the rapid phase change caused by the parasitic mode of ARES can be also found at the lead-ing part of the train. The simulation result (dashed red line) agrees well with the measurement. In the simulation, function of feedback control for cavity voltage regulation by LLRF control system is also included. From these results, validity of the new simulation code can evidently confirmed.

Simulation of phase modulation due to the bunch gap for SuperKEKB design current



From the new simulation study, it is predicted that the rapid phase change caused by bunch gap will be about 6 degrees in cavity field at the design beam current of SuperKEKB. The collision point shift (relative phase difference between the two rings) due to such large phase change could make significant reduction of the luminosity in future collision experiment. The measures to avoid the luminosity reduction have been also proposed by the simulation study.

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 I/Q 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 =-2 mode instability, which was negligible in KEKB, is predicted to be excited at the design current. Therefore, the =-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 =-1, -2 and -3 modes in parallel.

Refer to "O-21"