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LLRF CONTOL AND MASTER OSCILLATOR SYSTEM FOR DAMPING RING AT SuperKEKB

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Abstract

Damping ring (DR) has been newly constructed for positron beam injection for SuperKEKB in order to make the emittance significantly smaller. The beam commissioning of DR was conducted in February 2018 and it was successfully progressed for the Phase-2 commissioning of SuperKEKB. The Phase-2 commissioning of the main storage rings (MR) is now in progress.

Low Level RF (LLRF) control system developed for MR of SuperKEKB is also applied for DR cavity-field control; RF frequency of DR operation is common with MR. The DR-LLRF control system worked very well and contributed successful storage in DR commissioning. This paper reports the performance results of DR-LLRF controls, and also synchronization (master oscillator) system with the injection linac for the DR operation is introduced.

INTRODUCTION

The SuperKEKB project, which is aiming at a 40 times higher luminosity than KEKB [1], is going on. The first beam commissioning of SuperKEKB (Phase-1) was accomplished in 2016 [2], and the Phase-2 commissioning is currently in progress.

Damping ring (DR) has been newly constructed for positron beam injection for SuperKEKB in order to make the emittance significantly smaller [3]. The beam commissioning of DR was conducted in February 2018 and it was successfully completed before Phase-2.

A new low-level RF (LLRF) control system, which consists of FPGAs, has been developed for SuperKEKB to realize high accuracy and flexibility [4]. For nine RF stations, among a total of thirty, the LLRF control system was applied for the Phase-1 commissioning as shown in Fig.1. They worked well and contributed to success of the commissioning.

The new LLRF control technique was also applied for DR cavity-voltage (Vc) control; RF frequency of DR operation is common with the main storage ring (MR). This new system for DR also worked as expected, and successful beam storage in DR was accomplished shortly after tuning of the injection tuning for DR. This paper reports the performance results of DR-LLRF controls.

Additionally, synchronization among MR, DR (508.9 MHz) and the injection linac (2856 MHz) is one of the important issues for the total operation. Especially, for dispersion measurement study, the RF-frequency should be changed in only DR. After that, immediate recover of the synchronization with the linac and MR is required for successive injection after the dispersion measurement. In this paper, the master oscillator system to satisfy the requirement of the synchronization describe above is introduced. Timing system or event system is not described in this paper, so refer other publications (e.g. [5]) about them.

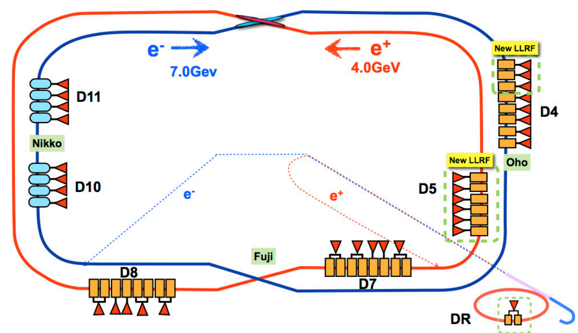

Figure 1: RF system layout for the Phase-1. Nine LLRF stations were replaced with the new ones. DR-LLRF control system was also newly installed.

Table 1: RF-Related Design Parameters of DR

Parameters		Unit
Energy	1.1	Gev
Charge of bunch	8	nC
# of Bunch	2	
Circumference	135.5	m
RF Frequency	508.9	MHz
Harmonic number	230	

LLRF CONTROL SYSTEM OF DR

DR has one RF station in the ring of 135.5-m circumference. Two cavities are driven by one klystron as shown in Fig. 2. Table 1 and Table 2 show the RF-related design parameters [3] ant the cavity parameters for DR, respectively [6].

Figure 3 shows the block diagram of the LLRF control. The Vc-regulation control and cavity-tuning control are shown in the figure. I/Q components are handled digitally for the amplitude and phase controls as shown in the figure. The hardware components are common with the MR-LLRF control system, which consists of MicroTCA-platformed FPGA boards [4][7]. The system has five FPGA boards: Vc-feedback controller (FBCNT), cavity-tuner controller (TNRCNT), inter-lock handler

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(INTLCNT), RF-level detector for the interlock and arc-discharge photo-signal detector. In DFBCNT, vector-sum control of the two cavities is processed for the DR-LLRF control system. On the other hand, in MR, one system controls one cavity unit (no vector-sum needed in MR). For slow interlocks (e.g. vacuum, cooling water) and sequence control, a PLC is utilized. EPICS-IOC is embedded in each of the FPGA boards and the PLC [8].

Table 2: Cavity Parameters for DR

Parameters		Unit
RF Frequency	508.9	MHz
R/Q	150	Ω
Q_0	30000	
Coupling	1.4	
V_c / cavity	0.8	MV
P_{wall} / cavity	150	kW

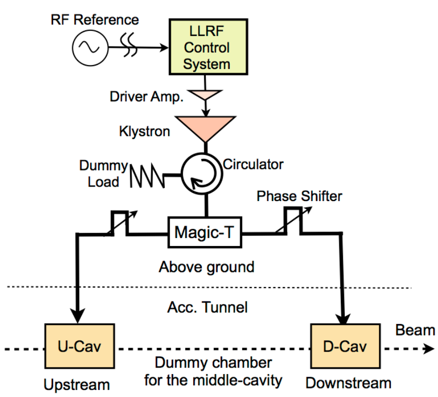

Figure 2: RF system for DR.

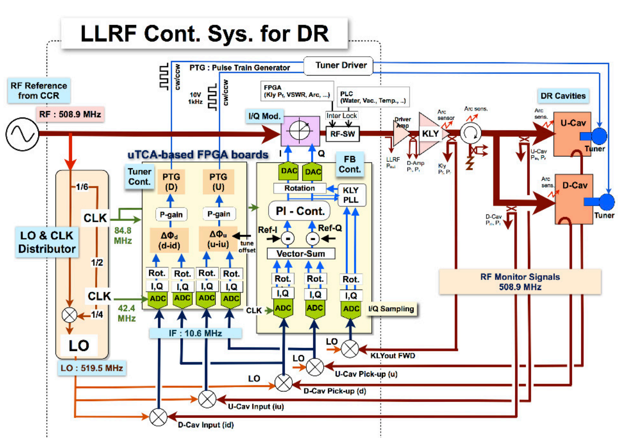

Figure 3: Block diagram for DR-cavity control.

PERFOMACE TEST OF LLEF CONTROL

The accelerating cavity was installed into DR at the beginning of 2017, and the performance of the LLRF control system, including the high power system with a klystron, was evaluated at 10-kW operation. The phase shifter of the waveguide system was adjusted to match accelerating phases of the two cavities each other for beam.

In the system evaluation, expected performance, which was the same as that of MR, was verified in Vc-regulation and tuning controls. Figure 4 shows the Vc-regulation result (amplitude in the upper side and phase in the lower side) of vector sum control of the two cavities. The stability of 0.1%, 0.05 degrees in amplitude and phase, respectively, was obtained in the vector sum field. On the other hand, in open-loop operation, periodical fluctuation of approximately 50 Hz was observed in both amplitude and phase of klystron output as shown in Fig 5 (upper side). The klystron power supply system is very old one, which had been used in TRISTAN. This klystron fluctuation is suppressed completely by the FB control as shown Fig. 5 (lower side).

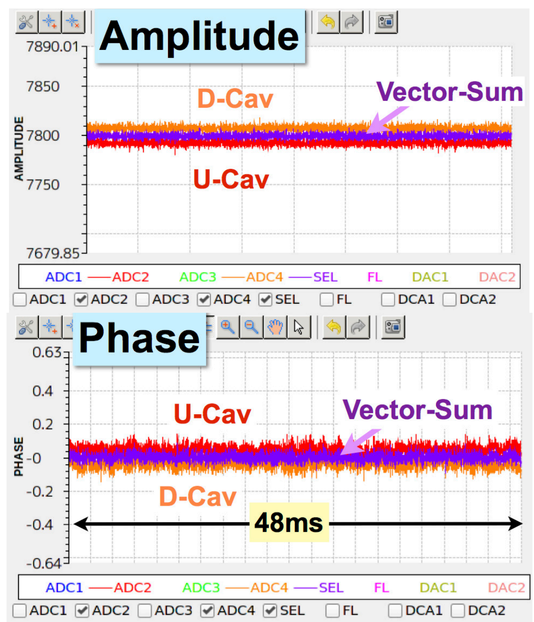

Figure 4: DR-cavity voltage (V_c) stability at 4-kW cavity input (V_c ~ 0.13 MV/cav) with vector-sum FB control. The stability (pk-pk) of amplitude and phase is 0.1% and 0.05 deg., respectively.

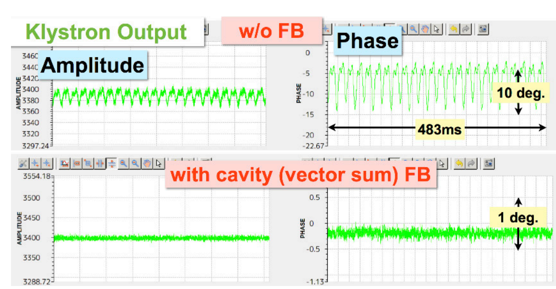

Figure 5: Klystron output signal (amplitude and phase) without FB control (upper side) and with cavity (V_c loop) FB control (lower side).

On June 2017, RF conditioning of the cavity was conducted, and required voltage for the operation was smoothly achieved.

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The DR commissioning was started in February 2018. After tuning of the beam transport beam line for DR injection, the first beam storage in DR was smoothly attained with the cavity phase tuning on 9th February 2018.

MASTER OSCILLATOR SYSTEM

RF frequency of DR is to be the same as that of MR for ordinary operation. Thus essentially, the RF reference signal for MR should be also distributed to DR. However, for study of dispersion measurement or chromaticity evaluation, the RF frequency only in DR has to be controlled independently with keeping of RF operation. Required maximum frequency change is about 50 kHz for the study; this large change of RF frequency is not allowable for the injection linac and MR in synchronizing. Besides, immediate recover of the synchronization with the linac and MR is needed for the successive inject after the dispersion measurement. The mutual RF phases among them should be also recovered.

In order to realize the requirement mentioned above, a dedicated master oscillator for DR is applied. Figure 6 show the block diagram of master oscillator system for the RF synchronization among the linac, DR and MR. In the figure, the acceleration sections are simplified to illustrate only the relationship among them. For the detail of the RF reference distribution, refer to [9][10]. Timing system or event system is omitted in this paper.

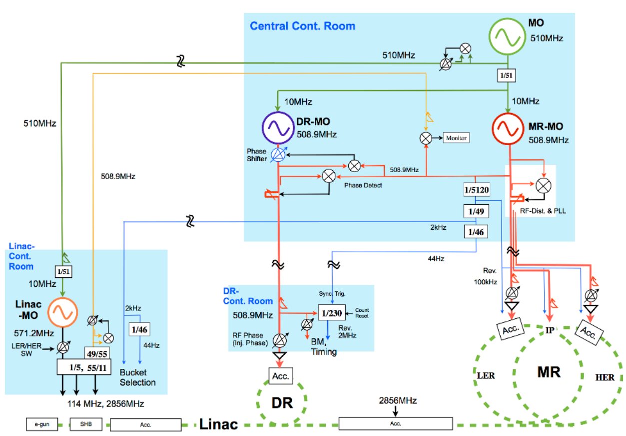

Figure 6: Schematic draw of master oscillator system for RF synchronization with the injection linac, DR and MR.

As shown in Fig. 6, the injector linac (Linac), MR and DR have an own master oscillator (MO), respectively, which are commercial ones of Agilent E8663 series. They are synchronized each other by the external 10-MHz reference generated by frequency dividing of 510-MHz reference into 1/51. The frequencies of Linac-MO and MR-MO are set so that the ratio between them is 55:49. The 510-MHz reference, which is generated at the central control room, is fine-tuned automatically to correct the MR-RF frequency for exact circumference of MR on a continuous basis in usual operation.

For dispersion measurement, the frequency of DR-MO is shifted by 50 kHz after injection while the beam is stored in DR with acceleration. After the measurement, the frequency is restored to the origin for the next injection. Though, in this case with this method, the RF phase is not recovered, so the injection phase and the bucket-ID are lost. Therefore, a phase shifter is inserted to recover the RF phase and to reset the bucket-ID (the revolution signal) of DR after the end of the dispersion measurement. This MO system can make seamless frequency control of DR-RF with keeping the beam stored for the commissioning study and can make also immediate recover for ordinary injection.

Nonetheless, slow phase swing of a few degrees, of which period is about an hour, is perennially observed in relationship between Linac and DR (MR). Therefore, we are planning to install feedback control for locking the mutual phases of MO's.

SUMMARY

Newly-developed digital LLRF control system for MR of SuperKEKB is also applied for DR, ant it worked as expected with good regulation performance. And also new master oscillator system and the RF reference distribution system were constructed for DR. This system, which has a dedicated master oscillator for DR, can make seamlessly independent operation of DR with changing RF frequency after the injection for the study, and can also make immediate recover of the synchronization with the linac and MR for the successive injection. These new LLRF control systems contributed much to short time success of the DR commissioning.

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