LOW-LEVEL RF CONTROL SYSTEM FOR THE TAIWAN PHOTON SOURCE

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Abstract

The low-level RF (LLRF) control system is an essential component of the RF system for Taiwan Photon Source. The LLRF control system will perform various functions including control loops for the cavity gap voltage and the phase feedback, RF system interlock protection and the diagnostics for a machine trip. The LLRF system is manufactured in house using the most recent commercial RF chips. The LLRF system has an analogue architecture similar to that used in the 1.5-GeV Taiwan Light Source (TLS). An overview of the system architecture and its functionality is presented herein.

INTRODUCTION

The Taiwan Photon Source (TPS) project proposes an electron accelerator with beam current 400 mA at 3 GeV and small emittance, 2 nm rad. Civil construction began 2010 February. Commissioning of the TPS machine is scheduled for late 2013. TPS will install two 500-MHz single-cell superconducting cavities of KEKB type in the storage ring and one conventional 5-cell PETRA cavity in the booster ring. During the initial stage of machine commissioning, to protect the SRF cavity from performance degradation caused by an inadequate vacuum, two 5-cell Petra cavities instead of the SRF cavity will serve for the machine commissioning until the beam current exceeds 100 mA. [1]

The LLRF RF system is designed in two versions: one is for the booster synchrotron, which will include the voltage-ramping function of the cavity gap at a rate 3 Hz, and the other is for the storage ring that will operate at a constant accelerating RF voltage.

The low-level rf system is based on an analogue circuit, which is designed to keep the deviation of the cavity voltage within 1% in amplitude, and $\pm 1^{o}$ in phase.[2] The various functions of circuits are integrated in separate modules, which are installed in NIM modules that enable ease of replacement of a failed module, or debugging the circuit of a module. An overall block diagram of the LLRF system is shown in Figure 1.

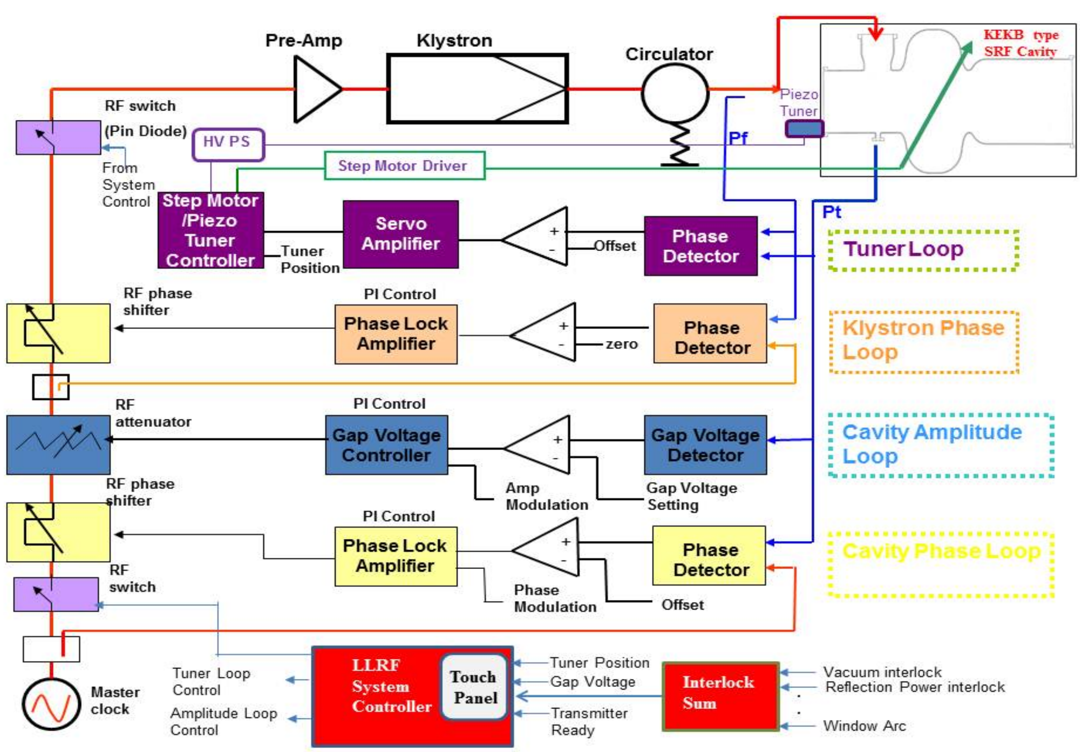

Figure 1: Block diagram of the low-level RF system.

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LLRF SYSTEM ARCHITECTURE

Amplitude and Phase-control Loop

The gap voltage-control loop keeps the amplitude of the cavity gap voltage constant in the storage ring, and ramping is synchronized with the beam energy in the booster. The cavity phase-feedback loop keeps the phase of the cavity field constant with respect to the phase of the master clock. In addition to the cavity-voltage phase-feedback loop, there is a klystron phase loop, which serves to compensate the phase variations caused by the klystron and the RF circulator.

LLRF System Controller

The LLRF system controller provides the following operating modes:

- OFF mode: turn off the driver power to the RF transmitter;
- TUNE mode: limited RF drive power is provided, with which the cavity frequency- tuning controller can tune the cavity to the resonance condition;
- OPERATE mode: the cavity voltage can be set by a machine parameter or a machine operator;
- Local/remote operation: in LOCAL operation, the LLRF system is operated through a local control panel; in REMOTE operation, the system is controlled by the remote control panel through an EPICS interface layer;
- Automatic cavity resonance-frequency tuning: an automated cavity-tuning procedure has been implemented in the LLRF central controller to tune the cavity to its resonant frequency.

The main components of the operating mode of the central controller are the Programmable Logic Controller (PLC) and a Touch Panel. The PLC implements control functions using a state machine method. The touch panel provides a GUI for local operation and all functions necessary to control the entire LLRF system. In addition to the functions mentioned above, important data for the machine operation such as the field amplitude and cavity-tuner position are displayed. Figure 2 shows the touch panel of the LLRF operating-mode controller.

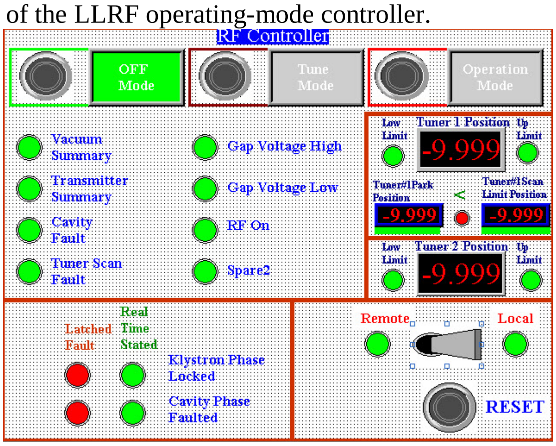

Figure 2: Touch panel of the LLRF system controller.

Cavity-tuning Loop

The RF load impedance of the RF cavity is varied on altering the cavity frequency or the operating beam current. The cavity tuners are mechanical devices designed to tune the cavity frequency for precise RF impedance matching while the cavity is in operation. The cavity-tuning loop tunes the RF cavity frequency based on the RF phase measurement (tuner-phase error) between the incident RF signal and the cavity RF field. The tuner phase-error signal is processed in a SERVO AMPLIFIER module that provides a PI feedback-control function. The TUNER controller uses the PI feedback-control signal to drive the stepping motor or piezo tuner.

The cavity-tuning functions used for the SRF cavity of KEKB type and the Petra cavity are explained below.

- KEKB superconducting RF cavity: There are tuner drivers of two types for the KEKB SRF cavity: one is a mechanical-step motor-tuner driver used for small- frequency variation, and the other is the piezoelectric tuner driver (PZT) used for rapid but small frequency variation.[3] The logic diagram for both tuner controllers is shown in Figure 3

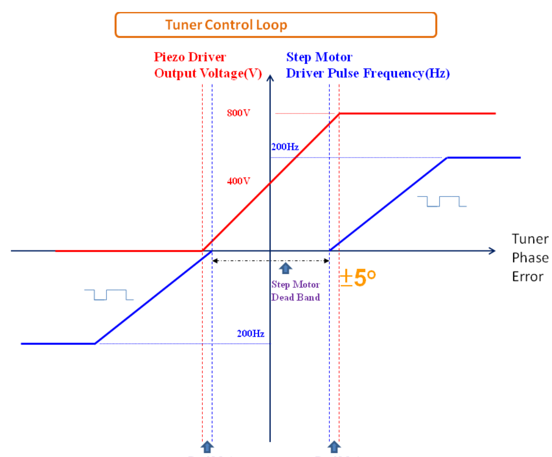

Figure 3: Tuner-phase Error vs Stepping-motor Clock/Piezo Driver Signal.

We divided the tuner phase error into four ranges: (1) stepping-motor dead-band and piezo-tuner range, (3) overlap range, (4) stepping-motor range and (5) tuner-speed-limiting range. When the tuner phase error is within the dead-band range, the stepping-motor drivers generate no tuner driver signal. The piezo-tuner driver generates a voltage, proportional to the tuner-phase error, to move the cavity-frequency tuner while the stepping motor stays in a stopped condition. When the tuner-phase error is in an overlap range, both piezo and stepping-motor drivers generate tuner-driver signals to move the cavity-frequency tuner. When the tuner-phase error is in the stepping-motor range, only the stepping-motor driver-clock signal is generated to move the cavity-frequency tuner; the driver-clock frequency is linearly proportional to the tuner-phase error. When the tuner phase error exceeds a limiting setting, the driver-clock frequency is limited to a constant, so the moving speed of the stepping- motor tuner is also limited. The details of the cavity tuner control logic are presented in Figure 3 .

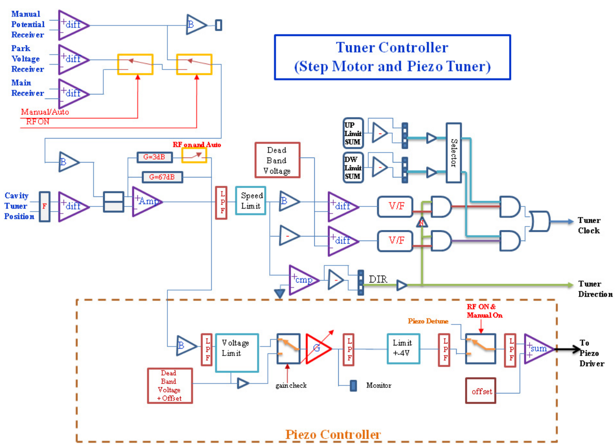

Figure 4: Block diagram of the KEKB SRF cavity-tuner controller.

- Petra-cavity Tuning: Two frequency plungers are installed in two of the five cavity cells for cavity-frequency tuning. We installed three RF pick-up ports on the Petra cavity: one is installed at the central cavity cell, whereas the other two are installed at cells at which frequency plungers are also installed. The pick-up RF signal from the central cell is used for the cavity frequency and RF gap-voltage control. The other two pick-up RF signals are used to keep the RF field balance in the cavity cells.

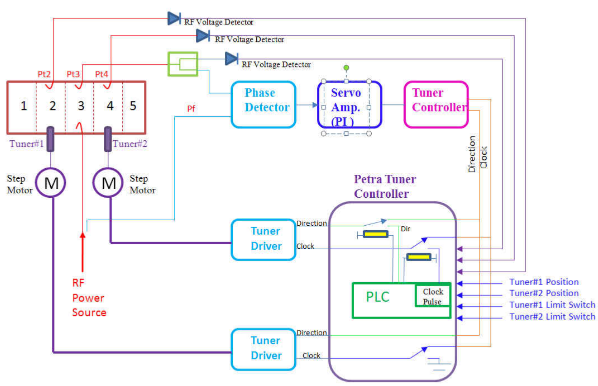

Figure 5: Function diagram of the Petra cavity two-tuner control.

CONCLUSIONS

One set of analogue LLRF systems has been integrated with a 300 kW-CW RF transmitter and a Petra cavity, and tested in operation at high power. Three other sets of LLRF systems are now under assembly and will be available at the end of 2011. More efforts on the piezo-tuner control and the Petra RF field-balance control are foreseen.

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