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ENERGY-SAVINGS FOR THE TPS BOOSTER RF SYSTEM AT THE NSRRC IN TAIWAN

Fu-Tsai Chung*, Meng-Shu Yeh, Fu-Yu Chang, Ling-Jhen Chen,Tsung-Chi Yu, Zong-Kai Liu, Lung-Hai Chang, Mei-Hsia Chang, Chih-Hung Lo, Yi Ta Li, Shian-Wen Chang, Chaoen Wang, Ming-Chyuan Lin,
National Synchrotron Radiation Research Center, Hsinchu 30076, Taiwan

Abstract

In this paper, we discuss an energy-savings control system for the Taiwan Photon Source (TPS) booster RF system. During top-up storage ring operation, a timing control is activated to reduce the booster RF transmitter energy consumption when no injection is required. Whenever injection into the TPS storage ring is needed, the booster RF transmitter is immediately adjusted to operating conditions. This timing-control system will save an energy of 380,000 kWh annually.

INTRODUCTION

The Taiwan Photon Source (TPS) is a third-generation 3 GeV synchrotron with a 518 m circumference, high brightness and low emittance. Since March 2016, the storage ring current has been increased to 400mA in top-up mode. The top-up injection mode is an important operating mode for synchrotron radiation sources, because the quasi-constant light intensity will maximize the delivered photon numbers. At the start of storage ring operation, a beam current of 405 mA is stored. After this initial fill, the system is switched to top-up mode and the booster ring delivers electrons to the storage ring every four minutes. When the top-up current has been delivered and the storage ring current of 405 mA is restored, the booster ring is switched to stand-by status. It is not economical to operate the klystron at full power for 24 hours and therefore the booster synchrotron should include a timing control system [1] during top-up mode of operations. An energy savings mechanism was developed to reduce the energy consumption of the booster RF system during stand-by. At the same time, the RF system of the booster ring must be synchronized accurately to the TPS storage ring.

The booster RF system is composed mainly of a RF cavity module, a 100Kw-500MHz RF transmitter to accelerate the electrons and a low-level electronic RF control system (LLRF) providing feedback control and system protection. Fig. 1 shows the function block of the booster RF system. The RF cavity module is a 5-cell Petra normal temperature cavity with a low-level analog electronic control system (LLRF) for the phase and amplitude feedback loop, cavity frequency tuning (used by the tuner) and interlock protection module. The energy consumption results from the product-integral of the klystron cathode voltage and cathode current delivered by the RF transmitter. A timing control system must be considered to reduce the cathode current during stand-by status of the booster ring in order to reduce energy consumption.

During stand-by, a small amount of RF power to the cavity is required to establish an acceptable gap voltage. Therefore, the cavity resonant frequency tuning feedback loop of the LLRF can still lock the tuner at the resonant position during stand-by. From here, the system can quickly ramp up the accelerating electric field when top-up injection starts.

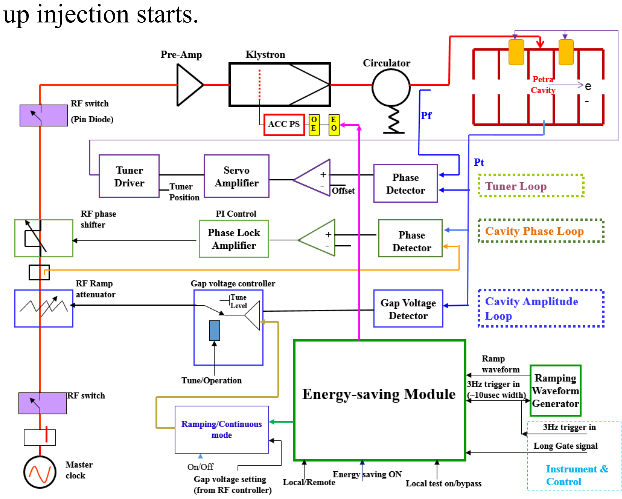

Figure 1: Function block for the booster RF system.

DESIGN AND IMPLEMENTATION OF THE ENERGY-SAVINGS CONTROLLER

The energy-savings controller is a home-made device for the booster RF system and is shown schematically in Fig. 2. The main mechanism is implemented in Complicated Programmable Logic Devices (CPLD). The controller panel includes three knobs to adjust the upper klystron cathode current limit for high power output and the lower cathode current limit as well as RF gap voltage for stand-by. In addition, the ADG436 is used for signal switching to suppress noise.

* gofor@nsrrc.org.tw

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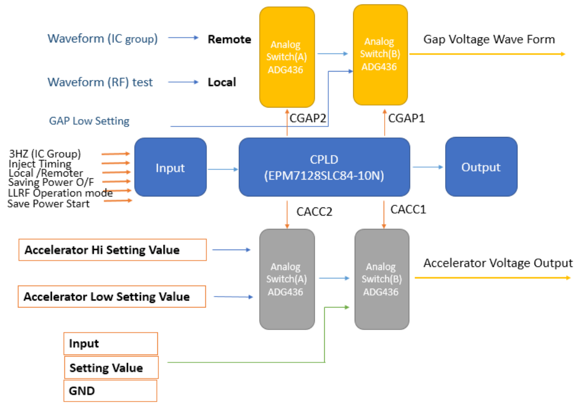

Figure 2: Schematic of the energy savings controller functions.

System Integration and Interface Description

The design goals of the system in addition to the timing-control-program, requires external signals generated by the Instrument Control (IC) Team group. The monitor panel (Fig. 3) for the external signals includes a remote/local switch, an energy-savings activation switch, seven indicator lamps, three adjustment knobs and three meters to help operators debug the energy-savings system.

The energy-savings system consists of three parts: the signal source, peripheral connections and software programming.

Figure 3: Monitor Panel.

Signal Source

The Instrument Control (IC) group at NSRRC provides a 3 Hz injection repetition rate trigger signal from which a new Pre-Inject-Timing signal for accelerator (ACC) power operation is generated to properly control the klystron microwave and to provide sufficient response time for the energy-savings system. As shown in Fig. 3, the status of the 3Hz INPUT and ACC HI is indicated by LEDs.

The energy-savings system generates a new injection window (Timing-Injection) via Pre-Inject-Timing based on the repetition rate signal. The Timing-Injection switches to high/low to rise/decrease the gap voltage upper limit for either full or energy savings operation. When the Timing-Injection switches to high, increasing external microwaves enters the cavity and the LED for GAP OPEN is illuminated on the Timing-Injection panel.

Three Omron meters and knobs are available for display and to set operation parameters, respectively. The Omron meters are of the model ACC HI/ACC LOW and GAP Contiguous value.

By pushing a toggle switch, the energy-savings system can be operated under remote- or local-control and two LEDs on the panel show the active control mode.

Peripheral Connections

A homemade panel is made as shown in Fig. 4. There are several BNC and terminal bus inputs (source) and outputs (for control) with specific names for wiring.

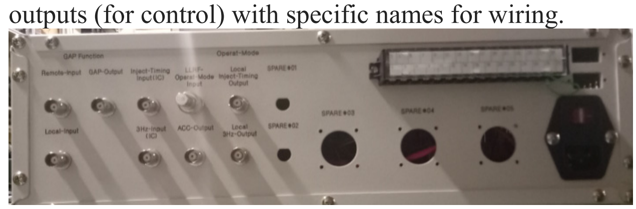

Figure 4: Peripheral connections.

Software Programming

The program control flow chart is shown in Fig. 5 with timing-control details. Each control-sequence must work under accurate timing to achieve the desired functionality. The yellow and blue circles represent the local- and remote-control functions, respectively.

All functions were tested in the laboratory on 2016-12-01 and the results are shown in Fig. 6. The energy-savings system was implemented on 2017-05-29 and the results are shown in Fig. 7.

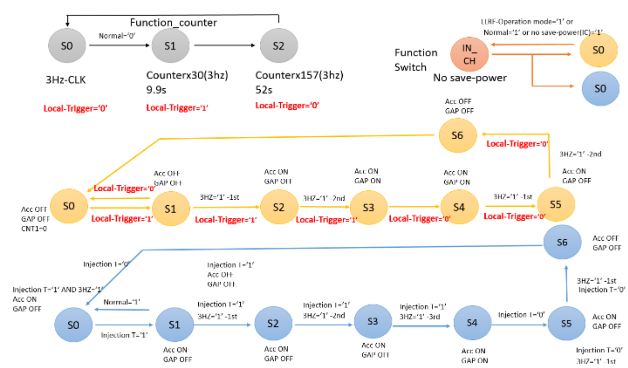

Figure 5: State machine for the CPLD program.

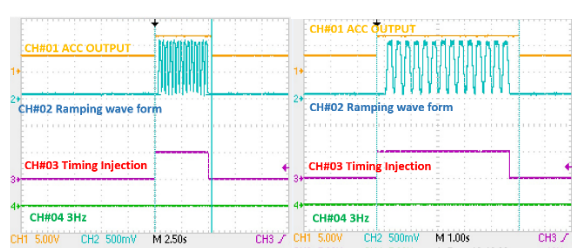

Figure 6: On-line test of the control functions.

The power consumption of the RF system is shown in Fig. 7. Before the implementation of the energy-savings system, the average energy consumption was about 2700 kWh per day which decreased to about 800 kWh after implementation of the energy-savings system. Therefore, the energy-savings system saves 1900 kWh per day or 380000 kWh per year assuming 200 working days.

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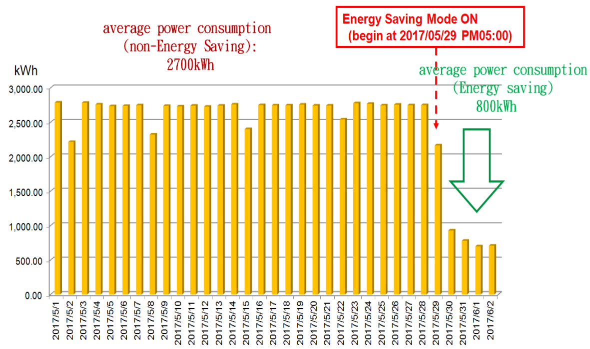

Figure 7: RF system energy consumption.

CONCLUSION

In order to save energy in the booster RF system and to facilitate automation, an energy-savings controller has been designed for the booster RF system with the following functions:

1. It can operate for continuous injection or top-up operation mode.
2. Controlled by the "injection timing", it can enter stand-by status or injection status to establish a ramping gap voltage.
3. It provides a self- detection function.
4. It can be interrupted by local-control at any time during remote-control periods.

The TPS energy-savings control system has been implemented in May 2017 and is currently operating in the booster RF system while saving RF energy of about 380,000 kWh per year. Due to the cathode current reduction during stand-by, the energy-savings system increases also the klystron life time.

REFERENCES

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