ENERGY SAVING CONTROLLER FOR THE TLS BOOSTER RF SYSTEM

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Abstract

The quasi-constant current operation is achieved in the NSRRC by periodically injecting electrons from the booster to the storage ring. It means the booster RF system keeps running during operation period, even the injection period occupies only a small portion of the total operation time. To benefit both the energy saving and klystron life, an energy saving controller has been developed and integrated into the TLS booster RF system. The cathode current of the klystron is decreased during the top-injection period. The energy consumption is thus dramatically reduced. A continuous record since the beginning of 2009 shows this controller can save about 78 percent of energy consumption of the booster RF system during normal operation. An overview of the control architecture and its functionality is presented herein.

INTRODUCTION

In the current top-up mode operation of Taiwan Light Source (TLS) in the National Synchrotron Radiation Research Center (NSRRC), the electron beam is ramped up to 1.5GeV in the booster ring and then injected to the storage ring periodically. The electron beam is accelerated by the RF system in the booster ring. The booster RF system mainly consists of one RF cavity powered by a 60 KW CW RF transmitter, and a low level RF system. A simplified block diagram of the booster RF system is shown in Figure 1. The cavity provides the peak accelerating voltage of up to 280kV with 10 Hz injection rate. The booster low level RF system (LLRF) is based on the analogy techniques designed and constructed by SLAC Microwave Engineer Group [1]. This LLRF system consists of the RF phase feedback loop, accelerating voltage feedback loop, cavity frequency tuner loop and interlock protection modules.

In order to operate the storage ring with a constant current of 300mA, the technique of top-up injection is performed [2]. Currently the electron beam is extracted from the booster ring every minute. But the injection process is actually–completed within 2 seconds, and thus the booster is under the standby mode in the rest 58 seconds. In the past years, the booster RF system was always operated at the full power output condition since the top-up mode operation was realized in TLS. Obviously a lot of energy contributes nothing to the operation. To reduce the power consumption, we analyzed the timing of TLS storage ring injection process and designed an energy saving controller for the booster RF system. This controller mainly reduces the klystron cathode current when the booster is under standby operation mode. However, to stabilize the klystron, the controller gets the cathode current ready some seconds prior to the injection command arrives.

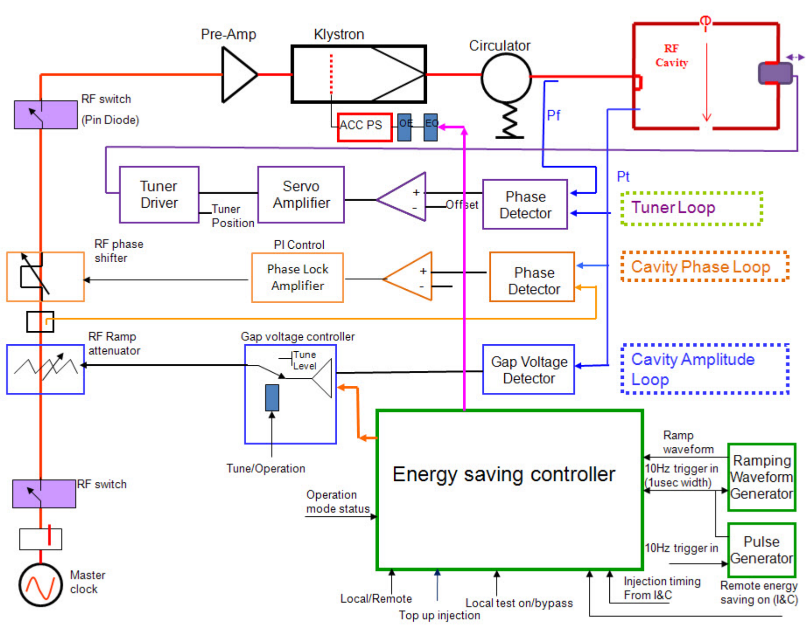

Figure 1: The block diagram of the booster RF system in TLS

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ENEGRY SAVING CONTROLLER

According to the booster RF system operation conditions, two modes are implemented in the controller:

(1) Continuous current injection mode: Once the storage ring must be filled from a low current to 300mA as the initial injection or after a beam interruption, the controller keeps the accelerator voltage of klystron at the operation setting and asks the RF transmitter to provide sufficient output power for booster ramping function. The accelerator voltage is set to follow a waveform generator with a repetition rate of 10 Hz. No power conservation function is implemented in this mode.

(2) Top-up injection mode: When the beam current of storage ring is periodically injected to 300 mA, the controller is switched to the top-up injection mode for energy saving. The control principle is described below.

As mentioned above, the actual current injection duration is only two seconds in every one minute. The energy saving controller thus counts 55 seconds as the energy-saving period followed by 5 seconds as the injection period. During the 55-second energy-saving period, the klystron accelerator voltage and the RF gap voltage are both set to a level as low as required so that the LLRF tuner loop can lock cavity resonance frequency. The energy is thus saved. During the 5-second injection period of the top-up injection mode, the booster RF system is operated at the full-power condition, as identical to the continuous current injection mode. The klystron is “waked up” 3 seconds prior to the real injection so that it can achieve a stable condition. And the cavity accelerating voltage can be quickly ramped up to follow the 10-Hz waveform generator, thanks to the cavity resonance frequency lock by keeping a low accelerating voltage during the energy saving .

Figure 2 shows the function blocks of the energy saving controller. As the core of the control timing, the

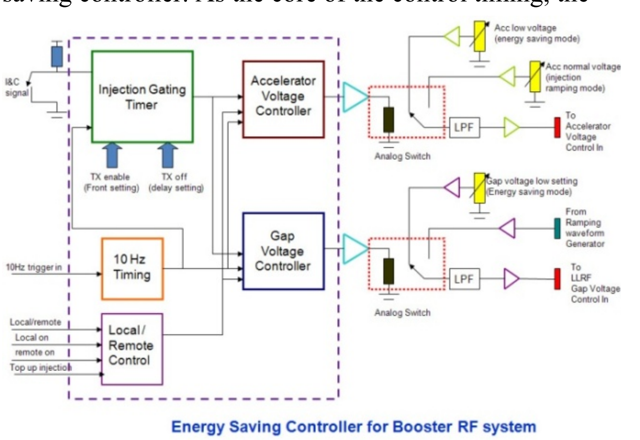

Figure 2: Function blocks of the energy saving controller.

injection gating timer block handles the injection timing of the energy saving controller. Its timing signal is synchronized with both the 10-Hz ramping signal of the booster injection timing system and the enable signal of the linac gun. Three potentiometers are used to adjust the operation setting levels, including the normal and low setting values of the klystron accelerator voltage and the low setting value of the cavity gap voltage. A complex programmable logic device (CPLD) provides the capability and flexibility to implement the timing control function of the energy saving controller. The CPLD device provides the capability and flexibility of in-system programmable. Instead of traditional relay, analog switching devices are employed in the circuit and thus reduce the signal surge from the signal switching as expected.

In addition, this controller also provides local and remote control function. In normal operation, the controller switches automatically between the continuous current injection mode and the top-up injection mode. If necessary, the remote control function works for manually switching the operation mode to the energy-saving controller for function test and so on. On the other hand, the local control mode is implemented for standalone test of the booster RF system. The controller generates all synchronous timing signals including 10Hz booster injection clock and linac gun enable signal.

Figure 3 shows a snapshot of the oscilloscope screen on the timing measurement of the controller under the top-up injection mode operation. As shown, the RF system switches the operation conditions with a period of one minute. The klystron accelerator voltage and RF gap voltage are held at the lowest values at the energy saving period. The linac gun enable signal rises up at the 40th second, i.e., 15 seconds prior to the beginning of the injection period. Thus it is adopted as the timing reference of switching the booster RF system from the energy saving mode to the injection mode. At the 55th second of every one minute, the klystron accelerator voltage raises up to provide 40 KW output and the RF cavity builds the ramping electric field. Consequently the booster finishes the processes of electrons ramping accelerating and injecting within the 5-second injection period. After the injection procedure, the RF system switches to the energy saving mode and waits for the next injection process.

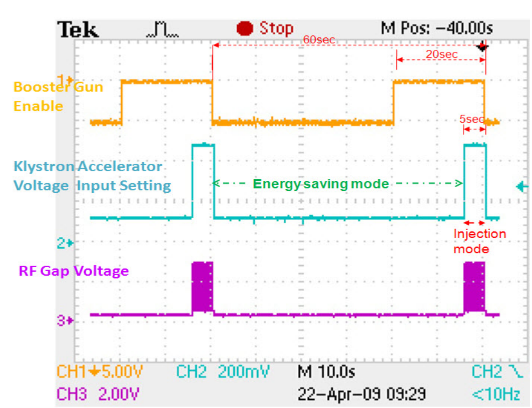

Figure 3: Timing measurement of the energy saving controller.

SYSTEM TESTING

The energy-saving controller was installed to the booster RF system at the end of 2008. The system integration tests followed right after the installation. Figure 4 shows the power consumption reduction effects of the energy saving controller. The slop of accumulated power consumption is obviously shown in this figure. In average, the required power of the booster RF system decreases from 70KW to 15KW, about 78% of the energy is thus saved.

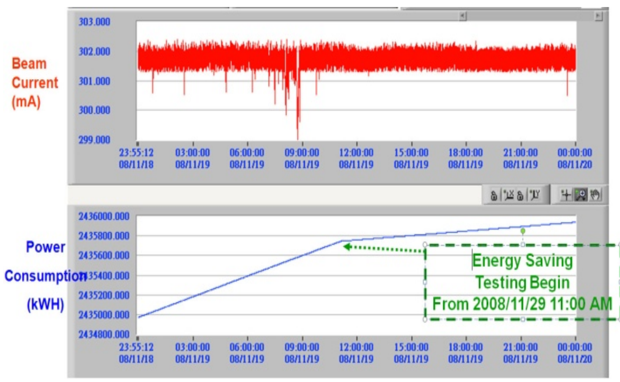

Figure 4: Power consumption reduction effects of the energy saving controller.

The energy and cost saving estimations are summarized in Table 1. The estimated annual energy saving are about 400 MWH, based on a 10-month operation per year.

Table 1: Energy and Cost Saving Summary

Booster RF Operation Condition	Total Power Consumption (kW)
Non-Energy Saving Mode	70
Energy Saving Mode	15

Energy and Cost Saving Summary	
Energy saving (%)	78%
Estimated annual energy saving (kWH) (based on 10 months/year)	400000 KWh
Estimated annual cost saving (US$ 0.07/kWH)	US$ 28000

When the energy-saving mode is on, the cathode current of klystron is periodically modulated. This differs from the fixed cathode current as operated in the past years. A concern on the life of the klystron raises. A periodical switching cathode voltage may age the klystron sooner than a constant high cathode voltage. Periodical checks on the cathode emission are thus performed to ensure the klystron performance. Figure 5 illustrates the testing results of the cathode current variation as functions of heater current. The results show that the energy saving operation does not harm the klystron so far.

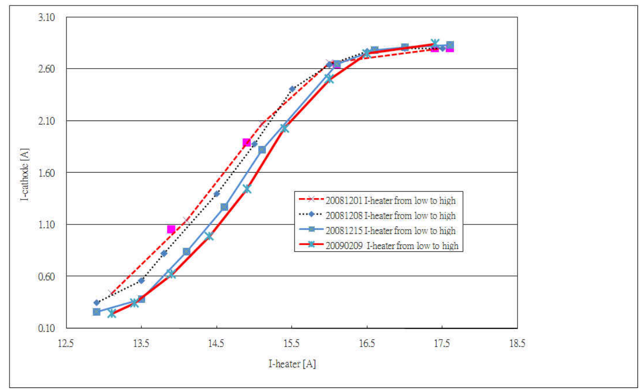

Figure 5: The testing results of the cathode current variation as functions of heater curren.t

CONCLUSIONS

The energy saving controller is successfully implemented onto the booster RF system in TLS. About 78 percents of the electrical power is thus saved and no aging effect on the klystron is observed. This great success is expected to be adopted in the booster RF system of the Taiwan Light Source in construction.

REFERENCES

[1] M. S. Yeh et al.,"Low-level RF System Development for the Superconducting RF cavity in NSRRC" in Proceedings of the 2006 European Particle Accelerator Conference, p. 1477

[2] G. H. Luo et al., "Top-up Injection Operation in NSRRC storage ring", OCPA'04/Accelerator Physics Satellite Meeting.