國家同步輻射研究中心
National Synchrotron Radiation Research Center

A Klystron Phase Lock Loop for RF System at TPS Booster Ring

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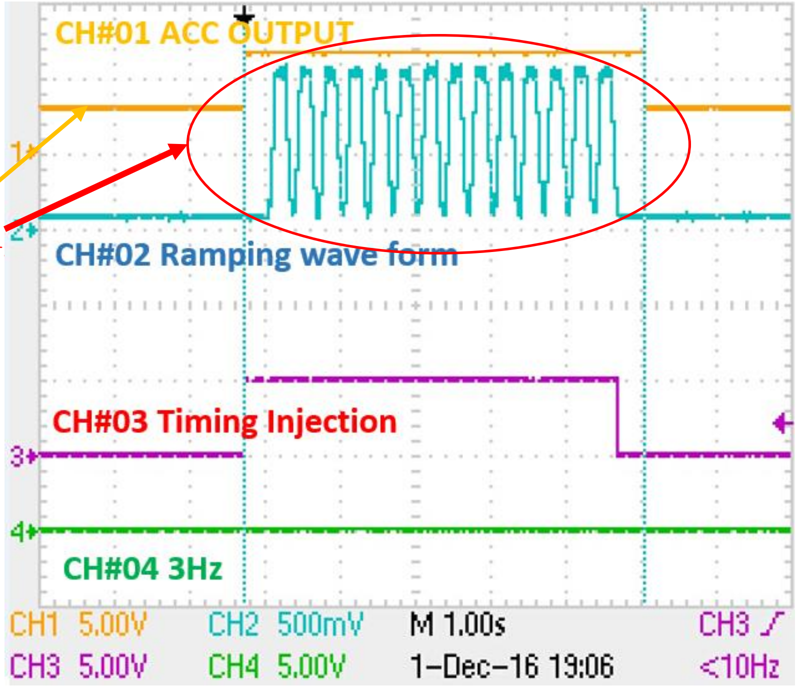
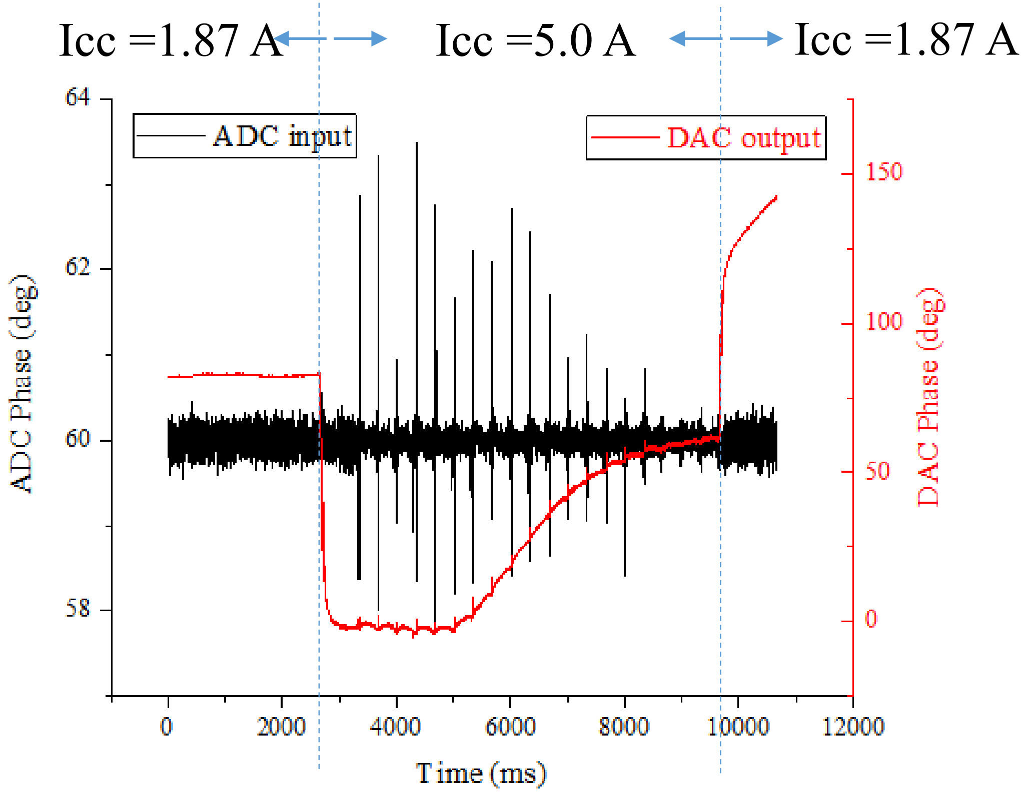
Introduction

- As the energy shortage in the whole world, the accelerator should work for decreasing power consumption.
- The time for injection is about 3~7 seconds while the booster ring is operated at 900 kV gap voltage with rampin mode.
- The transmitter gets into standby condition and decreases the cathode current when the time is not injecting.
- Energy saving module regulates the cathode current by changing the anode voltage setting.



Phase Change Due To Energy Saving Module @ TPS BR

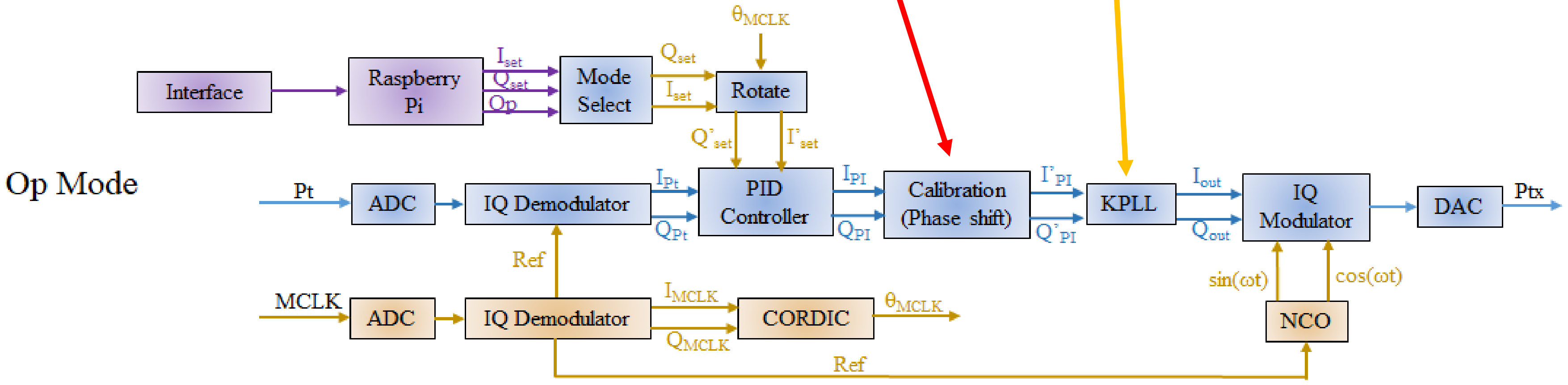
- Total time of this injection is 6 seconds from 3 to 9 sec.
- The cathode current of klystron increases from 1.87 A to 5.0 A at ~2.6 sec and comes back to 1.87 A at ~9.6 sec.
- As the changing of cathode current, the transmitter phase has a large jump from 82° to -2° at ~2.6 sec and the other jump from 61° to 142° at -9.6 sec.
- PI controller sometimes is easy to saturation or hang due to providing such large phase compensation.



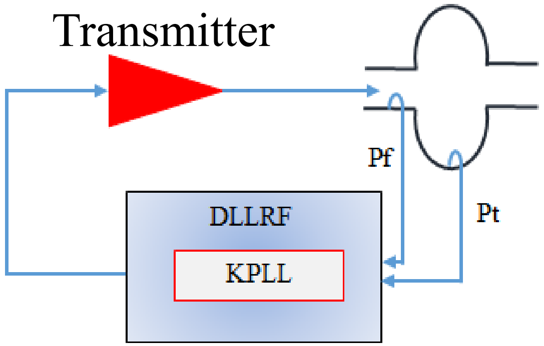
KPLL

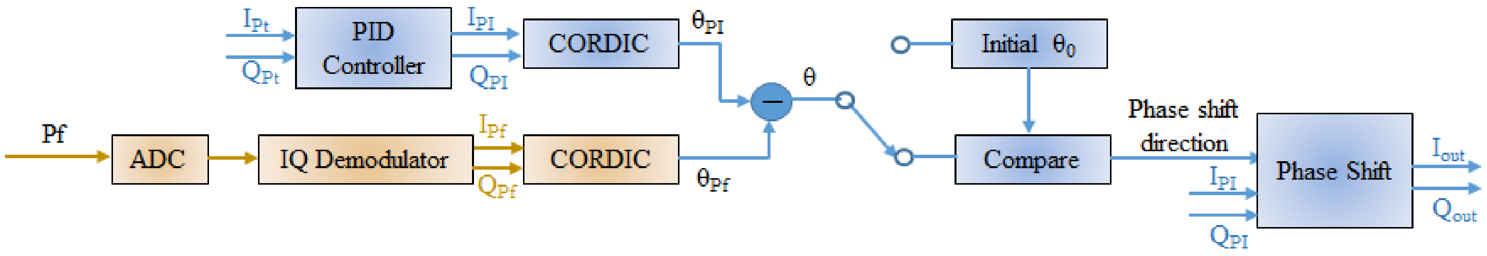
- KPLL is developed to compensate the klystron phase change and used to stabilize the PI controller.
- Calibration function is the compensation angle of the difference between θ_{Pt} and θ_{out} at non-feedback mode (PI controller output is constant).
- KPLL is put in front of IQ modulator and used to compensate the dynamic phase shift due to the klystron (or the transmitter) which works in different conditions, including low/high power and various cathode currents.

DLLRF architecture of the TPS



KPLL Logic





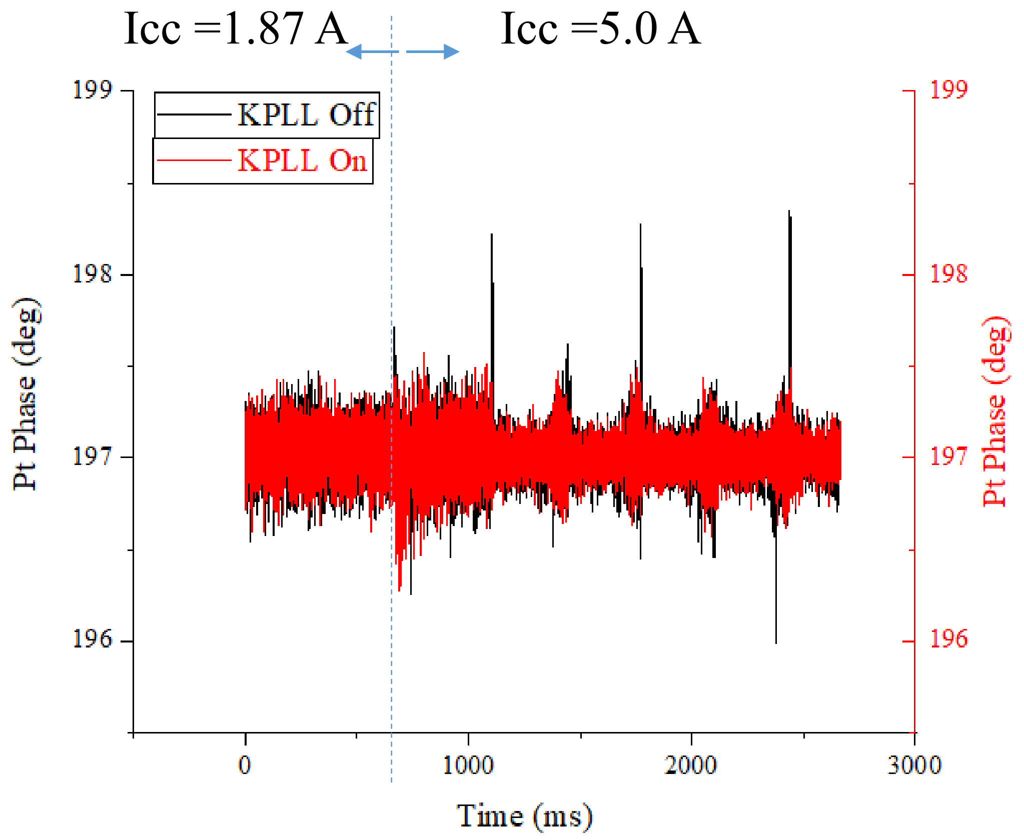
- If the difference θ between θ_{PI} and θ_{Pf} is different from the initial θ_0, it means that a phase shift occurs to RF system.

- According to the variation of θ, KPLL can provide the dynamic compensation angle for the transmitter under the different cathode currents while RF system is in feedback mode.

Effect of KPLL

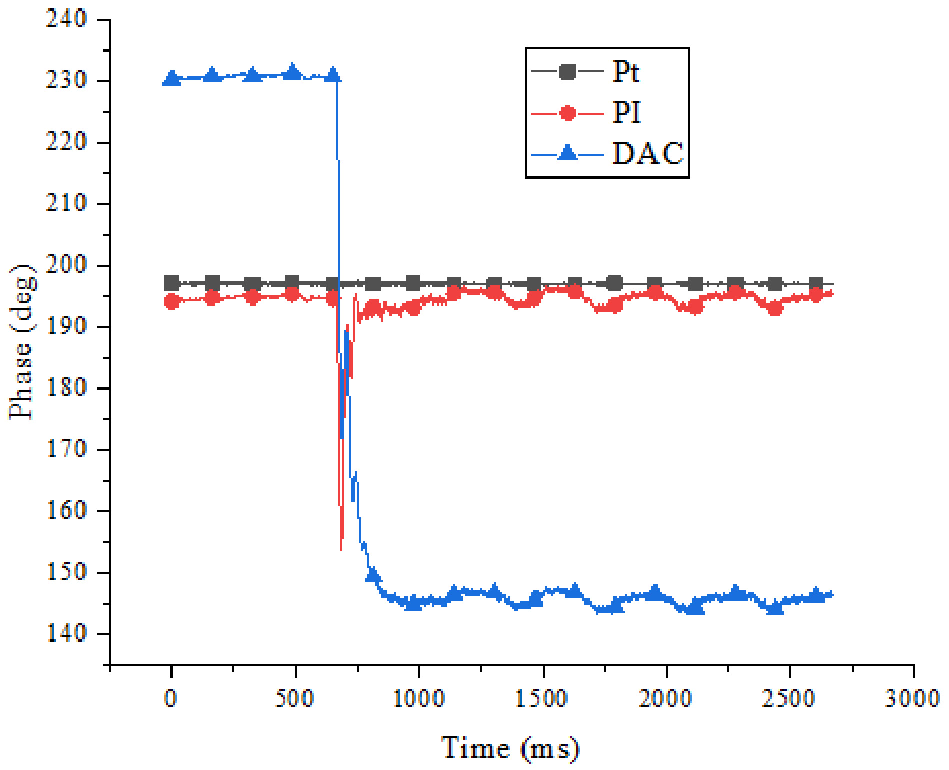
- The transmitter increases the cathode current at 700 ms, the gap voltage begins to ramp at 1100 ms, and also θ_{Pt} has spikes at every ramping cycles.

- The maximum phase spike is about 1.5° with KPLL off and it reduces to 0.35° with KPLL on.



Effect of KPLL

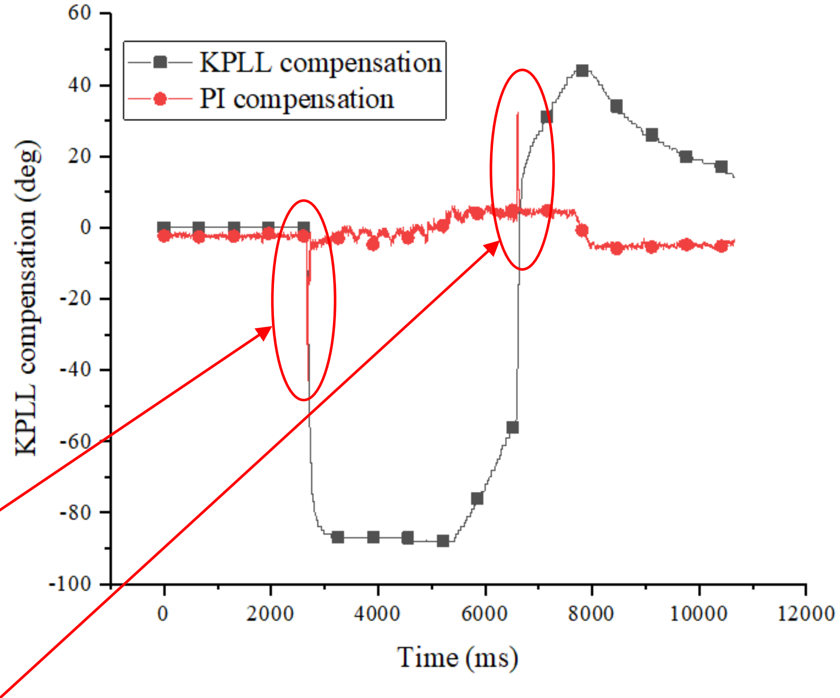
- θ_{Pt} represents the phase of cavity and it keeps stable at 198°.
- θ_{PI} is the output signal phase of PI controller and it has a large drop about 40° at 700 ms and comes back immediately.
- θ_{DAC} is the final output signal phase of DLLRF system and it has a large change from 230° to 145° at 700 ms.



Effect of KPLL

- The curve of KPLL phase compensation fits to the phase change of klystron.

- Because the speed of KPLL is 1˚/ms, the PI controller gives temporary compensation about -40˚ at the star of injection and about 30˚ at the end.

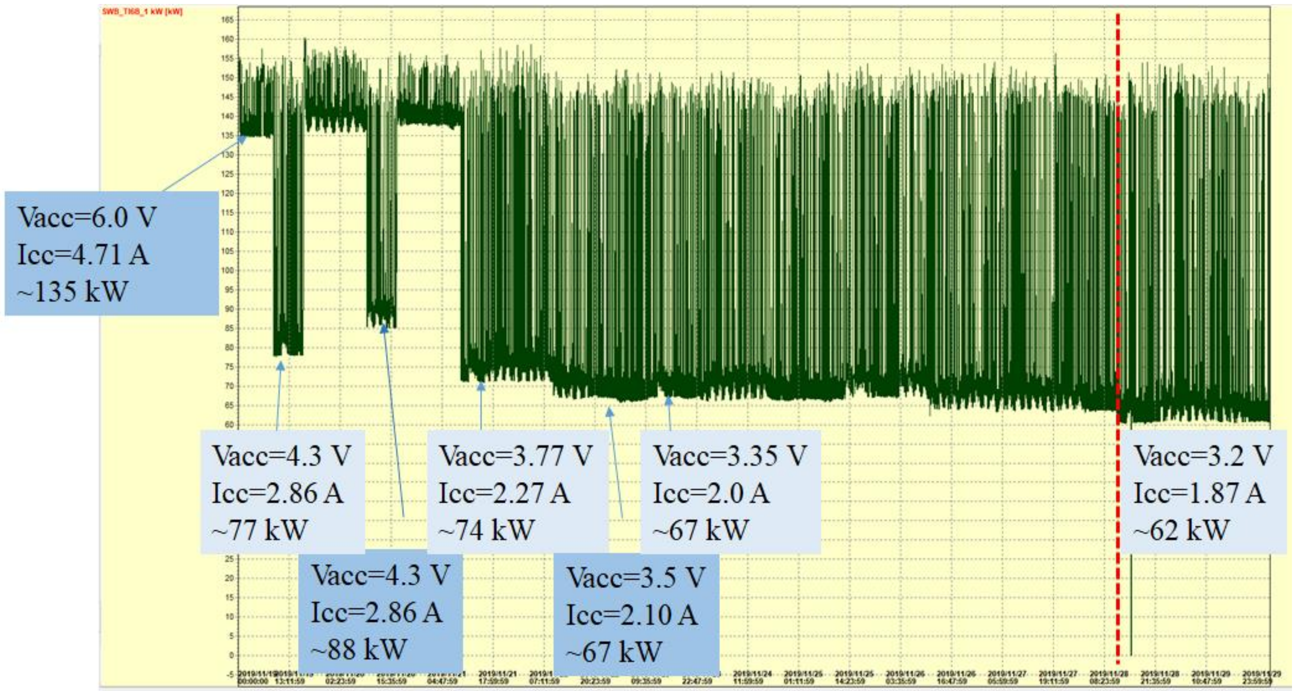


Power Consumption

- Before the KPLL function is applied, Icc is set as 2.86 A at standby period, the PI controller sometimes is easy to saturation or hang and affects the injection efficiency when Icc raises from 2.86 A to 5.0 A.

- After KPLL function is applied, the loading of phase compensation of PI controller decreases. PI controller can work smoothly while Icc raising and falling.

- We can set Icc as 1.87 A at standby and the power consumption is 62 kW.



Conclusions

- In this study, the KPLL is successful to stabilize the PI controller while regulating the cathode current of klystron.
- After applying KPLL, DLLRF system at TPS BR can suffer ~88° klystron phase change.
- Under this operating condition, the standby (not injecting) power consumption reduces from 135 kw to 62 kw. The maximum saving power is about 797 MWh a year.