SIMULATION THE ITERATIVE LEARING CONTROL APPLIED TO THE TPS BOOSTER RING QUADRUPLE MAGNET POWER SUPPLY

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Abstract

In the newly built TPS (Taiwan Photon Source), the AC power supplies of the Booster ring are required to operate in DC and AC mode with accuracy. Especially in AC mode, during the booster ramping process, the current ramping profiles of the Quadruple Magnets have to track that of the Dipole AC power supply with precise phase and amplitude to maximize the beam energy boost efficiency. At the present time, analog controllers are used for all the booster supplies and the tracking waveforms are generated externally in an EPICS control unit, converted to analog signals with precision Digital-to-Analog Converters (DACs) and then distributed to all the booster power supplies with differential signal pairs. In this paper, here we propose a hybrid iterative learning control algorithm combined with discrete PID feedback controller with the objective to eliminate the signal integrity problem inherent in analogue signals, so that boosting the beam energy might become more reliable. The proposed digital controller algorithm for the TPS booster ring magnet power supply and quadruple magnet load has been simulated with success.

INTRODUCTION

The booster ring had been successfully commissioned and the electron beam was accelerated efficiently from 150MeV to 3 GeV with 3Hz repetition rate on December 16 2014. At the end of 2015, the TPS stored beam current had been pushed to 521mA, which is beyond the designed 500mA goal.

The control infrastructure of the TPS booster ring power supplies is illustrated in Figure 1[1-3].

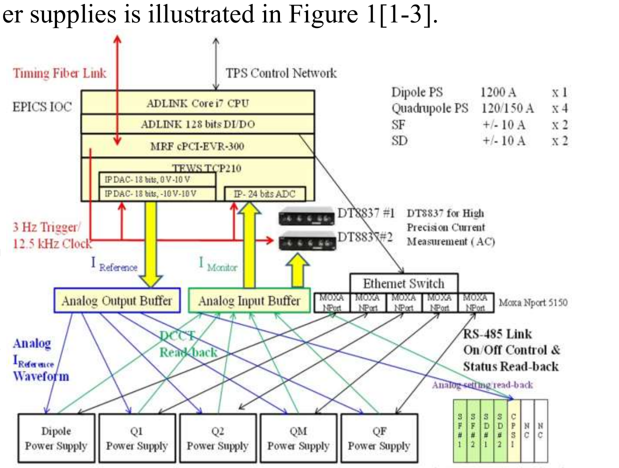

Figure 1: The control of TPS booster ring power supplies.

As shown in Figure 1, an EPICS control unit is responsible for controlling and monitoring the booster ramping power supplies in a synchronous manner. Digital ramping waveform data profile are preloaded to the unit through Ethernet, converted to analog differential signals by 20 bits DACs and then output to the entire booster ramping power supplies synchronously. High resolution 24 bits Analog-to-Digital Converter (ADCs) DT8837 are used to provide more high precision current monitoring.

To confirm the accuracy of iteration learning control(ILC) algorithm with PID compensator before implementation of the circuitry, this digital regulation quadruple magnet power converter is simulated with Matlab simulink, the behaviour of Quadruple magnet power converter structure, ILC algorithm and the P-I compensator are included. There are four main components are embedded in the compensation simulation of magnet power converter, discrete PID feedback controller, the iterative learning control algorithm, and the simulation performance is verified by using the parameter of TPS QF power supply as the according.

ITERATIVE LEARNING CONTROL

In this design stage, tracking error reduction method based on iterative learning control will be presented.

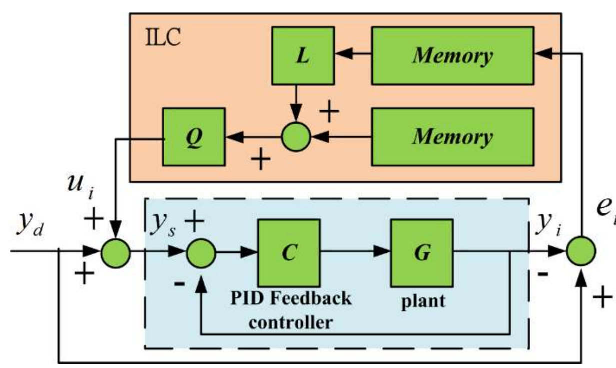

Figure 2: ILC feed forward with PID feedback control.

Figure 2 depicts the iterative learning method functional block diagram. This error reduction algorithm is called indirect iterative leaning control (ILC), which is commonly used to cooperate with existing feedback controller loop like PID to minimize tracking error in repeated processes. Since the 3Hz current ramping of the TPS booster ramping behaves like a repeated process, the ILC ideal can be applied to minimize the tracking error of the ramping current iteration by iteration. It can be seen as a feed forward control to update the current set-point to minimize the tracking error between the reference current command and the actual current output waveform. As shown in Figure 2, in the *i*th iteration, the updated set-point $y_s(i,k)$ is given by

$$y_s(i,k) = y_d(k) + u(i,k) \qquad (1)$$

Where y_d is the desired current profile, u is the set-point modification term from ILC and k is the time sample within iteration i. The ILC update law is expressed as

$$u(i+1,k) = Q(u(i,k) + L(e(i,k+1))) \quad (2)$$

Where Q and L are called the Q filter and learning gain respectively. In this paper, the cut-off frequency of the Q filter is set 3Hz that the compensation loop could be avoided of interference from the switching noise and L is set as a simple gain value to be changed for fast and stable convergence.

This type of ILC algorithm is called P-type ILC, which is the most commonly used method with solid robustness, if the gain L is properly chosen [4-6].

The proposed full digital regulation architecture has been verified and applied to control a TPS quadruple power supply and QF magnet load to test the simulated performance as requested.

TPS BOOSTER RING QUADRUPLE POWER SUPPLY

This uni-polar power supply is specially designed for TPS booster ring quadruple magnets. The converter can delivers 120 Amperes up to ±425 Voltage. Figure 3 shows the picture of the quadruple magnet power converters, which is buck converter employing full bridge IGBT as switches and a high precision DCCT as feedback element. The current output long term stability within 16 hours is well below 10ppm. The specification of the quadruple magnet power converter is listed in Table 1. [7]

Figure 3: TPS quadruple magnet power converters.

Table 1: Specification of Booster Ring Qquadruple Power Supply

Output(A/V)	120A/±425V
Short term stability	±5ppm /± 0.6mA
Long term stability	±10ppm /± 1.2mA
Resolution	18bits
Accuracy	±50ppm

MATLAB SIMULATION

To confirm the accuracy of the ILC and discrete PID controller policy that applied in the digital regulation control circuitry, the characteristic of circuitry, the ILC memory block, the P-I compensator and the PWM regulation algorism are simulated with MATLAB SUMILINK. Fig. 4 is the diagram of power converter circuit for simulation, this diagram includes the full bridge power stage、the output L-C filter、the P-I compensator and PWM regulation block. The design parameters of the quadruple magnet power converter are listed in the Table 2.

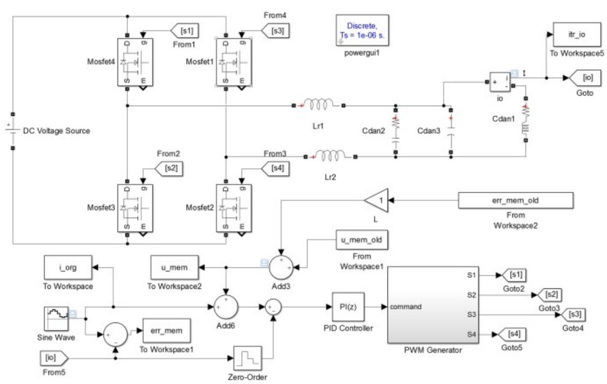

Figure 4: TPS quadruple magnet power model.

Table 2: The Design Parameters of Booster Ring Quadruple Magnet Power Supply

Main component's parameters TPS quadruple Magnet Converter	
Low-pass Filter Parameters	
L_f	600 μH
C_f	240 μF
C_d	120 μF
R_d	2.5 Ohm
QF Magnet Parameters	
L_m	224 mH
R_m	2419mOhm

SIMULATION RESULT

The circuit simulation model of the hybrid controller system is illustrated in Figure 5 and the tracking error current at the 13.7ms injection point with 20 iteration ramping cycles and the learning gain L is set as 0.1, 0.5 and 1 respectively are depicted in Figure 5. It is shown as L is set 1, it take only 3 iterations for the error current to converge to near zero.

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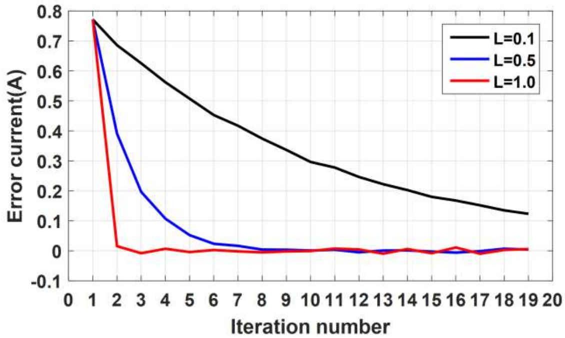

Figure 5: Tracking error current convergence curve with L set at 0.1, 0.5 and 1.

It is shown in Figure 6 the waveforms of the reference input and current feedback when the tracking error compensation function is disabled. It can be observed that there is a phase lag between these two waveforms due to the controller and the magnet loads.

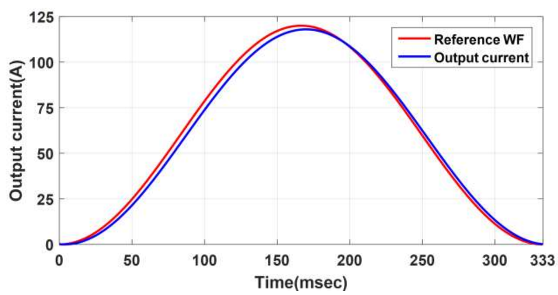

Figure 6: Reference and output waveform when waveform compensation is off.

In the Figure 7 illustrates the waveforms of the reference input and current feedback and the NRE error after three iterations when the compensation function is enabled. It is shown with compensation function enabled, the NRE is largely reduced and it takes only 2~3 iterations for the NRE to fall below 0.1% at the 13.5ms injection point during the 333ms time period of the 3 Hz ramping frequency for TPS booster ring ramping.

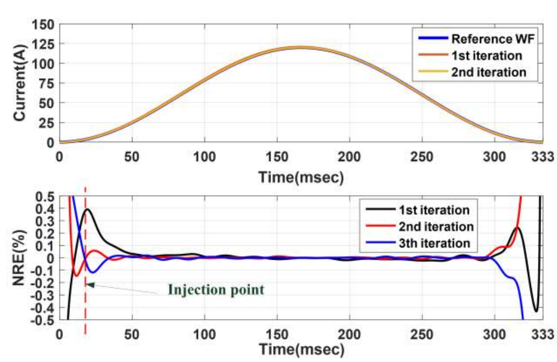

Figure 7: Reference and output waveform and NRE when waveform compensation is on.

CONCLUSION

The simulation of iterative learning control algorithm for TPS booster ring quadruple power supplies is presented to evaluate whether the specified requirements are met. It has been proved in the simulations that this ILC algorithm architecture is capable of auto calibrating the output magnet current so that the power converter's current output waveform will converge to that of the incoming 3 Hz reference with NRE error well below 0.2% during the 3 Hz ramping cycle. After the successful simulation, this proposed architecture will be applied to the booster ramping power supplies in the near future, hoping to eliminate the signal integrity problem inherent in analogy signals so that the beam energy boost up could be more reliable and efficient.

REFERENCES

[1] H. J. Tsai *et al.*, “Hardware Improvements and Beam Commissioning of the Booster Ring in Taiwan Photon Source”, IPAC’15, Richmond VA, USA (2015).

[2] Y. C. Chien *et al.*, “Status of AC Power Supplies for TPS Booster Ring”, IPAC2015, Richmond VA, USA.

[3] C. Y. Wu, *et al.* “Control interface and functionality of TPS booster power supply,” in *Proc.* IPAC’15, Richmond, VA, USA, pp. 1094–1096.

[4] D. A. Bristow, M. Tharayil, and A. G. Alleyne, “A survey of iterative learning control,” *IEEE Control Syst. Mag*., vol. 26, no. 3, pp. 96-114, 2006.

[5] Y. Wang, F. Gao, F. R. Doyle III, “Survey on iterative learning control, repetitive control, and run-to-run control”, *J. Process, Control,* vol. 19 no. 10, pp. 1589–1600, 2009.

[6] Y. Q. Wang and F. J. Doyle III, “Stability analysis for set-pointrelated indirect iterative learning control, in *Proc.* 48th IEEE Conference on Decision and Control, 2009, pp 5702_5707.

[7] Eaton, *TPS Booster Quadrupole Power Supply Installation, Operation and Maintenance Manual*, Eaton, Canada, 2013.

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