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STUDY ON THE CONTROL TECHNOLOGY OF LARGE–LOAD TIME CONSTANT ACCELERATOR MAGNET POWER SUPPLY*

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Abstract

With the increasing application of power supply to industrial system, digital control system has become the mainstream of modern industrial control system. The wide application of digital control system has also led to the rapid development of digital controller. In the field of accelerator magnet power supply, the adoption of digital closed-loop control has become a trend in recent years. Due to the system's tracking and regulation characteristics, the output current will slowly track the change of the given value in the course of the given current gradually rising. When the system reaches steady state, the disturbance of the system requires the regulator to adjust at a faster rate to correct the impact of the disturbance on the system. Today's digital power supply control method mainly reflected in when load time constant is large, interference or load change, the power output is prone to overshoot or adjust the time is long, so the tracking and adjustment features cannot be met simultaneously. Therefore, this paper will study the power supply digital control technology for large - load time constant and the independent control method of tracking and regulating.

INTRODUCTION

The control algorithm of digital controller is one of the key factors that affect the performance of digital power supply. Compared to the traditional analogy power and digital power supply has the short design cycle, flexible control method, is easy to realize the modular management, to eliminate instability caused by discrete components and the characteristics of electronic jamming, so digital power source is a development trend of accelerator magnet power supply. Digital power supply control module has a great influence on the performance of the digital power supply, if digital control technology want to get further development in the digital power supply, depends on whether can achieve what we need in accelerator magnet power supply control algorithm.

Due to the tracking and regulation characteristics of the system, the output current will slowly track the change of a given value in the course of a given current. When the system reaches steady state, the disturbance of the system requires the regulator to be adjusted at a faster rate to correct the influence of the disturbance on the system. Today's digital power supply control method generally uses the traditional digital PID control algorithm [1], but poor dynamic performance of traditional PID algorithm, mainly reflected in when load time constant is large, there is interference or load change, the power output is prone to overshoot, or adjust the time is long, the tracking and adjusting performance cannot be consideration. This topic makes it possible to obtain the desired tracking behaviour (following the reference) independent of the desired regulation behaviour (rejection of a disturbance).

LOAD TIME CONSTANT

For any accelerator magnet power supply, its load characteristics are the basis of power closed-loop control. For the normal temperature magnetic we generally adopt, for example, digital proportional integral differential (PID) control as a closed loop control algorithm, and the design of the core of current loop integral time constant will be set mainly depends on the load time constant. This research institute is aimed at the load of a special kind of accelerator magnet power supply, namely the superconducting magnet load with very large time constant.

High energy particle accelerator technology has led the rapid development of superconducting technology in the past 30 years. The Fermi national accelerator laboratory (Fermi lab) in the 1980s of the construction of the TEVATRON collider particles, using the 774 for the first time in the world based on the technology of titanium niobium NbTi superconducting accelerator dipole magnets, applying NbTi superconducting technology from the laboratory into the industrialization level, to promote this technology in the civilian fields such as medical nuclear magnetic spectrometer (MRI) and so on a wide range of applications. Compared with the normal temperature magnet, the superconducting magnet can achieve the super high field strength that ordinary magnet cannot reach with a smaller volume. At the same time, due to the superconductivity of the load, its resistance is almost zero, which can greatly reduce the output voltage demand of the excitation power supply and reduce the operating cost of the accelerator excitation power system.

For example, BEPCII quadrupole magnet power supply (normal temperature magnet) and the LHC's diode of superconducting magnet power supply load [2], the time constant of the different types of load ratio on the following: time constant has the difference of several orders of magnitude. For different loads, the bandwidth and algorithm of the current closed-loop of digital controller will be different.

BEPCII quadrupole power supply load: Resistance $=0.266\Omega$, Inductance=0.14H and Time constant $\tau=L/R=0.14/0.266 = 525$ms.

LHC diode load: Resistance=0.8mΩ, Inductance=18H and Time constant $\tau=L/R=18/0.0008=22500=6.25$ h.

Taking the future circular collider CEPC-SPPC project as an example, In order to deflect and focus on high-energy proton beams, the SPPC needs to install thousands of high field strong diodes and quadrupole magnets in a 100-kilometer circular tunnel in order to deflect and focus

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on high-energy proton beams. The effective aperture of these magnets is 40~50mm, the field intensity of the dipole magnet is as high as 12~24 T, and the field uniformity needs to be 10 to the minus fourth magnitude within 2/3 of the aperture. Such high field strength and performance demand make high field accelerator magnet technology one of the most challenging technical requirements in SPPC design. Therefore, the research on the power digital control technology of this type of load is one of the key technologies in the future research of accelerator power system based on superconducting magnet load.

THE CLOSED LOOP ALGORITHM

Authors are requested to go over the following checklist for electronic publication: At present, the accelerator of using digital control power source such as Swiss light source (SLS) adopts PID control scheme (see Fig. 1). In recent years, the newly built accelerator in China, its magnet power supply basically adopts the digital PID method to complete the closed-loop control [3], as shown in Eq. (1).

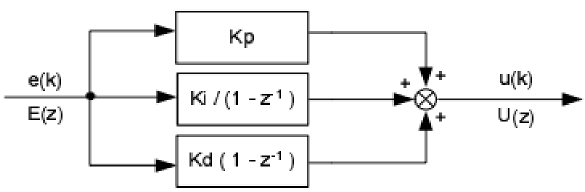

Figure 1: PID algorithm block diagram.

$$\begin{aligned} u_p(k) &= K_p e(k) \\ u_i(k) &= K_i \textstyle\sum_{j=0}^{k} e(j) \\ u_i(k) &= K_d\left[e(k)-e(k-1)\right] \end{aligned} \qquad (1)$$

PID control has been widely applied because of its simple structure, parameters, easy setting, characteristics such as good robustness as well as the development of mature, the right to adjust the three parameters of PID control can obtain good control effect. Because of when no-load model of the power supply similar to a second order critical link of oscillation, the existence of the integral term makes the phase lag. On the premise of guarantee the system stability, must limit proportion coefficient, namely reduces the dynamic performance of the control system. The disadvantage of PID control technology is that it can't effectively suppress the disturbance caused by nonlinear load, and the system's stability is limited, so it can't be tracked without directional tracking. In accelerator magnet power supply closed loop control, because the PID parameters is easy to adjust and mainly static power, and the dynamic response of the power supply without strict requirements, so for ordinary magnet load digital power supply usually use PID control algorithm.

In the large hadron collider (LHC) high-power superconducting magnet power supply [4], due to the strict requirements for beam damage, the current of each power supply in the process of rising can accurate control, and can quickly response to the disturbance. An independent control algorithm with closed-loop tracking and adjusting characteristics is adopted to overcome the shortcomings of PID controller which cannot be tracked and adjusted simultaneously (see Fig. 2 and Fig. 3).

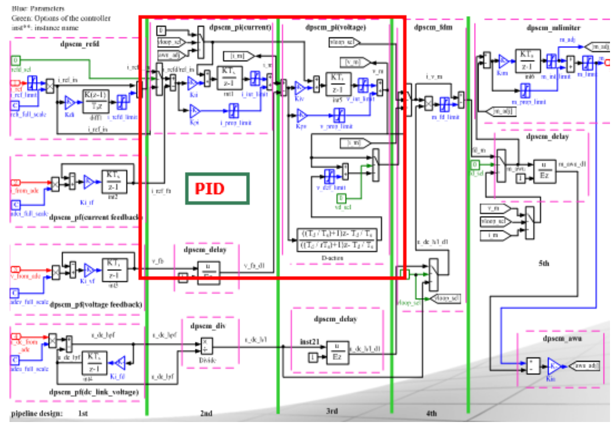

Figure 2: Flow chart of DPSCM closed-loop algorithm.

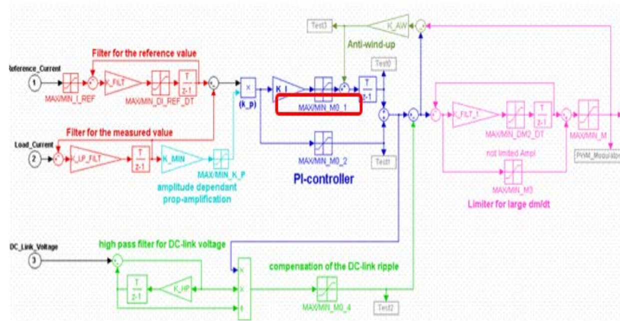

Figure 3: The closed-loop control block diagram of digital controller DPC of Swiss light source.

RST CONTROLLER DESIGN

The general structure of RST regulation is divided into three parts: forward control polynomial module S(z-1), feedback polynomial module R(z-1) and precompensation polynomial module T(z-1) (see Fig. 4).

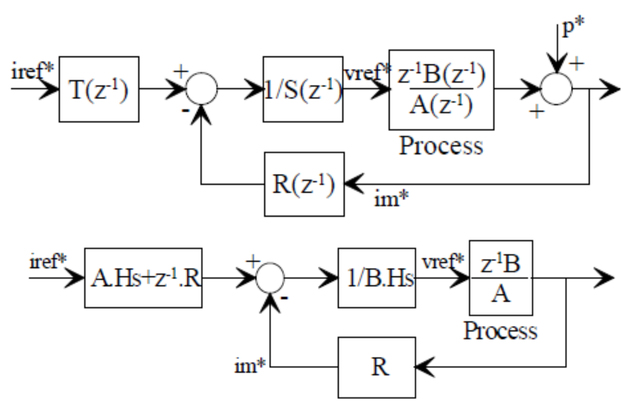

Figure 4: RST controller block diagram.

The tracking transfer function is shown in Eq. (2):

$$\frac{r(k)}{y(k)} = \frac{z^{-d} \cdot B \cdot T}{A \cdot S + R \cdot B \cdot z^{-d}} \qquad (2)$$

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And the regulation transfer function is shown in Eq. (3):

$$\frac{y(k)}{P}=\frac{A\cdot S}{A\cdot S+R\cdot B\cdot z^{-d}} \tag{3}$$

The RST controller makes it possible to obtain the desired tracking behaviour (following the reference) independent of the desired regulation behaviour (rejection of a disturbance) [5]. The RST control can be evaluated by the "Tracking and Regulation with Independent Objectives" method (R and S give the regulation behaviour and T gives the tracking behaviour) (see Fig. 5).

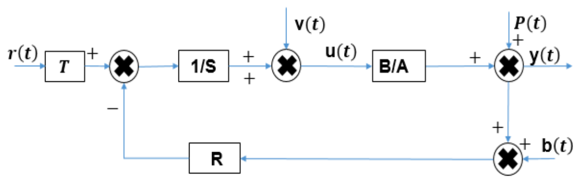

Figure 5: Tracking and regulation with independent objec-tives.

Interference and output ($\mathbf{p}\to \boldsymbol{y}$) transfer function is shown in Eq. (4):

$$S_{yp}(z^{-1})=\frac{A(z^{-1})S(z^{-1})}{A(z^{-1})S(z^{-1})+B(z^{-1})R(z^{-1})} \tag{4}$$

Interference and input ($\mathbf{p}\to \boldsymbol{u}$) transfer function is shown in Eq. (5):

$$S_{up}(z^{-1})=\frac{-A(z^{-1})R(z^{-1})}{A(z^{-1})S(z^{-1})+B(z^{-1})R(z^{-1})} \tag{5}$$

Noise and output ($\boldsymbol{b}\to \boldsymbol{y}$) transfer function is shown in Eq. (6):

$$S_{yb}(z^{-1})=\frac{-B(z^{-1})R(z^{-1})}{A(z^{-1})S(z^{-1})+B(z^{-1})R(z^{-1})} \tag{6}$$

Input interference and output ($\mathbf{v}\to \boldsymbol{y}$) transfer function is shown in Eq. (7):

$$S_{yv}(z^{-1})=\frac{B(z^{-1})S(z^{-1})}{A(z^{-1})S(z^{-1})+B(z^{-1})R(z^{-1})} \tag{7}$$

SIMULATION

The accelerator, which requires very strict beam damage, is also more stringent for accurate current control. Taking the large hadron collider as an example, the superconducting diode magnet is 27 km, working at a low temperature environment of 1.9 K, and the excitation current is strong to 13 kA, resulting in a curved magnetic field of 8.4 T. These thousands of magnet currents must be precisely controlled to reduce the beam loss. Because even a very small beam loss can generate enough energy to cause a superconducting coil to lose its superposition. Therefore, the precise control of the dynamic process is the basic requirement of the LHC superconducting magnet power supply [6]. To evaluate the synthesis and the performance of the RST controller, a digital simulation has been performed using MATLAB software (see Fig. 6 and Fig. 7).

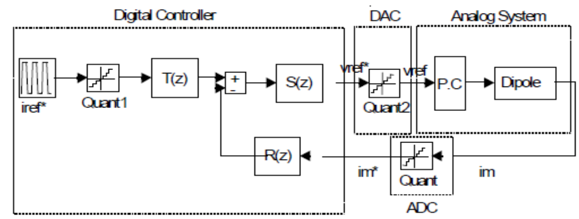

Figure 6: The MATLAB simulation diagram.

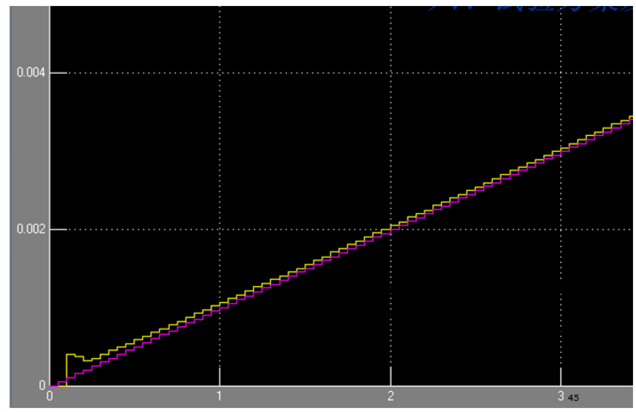

Figure 7: The simulation results.

CONCLUSION

As a result of the tests completed to date, the digital loop using RST controller seems to fulfil all the performance requirements of the LHC (no overshoot, static or lagging error below 1ppm). The robustness of the algorithm avoids the use of more complex adaptive control. The following research mainly focuses on the parameter calculation of RST algorithm.

ACKNOWLEDGEMENT

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