POWER SUPPLY DECOUPLING DESIGN

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Abstract

In this study, a decoupling controller of the phase-shifted magnet power supply was designed to reduce the mutual coupling current generated by coupled magnet modules. The experiment results show that the design does not only successfully reduce the coupling current, but also shortens the rising time of the power supply current and increases the power supply bandwidth.

INTRODUCTION

Since the structure of phase-shift magnet is more complicated than the single coil structure, there are many factors need to be considered when designing the phase-shift magnet power supply. It was known that the power module would generate the pulse current due to the influence from the electric field of another power module. Therefore, this study conducted the decoupling controller to effectively improve the magnetic field output characteristics of phase-shifted magnets and avoid the power supply damage.

POWER ARCHITECTURE

The phase-shift magnet architecture was shown in Figure 1, and the ratio of the magnetic field was set to 1:2:1. As the electron beam go through the phase-shift magnet, the bend path changes, and thus the wavelength of the photon were changed [1].

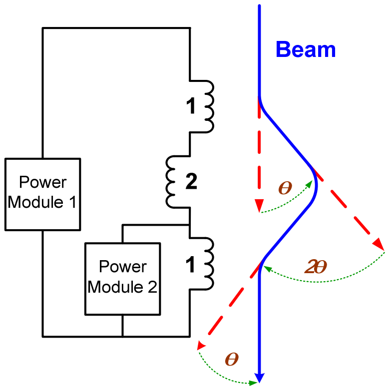

Figure 1: The electrons moved schematic.

If the phase-shift magnet is ideal, only one set of current source modules can be manufactured a theoretically perfect ratio of magnetic field and thus obtain the predicted electron beam path. The phase shift magnets actually are not at ideal conditions. Therefore, two sets of current source power supply modules are required. The predetermined magnetic field current is an output by the module 1, and then the output magnetic field current is finely adjusted by the module 2 to correct the magnetic field strength and the electron beam emitting angle. So it can avoid the electron beam touching the vacuum chamber.

Power System Architecture

The power supply system architecture is shown in Figure 2. The phase shift magnet is divided into two groups of magnet: the magnet 1 and the magnet 2. It's in order to fa-cilitate the design and to simplify the complicated mathe-matical calculations [2].

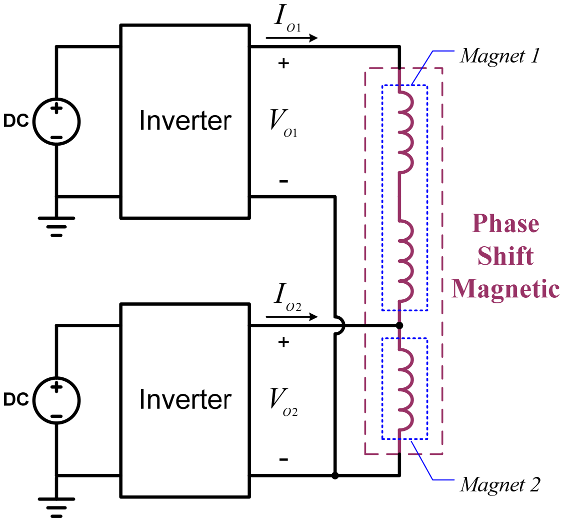

Figure 2: Power system architecture.

The inductance and resistance values of each coil are measured by a LCR meter as shown in Table 1. From the inductance values in Table 1, they can verify the phase-shift magnet has inevitably errors.

Table 1: Inductance and Resistance Values

	Inductor	Resistor	
Coil 1	68.2 mH	220 mΩ	Magnet1
Coil 2	78.7 mH	440 mΩ	
Coil 3	80 mH	220 mΩ	Magnet2

The power supply output equations are calculated as shown in equation 1 and 2.

$$I_{O1} = \left(V_{O1} - V_{O2}\right) \Big/ R1 + j\omega L1 \tag{1}$$

$$I_{O1} + I_{O2} = \left(V_{O2}\right) \Big/ R2 + j\omega L2 \tag{2}$$

Two modules of magnets are controlled by two current source power supply modules. The power system architecture diagram is shown in Fig. 2. That was transformed into the load system control block diagram in Fig. 3. By calculation, the control system can be conveniently designed and planned [3].

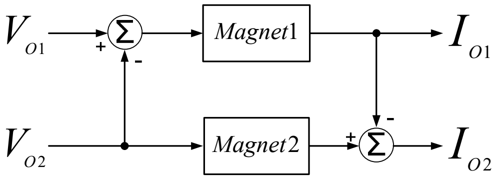

Figure 3: Load control block diagram.

PHENOMENON ANALYSIS AND COUNTERMEASURES

The setting value and real output value of output current of module 1 were shown in Fig. 4. The real output currents were ±10 A when operating with 1.73 Hz and 3.3 Hz. But the output current was almost unable to reach ±10 A while operating with 5 Hz. Thus, the critical operating frequency of the magnet was 5 Hz. The same situation also occurred in model 2 as shown in Fig. 5.

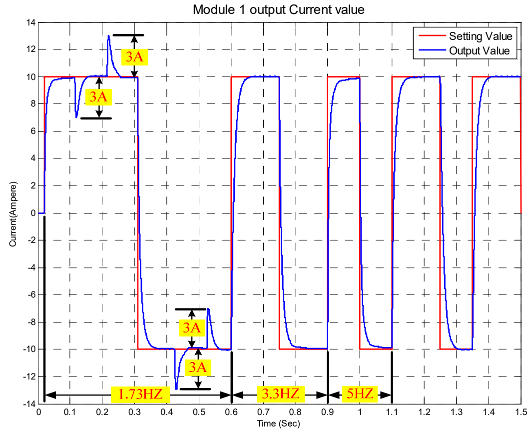

Figure 4: Module 1 settings and output waveforms.

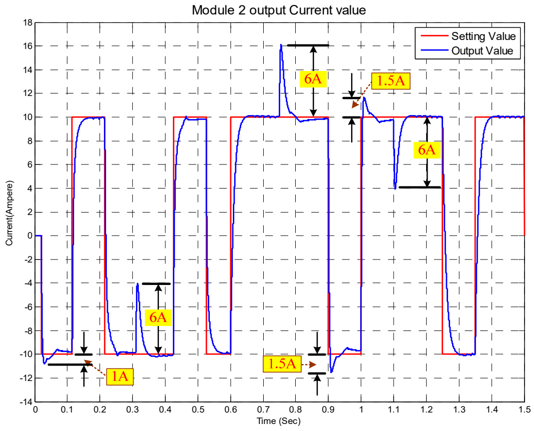

Figure 5: Module 2 settings and output waveforms.

The module 1 and module 2 output current waveforms were plotted together, as shown in Fig. 6. At 0.12 sec, the output current of the module 2 was changing from -10 A to +10 A while the module 1 output current waveform occurred a 3 A pulse. The module 1 output current was changing from 10A to -10A at 0.32 sec, while the module 2 had a 6A pulse. Thus model 1 and model 2 affected each other by the coupling effect when their current were changing. The same pulse phenomenon occurred at 0.9 sec. However, there was no pulse at 1.25 sec because the output currents of the module 1 and the module 2 were simultaneously changed from +10A to -10A. After 1.25 sec, the model 1 and model 2 were operating under the same condition, their output current waveforms were similar, and no coupling pulse occurred.

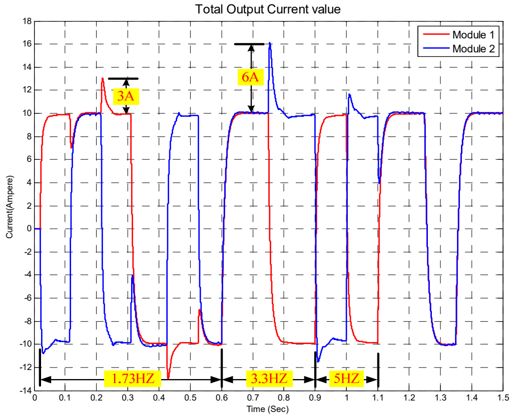

Figure 6: Total modules settings and output waveforms.

Improvement Strategy

According to Eq. 1 and Eq. 2, all the relevant signals during operation can be retrieved. The design of the controller is shown in Fig. 7. The overall control block diagram is shown in Fig. 8. When one set of the power modules was about to change the current, the other set of power modules was produced a restraining signal to suppress the generation of pulse current.

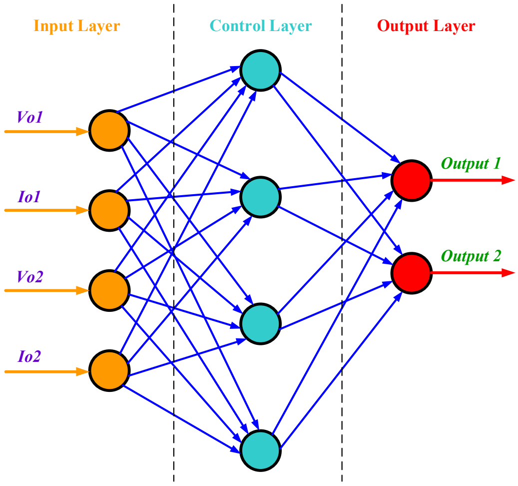

Figure 7: Controller design architecture.

From the Eq. (1) and (2), they indicate that the output current I_{o1} was affected by the output voltage V_{o2}, and the output current I_o2 was affected by the I_{o1}. The effect of the signal V_{o2} must be subtracted as controlling the output current I_o1, as shown in Fig. 8. In addition to compensate the error value between the set value I_{set1} and the output current feedback value I_{o1}, the controller eliminates the effected of V_{o2} on I_{o1}. The effect of the signal I_{o1} must be subtracted as controlling the output current I_o2, and the I_{o1} was controlled by the output voltage V_{o1}, as shown in

Figure 8. In addition to compensating the error value between the set value I_{set2} and the output current feedback value I_{o2}, the controller eliminates the effected of V_{o1} on I_{o2}.

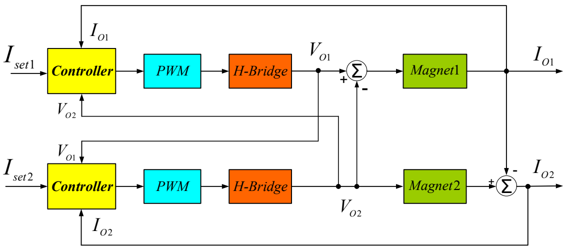

Figure 8: Control block diagram.

SIMULATION AND RESULTS

In the previous sections of the theoretical derivation and design plan, simulation will be discussed in this section. As shown in Fig. 9, when the output current of the module 2 was stabilized to 0A, the output current of the module 1 was changed from 0 to 10A. It can be seen in Fig. 9 that the current pulse wave of the unmodified front module 2 is about 3A. After decoupling control was applied, it can be improved to 0.1A and 96.67% of the pulse current was suppressed. The current climb speed was increased, shortened from 40ms to 6.5ms time reduced by 83.75%.

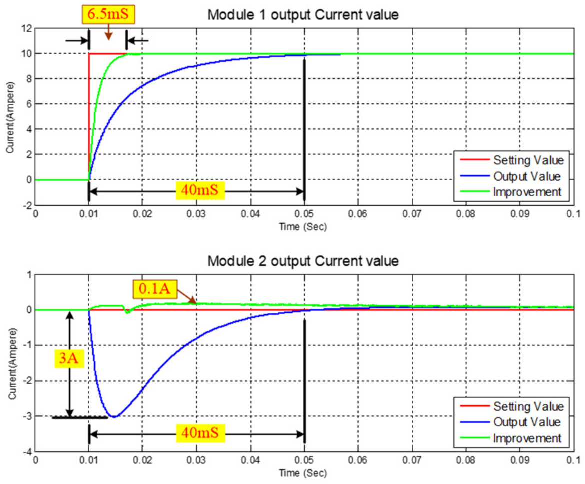

Figure 9: Simulation the module 2 output current maintained at 0(A) and changed the module 1 output.

As shown in Fig. 10, when the output current of the module 1 was stabilized to 0A, the output current of the module 2 was changed from 0 to 10A. It can be clearly seen in Fig. 10 that the current pulse wave of the unmodified front module 1 was about 1.5A. After decoupling control was applied, it can be improved to 0.15A and 90% of the pulse current was suppressed. And the current climb speed was increased, shortened from 20ms to 6.5ms time, which is reduced by 67.5%. In the output current of module 1 of Fig. 10, although most of the pulse current was suppressed, the time was doubled when the output current recovers to 0A.

However, it was found in Fig. 10 that the steady-state time was elongated due to the approximate solution was used in the design of the control parameters, this causes an internal control error in the controller. Therefore, the exact solution was suggested to solve this problem.

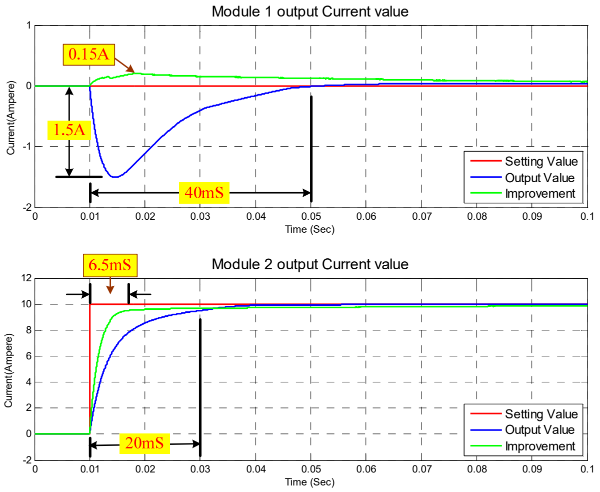

Figure 10: Simulation the module 1 output current maintained at 0(A) and changed the module 2 output.

CONCLUSION

This study suggests a new design of the phase-shifted magnet power supply with decoupling supply to decrease the coupling current and improve the electric characteristic. The feasibility of this control method was proved by the actual simulation test. The waveform of the simulation test proved the feasibility of the new design, and indicated that the design does not only decrease most of the pulse current, but also accelerate the rising speed of the current.

REFERENCES

[1] M.S. Chiu *et al.*, "Double mini-betay lattice of TPS storage ring", in *Proc. IPAC'11*, pp. 2082-2084, WEPC035.

[2] Y.T Li*, B.S Wang, K.B Liu, Y.S Wong , "Phase Shifter Power Supply Design" in *Proc. International Particle Accelerator Conference (IPAC)*, 2016.

[3] B. C. Kuo, "Automatic Control System", Prentice Hall PTR Upper Saddle River, NJ, USA ,1987.