High precision current control with parameter estimation in the gradient amplifier for MRI

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Abstract

A digital feed forward control scheme developed for the switch-mode gradient amplifier with an H-bridge configuration is proposed in this paper to obtain gradient coil currents with fast ramp speed and low ripple level. A simplified load model based on the state vector equations is used in the feed forward controller design and a final current correction is obtained by a conventional feedback loop employing a PI regulator. Parameter estimation of the plant provides a type of self-tuning of the proposed controller. Computer-aided simulations are presented and the results indicate that the digital scheme is effective.

Introduction

MRI systems are improving very quickly for fast imaging and high quality images. Diagnosis of the moving parts has been realized in MRI where images should be taken in several dozens of milliseconds. For the purpose of high speed imaging, the gradient amplifiers are required to provide fast response currents as well as high precision control. Some multiple-bridge type gradient amplifiers using IGBTs and digital optimum control scheme were presented in recent years [1] [2]. A digital feed forward control strategy with parameter estimation for the H-bridge MOSFET gradient amplifiers is developed. The simplified load model in addition to a conventional PI regulator used in the controller results in fast and robust response performances as well as simple digital processing calculations while the parameter estimation makes the proposed algorithm have a self-tuning ability for circuit parameter deviations. Simulations by computer are presented and the results indicate that the proposed scheme is effective.

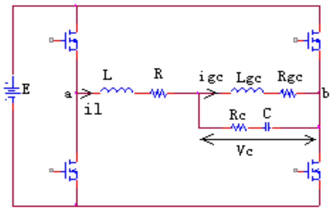

Fig. 1 Configuration of the H-bridge gradient amplifier

System description and the control algorithm

Fig.1 shows the configuration of the H-bridge gradient amplifier with one-stage low pass filter. Ignoring the voltage on Rc the state vector equations of the output system can be obtained as (1). After some substitutions of (1) the output voltage of the H-bridge converter is given by (2). In general the LC parameters of the low pass filter are quite small in comparison with the load. So equation (2) can be simplified as (3). Using the sampling interval T and replacing i_{gc} with the reference signal i_{ref} we can obtain the discrete feed forward control law as (4). Then parameter estimation technique is used to determine the coefficients. By the least square error (LSE) method the estimated parameters can be obtained as (5). The whole control diagram is shown in Fig.2.

$$\begin{cases} Vc = L_{gc}\dfrac{di_{gc}}{dt} + i_{gc}\cdot R_{gc} \\ i_l = i_{gc} + C\dfrac{dV_c}{dt} \\ u_{ab} = L\dfrac{di_l}{dt} + i_l\cdot R + V_c \end{cases} \qquad (1)$$

$$u_{ab} = C\cdot L\cdot L_{gc}\cdot\frac{d^3 i_{gc}}{dt^3} + (L\cdot C\cdot R_{gc} + C\cdot L_{gc}\cdot R)\frac{d^2 i_{gc}}{dt^2} + (L + C\cdot R_{gc}\cdot R + L_{gc})\frac{di_{gc}}{dt} + (R + Rgc)i_{gc} \qquad (2)$$

$$u_{ab} \approx (L + C\cdot R_{gc}\cdot R + L_{gc})\frac{di_{gc}}{dt} + (R + Rgc)i_{gc} \qquad (3)$$

$$\begin{cases} u_{ab}(k) = a * iref\ (k+1) + b * iref\ (k) \\ a = (R + R_{gc})/(1 - e^{qT}) \\ b = (R + R_{gc})/(1 - e^{-qT}) \\ q = -(R + R_{gc})/(L + CR_{gc}R + L_{gc}) \end{cases} \qquad (4)$$

$$\begin{bmatrix} \frac{1}{a} \\ \frac{-b}{a} \end{bmatrix} = (M^T M)^{-1} M^T X\text{, where } M = \begin{bmatrix} u_{ab}(0) & i_{gc}(0) \\ \vdots & \vdots \\ u_{ab}(n) & i_{gc}(n) \end{bmatrix},\ X = \left[i_{gc}(1), \ldots, i_{gc}(n+1)\right]^T \qquad (5)$$

$$\begin{cases} a = 14.9552 \\ b = -14.8052 \end{cases} \quad (6) \qquad \begin{cases} a = 14.9514 \\ b = -14.8008 \end{cases} \quad (7)$$

Simulation results

Computer simulations were carried out with the circuit parameters shown in Table □. The coefficients of the feed forward controller calculated by theoretical formulations are given by (6) and the estimated results by LSE are given by (7). It can be seen that the estimated results agree with those of theoretical analysis quite well.

Table□ Circuit Parameters

E: 200 V	L: 72 μH	C: 0.5 μF	L_{gc}: 0.3mH
f: 40 kHz	R: 50 $m\Omega$	Rc: 7 Ω	R_{gc}: 0.1 Ω

Using the estimated parameters and the proposed control method, the computer-aided analysis is performed with different input reference current signals. Fig.3 shows the load current waveform i_{gc} with a ramped-square reference signal i_{ref}. The load current ripple is less than 80mA on the 100A flat top. When the reference signal is a sinusoidal waveform with the amplitude of 50A and the frequency of 1kHz the load current waveform is shown in Fig.4. As can be seen, a high current tracking accuracy is achieved.

Conclusion

A digital control scheme with parameter estimation has been developed that can improve the output current tracking performances of the gradient amplifier with simple digital calculations. Simulation results confirm that fast dynamics and good tracking performance can be obtained by the proposed controller.

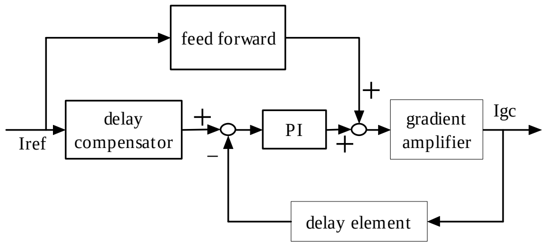

Fig. 2 control diagram

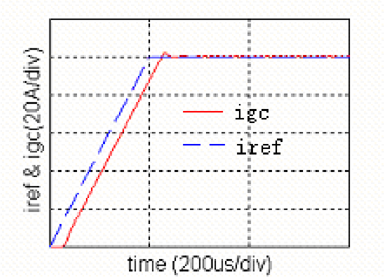

Fig. 3 response of ramped-square input signal

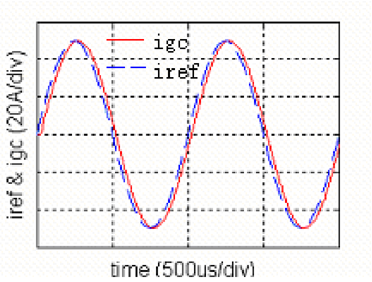

Fig. 4 response of 1kHz sinusoidal input signal

Reference

[1] S. Watanabe, et al., Proceedings of PESC, Vol.2, pp.909-913, 1999

[2] S. Watanabe, et al., Proceedings of PCC, Vol.3, pp.999-1004, 2002