STABILISATION AND ACCELERATION OF MAGNETIC FIELD GRADIENTS

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Abstract. *Implementation of hyperpolarized 3He MRI for lung imaging needs fast acquisition and ADC mapping methods, which put severe requirements on the gradient system performance in term of speed, spatial homogeneity and reproducibility. An upgrade of the gradient system consisting of reproducibility improvement of the current source, accurate pre-emphasis adjustment and gradient commutation speeding is hereby described.*

Keywords: magnetic field gradient measurement, eddy current compensation, high stability current source, current accelerator

1. Introduction

Existing gradient system uses design based on linear power amplifiers (Techron 7780) that suffers from some drawbacks, namely poor gradient reproducibility and low speed. Therefore our goal was three fold:

- accurate control of gradient current
- accurate measurement of magnetic field gradients
- gradient current commutation speeding-up

2. Subject and methods

An accuracy of gradient current control depends on power amplifier performance. We have observed the following defects of Techron 7780**:**

- variation of output offset voltage (and current) with internal heating;
- variation of current delivered within pulse and with internal heating as well;

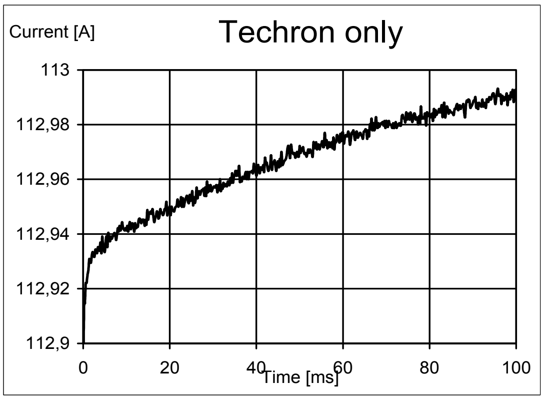
Detail analysis of amplifier construction leaded to following explanation for observed imperfections:

- internal electronics exposed to cooling air exhaust leading to its temperature variation in the range 20°C - 100°C
- shunt resistor of poor performance without any temperature stabilisation

Proposed solution to found instabilities was hence straightforward:

- temperature stabilisation of electronics and shunt resistor
- shunt resistor with low temperature coefficient
- external feedback with critical components carefully selected [1].

Output current of power amplifier (Techron 7700 series) before and after implementation of external stabilisation loop is shown on Fig.1 and Fig.2 respectively.



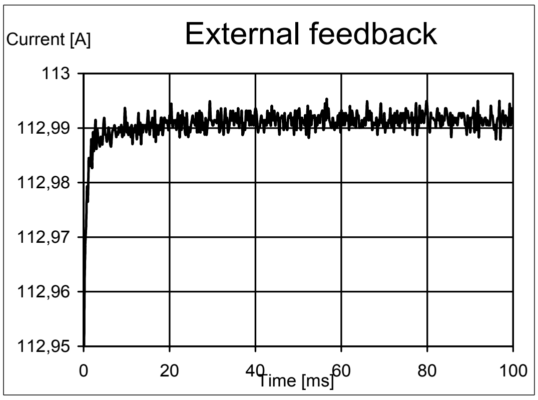


Fig.1 Output current of Techron 7780 only Fig.2 Output current with external feedback

An accurate measurement of magnetic field gradients

Correct compensation of eddy currents effect (preemphasis) requires an accurate method of magnetic field gradient measurement. Simple method based on analogue integration of a difference voltage induced in a couple of balanced coils placed along the investigated gradient was designed. Accuracy of this method is 10^{-4} and its principle is depicted on Fig.3.

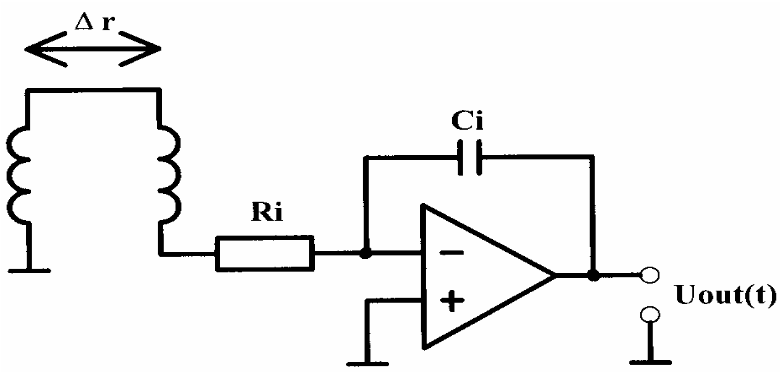


Fig.3 Apparatus for inductive measurement of magnetic field gradients

$$u_i(t) = -nS\left(\frac{dB(t)}{dt}\right) \qquad \Delta u_i(t) = -nS\Delta r\left(\frac{dG(t)}{dt}\right)$$

$$U_{out}(t) = -\frac{1}{R_i C_i}\int_0^t \Delta u_i(t')dt' \qquad G(t) = \frac{R_i C_i}{nS\Delta r} U_{out}(t)$$

where: n – number of coil turns, S – single turn area.

Gradient time shapes with eddy current effect (without preemphasis compensation) and after careful preemphasis adjustment are shown on Fig.4 and Fig.5 respectively.

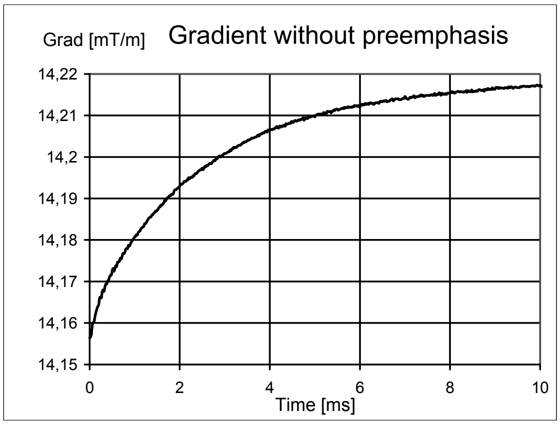


Fig.4 Gradient affected by eddy currents

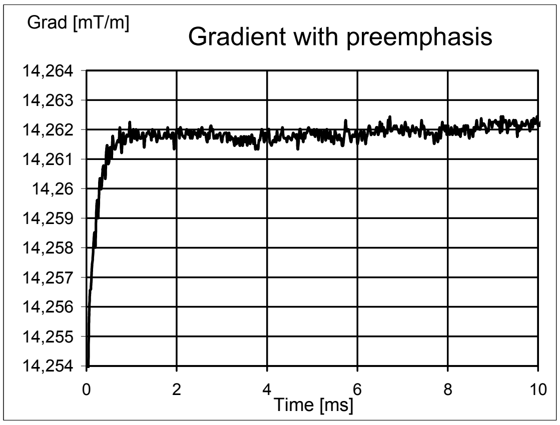


Fig.5 Gradient with correct pre-emphasis

Gradient commutation speeding-up – current accelerator

A current rise to gradient coil corresponds to a transient response of LR circuit:

$$I(t) = \frac{U}{R_c}\left(1 - \exp\left(-\frac{t}{\tau}\right)\right) \qquad \frac{dI(t)}{dt} = \frac{U}{L_c}\exp\left(-\frac{t}{\tau}\right)$$

where $\tau = \frac{L_c}{R_c}$, L_c and R_c are inductance and resistance of a gradient coil respectively.

From previous equations we can see that current speeding could be achieved in two ways:

- reduction of coil inductance (physical limitation)
- increasing of applied voltage

An increasing of applied voltage can be achieved by adding more amplifier in series (expensive) or using a system that apply an additional voltage with appropriate polarity in series with amplifier during current rise time – a current accelerator – Fig.6.

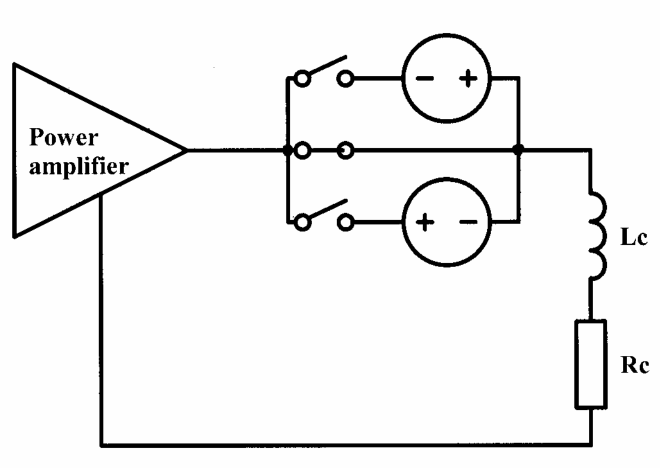
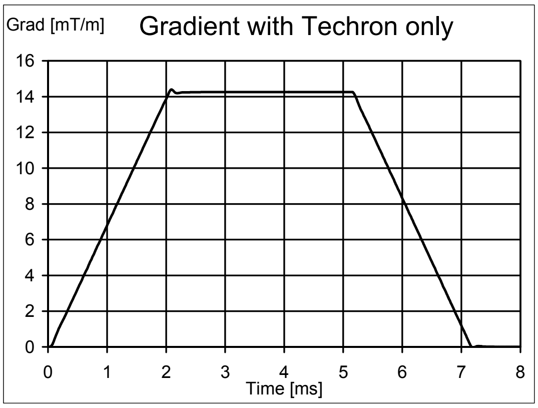


Fig.6 Principal schematics of an accelerator



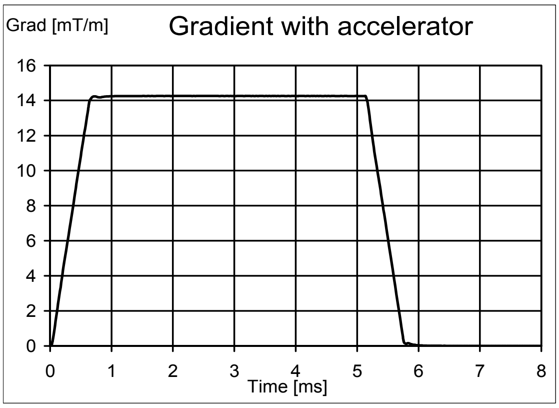


Fig.7 Gradient without accelerator

Fig.8 Gradient with accelerator

3. Results

External feedback improved current control accuracy by one order of magnitude down to less than 100 ppm; output current offset was reduced from typically mA level down to noise level (approx. 100μA).

New method form magnetic field gradient measurement was developed and tested with measurement accuracy better than100 ppm. Thanks to this the preemphasis units could be finely adjusted leading to stability of gradient plateau ~100 ppm. The method was successfully used also for ΔB_0 compensation adjustment on 7T superconductive middle scale scanner and suppression of ΔB_0 component down to 0.1 ppm level has been achieved.

Current accelerator is a cost effective solution to need of gradient current commutation speeding-up. Speeding factor of 3 was achieved. Financial effectiveness is approximately 50 000$ per axis compare to multiple amplifier configuration with similar performance.

Acknowledgements

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