# Preliminary Evaluation of a High Performance Gradient Coil for 3T Head Specialty Scanner

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**Target audience:** Gradient coil and MRI hardware system developers.

**Introduction:** A large-aperture head gradient coil was built as an investigative tool for image quality assessment and systems integration with a dedicated 3T head system. Due to their smaller dimensions and field of view (FOV) size, head gradients are known to deliver higher strengths, switching speeds and peripheral nerve stimulations (PNS) thresholds [1-2]. The design configuration presented here was selected to provide excellent patient ergonomics due to a 42 cm inner diameter that opens up to 45 cm at 15 cm from isocenter. Moreover, the prototype is relatively short since it only extends by 20 cm from isocenter in the direction of the patient's shoulders ($Z_{patient}$) (Fig.1). These physical dimensions, combined with a relatively large 26 cm FOV are expected to enable high-quality imaging down to the cervical vertebra (C2 junction) compared to other existing configurations [3-4]. Here we report on preliminary testing results related to gradient efficiency, resistance, inductance and eddy currents.

Figure 1: Layout of step design in asymmetric gradient

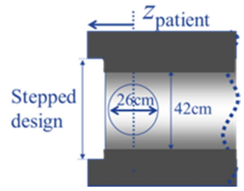
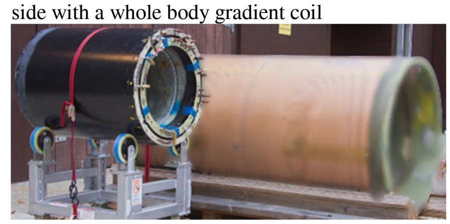



Figure 2: Picture of head gradient prototype side-by-side with a whole body gradient coil



**Methods:** An actively-shielded head gradient coil was built based on the design presented in [5] using standard manufacturing methods (Fig. 2). A dynamic signal analyzer (Agilent 35670A, Santa Clara, USA ) was used to produce impedance sweep data. The gradient coil was centered inside a 10 mm-thick aluminum cylinder that could represent a conductive structure inside the cryostat of a superconducting magnet. The gap between the outside surface of the gradient coil and the inside surface of the cylinder was 28 mm. An array of eight fluxgate probes (Bartington, Witney, UK) was used for gradient field and eddy current measurements. The probes were distributed on the corners of 14 × 14 × 14 cm$^3$ cube (circumscribed sphere diameter = 14 × sqrt(3) = 24.2 cm). The cube itself was centered on the gradient coil's isocenter (Fig. 3). The gradient coil was driven with trapezoidal pulse shapes and field data were recorded, providing information about the gradient efficiency (gradient amplitude/A) and eddy current magnitude (Fig. 4). All data were compared to prediction.

Figure 3: Spatial location of fluxgates sensors around gradient isocenter

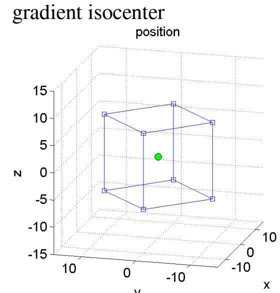



Figure 4: Raw signal from the fluxgate sensors in response to a gradient pulse

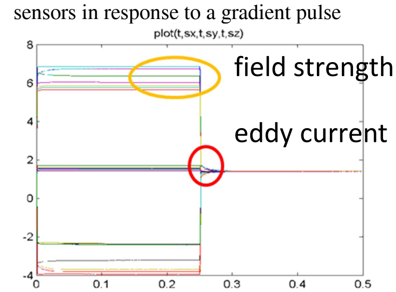



Table 1: Measured and predicted values of Inductance and Resistance

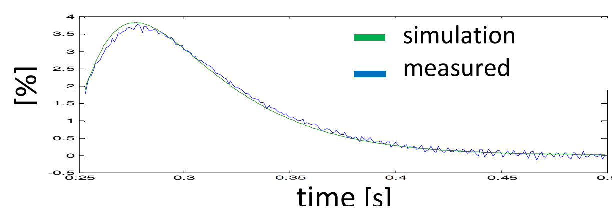
| Measured | L (5 Hz) | R (5 Hz) |
|---|---|---|
| Gx | 0.341 mH | 91 mΩ |
| Gy | 0.327 mH | 85 mΩ |
| Gz | 0.266 mH | 126 mΩ |
| **Simulated** | **L dc** | **R dc** |
| Gx | 0.336 mH | 55 mΩ |
| Gy | 0.326 mH | 40 mΩ |
| Gz | 0.269 mH | 71 mΩ |

Table 2: Measured and predicted values of gradient efficiency (mT/m/A)

| | $\gamma_x$ | $\gamma_y$ | $\gamma_z$ |
|---|---|---|---|
| Analytical Prediction | 0.129 | 0.140 | 0.148 |
| Measured | 0.127 | 0.134 | 0.146 |
| % difference | -1.1% | -4.0% | -1.0% |

**Results and Discussion:** Table 1 shows very good agreement between the measured and predicted values for the DC inductance. The DC resistance prediction was underestimated due to the fact that the simple analytical expression that was used is based on idealized continuous current distribution. While this provides an order-of- magnitude estimate, it does not take into account manufacturing variation and actual conductor cross-section. More in-depth results of AC resistance can be found in [6]. The gradient efficiencies predicted at the location of the fluxgate probes are within 4% of the measured values, which validates the precision of the manufacturing processes (Table 2). Figure 5 shows very good agreement between theoretical prediction and measurement of the B0 eddy currents generated by the Z coil in the aluminum cylinder. The data averaged over all the sensors for the eddy current generated from the X and Y coils showed that the simulation methods provided predictions of the measured eddy currents that are within 0.45% of the applied gradient field. Adequate prediction of eddy currents within surfaces close to the gradient coil is necessary for the design of a compact specialty scanner.

Figure 5: $B_0$ Eddy Current response of Z coil at one centimeter from isocenter (Comsol)




**Conclusion:** The prototype described here meets the design specifications. The preliminary testing data presented indicate that we can proceed to more in-depth testing, including PNS characterization and assessments of various aspects of image quality. This work represents substantial progress towards a large-bore, head-only gradient coil, suitable for integration with a dedicated scanner.

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**References:** [1] Turner, MRM, 11:903-920 (1993), [2] Chronik et al., MRM 44:955-963 (2000), [3] Alsop et al., MRM 35:875-886 (1996); [4] Green et al., ISMRM 16 (2008), #346, [5] Mathieu et al., ISMRM 20 (2012), #2588, [6] Lechner et al., ISMRM 21 (2013)