Experimental Investigations on Gradient Coil Induced Magnet Heating in MRI System

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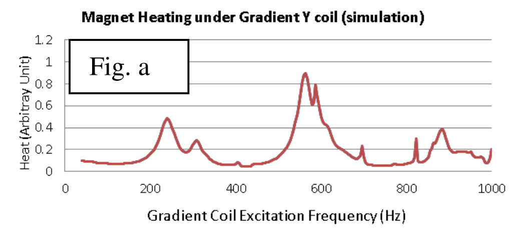
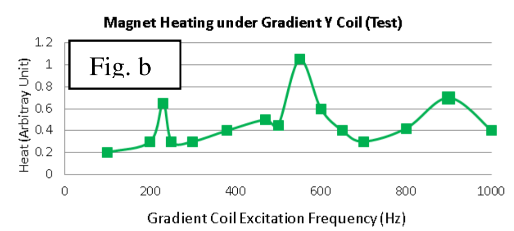
Introduction:

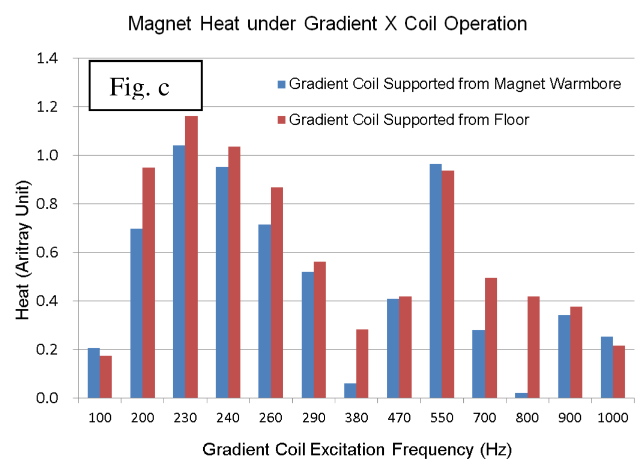
The dynamic coupling between gradient coil and magnet has been one of the greatest challenges in MRI resonator design. This effect generates image quality issues at low frequencies [1] and limits operational duty cycle due to induced magnet heating at medium and high frequencies. With increasing demand for high patient through-put in high field MRI systems with high performance gradient coils, the challenges on dynamic coupling induced Joule heating in magnet become very apparent [2]. Numerous efforts to understand and reduce the Joule heating induced helium boil-off have been attempted [3]. Recently, a fully mechanical-electro-magnetic coupling analysis [4] was pursued to simulate and understand the dynamic coupling on a whole body magnet with hermetically sealed cooling system. In this study, experimental results are presented to understand gradient coil induced magnet heating under different gradient coil mounting conditions. In addition, simulation results are compared with experimental data.

Method & Results:

When a gradient coil is pulsed, a magnet responds mechanically by vibration through gradient coil mounting and electrically by electro-magnetic coupling due to gradient coil leakage field on magnet cryostat. Furthermore, the leakage field, coupled with background static magnetic field, will generate significant Lorentz force which will excite resonaces of the cryostat. The vibration induced eddy current will be further amplified at the resonances. The eddy current induced Joule heating will cause helium boil-off. In this study, a whole body MRI magnet with hermatically sealed cryogenic system was designed and manufactured. A series of sine wave protocols in a frequency range of interest are created to match the total power of gradient coil under normal operation. The pressure rise rate at each frequency was monitored and converted to magnet heat by using the thermodynamic relationship between pressure rise and heat. A couple of representative results are presented as below. It has been observed from Fig (a) and (b) that experimental data is very consistent with the simulation. In order to understand vibration transmission component to helium boil-off, both magnet and gradient coil were supported from the ground. It is observed that vibration through gradient coil mounting has very little effect on magnet heating as shown in Fig. (c).







Conclusions:

MRI system duty cycle will be significantly limited due to helium boil-off if there exists a strong coupling between gradient coil and magnet. Both experimental and analytical results in this study have indicated that the magnet heating has strong frequency dependence. The detailed analyses of cryostat vibration under background magnetic field [4] have suggested that the resonances of the cryostat contribute to this frequency dependent magnet heating phenomenon. It should be noted that vibration analysis of the cryostat without the magnetic field, and its associated magnetic stiffness and damping [1] & [4], are unable to explain this behavior. The peaks in magnet heating plot may be reduced if the gradient coil induced eddy current pattern does not excite cryostat resonances, or if application protocols are carefully tailored to avoid cryostat resonances. The latest whole body MRI scanner with hermetically sealed cryogenic system having very limited helium volume was designed in such a way that 100% duty cycle of gradient coil operation has been achieved.

References:

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