Frequency Spectrum of Partial Discharge Events

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Introduction

A significant impediment to performance in an MRI imaging system is the radial space separation of the gradient coil between adjacent gradient axes. The gradient coil also occupies potential patient volume. A typical gradient coil consists of an inner field-generating coil and an outer field-canceling coil. Each gradient coil, inner and outer, consists of three layers corresponding to the X, Y, and Z-axes of the gradient coil. The inner and outer gradient coils each have two radial spaces between adjacent axes. The radial spacing between adjacent axes is required to reduce the occurrence of "white pixels" and voltage breakdown during an MRI scan. If the "white pixel" performance of the gradient coil can be increased, the radial space savings can be incorporated into an increased patient bore, reduced magnet expenditure, or increased gradient slew rates with higher applied gradient voltages.

Frequency Content of a MRI Gradient Coil PD Signal

White Pixels" refer to short duration bursts of electromagnetic energy that are picked-up during reception of magnet resonance data. These bursts cause "ripples" in images (corduroy artifact) and can be seen as bright spots (white pixels) in raw data images. The susceptibility of a gradient coil generating a "white pixel" is demonstrated in an off-line electronic test where the partial discharge inception voltage (PDIV) is measured. At the partial discharge inception voltage (PDIV) a small spark bridges the void and causes emission of a radio frequency noise burst. An MRI scanner can detect the noise burst and cause artifacts in the MRI image. A MRI gradient coil, consisting of several layers of copper boards and insulation layers, is susceptible to partial discharges if voids are left in the insulation layers during vacuum pressure impregnation (VPI) or due to bonding imperfections.

After the VPI process is complete, a PDIV test is conducted with one voltage lead attached to each axis pair (X-Y, Y-Z, X-Z) and the voltage is recorded when the partial discharge is detected. The gap between adjacent conductor layers is typically ~3 millimeters. For a "white pixel" free gradient coil, the inception voltage is required to be greater than the maximum voltage provided by the gradient amplifier at the maximum slew rate.

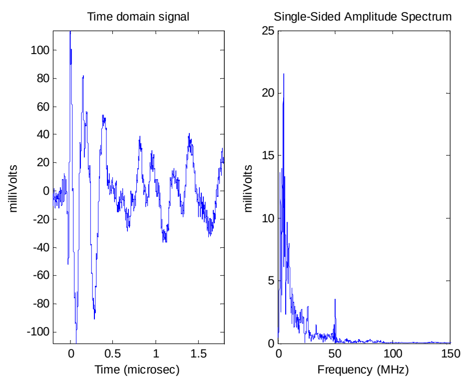

Figure 1. A PD event between the X-Y axis shows a PD pulse of 149 pC with frequency content less than ~25 MHz.

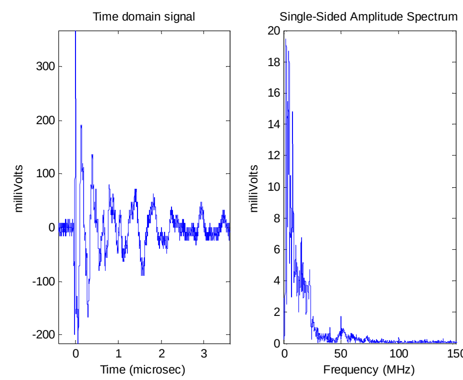

Figure 2. On a different gradient coil, the PD event between the X-Y axis shows a PD pulse of 65 pC with frequency content less than ~25 MHz.

Several gradient coils PD events where measured with an oscilloscope through a 2 MHz high pass filter to remove the residual 60 Hz voltage from the signal. The PD pulse where observed and recorded using a Tektronix oscilloscope. The PD pulses are measured directly on the output of the Power Diagnostix 1-nF quadrapole coupling capacitor. The PD voltage waveforms were acquired at voltages slightly above inception and the attempt was made, using the triggering of the oscilloscope, to capture the largest picocoulomb discharges. Two example time and frequency domain data on different gradient coils are shown in Figures 1 and 2. The picocoulomb level was calculated in 50-ohm system using the IEC 60270 standard, $q = \frac{\sum_{\text{first peak}} V_i \cdot t_i}{50} \cdot 10^{12}$.

After testing three different gradient coils and all axis combinations at voltages of 3.5 kVp, slightly exceeding inception voltage, the frequency content of the waveform was consistently less than 25 MHz. The frequency content of the waveform is significantly below MRI imaging frequencies. To confirm the gradient coils were "white pixel" free, a waveform was developed at the maximum driving voltage for all axes and is shown in Figure 3. All axes combinations passed the "white pixel" test.

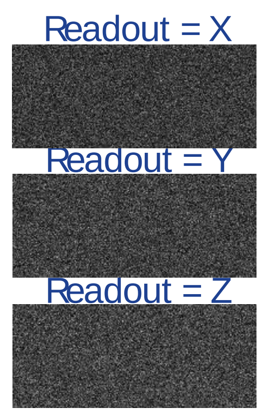

Figure 3. A MRI "white pixel" scan was run with maximum voltage on each axis combination.

Conclusions

The PD inception voltage of the VPI gradient coil exceeds the maximum gradient amplifier voltage in the frequency band of ~25-200 MHz. With the frequency content of the PD pulse less than 25 MHz, there is room to reduce the radial spacing between adjacent axes in the gradient coil and improve the efficiency and/or increase the slew rate of the gradient with higher applied voltages.