MR testing of gradient-induced vibrations using an optical contact-free sensor within the switched gradient magnetic field of a 1.5 Tesla MR system.

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Objective

A likely, but less investigated interaction of the switched gradient field with medical implants is gradient-induced vibration [1], [2]. Vibrations are caused by induced local magnetic fields due to eddy-currents in electrically conductive structures of medical devices counteracting with the static main magnetic field. Measurement of vibrations in an MR environment is a complex experiment, especially if not contacting objects mechanically and thus preventing influence to the measurement. Therefore it is a desire using a contact-free measurement system. We describe an investigation using an optical sensor for measuring gradient-induced vibration on copper and titanium circular plates (dummy implants of a pacemaker can) as well as a real hip stem implant.

Methods

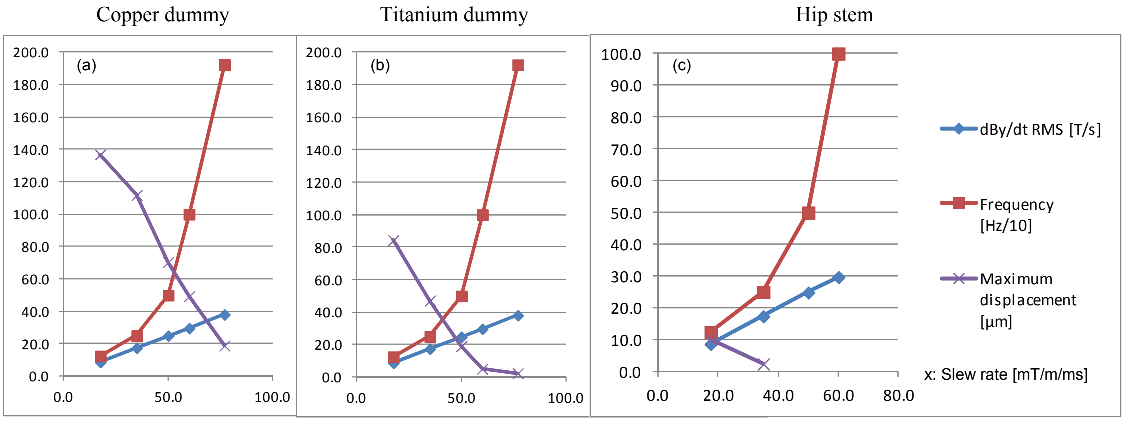
The test set-up was built at the magnet bore entrance of 1.5 Tesla Avanto MR scanner (Siemens Medical Solutions, Erlangen, Germany) having a SQ engine gradient system with max. z-gradient amplitude of 45 (x, y: 40) mT/m and slew rate of max. 200 T/m/s. In pre-tests we measured a location at the bore entrance for finding a pulsed gradient RMS exposure of 52.5 T/s using all 3 gradients and a pulse form with 100% duty cycle. 3 test objects were used suspended at the test location free of mechanical-induced vibration: a reflecting non-conducting foil (used for all objects) has been attached to a circular copper plate 46.5 x 0.6 mm, a circular titanium plate 46.5 x 0.5 mm and the hip stem. The main plane of the test objects have been oriented orthogonal related to the main static magnetic field B_0. We investigated the vibrations using an optical sensor with 6 mm in diameter, which is measuring the vibration frequency by reflection. A gradient magnetic field was switched using sinusoid pulses with gradient amplitudes from 6.5 to 35 mT/m and frequencies of 125 to 4160 Hz (TAB. 1).

Results

We received quantitative data for the 3 test runs: maximum vibration amplitude of the used frequencies for 1) copper dummy of 137 µm, 2) titanium dummy of up to 84 µm and 3) hip stem up to 10 µm, also shown in FIG. 1. The frequency of all curves show approximately the source frequency of the gradient system applied. Dependent on the materials conductivity, the results show an increase in vibration with a higher conductivity and a decrease in addition with a higher test object mass.

				1) Copper dummy			2) Titanium dummy			3) Hip stem		
Gradient amplitude [mT/m]	Slew rate [mT/m/ms]	dB_y/dt RMS [T/s]	Frequency [Hz]	Maximum displacement [µm]	Maximum velocity [m/s]	Maximum acceleration [m/s²]	Maximum displacement [µm]	Maximum velocity [m/s]	Maximum acceleration [m/s²]	Maximum displacement [µm]	Maximum velocity [m/s]	Maximum acceleration [m/s²]
35	17.5	8.7	125	137	0.11	84.4	84	0.07	52	10	0.01	6
35	35.0	17.4	250	112	0.18	275.9	47	0.07	116	2	0.00	6
25	50.0	24.9	500	70	0.22	695.6	19	0.06	189	n.m.	n.m.	n.m.
15	60.0	29.7	1000	49	0.31	1952.4	5	0.00	0.1	n.m.	n.m.	n.m.
10	76.9	38.1	1923	19	0.23	2756.6	2	0.00	0.0	n.m.	n.m.	n.m.
6.5	108.2	52.5	4160	7	0.00	0.1	5	0.00	0.1	n.m.	n.m.	n.m.

TAB. 1: Gradient sequence parameter and vibration test results on different test objects. Red numbers are distorted values due to resonance frequency of the test object. Note: gradient amplitude is decreasing because of constant gradient amplifier power, while increasing the frequency and slewrate. n.m. = not measureable.


Copper dummy

Titanium dummy

Hip stem

FIG. 1: (a-c): Gradient-induced vibration plots of 3 different test objects inside the pulsed gradient field.

Discussion & Conclusion

The data received in this experiments show the feasibility of measuring vibration amplitudes and frequencies of electrically conductive structures, e.g. implants, in the MR environment. The difference of the copper and titanium plate vibrations can be detected as an absolute value. In further measurements, the method needs to be validated using for example a second high accurate laser vibrometer. However such devices are expensive and are magnetic. Therefore we have investigated a solution presented in this abstract using an optical sensor inside the static magnet field, very close to different test dummies and a real hip implant for evaluating the test methodology capability of detecting gradient-induced vibrations of a device quantitatively for MR safety assessment.

References:

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