RF Safe Interactive Catheter Traking with Variable DC-Susceptibilty Artefacts

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Introduction: Despite of many obstacles, vascular interventions guided by MR imaging are widely applied [1]. Interactive guidance of intravascular instruments (catheter tracking) is an attractive option but still needs improvement. Passive concepts are judged to be unreliable and unsafe. In contrast, active methods, however, are technically complex and costly. Since direct current (DC) artifacts are adjustable by varying the applied current, their intensity and size may be interactively adapted by the interventionalist. However, to bring the current to the catheter tip wire leads are required, which hold the risk of uncontrollable induction of alternating currents in a high-frequency (HF) environment. Konings et al suggested to create the current directly in the catheter tip by photovoltaic cells irradiated with a laser beam [2]. Unfortunately, this concept has so far not been feasible for clinical use due to the relatively large catheter diameter in their catheter prototype. Here we present a miniaturized optoelectric configuration integrated into a standard angiography catheter and show its feasibility in a phantom environment.

Materials und Methods: 2 kinds of commercially available photodiodes (EPD 660-3-0.5 / EPD 525-3-0.5, Epigap, Berlin, die edge length 500 µm) for the visible light spectrum were used to test the efficiency of transforming light energy into DC. Based on a frequency-doubled continuous wave Nd:YAG infrared laser, a green laser was used as light source at a wavelength of 532 nm. It provided stable laser power from 10 mW to 1500 mW and power was adjustable in a continuous manner. Different coil configurations (cylinder, cross, straight) made of 150 µm copper wire were evaluated for their efficiency of producing susceptibility artifacts at applied DC. The dependence on artifact size and intensity was determined in a 1.0-T open MR scanner (Panorama HFO, Philips Healthcare, Best, NL). A battery-driven DC generator was used that prevented HF induction through lead wires. The feasibility of the optoelectric circuit in the scanner was tested. Temperature increase arising from Laser energy and DC in the wire coil was measured directly by a digital technical thermometer as well as by MR thermometry. The technical performance of this miniaturized optoelectric catheter prototype was tested successfully in a phantom.

Results: Small optoelectric devices (500 µm edge length) could readily be integrated into a standard vascular catheter and generated DC up to 24 mA, which caused a strong and intense susceptibility artifact. A cylindrical antiparallel coil configuration proved to be more efficient for producing artifacts at DC application (25 mA) than cross and straight configurations. A magnification factor of 3.1 was achieved compared to a standard catheter without modification. The wire itself did not produce any significant susceptibility artifact. The optoelectric circuit worked in the HF environment of the scanner and DC in the HF field produced no significant thermal burden. After 1 hour the temperature around the wire (DC, 150 mA) was in equilibrium with room temperature (20°C). During a continuous laser irradiation of 1 hour, the photodiodes did not raise the temperature above 34°C in aqueous gel.

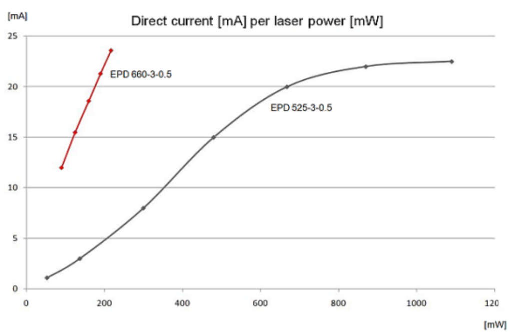

Figure 1. Efficiency of different photodiodes working in the visible spectrum (green light). Around 220 mW of laser power on EPD 660-3-0.5 (red graph) shows a much higher efficiency than EPD 525-3-0.5 (black graph) generating about 24 mA of DC.

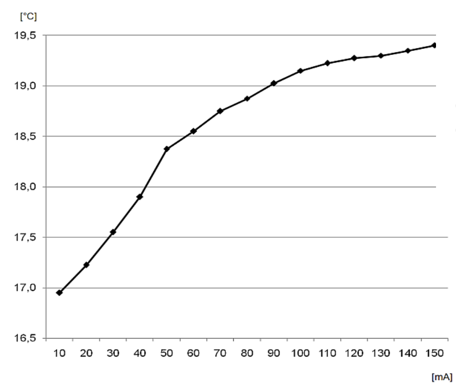

Figure 2. Dependence of coil temperature on DC application.

The catheter prototype was tested successfully in the vessel-phantom and produced a strong susceptibility artifact when DC was applied.

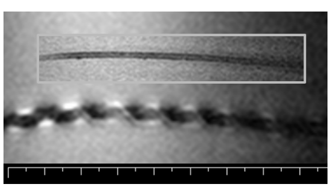

Figure 3. Antiparallel cylindrical coils with no (small box) and 25 mA DC in a water bath at T2-weighted turbo-spinecho imaging (TR/TE = 2000ms/80 ms).

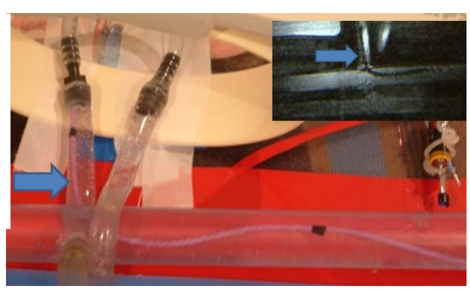

Figure 4. Feasibility of DC-induced artifact creation in a phantom model that simulates renal artery and vein with pump-driven fluid circulation. 25 mA DC were applied in an antiparallel cylindrical coil integrated into a 7F standard vascular catheter. T1 weighted 3D phase contrast MR angiography of the phantom (small box). Arrows mark corresponding positions of the catheter.

Discussion: This study shows that an adequate miniaturizing of optoelectronic circuits for interactive vascular catheter tracking in interventional MRI is feasible. The diameter of this prototype catheter does not exceed 7F. Highly efficient photovoltaic devices are available that allow desired limitation of laser power and DCs when combined with efficient coil configurations. As concerns with respect to high thermal or electric burden can be ruled out, this type of miniaturized catheters appear promising for clinical applications.

References:

1. **Bock M, Wacker FK. *MR-guided intravascular interventions: techniques and applications.* J Magn Reson Imaging 2008;27:26-38.**
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