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*i*MPI – interventional Magnetic Particle Imaging

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Abstract

Magnetic Particle Imaging (MPI) has become a promising candidate for medical applications, especially cardiovascular interventions. Necessary milestones have been reached in multiple pre-clinical experiments and studies and are ready to be tested on human-scale MPI scanners. Only few human-sized scanner systems designed for dedicated applications are available. In this abstract, a novel approach is presented for a dedicated human-sized interventional MPI scanner.

I. Introduction

Over the past decade, Magnetic Particle Imaging (MPI) has become a promising tomographic method for multiple applications in biology, chemistry, medicine and physics [1]. For cardiovascular medicine in particular, MPI could become an applicable radiation-free technique for endovascular interventions supporting the common x-ray gold-standard (digital subtraction angiography – DSA) [2, 3].

As next step on the path of MPI into clinical practice, MPI hardware needs to be scaled up for human-sized applications [4, 5]. This comes with several challenges when keeping the flexibility and speediness of MPI. Furthermore, additional issues related to SAR (specific absorption rate) and PNS (peripheral nerve stimulation) limitations [6] due to strong magnetic field gradients required for high spatial resolution have to be kept in mind.

In this abstract, a first dedicated concept for a human-sized MPI scanner based on the Traveling Wave approach is presented [7], which is specifically designed to meet the requirements for real-time cardiovascular interventions such as percutaneous transluminal angioplasty (PTA) and stenting.

II. Material and methods

The aim of the interventional MPI scanner (iMPI) is to provide a radiation-free system comparable to the clinical gold-standard DSA (digital subtraction angiography). This requires spatial resolution in the range of millimeters [8], high temporal resolution below 100 ms per image [9], near real-time visualization with low latency [10], and an open design that provides a comfortable and flexible environment for patients and medical staff, as well as sufficient space for interventional instrumentation and its operation. Additionally, the open design allows for simultaneous conventional DSA, which is especially important in the trial and testing phase [11].

To provide a sufficient magnetic field gradient, which is required for a high spatial resolution in MPI, a novel hardware approach is used to generate a field-free line (FFL) dynamically within a specific region of interest

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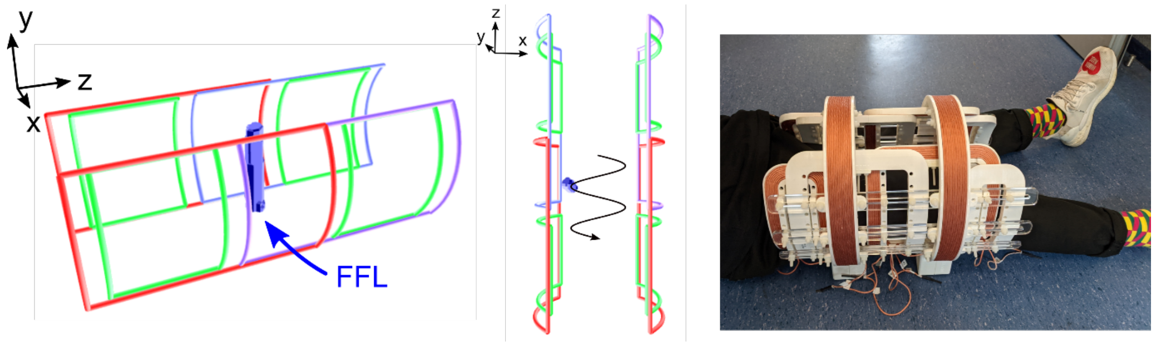

Figure 1: left: basic hardware concept for the generation of the field free line (FFL) encoding scheme. The main gradient system generates dynamically the FFL aligned into y-direction. Additional coils are used for deflection in x-z-plane for generating the projection image. Right: picture of the first iMPI prototype.

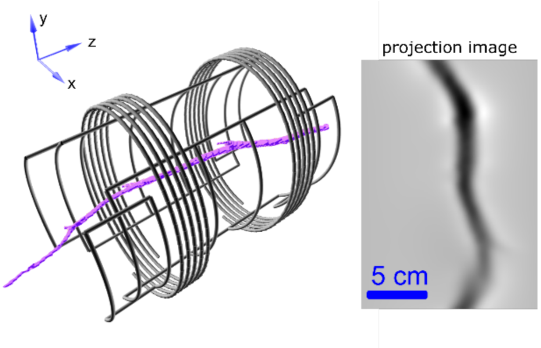

Figure 2: Simulation example of a projection image of a femoral artery @0.7 T/m.

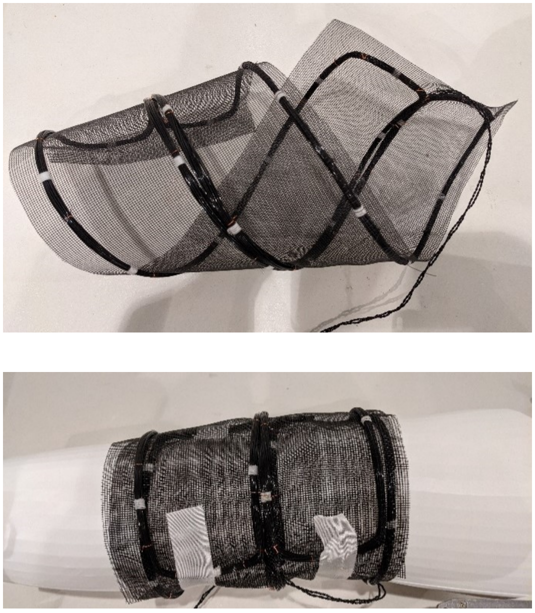

Figure 3: Example of a flexible dual-channel receive coil, which can be wrapped around the sample to increase the SNR.

(ROI) (see Fig. 1 left) based on the traveling wave concept [12]. By rapidly moving the FFL along specific sinusoidal trajectories through the ROI using additional coils, the nonlinear response signal of the tracer (superparamagnetic iron-oxide nanoparticles – SPION) is used to determine their spatial distribution [13]. The result is a projection display comparable to DSA, e.g., of vascular structures and stent positioning as indicated in a simulation in Fig. 2.

III. Results and discussion

To guarantee a strong magnetic field gradient of about 0.7 T/m within a usable FOV of about 25 cm in length and 20 cm in diameter, currents of about 200 A driving the main electromagnets (number of windings N=32 per coil element, litz wire 300×0.1 mm, Pack-Feindrähte, Germany) are required. As power supply, a cabinet of high-power audio amplifiers is used (12.2, Hoellstern, Germany), which is supported by a computer-controlled console for signal generation and processing of acquisition data.

In the result, a power dissipation of about 50-60 Kilowatts in continuous mode has to be handled, which requires a sophisticated cooling management and specific requirement on the stability of the coils. Driving the system in a pulsed measurement mode, where a short sequence (<1 ms) is generated to scan the ROI sequentially allows an easier usage of the scanner without overheating but requires a more sophisticated reconstruction processing.

However, to guarantee real-time imaging, in combination with high spatial resolution, the acquisition sequence has to be modified to overcome the issue, which is provided by the design. Since there is no shielding available for the scanner, the receive chain has to be optimized for high SNR and sophisticated data processing.

In Fig. 3, an example of a flexible dual channel receive coil is shown, which can be wrapped around the sample as close as possible to increase the SNR.

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IV. Conclusions

A first human-sized projection MPI scanner for interventional treatment of human-sized legs has been designed and built providing promising results to pave the way to clinical routine.

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Author's statement

Conflict of interest: Authors state no conflict of interest.

References

[1] B. Gleich & J. Weizenecker, Tomographic Imaging using the nonlinear response of magnetic particles, Nature, vol. 435, pp. 214-7, 2005.

[2] S. Herz et al., Magnetic Particle Imaging Guided Real-Time Percutaneous Transluminal Angioplasty in a Phantom Model, Cardiovasc Intervent Radiol,vol. 41(7), pp. 1100-5, 2018.

[3] S. Herz et al., Magnetic Particle Imaging-Guided Stenting, J Endovasc Ther.vol. 26(4), pp. 512-9, 2019.

[4] M. Graeser et al., Human-sized magnetic particle imaging for brain applications, Nature Comm, vol.10:1936, 2019.

[5] E.E. Mason et al., Design analysis of an MPI human functional brain scanner, Int J Magn Part Imaging, vol. 3(1):1703008, 2017.

[6] E.U. Saritas, Magnetostimulation Limits in Magnetic Particle Imaging, IEEE TMI, vol. 32(9), pp. 1600-10, 2013.

[7] P. Vogel et al., Traveling Wave Magnetic Particle Imaging, IEEE TMI, vol. 33(2), pp. 400-7, 2014.

[8] P. Vogel et al., Micro-Traveling Wave Magnetic Particle Imaging – sub-millimeter resolution with optimized tracer LS-008, IEEE Trans Magn, vol. 55(10):5300207, 2019.

[9] P. Vogel et al., Real-time 3D Dynamic Rotating Slice-Scanning Mode for Traveling Wave MPI, IJMPI, vol. 3(2):1706001, 2017.

[10] P. Vogel et al., Low Latency Real-time Reconstruction for MPI Systems, IJMPI, vol. 3(2):1707002, 2017.

[11] P. Vogel et al., Magnetic Particle Imaging meets Computed Tomography: first simultaneous imaging. Nature Sci Rep, vol. 9:12627, 2019

[12] P. Vogel et al., Traveling Wave Magnetic Particle Imaging, IEEE TMI, vol. 33(2), pp. 400-7, 2014.

[13] P. Vogel et al., Flexible and Dynamic Patch Reconstruction for Traveling Wave Magnetic Particle Imaging, Int J Magn Part Imaging, vol. 2(2):1611001, 2016.

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