Non-linear effects at high-speed moving table imaging

U. Katscher[1], and O. Lips[1]

[1]Philips Research Europe - Hamburg, Hamburg, Germany

Introduction: Continuously moving table imaging [1-4] is an alternative to multi-station techniques, offering enhanced patient through-put and less artefacts along the interfaces between different subimages. Initially developed for MR angiography [2], possible applications might range, e.g., up to obesity-related diagnostics [4]. In the past years, the provided table speed increased from typically 1-2 cm/s [2] up to 5.3 cm/s [4]. Assuming a long-term continuation of this trend of increasing table speed, one has to keep in mind that at table speeds approaching $v \approx 3{\cdot}10^9$ cm/s, non-linear, relativistic effects have to be taken into account [5]. This study investigates possible consequences, particularly on scan time and the Lorentz transformed RF fields. The study is based on simulations due to the current lack of suitable MR systems.

Theory: Given a table speed v, the patient length measured in the table frame L_{tab} and the laboratory frame L_{lab} differs by a factor γ

$$L_{lab} = L_{tab}\sqrt{1 - v^2/c^2} \equiv L_{tab}/\gamma \tag{1}$$

with $c = 3{\cdot}10^{10}$ cm/s the vacuum speed of light (see Fig. 1). The factor γ also determines the time dilatation in the patient frame

$$t_{lab} = \gamma t_{tab} \ . \tag{2}$$

The electromagnetic fields as seen by the patient during the scan are described via the homogeneous Lorentz transformation Λ [5]

$$F_{tab}^{\mu\nu} = \Lambda^{\mu}_{\alpha}\Lambda^{\nu}_{\beta}F_{lab}^{\alpha\beta} \tag{3}$$

with the F the field tensor in the two different frames. Evaluating (3) shows that only transverse electromagnetic components B^T, E^T are affected,

$$B_{tab}^T = \gamma\left(B_{lab}^T + E_{lab} \times v/c^2\right), \quad E_{tab}^T = \gamma\left(E_{lab}^T - B_{lab} \times v/c^2\right) \tag{4}$$

i.e., the active components of the RF fields. Main and gradient fields are assumed to be parallel to v, and thus, are the same in both frames regarded.

Methods: A 3T MR system (Philips Achieva, Philips Medical System, Best, The Netherlands) equipped with a continuously moving table was simulated. Table speeds between v=0.2c and v=0.9c were assumed. Regarding speeds of $v \approx 0.999999c$ achievable in particle accelerators, this seems to be a conservative estimation for corresponding, up-coming continuously moving table MR systems. For the sake of simplicity, it is assumed that the table movement starts and stops instantaneously, skipping the acceleration and deceleration phase of the table movement.

Results/Discussion: For an assumed patient length of L_{tab} = 2m, the patient's traversing time reduces from 33 ns for $v = 0.2c$ (γ= 1.02) to 3.2 ns for $v = 0.9c$ (γ= 2.3), and so does the total scanning time. For comparison, today's table speed v = 5 cm/s yields $\gamma \approx$ 1+1e-20, corresponding to a patient length reduction L_{tab}-L_{lab} of almost 0.03 am. The Lorentz transformation of the RF fields (3,4) has three major consequences. (a) Part of the laboratory electric field appears as magnetic field in the table frame (see Fig. 2). However, simulations for a quadrature body coil reveal that the resulting field distortions are relatively small. Even for v=0.9c, the corresponding field distortions are typically below ±10% (see Fig. 2). (b) To achieve the desired flip angle, transmitted B1 fields have to be lowered by the factor γ. This feature will help to relax future RF amplifier requirements. On the other hand, lowering the B1 amplitude by a factor of γ ensures that the physiologically relevant electric fields in the table frame (4), and thus, SAR_{tab} remains in the same order of magnitude as the conventional SAR. (c) Due to time dilatation (2), the frequency of the submitted RF field has to be increased by the factor γ to fit the Larmor frequency in the table frame.

Conclusion: Relativistic table movements have several consequences on the physics of MRI and offer a bunch of possible advantages. Patient through-put benefits from significantly reduced scan time, not only due to table speed, but also due to the occurring length contraction of the patient. It is expected that this length contraction also triggers advanced developments of gradient and RF coils with a total length adapted to the contracted patient length, possibly resulting in lower system costs. Open MR systems would particularly benefit from relativistic table speeds due to the amplification of the vertical main field $v \perp B_0$. Of course, a lot of technical issues are still open, particularly concerning table motor and its power consumption, and the exact synchronisation of sequence and current patient position. Moreover, it cannot be excluded totally that the discussed table movements may have physiologic impact, e.g., on the patient's angio-dynamics. However, the outstanding exciting possibilities in this framework make it worth to enter this new area of MRI and to explore the related effects in more detail.

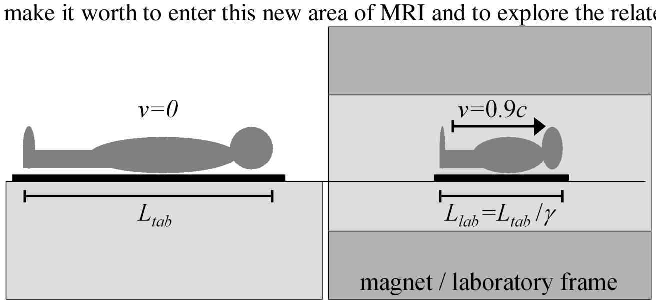

Fig. 1: Sketch of patient's length contraction (see Eq. (1)) for high speed moving table imaging. A length contraction of γ = 2.3 corresponding to a table speed of $v = 2.7{\cdot}10^{10}$ cm/s = 0.9c is depicted.

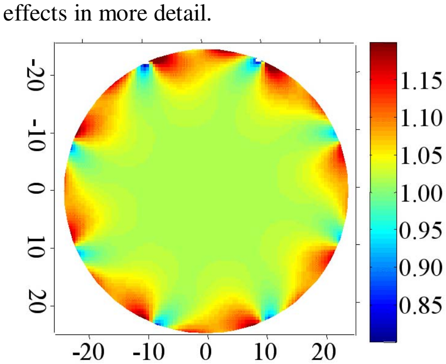

Fig. 2: RF field distortion of a quadrature body coil due to the Lorentz transformation (3,4). The plot shows the B1 field transmitted in the laboratory frame, as seen in the table frame for a table speed of v=0.9c, normalized by γ and the B1 field at v=0. The transverse slice has a longitudinal off-center of 20 cm. Even for this case, field distortions are roughly below ±10%.

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