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INFORMATION, COMMUNICATION & COMPUTING

Fields of Expertise TU Graz

Kay Uwe Römer, Information, Communication & Computing
Source: Lunghammer – TU Graz

For the first time, an open-topic Field of Expertise tenure-track assistant professorship was opened, where candidates who work in one of the subfields of the Field of Expertise Information, Communication & Computing across all participating faculties could apply. We received 150 applications, many of them outstanding. One reviewer even congratulated us for such an impressive set of applications. The selection process was therefore very demanding, where a large selection committee with representatives from electrical engineering, informatics, and mathematics not only had to screen and assess 150 applications, but had to compare applicants across different disciplines, which was often not easy. In the end nine candidates were invited for interviews – this, too, was quite challenging as due to the Covid-19 situation a visit in person was not possible. We thus had a public talk and closed interview via the video conferencing platform WebEx, followed by individual online meetings of each applicant with members of the selection committee and representatives from different institutes, such that the candidates could get a good virtual impression of TU Graz and could decide to which institute and faculty they wish to be assigned. In the end, the highest ranked candidate accepted our offer and will join us in September 2021, filling a topic that was not well-represented at TU Graz before and which offers good opportunities for collaboration among all three faculties participating in the Field of Expertise Information, Communication & Computing. You will certainly hear more about the winner in September. Overall, these open-topic Field of Expertise tenure-track assistant professorships are introducing a very promising new instrument that allows us to attract top talent to TU Graz!

In this edition of TU Graz research, Manfred Kaltenbacher writes about his research. He recently joined the Institute of Fundamentals and Theory in Electrical Engineering as a full professor and head of institute. Enjoy reading!

Manfred Kaltenbacher

Modelling, Simulation and Optimization of Complex Technical and Medical Systems

In most cases the fabrication of prototypes within the design process is a lengthy and costly task, and reliable computer tools capable of precisely simulating the multi-field interactions are of utmost importance. Arbitrary modifications of geometry and selective variation of material parameters are easily performed, and the influence on behaviour can be studied immediately. In addition, simulation provides access to physical quantities that cannot be measured, e.g. the magnetic field in a solid body, and simulations strongly support insight into physical phenomena.

The modelling of complex technical as well as medical systems leads to so called multi-field problems, which are described by a system of nonlinear partial differential equations. The complexity consists of the simultaneous computation of the involved single fields as well as in the coupling terms, which in most cases introduce additional nonlinearities, e.g. moving/deforming conductive bodies within an electromagnetic field. For the efficient solution of these multi-field problems, we have developed an enhanced simulation environment based on the finite element (FE) method, which is continuously improved by new numerical schemes, advanced material models and coupling strategies. Just recently, we have transferred this software to free and open source under the MIT license, see https://opencfs.org. With a special focus on electromagnetics, structural mechanics, acoustics, and heat transfer, *openCFS* allows high-end computations of the following coupled fields: electromagnetics-mechanics-acoustics; piezoelectrics-acoustics; electro-thermo-mechanics; electrostatics-mechanics-acoustics; aeroacoustics.

The following features, which set *openCFS* apart from commercial simulation programmes, provide an overview of methodological capabilities of *openCFS*:

- FLEXIBLE DISCRETIZATION:
  Non-conforming grid techniques can handle computational grids being considerably different in adjacent subdomains. Through this, not only can the numerical error be strongly reduced, but also the pre-processing of complex geometries is significantly simplified.
- COUPLING STRATEGIES:
  openCFS allows for both volume as well as surface coupling between different physical fields and performs a simultaneous solution of the coupled fields.
- HIGHER ORDER FINITE ELEMENTS:
  In addition to standard FE methods (isoparametric approximation), *openCFS* allows for higher order elements, which guarantee optimal convergence rates and therefore computational efficiency.
- OPTIMIZATION / INVERSE PROBLEMS FRAMEWORK:
  openCFS has capabilities both to perform shape as well as topology optimization, and provides inverse schemes for material parameter determination, source localization, etc.

The Institute of Fundamentals and Theory in Electrical Engineering (IGTE) has a strong research focus on modelling, numerical simulation and optimization of complex technical and medical systems ranging from antenna design, electromagnetic compatibility of electronics based systems, induction heating, MEMS (Micro-Electro-Mechanical-Systems) devices, and sound design to medical applications such as human phonation and impedance cardiography for detecting aortic dissection. To demonstrate the applicability of our developed advanced FE formulations, we will illuminate two highly challenging topics: induction heating and human phonation.

INDUCTION HEATING

Induction heating is a pollution-free, fast and secure technology with highest energy efficiency, and allows a targeted heating for applications including surface hardening, melting, brazing, soldering and heating for shrink fitting, to name just a few. Figure 1 schematically displays a transverse flux induction heating system including the inductor and the metal sheet moving with velocity **u**. As shown the magnetic field **B** indicated by the dashed flux lines is perpendicular to the sheet, resulting in eddy current loops parallel to the inductor with three turns.

The challenge for the numerical simulation of the induction heating process is the large time scale disparity between >

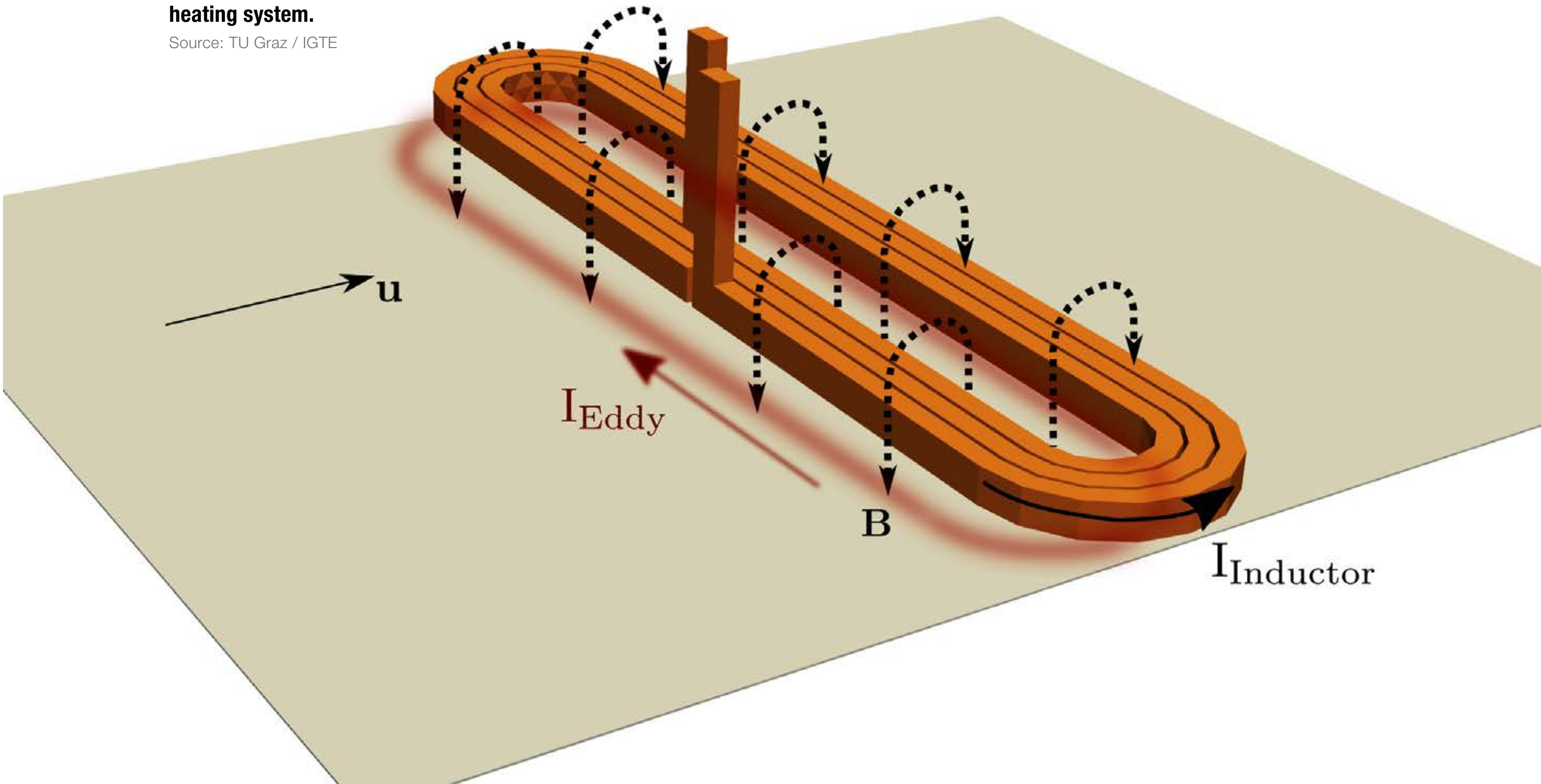


Figure 1: Principle of the transverse flux induction heating system.
Source: TU Graz / IGTE

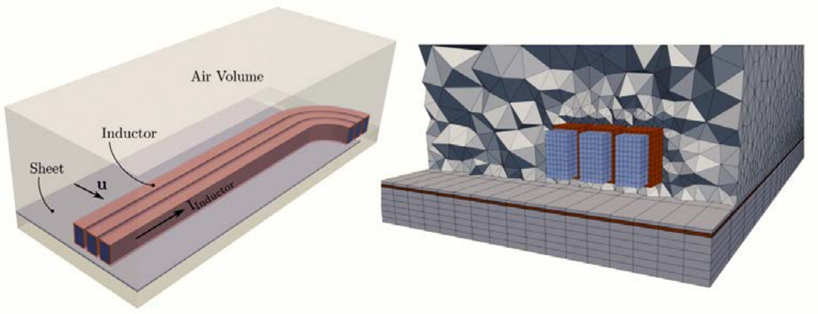


Figure 2: Computational domain (quarter setup) and details of the non-conforming grid.
Source: TU Graz / IGTE

the electromagnetic field changing in microseconds and the thermal field changing in seconds. To achieve a computationally efficient scheme, we have developed a coupling scheme in which the nonlinear electromagnetic field is computed in the frequency domain via the harmonic balancing method and the thermal field in the time domain. In doing so, within each time step of the thermal field we solve the electromagnetic field in the frequency domain with the current temperature distribution, evaluate Joule's losses (due to the induced eddy currents in the metal sheet) and use them for computing the new temperature distribution. Figure 2 displays the computational domain (due to symmetry just a quarter setup is used) and the generated non-conforming computational grid. Due to such a non-conforming grid we can strongly reduce the size of the algebraic system of equations obtained by applying the FE method, and in addition the high quality grid strongly reduces the numerical error.

Figure 3 shows the comparison between measured and simulated temperature distribution along the steel sheet.

The highly efficient numerical scheme allows us to proceed to the next step, which is the topology optimization of the inductor. Together with our industrial partner Berndorf Band Austria, we will apply and extend openCFS to achieve an inductor geometry which minimizes the temperature overshoots near the edges of the metal sheet (see Fig. 3).

HUMAN PHONATION

The voice, the carrier signal of speech, is modulated by pharynx constrictions, tongue motion and oral-nasal area. The process of voice production can be described by the interaction between the tracheal airflow and the two elastic vocal folds (VF) inside the larynx that oscillate periodically (see Fig. 4).

Thus, the two oscillating vocal folds (usually at about 120Hz for male and 240Hz for female) interrupt the expiration air stream periodically forming the primary acoustic voice signal. It is the prevailing assumption that for a healthy primary voice signal the VF vibrations need to fulfill three conditions: (1) The VFs have full contact during the oscillations, i.e. the gap between the VFs is temporary fully closed during an oscillation cycle; (2) the VFs oscillate symmetrically; (3) the VFs oscillate period-

Figure 3: Comparison of temperature fields from experiment (left) and simulation (right).
Source: TU Graz / IGTE

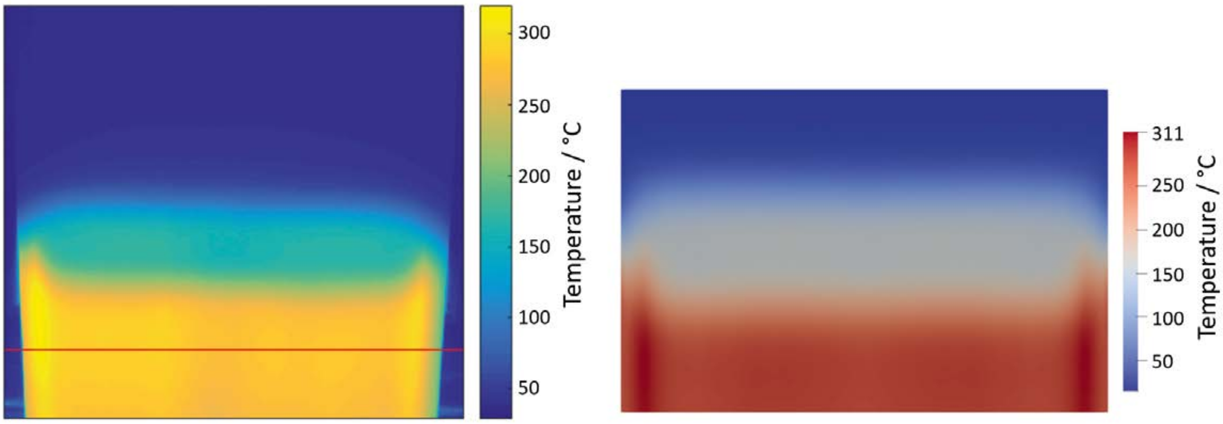
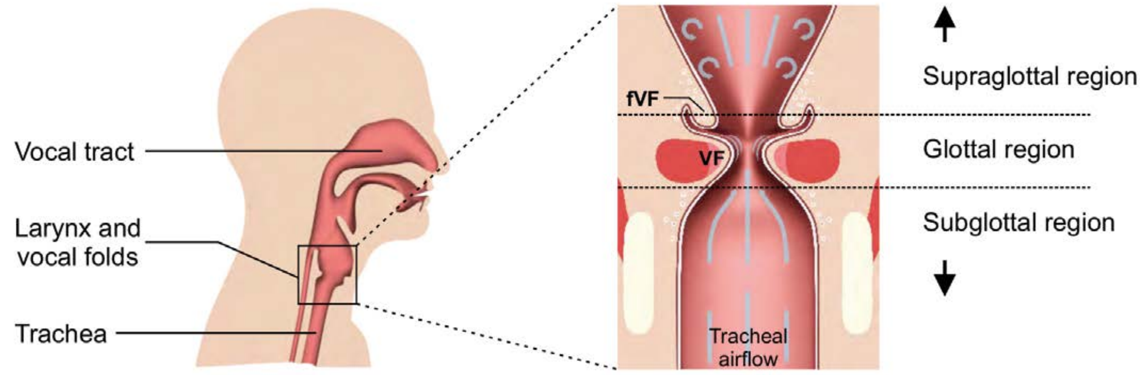


Figure 4: Sagittal view of the upper airways (left) and coronal section of a human larynx (right) with vocal folds (VF), ventricular (false vocal) folds (fVF).
Source: TU Graz / IGTE



ically. The primary generated voice signal is further modulated within the vocal tract and emitted from the mouth resulting in the audible voice. We use our voice continually and take it for granted. However, the exact causalities between airflow, vocal fold dynamics, and resulting acoustic signal are still not fully understood.

For many years, we have had a strong co-operation with Michael Döllinger and his research group, Division of Phoniatrics and Pediatric Audiology, Department of Otorhinolaryngology, Head & Neck Surgery at Friedrich-Alexander University Erlangen-Nuremberg. Our central objective is to develop an aeroacoustic computational model simVoice for clinical applicability. The incompressible flow computation using a LES (Large Eddy Simulation) turbulence model is based on prescribed vocal fold oscillations identified by in-vivo high-speed imaging. In this way the fluid-solid interaction problem, whose accuracy critically depends on reliable geometrical and material parameters of all layers of the vocal folds, is circumvented. According to a perturbation ansatz, the acoustic model is based on the perturbed convective wave equation with the substantial derivative of the incompressible pressure as a source term. The final numerical model simVoice will be made available for scientific and clinical colleagues, and will enable us to judge the effectiveness of therapy techniques, help to suggest changes of existing therapy or even help to support development of new therapy approaches. Currently, a main investigation is the analysis of the acoustic sources in the larynx and especially the changes due to organic dysphonia and post-surgery states. Figure 5 displays the acoustic source terms of a healthy voice at an instant of time when the vocal folds are fully open.

Summarizing, we can state that such investigations are only enabled by numerical simulations based on validated physical / mathematical models solved by efficient numerical schemes. In doing so, we highly appreciate the co-operation with the Graz Center of Computational Engineering (GCCE), and we are optimistically looking forward to the new study programme in digital engineering

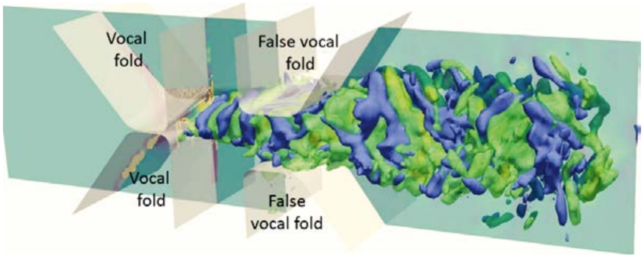
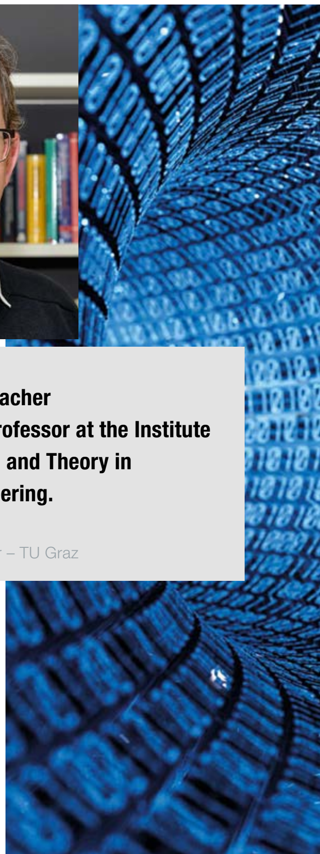


Figure 5: Source terms within the larynx.
Source: TU Graz / IGTE



Manfred Kaltenbacher is head of and professor at the Institute of Fundamentals and Theory in Electrical Engineering.

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