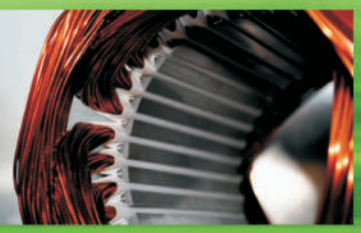

Innovations for the electric motor production of tomorrow

From new process technologies, automation solutions through to Industry 4.0 approaches

Research Sector Electromechanical Engineering

New requirements for electric motor production

The spread of electric mobility will fundamentally change the automotive industry. Apart from high-performance batteries, efficient drives must be developed that meet the strict requirements of the automotive industry in terms of costs, quality, reliability and operational safety. Regarding electric motors, the reduction of installation space, weight and noise emissions is of particular importance. Further objectives include increasing power density, optimizing cooling concepts and improving controllability.

This results in a need for research not only for the development of electric motors but especially for their production. Since industrial motors in higher power classes have only been manufactured in small quantities so far, their production is largely manual. However, for an economical and series-flexible production of electric traction drives, efficient and highly automated manufacturing processes are indispensable. Therefore, far-reaching new developments are necessary to enable existing production technologies of electromechanical engineering for the automotive industry. The cost and quality goals of the automotive industry can only be achieved by a close combination of functional and process optimization measures. ■

Electromechanical engineering at the FAPS institute

In order to meet these new challenges, researchers at the Friedrich-Alexander University Erlangen-Nuremberg (FAU) are working, among other things, on the series-flexible automation of the electric motor production. In the research sector Electromechanical Engineering of the Institute for Factory Automation and Production Systems (FAPS), innovative manufacturing technologies are being researched with the aim of transferring the knowledge gained to industrial practice *(Fig. 1)*. Aside from production-oriented design, the main focus is set on the development and optimization of production processes for components and systems of electric drive technology, particularly for electric mobility and hybrid electric aircrafts. In addition, processes for manufacturing inductive charging systems are being researched.

Electric motors and inductive charging systems represent important components of future forms of mobility. However, they must always be considered in con-

Fig. 1: *View of the demonstration plants for different winding technologies in the laboratory of the research sector Electromechanical Engineering of the FAPS institute* ■

junction with other central components such as energy storage, wiring systems or power electronics. Therefore, the research activities in the field of electromechanical engineering are supplemented by the complementary work of the institute‘s adjacent research sectors Electronics Production, Wiring Systems and Efficient Systems. In total, the FAPS institute employs around 100 people, spread over its two sites in Erlangen and Nuremberg. ■

Research laboratory with extensive plant equipment

Due to the high application relevance of the FAPS institute‘s research, numerous demonstration plants have been set up and optimized in practical test series within the scope of past projects. Sufficient space is provided by the laboratory and office facilities on the former AEG site, on which the research sector Electromechanical Engineering has been located since mid-2011. The large laboratory hall comprehensively covers the various technologies of electric motor production *(Fig. 2)*.

The extensive plant equipment is not only used for the work on research and industrial projects but also for the practical training of FAU students. ■

Research projects along the entire process chain

The numerous past and current research and development projects are distributed along the entire process chain of electric motor production. Thus, the following descriptions are only a small excerpt of the research activities of the research sector Electromechanical Engineering.

As a complementary alternative in the processing of electrical steel, the continuous process of rotary cutting is investigated *(Fig. 3)*. Flexible laser cutting, on the other hand, is used for rapid prototype production. In order to increase the motor's efficiency, a further aim is to minimize the hysteresis losses of laminated cores. For this purpose, the materials used and the respective packetizing processes are being optimized in a current project.

In order to minimize product-specific tool costs, various robot-based winding and pull-in techniques are being tested. Robot-based winding techniques for high-frequency litz wires also enable the production of complex coil geometries for inductive charging systems. In addition, an innovative universal winding machine is being developed, which can be used to produce various winding patterns with varying wire geometries *(Fig. 4)*. A CAD/CAM chain allows a fast and flexible offline programming of the machine.

The next generations of electric traction drives will increasingly use semi-open form coils, so-called hairpins. While hairpins are easier to handle in an automated way, they go along with a high number of contact points. Thus, a central challenge of hairpin technology is the contacting. Here, a promising approach is laser welding, which is being holistically researched and further developed in the research sector Electromechanical Engineering *(Fig. 5)*. Additionally, other projects investigate hot-crimping and innovative ultrasonic welding for contacting enameled copper wires. In the same context, various methods for the removal of insulation from flat copper wires are qualified. Moreover, new concepts for the assembly and twisting of hairpins are examined.

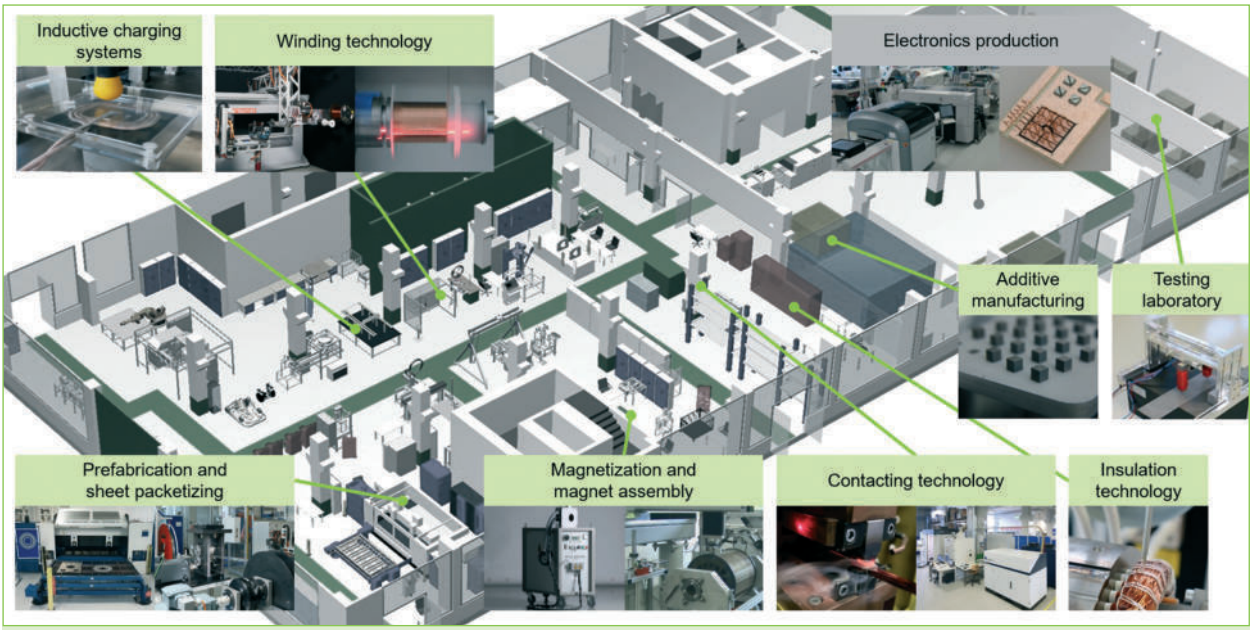

Fig. 2: *Overview of the laboratory hall of the FAPS institute at the site in Nuremberg with numerous demonstration plants on innovative technologies in the field of electromechanical engineering* ■

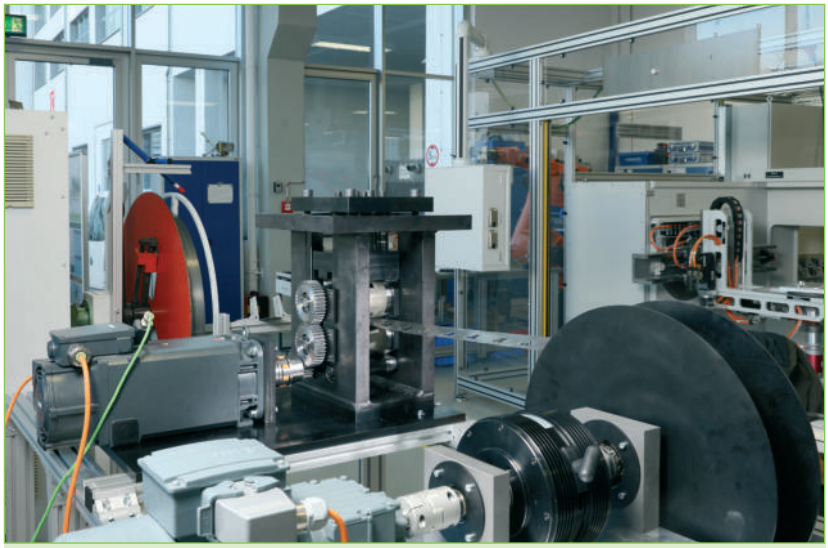

Fig. 3: *Prototype plant for rotary cutting of electrical steel as a complementary alternative to conventional punching* ■

Further optimization potential lies in the manufacturing of the insulation in electric motors. Compared to conventional slot liners, powder coating can significantly improve the copper filling factor of rotors and stators. In addition, the inductive curing of insulation resins is investigated as a resource-efficient alternative to furnace processes. For this purpose, different approaches for effective temperature control and monitoring have been developed.
A further focus of the research sector Electromechanical Engineering is the handling and assembly of permanent magnets already magnetized. Besides feeding devices, precise positioning systems and gluing processes are investigated. In addition, inline measuring systems for rotor testing and a magnet intralogistics system for selective magnet assembly are currently being developed.
Apart from that, automated process chains for the manufacturing and balancing of rotor-shaft connections are investigated. Hereby, a new concept for the combination of packetizing and magnet assembly has been established.
Due to the increased quality requirements for traction drives, it is necessary to develop efficient inline testing methods. As a result, new testing techniques are applied and further developed to enhance product understanding and defect detection. Hence, the magnetic field measuring laboratory of the research sector Electromechanical Engineering provides various magnetic field probes and measuring systems for the characterization of hard magnetic materials, electrical steel sheets or other ferromagnetic components. In addition, various high-voltage testing devices allow the qualification of primary insulation and insulation systems in accordance with standards.
Furthermore, specially developed methods enable the detection of insulation weaknesses caused by manufacturing processes.
Due to the limited availability and the high value of many materials used in electric motors (especially rare earths, non-ferrous and heavy metals), procedures for recycling as well as processes for minimizing the material consumption have also been developed.
The trend topics additive manufacturing and Industry 4.0 are also increasingly being addressed in the production of electric drives. For the additive manufacturing of permanent magnets, for example, the processing of rare-earth magnetic material by laser beam melting in a powder bed is being researched. Furthermore, computer-aided methods of the digital factory are used for the simulation of production systems and virtual process validation. In the context of Industry 4.0, data-driven approaches using machine learning methods offer great potential. In ultrasonic welding, for example, the connection quality represented by the electrical contact resistance could be predicted solely on the basis of sound emissions and images of

Fig. 4: *Innovative universal winding machine for the flexible production of different winding patterns with varying wire geometries* ■

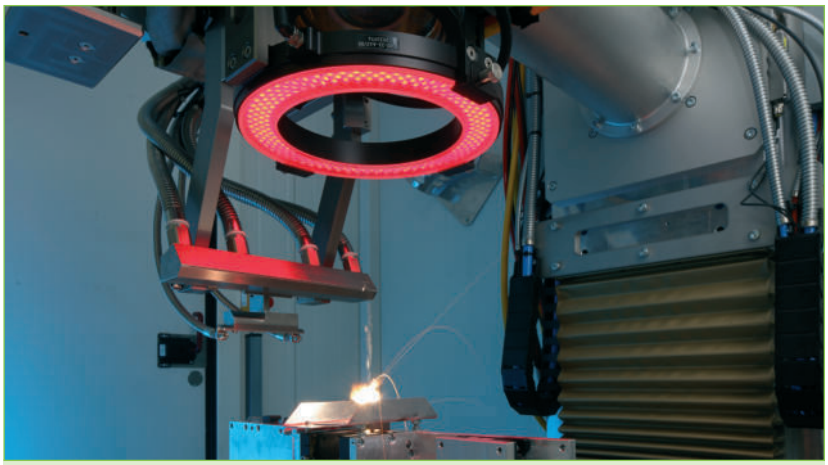

Fig. 5: *Experimental cell for laser welding in order to investigate laser-based processes for joining copper materials* ■

the burnup. Further applications for machine learning methods are currently being investigated in close cooperation with industry. ■

Forms of cooperation and technology transfer

With its research on innovative production technologies for tomorrow's electric drives, the research sector Electromechanical Engineering fits perfectly into the Bavarian cluster initiatives for mechatronics and automation, automotive as well as environmental technology. Since the foundation of the research sector Electromechanical Engineering in May 2010, a high number of research and industrial projects have already been completed. In the course of the E|Drive Center, the Bavarian Technology Center for Electrical Drive Technology funded by the Free State of Bavaria, the cooperation with partners from industry and science has been sustainably strengthened. In doing so, the FAPS institute has been established as a recognized teaching and research institution in the field of electromechanical engineering.

In addition to several invention disclosures, numerous technical seminars, lecture series and conferences were organized. Within the WGP seminar „Production of Electric Drives", scientists from the research sector Electromechanical Engineering invite you once a year to an intensive transfer of knowledge involving lectures, expert discussions and demonstrations in the research laboratory. The seminar program also offers the opportunity to discuss individual problems in electric motor production.

With the E|DPC, the International Electric Drives Production Conference, the research sector also organizes an internationally unique scientific congress *(Fig. 6)*. This year's E|DPC in Esslingen from December 3 to 4 will be the ninth time in a row that a unique platform for an intensive experience exchange on the production of electric drives between science and practice will be offered. ■

Fig. 6: *Annual international conference and accompanying exhibition on electric drives production* ■

E|Drive-Center
Bayerisches Technologiezentrum für elektrische Antriebstechnik

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