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ROBOT-BASED WINDING-PROCESS FOR FLEXIBLE COIL PRODUCTION

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Abstract: Recent technological and market-driven developments are challenging for the winding industry. Highly customized winding products, smaller lot sizes and quantities in conjunction with the necessity for a higher economic efficiency are requirements that can not be met sufficiently with currently available winding technology. Highly productive automated winding systems are not flexible enough and manual labour causes high product costs. For reducing the amount of manual process steps and increasing the flexibility the concept for an alternative winding method was designed at the chair for Manufacturing Automation and Production Systems FAPS. Conventional winding methods generate the winding movements by joining a combination of different axis under the aid of special wire-guiding elements. The new approach realizes the wire placement only by moving a guiding nozzle on a bobbin adapted trajectory with a tripod robot. The bobbin remains stationary during the winding process on a work piece pallet. Hence the number of handling steps can be reduced and flexibility concerning wire placement is increased. In the paper the robot-based winding method is presented and several specific advantages are discussed.

Key Words: Coil winding, Robot, Flexible Production

I. INTRODUCTION

For the utilization of the electro-magnetic effect coil winding products can be found in numerous electronic appliances, especially in automotive, telecommunication and industrial electronic products. The world's market volume for inductive components was in 2008 about 9.6 bil. $ and will be about 7.9 bil. $ in 2009 [ZVEI]. Due to market-driven trends and innovative technological developments of the recent year's specific challenges arise for manufacturers of winding products. Aims, like smaller lot sizes or higher product flexibility, can not be achieved sufficiently with conventional winding systems. Further, new design options, facilitated by innovations in electronics production, can not be utilized entirely when conventional winding methods are used. For these reasons and with respect to the growing demand for innovative winding products the concept for an alternative winding method was developed at the chair for manufacturing automation and production systems of the University-Erlangen-Nuremberg. The method is based on an industrial delta-robot which places the wire on a programmable trajectory (see also [3]). By using the robot for wire placement new possibilities for a flexible process design arise.

II. STANDARD WINDING TECHNIQUES AGAINST THE BACKGROUND OF CURRENT TRENDS

"Coil winding" can be defined as "joining of a core with magnetic wire by a continued bending around the core". For this a rotational movement between the core and the wire is required. In order to achieve a helical structure, an additional feed motion is necessary. The need for winding products in a wide range of applications has led to various coil constructions and hence to different winding techniques. Besides several problem-specific solutions, spindle winding and fly winding are the most common methods [6; 8]. Their characteristics are discussed in the following.

> Fly Winding

Usually this method is used if the bobbin shape does not allow a rotation for applying the windings, as it is for example the case with motor-armatures. In fly winding the wire is transferred via a hollow main spindle and a flyer arm to the stationary bobbin. By rotating around the bobbin the flyer winds the coil (see fig. 1).

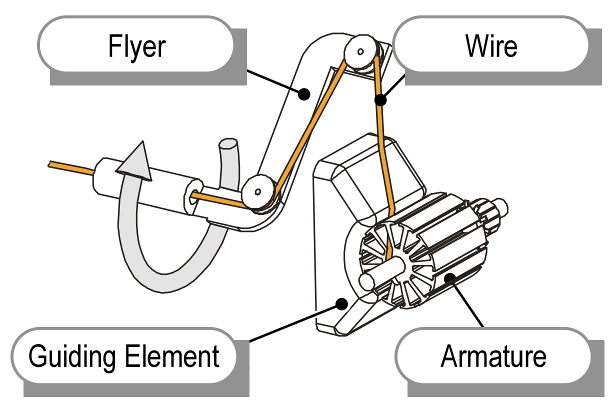

Figure 1. Fly Winding Process

One of the main disadvantages of fly winding is the necessity of guiding elements for forming the coil. As these aids are specially designed and constructed for each coil type, product changes are linked with high expenditure of time and costly machining processes for producing the wire guides. A further disadvantage of fly winding is the poor precision concerning wire placement and uniformity of the coil. [1]

> Spindle Winding
For winding small, axially symmetrical coils spindle winding with rotating bobbin is used. Here, the wire passes from the wire source via the wire guide to the rotating bobbin on the spindle. By a traverse movement of the wire guide between the two flanges of the bobbin the winding machine places the wire side by side, layer upon layer on the bobbin (see fig. 2).

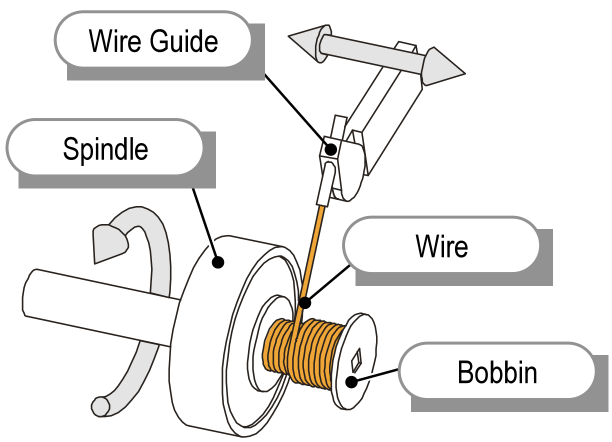

Figure 2. Spindle Winding Process

Spindle winding is not appropriate for winding strongly asymmetrical bobbins, as they cause unbalance effects at high winding speeds. Furthermore this method is not suitable for delicate products, as their structure would be damaged by the high centrifugal forces. Besides this, a direct, unlimited accessibility to the winding space is essential. This means that bobbins integrated into housings or placed very tight can not be wound with this method.

Current trends in production technology are challenging for the conventional winding methods shown. Requirements like highly customized winding products, smaller lot sizes and quantities in conjunction with the necessity for a higher economic efficiency [7] can often not be met sufficiently with winding technology currently available. For instance, machines used for fly winding are characterized by a high complexity and a highly specialized construction. Further more significant machine set-up times (adjusting flyers, shields, guiding elements etc.) in conjunction with small lot sizes affects the profitability negative. Also for conventional spindle winding machines the described trends are challenging. For instance, with single spindle-machines it is possible to realize a lot size and variant flexible production. However, due to the high amount of manual process steps at the expense of the cycle time. Multi-spindle machines, especially designed for high volume production, have a very product specific set-up. Hence, every product change causes significant down times and reduces the productivity.

In addition, innovative technological developments are both, challenges and opportunities for the winding industry. For example, the 3D-MID technology offers by a combination of mechanical and electrical features new design possibilities for electronic products [4]. Hence the size of electronic products can be reduced by integrating bobbins into the circuit board or the housing. Winding such integrated coils with conventional methods is almost unrealizable. Further, areas such as medicine or automotive technology have higher demands on the design of inductive components. Especially the design of the coil shape according to the product's shape will gain importance in future, whereby their production with conventional winding methods is hindered [2]; [5].

To sum up, it can be stated, that it is not sufficiently possible to face current market driven requirements, such as small lot sizes or high product flexibility, with traditional winding methods. In addition, the design possibilities, facilitated by current developments in the field of electronic production, can not be fully utilized.

III. CONCEPT FOR THE ROBOT-BASED WINDING-PROCESS

Considering the shown deficits of standard winding techniques and against the background of the expected increase in demand for innovative winding products, such as RF-ID or drive electronic components for the automotive sector, an alternative winding method was developed at the institute FAPS. It offers both, potential for the economic production of conventional coils as well as for the flexible manufacturing of innovative winding products.

With conventional winding methods the motions needed for winding the wire are realized by a combination of different individual kinematic elements or/and by using special wire guiding aids. In contrast to this, the invented winding process generates the winding movement solely by moving the wire guide on a bobbin-adapted trajectory. The bobbin remains stationary during the winding process and for laying the wire no additional wire guiding elements are necessary. To obtain maximum flexibility in designing the trajectory an industrial robot is used for positioning the wire guide. As a result, the winding motion can easily be adapted to the requirements of different winding products. In the following the possibilities of the new method will be shown in contrast to the respective conventional winding methods.

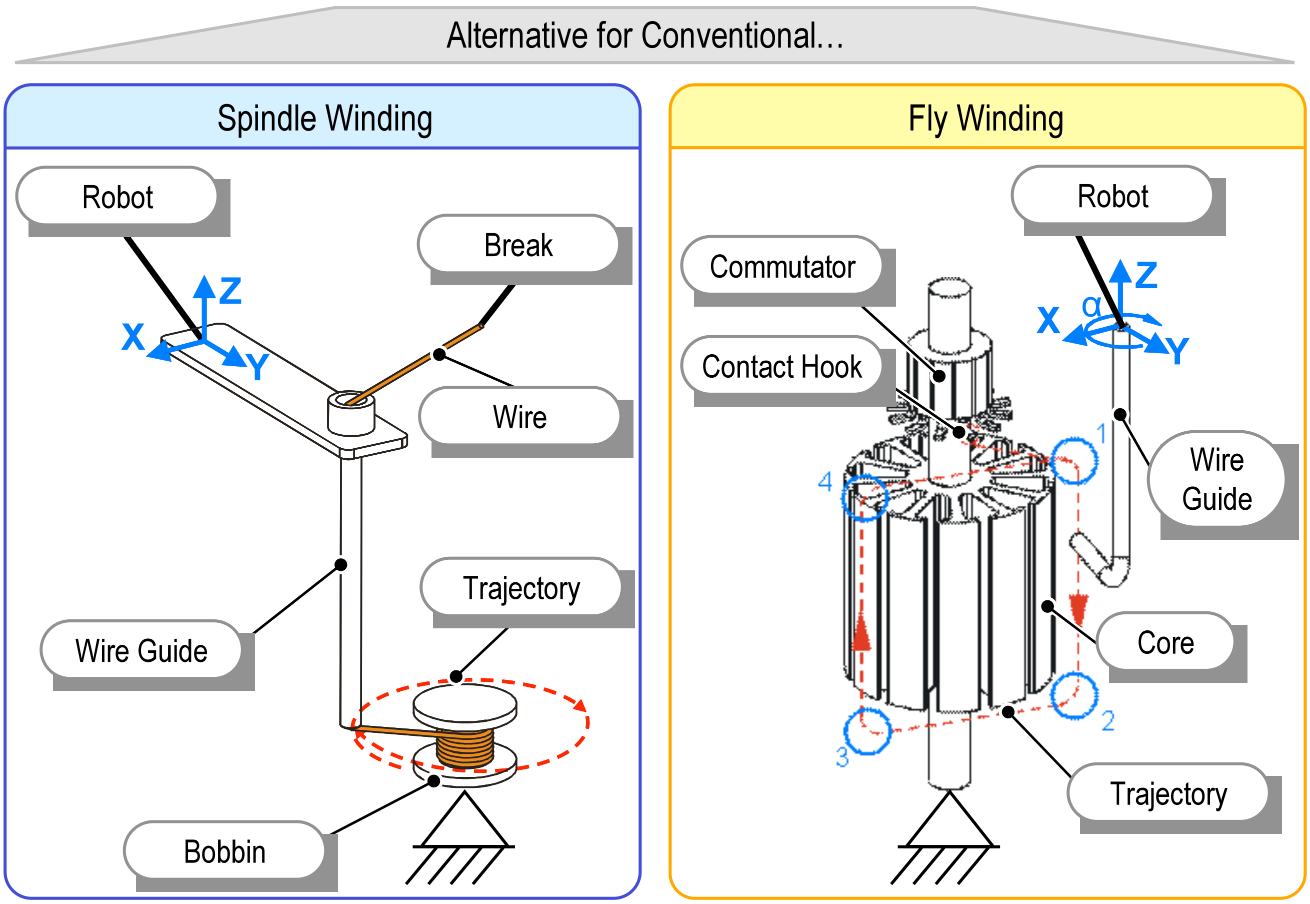

Figure 3. Alternative Processes of the Robot-Based Winding-Method

In fig. 3 the alternative processes of the developed method are shown. Coils traditionally manufactured by spindle winding can be produced with the new method by moving the wire guide helically around the bobbin. The pitch of the helix corresponds to the feed rate of a conventional winding machine. By an appropriate programming of the robot, it is also possible to move the wire guide stepwise in Z-direction at the transition between two windings, whereby the production of so called orthocyclic coils (coil shape with improved electrical and mechanical properties) is facilitated. Besides circular bobbins it is also possible to wind on bobbins with arbitrary shape by simply adjusting the wire guide trajectory according to the bobbin's cross-section.

Winding armatures or similar multi-chamber bobbins is also possible by using a rotatable, L-shaped wire guide. Here the wire guide is moved on a trajectory around the perpendicularly standing armature. The trajectory is programmed according to the pole dimensions of the armature. After finishing a pole the wire guide is rotated by an angle according to the number of poles. Then the wire is connected to the commutator and the next pole is wound. As the wire guide is rotatable, the armature can remain stationary throughout the winding process. So the mechanisms conventionally needed for handling the armature in a fly winding process are obsolete.

In comparison to conventional winding methods, the robot-based offers several advantages. Especially the flexibility concerning the bobbin shape, facilitated by the freely programmable wire guide trajectory, has to be considered as an advantage. Thus, it is possible to wind virtually any winding pattern on arbitrary formed bobbins or to produce armature windings without special wire guides, as they are necessary with conventional fly winding machines. By the removal of these auxiliary aids, flexibility is increased, setting up effort is reduced and thus a significant contribution to the availability of the winding system is made.

In addition, with the presented method, bobbins can be wound directly on a workpiece pallet. Through this, the number of handling steps is significantly reduced compared to conventional winding methods. Hence, cycle times can be reduced and system stability is increased. Moreover, winding operations can easily be parallelized, since by the combination of multiple wire nozzles to a wire guide comb the movements of the robot can be used for the simultaneous winding of several bobbins. So a complete row of bobbins on a workpiece pallet can be wound in a work cycle.

Another advantage lies in the procedural and functional integration. On the one hand, the functionality of different conventional winding methods are combined, on the other hand, the robot can also be used for assembly tasks (e.g. winding an armature and then assembling the motor). This would allow the usage of low-priced standard automation solutions instead of complex special winding machinery for winding as well as for assembly. Further the function integration reduces the number of handling and loading operations and hence the process chain "winding" becomes more robust. The stated advantages are summarized in fig. 4.

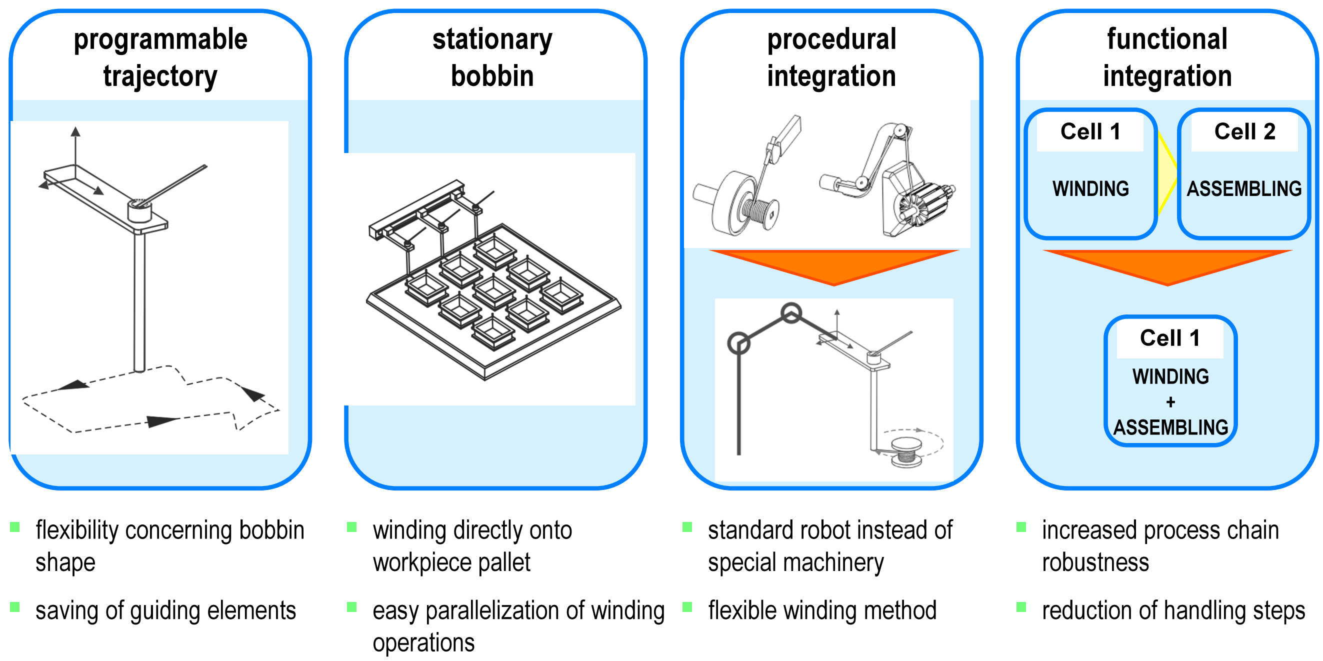

Figure 4. Advantages of the Robot-Based Winding Method

IV. EXPERIMENTAL SETUP

The structure of the experimental production cell is shown in fig. 5. The main components, detailed described in the following, are a highly dynamic delta-robot from ABB that positions the wire guide, the tensioner for breaking the wire and the conveyor for the material handling.

> Robot

The performance of the robot-based method depends largely upon the robot's kinematic. In principle every robot offering the required degrees of freedom (X, Y, Z and α) for positioning the wire guide in space can be used. However, robots with a serial kinematic like Scara-, Six-Axis- or Linear-Axis-Robots, are not suitable due to

their low speed. In contrast to this, robots with a parallel kinematic, like tripods or hexapods offer much higher velocities and accelerations. In particular, tripods have excellent dynamic characteristics (about 4 times faster compared to serial kinematics). Hence, for the construction of the experimental winding system a so-called tripod with an additional rotational axis for rotating the wire guide was used. The setup of the winding system is shown in fig. 5.

For the prototypical winding system an IRB 340 Robot from ABB was chosen. Unlike to conventional industrial robots the drive axes of this tripod kinematic are connected in parallel to the end-effector. The robot consists of a fixed and a moving platform connected via several parallel-kinematic links. This results in a number of advantages:

- increased accuracy and rigidity, as positioning errors and resiliencies of the single drive axes do not add up
- better load-mass-ratio, as drives only have to handle the load and no other robot parts like in conventional serial kinematics

With the IRB 340 the end-effector is moveable in three axes X, Y, Z translatory and rotatory around the Z-axis by a double-cardan shaft mounted in the centre. The maximum payload of 1 kg allows the processing of wires up to a diameter of 0.42 mm, whereby a wide range of winding products is covered. The maximum speed is 10 m/s at an acceleration of 100 m/s². The maximum speed of conventional robots is about 2.5 m/s at an acceleration of 20 m/s².

> Wire Guides

For the described application fields, two types of wire guides were designed. For coils traditionally produced with spindle winding, a straight guide is used. It is mounted in a holding plate which is eccentrically fixed on the tool flange of the robot. To reduce the stress on the wire at the inlet to the wire guide, a ceramic ring reduces the friction between the wire and wire leader. Hence additionally, wear (running brands, abrasion, etc.) of the wire guide is significantly reduced.
For winding products requiring an additional rotation of the wire guide a around the Z-axis rotatable "L"-shaped wire guide is used. The rotational positioning is carried out by the fourth axis of the robot with the rotary motion transferred by a toothed belt. To minimise additional impact on the wire also here a ceramic ring is at the inlet of the guide wire.

> Tensioner

For a correct winding structure without loops or loose windings the wire has to be loaded with a tensile force. For this purpose a wire tensioner is placed between wire source and wire guide. It creates a tensile force according to the wire diameter. In the experimental set-up a tensioner from Meteor is used. It features tensions between 10 – 300 cN and wire pullback, especially necessary when winding non circular bobbins. The brake is connected via RS 232 with the robot-controller for Start/Stop changing the Set-Value or for indicating Wire-Break.

> Assembly Conveyor

The winding robot is loaded with bobbins via a work-piece pallet based conveyor controlled by the robot via digital IOs. The pallets with a size of 300 x 300 mm allow the simultaneous transport of several bobbins into the working area of the robot. As a result two advantages arise. On the one hand, work-piece changing times are reduced, since there are only changing times for the work piece carrier and not for each single bobbin. On the other hand, cycle times can be reduced by the use of several wire guides for winding several bobbins simultaneously on one work piece pallet.

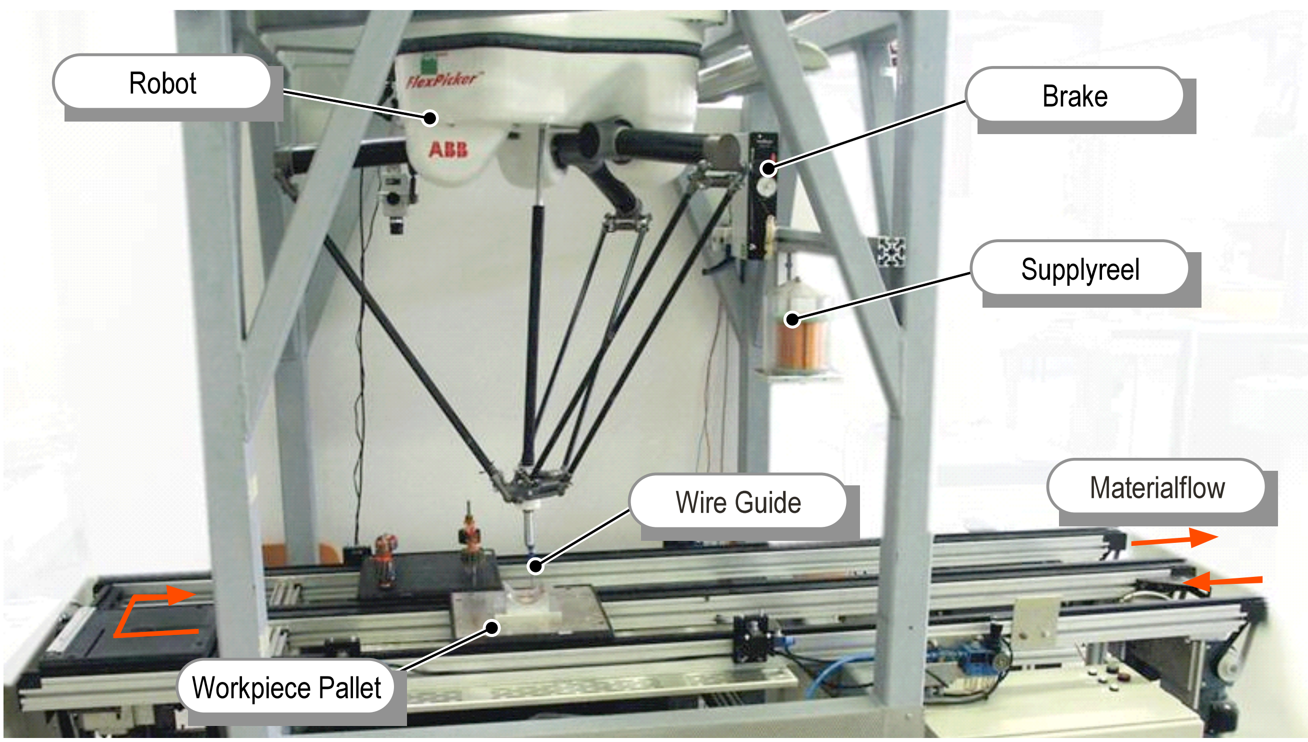

Figure 5. Main Components of the Experimental Setup

V. EC-MOTOR AS CASESTUDY

To prove the functionality of the prototypical winding system and to demonstrate the benefits an electronically commutated motor was developed as demonstration product. It consists of a stator with coils wound on and an armature with permanent magnets. The coils in the stator are commutated via a bridge circuit of transistors driven by a microcontroller. Therefore this motor type is called electronically commutated (EC-motors). In fig. 6 the winding process of the stator is shown.

With conventional winding methods it would not be possible to wind the single poles directly onto the stator. Instead the single coils would have to be wound from self bonding wire individually on a spindle winding machine and assembled and interconnected afterwards. Hence, with conventional winding methods an enormous number of handling steps would be necessary, causing high production costs. In contrast, with the new method it is possible to wind the poles of the motor directly on the stator. As the stator remains on the workpiece pallet throughout the whole winding process, no additional workpiece handling is required. Furthermore, as wire is laid without being cut and connected directly to the connector pins the wiring effort is reduced significantly. For finishing only the wires have to be soldered to the connector pins.

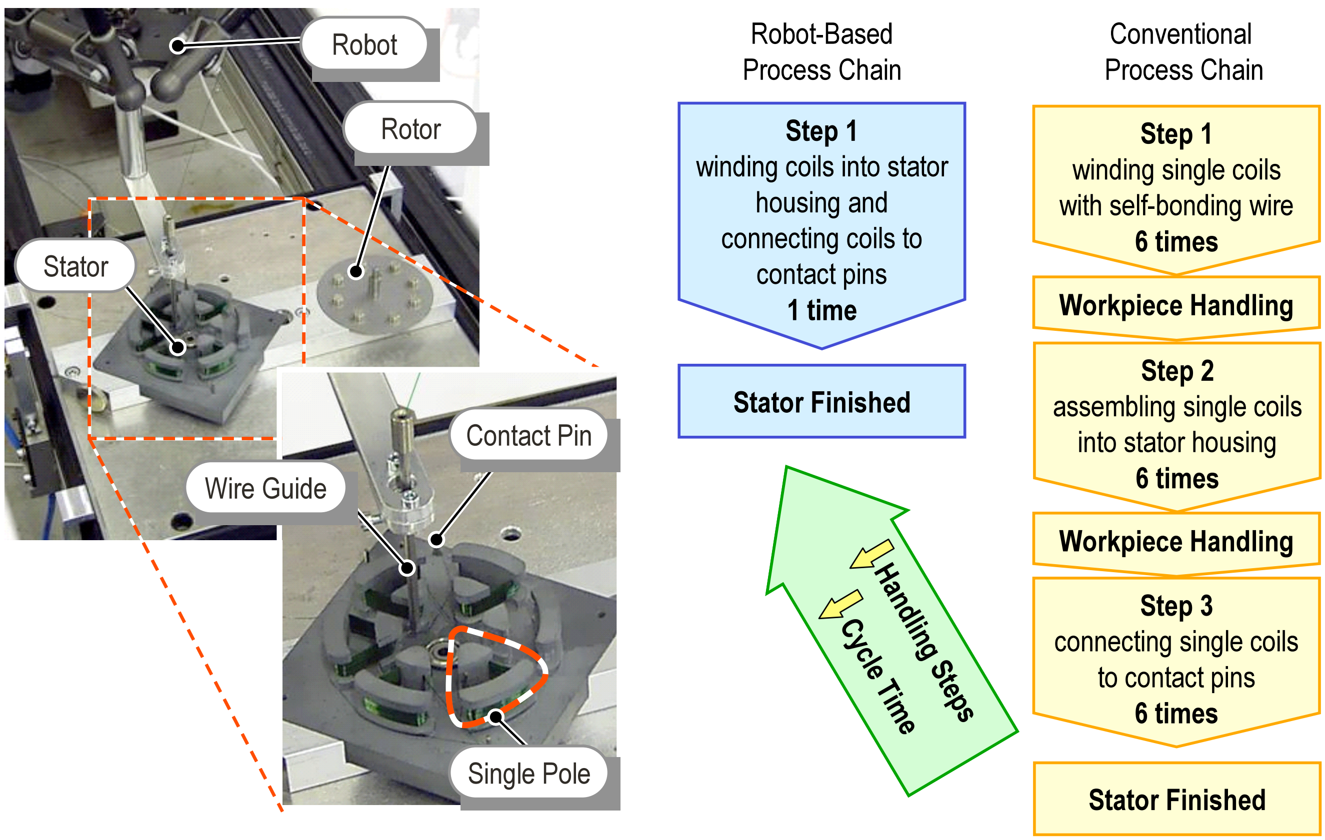

Figure 6. left: Winding the Stator of the EC-motor in the Experimental Production Cell
right: Comparison of a Conventional and the Robot-Based Production Chain

VI. CONCLUSION

Recent technological and market-driven developments are challenging for winding technology. Customized winding products, smaller lot sizes and quantities in conjunction with innovative technological developments in the field of electrical engineering pose challenges and opportunities. In this paper the concept for an alternative winding method developed at the Institute for Manufacturing Automation and Production Systems FAPS was presented. The new method was implemented prototypically. With the experiments carried out it was possible to prove the stated advantages and to show that a significant contribution to the economic production of winding products is made.

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