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Robotic Automatization of Handling and Contacting the Ends of Windings for Mounting Electric Drives

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Abstract— **The connecting process is still one of the most time-consuming processing steps in the production of electric drives. For this reason, the E|Drive-Center at the Institute for Factory Automation and Production Systems (FAPS) from Friedrich-Alexander University Erlangen-Nuremberg (FAU) is researching a solution centered on the flexible automation of this process. This paper examines the possibility of automating the contact of windings' ends in an asynchronous motor with a universal, ambidextrous robot using a contact base. Here, the related ends of the enameled copper wires are connected before plugging in the power supply. In doing so, the robot saves the ends directly after manufacturing the coils in a winding machine and transports them to the face side of the stator. The final connection with the motor periphery is implemented with termination clamps whereby a blade cuts through the wire insulation and produces an electrical connection, while the wiring for the motor concept is actualized by a wiring institution in the form of a plastic ring with printed conducting paths. This form of contacting the ends of windings while mounting an electric drive with a universal, ambidextrous robot has the potential to save time and improve process stability.**

Keywords—electrical drive production; contacting; connecting, robot; wiring; automation;

I. Introduction

In the 19th century wheels were moved by steam engines, water power or simply muscle. Nowadays those drives have been replaced by more efficient and stronger engines, which are driven by electrical energy. Electric drives have gained in importance and are indispensable in industry and trade, in vehicles and also in everyday life. In Germany more than half of the produced electrical power is consumed by electrical engines [1]. Such engines will continue to become more and more important, as the relevance of combustion engines fades due to the scarcity of resources [2].

This is an opportunity for companies within the sector, but also represents a big challenge: the mounting of electrical engines for small lot sizes or big motors is slightly automated.

Because of a high degree of required flexibility most process steps are performed manually. Since manual labor is becoming more and more expensive in industrialized nations like Germany, researchers and leaders must determine how to make manufacturing cheaper and more economical. Thus, concerned companies have to outsource added value to low-wage countries. A solution is the automation of sub-processes or the whole process chain. [3]

The current resource for combining automation with a maximum of flexibility is standard robots, which are becoming ever more important. Manufacturing lines within the automotive construction emphasize this development. For this reason, the E|Drive-Center at the Institute for Factory Automation and Production Systems at Friedrich-Alexander-University Erlangen-Nuremberg (FAU) is researching ways to assemble the stator of an asynchronous motor with a dual-arm robot. [4]

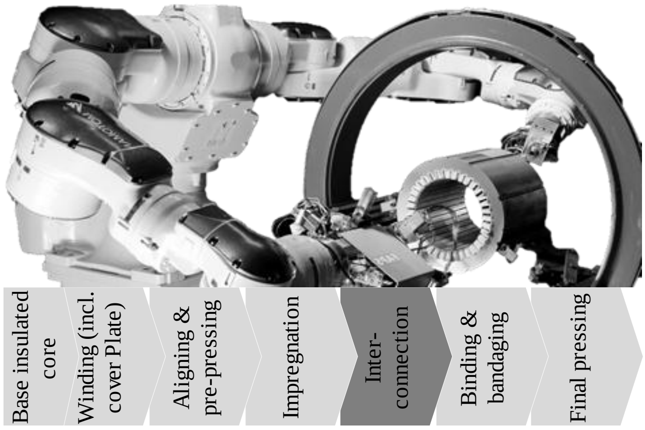

Fig. 1. Process chain of the robot-based stator assembly

The following work addresses the process step of interconnection, especially the contacting of the windings' ends. In this paper the contacting methods in electromechanical engineering are first described. After discussing the evolution of these different technologies the development activities at the automation cell are described. Finally the engineered assembly tools will be shown.

II. Methods for Electrical Contacting While Mounting an Electrical Drive

Within electrical engineering, many different methods exist for contacting the ends of windings. Currently it is not known which of them are actually applied, but according to

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their construction the methods can be classified as:

- Contacting by using a contact base
- Contacting without using a contact base

Both methods differ in the element with which the ends of windings are connected in accordance with the wiring concept of the engine. In the following, a short description of both versions is provided.

A. Contacting by using a contact base

Fig. 2 illustrates contacting by using a contact base (contact elements fixed on a base part).

This method is characterized by the use of a contact element, which is fixed on a base part (contact base), and which forms the connection point for the wire ends inside the stator and the motor periphery with a power supply. Both the contact element and the base part can differ in form and connection process. [5]

The common connection processes for the contact elements are soldering, welding or press contacting. The sort of connection influences the form of the element decisively. Base part versions can be divided into parts with and parts without conducting paths.

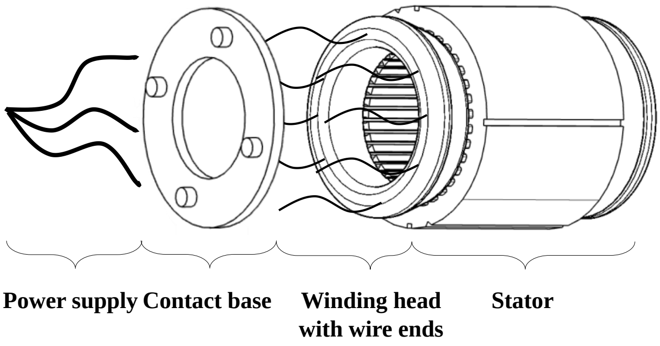

Fig. 2. Contacting by using a contact element

B. Contacting without using a contact base

The method without using a contact base to bond the end of windings forms the electric connection by bringing the connecting parts together at an imaginary point (as shown in Fig. 3). The related enameled copper wire ends are linked with the help of an electrical terminal element [6]. Depending on size and function, the structure can vary in many different ways.

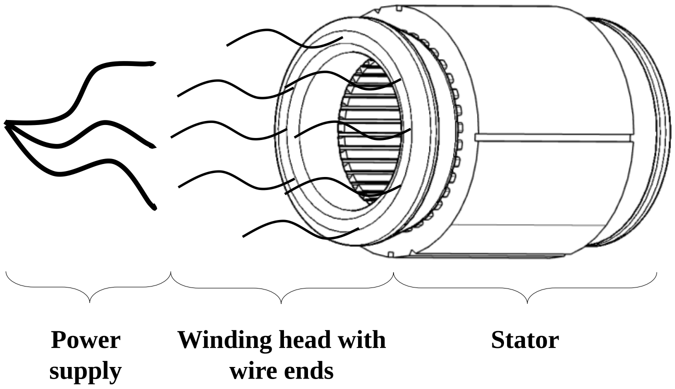

Fig. 3. Contacting without using a contact element

This procedure is commonly used in practical applications for bigger, asynchronous motors. The main advantage is the higher current carrying capacity of the system without a contact base. [7] [8]

C. Comparison of the different contacting methods with regard to the existing assembly cell

The assembly cell at the Institute for Factory Automation and Production Systems includes a winding machine as well as a dual-arm robot SDA 20D from Yaskawa, which mounts a stator at a shaft height of 85 mm. The stator is fixed in a stator holder (cf. Fig. 11). With regards to the assembly system both main types of contacting show special advantages with regard to processing the wire ends. The most important aspects that are attributed to the two methods are listed in Table I.

It is often problem to choose one of the contacting methods with the given information. A more exact selection process and first experiments are necessary for figuring out the better strategy for contacting with the help of a universal, ambidextrous robot.

TABLE I. COMPARISON OF THE DIFFERENT CONTACTING METHODS

Crite-rion	**Contacting method…**	
	…with a contact base	***…without a contact base***
Main advantages for the assembly cell in question	• High degree of automation • No need for external machining process • Defined position during the whole process • Higher processing speed possible • Time efficient • Advantages in stability and functionality • Economical for big quantities • Straightforward structure	• High degree of flexibility • No need for additional building components • Universal method • No need for system adaptation • Applied and proven way of contacting

Ultimately, a choice is made because of the higher degree of automation and due to the fact that contacting by using a contact base is not common for electrical motors of greater shaft heights. This, combined with the possibility of simplifying and optimizing the stator mounting with a robot, is the decisive reason for pursuing the unconventional use of a contact base.

III. COMPOSITION OF THE ENTIRE CONTACTING SYSTEM

To design a contacting system as shown in Fig. 2 the concept has to deliver the following results:

- A processing method for manufacturing the electrical connection
- A contact element based on the processing method
- A base part to apply the contact elements
- A connecting process to attach the base part at the stator face side in question
- Wiring based on the motor concept

The primary goal is to find an optimal, basic solution structure for the existing assembly cell.

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The components have to adapt to the circumstances of the SDA 20D. In the following, the particular elements are described since they have been designed one by one.

A. A processing method and contact element for manufacturing the electrical connection

The electrical connection is the most important element of the endeavored contacting system since it forms the base for stable functionality. For that reason, special attention is given to this component.

Many different techniques exist for forming an electric contact. The most advantageous technique for the given circumstances is the integration of termination clamps. These cutting elements show numerous preferences in terms of the work task as listed in Table II.

TABLE II. ADVANTAGES OF TERMINAL CLAMPS FOR ROBOTIC CONTACTING

Advantages regarding…	
…previous and common methods	***…broader view***
• No need for further means of production • No external, thermal input • Stripping, contacting and cutting to length of the enameled copper wires integrated into one operation • Robot-internal energy source sufficient to implement the process	• Simple and linear motion with defined coordinates • High degree of automation • Minimal processing time • Novel system

The main reason for selecting the terminal clamps is the fact that no external means of production are required as well as the possibility of integrating stripping, contacting and cutting into one process step.

Instead of using purchased parts, a specially designed cutting element (as shown in Fig. 4 b) is manufactured at FAPS and adapted to the task. The principle and the joining motion of the contact element is illustrated in Fig. 4 a.

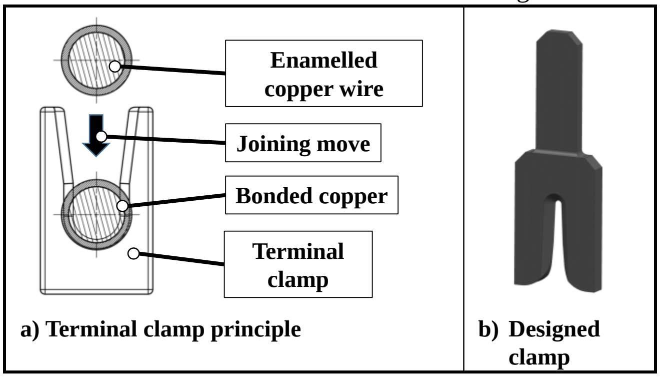

Fig. 4. Terminal clamp; working principle and implementation

B. Base part for applying the contact elements

To complete the terminal clamp connection a further part is needed to apply the cutting elements. This part receives and saves the ends of windings until the clamps are joined. In addition, it is beneficial to optimize the geometry for downstream process steps like forming the winding head by creating the inner counter based on the maximum head dimensions. After several attempts, a base part can be designed as shown in Fig. 5 b.

Within the component cross-chamber pockets are provided to receive the copper wire as well as the terminal clamps. An arrangement of the pockets according to the motor wiring concept (cf. Fig. 5 a) is indispensable.

For a demonstrating stator with the three phases U, V, W and single copper winding, a pocket for every third stator slot is required. Beyond that, the robot tool must be easily accessible. The base part as installed in an assembly cell is shown in Fig. 5 b. While pockets are provided for the completed ends of windings throughout, the contact elements are joined in the perpendicular openings of the chambers. The part is designed in order to support parallel mounting steps.

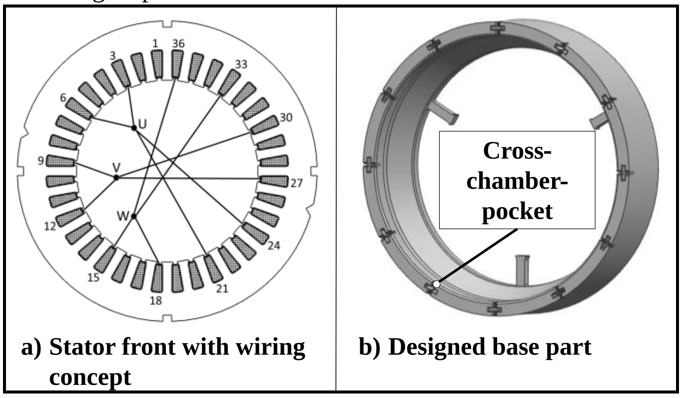

Fig. 5. Wiring concept and designed base part

The designed part itself can be fixed to the stator face side with glue. Added notches guarantee an orientation in the correct position.

C. Wiring institution to complete the system

To create a functional electric stator a wiring based on the motor concept as shown in Fig. 5 a) is required. This connection can be finalized in different ways. The most important aspect to be considered is a stable electrical transmission with a sufficient current carrying capacity.

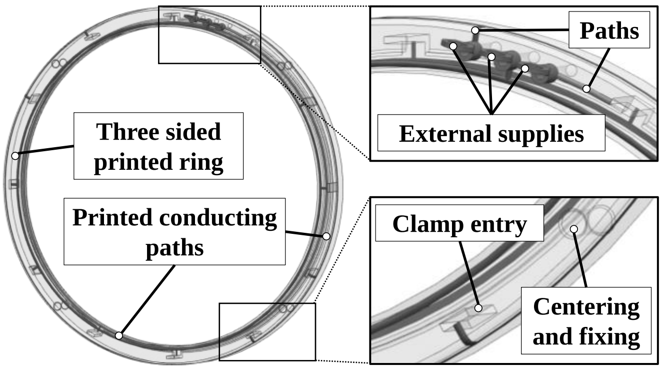

Fig. 6. Wiring by surface-printed conducting paths

The two selected manners for connecting the ends of the terminal clamps differ in the component that contains the conducting paths. One way is the application of electrical paths on the surface. The primary disadvantage of this version is the vulnerability to damage from the robot's operations.

In this way the tracks cannot be placed on the base part itself, rather a further base has to be installed.

The most obvious solution is a simple ring, adapted to the face side of the base part (cf. Fig. 6). The conducting paths are printed on the surface of the ring.

Another method developed to complete the wiring system is accomplished through the integration of an electrical path skeleton within the designed base part (cf. Fig. 7). This technique provides the opportunity to rationalize additional operations for the universal, ambidextrous robot as well as waiving further parts. Identical to the paths, the terminal clamps are integrated within the base part. The cutting edges are the only visible elements of the electro conductive system.

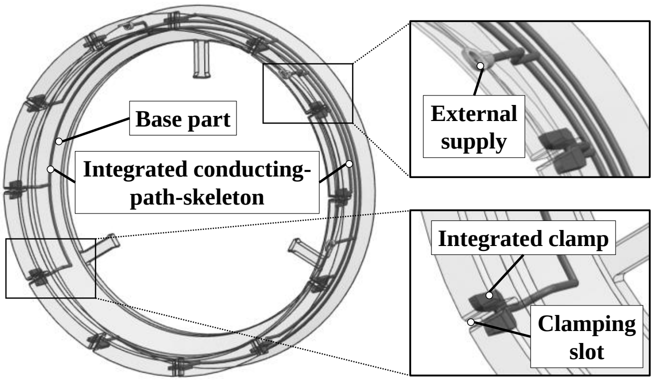

Fig. 7. Wiring by an internal conducting-path-skeleton

Due to the complex structure, this version and the challenging manufacturing only makes economic sense if applied in mass production.

Both versions contain external supplies to feed the stator with electrical power. In spite of the main advantages that exist with a skeleton model, the surface version is implemented afterwards.

D. Overall construction of the designed contacting system

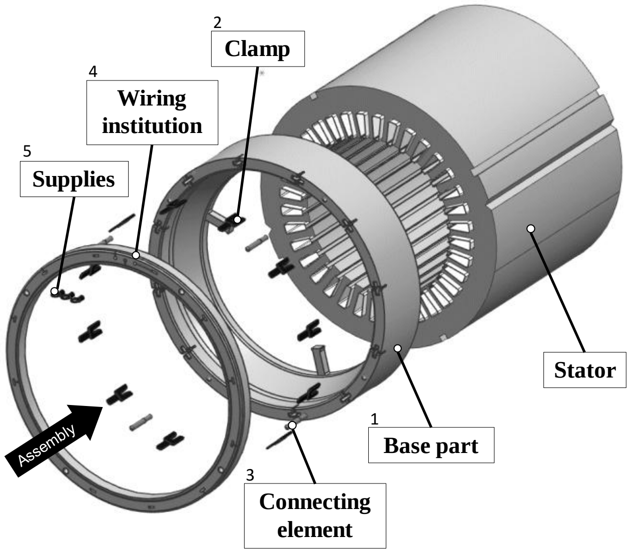

Fig. 8. Overall construction of the designed contacting system

The complete contacting system as designed contains five different elements to be handled by the dual-arm robot:

1. A base part with cross-chamber pockets
2. Terminal clamps for contacting
3. Connecting elements to fix the wiring institution
4. A wiring institution with printed conducting paths
5. External supplies for electrical power

Fig. 8 illustrates the component parts as well as the mounting progression and clarifies that all joining movements chosen are rectified and linear. This favors the contacting performance of an ambidextrous robot.

IV. Robot-tool for handling and mounting

For handling and mounting the ends of windings a special robot tool needs to be integrated in the assembly cell. As the robot supports pneumatic components, the functional elements are driven with pressurized air.

The conceptualized tool takes and saves the wire ends straight away at the upstream automatic coiling machine. Both ends of one coil are stored on the left and the right side of the manufactured winding by three angular grippers (cf. Fig. 9). A parallel gripper severs the wire from the feeder and enables the winding-transportation.

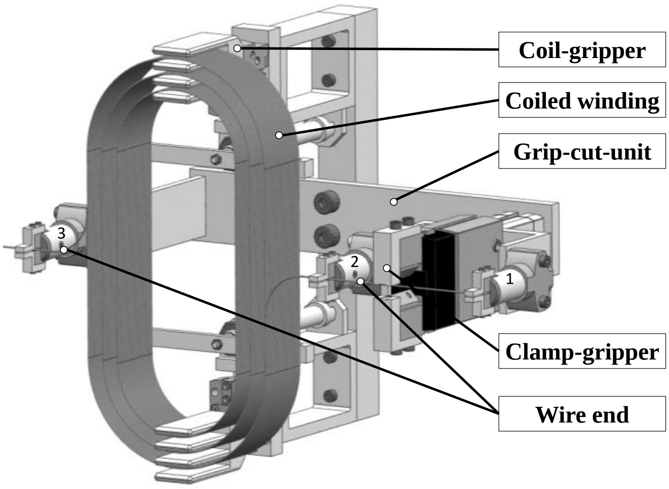

Fig. 9. Robot-tool for handling and mounting

The robot transports the coiled winding to the stator face side and pushes the wire ends in the provided clamping slots within the base part as shown in Fig. 10. This process step has to take place before mounting the windings in the stator slots.

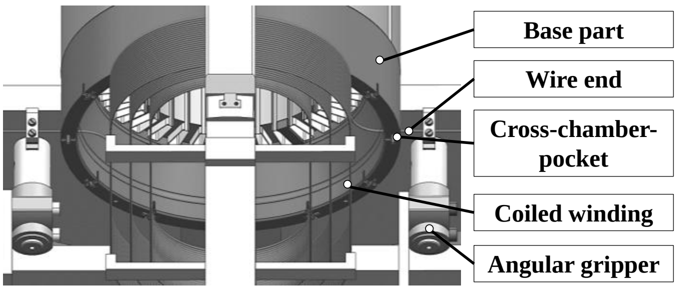

Fig. 10. Joining of the wire ends within the base part

Immediately after dropping the windings and the wire ends onto the desired positions, the robot can reset the tool back to the starting position of the coiling machine. The described process has to be repeated until the stator is filled with the intended number of coils, followed by the mounting of the clamps and the affixing of the wiring institution.

If the final process step is completed automatically, a further tool for handling the wiring ring has to be inserted. The implementation of the contacting process only needs one arm of the robot as operations on just one stator face side are performed. As a result, the second arm can be used to execute other process steps at the same time (Fig. 1), e.g. die assembly of the cover plates.

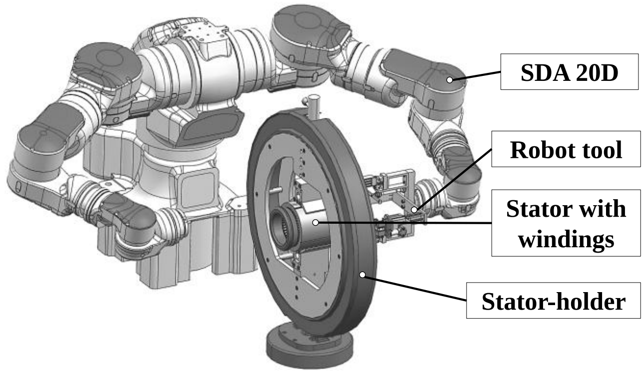

Fig. 11. Assembly cell with robot SDA 20D and stator

V. Integration of the Entire Connection Process

As the development of the assembly cell at the Institute for Factory Automation and Production Systems has progressed far in practice [9], the contacting system can be integrated into the entire process. The following diagram illustrates the essential steps of the mounting explanation. Operations that are not a direct part of the contacting process are not precisely defined (mounting the windings and forming the winding head) but are still important for classifying the separate steps.

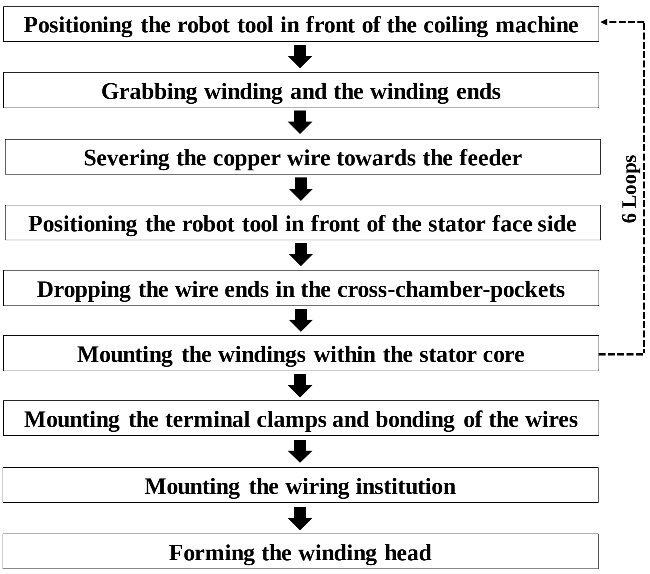

Fig. 12. Step-by-step explanation of the contacting process

As was mentioned before, the process from the start until the mounting of the windings within the stator core has to be repeated six times to fill the stator with coils and to position the wire ends in the cross-chamber-pockets. The forming of the winding head (with the SDA 20D) end with the mounting of the stator.

In total the entire process that needs to be performed is much more complicated in reality than is shown in this chapter. The steps listed above merely represent the main process steps. However, to first comprehend and organize the steps in a general context the basic explanation is sufficient.

VI. Results and Conclusion

Summarizing the contacting system with a contact base achieves good results. The expected functionality within the assembly cell in collaboration with the robot was proven. Compared to previous research without using a contact base the designed system functions properly. The winding ends are defined at any time and there is less handling and mounting work necessary. The compatibility with other process steps is ensured and additionally, the developed solution is characterized by operational safety, strength and little susceptibility to damage.

In addition, there is definite time-savings potential. The processing times for contacting and forming the winding head can be reduced significantly. Moreover, no tool replacement for connecting the wire ends with the periphery is needed.

The task for future research is to make the contacting system more economical for mass production. In this regard, it is recommended to insert the base part with an internal conduction-path skeleton. Overall the designed contacting system with a universal, ambidextrous robot offers a solution to how future automation challenges could be solved. For that reason, a changeover to a contact base used contacting system is recommended.

References

[1] German Electrotechnology Association (VDE), Effizienz- und Einsparpotentiale elektrischer Energie in Deutschland: Perspektive bis 2025 und Handlungsbedarf;. VDE-Study. Frankfurt, Main. VDE, 2008.

[2] Schröder, D., Elektrische Antriebe - Grundlagen: Mit durchgerechneten Übungs- und Prüfungsaufgaben, 5., überarb. Aufl. 2014. Springer-Lehrbuch. Berlin: Springer Berlin, 2013.

[3] J. Franke, FAPS, Insitute for Factory Automation and Production Systems; Lecture Handhabungs- und Montagetechnik. Friedrich-Alexander-University Erlangen-Nuremberg, 2014.

[4] Kuehl, A. and Franke, J., "Innovative Assembly of Stators using Ambidextrous Kinematics," 2015. In WCECS 2015 - World Congress on Engineering and Computer Science 2015: Proceedings Vol. 1, ed. International Association of Engineers, pp. 362–65.

[5] A. Dobroschke, "Wickeltechnik," in Edition Handbuch der Fertigungstechnik, Handbuch Fügen, Handhaben, Montieren: Handbuch der Fertigungstechnik, K. Feldmann, V. Schöppner, and G. Spur, Eds, München: Carl Hanser Verlag, 2014, pp. 197–223.

[6] E. W. Frank, "Device for converting electric energy into a mechanical one and/or for doing the opposite and method for producing such a device", Deutschland 99955952.9.

[7] Siemens Dematic AG, Ed, Surface Mount Technology Basics, Technology Manual, 08th ed. Munich.

[8] Materne, T. and Luetkenhaus, N. "Kontaktierung von Motorwicklungen," DE19903069 (A1), filed Jan. 27, 1999, issued Aug. 3, 2000.

[9] Kuehl A., Flexible Automatisierung der Statorenmontage mit Hilfe einer universellen ambidexteren Kinematik: Dissertation. Bamberg: Meisenbach, 2014.

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