Parametric Tool for Automated Slot Insulation Insertion in Small-Scale Electric Motor Stator Production

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*Abstract*— The increasing trend toward automation in electric motor manufacturing has led to the development of robotic systems for processes such as winding insertion, lamination stacking, and stator assembly. One critical step, slot liner insertion, is typically automated in large-scale production using dedicated Slot Liner insertion machines. However, in small-scale manufacturing, this process is predominantly performed manually due to low production volumes and the impracticality of configuring specialized machines for each variant. This paper presents a flexible and scalable approach by using a parametric funnel in conjunction with a UR 10e robot equipped with a HEX Force-Torque sensor and a RG2 Gripper to insert the slot liner into the stator. The parametric funnel, modeled using CAD, enables rapid adaptation to different stator slot geometries by generating customized insertion tools. This method aims to reduce manual effort, setup time, and cost, making it suitable for low-volume, high-variability production environments. Experimental validation demonstrates the feasibility and repeatability of the proposed system, indicating its potential for improving flexibility in motor manufacturing.

Keywords— Slot Liner Insertion, UR10e Robot, Parametric funnel, low-volume high variability production

# Introduction

Electric motor production is experiencing unprecedented growth to meet the rising demand in various industries. As a result, both the design and manufacturing processes are undergoing continuous optimization. An electric motor generally consists of three main components: the stator, rotor, and housing. The housing is typically produced through pressure die casting, followed by precision machining. The stator and rotor cores are made from laminated electrical steel sheets, which are shaped using either punching or laser cutting methods. These laminations are then assembled using techniques such as riveting or adhesive bonding. Once assembled, slot liners and copper windings are installed in the laminated core. The winding phases are then insulated, formed, and interconnected. The ends of the enameled wires are connected through soldering or welding, followed by processes like bandaging, electrical testing, and impregnation to finalize the stator [1]

This paper focuses on optimizing the slot liner insertion process. In low-voltage electric motors, the slot liner serves two key purposes: it provides electrical insulation for the winding and facilitates effective thermal dissipation. Enhancing the thermal conductivity of the slot liner while retaining its insulating properties can contribute to improved motor efficiency [2]

A close up of a plastic container

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Fig.1 Image of Stator with slot liner insertions. Elmotec Statomat

Need for Small scale Automation –

* Production of electric motors in small batches is common in industries such as aerospace where electric motors are custom designed based on the specific requirements
* In such a context, implementation of a dedicated slot-liner insertion machine for every stator size and design is not feasible
* Manual insertion is usually done here, which can be:

1. Operator dependent, leading to variability in quality
2. Less scalable and harder to document
3. Prone to errors and physically straining when repeated over long durations

* Automating this task using a general purpose industrial robot (such as UR10e) combined with a parametric tool for different stator sizes can significantly improve:

1. Process repeatability
2. Efficiency and cycle times
3. Flexibility for high mix, low volume production

# State of the Art

## Solutions for large scale production

A metal roller with words

AI-generated content may be incorrect.In state-of-the-art electric motor manufacturing, particularly for distributed windings, advanced slot insulation processes are employed to ensure precise and reliable electrical insulation of the stator slots. One prominent example is the system developed by Schaeffler ELMOTEC STATOMAT, which uses automated machinery to insert specially shaped insulation paper (e.g., U-, O-, B-, or S-shape) into each stator slot. This process involves a sequential combination of creasing, folding, inserting, and cutting the insulation material to exact specifications. The system ensures accurate paper protrusion on both flat surfaces of the stator stack, protecting the copper winding from sharp edges and avoiding interference during insertion. The machines are designed for both small and large series production, offering high adaptability through features such as an automatic empty cycle mechanism to accommodate varying slot geometries. With insertion speeds reaching up to three sleeves per second, the system provides a balance of flexibility, precision, and high throughput, thereby supporting efficiency and scalability for motor production processes [3]

A diagram of a grooving roller

AI-generated content may be incorrect.In addition to Schaeffler’s ELMOTEC STATOMAT systems, several other industrial manufacturers offer advanced solutions for automated slot insulation in electric motors. **Alliance Winding Equipment** offers machines that form, cuff, and insert insulating materials into stator or rotor slots. These systems integrate cam and servo controls for both speed and precision and allow rapid tooling changes to support multiple lamination types with minimal downtime [4]. **GROB** provides programmable insulation machines with user-friendly operation, offering precise control over insulation length, height, width, and cuff formation—delivering high performance in both accuracy and productivity [5]. **Delta S.R.L.** contributes with slot insulation machines that cut, shape, and insert insulators tailored to the specific slot geometry. These machines support robotic stator handling, quick mold changeovers, and automated height adjustment, making them ideal for high-output production environments.

A machine with a screen and buttons

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Fig 2 Dedicated slot liner insertion machine from alliance winding equipments

## Solutions for small scale production

Despite significant advancements in automation, manual insertion of slot liners remains the standard practice in the small-scale manufacture of electric motors.

* In such setups, operators typically cut, fold, and insert the slot liners entirely by hand, or use machines for cutting and folding while performing the insertion manually with simple jigs. This process relies heavily on visual inspection and tactile feedback to ensure proper alignment.
* However, with the growing demand for electric motors, the need for scalable and streamlined production is increasing. In this context, automation becomes a better alternative—not because manual methods are ineffective, but because they are difficult to integrate into digital workflows, challenging to scale, and not easily documented for consistent reproduction.

Fig 3, 4 grooving module and process adapted from [6]

## Automation Principles

1. **Parametric tooling for flexibility with different variants.** CAD based funnel models are parametrically defined to allow quick adaptation to different slot geometries. Advantages – low cost and low lead times when changing stator configurations
2. **Low-cost automation for small scale production.**The focus is on creating a cost-effective alternative to high end slot liner machines for small scale high variability production. A UR10e robot is used here, due to its balance of affordability, ease of deployment and a user-friendly interface for programming
3. **Mechanically guided precision** - Use of a parametric funnel helps mechanically align theslot liner with the stator slot, minimizing the reliance on sensors or vision systems.
4. **Scope for expansion –** The system architecture, including the force-torque sensor and gripper, supports modular upgrades such as real-time force feedback or adaptive control**.** Potential to integrate vision in future stages. Code and hardware setup remain modular to accommodate future feedback loops or dynamic planning

## Flexibility in automation

* The use of a **parametric funnel design** enables rapid customization of insertion tools to match different stator slot dimensions.
* The integration of a **HEX-E force-torque sensor** offers the potential for future implementation of feedback-driven insertion strategies, enhancing robustness against misalignment or friction-based resistance
* An **RG2 adaptive gripper** allows flexible grasping of slot liners or funnels, supporting different sizes and insertion techniques without mechanical reconfiguration.
* The robot, sensor, and gripper combination form a **modular, reconfigurable automation cell**, well-suited for research environments and evolving production needs

## Parametric tools and processes for flexibility enlargement

* The automation setup is designed to adapt to varying stator geometries and slot designs, common in production of electric motors in small batches. This is achieved through modular hardware and a parametric tool design.
* Interchangeable parametric tools – Custom funnels are generated through parametric CAD models, enabling rapid reconfiguration for different stator types. These tools can be easily fabricated through 3D printing.
* **Sensor-Assisted Modularity**
  + The integrated **HEX-E force-torque sensor** actively monitors contact forces during **funnel insertion**, enabling force-based feedback to ensure correct positioning and avoid excessive contact forces or misalignment.
  + This sensor-based interaction enhances robustness during setup and allows the robot to respond to resistance, improving insertion accuracy.
  + The presence of the sensor also makes the system extensible—allowing future integration of **active force-feedback control** during slot liner insertion, enabling more precise and adaptable operation under variable tolerances. ???

*F. Derivation of consequences*

# Proposed Parametric Tool and Process

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*a**b* 

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## Proposed automation insertion Pipeline

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References

[1] A. Mayr *et al.,* "Electric Motor Production 4.0 – Application Potentials of Industry 4.0 Technologies in the Manufacturing of Electric Motors," in *2018 8th International Electric Drives Production Conference (EDPC)*, Schweinfurt, Germany, 2018, pp. 1–13.

[2] N. Boulanger *et al.,* "Aramid Based Slot Liners for Low Voltage Electric Motor Applications," in *2024 IEEE Electrical Insulation Conference (EIC)*, Minneapolis, MN, USA, 2024, pp. 17–21.

[3] Schaeffler ELMOTEC STATOMAT, *Slot Insulation Machines* (accessed: May 7 2025).

[4] Alliance Winding Equipment, *Slot Insulation Machines* (accessed: May 7 2025).

[5] GROB, *Slot Insulation Machine*.

[6] D. Mayer, L. Hausmann, N. Maul, L. Reinschmidt, J. Hofmann, and J. Fleischer, "Systematic Investigation of the Grooving Process and its Influence on Slot Insulation of Stators with Hairpin Technology," in *2019 9th International Electric Drives Production Conference (EDPC)*, Esslingen, Germany, 2019, pp. 1–7.