Digitisation of Skill-Intensive Manufacturing Processes: Towards In-Process Inspection

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In-Process Inspection for EM

• **Vision:** Zero-defect manufacturing of Electrical Machines (EM) through inspection, verification and digital certification at the point of manufacture

• **Opportunity:** Potential to “reshape current assembly research” by addressing the unique features of EM manufacture, such as coil windings, insertions and terminations that all involve skill-intensive tasks with deformable materials
Manual Tasks in EM Manufacture

Examples:
Insulation Insertion

• Different electrical machines require different manual interventions
• One-off mistakes can lead to catastrophic failures, for example, shorting and grounding of wiring

Source: https://www.youtube.com/watch?v=7tEsJ-xAoEQ
Manual Tasks in EM Manufacture

Examples:

Top - Coil Winding Insertion

Bottom - Coil Binding

Source: https://www.instructables.com/id/Rewinding-3-Phase-Motor/
Manual Tasks in EM Manufacture

Source: https://www.youtube.com/watch?v=MSxgFs1FXps
# State of the Art: EM Production 4.0

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<th>Industry 4.0 Technologies</th>
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<td>Laminated Core Production</td>
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<td>Final Assembly and Testing</td>
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<td>Overall Process</td>
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● Addressing electric motor production  ○ Derived from related fields  ○ No approaches identified yet

*Mayr et al., 2018*
State of the Art: Coils and Windings

“A vision system for the online quality monitoring of industrial manufacturing” 2017

“Monitoring and evaluation of the wire drawing process using thermal imaging” 2018

“Model-free learning of wire winding control” 2013
State of the Art: Termination Endings

FEM Modelling

“Explicit FEM Analysis of a New Contacting Method for Electronic Devices with Novel Wiring Harnesses” 2015

Acoustic Sensing

“Conceptual Design of an Ultrasonic Crimping Process using Machine Learning Algorithms” 2018

Computer Vision

“Potentials of Machine Learning in Electric Drives Production Using the Example of Contacting Processes and Selective Magnet Assembly” 2017
Proposed Framework for Digitisation

Digitisation of Human-Workpiece Interactions

- Digitisation of Human Actions
- Digitisation of Objects and Environments
- Digitisation of Manufacturing Processes

In-Process Inspection and Verification

Intelligent Automation
Proposed Framework for Digitisation

Capture → Segment → Model

Analysis → Observation → Human

Action → Workpiece

Feedback → Reproduce → Decode → Extract

Hidden Human Action States → Observable Workpiece States

HMM - 1, HMM - 2, ..., HMM - n
In-Process Inspection and Verification

Wing Equipping:
In-Process Inspection and Verification
Composites Layup:
In-Process Inspection for EM: Stage 1

Development of a ‘sensorised workbench’ for capturing manufacturing data

- Capture process characteristics using networked sensors
- Map defects with process characteristics
- Develop a workbench for real-time spatio-temporal data capture: coil winding, terminations, wiring, insertions and connections
In-Process Inspection for EM: Stage 2

In-process analytics for defect modelling, simulation and forecasting

- Build a ‘digital twin’ to model and simulate causal factors for defects and failures
- Model process characteristics and their interdependencies
- Investigate how changes in one part of the process can have downstream effects in another
In-Process Inspection for EM: Stage 3

In-process defect detection, mitigation and certification for manual activities

• Undertake spatio-temporal segmentation of the captured continuous data into human and workpiece states

• Investigate relationships between human actions and their effects on workpieces

• Develop autonomous-learning models to provide defect detection, mitigation and certification
Acknowledgements