DIGITAL MANUFACTURING AND PROOF-OF-PROCESS FOR AUTOMOTIVE FUEL CELLS

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DELIVERABLE REPORT D4.3

PROOF OF PROCESS DEVELOPMENT FACILITY IMPLEMENTED

D4.3 – PROOF OF PROCESS DEVELOPMENT FACILITY IMPLEMENTED	
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PU	*Public*	***Y***
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NATURE OF THE DELIVERABLE		
R	*Report*	***Y***
P	*Prototype*	
D	*Demonstrator*	
O	*Other*	

SUMMARY	
Keywords	***DIGItal MANufacturing and Proof-of-Process for Automotive Fuel Cells – PROOF OF PROCESS DEVELOPMENT FACILITY IMPLEMENTED***
Abstract	The DigiMan project focuses on the development of an automated fuel cell assembly system. Cell assembly is uplifted from the incumbent semi-automated system to full automation and output to Intelligent Energy's (IE) pre-existing automated stack assembly module for its AC64 stack technology platform. This deliverable report under Work Package 4 presents the implemented Proof of Process development facility, including the PoP Demonstrator implemented design, the system and control architecture, Digital engineering activities, Factory Acceptance Tests and details further planned work to be reported within D4.4 "PoP Demonstrator Cycling Trials Report" and D4.5 "Production Relevant Environment Facility".
Public abstract for the public website (only for confidential deliverables)	

DELIVERABLE 4.3

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NOMENCLATURE

Symbol/Acronym	Description
GDL	Gas Diffusion Layer
MEA	Membrane Electrode Assembly
AC	Air Cooled
IE	Intelligent Energy
KPI	Key Performance Indicators
EoL	End of Life
PoP	Proof-of-Process
WMG	Warwick Manufacturing Group
MM	MagneMotion
EOAT	End of Arm Tool
DES	Discrete Event Simulation
VES	Virtual Engineering Simulation
FAT	Factory Acceptance Test
SAT	Site Acceptance Test

1. Introduction

The DIGIMAN project focuses on the development of an automated fuel cell assembly system, the output of which should be capable of interfacing with Intelligent Energy's (IE) existing/future automated cell test and stack assembly module for its AC64 stack technology platform.

The purpose of the DigiMan project is to demonstrate and prove the concept of uplifted automation for a fully integrated assembly production line that could be scaled up to deliver production capacity > 50,000 stacks/year with processing time < 5 seconds per station. In order to achieve this goal, innovation has been implemented in both mechanical and automation technologies for the existing process to be validated on a Proof of Process (PoP) Demonstrator.

This deliverable report D4.3 has inputs from the University of Warwick (WMG) and IE, reporting the following content that leads to the Proof of Process development facility being implemented:

- The PoP Demonstrator implemented design
- The system and control architecture
- Digital engineering activities
- Factory Acceptance Tests

2. PoP Demonstrator Implemented Design

2.1 Overview

The PoP Demonstrator implemented design will address the technical requirements and constraints with reference to IE's AC64 cell design and assembly process.

2.2 Transportation and Carrier solution

The PoP Demonstrator requires an intelligent transport system that is capable of fast, precise movement, positioning, and handling of small, light loads, it must support the carrier system both within and moving between stations during the fuel cell assembly processes.

Rockwell's MagneMover (MM) LITE was selected based on criteria defined within D4.2. The MM LITE transport system is a configuration of linear synchronous motors (acting as the track) and related control electronics that move independently commanded carriers (vehicles/pucks) in a controlled manner at various acceleration/deceleration and velocity profiles while carrying the fuel cell materials. Figure 1 shows the MM LITE transport system elements:

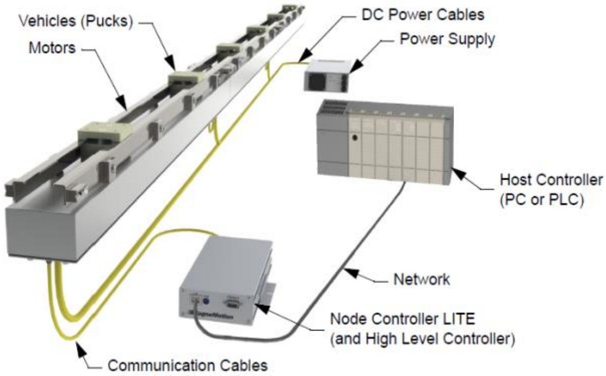

Fig 1: MagneMover LITE transport system

2.3 Track layout design

The PoP Demonstrator track layout design implemented has the following features:

- Subservient positional control which relinquishes drive to the in station mechanical alignment features but resumes control on exit.
- A circular track design to minimise PoP demo footprint and allow validation of material handling through corners.
- Merge capability to allow for changes of feeder / carrier orientation and a load/unload station.

2.4 Smart untethered puck design

The implemented puck design has the following features:

- Vacuum clamping of the non-rigid, lightweight components in combination with mechanical alignment (in-board tooling pins)
- Permanent smart vacuum clamping on the untethered carriers. Carriers are free to move and vacuum is re-energised at designated station points
- In-station mechanical clamping of the carrier to facilitate mechanical alignment. Male/Female clamping system allows mechanical alignment of puck to desired position.

2.5 Anode & Cathode plate Pick & Place

2.5.1 Anode Plate Pick & Place

The Anode plate station operates a basic pick and place function using pneumatics and vacuum techniques to accurately place the plate over alignment pins. As part of this process the plate is picked from a pre-loaded nest, scanned for traceability and placed onto the puck. A number of sensors are activated throughout the procedure in order to ensure critical positions are achieved prior to placement.

2.5.2 Cathode plate Pick & Place

Much like the Anode plate process the Cathode plate is also a pick and place procedure using similar techniques. Due to the nature of the component profile alternate operations have been developed to radially pre-align the component to a specific orientation prior to the picking operation. The pre-load nest has also been adapted to compensate for this supplementary operation.

2.6 Anode Gasket

The Anode gasket operation is accomplished via a reel to reel system whereby pre-cut gaskets are laminated onto the stationary puck and the interliner is removed. Gaskets are located into pre-load position by applying tension into the reels and using several sensors to verify quality factors such as presence and position. A dedicated laminating tool is passed over the interliner laminating the gasket in place.

2.7 Anode and Cathode GDL

Both Anode and Cathode GDL's operations are completed using pick and place method. The robot EOAT uses floatation techniques to position the GDL's with high precision and reliability. As with all stations, the components are picked from a pre-loaded nest and based on LEAN methodology the GDL nests have been designed to include various quality checks prior to placement steps.

2.8 MEA and Cathode Gasket

Due to the complexity of the MEA component they are pre-loaded into individual nest slots on a purposely designed tooling fixture. The fixture holds the MEA in place through a number of lateral positional movements during operational cycles. The fixture moves into its respective position in coordination with the gasket lamination procedure. The fixture is manipulated to press the MEA into required position in order to perform both MEA location followed by gasket lamination process as described in operation 2.6 "Anode Gasket"

2.9 Manifold Seal

Dedicated manifolds are placed at either end of the cell through pick and place operation. As with previous stations the manifolds are pre-loaded into the predetermined orientation nests. The respective EOAT is selected and both male and female manifolds are sequentially picked and placed to their respective coordinal position on the cell.

The final product, the fully automatically assembled cell, is then released to travel to the load/unload position to be removed and progressed to cell testing operations.

2.10 Traceability & Data Collection

Traceability and data collection steps have been integrated into the POP demo machine design. All component materials/parts are barcode scanned. Within the POP demo cycle operation, the barcode details scanned will be assigned to a unique QR code located on the Anode plate that is scanned prior to placement on the carrier. Data collected throughout the PoP Demo cycle is stored in a dedicated database to be developed by WMG and IE to allow identified quality critical data to be analysed and correlated via a Cause and Effect dashboard (Work package 6). Figure. 2 below shows the data collection architecture.

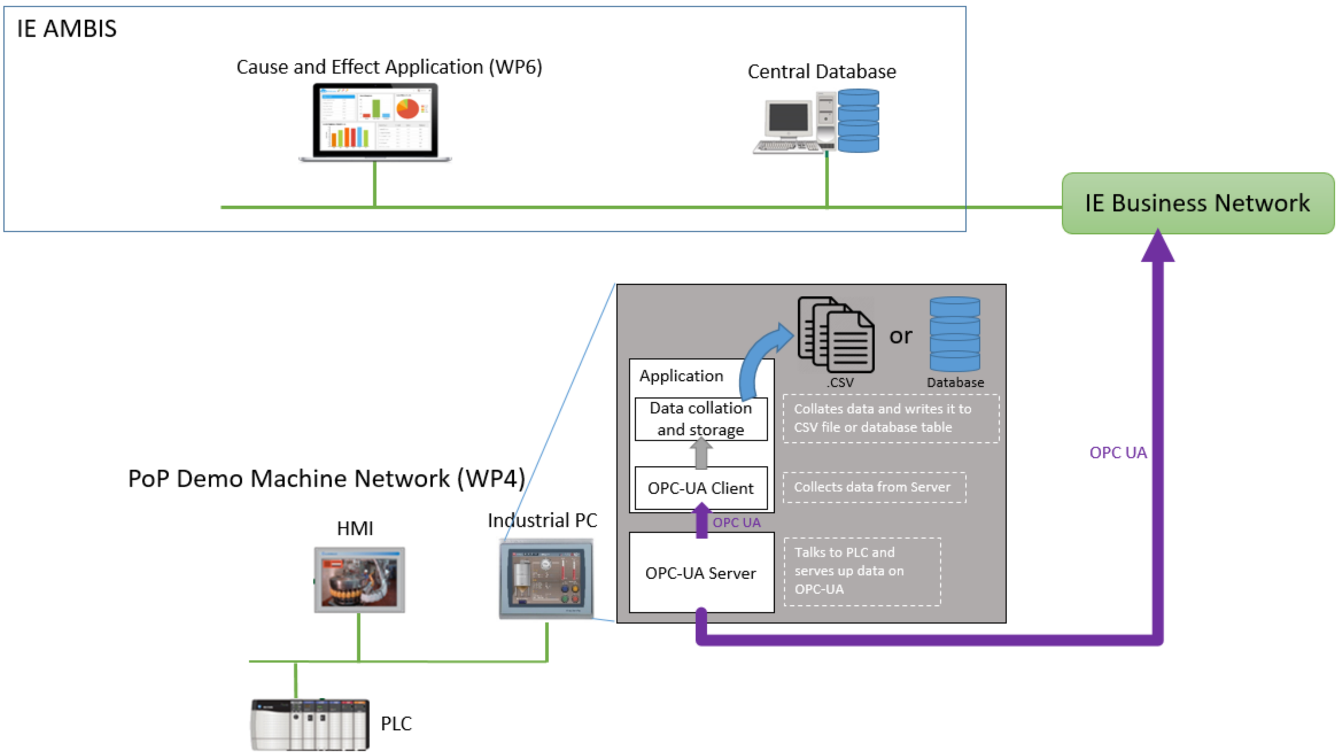

Figure 2 PoP Demo Cause Data collection

3. SYSTEM AND CONTROL ARCHITECTURE

During the Control System design review WMG and IE used the following checklist:

Hardware:

1. Control panel design review.
2. PC hardware specifications, including network interfaces.

Software:

1. Software design review for the PLC code (software program structure).
2. HMI design specifications; structure for HMI screens, interfaces between PoP Demo machine and operator such as recipe interface and set points.
3. HMI Alarms & event lists, and alarm priorities.
4. HMI Access levels.
5. PoP Demo control modes (manual, automatic, semi-auto, dry cycle, and single cycle).
6. Sequence of operation review and bypassing features (in case the operator wants to override one or more step of the sequence from the HMI).
7. Safety and interlocks
8. In case of faults during machine operations, how the machine will react, e.g. discard that sequence and start from beginning or continue from that step.
9. Machine fault diagnostics from HMI.
10. Hold and resume features from the HMI.
11. The data structure and frequency from PLC to PC to IE via OPC UA.

Network architecture:

1. How PLC communicates with the robot and NC (node controller) for MM LITE.
2. How PLC communicates with PC.

4. DIGITAL ENGINEERING

Assembly simulation consists of two main parts; discrete event simulation (DES) and virtual engineering simulation (VES). DES aims to simulate the complete system and analyse the overall cycle time, giving different scenarios and statistical output data in order to prove or validate the PoP Demonstrator or blue print design concept. On the other hand, VES aims to model each individual stage in detail within the system and shows process performance in a 3D presentation.

The key outputs of the DES Simulation are:

- Cycle time analysis.
- Bottleneck analysis.
- What-if analysis.
- Production forecasting and Productivity optimisation.
- System behaviour.
- Costing.

The key outputs of the VES Simulation are:

- 3D visualisation
- Real time visual representation
- Single station operation through to full cycle demonstration
- Layout and footprint validation

A scoring scheme with specific criteria was used to evaluate and select DES and VES tools as to their fit for DigiMan and appropriate licences sourced.

5. FAT & SAT

5.1 FAT Overview

The key objectives for the FAT/SAT (Factory/Site Acceptance Test) are to validate the functionality of the PoP Demonstrator. The FAT document has been developed using current Automotive best practice methodology to identify desired outcomes in order to ensure all structural, mechanical and safety features of the machine are adequately operational in order to progress to site installation and operational stages of the project.

5.2 FAT (Factory Acceptance Test)

The FAT took place onsite at the equipment builder and was attended by both IE and WMG, the acceptance tests were carried out over 3 days and were led by IE. While basic operational aspects such as dry cycle and single cycle were operational the demonstration of the automatic mode could not be showcased due ongoing development of the vision system. Despite this, it is worth noting the machine build itself with regard to all H&S and general build features in the FAT/SAT document had been executed to a very high level and easily identifiable.

Figure 3 PoP Demo Equipment at FAT

6. CONCLUSIONS AND NEXT STEPS

The SAT onsite at IE will be reported within Deliverable D4.5 "Production Relevant Environment Facility".

6.1 DES Future work

The DES will be developed to show a digital representation of the machine operation, the model will show real time functionality and demonstrate a range of scenarios such as cycle time analysis and bottlenecks through to EOL quality testing and commissioning.

The first stage of the DES construction is to build a linear base model showing stations as detailed in the operational process sequence flowchart. Crude timings were taken during the FAT where cycle times where logged at specific points, namely carrier clamp on to carrier clamp off. This data was implemented in the DES base model to replicate the machines individual station operation time. A nominal time has been applied to represent travel time between stations resulting in a complete digital base line of the POP demonstrator. Planned work will include more realistic cycle time and non-conformance distributions.

6.2 VES Future work

The plan for the VES is to construct a basic visual representation to emulate current machine layout which will be adapted as results are produced in the DES. From this exercise a VES model could also be created to compliment the final blue print design and showcase a fully optimised production ready layout.

6.3 Dry Cycling

The POP demo dry cycle plan has been adapted to take into account the number of operations which require mechanical override due to no components being present. The dry cycle plan will be developed to ensure the mechanical, electrical and control systems operate consistently over numerous operation parameters such as, number of repeated cycles or number of continuous hours run while considering how modified technologies perform when used outside of their standard operations.

This will be reported within Deliverable D4.4 "PoP Demonstrator Cycling Trials Report"

6.4 Plan for MRL6 Validation

A commitment within the project's proposition and charter is to advance (MRL4 > MRL6) the critical steps of the PEM fuel cell fully automated assembly processes, advancing IE's existing and well proven semi-automated stack assembly processes. Work package 6 scope includes (Task 6.4) demonstration of MRL6 attainment - capability to produce a prototype system or subsystem in a production relevant (i.e. automotive) environment. It advances existing state-of-the-art process technology validated in laboratory at IE (MRL4) and uplifts to full automation.

Within an industrially relevant production environment the automation uplifts will be demonstrated to MRL6, via output of cells which will then be tested and assembled into stacks (via one of IE's incumbent fully automated stackers). These stacks will be tested to prove that the uplifted automation is not detrimental to the AC64's performance, meeting KPI of 0.7 A/cm2 @ 0.7V BoL (Beginning-of-Life), attaining MS4 (*PoP Demonstrator MRL6 validated*) and reported via D4.6 (*PoP Demo MRL6*). They will then progress, via to a robust, full validation programme, to show MS9 (*Stack Validation*) attainment as reported via D6.4 (*Stack Validation*).

6.5 PFMEA Plan

The PFMEA criteria will be based on current IE non-conformance data and executed as a paper exercise. The outcome of this exercise will drive future works and optimisation projects giving insights to operational requirements such as TPM or SPC exercises.