Advances in Manufacturing Technology XXXVI
A. Thomas et al. (Eds.)

doi:10.3233/ATDE230912

Upgrading Conventional Production Lines Through Implementing an Industry 4.0 Strategy

Manaf AL-AHMAD[a], Song YANG[a], Yankang TIAN[a], Georgios CHRISTOFORIDIS [a], Jian GAO[a], Yi QIN[a,1]

[a] *Centre for Precision Manufacturing, Department of DMEM, The University of Strathclyde, Glasgow, United Kingdom*

Abstract. Although Industry 4.0 and the Internet of Things (IoT) have been implemented in various manufacturing sectors, medium and small enterprises have limited integrations with this strategy, especially those that still rely on conventional production lines and lack the capacity for transition in near future. This paper presents a work demonstrating how conventional production lines could be upgraded for implementing an Industry 4.0 strategy, using plastic injection moulding as a case study. This transformation helps to achieve a real-time optimised value chain, considering factors such as cost, availability, and resource consumption, while the implementation cost is kept low.

Keywords. Industry 4.0, Internet of Things (IoT), Plastic Injection Moulding (PLM), Manufacturing Execution System (MES), Data Acquisition System (DAQ)

1. Introduction

Today many enterprises are adopting new intelligent manufacturing concepts which depend on digitalisation and advanced technologies to achieve improvements in factory management and production automation [1][2]. Injection moulding is one aspect that has received attention from an Industry 4.0 perspective [3]. Automation layers are applied according to the automation standard ISA-95, and equal attention is paid to each level from the shop floor to the business level. Where in-mould and in-machine sensors are installed [4][5], and at the control level, Data Acquisition System (DAQ) is utilised to collect and refine the data coming from the machine [6]. Also, the Manufacturing execution system plays an essential role as the link between the shop floor layer and the enterprise layer. Many studies and applications explain the methodology of the communication between the DAQ, MES, and Enterprise resource Planning (ERP) systems [7][8] and the approaches that should follow to achieve the right communication between these systems, such as the OPC-UA [9] and APIs [10] to monitor the production process in real-time. As the digitalization trend continues, small and medium-sized enterprises (SMEs) necessarily need to adapt their manufacturing processes to align with Industry 4.0. They face many challenges in incorporating IT and

[1] Corresponding Author: Yi Qin, qin.yi@strath.ac.uk

automation to compete in a globally interconnected market. So, upgrading their production lines will be the optimal solution instead of replacing them due to the excessive costs associated with replacing outdated machinery with advanced alternatives and the time consumed to automate all production lines.

2. Analysis of the Current Systems

Injection moulding is a crucial manufacturing process that combines mass production capabilities, rapidity, and low cost. To ensure continuous production and maintain the quality of moulded parts, it is essential to integrate injection moulding into the Industry 4.0 framework. This entails real-time monitoring of the process, capturing comprehensive process data, and optimizing factors such as pressure, temperature, and speed that influence the part quality and machine stability.

The project partner, Pascoe Engineering Ltd, has eighteen plastic injection moulding machines and offers injection moulding services such as design and produce moulded parts. Most of the machines were made between 1992 and 1998. The main control panels of machines are basic and unable to communicate with any external modern industrial or business equipment or systems by any type of communication protocol. Digital signals are limited to open and close mould, ejector position and switch-over point. The machines lack the ability to control the moulded parts' quality and monitor the total production process, additionally, the inability to connect to any advanced systems makes the process of enhancing productivity, quality, energy consumption, and minimizing cost very difficult, especially in terms of rapid production of high-quality parts which are very critical in this kind of manufacturing in industries such as the medical, electronics, and aerospace industries.

In this study, a Battenfield BA 600 CDC injection moulding machine, which is equipped with a basic control panel and manufactured in 1998, is utilized. The company owned an ERP system (e-max) where all data and information from the shopfloor and the management level are entered into the system manually. This is considered a challenge to the time and accuracy of transformed data, and this will reduce the efficiency, availability, and the quality of the total production process.

3. Proposed System Description

3.1. Accessing the IMM parameters data

The BA 600 machine is equipped with a basic control panel that allows for tracking simple signals such as mould open/close, switch over point, and ejector functions.

To gather process data from the machine and the mould, a set of sensors is installed on the machine and the mould (Fig.1). A hydraulic pressure sensor (type 4262A, Kistler), Nozzle temperature sensor (type 4021B, Kistler) and Screw position sensor (type P510, Kistler) are installed on the machine. At the same time, the mould cavities are equipped with two combined pressure-temperature sensors (type 6188A, Kistler). Additionally, a cooling water temperature sensor (TRACER® vm base) is placed on the main pipe that supplies cooling water to the mould.

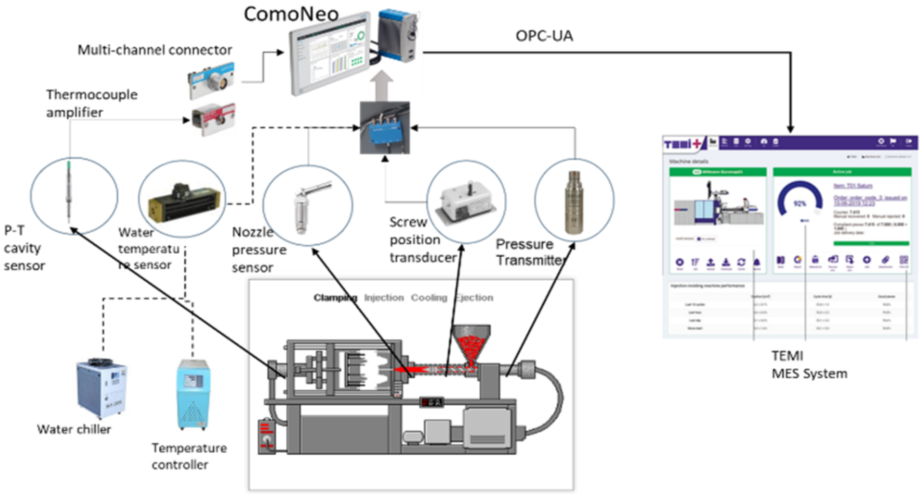

Figure 1. The design of experiment

3.2. Acquisition of machine Controller and sensors data

At the control layer, data are collected by Data Acquisition System, ComoNeo developed by Kistler. This system captures data from both the control panel and the installed sensors. ComoNeo is available with different communication protocols such as ProfiNet and Ethernet/IP and is able to collect digital and analogue signals, so it can connect with different models of injection moulding machines. For the analogue signals that come from machine sensors, it is necessary to utilise a charge amplifier to convert the signals to digital. The system contains Up to 128 monitoring functions that enable sorting the good parts from defects on the basis of recorded data.

3.3. Implementing of Manufacturing execution system

At the business layer, the manufacturing execution system (TEMI+) is used which has been designed by ICE-flex for the needs of the plastic industry. To provide advanced overall equipment effectiveness (OEE) calculations and data integration of the plastic moulding machines, many communication languages of press manufacturing like Euromap77 and the OPC-UA are available. These allow communication between auxiliary equipment located around the injection machine. The system acts as an intermediate layer between the enterprise resource planning (ERP) system and a machine control system (Fig. 2).

The system operates across multiple functions such as job planning, process monitoring, product life cycle, resource scheduling, order execution and dispatch, production analysis and downtime management for overall equipment effectiveness (OEE), product quality, and materials track and trace. The data of customers, materials, inventory, and orders can be collected from the ERP system or by uploading the data to the MES system. After transferring or uploading the data to the MES system, the enterprise is able to distribute the orders to the machines by setting up the time and date of each order.

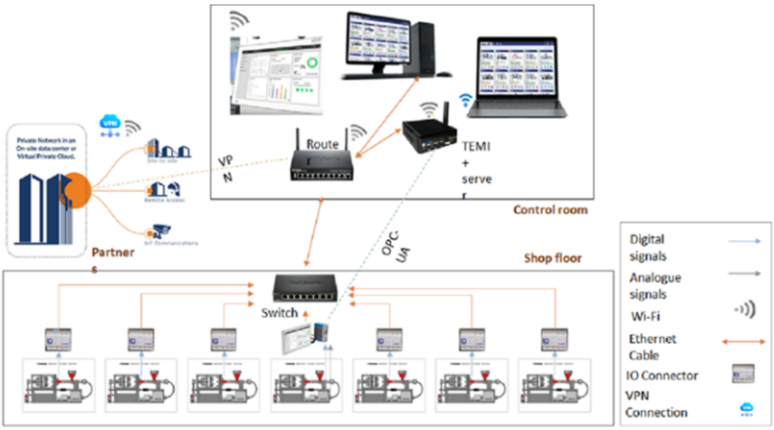

Figure 2. The final design of the production line includes the four automation layers.

4. Production trials with new setup

Analogue signals are obtained from sensors and digital signals are obtained from the machine controller. These signals provide the data acquisition system with the required information. The closing mould signal indicates the beginning of a new injection cycle, while the switch-over signal indicates the switch from the injection phase to the packing phase during the cycle. All signals' threshold values can be defined in real-time during the cycle by the ComoNeo. These thresholds specify the values of each variable that ensure the quality of the final moulded part.

Any parameters that exceed the threshold limits indicate the moulded part will be classified as a defect. The values of each threshold will be obtained after analysing the process depending on the complexity of the part's geometry, the utilized material, the shape of the runner and sprue, and the design of cooling water channels inside the mould. DoE is applied to obtain the optimal values of the parameters which lie within the thresholds, from these values the bad or good moulded part is specified.

This data is transformed into the manufacturing execution system TEMI through the OPC-US architectural standard which supports the TCP communication standard. The TEMI$^+$ process planning defines each operation and its sequence through the production cycle, starting with the raw materials and ending with the final product. TEMI+ covers decision-making and process scheduling. TEMI+ receives the orders created at the ERP level. The MES will check the resource and materials' availability and then try to implement the planned schedule for a specific operation period and respond to any sudden fault in the production process by resolving the issue without disrupting the order schedule. The communication between DAQ and MES will specify the number of moulding cycles in real-time and then the number of good parts. This provides the enterprise with accurate data about the total moulding process.

The efficiency of the production equipment is evaluated and visualized using Overall Equipment Effectiveness (OEE) (Fig. 3), while the quality of parts will provide a comprehensive overview of the manufacturing process.

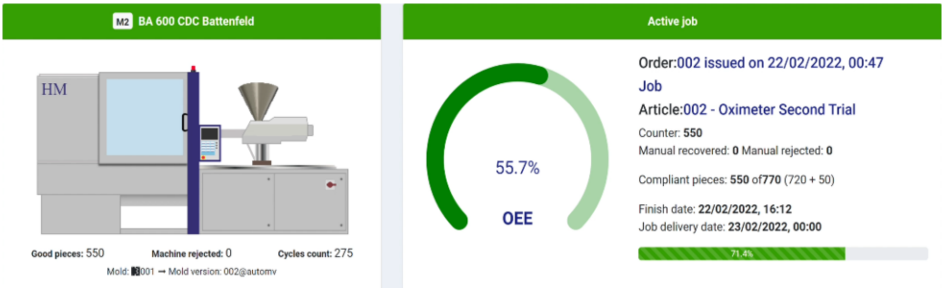

Figure 3. OEE of production process which shows the accurate values.

5. Discussion and Conclusions

The company faced many challenges due to following the traditional methods of manufacturing. Most of the obstacles fell within the scope of management. There was poor monitoring of the quality, management of production time, determination of the technical and management jobs within the enterprise, and difficulty in resolving the issue of paperwork. Even with the enterprise's own ERP system, communication between the different levels was inflexible and unable to provide management with accurate information about the production process. The trial described here indicated significant advancements in the production line as a result of integrating different systems at different levels in terms of improving productivity, reducing inspection, maintenance, and production cycle time, and increasing overall equipment effectiveness (OEE) for the entire manufacturing process. These improvements have enabled the enterprise to bridge the technological gap between its conventional production line and modern technologies which are the foundation of the manufacturing sector.

Intelligent manufacturing systems and interconnection protocols were used without the need for any modifications. This meant hardware integration, software integration and a consolidated database was achieved while maintaining flexibility and reliability. In addition, easy data transfer in real-time between the systems with zero error was obtained.

DAQ played an essential role by collecting and translating signals coming from the shop floor. This enabled full control of the process and sorted out the good parts from the defective ones. The MES enabled management to access real-time data on products and markets thus empowering the management team to comprehend market responses and trends and make necessary adjustments to the enterprise strategy. The data coming from the DAQ, such as the operation and job time and the number of good/bad moulded parts, was able to help determine much information at the management layer such as the amount of raw materials used for each batch, required time to complete each job and the time-plan for following batches.

Reducing production time and the total production cost, and increasing productivity were the main results that were achieved during the trial. This resulted from the accurate control of the process starting from the required time to start the work to the ready packaged products.

During implementation of an upgrade, there are many challenges facing the enterprise such as supporting and developing the security of the network and how to deal with cyber espionage. Moreover, each machine is unique in terms of design and structure so this factor should be considered when planning to upgrade a conventional production line regarding choosing the compatible hardware and software. Future work aims to extend this work to include all accessories of the machines and cover communication with different systems such as the supply chain management system and customer relationship management system.

This study aimed to upgrade and evaluate a conventional injection moulding production line to be compatible with Industry 4.0 and explained the type of communication protocols utilised by applying the ISA-95 Standard. This paper also explained the methodology followed to monitor the moulded part quality within the supervisory control and data acquisition layer. It also explained how the parts quality data transformed into the MES layer to be translated by the Overall Equipment Effectiveness (OEE) added as an essential value to the total process quality.

Acknowledgements

This research has received funding from the European Union Horizon 2020 research and innovation program under grant agreement No.101016262. The project aimed to create medical supplies through injection moulding systems. one of the project objectives is to upgrade conventional production lines.

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