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AUTOMATION OF A STEEL WALL FRAMING ASSEMBLY

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Modular construction has become increasingly popular in North America in recent years. In this emerging paradigm of building construction, building components are manufactured off site and then transported to the construction site for assembly. In Canada, automated modular steel structure fabrication is in high demand. Offsite manufacturing of steel wall frames for residential and commercial buildings provides timesaving and improvement of working conditions and morale that translates to improved productivity and safety performance. This paper demonstrates the feasibility of efficiently fabricating steel wall frames for offsite modular construction using automated assembly controlled by a Programmable Logic Controller (PLC) and connected in a cost-effective and efficient electrical installation and centralized communication by Fieldbus technology. In particular, this paper describes the control strategy used to automate a steel wall framing assembly that incorporates a PLC and Fieldbus technology.

Keywords: Programmable logic controller (PLC), Fieldbus technology, Modular construction, Automated assembly.

1 INTRODUCTION

Offsite production of steel wall frames traditionally involves the extraneous physical work of bending down to manually lift and handle heavy pieces of steel. Extraneous physical work is reduced when steel wall frames are produced in a factory environment that is conducive to safer work conditions and automation. Furthermore, transport and assembly of factory-manufactured steel wall frames results in an overall reduction of construction cycle time. Given these benefits, automated modular steel structure fabrication is in high demand in Canada.

Automating the manufacturing of steel wall frames requires a control system, which mainly embodies the software and the appropriate hardware that accomplish the operational sequences involved in the process. This paper describes the control system for automating a steel wall framing assembly using programmable logic controller (PLC) and Fieldbus technology. In the following sections, a brief description of the steel wall frame manufacturing process is presented, followed by an illustration of the PLC-driven automated system, the Fieldbus architecture adopted for the control system, and the advantages of Fieldbus technology.

The development of the control system is based on the objective defined in Section 2 and on the current manufacturing industry practice as presented in Section 3. The rest of the paper is organized as follows. Section 4 describes the basic operation of the steel wall framing assembly. Section 5 details the control system that satisfies the criteria provided in Section 2. Section 6 expands on the chosen communication architecture i.e., Fieldbus system, briefly discussed in Section 5. Section 7 summarizes the research achievements and outlines opportunities for future work.

2 DESIGN OBJECTIVE

The objective of the current project is to design the associated control system for automating a steel wall framing assembly, focusing on the following criteria:

- Cost effectiveness,
- Efficiency of electrical installation, and
- Centralized communication.

The resulting control system defines the SCADA/Device level of the manufacturing hierarchy, which can be readily integrated vertically to the upper layers of the manufacturing hierarchy if desired in the future.

3 LITERATURE REVIEW

Safety, efficiency, and worker comfort have driven the widespread adoption of automation in the construction industry. Bock (2015) indicates that the limitation of conventional construction methodology is the motivation behind automation. In building prefabrication, he suggests automation and robotic technologies for customized components such as concrete, wood, steel, and masonry. Leyh (1995) discusses the use of robot technology in building assembly and in the application of a gantry robot to the manufacturing of prefabricated walls. Details on the implementation of SCADA (Supervisory Control and Data Acquisition) and field devices are not provided by Bock (2015) or Leyh (1995), however. Following the assertion of Erickson (1996) that PLCs represent the forefront of manufacturing automation for cost and quality benefits, the control methodology for the steel wall framing assembly described in this paper adopts a PLC-based strategy.

In their comprehensive survey of standards for digital data exchange in Smart Manufacturing Systems (SMS), Lu *et al*. (2016) refer to the Manufacturing Pyramid as the hierarchy that comprises the SCADA/Device, manufacturing operations management (MOM), and Enterprise levels. The present paper only deals with the Human Machine Interface (HMI), PLC, and field devices in the SCADA/Device level. However, a PLC-based system that supports Fieldbus architecture can easily interface with the MOM and Enterprise levels constitutes a viable and compelling area of potential future research. Ethernet-based network is adopted in the current work since strong growth in this sector can be expected with respect to Fieldbus communication and Ethernet-based components (Jämsä-Jounela 2007).

4 STEEL WALL FRAME FABRICATION ASSEMBLY

Figure 1 presents the steel wall framing assembly consisting of two tables (A and B) with stationary and non-stationary parts and a gantry. Four squaring mechanisms grab the panel on the *y*-axis and move it along the length of the table on the *x*-axis. (Moving of the squaring mechanisms along the *x*-axis is referred to as dragging operation.) Each table is adjusted to the required width of the panel using a linear actuator that moves the non-stationary part of each table.

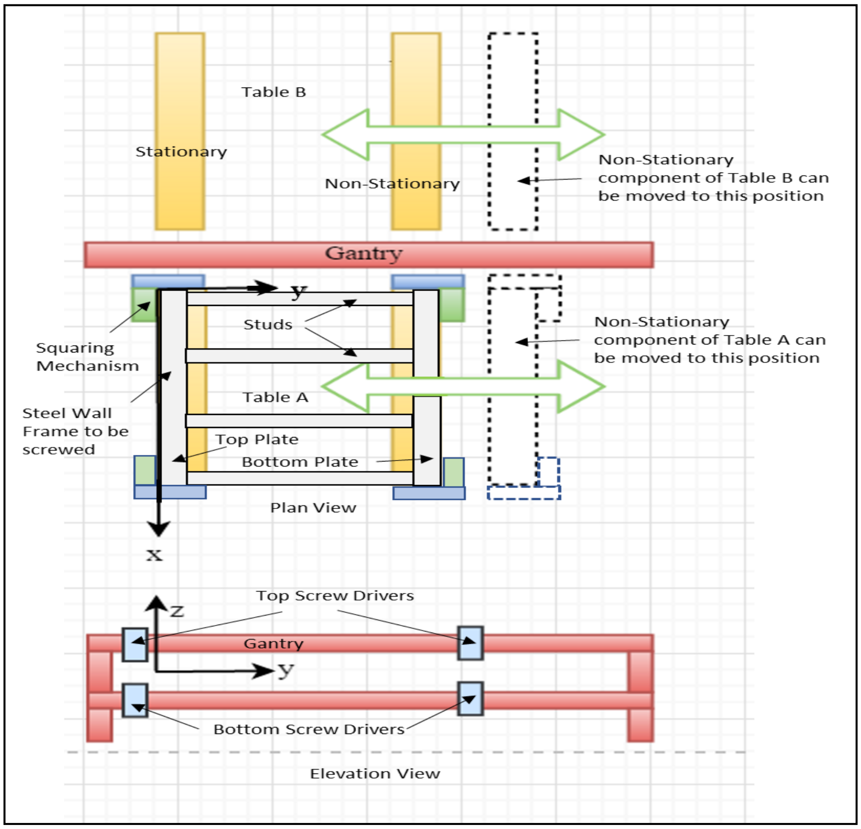

Figure 1. Plan and elevation views of steel wall framing assembly (Singh 2017).

Mounted on the gantry are two sets of pneumatic screwdrivers that drive screws into the top of the wall frame or the bottom of the panel. The top screwdriver of each set simultaneously moves with its corresponding bottom screwdriver to the predetermined position on the *y*-axis. These two sets of screwdrivers move toward the panel on the *z*-axis. Positions vary depending on the type of panel to be fabricated. Panels, in turn, vary in size and design to account for windows, doors, or studs. These positions or coordinates are read from the Computer Numerical Control (CNC) file discussed in the next section.

5 CONTROL SYSTEM

A control strategy that realizes the manufacturing process of steel wall frames requires a description of its sequence operation and its implementation on a PLC.

5.1 Sequence of Operation

The process of manufacturing steel frames involves the following operations:

- Preparation,
- Squaring,
- Soft connection,
- Hard connection, and

- Dragging.

Preparation is the manual operation of laying out the steel wall frame on the table assembly. Here, the operator sets the required width of the table and lays only the basic frame components for squaring. The operator then activates the mechanisms that hold the frame squarely to enable them to snap the rest of the studs in place through soft-connection guides.

Once the wall frame has been manually assembled, the rest of the process is carried out automatically. Hard connection is the automated process of applying screws at the predetermined coordinates of the wall frame. This procedure is followed by a dragging operation that positions the wall frame for applying the next set of screws, and the hard connection and positioning sequence are repeated throughout the entire length of the wall frame. Once the hard connection has been applied to the entire length of the panel, the panel is dragged to Table B and manually moved to another process. Having cleared Table B, the operator repeats the sequence of operation.

5.2 Implementation of the Control System

Automation of the steel wall frame sequence is realized on a PLC with 43 I/O (input-output) points, comprising:

- Discrete Inputs (DIs) from proximity sensors for material detection,
- Discrete Inputs (DIs) from safety limit switches,
- Discrete Outputs (DOs) to activate squaring electromagnets,
- Discrete Outputs (DOs) to activate squaring pneumatic cylinders and screw drivers, and
- Motor drive outputs for positioning squaring mechanisms, pneumatic screw drivers, and table linear actuator.

A Human Machine Interface (HMI) facilitates the operation of the automated wall frame process. This device utilizes a touchscreen monitor and a stand-alone PC connected to the PLC through an Ethernet/IP cable. A schematic of the process displayed on the HMI provides the operator a picture of what is taking place in the process and the necessary information to determine when to intervene in the process. It is through the HMI that the operator uploads the CNC file required by the PLC in order to accurately position the squaring, screw drivers, and table motors. The CNC file contains the geometry of the given steel wall frame as obtained from design drawings.

Safety during the manufacturing process is ensured through emergency shutdown (ESD) push buttons, which are strategically situated around the assembly. These ESD devices are wired independently of the PLC to enable the operator to immediately stop all moving components from operating if an abnormal situation is observed.

The components discussed so far constitute the hardware portion of the control system. Configuration of the unique address for every I/O device and motor is accomplished through the software that runs the PLC. This software allows the implementation of the operation sequence through programming. Users may choose from any of the PLC programming languages: ladder logic, functional blocks, and sequential function chart.

Wiring a PLC control system can be an intricate task, even with 43 I/O points. Thus, Fieldbus technology is adopted to simplify the wiring effort. Aside from simplified wiring, there are other advantages associated with Fieldbus. This chosen technology is described, along with its advantages, in the next section.

6 FIELDBUS TECHNOLOGY

Fieldbus is described in Thomesse (2005) as a distributed control network of interconnected field devices such as sensors and actuators, PLCs, and HMIs. Fieldbus technology arose from the end-user need for a truly hierarchical or distributed control system that is mainly an open system. An open system enables the end user to install different brands of field devices from suppliers on the network. Among the predecessors of Fieldbus technology are: Modbus from Modicon in the late 1970s, WDPF from Westinghouse in the early 1980s (Thomesse 2005), and HART from Rosemount in the late 1980s (Spectrum Controls 2017). In the late 1980s the International Society of Automation (ISA) initiated the standardization of Fieldbus through the SP50 committee (Thomesse 2005).

Scott and Buchanan (2000) describe the three topologies and advantages of Fieldbus technology. Field devices in Fieldbus architecture can be connected through junction boxes on a common bus (spurs topology), in series (daisy chain topology), or by multiple drops branching out from a single junction box (tree topology). Installing the field devices on a Fieldbus offers the following advantages:

- An open system that enables the end user to install different brands of field devices from suppliers on the network.
- Significantly less wiring and smaller control panels, and cost savings from the use of a digital communications protocol.
- Enhanced commissioning and troubleshooting capabilities due to the availability of control algorithms and information from the field devices. (Field information consists of device configuration parameters and diagnostics.)

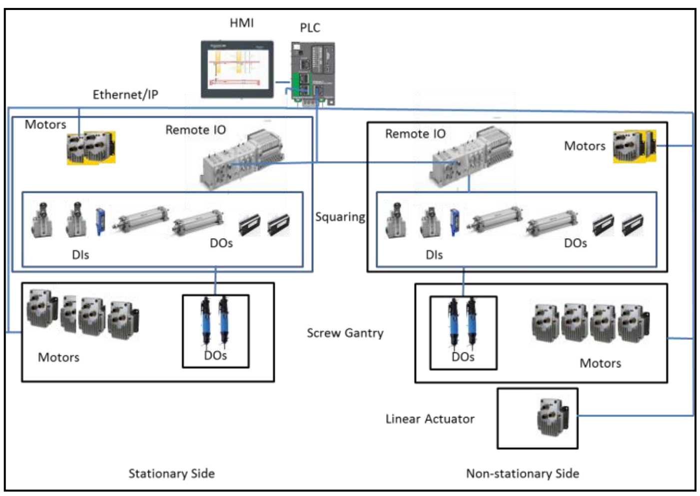

Figure 2. Fieldbus architecture of steel wall framing assembly.

The Fieldbus topology of the steel wall framing assembly follows that of a tree. Figure 2 illustrates the adopted topology and the components described earlier. At the top of the hierarchy of the network is the HMI, which serves as the operator’s window to the process. In the next layer is the field controller, or PLC, which processes the information from the field devices to accomplish the required sequence of operation implemented in the program. Prior to programming, the configuration of the field devices is performed on the PLC. At the bottom of the hierarchy are the field devices. Whenever the control strategy calls for different brands of field devices, the steel wall framing takes advantage of the open system capability of the Fieldbus technology.

Each side of the steel wall framing assembly, stationary or non-stationary, is independently controlled. Thus, there are two junction boxes that branch out to the field devices. Motors, remote I/Os, and actuators are equipped with intelligence to provide the configuration information and diagnostics to the PLC. Built into the motors are the drives that enable them to communicate with the PLC. Included in each of the motors is an encoder that provides the feedback signal for a closed-loop control strategy residing on the PLC. Remote I/Os are basically manifolds serving the pneumatic signals for driving the squaring cylinders and pneumatic screwdrivers and all the other DOs. As indicated in the previous section, the ESD devices are wired independently of the PLC.

7 CONCLUSION

An increasing demand for modular steel structure fabrication in Canada offers an opportunity for automation. Details of the hierarchical structure of the PLC-driven control system, referred to as Fieldbus architecture, for the automated steel wall framing assembly have been provided in this paper. This control system profits from several advantages that have been enumerated for Fieldbus technology. Current work covers the design of the SCADA/Device level of the manufacturing hierarchy. In future work, the control strategy described herein can be expanded to the highest level of a manufacturing hierarchy, which is the Enterprise level, to enable agile manufacturing capability.

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