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Design and implementation of a control system for a steel plate cutting production line using programmable logic controller

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ABSTRACT

Most of the old machines installed in different industries are managed manually by system operators. This action makes their productivity low and not suitable to cover the needs in other sectors. In addition, these machines are not without risks due to the proximity of the operators to them. The installing a new full system instead of the old one on the same site requires very high costs. So, modernizing the same old system by making its operation automatic has become necessary to reduce the economic cost significantly. In this paper, an automatic control system based on programmable logic controller (PLC) for the cutting steel plate machine that had been managed manually in a factory is designed. The system includes an Encoder that is used to specify the length of the steel plate to be cut by sending a signal to the PLC. The system operation is completed by using human machine interface (HMI) unit to monitor and control the system performance by the system operator. A practical test for the developed system offered more productivity (more than 30%), more safety, reduces human efforts and the total daily production cost (less than one third).

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1. INTRODUCTION

Nowadays, developers are searching for numerous methods to minimize labor efforts, cost and time [1], [2]. The idea of freshening conventional machines that managed manually is a popular rule in many factories. Developing the same longstanding systems by adding automation to them has become vital to increase the productivity and profits [3], [4]. Programmable logic controller (PLCs) are commonly employed in manufacturing automation, and are characterized by high flexibility, accuracy, reliability and strong real-time performance [5], [6].

Steel plate cutting machines are important machines that are installed in many factories and used in many applications such as water tanks, cars bodywork, roof works for garages, and buildings. To increase productivity and safety, PLC systems are used to control these machines. Also, a display tool such as a computer or human machine interface (HMI) is used to monitor the progress operation of such systems [7].

In this paper, a control system for a conventional steel plate cutting machine located in a factory using PLC and HMI is built. PLC system helps control the speed of the induction motor that responsible for the movement of the steel plate by the variable frequency drive (VFD) and the encoder. The operator enters the panel length and number of panels through the HMI to obtain the desired product.

The organization sections of this paper as: in section 2, literature review is given. In section 3 the hardware tools that include mechanical and electrical parts are described. In section 4, architecture of control strategy is illustrated. In section 5, software description is specified. In section 6 experiment results are offered. Finally, the conclusions are given in section 7.

2. RELATED WORK

PLC and HMI are widely used to control many industrial processes. Therefore, many researchers have addressed the use of PLC to control production lines in factories. Kumar and Prasad [5] presented a case study of modifying automation system of a filament coiling machine to increase its activity and accuracy. The developed machine was reducing the human labor and increasing the robustness of the system using Delta PLC. The speed feedback control is designed by digital encoder for constant speed operation. VFD is used to control the speed of an induction motor which drive the required load. The PLC monitors and controls all the input and output apparatuses through HMI. Gafar and Said [7] discussed modifying a control system using a PLC for a wire cutting machine used in an air cooler refrigerators plant. The paper was focused on how the control system is able to increase production, safety, and benefits as well as decrease workers, stopping time, failures, and waste. Kamau [8] proposed a case study to modify and control the machine by using PLC. The electrical board that controls the machine was an old PCB board and the faults were frequent and it was very expensive to repair. The new design with the help of Siemens PLC provides more efficiency and higher production. Han *et al*. [9] introduced an automatic control system using PLC for "cutting metal plates in the flame cutting machine". The developed system is able to perform fixed lengths of plates with high accuracy. The system has many operation modes and meets the requirements of many types of products.

Syufrijal *et al.* [10] designed a system that controls a "pipe cutting machine" using PLC and HMI with high accuracy. The system employed an "servo motor". PLC received a signal from proximity and Encoder. Proximity is used to detect the existence of pipe whereas the Encoder detects servo motor speed and hence the pipe Length. The machine cuts pipes automatically depending on the number and length of the pipes required. Bhatlawande *et al.* [11] proposed an automated system using a PLC to control on "Velcro cutting machine" with the help of stepper motor and the encoder. The roller is controlled by stepper motor rotations. The encoder is used for giving a pulse per each movement of the roller. Heater's temperature is sensed by temperature sensor that fed the feedback signal to the PLC to control the heat of the cutter which cuts the product properly. Gadale *et al.* [12] presented a study on the importance of automation in the traditional cutting machines used in industrialization. The cutting machine has lower execution time, greater productivity, and less damage to the workers when using a PLC control system. Kumar *et al.* [13] designed a control system for a "powder press machine" using PLC, servo motor and linear displacement Encoder. Servo motor operation is controlled by VFD. LVDT device is used to send the servo motor positioning to the PLC. The outputs terminals of PLC are connected to valves, VFD and HMI. PLC helps reduce the cost, increase production, and save on energy.

3. DESCRIPTIONOF HARDWARE TOOLS

3.1. Mechanical parts

The mechanical parts of the cutting steel plate machine have been presented in Figure 1. The first part is a steel coil that is rotated by a three-phase induction motor. The leveling parts pull the steel plate due to the force of friction and make it flat and balanced. The plate passes through a cutting press that cuts the plate to the desired length. The cutting section includes a three-phase induction motor and a saw blade. The encoder, which is tangent to the steel plate, starts to rotate and sends pulses to the PLC to determine the length of the steel plate continuously. Figure 2 shows a screenshot of the mechanical parts of the system.

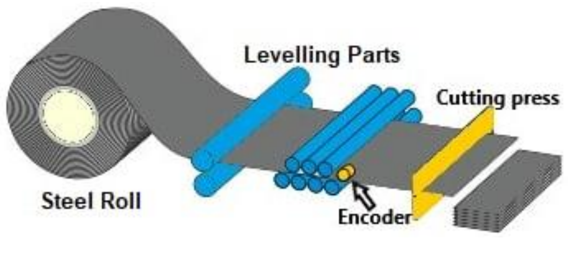

Figure 1. Mechanical parts of the cutting steel plate machine

Figure 2. Photograph of the mechanical parts of the system

3.2. Electrical parts

The electrical parts of the system include several elements. The important part of the system is the PLC unit, which is the main control for the rest of the parts. The VFD has the function of controlling induction motors in the system. The system also contains an encoder whose function is to sense the movement of the steel plate and to present its signal as input to the PLC. The HMI is an important part of the integration of the system's work as it is used to monitor and enter all the required data.

The system contains secondary accessories that include motor protection circuit breaker (MPCB), oil pump system, A 3-Pole miniature circuit breaker (MCB), switched-mode power supply (SMPS), transformer and relays. The following sections describe the main electric parts.

3.2.1. Variable frequency drive

Variable frequency drive (VFD) is an electrical device that converts input AC power into AC with adjustable voltage and frequency [14]. The VFD is used for speed control of a three-phase asynchronous motor [15], [16]. The VFD has many advantages such as reliable energy saving, accurate speed control, and easily realize automatic control [17], [18]. Figure 3 shows the block diagram of the VFD circuit [19].

In this work, VFD used to control the speed of leveling motor. At the beginning, the leveling motor rotates at full speed and before the plate reaches the specified length, the motor slows down its speed and finally break. Table 1 shows the VFD specifications.

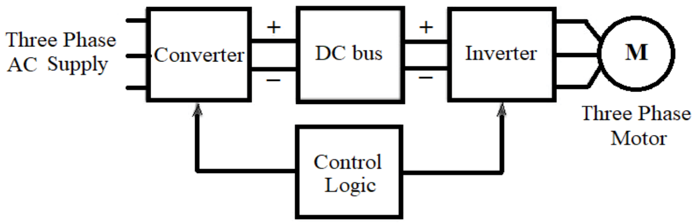

Figure 3. Block diagram of the VFD

Table 1. VFD specifications

Rated power (KW)	Rated voltage (V)	Rated current (A)	Frequency (Hz)
5.5	380	13	0-400

3.2.2. Encoder

An incremental rotary encoder is a device that converts mechanical movement into an electrical signal. It is employed vastly in industrial automation systems like speed estimation of motors [20], [21]. It is used in measuring lengths, angular position, and speed. The pulses generated by the encoder are proportional to the variable to be measured [22]. Figure 4 gives a pictorial image of the encoder used in this work. Specification of the encoder is given in Table 2.

Figure 4. Incremental rotary encoder

Table 2. Specification of the rotary encoder

Model	Shaft external diameter	Pulse number per revolution	Phase type	Voltage
E50S8	8 mm	500	3: A, B, Z	12-24 V DC

4. ARCHITECTURE OF THE CONTROL SYSTEM

The architecture of the whole system of cutting steel coil machine can be seen in Figure 5. The 3-phase voltage of the main power supply passes through the MCB to feed the control board. VFD and power contactor are fed via the MCB directly. The SMPS received 220 Vr.m.s via the transformer and step-down and rectified it to the 24 Vdc which represents the input to the PLC, limit switch, and the encoder. The operation principle can be illustrated as:

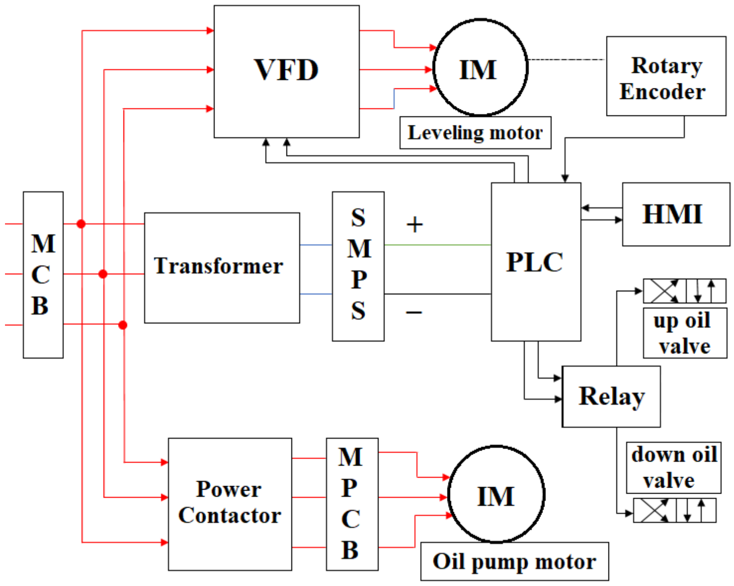

Figure 5. Block diagram of control system

At the beginning of the operation, the initial parameters of the system must be specified by the system operator using HMI to control and monitor the work of the machine. These parameters include length of each plate and the number of the plate to be cutting. The system operation is started when the push button is pressed ON. VFD will be received a signal from the PLC to control the speed of the induction motor (levelling motor). The encoder starts to rotate and sends pulses to the PLC to define the length of the steel plate continuously. Before the plate reaches to the required length (90% of length), PLC sends a signal to the VFD. The levelling motor received the control signal from VFD and then it reduces its speed gradually and finally stopped when the plate reached to the required length. After that, PLC sends a signal to the relay, which is in turn sending it to the cutting device to cut the steel plate. When the cutting process complete, the control process is repeated for the next plate until reach to the required number of the steel plates.

5. SOFTWARE DESCRIPTION

The program was implemented for Delta PLC Table 3 gives its specifications based on logical instruction where it works on two states (ON and OFF) [23], [24]. The programming method used is the ladder diagram (LAD) method. The designing LAD can be running and verifying by a personal computer [25]. PLC takes the sensors signal and processed them by the program then gives the signal to the VFD which again processes this input signals and finally controlling the motor speed. In this project, programming of PLC was performed employing WPLSoft 2.5.0 version. This software integrates all the modules connected to the PLC and the devices connected to its HMI, VFD, induction motor and hydraulic motor. Also, the monitor and control are achieved through HMI and its screens are developed using DOPSoft version 1.00.11. The flowchart of the automatic cutting steel plate machine given in Figure 6, while Figure 7 shows the screen shot of part of ladder logic program for the control system.

Table 3. Delta PLC specifications

Model	Operating voltage	Max. frequency	Input/Output ports	Comm ports
DVP12SE11R	24 V_{DC}	100 kHz	8 input/4 output digital	1 Ethernet, 2 RS-485, 1 RS-232

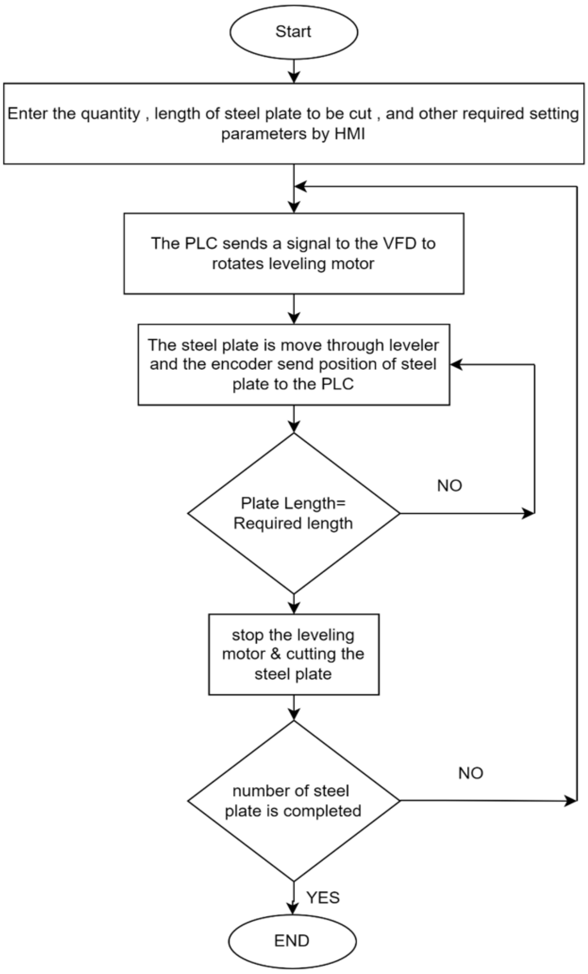

Figure 6. Flowchart of the control system of the cutting steel plate machine

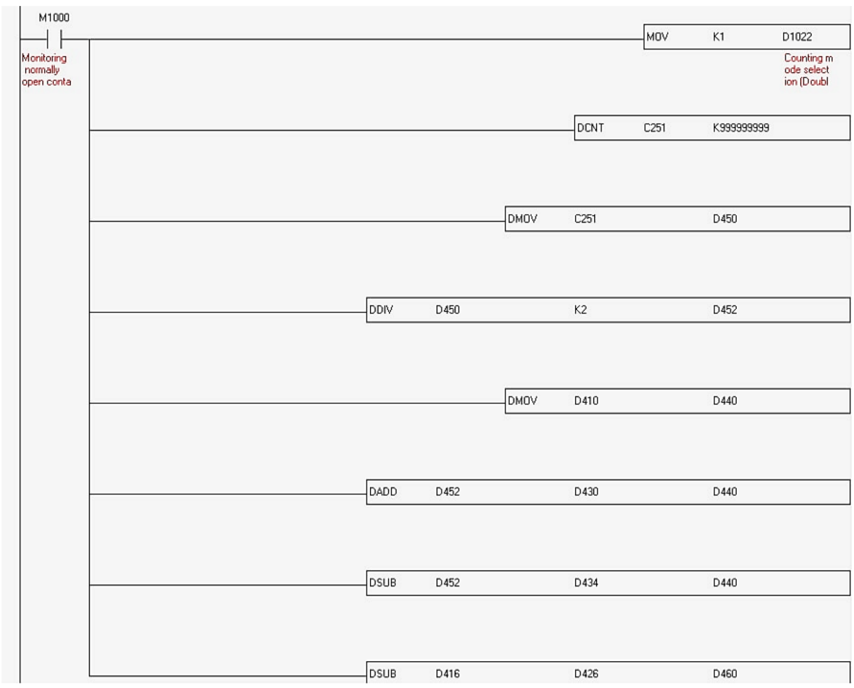

Figure 7. Screen shot of the ladder program for the control system

6. EXPERIMENT RESULTS

The testing of the design system is done practically to determine how the control system used to cut the steel plate with satisfactory accuracy. Figure 8 shows a picture to the main control board. Figure 9 illustrates the control panel that used by operator of the system to enter the required implementation. Figure 10 gives the HMI that used to input and display the following data: i) input length: the required length of the steel plate; ii) number of plates: represents the required number of the steel plate; iii) instant distance: represents the instant length of the steel plate moving through the cutting press. This distance is important to give indication to the operator before the plate reaches the cutting point; iv) number of completed plate: gives the completed steel plate that were cutting; v) cleared (CLR): pushbutton for clearing the system; vi) run and stop; and vii) forward (FWD) and reverse (REV) rotation of levelling motor respectively.

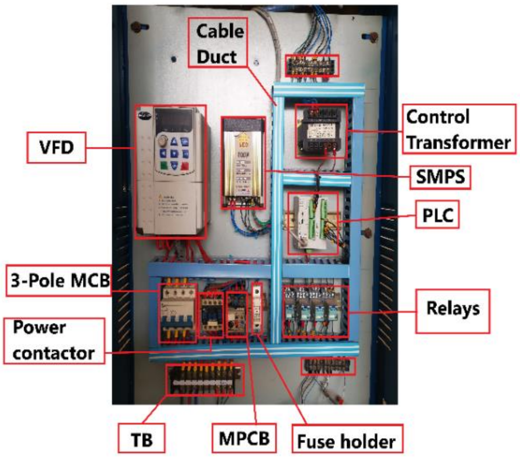

Figure 8. Main control board

Figure 9. Control desk panel

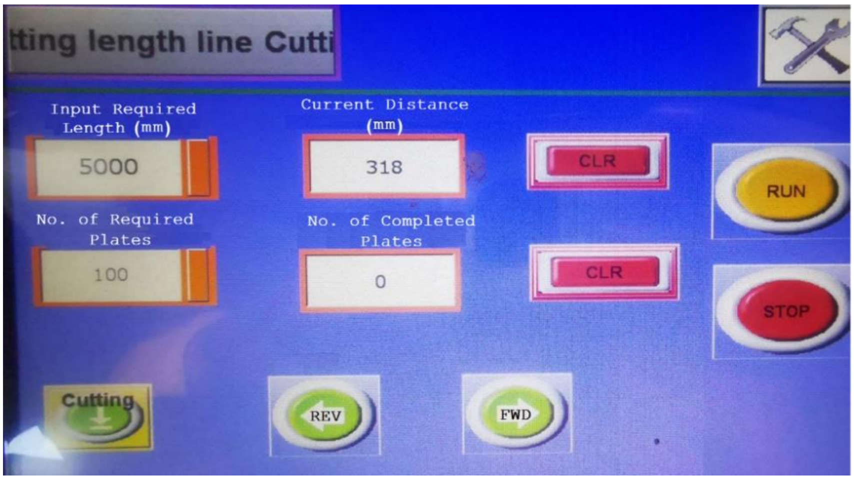

Figure 10. HMI that used to input and display data

Figure 11 shows the increase in productivity before and after system renewal. One can notice that the increase in the number of production plates is inversely proportional to the length of the plate (the increase in productivity was from 150 plate/hour to 190 plate/hour when the length of the plate was 1 meter, while the increase was from 20 plate/hour to 32 plate/hour when the length of the plate 9 meter). The reason for the difference in increasing rate of the productivity is the stopping that occurs after the production of each plate. Figure 12 gives the relation between the length of the plate and the pulses of the encoded. Table 4 illustrates the total production cost per day before and after development ($90/day and $28/day respectively). This means that the total cost decreases significantly (less than one third).

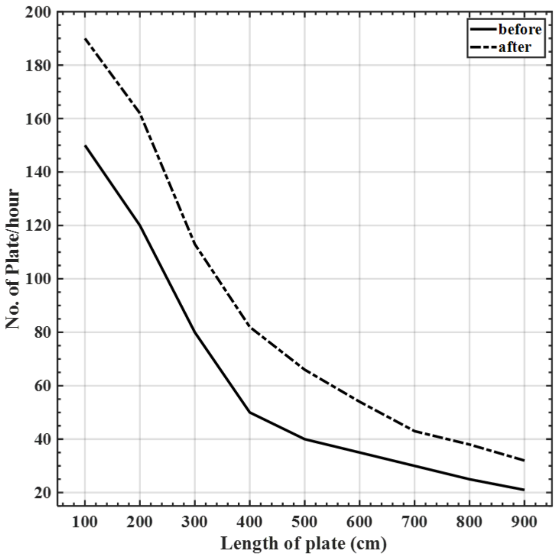

Figure 11. Increase in productivity before and after system development

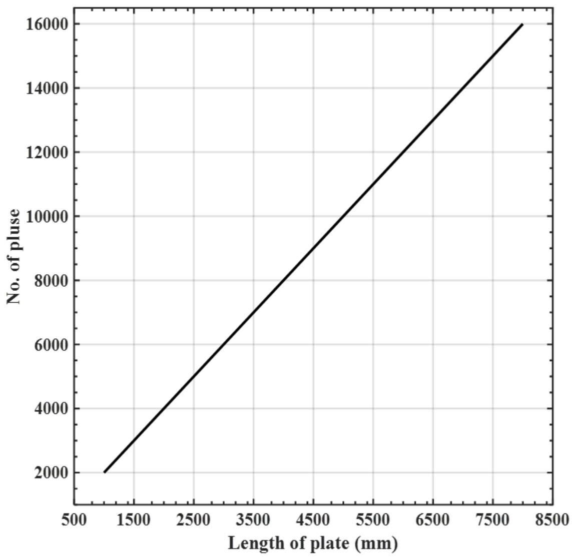

Figure 12. Relation between the length of the plate and the pulses of the Encoded

Table 4. Average production cost

Cost type	Before development	After development
Product deterioration	40$	10$
salaries of operators	45$, for three operators	15$ for one operator
other costs	5$	3$
Total/day	90$	28$

7. CONCLUSION

In this paper, an automatic control system based on PLC and HMI was designed. The system is used to develop the work of the steel plate cutting machine that has been installed early in one of the production factories. This update is saving the capital of buying a new entire new product. The operator enters the plate length and plate number through the HMI which represents important part of the updating system. The position of the length of the plate that was driven by the motor can be sensed by the encoder. The signal of the encoder is sending to the PLC, which in turn sends a signal to the motor. The motor slow down gradually until it reaches the desired length, then it stops. After that, PLC sends a signal to the cutting motor to cut the plate, then the process is repeated again. In order to confirm the usefulness of the developed system, it was verified experimentally in real-time production line. The output production capacity of the updated system was increased due to the reducing in stopping time that occurs after each cutting of plate by system operator. Also, there is an increase in the safety of the system and a saving in labor from 3 persons to one.

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