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Development of Cut to Length Machine using Programmable Logic Controller with Human Machine Interface

Sumaiya Mashori[1], Ashok Kumar Ganesen[2], Lam Hong Yin[3], Norain Sahari[4], Rasida Norjali[5], Sim Sy Yi[6]
[1,2,3,4,5,6] Department of Electrical Engineering Technology, Faculty of Engineering Technology,
Universiti Tun Hussein Onn Malaysia (UTHM), Malaysia
sumaiya@uthm.edu.my, ashokkumarganesen@gmail.com, hylam@uthm.edu.my, norains@uthm.edu.my,
rasida@uthm.edu.my, sysim@uthm.edu.my

ABSTRACT

Industrial automation helps to eliminate the possibility of human error, reducing costs, saves time-consuming, and achieves higher productivity with better quality with the helps of the control system and technologies that enable industrial processes and machinery to operate automatically. For paper cutting applications, an automated cutter that able to cut the paper at specific lengths and operate according to the parameter setting by the user could help to save cost and time. Therefore, this work is to develop a cut to length machine using the Unitronic Jazz Programmable Logic Controller (PLC) with the combination of Human Machine Interface (HMI) features. This work aims to design and fabricate a small scale cutting machine controlled via a PLC software. To enhance the security system, one-stop center control panel is developed. The iron framework is chosen as a basement of the conveyor and cutter, with the fabrication process consists of five stages. The relationship between the measured speeds of the Alternating Current (AC) induction motor over the frequency range is discussed. From the experiment, the result shows that the machine able to cut the paper with a good precision and accuracy at the length of 1, 5, 6 and 7 inch for the paper type of 50, 70 and 80 gram per square meter (gsm) with the constant pneumatic pressure of 7.5MPa and constant motor speed at 60rpm (2Hz).

Key words: Cut to Length Machine; Paper Cutter; Unitronics Jazz PLC; HMI.

1. INTRODUCTION

Nowadays, the automation helps to improve performance by reducing the possibility of human errors, elimination routines of manual and clerical tasks, cleaner technology, minimize energy consumption, achieve higher productivity with better quality and speed, and in some cases, automation achieving outcomes that go beyond human capabilities [1]-[4]. While, according to Grigor [5], automation is appropriate at solving the problem with large batch orders and quantity, improve the working environment conditions, increased the human safety and performing complex operations at one time.

In general, there are several systems that play an essential role in industrial automation. Such a system includes PLC, Supervisory Control and Data Acquisition (SCADA), HMI or, Distributed Control System (DCS), which depends on the scale of the industrial process and numbers of field instruments [6].

Usually, the conventional cutting machine is manual or semi-automated operating system, less production rate, unsafe working, required more time for startups and operated with more manpower. Basically, with the good quality procedure, the involvement of automation components such as PLC, HMI, computers and sensors in conventional cutting machines able to save production time in the manufacturing industry. Hence, the objective of this research is to develop a small scale of cut to length machine controlled by PLC and measure the performance of the prototype machine for cutting paper applications. For the design and fabrication of cutting machine is useful to cut the material in accurate length and diameter, hence could eliminate the human errors and reduce the operating time.

The design and analysis of cutting, sorting and bunding machine was analyzed by Nanu S et al. [7], they presented a cutting accuracy and speed between the manual rod processing methods and proposed mechanism. This analysis presents that the proposed design able to reduce the overall processing costs up to five times compared to manual labour, with the measurement errors under ±2% between the manually calculated length and the machine measured. Some researchers [8] used the Geneva Mechanism to produce intermittent motions at the beginning and the end of active phases. Based on the analysis, the paper cutting machine designed using Geneva Mechanism able to cut the paper accurately and reduce the timing for paper cutting. However, the proposed system not able to cut the papers above 15 cm width and a bunch of papers consists of more than 5 papers.

In [9], Banupriya et al. discuss the development of automated four differents sectional drive paper machine-controlled using PLC with the given input command and output parameters displayed using HMI, replacing the existing linear shaft drive paper machine. The authors specify that the machine operation for the dryer section and the pop reel requires less manpower, increase the quality of the product, good accuracy and repeatability.

Amanpreet Kaur and Er. Pardeep Singh [10] present the design and analysis of automation paper making machine based on PLC, VFD's and HMI. In their studies, in order to improve the quantity and precise quality of paper, they presented an upgrading dryer attached with PLC to replace the conventional parts such as relays, contactors and timers, to program the motor to run at various speed VFD, and given input command and displayed important parameters using HMI. As a result, the dryness is increased to 35% from 30% and reduce the energy consumption of the paper machine from 2390949kWh to 2070063kWh with 320886kWh energy saving after introduced VFD to the system.

The research of the electro-pneumatic actuator had been conducted by Bhagyesh Vaidya et al. [11]. In their studies, the position of the piston for both double-acting cylinder with an operating pressure limit of 0.1Mpa up to 0.9MPa had been controlled by a 5/2 way directional control valve. The double-acting cylinder will move downwards for cutting action and will be brought to the top position after cutting of material is done. Futhermore, according to Prof. Amey Shirodkar et al. [12] pneumatic cutting machine operated under pressurized air within a range of 4 to 6 MPA will move forward and backward motion for the cutting process. Previous work demonstrates that the pneumatic cutting machines able to increase productivity, reducing human intervention, less hazardous and faster execution time.

This project presented the working principle of cut to length machine using a Unitronics Jazz PLC controller with the combination of HMI features (part number: JZ20-J-R16-Z) that operated at $24V_{DC}$ supplied from OMRON Power Supply (part number: LRS-100-24). The input in this project is an optical shaft encoder, HMI, push buttons and the output are Delta Variable Frequency Drive (VFD) (model: VFD007L21A), 0.75kW 4-pole AC induction motor (part number: EM80B4).

The cutting mechanism will be controlled by a 5/2 way directional control valve to move double-acting cylinder downward for the cutting process and move upward after cutting paper is done. Section 2 detailed the development of the hardware setup with respect to the whole system, including a brief discussion on the ratio of conveyors movement to length calculation. The measured performance and result had been discussed in Section 3. Finally, conclusions with respect to the developed system are made in Section 4.

2. METHODOLOGY

The development of the hardware setup will be discussed briefly in this section.

2.1 Control Panel Design

The design of the control panel on this project, had been developed as a One-Stop control center, which means all electrical components will be placed inside it and hardwired accordingly. Figure 1 shows the developed control panel design with the length, height and width measurements, which are 16inch (in), 20in and 6in respectively. Unitronics Jazz PLC, ON/OFF selector switch, push-buttons (green to start and red to stop the process) and pilot lamps (yellow to indicate ON, green to indicate process running and red to indicate process stopped) is suitable to be placed at the door of the panel, while the wiring placed behind the door of the panel. This also enhances the security of the system, user and all personnel involve directly or indirectly with the machine. Inside the control panel, 6A single pole Main Circuit Breaker (MCB), 4A fuse and Omron Power Supply to convert single phase AC to $24V_{DC}$ is placed at the top part, while on the lower part, there are the outgoing terminal blocks and VFD.

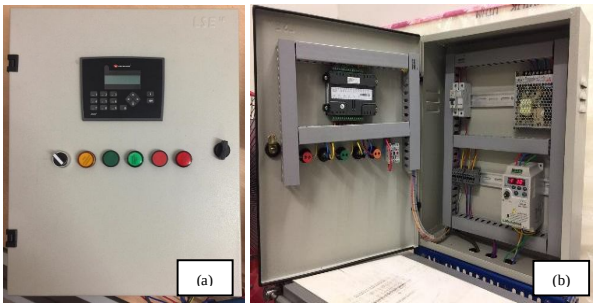

Figure 1: Control Panel (a) Front door (b) Inside view

2.2 Conveyor and Cutter Design

The design of the conveyor and cutter had been developed on small scale by referring to the previous researchers [8]. Figure 2 shows the design of the conveyor and cutter by using the SOLIDWORKS software. For this project, the fabrication process has five stages as shown in Figure 3. The first process is fabricated the iron framework as a basement of the conveyor and cutter based on the design in Figure 2. Then the cutter is embedded with two units of double-acting cylinders that controlled by using a 5/2 way double solenoid valve, whose function is to control the cutter movement. After that, during the conveyor movement, the conveyor belt will waver. Therefore, the supporting frame is necessary to ensure the paper move straight, and the conveyor belt does not waver.

In the next process, the $240V_{AC}$, a 4-pole induction motor is attached to the basement of the conveyor and cutter. A coupler had been made and tested for the motor and prime roller so that it doesn't slip during rotation. The connection of the motor inside the T-box is in Delta connection due to the VFD's output is varying frequency at $240V_{AC}$. Then, the cutter is connected to the basement, in line with the motor.

Finally, after the fabrication of the designed conveyor and cutter is completed, the control panel is attached together with the conveyor. Figure 4 shows the assembled model of the proposed cut to length machine.

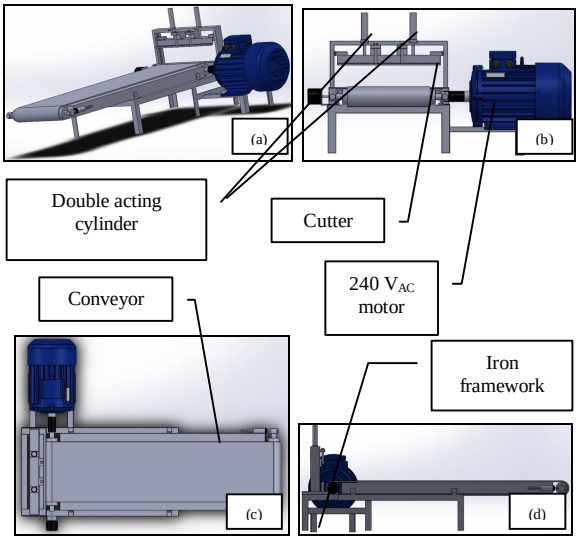

Figure 2: Conveyor and cutter design (a) Fully assembled (b) Rear-view (c) Top view (d) Side view

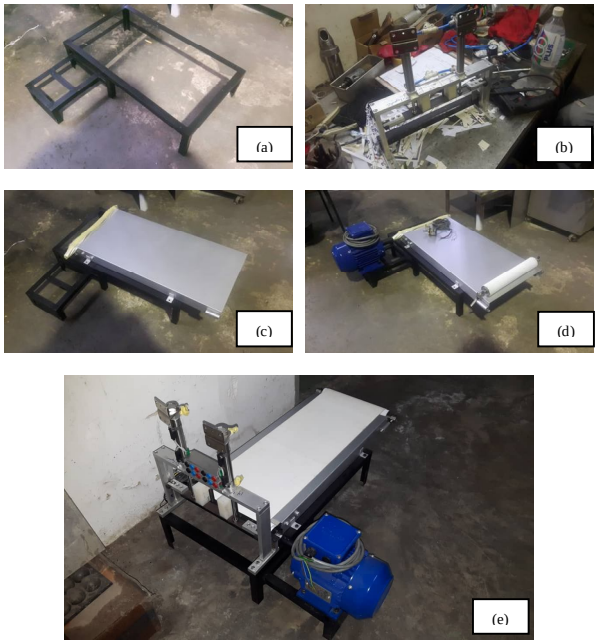

Figure 3: Fabrication process (a) Basement (b) Assembled cutter (c) Embedded supporting frame for the conveyor (d) Tested induction motor and prime roller (e) Attached cutter to the basement

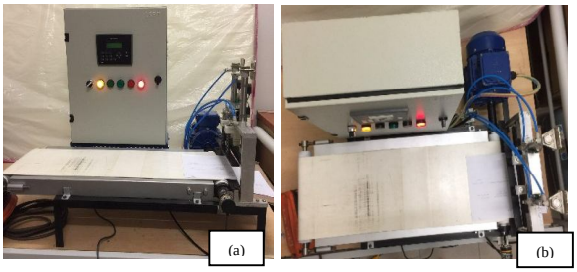

Figure 4: Cut to Length Machine (a) Front view (b) Top view

2.3 Cut to Length Machine Operation Principles

Figure 5 illustrates the system block diagram which separately into the input, controller and output of the system. In principles, the system will receive basic parameters input settings from the user via HMI. After that, the PLC controller will process the length cutting requirement with the combined output of VFD, motor, solenoid and cylinders. The cut to length machine will then cut the paper at a specific length according to the parameter set by the user or operator at HMI.

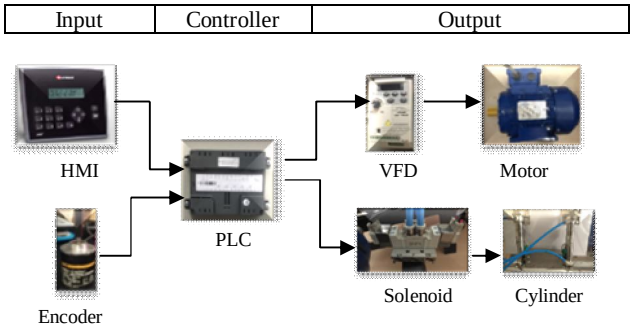

Figure 5: Block diagram of the machine

The flowchart of the machine is shown in Figure 6. When the system is on, the $24V_{DC}$ power supply is supplied to the controller, while for the pneumatic supply, a general compressor that able to supply the pneumatic pressure up to 7.5MPa is used and powered by $240V_{AC}$ from the direct domestic electrical power source. Then the solenoid valve is linked to a compressor for the cylinder movement.

The control system had been designed using an Unitronic Jazz PLC, in which the input is an encoder while the outputs are an inverter, motor, and two double-acting cylinders. When the start button is pressed, VFD and conveyor motor will run. The encoder will send the signal to PLC to stop the conveyor when the length needed is attained and the solenoid valve will activate the double-acting cylinder attached with the cutter to move downward to cut the paper. Both double-acting cylinders will be extended for two seconds and retract back to its initial position. Fully retraction of both cylinders will reset the counter of optical shaft encoder and repeat the whole process. If the Stop button is pressed, all the process will stop.

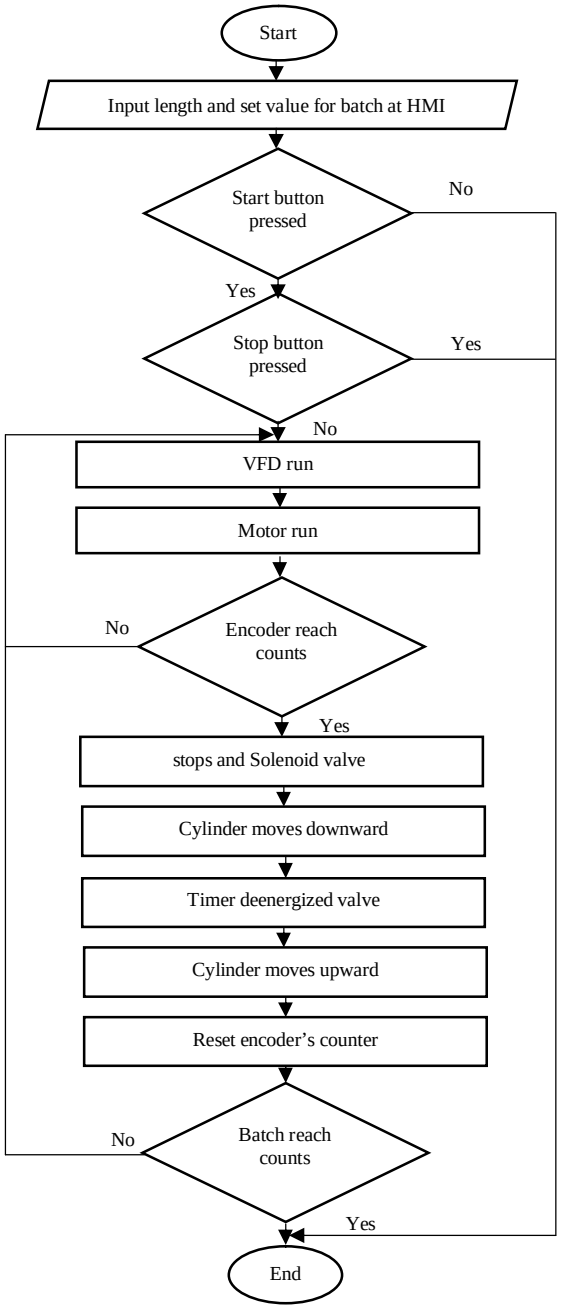

Figure 6: The flowchart of the machine

2.4 Ratio of Conveyor's Movement to Length

For this project, the roller used has a diameter of 2in. The conveyor's movement can be quantified in pulses from the encoder where the pulses for each revolution of the roller respectively to motor's movement is 1000 pulse. Equation 1 shows that every 159.15 pulses, the conveyor move by 1in. In other words, for every inch of paper is equivalent to 159.15 pulses of the encoder.

$$Length(inch) = \frac{Pulse}{PulsesPerInch} = \frac{Pulses}{\frac{PulsePerRevolution}{CircumferenceOfRollerOfConveyor}} = \frac{Pulses}{\frac{1000\frac{p}{r}}{\pi(2inch)}} = \frac{Pulses}{159.15\,ppi} \quad (1)$$

3. RESULT AND DISCUSSION

The development of this cut to length machine for paper cutting application is focused on the need to be synchronized with the speed of the conveyor so that the cutting process can run smoothly. Figure 7 shows a tachometer is used to take the reading of the 4-pole motor's speed.

Figure 7: The experimental setup of parameter design

Initially, the data of the motor's speed at the respective frequency of the output from VFD, are measured, then the value of the motor speeds are calculated and measured, and the differences between the calculated and measured speed, known as slip are measured and recorded thought the experiment and tabulated in Table 1. The relation between the frequencies of the output from VFD against measured speed is also measured. The frequency is varied from 1 to 60Hz. Based on the data given in Table 1, it shows that the measured and calculated speeds are almost the same values. From the data plotted in Figure 8, it shows that the speed is directly proportional to the frequency, whereby the speed increases linearly as the frequency increases.

Table 1: Speed of motor over the frequency range

Frequency, f (Hz)	Measured Speed, N_s (rpm)	Calculated speed, N_s (rpm) $= \frac{120 \times f}{p}$	Slip, s $(s_\%) = \frac{N_s - N_1}{N_s} \times 100$
0	0	0	0
1	29.31	30	2.3
2	59.85	60	2.5
10	292.7	300	2.43
20	575.8	600	4.03
30	889.0	900	1.22
40	1186	1200	1.17
50	1465	1500	2.33
60	1776	1800	1.33

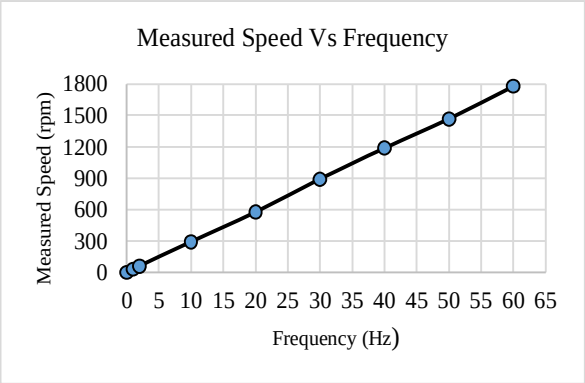

Figure 8: The relationship between the measured speed and frequency

The suitable speed for this project will be from 60 revolutions per minute (rpm) (2Hz) to 300 rpm (10Hz). However, for the best accuracy and precision of paper cutting, the speed of the motor is set at 60rpm (2Hz). This speed is fixed at this level because the material of the conveyor belt couldn't withstand a higher range of speed values. Other than that, the weight of the paper is too light to be moved using a high-speed conveyor, where it tends to slip off or having high inertia during stopping which will cause the length cut by cutter deviated.

Next, the performance of cutting mechanism to cut the paper length accurately at different types of paper which is 50, 70 and 80 gsm with a constant pneumatic pressure of 7.5MPa or 7.5 bar based on the parameters input setting from the user via HMI is conducted. Each type of paper has been tested from 1 to 7in length 3 times on each length.

Based on the result in Table 2, it shows that at the length of 1, 5, 6 and 7in, the machine able to cut with a good precision and accuracy. The result also shows that the machine is not able to cut the paper precisely at the length of 2, 3, and 4in, due to the design of the conveyor and the cutter. The plate that attached to support the cutting process is designed and placed a bit lower than the roller of the conveyor is to ensure that the paper will not stuck when moves out from the conveyor, but eventually, there's a fall of paper during the pressing and cutting process by the cutter. This result shows that the cutting performance of the cut to length machine is affected by the length of the paper, not by the type of paper.

Table 2: Summary of length cut by the machine.

Test	Length (inch)	Type of paper	Measurement (inch)			Average (inch)
			1st	2nd	3rd	
1	1	50 gsm	1	1.1	1.05	1.05
	2		1.8	2.65	2.75	2.40
	3		3.7	3.65	3.6	3.65
	4		4.65	4.65	4.65	4.65
	5		5	5	4.95	4.98
	6		5.9	6.05	5.95	5.97
	7		6.8	6.9	6.9	6.87
2	1	70 gsm	1	1	1.05	1.02
	2		2.45	2.6	2.65	2.57
	3		3.6	3.55	3.4	3.52
	4		4.7	4.6	4.65	4.65
	5		5	5.05	4.9	4.98
	6		6	5.9	5.95	5.95
	7		6.95	6.95	7	6.97
3	1	80 gsm	1.05	1	1	1.02
	2		2.6	2.65	2.65	2.63
	3		2.95	3.35	3.65	3.32
	4		4.35	4.4	4.3	4.35
	5		5	5	5.05	5.02
	6		6	5.9	5.9	5.93
	7		7.25	6.7	6.9	6.95

4. CONCLUSION

In conclusion, this project has been successfully developed, starting from the designing and fabricating of the control panel, conveyor and cutter, then assembling the control panel with conveyor and cutter to the machine, and lastly designing the control procedure of the cutting process using Unitronics Jazz PLC controller with the combination of HMI features. The result shows that the developed cut to length machine able to cut the paper with good precision and accuracy at the length of 1, 5, 6 and 7in, with the speed of motor is set at 60rpm (2Hz). For future improvement, it is suggested to add another roller above the roller near to the cutter in order to avoid the paper from falling, due to imbalance weight of paper before and after the cutting process. Also, it is suggested to increase the position of the supporting plate for the cutter a bit higher, almost in equal level with the conveyor. This is important to avoid further paper movement when the paper had been pressed by the cutter. Finally, for the control system, it is suggested to apply magnetic proximity sensors attach to double acting cylinder to get precise input to the controller instead of a timer.

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