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Enhancing Manufacturing Efficiency at Telkom University: Advanced Automation of Bucket Conveyor and Hammer Mill Machine with PLC and HMI Through the Waterfall Method

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ABSTRACT

The abstract presents a study on the enhancement of manufacturing technology at Telkom University, specifically aimed at improving the production of raw materials for charcoal briquettes and animal feed. Initially hindered by a lack of a sophisticated monitoring and control system, the existing production relied heavily on manual time calculations, leading to high risk of inaccuracies and errors. To address this, the study proposes a novel redesign of the control system for the hammer mill machine, particularly in the panel section, using the waterfall design methodology. This strategic redesign has led to the implementation of an advanced automation system, which significantly streamlines the process by automatically displaying time and power consumption data on the HMI display. This enhancement not only simplifies monitoring and control, but also substantially boosts efficiency. The results show a reduction in the hammer mill machine's operating time by 13 seconds, an increase in productivity by 48%, and reveal power consumption details for the motor and conveyor bucket. These results demonstrate the efficacy of the redesigned system in enhancing operational efficiency and monitoring precision in the manufacturing process.

1. Introduction

In an industry, there is manufacturing within it as a branch of industry that operates equipment, machines, and labor in a process medium to process raw materials, spare parts, and other components to be produced into finished goods with selling value [1]. Telkom University plans to produce the raw materials needed to be produced into charcoal briquettes within the campus environment [2]. Telkom University has a hammer mill machine that will be used as a production

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tool. Before carrying out mass production, it is necessary to pay attention to the suitability of the machine, human resource requirements, raw materials, and the power requirements produced by the machine, bearing in mind that the machine is run using electrical power connected to an electrical room located around the production house [3]. A hammer mill machine is used to change a material's size into a smaller size. In every production process, the industry needs a system to monitor and determine machine performance during the production process [4]. The production process that takes place using a hammer mill machine does not yet have a system for viewing machine performance results, electrical data, and production time calculations, which are still done manually. This allows for human error to occur in calculating the performance of manufacturing machines, thus allowing for errors in manual calculations [5]. If an error occurs, a recalculation must be carried out, which takes a very long time. This can identify that the manual calculation system is not running optimally, so it requires an automation system that utilizes virtual control technology in the calculation process and monitoring system. This system can display the results of the production process from manufacturing machines automatically [6].

In the process of using hammer mill machine production tools, several steps or procedures need to be carefully considered so that errors do not occur during operation, which will impact the smoothness and safety of the production process. There are two main panels to operate the hammer mill machine. Each panel has a different function, and the operator needs to pay attention to this to avoid errors [7]. Based on the results of observations made on existing conditions, the machine operation section consists of 10 process stages, of which 70% of the process is carried out manually. The time obtained when operating the machine is around 27 seconds. To minimize errors, it is necessary to make changes to the machine control by creating a new panel with an automated system [8]. This can help the operator operate the machine because it will be easier for the operator to understand the features or buttons used during the production process. Figure 1 shows the hammer mill panel.

Fig. 1. Hammer mill panel

The automation system's integration into the hammer mill machine represents a significant step forward in the industrial sector, particularly in the realm of manufacturing efficiency and worker safety. With the PLC and HMI at its core, this system not only streamlines the operation process but also enhances the precision of production outputs. By automating data collection and analysis, it minimizes human error and allows operators to focus on more critical tasks, thereby increasing [9] overall productivity. Moreover, the system's ability to provide real-time feedback on the machine's performance and electrical parameters aids in proactive maintenance and troubleshooting, potentially reducing downtime and operational costs. Ultimately, this innovation is expected to set a new standard in machine operation, paving the way for more sophisticated and user-friendly industrial machinery in the future [10].

2. Automation

Automation is a technology used to carry out work processes or procedures without direct human involvement [11] . This process is carried out using an instruction program combined with a control system to carry out instructions in a process [12]. This technology combines the application of mechanics, electronics, and computer-based systems through processes or procedures arranged according to instruction programs and combined with automatic control to ensure that all instructions are carried out correctly to increase productivity, efficiency, and flexibility. Automation can work for repetitive activities and activities that cannot be done by humans [13].

2.1 Programmable Logic Controller (PLC)

A programmable Logic Controller (PLC) is an electronic circuit that can carry out various control functions at a complex level in a design or automation system [14]. PLC is a device that can be programmed, controlled, and operated. PLC works by detecting input (via related sensors), then carrying out the process and acting according to what is required. The user creates a program, which will then be executed by the PLC [15]. PLC is a digital electronic system designed to control machines by implementing sequential control logic functions, timing operations, counting, and arithmetic operations. PLC is a digital computer with a processor, memory unit, control unit, and input/output unit [16].

2.2 Human Machine Interface (HMI)

Human Machine Interface (HMI) is computer-based interface software in the form of a connecting display between humans and the machine or equipment being controlled [17]. HMI can create real visualizations of technology or systems, which are equipped with real data and appropriate to conditions in the field. Furthermore, the visualization is displayed on the monitor in the control room in real time. It can even be accessed online via electronic equipment wherever and whenever there is an internet network. In simple terms, HMI functions as a link for operators to understand the processes that occur on the machine. HMI aims to improve interaction between machines and operators through computer screen displays to meet user needs regarding information systems [18].

2.3 Hammer Mill

A hammer mill is a machine that breaks or crushes material into small pieces. Hammer placement and design are determined based on operating parameters such as rotor rotation speed, engine power, and open areas in the screen [19]. This machine functions to change the size of raw materials into smaller ones, such as fine powder particles. The working process in a hammer mill is that the material will be inserted and then crushed by the hammer, passing through the gaps between the hammers and going to the sieve. Material with a size smaller than the sieve hole will come out as a product, while larger material will be carried back by the hammer so that further crushing occurs [20].

2.4 Conveyor

A conveyor is a mechanical system that moves goods or raw materials from one place to another. Conveyors are widely used in industry to send goods in large quantities on a sustainable scale. Under certain conditions, conveyors are widely used because they have economic value compared to heavy transportation equipment such as forklifts or dump trucks. In the process of moving goods, there must be a fixed location so that the conveyor system has economic value. In the industrial world, the raw materials used for production sometimes contain heavy or dangerous ingredients to human health.

2.5 Waterfall

A waterfall is an approach used to develop a system in the form of a systematic and sequential device or project [21]. The waterfall method was first introduced by Winston W. Royce in 1970. Royce described this model as an efficient approach to managing complex projects at that time. The use of the Waterfall Method follows a linear or sequential approach. Where development is carried out in clear and interrelated stages [22]. There are five steps in development using the waterfall method: requirements analysis and definition, system and software design, implementation and unit testing, integration and system testing, and operation and maintenance [23].

3. Methodology

Figure 2 shows the research systematic that contains an explanation of the procedures or steps taken in research design using methods determined by the researcher. This research uses the waterfall design method. The waterfall method is a method that is carried out systematically. This method has five stages, including the requirements analysis and definition stage, system and software design, implementation and unit testing, integration and system testing, and operation and maintenance [24]. Adopting the waterfall method in this research ensures a linear and sequential approach, which is particularly beneficial for projects where clear objectives and stable requirements are defined from the outset. Each stage of the method builds upon the previous one, ensuring a thorough and methodical progression through the research. This approach minimizes the risk of overlooking critical details, as each phase must be completed before moving on to the next. Furthermore, the clear demarcation of stages allows for easier management and evaluation of progress, making it simpler to identify and address any issues that arise. By employing the waterfall method, the research is positioned to yield comprehensive and well-structured results, ultimately contributing valuable insights and developments in its respective field. The systematic nature of this approach also facilitates better documentation and easier handover processes, making it an ideal choice for this research endeavor [25].

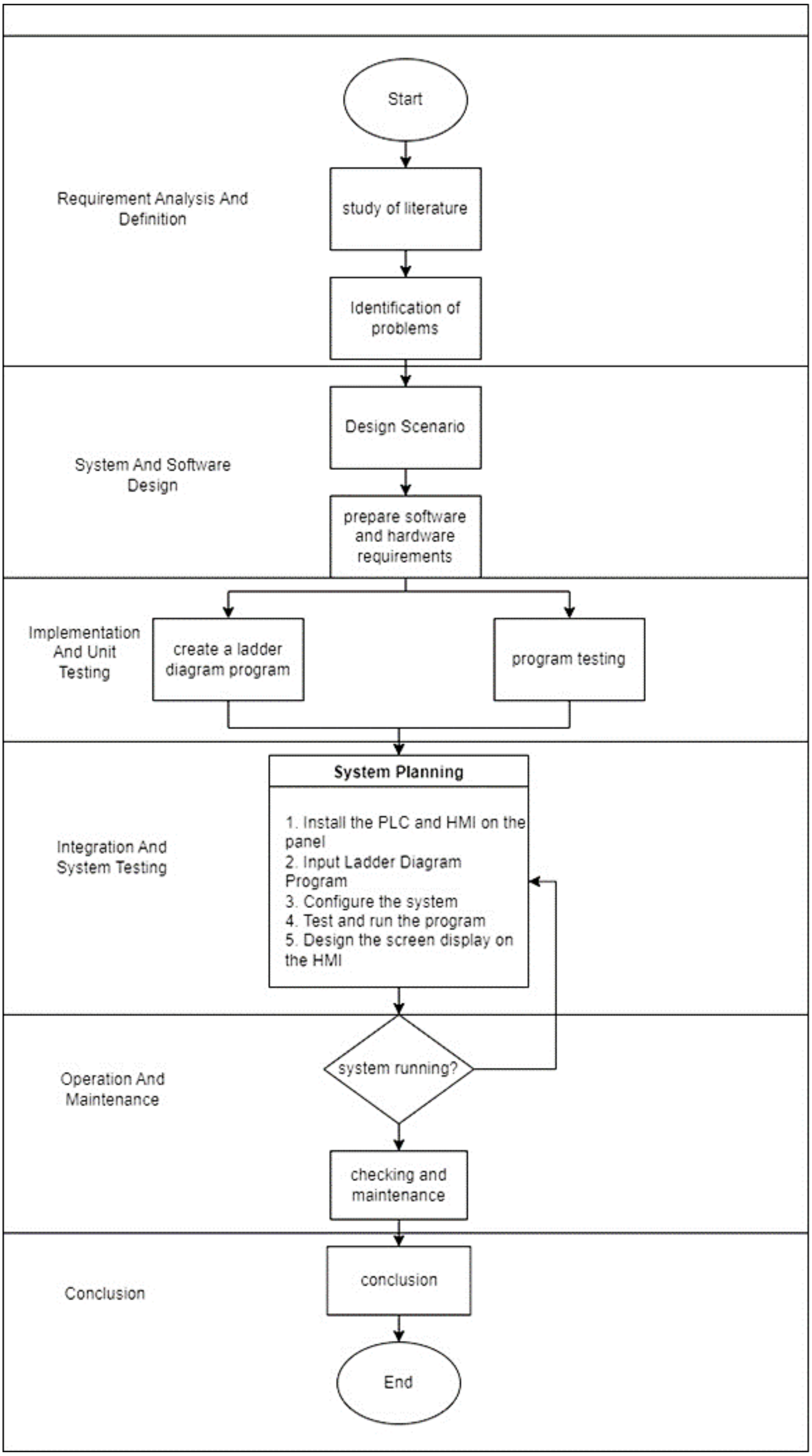


Fig. 2. The waterfall design method

The waterfall method can be summarized as follows:

i. **Requirement analysis and definition:** At this stage, the researcher collects information in the form of potential problems and then looks for reference sources to make it easier to find an overview of the design process that will be carried out. At this stage, a literature study is carried out by looking for sources of information and references from journals, e-books, the internet, and articles related to the research.
ii. **System and software design:** At this stage, preparations were also made regarding complete software and hardware to support this research. In this research, the software used is CX-Programmer V4.51 to create.
iii. **Implementation and unit testing:** At this stage, programming is carried out using ladder diagram language. Then, in this phase, testing and checking the functionality of the program that has been created is also carried out, whether it meets the desired criteria or not.
iv. **Integration and system testing:** After carrying out the testing process on the program that has been created successfully, the next stage is to integrate all the components that have been prepared previously.
v. Operation and Maintenance

This stage is the final stage of the waterfall method to determine whether the system that has been created is functioning. Then, maintenance and inspection will be carried out.

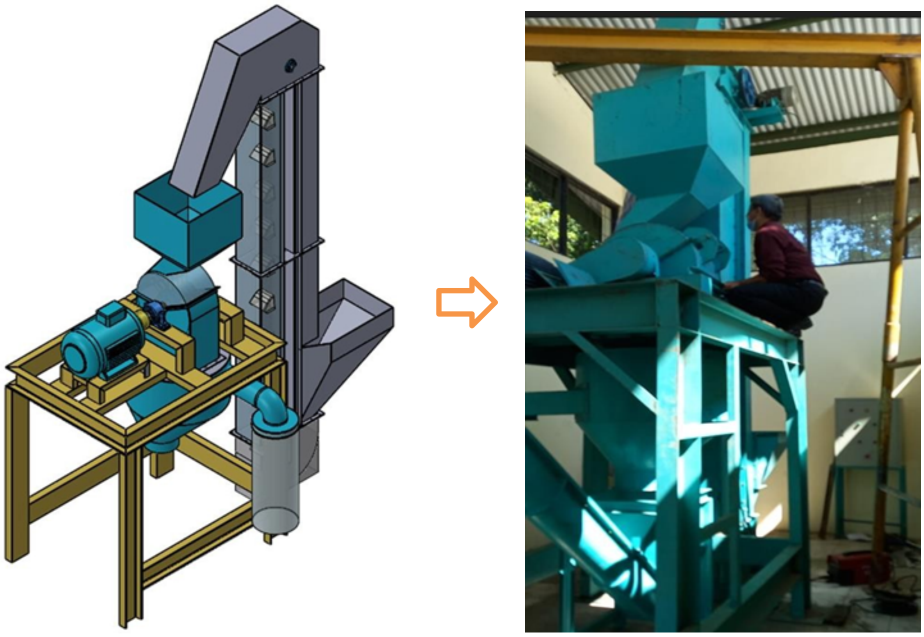
3. Results

3.1 Machine Description

In a case study on a hammer mill machine, researchers observed the work process of a hammer mill machine carried out manually by the operator. In the production process, there are several controllers to operate the machine. The following is the flow of the production process.

Figure 3 is a picture of a hammer mill machine. Based on this picture, the production process of this machine can be explained. Below are the stages of the production process:

i. The material will be put into a hopper or tub for transportation using a bucket conveyor.
ii. The material will be transported to the hammer mill machine using a bucket conveyor.
iii. The material will be ground and smoothed using a hammer mill machine.
iv. After grinding and smoothing, the material will come out and immediately put into the bag.
v. The finished material will be weighed to determine the output or product yield.



(a) (b)

Fig. 3. Hammer mill (a) 3D design (b) real machine

3.2 Hammer mill machine Automation Panel Control system

Figure 4 is a flow image of the control system on a hammer mill machine that has been automated. The following is a description of the above process:

i. The operator opens the hammer mill panel to press the MCB switch.
ii. After the MCB switch is pressed downwards, electrical power will be connected to the inverter panel and PLC panel, and each panel's indicator lights will light up.
iii. After that, the operator will open the PLC panel cover and press the switch downwards.
iv. The electricity source will flow to the PLC panel, and the inverter panel system will turn on.
v. Once the PLC panel is active, the HMI screen will light up and display the login page immediately.
vi. After successfully logging in, you will immediately switch to the HMI home screen to input the motor frequency on the hammer mill machine.
vii. After inputting the frequency of the hammer and conveyor motor, the next step is to press the green button on the hammer and conveyor section and then select the operating mode. There are auto and manual modes for operating the machine. If auto mode is selected, then the hammer mill machine motor and conveyor bucket will turn on automatically. If manual mode is selected, then you must press the ON hammer button to turn on the machine motor and the ON conveyor button to turn on the conveyor bucket motor.
viii. After the production process is complete, the operator will press the stop button in auto mode, and all working motors will stop automatically. If the operator selects manual mode, the operator will press the OFF-hammer button to stop the hammer machine motor and the OFF-conveyor button to stop the conveyor motor.
ix. The operator will press the MCB switch upwards on the PLC panel to turn off the inverter panel system, and the HMI screen will turn off.

x. The operator will press the MCB switch upwards on the hammer mill panel to turn off all panel systems, and all indicator lights will turn off.

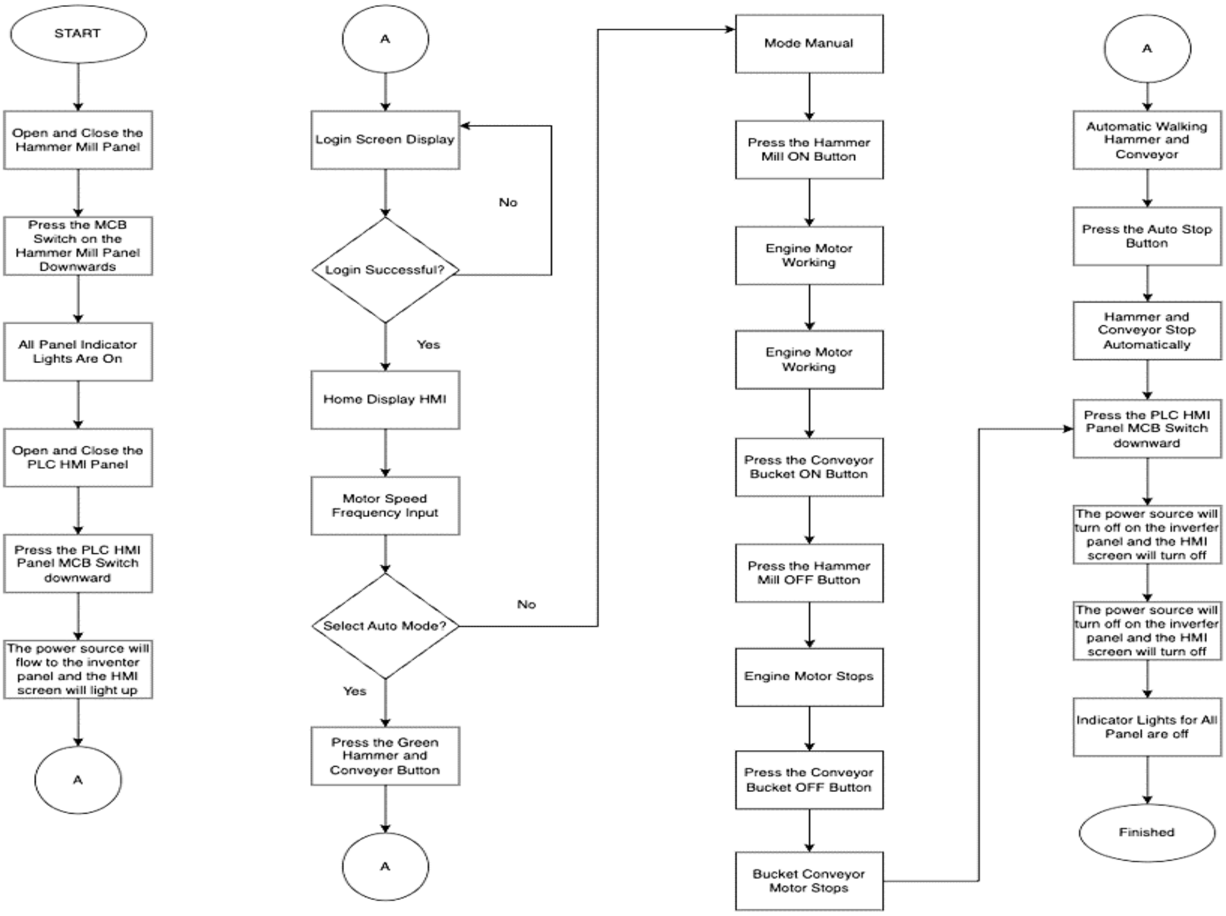


Fig. 4. Hammer mill machine automation panel control system

3.3 PLC Program

In designing a system, a program design is required to be input into the PLC. The programming is made using CX-Programmer software, namely, ladder diagram language, which will later be processed into the PLC using a communication port cable [26]. Table 1 illustrates the identification of the address used.

In programming, addresses of the input, output, and memory types will be used. These addresses will work according to a previously planned scheme. The input, output, and memory addresses aim to determine the addresses used in the PLC's programming process. The address determination is made based on the needs of the system to be run [27].

Table 1
PLC program used in this study

Adress	Tag name	Function	Type
0.00	Emergency	Button for when an emergency occurs	Input
0.01	Data 1	Switch to select Bucket and Hammer	Input
W9.00	Selector	Choose whether the machine runsauto or manual via HMI	Memory
W1.04	AutoStart	Switch in HMI to start the automatic system	Memory
W1.05	Auto Stop	Switch on HMI to stop the system automatically	Memory
100.04	Yellow lamp	Indicator if the system is runningmanually	Output
100.05	Red Lamp	Indicator in case of emergency	Output
100.06	Green Lamp	An indicator if the system is running automatically	Output
Function BlockDiagram	Write Hammer	Turn on and set the Hammer motorfrequency	Memory
Function BlockDiagram	Read Hammer	Take actual Voltage, Current andFrequency data on the hammer motor	Memory
Function BlockDiagram	Write Bucket	Turn on and set the bucket motorfrequency	Memory
Function BlockDiagram	Read Bucket	Retrieve actual Voltage, Current, and Frequency data on the bucket motor	Memory

3.4 Program Testing

The program testing carried out aims to see whether the program script that has been created is by what was planned. Testing was carried out on the hammer mill machine automation system design. Table 2 is a PLC program test scenario in tabular form.

Table 2
PLC program testing

Address	*Tag name*	Function	Test	Expected Outcome
0.00	Emergency	Button for whenan emergency occurs	Press the emergency switch button	The red indicatorlight is on
0.01	Data 1	Switch to select. Bucket andHammer	Turn the selector switchto the left	CP1W-CIF11 indicator is blinking
W9.00	Selector	Choose whether the machine runsauto or manual via HMI	Pressing the auto or manualbutton on the HMI screen	The machine operates automatically or manually as desired
W1.04	AutoStart	Switch in HMI tostart the automatic system	Pressing the auto button onthe HMI screen	The hammer mill machine and bucket conveyor run automatically
W1.05	Auto Stop	Switch on HMI tostop the system automatically	Press the stop button on theHMI screen	The hammer mill machine and bucket conveyor stop automatically

100.04	Yellow Lamp	Indicator if the system is runningmanually	Pressed SwitchData Type on the HMI Screento manual mode	The yellow light ison
100.05	Red lamp	Indicator in case of emergency	Pressed the emergency switch	The red light is on
100.06	Green Lamp	An indicator ifthe system is running automatically	Press the Data Type Switch on the HMI screen to auto-mode	The green light is on
FunctionBlock Diagram	Write Hammer	Turn on and set the Hammer motor frequency	Fill in Set Freq Hammer on theHMI and press the auto or manual start button	The hammer motoris on, the numbers entered in the HMIwill appear on the inverter
FunctionBlock Diagram	Read Hammer	Take actual Voltage, Current,and Frequency data on the hammer motor	Turn on the hammer motorand set the frequency	Display data on the monitoring page and record data onthe HMI
FunctionBlock Diagram	Write Bucket	Turn on and set the bucket motorfrequency	Fill the Setting Freq Bucket on the HMI and press the auto or manual start button	The bucket motor ison, the numbers entered in the HMI will appear on the inverter
FunctionBlock Diagram	Read Bucket	Retrieve actual Voltage, Current,Frequency data on the bucket motor	Turn on the bucket motorand set the frequency	Display data on the monitoring page and record data onthe HMI

Table 2 is the result of PLC program testing that has been carried out. The results of the test are in accordance with what was desired.

3.5 Analysis of Operating Process Times

After the automation design and testing are complete, a comparative analysis is carried out on the system before automation with the system that has been automated. This comparison is a comparison of the operating time of the control system for each panel, namely the manual panel and the automation panel.

In Figure 5, there is a comparison of the time between the operating process on panels that were before automation and those that have been automated. On the panel before automation, the processing time was 27 seconds, with an average of 2.7 seconds. Then, on the automated panel, the processing time was 14 seconds, with an average of 1.4 seconds. This is because a process sequence has been simplified using an automation system. On panels before automation, the operator will press the button manually. In contrast, on panels that have been automated, the operator can immediately select auto mode, which can move and activate the entire machine system. This can shorten the operating process time on the panel by 13 seconds and increase operating productivity time by as much as 48%.

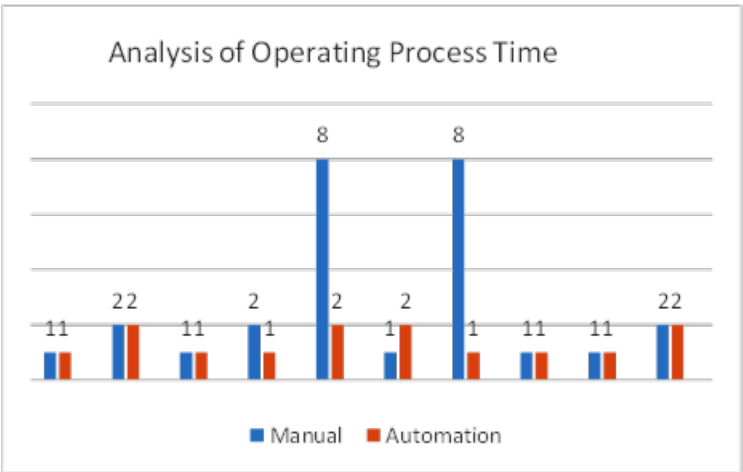


Fig. 5. Operating process times

3.6 Data Analysis of Production Results of Automation System on Hammer Mill Motors

Figure 6 is a graph between the number of frequencies used and the electrical power (Watts) produced. The greatest power value produced is 5227 watts with a motor speed frequency value of 34 to 35. The value obtained will increase and decrease according to the frequency speed, electric current (A), and voltage (V) values obtained. The value will decrease as the motor speed decreases because the production process has been completed, and no electricity flows to the hammer mill machine.

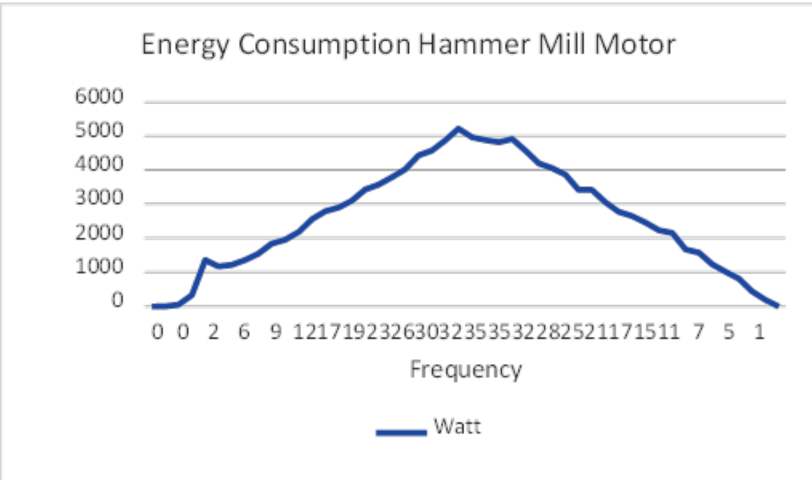


Fig. 6. Graphic energy consumes hammer mill motors

3.7 Data Analysis Production Results of Automation System on Conveyor Motors

Figure 7 is a graph between the number of frequencies used and the electrical power (Watts) produced. The greatest power value produced is 492.1 watts with a motor speed frequency value of 20. The value obtained will increase and decrease according to the frequency speed, electric current (A), and voltage (V) values obtained. The value will decrease again as the motor speed decreases because the production process has been completed, and no electricity is flowing to the bucket conveyor motor.

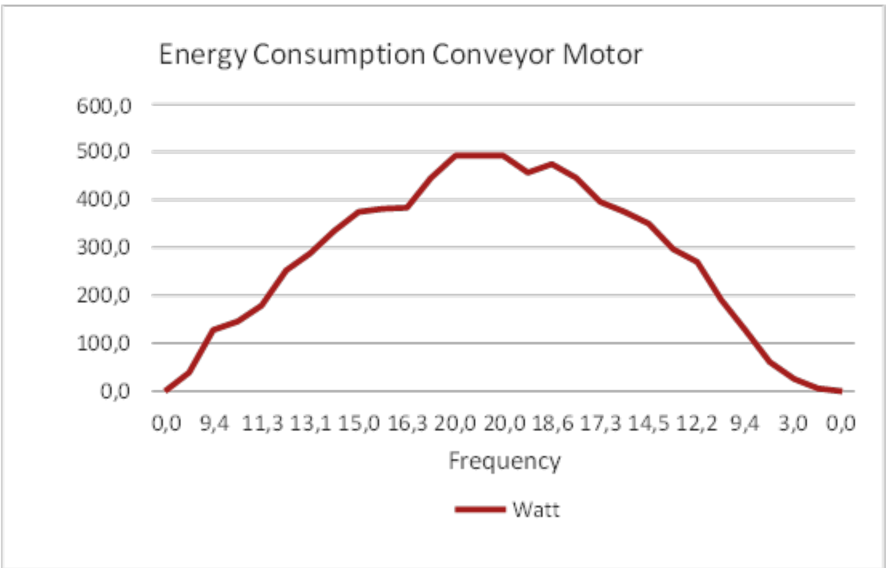


Fig. 7. Graphic energy consumes hammer mill motors

4. Conclusions

Based on the results of data processing and analysis that has been carried out using the waterfall design method to solve problems in the hammer mill machine system, the following conclusions are obtained:

i. Based on the results of the system design that has been carried out by directly implementing the Programmable Logic Controller (PLC) and Human Machine Interface (HMI), the results obtained are a reduction in time during the operation of the hammer mill machine by 13 seconds from the original 27 seconds to 14 seconds with an increase in productivity of 48%.
ii. During the production process, the amount of power consumed by the hammer mill machine and bucket conveyor can be known. The power consumption issued by the hammer mill machine is 5227 watts at frequency 35, then on the bucket conveyor, it is known that the power consumption issued is 492.1 watts at frequency 20. This can be a reference in the future production financing process.
iii. The hardware components and programs used for system design can operate properly.

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