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Performance improvement of the shredder machines using IoT-based overheating controller feature

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Abstract — Plastic shredding plays an essential role in plastic waste recycling. Plastic waste can be enumerated manually using a knife and scissors or a crushing machine. The use of a shredder machine to chop plastic waste, especially whose primary drive is an electric motor, often experiences problems. The main obstacle is the need for high power consumption (more than 1 HP) and the reliability of the drive elements against overheating. Overheating can damage the electrical circuit components that connect the power supply to electric motors, especially AC electric motors, causing a lot of loss in terms of performance and user safety. Internet of Things (IoT) technology is widely used to minimize energy resources by automating various systems. This study proposed the design of a shredder machine with a control system using IoT technology integrated with a shredder and conveyor machine designed using the Quantity Functional Diagram (QFD) method. The shredder machine presented in this study can operate at home using electric power, is more flexible, and minimizes overheating with an IoT-based overheating controller. This research succeeded in keeping the temperature of the electric motor of the shredder machine stable at a temperature of $40°C - 55°C$. The average delays of the IoT module to control on and off the shredder machine design system in this study are 219 ms and 200 ms, which are in the good category according to the Telecommunications and Internet Protocol Harmonization Over Network (TIPHON) standard.

Keywords – IoT, overheat, plastic waste, shredder machine, TIPHON

I. Introduction

Garbage is a global problem, not to mention in Indonesia, that needs attention in the management process because it causes pollution and disease, which disturbs the beauty of the environment. The composition of waste generated from human activities is organic waste, as much as 61.62%, and the rest is non-organic waste, 38.38%. Meanwhile, non-organic waste is dominated by plastic waste, as much as 13.14% [1]. The World Bank evaluates that the global pile of plastic waste by 2025 will jump to 9-13% of total municipal waste, which varies from country to country [2].

Plastics take hundreds of years to decompose. In addition, plastics consist of polymeric materials, which are potentially highly toxic and can cause significant harm to the environment in terms of air, water, and soil pollution [3], [4]. Plastic waste management can be done by recycling, which involves six primary stages: collecting, sorting, washing, shredding, melting, and pelletizing [5].

Plastic shredding plays an essential role in the plastic waste recycling process. Plastic waste collected from various places is first classified according to the thickness and plastic type before enumeration [6]. The enumeration process aims to change the size of plastic waste into smaller sizes. Enumerating plastic waste can be done manually using knives, scissors, or a shredder machine [7], [8].

The development of chopping machines for plastic waste management cannot be underestimated. Previous studies have developed many waste shredders, both from plastic waste types (high-density polyethylene,

polyethylene, polypropylene, polyethylene terephthalate, thermoplastic composites) [3], [4], [7], [9]–[11], electronic waste [12], agricultural waste [13], cardboard and paper [14], [15].

Over the years, the development of shredder machine research has emphasized the need for an efficient cutting unit of the machine [16]–[18]. The shredder machine cutting unit consisting of fixed and rotating blades and pins is widely researched to improve the performance of the shredder machine. The plastic shredder machine designed by [19] produces low efficiency and output because the blades are not manufactured using a CNC machine. The shredder machine's blade construction relies on the manufacturing method of cutting and joining steel plates using the welding process. Research conducted by [4] designed a shredder machine for chopping HDPE, Polyethylene Terephthalate (PET), and PVC plastic waste using a belt drive and gears to avoid the disadvantages of the commonly used single belt crusher.

Shredder machines for chopping plastic waste, especially those with the primary mover using an electric motor, often experience problems. The main obstacle is the need for high electrical power consumption (more than 1 HP) and the reliability of the driving element against overheating. The overheating phenomenon in electric motor components causes a lot of losses in terms of performance and user safety. Overheating can damage the electrical circuit components that connect the power supply to the electric motor, especially the AC electric motor, and can endanger the operator because it can potentially cause a fire. Several attempts to overcome the overheating phenomenon can be made by using an additional cooling device as a fan. Although fans can help cool the electric motor, electric power consumption also increases.

The era of the industrial revolution 4.0 has brought changes from manual systems to automated systems. This era makes the internet an inseparable part of human life. The internet provides a place for connected devices and can be controlled wirelessly through a network infrastructure called the Internet of Things (IoT) [20]. IoT is widely used to minimize energy resources by automating various systems such as light switches [21]–[23], smart homes [20], and so on.

Advances in IoT technology support innovative Solid Waste Management (SWM) so that the sorting and recycling rate is more optimum [24]. Therefore, the IoT concept can be applied to the shredder machine so that the machine's performance can be controlled automatically and effectively to overcome the problem of overheating in the electric motor and improve the work efficiency of the shredder machine. However, research related to automation on shredder machine control systems has not been as much as manual shredder machines that are run with an open-loop system. Several studies related to automation on shredder machines discuss more processing information in real-time on the factors that affect the chopping process, which include: the amount of plastic waste that is fed to the device, monitoring of mass flow data, and material volume on the shredder machine, automation of sorting commercial mixed waste with image capture techniques [24]–[26]. Meanwhile, research on the shredder machine control system due to the overheating phenomenon in the electric motor is needed.

Based on these problems, this study proposed the design of a shredder machine by developing an IoT-based overheating controller feature integrated with a shredder and conveyor machine. The purpose of the offered design shredder machine is to anticipate the failure of the shredder machine's mechanical design due to the electric motor's overheating phenomenon. Therefore, the shredder machine is designed using the Quantity Functional Diagram (QFD) method to produce a machine design that suits the user's needs. The cooperative waste management will utilize the plastic shredder machine with an IoT-based overheating controller feature proposed in the research.

The performance of the shredder machine using the IoT-based overheating controller feature developed using the QFD method was carried out with two tests. The first test is to measure the time of the IoT module when the shredder machine runs until overheating occurs or the stator surface temperature on the shredder machine reaches $55°C$. The second is to measure the delay time between the IoT module turning off or restarting the shredder machine after the temperature sensor reads the upper or lower limit of the surface temperature of the shredder machine motor.

This paper is structured as follows. Section II describes the material, the proposed design of the shredder machine, and the testing model. Followed by section III that describes the results, and discussion of the proposed design of the shredder machine in section IV. Finally, section V is the conclusion.

II. Research Method

This section discusses the materials, machine design method, and our poroposed design.

A. *Materials*

The shredder machine consists of several components consisting of an AC electric motor with a power of 2 HP, 14 units of double claw shredder blade, 1:20 gearbox reduction, a hopper made of steel plate thickness of 1 mm, a rectangular profile frame of size 30x30 mm, and a shaft made of steel ST 37. The shredder machine is designed using 14 blades rotating on a hexagonal shafts axis. The knife material is made using ST 37 steel. The knife has a diameter of 120 mm with a chopping capacity of up to 50 kg/hour using an electric motor with 2 HP power.

The IoT-based control system in this study uses the Node MCU ESP 8266 microcontroller component. In addition, other components used in the IoT system circuit are relay modules, L298N type DC electric motor driver modules, and 12 V PSU (Power Supply Unit). Internet using the Blynk android application. Meanwhile, the temperature sensor used is a thermocouple type DS18B20.

B. Machine Design Method

The method of designing a shredder machine according to consumer needs in this paper uses the QFD method. The stages of the QFD method are shown in Fig. 1.

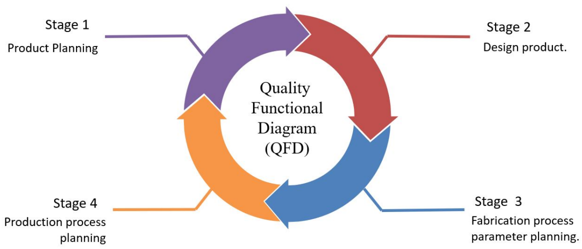

Fig. 1. Stages of the QFD method.

a. Stage 1: Product Planning
The product planning stage obtains initial data by identifying customer needs. A series of interviews and discussion methods are carried out to identify customer needs. The data obtained from identifying customer needs are then arranged based on priorities according to the needs and limitations of the customer. Customer needs or the voice of the customer is then translated into a technical response. Based on the results of the identification of the plastic crushing machine designed in this study, it is used by cooperatives that manage plastic waste. Therefore, the shredder machine specifications are designed to operate with household electricity, be driven flexibly, and minimize overheating.

b. Stage 2: Product Design
The technical response data obtained in stage 1 is then used to help conceptualize creative ideas for the shredder machine product design. The information in the technical response data serves as a guide for pictures to be more in line with the voice of the customer. Making the shredder machine design is done by brainstorming with the best concept selection method using product champion criteria. The concept selection criteria using product champion is a way of selecting a concept based on the personal preferences of each team member. The idea most chosen by team members based on these preferences is then selected as a product design concept to be fabricated.

c. Stage 3: Fabrication Process Parameter Planning
The fabrication process in this research is planning the machining process parameters. The shredder machine is fabricated using both non-conventional and conventional machining methods. Conventional machining methods include manufacturing processes consisting of turning, milling, drilling, grinding, and Shielded Metal Arc Welding (SMAW). Meanwhile, non-conventional machining methods use plasma cutting. The machining process parameters are set according to the engineering drawing by shredder machine reference with the measurement tolerance level using the open tolerance type.

d. Stage 4: Production process planning
Production process planning is regulated by using work instruction process documents. The work instruction process is a document that shows the sequence of steps performed in the shredder machine fabrication process. By applying the work instruction process, the production process's planning can occur orderly. In addition, the quality of the shredder machine obtained is also to the design planning standards.

C. Proposed Design

The proposed design of the shredder machine using IoT-based overheating controller features integrated with the shredder and conveyor based on the QFD method has the main components shown in Fig. 2. The main components of the shredder machine include a 0.75 HP AC motor, crusher, 1:20 speed reducer gearbox, hopper, and wheels. The main features of the conveyor consist of a 12 V DC motor, belt conveyor, conveyor frame, and conveyor wheels.

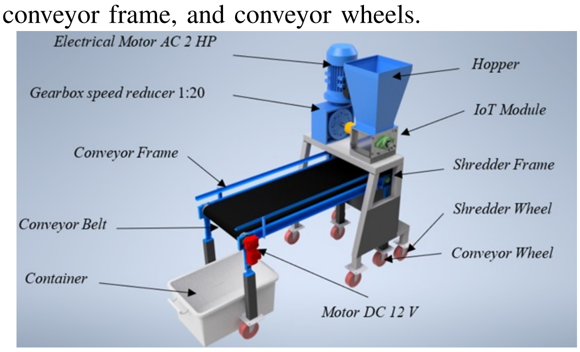

Fig. 2. Shredder-conveyor machine components.

The block diagram design of a shredder machine with an IoT-based overheating controller feature is shown in Fig. 3.

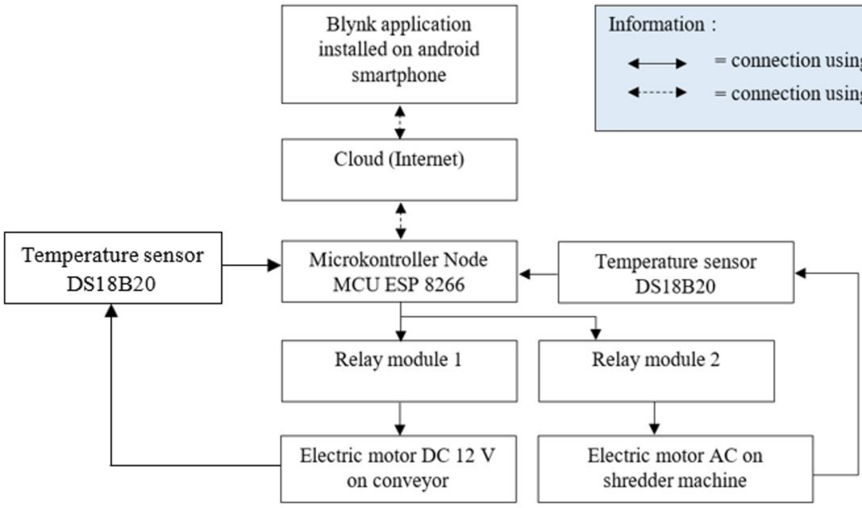

Fig. 3. The block diagram design of a shredder machine with an IoT-based overheating controller feature.

D. Testing Model

The testing of the overheating controller feature of the shredder machine designed using IoT technology proposed in this study is based on observing the temperature rise of the electric motor driving the shredder when it is working on the chopping process or not. The overheat temperature setting used to disable the shredder machine in this study is $55°C$, and to activate the shredder machine, the lower limit temperature is set at $40°C$. The determination of the upper and lower limits in this study is based on observations of the condition of the electric motor when used for shredding and the vibrations that arise which affect mechanical components, especially bearings. So that the upper limit of temperature is $50°C$ and the lower limit is $40°C$.

The selection of lower and upper limit values to control the activation of the shredder machine is based on research conducted by [27]. The results of the [27] study stated that if the temperature sensor readings were less than $41.56°C$, the electric motor was in the not yet hot category. Based on this research, the lower limit temperature to control the activation of the shredder machine is set at $40°C$. If the motor temperature is set to $40°C$, the electric motor temperature has cooled so that the shredder machine can be active again. The study's [27] results stated that the maximum temperature value on the surface of a single-phase electric motor so as not to overheat at a temperature of $79.59°C$. If the electric motor used is 0.75-phase, then the maximum temperature to avoid overheating is $59.7°C$. The shredder machine designed in this study uses a 0.75 phase; the maximum temperature to control overheating was chosen at $55°C$ for safety reasons.

The performance of the IoT module is analyzed based on the size of the response speed of the IoT module, which controls the ON/OFF function on the shredder machine through the BLYNK android application. The test is carried out by measuring the response time (delay) between when the I/O device starts showing a temperature of $55°C$ with the shredder machine off or when the shredder machine turns on again when the I/O device shows a temperature of $40°C$. The measurement results of the ON/OFF process delay on the IoT module are then compared with the standard delay specifications according to Telecommunications and Internet Protocol Harmonization Over Networks (TIPHON). The delay specification table according to the TIPHON standard [28] is presented in Table 1.

Table 1. Delay Specification

Delay Category	Delay (ms)	Index
Very Good	$<$ 150 ms	4
Good	150 - 300 ms	3
Not Good	300 - 450 ms	2
Poor	$>$ 450 ms	1

III. RESULT

The result of designing a shredder machine using the QFD method proposed in this study is a shredder machine driven by an AC electric motor with a power of 0.75 HP. The electric motor works by rotating the worm gearbox transmission shaft with a reduction ratio of 1:20. Two advantages of the assembly feature of the shredder machine are the presence of a wheel component feature that allows the shredder to be moved according to the position of the belt-type conveyor and the IoT module that will manage the work of the shredder machine after activated.

A. The Workflow Scheme of the Shredder-conveyor Machine

The workflow scheme of the shredder machine is divided into three stages, as shown in Fig. 4.

The stages of each workflow are as follows:

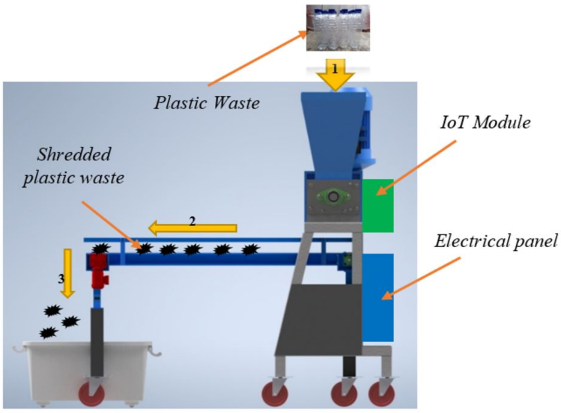

Fig. 4. Shredder machine schematic workflow.

a. Stage 1: The shredder and conveyor machines are activated using the Blynk application installed on an Android smartphone connected to the internet. The shredder machine will crush plastic waste that has entered the hopper. Then the plastic waste is fed through the hopper component. The chopping results using the proposed shredder machine design on a sample of PET plastic waste are shown in Fig. 5. The results of plastic chopping have variations in the length of plastic slices ranging from 0.1 - 1 cm.

Fig. 5. The result of shredded PET type plastic which is chopped using a shredder machine.

b. Stage 2: The results of the PET-type plastic shredder from the shredder component then move to the belt conveyor due to the gravity of the chopped plastic.
c. Stage 3: The belt conveyor carries the plastic pieces to the container.

The IoT module will manage the work of the shredder machine after the shredder machine is activated. First, the temperature sensor on the IoT module will take measurements. The measurement results from the temperature sensor will be sent to the temperature database on the Blynk server via the MCU ESP 8266 Node Microcontroller. Then, the chopping continues until the temperature sensor detects the stator surface temperature of the electric motor reaches $55°C$ when the temperature of the shredder motor reaches the value of $55°C$, the shredder motor and conveyor motor will stop. The cessation of the shredder motor aims to stabilize the stator surface temperature at its average operating temperature of $40°C - 55°C$ when the temperature of the shredder motor reaches a temperature of $40°C$, the Node MCU ESP 8266 microcontroller will activate the shredder motor and conveyor motor to be active again.

B. IoT-based Overheating Controller Feature Design

The schematic for installing the IoT-based overheating controller feature components on the shredder motor and conveyor motor based on the block diagram design Fig. 3 is shown in Fig. 6.

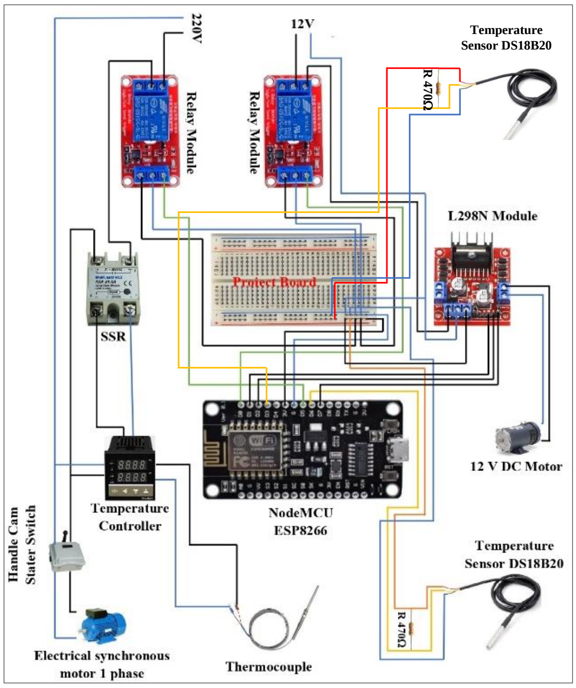

Fig. 6. Shredder motor and conveyor motor IoT system wiring diagram.

Fig. 7 shows the IoT module algorithm for overheating controllers on a shredder machine. The next step is coding and designing the application user interface for the IoT-based overheating control feature. The interface is made using the drag-and-drop configuration feature found in the Blynk application. In addition, the interface design is also equipped with a feature to display the surface temperature value of the electric motor of the shredder machine in real time.

Fig. 8 shows a smartphone interface screen created to display temperature data information that is read by the system when the shredder and conveyor control system conditions are off and when the shredder machine is on.

IV. Discussion

The scenario of observing the increase in the temperature of the electric motor on the shredder machine

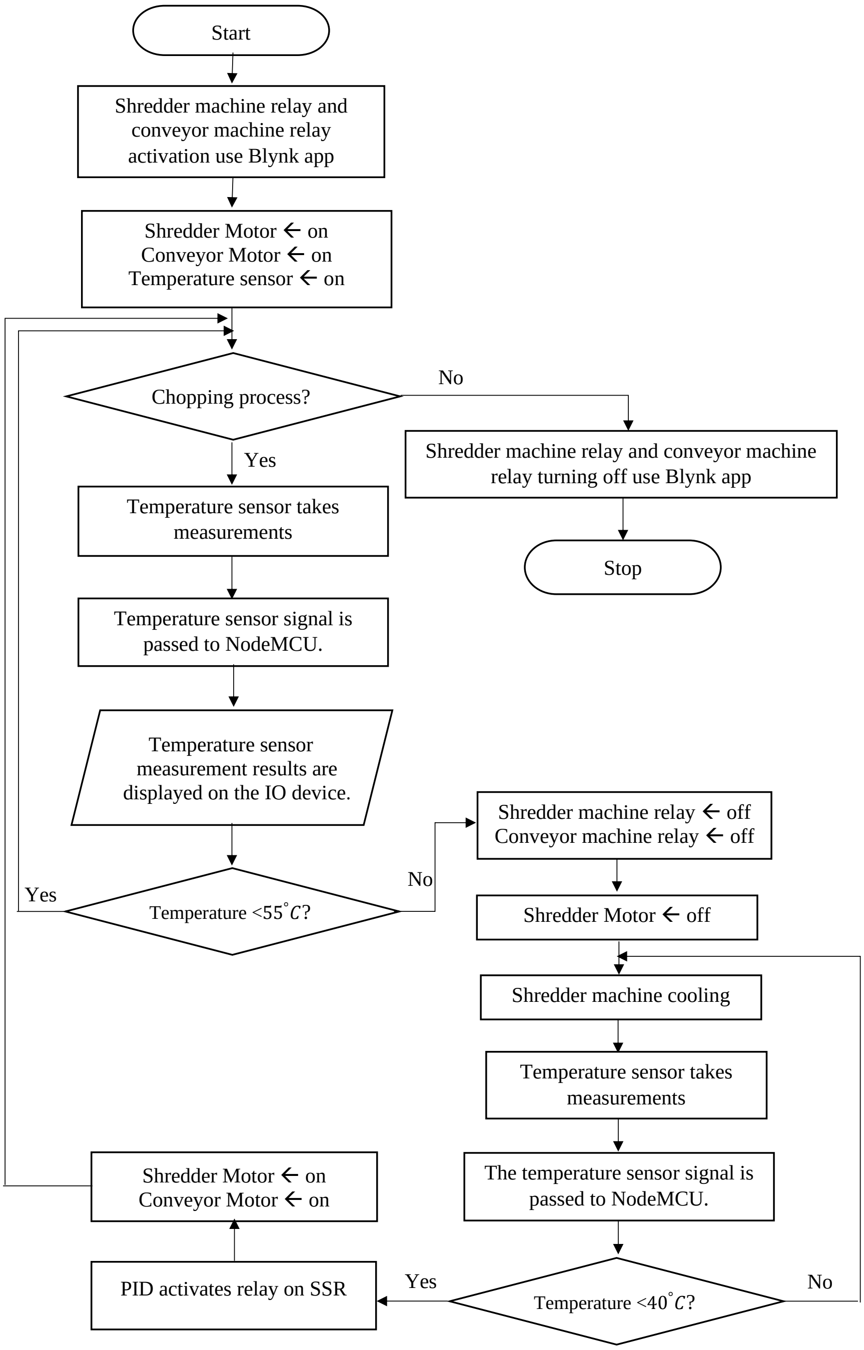

Fig. 7. The IoT module algorithm for overheating controller feature.

is carried out in two different operations. The first scenario measures the time the shredder machine actively chopped plastic waste. The second scenario is the shredder machine is on but does not chop the plastic waste.

a. When machine is active without chopping process, time to raise electric motor surface temperature $40°C - 55°C$ in 90 minutes. Based on this test, the temperature increase without the chopping process follows the equation (1)

$$y = 0.0032x + 43.54. \tag{1}$$

b. When the machine is running, and the chopping process is in progress, the surface temperature of the electric motor rises from $40°C - 55°C$ within 35 minutes. The increase in the surface temperature of the electric motor when the machine is used to chop plastic waste follows the

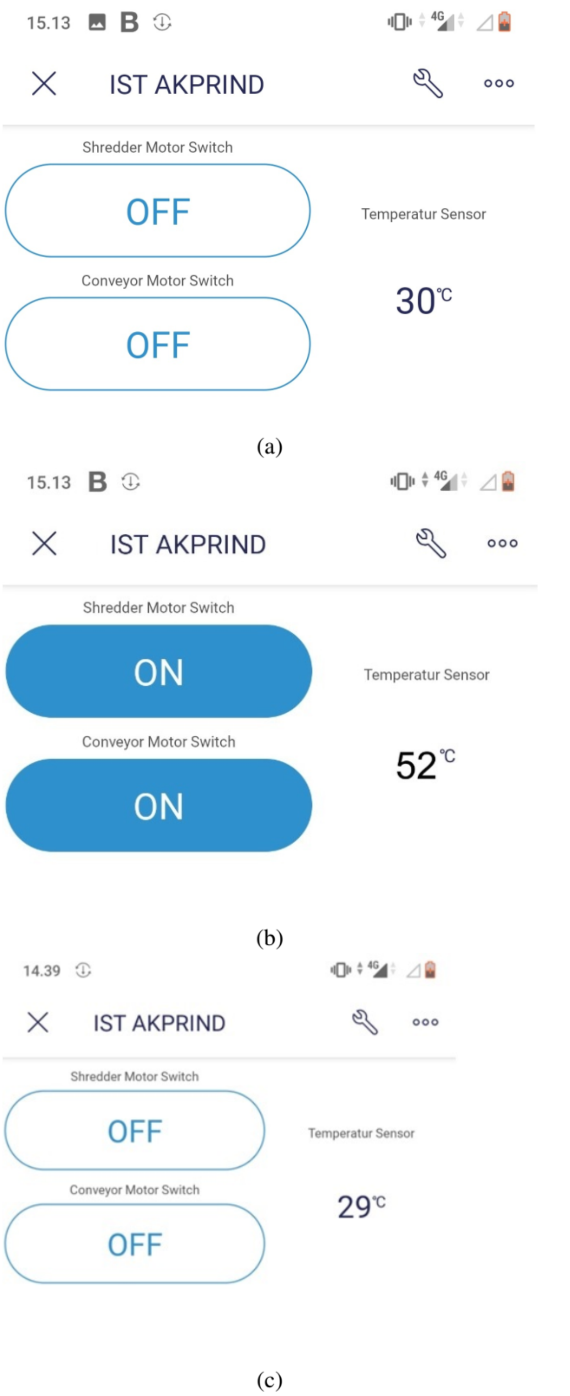

Fig. 8. Application interface displays in state mode (a) the shredder and conveyor are off, (b) the shredder and conveyor are both on, and (c) the shredder and conveyor are off to overheating phenomenon.

equation (2)

$$y = 0.004x + 47.23. \quad (2)$$

The time difference in the two scenarios above shows that electric power is more significant when the engine is on and the chopping process is in progress than when the engine is on and there is no chopping process. The conversion of electrical energy into heat released by an electric motor can be identified by the increase in the surface temperature of the electric motor, as shown in Fig. 9.

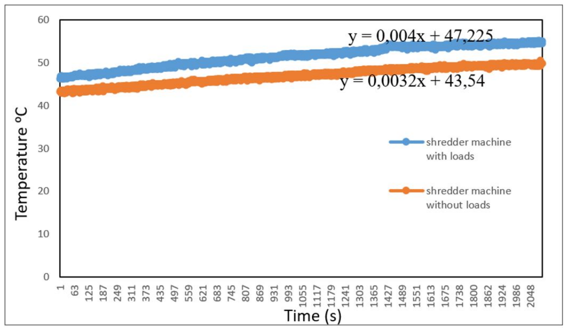

Fig. 9. Temperature gradient of electrical motor AC 2 HP shredder machine in two different operations.

The test results of the proposed shredder machine design prove that the energy in the form of heat released by the electric motor when the shredder is active and the chopping process takes place results in the conversion of electrical power into higher heat energy. The test results show the temperature rise on the surface of the electric motor when used for 35 minutes or 2.57 times faster than when the machine is not used for chopping. The increase in temperature (ΔT), which is the same but produces a more immediate duration of time (t), indicates a greater consumption of energy (E) of electricity which is converted into heat when the shredder is active by chopping plastic waste. The operating condition of the shredder machine without the chopping process will have a lower gradient value, as shown in Fig. 9. The value of the gradient proves that the energy consumption when the machine is not used for chopping is also lower. The temperature rises graph (see Fig. 9) obtained in this test has a linear pattern with an upward trend. This pattern is similar to the study conducted by [29] for the case of temperature rise in electric motors.

Testing of the IoT module to control overheating on the electric motor of the shredder machine is carried out by measuring the delay from the temperature sensor reading $55°C$ to the shredder machine off and the temperature sensor reading $40°C$ until the shredder machine is on. The test was performed ten times by measuring the delay time using a stopwatch. The test results are shown in Table 2.

Table 2. Delay Testing

Test Number	D_1	D_2
1	220	200
2	220	190
3	230	200
4	220	210
5	210	190
6	220	200
7	210	200
8	230	210
9	220	200
10	210	200
Average	**219**	**200**

where D_1 is the delay until the shredder machine turn ON (ms) and D_2 is the delay until the shredder machine turn OFF (ms).

The average delay value of the test results in Table 2, when compared with the expected delay according to TIPHON in Table 1, shows that the IoT module to control overheating in the shredder machine designed in this study can be classified into the good category. The IoT module design is proven to have a fast response time to overheating at 200 ms. A quick response can improve the performance of the shredder machine because it does not heat up quickly, so it can extend the device's service life. In addition, with the control feature against overheating, the engine does not work continuously but has a rest period to reduce electrical power consumption.

V. Conclusion

This study proposed the design of a shredder machine using an overheating controller featuring IoT technology integrated with a shredder and conveyor. The shredder machine proposed in this study was designed using the QFD method, so it has the following advantages: a) it can be operated at home with electric power; b) it is flexible because it can be moved and assembled quickly, and c) it can minimize overheating to prevent mechanical system failure on the shredder machine that occurs in electric motors.

The IoT system designed in this study succeeded in maintaining the temperature of the electric motor of the shredder machine so that it was stable at a range temperature of $40°C - 55°C$ to avoid overheating. If the shredder does not perform the chopping process, the proposed shredder control system will turn off the crushing motor and conveyor motor automatically in 90 minutes times on average. The increase in temperature in the absence of a chopping process follows the equation (1). The average duration of the shredder machine control system shutting down the shredder motor and conveyor motor automatically is 35 minutes with an increase in the surface temperature of the electric motor following equation (2) when the shredder machine performs the chopping process.

The average delay value of the test results according to the TIPHON standard shows that the IoT module to control overheating on the shredder machine designed in this study can be classified in a good category. The IoT module design is proven to have a fast response time to overheating. It can improve the shredder machine's performance to extend the device's life and reduce electrical power consumption.

As part of future work, the value of thermal energy released by the shredder machine needs to be studied further related to the conduction and convection phenomena on the surface of the electric motor.

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