Design and implementation of pipe cutting machine with AC servo motor and PLC based on HMI

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Abstract. This research aims to design a pipe cutting machine using an AC servo motor and PLC as a controller based on HMI (Human Machine Interface). The use of AC servo motors is done to maintain accuracy and precision in cutting pipe lengths. This research uses experimental methods which include hardware and software design. PLC LS XGT Series is used to control the pipe cutting machine automatically based on the input signal from the proximity and encoder. Proximity is used to detect the presence of pipe while the encoder is used to detect AC servo motor rotation. By knowing the number of turns of the AC servo motor through the encoder, the length of the pipe can also be determined. The AC servo motor with Mitsubishi HC-KFS43 400W models is used to pull the pipe, gripping the pipe, and moving the cutting machine while a modified AC circle saw motor is used to drive the cutting blade. Based on the results of the study, the cutting machine can cut pipes automatically according to the desired number and length of the pipe. The work process can be monitored and controlled on a computer through HMI.

1. Introduction
Currently, the construction of housing, apartments, and roads has increased quite rapidly, this has an impact on the number of requests for building materials, one of which is an iron pipe. With intense market competition, building iron stores must continually improve quality services for their customers. One of them is by providing pipe cutting services following the length desired by the customer. The cutting of iron pipes can be done by hacksaw or by cutting machines through human labor. If cutting many iron pipes will certainly cause the resulting cutting efficiency is not optimal because it requires a long working time and the accuracy of cutting results may be reduced. One of the efforts made to improve cutting production efficiency is to make the automation of pipe cutting machines.

The automatic controller that can be used to control a pipe cutting machine is PLC (Programmable Logic Controller). In Bhagyesh and Swapnil, they designed an automatic hacksaw machine for cutting pipes via a conveyor system using PLC so it can give high productivity in a short time in comparison with the conventional hacksaw machines [1]. PLC is a digital computer used for automation that continuously monitors the state of input devices and makes a decision based such as controlling machinery. In Harshitha and Srinath [2] and Veena et al [3], they developed an automatic cutting machine with PLC. One of the most important parts of machinery that require precision operation is a servo motor [4]. The servo motors needed in many manufacturing applications for motion controls in a variety of electro-mechanical industries such as robotics, CNC manufacturing, aerospace technology,
automotive and textile industry. In Xu et al., they design a full servo planetary pole symmetric pipe cutting machine using PLC as a controller [5]. In Rashmi and Shrutika, PLC and servo drives are used to control grinding machines application [6]. In Lei, the author design an AC servo-control system based on PLC and HMI for an automatic production line [7]. In Harshavardhan and Jack, they design PLC-based robot manipulator control using position and imaged based algorithm, where servomotor used for controlling belt conveyor and another servomotor for displacing a component as a kicker [8]. In Arun and Subir, they demonstrated force control of robot manipulators using AC servo motor and PLC Beckhoff as a controller [9]. In Haidong, based on PLC and servo control module, an automatic test system for the walk-through metal detector is constructed [10].

The servo motor is specialized for high-response, high-precision positioning. As a motor capable of accurate rotation angle and speed control, it can be used for a variety of equipment. The servo motor is composed of three elements: the motor, the encoder, and the driver. The Servo motor drivers convert pulse signals from the controller into motor motion to achieve precise positioning. While The encoder is a sensor that notifies the driver of the speed and position of the motor.

Based on the previous study, the purpose of the current study will design and implement of pipe cutting machine with ac servo motor and PLC to get accuracy and precision in pipe cutting. The work process of this tool can be controlled and monitored using HMI (Human Machine Interface).

2. Material and method

This study uses an experimental method by designing system hardware and software. This research method includes designing the mechanical system of pipe cutting machine, design of installation ac servo motor to servo drive, setting parameter ac drive servo, designing an automatic pipe cutting machine using PLC and designing a system of monitoring the process of cutting machine using HMI.

2.1. Hardware design

The hardware of the pipe cutting machine consists of an AC servo motor, servo drive, encoder, pushbuttons, proximity sensor. The automatic controllers used in the pipe cutting machine is PLC LS with CPU XGK-CPUs. The block diagram of the control system can be seen in figure 1.

![Block diagram of control system.](image)

As shown in Figure 1, The input devices used as input signals to the PLC are push buttons and proximity sensors. Push-button is used to turn on/off the system. The proximity sensor is used to detect the presence of pipes. The PLC output signal that is used to control servo drives and relays. The servo drive is used to drive the AC servo motor while the encoder is used to detect the motor rotation so that by knowing the number of motor rotations the length of the pipe to be cut can also be known. The relay functions to drive the AC motor saw circle and indicator lights. The ac servo motor functions to pull
pipes, advance/rewind cutting blades and clamp pipes, so the pipe doesn’t shake when cut. While the circle saw motor is used to cut pipes. The process of cutting pipes, starting from the initial setting of the size of the pipe, number and length of pipe and then proceed by entering the pipe manually. After that, the pipe will move automatically. When the desired pipe length is reached, the pipe will be clamped and cut. The HMI (human-machine interface) can be used to controlled and monitored the work process of the system. The design of the pipe cutting machine can be seen in figure 2.

![Design of pipe cutting machine.](image)

2.2. AC servo motor control
In this research, the AC servo motor with Mitsubishi HC-KFS43 400W models is used to pull the pipe, clamp the pipe and moving the cutting machine. The ac servo motor is controlled by controlling its position using PWM (Pulse Width Modulation). The width of the pulse applied to the motor is varied and send for a fixed amount of time. The pulse width determines the angular position of the servo motor.

The ac servo motor consists of 2 main parts, namely the motor itself and the encoder that will detect the movement of the motor. In HC-KFS43 servo motors, the type of encoder used is digital with absolute sensors. Absolute encoder is an encoder that is designed in such a way that it can detect rotation angles as best as possible, more precision than incremental encoders. So that it is not possible to do a calibration every time you operate. The absolute encoder is used to maintain the track position of the motor shaft rotation even though the power suddenly turns off and the rotation occurs when the power is turned off.

While the type of ac servo drive used is the Mitsubishi Melservo MRJ2S 40A. The ac servo drive or commonly called a servo amplifier to function to control the servo motor according to the command signal instructions from the PLC positioning module. In operation, the ac servo drive will process the error signal to correct the difference between the input (reference) signal and the feedback signal from an encoder so that the servo drive will continue to ensure the ac servo motor is operating according to instructions and correct any errors that are needed. The servo amplifiers consist of a comparator that processes error signals and power amplifiers that amplify the signal to be able to move the ac servo motor. MRJ2S can control the position mode, speed, and torque that can be selected one or a combination as needed. The ac servo motor mechanism via PLC positioning module can be seen in figure 3.

The PLC LS with the positioning module uses to control the AC servo motor via servo drive. The type of positioning module is XGF-PD2A. This positioning module can send a pulse command signal up to 2 servo drives at a time or is called a 2 axis where the axis is the number of motors controlled. To move an object, the positioning module will generate and send a pulse command signal to the servo drive. The servo motor will rotate according to the number of pulse commands issued from the positioning module to the servo amplifier. While the design of the installation of the ac servo motor to the ac servo drive can be seen in figure 4.
Figure 3. The servo motor mechanism via PLC positioning module.

Figure 4. Installing AC servo motor to servo drive.

As shown in figure 4, MRJ2S servo drives can be supplied by a 3 phase 200VAC source. However, this study uses a 220VAC 1 phase supply connected to L1 and L2. Meanwhile, L3 is left unconnected. As for the control terminal circuit block, L21 is paralleled to L2 while L11 is paralleled to L1. The ac servo motor is connected to the ac servo drive via the power connector (U, V, W) while the servo motor's ground is connected to the ground on the drive (PE). The encoder connector is connected to the CN2 connector on the servo drive. The ac servo drive has RS-232C and RS-422 serial communication functions so that it can be connected to a computer via the CN3 connector, then from our computer can
perform several functions such as setting parameters, monitoring, operating tests, using the MRZJW3-SETUP25E software. All these functions can also be performed on the drive directly via a push-button with a seven-segment display on the display. The PLC positioning module can be connected to the ac servo drive via the CN1A connector.

2.3. Software design
The programming of the PLC LS XGT series uses XG5000 software. The number of I/O addresses that can be used on PLC LS XGK-CPUs as many as 32,768 points, starting from P00000-P2047F. Where the 4 initial numbers after "P" are word numbers and the fifth number or letter after "P" is called a bit. The program used to set parameters in the positioning module is the APM package software. The positioning module with XGF type has its separate software from the main XG5000. The APM package software is a special type of APM positioning module that is used to set parameters, axis data, monitoring, tracking, simulation, diagnosis. While the programming of HMI uses XP Builder software. The flowchart of the automatic pipe cutting machine can be seen in figure 5.

![Flowchart of automatic pipe cutting machine](image)

3. Result and discussion
The testing of servo positioning is done to determine how many pulses are given to the ac servo motor through the servo drive so that the length of the pipe to be cut is known. This test is carried out by moving the pipe puller, pipe cutter, and pipe clamp. The command signal used to cut the pipe is forward (CW) while for returning to the initial position, the given command signal is reverse (CCW). The servo position test results can be seen in Figures 6, 7, and 8 while the implementation of automatic pipe cutting machines can be seen in figure 8.
As seen in figure 6, when the pulse given to the ac servo motor on the pipe puller is 131072 pulse, the ac servo motor will rotate one rotation so it can pull the pipe with a length of 13 cm. When the length of the pipe to be cut is 52 cm, the pulse given to the servo motor is 524288 pulse so the ac servo motor will rotate four rotations. As seen in figure 7, when the pulse given to the ac servo motor on the pipe cutter is 65536 pulse, the ac servo motor will rotate half rotation so the distance of movement of the cutting tool is 9.4 cm. The pipe can be cut, when the pipe cutter moves with a maximum distance of 14.1 cm and the pulse is given to ac servo motor by 98304 pulses. As seen in figure 9, the pipe can be clamped when the degree of pipe clamp is 60°. The pulse is given to the ac servo motor on the pipe clamp of by 65536 pulses.

4. Conclusion
In this research, the automatic pipe cutting machine using AC servo motor and PLC LS has been successfully made and the work process of the tool can be controlled and monitored through HMI (human-machine interface). The pipes can be cut automatically according to the desired number and length of pipes.
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