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Retrofitting the MyFord 254S lathe with PLC and SCADA control for spindle motor speed regulation

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ABSTRACT

The MyFord 254S lathe in the Mechanical Engineering Department of Politeknik Negeri Manado (Polimdo) will be retrofitted with new technology or features into the old system, becoming semi-automatic, combining PLC and SCADA technology. This research uses the experimental method, where the author designs by creating a ladder diagram in CX-Programmer software and uploading it to the Omron PLC, whose output will be connected to the Variable Frequency Drive (VFD) to control and drive a 3-phase induction motor as a spindle driver with a single-phase AC input voltage on the VFD. It creates a control design in NB-Designer software to be uploaded to the Omron HMI as a SCADA control display. The ladder diagram programming on the Omron PLC designed with CX-Programmer software includes motor frequency options of 15 Hz (602 rpm), 20 Hz (802 rpm), 25 Hz (1003 rpm), 30 Hz (1204 rpm), 35 Hz (1404 rpm), 40 Hz (1605 rpm), 45 Hz (1806 rpm), and 50 Hz (2006 rpm). As a result of the addition of PLC and SCADA to this lathe machine, the spindle speed can be easily adjusted compared to manual settings, as it only requires pressing on the HMI.

Contribution to Sustainable Development Goals (SDGs):
SDG 9 – Industry, Innovation, and Infrastructure
SDG 4 – Quality Education
SDG 12 – Responsible Consumption and Production

1. INTRODUCTION

1.1. Research Background

One of the conventional machine tools in the Mechanical Engineering Department production laboratory at Politeknik Negeri Manado (Polimdo) is the MyFord 254S Lathe Machine, which has been used for student practice since 1988. In 2010, it was damaged due to the burning of the primary motor windings, rendering it unusable for student practice. The specifications of this driving motor are 2 HP with an input voltage of 380 Volt AC, 3 Phase, 50 Hz. Therefore, it is necessary to repair it by retrofitting the driving motor with a new replacement and implementing new technology and functionality using PLC-based speed control, HMI, and SCADA with VFD. [1], [9], [11].

1.2. Literature Review

Previous research on lathe machine retrofit has discussed speed control using a potentiometer regulated by a VSD and speed monitoring with an Autonics MP5-4N Pulse Meter [1]. Another research focused on speed control of a 3-phase induction motor by altering frequency using an ALTIVAR 12P inverter [11]. Additionally, different retrofit research kept spindle speed constant during cutting operations using a PI Gain Scheduling controller. This controller was selected due to its short computation time, hoping the control algorithm could be a reference for CNC machine control design [5]. Moreover, another research retrofitted a lathe machine into a CNC system using Mach 3 control for two axes [6]. Research conducted by Yuliadi Erdani and Hidayatulloh implemented a retrofit by utilizing two stepper motors to move the carriage on the X-axis (diameter feeding) and Z-axis (depth of cut). The stepper motors were driven by a TB6600 driver module, controlled via a Raspberry Pi 3 B+ using Python programming. The tool movement control and monitoring process was handled through an interface developed with LabVIEW 2020 [7]. Similarly, other research has transformed lathe machines into CNC systems [8], [10].

Our research focuses on selecting eight preset speeds displayed on the HMI monitor, which is PLC-based and SCADA-controlled [3] & [4].

1.3. Research Objective

This study aims to regulate the spindle rotation speed of the MyFord 254S lathe machine by adjusting the electrical frequency using a VFD, which is controlled by PLC, HMI, and SCADA

2. MATERIALS AND METHODS

This research was conducted in the Production Laboratory of Politeknik Negeri Manado, using an experimental method to regulate the spindle speed of the MyFord 254S lathe machine. The system utilizes a Variable Frequency Drive (VFD) with an input voltage of 220V AC (single-phase) and an output voltage of 220V AC (three-phase) for the spindle motor, connected via a delta (Δ) configuration. The frequency can be adjusted as desired, ranging from 0 Hz to 50 Hz.

To control the VFD, a Programmable Logic Controller (PLC) is required, along with a Human Machine Interface (HMI) and an integrated SCADA system, as shown in the Figure 1.

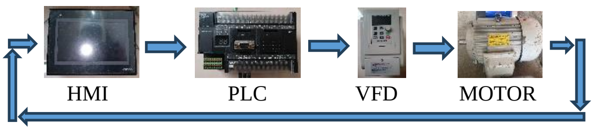


Figure 1. Research Wiring Diagram

Description:

HMI: Programmed as an operator interface for the induction motor of the lathe machine, allowing control via the display for ON/OFF, Forward/Reverse, and selection of eight speeds.

PLC: Programmed to regulate the rotation of the induction motor, enabling forward or reverse movement and eight-speed settings based on Table 1.

VFD: Controls the induction motor rotation, including Run/Stop, Forward/Reverse operations, and frequency adjustments at 15 Hz, 20 Hz, 25 Hz, 30 Hz, 35 Hz, 40 Hz, 45 Hz, and 50 Hz.

Overall, it can be seen in the Figure 2.

Figure 2. Lathe Machine MyFord 254S

The materials used in this research include:

1. **Programmable Logic Controller** Brand Omron Type CP1H-X40DR-A

Figure 3. PLC Omron

2. Human Machine Interface (HMI) Omron, Type NB7W-TW00B

Figure 4. Human Machine Interface

3. Three-phase Asynchronous Motor, SEM Type Y9OS, 1,5 HP, 1400 rpm.

Figure 5. SEM Three-Phase Asynchronous Motor.

4. Variable Frequency Drive (VFD) XSY-AT1, Cap. 2 HP.

Figure 6. Variable Frequency Drive

The control of the Spindle Motor from the VFD XSY-AT1 is based on Table 1.

Table 1: Multi-speed input frequency control table.

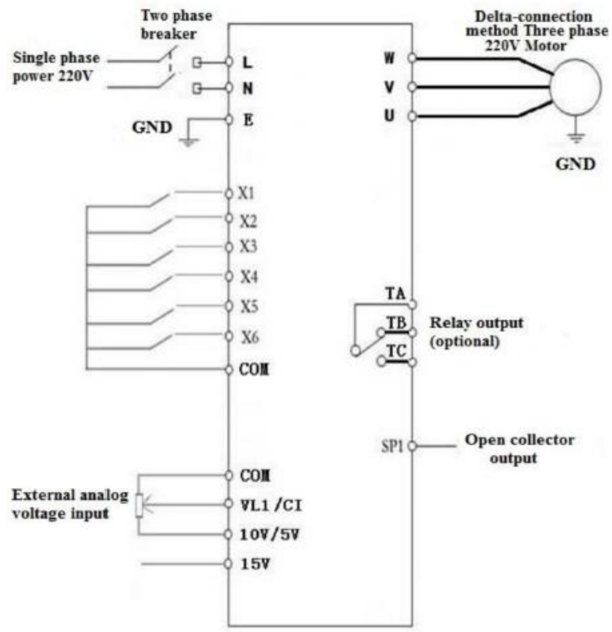
	Section Speed Input 1	Section Speed Input 2	Section Speed Input 3	Original Frequency
Section Speed 1	0	0	0	15
Section Speed 2	0	0	1	20
Section Speed 3	0	1	0	25
Section Speed 4	0	1	1	30
Section Speed 5	1	0	0	35
Section Speed 6	1	0	1	40
Section Speed 7	1	1	0	45
Section Speed 8	1	1	1	50

Source: Operating Instruction Inverter VFD XSY-AT1, 2024

Table 2: Terminal description VFD

Port	Function description	Instruction
15V/24V	15V/24V power output	200mA 15V/24V output
X6	Input port 6 (Reversing switch)	Short Port X6 and COM, input signal effective
X5	Input port 5 (Reverse rotation Control switch)	Short Port X6 and COM, input signal effective
X4	Input port 4 (Forward rotation Control switch)	Short Port X6 and COM, input signal effective
X3	Input port 3 (Section-speed 3)	Short Port X6 and COM, input signal effective
X2	Input port 2 (Section-speed 2)	Short Port X6 and COM, input signal effective
X1	Input port 1 (Section-speed 1)	Short Port X6 and COM, input signal effective
485+/485-		

Source: Operating Instruction Inverter VFD XSY-AT1, 2024



Source: Operating Instruction Inverter VFD XSY-AT1, 2024

Figure 7. Basic operation wiring diagram VFD XSY-AT1

Output PLC Addresses to VFD:

1. 100.02 = X1 (Section Speed Input 1)
2. 100.03 = X2 (Section Speed Input 2)
3. 100.04 = X3 (Section Speed Input 3)
4. 100.05 = X4 (Forward)
5. 100.06 = X5 (Reverse)
6. 100.07 = X6 (Emergency Stop)

The flowchart is as follows:

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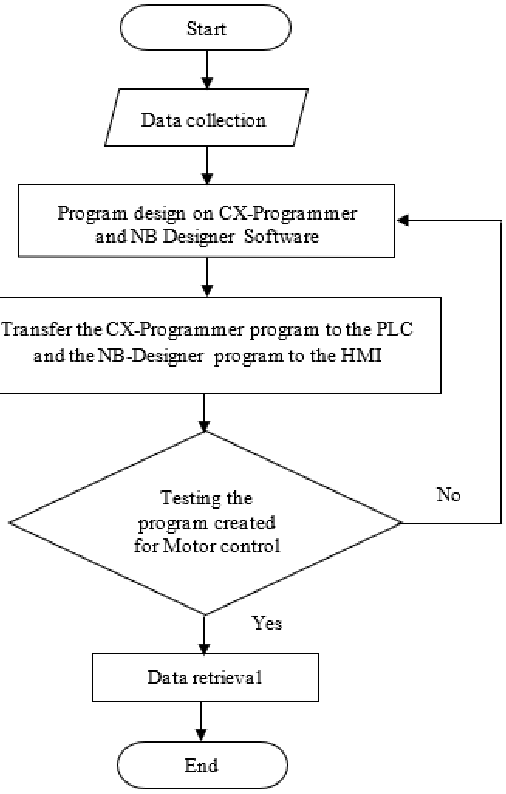

The HMI Omron screen display consists of several control buttons as follows:

- ON PLC Button
- OFF PLC Button
- FWD (Forward) Button
- STOP Fwd/Rev Button
- REV (Reverse) Button
- Spindle Motor Speed Selection Button

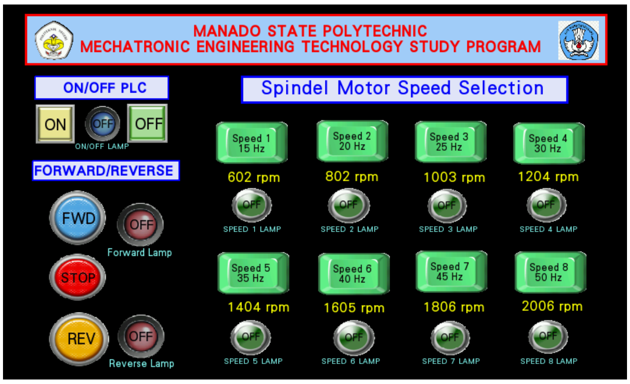

Figure 8. Display on NB-Designer Software

3. RESULTS AND DISCUSSION

3.1. VFD Ladder Logic Based on Omron CP1H PLC

From the ladder diagram design results, the control system on the PLC can be explained as follows:

1. The ladder diagram in the Input program, where the ON/OFF buttons on the panel box and HMI with input addresses 0.00 and 0.01 function to activate and deactivate the control system. When the ON button is pressed, the coil output with address 200.00 (Internal Relay 1) will be active, causing the current in all ladder program circuits to be automatically activated. Conversely, all circuits will be OFF when the OFF button is pressed. Also, if the Emergency button on the panel box is pressed, the entire system will be OFF.

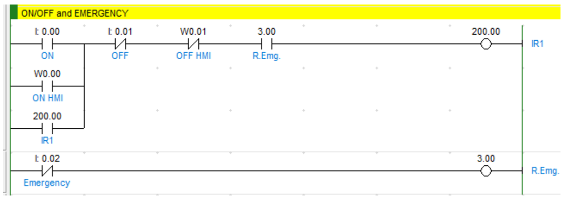

Figure 9. Ladder diagram ON/OFF and Emergency

2. The Forward/Reverse ladder diagram makes the motor rotate clockwise or counterclockwise. When the button with HMI input address W0.03 (Forward) is pressed, the output coil with internal relay 4.03 will activate the output address 100.05 on the PLC, which in turn will activate the Variable Frequency Drive (VFD), causing the motor to rotate Forward. Press the Stop button on the HMI with input address W0.02 to stop. Conversely, if HMI input W0.04 (Reverse) is pressed, the output coil with internal relay 4.04 will activate the output address 100.06 on the PLC, activating the VFD, causing the motor to rotate Reverse. Once the Forward/Reverse buttons are activated, the motor rotates at a frequency of 15 Hz with a motor speed of 602 rpm for Speed 1.

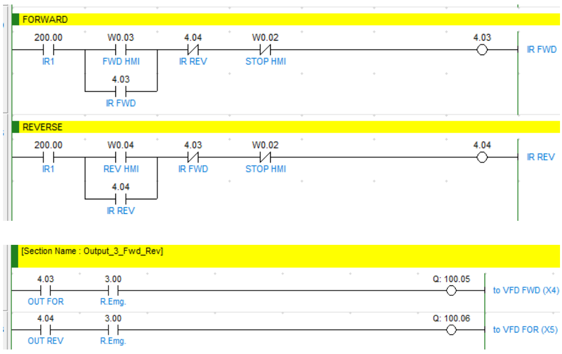

Figure 10. Ladder diagram Forward and Reverse

3. To achieve motor rotation with 8 speed levels based on the Multi Speed Input Frequency Table of the VFD used (see table 1), when address W0.06 (Speed 2) is pressed, the internal relay output coil at address 3.02 (SP3) will be activated, which in turn activates the internal relay output coil at address 200.02 (IR3). This also activates the internal memory output at address 4.02, then connects to the output address 100.04 on the PLC, which is connected to the VFD port (X3), causing the motor to run at a speed of 747 rpm.

When Input address 0.07 (Speed 3) is pressed, the internal memory output coil at address 3.03 will be activated, activating the internal relay output coil at address 200.03 (IR4). This also activates the internal memory output at address 4.01, then connects to the output address 100.03 on the PLC, which is connected to the VFD port X2, causing the motor to run at a speed of 933 rpm. Similarly, when activating the Speed 4 ladder circuit, the spindle will rotate at 1120 rpm, while output coil at address 200.04 (IR5) activates the internal memory output at addresses 4.01 and 4.02, then connects to the output address 100.03 and 100.04 on the PLC, which is connected to the VFD port X3 & port X2, continuing up to speed 8, where the spindle rotates at 2000 rpm, or vice versa, refer to the Multi-speed input Frequency control table-1.

4.

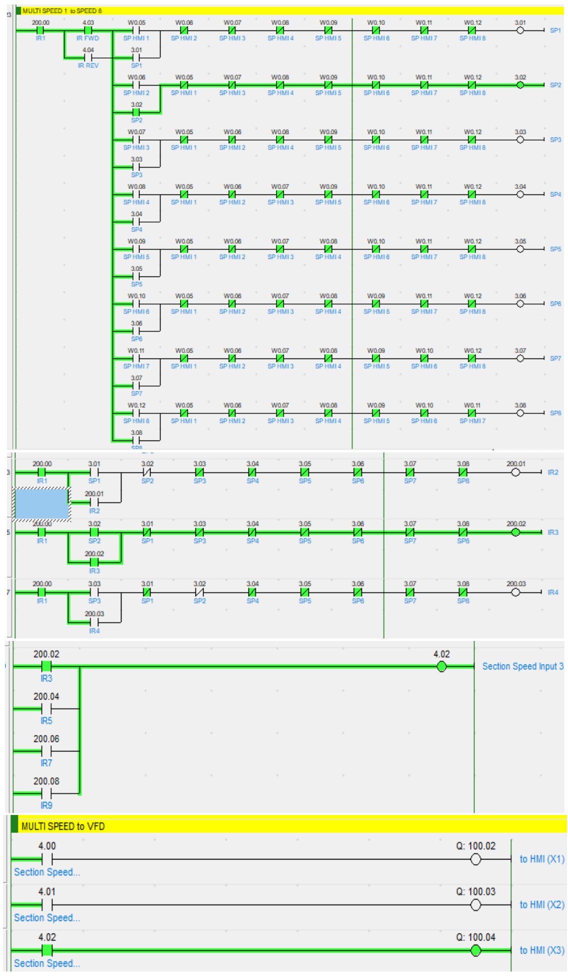

Figure 11. Ladder diagram Speed 2.

3.2. SCADA System Testing between HMI and PLC to control VFD

For spindle motor rotation is as follows:

1. Speed 1 with a spindle rotation of 602 rpm will activate immediately when the Forward or Reverse button on the HMI screen is pressed.
2. For Speed 2 with a spindle rotation of 802 rpm, press directly on the HMI screen the button labeled 20 Hz.
3. Similarly, for Speed 3 with a spindle rotation of 1003 rpm, press the button labeled 25 Hz, and so on up to Speed 8 for a rotation of 2006 rpm by pressing the button labeled 50 Hz.

3.3. Pulley Rotation Calculation

To achieve spindle rotation on the lathe chuck, refer to the following formula:
Here's how to calculate it:

$$n_2 = \frac{D_1 \times n_1}{D_2} \quad [2]$$

Where:

- n_1 = motor speed
- n_2 = spindle speed
- D_1 = motor pulley diameter
- D_2 = spindle pulley diameter

For a motor speed of 1400 rpm, a motor pulley diameter of 130 mm, and a spindle pulley diameter of 90 mm. Refer to Table 3 below.

Table 3: Spindel Speed Calculation

Speed	Frequency (Hz)	Motor rotation (rpm)	Spindel rotation (rpm)
1	15	420	607
2	20	560	809
3	25	700	1011
4	30	840	1213
5	35	980	1416
6	40	1120	1618
7	45	1260	1820
8	50	1400	2022

The motor rotation values in Table 3 are displayed on the VFD, and the spindle rotation values are calculated using the abovementioned formula.

Table 4: Spindle Speed Measurement Results

Speed	Frequency (Hz)	Motor rotation (rpm)	Average Measurement Results (rpm)
1	15	420	602
2	20	560	802
3	25	700	1003
4	30	840	1204
5	35	980	1404
6	40	1120	1605
7	45	1260	1806
8	50	1400	2006

The data in Table 4 represents the average measurement results from multiple datasets. It shows a decrease in spindle rotation compared to the results in Table 3. This reduction is caused by a slip between the V-belt and the pulley.

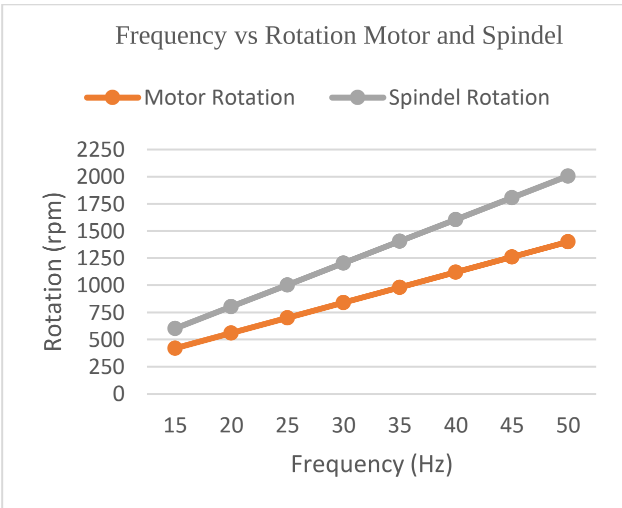

Figure 12. Chart Frequency vs Rotation Motor and Spindel

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Graph 12 illustrates that the spindle rotation speed increases by approximately 1.4 times compared to the motor rotation speed.

3.4. Discussion

After conducting research on retrofitting the MyFord 254S lathe machine by regulating the speed of the driving motor, the process proved to be highly time-efficient. The motor rotation can now be adjusted instantly by simply pressing a button on the HMI, including reversing its direction. In contrast, prior to the retrofit, the initial condition required manual adjustment of the gearbox selector on the lathe machine, which was comparatively time-consuming.

4. CONCLUSION

In the retrofit of the MyFord 254S lathe with PLC and SCADA control for spindle motor speed regulation, it can be concluded that: The spindle motor speed can be directly controlled on the HMI monitor by pressing the Forward/Reverse button for a spindle speed of 602 rpm. For subsequent spindle speeds, selections can be made through the HMI screen from 20 Hz (spindle speed 802 rpm), 25 Hz (spindle speed 1003 rpm), 30 Hz (spindle speed 1204 rpm), 35 Hz (spindle speed 1404 rpm), 40 Hz (spindle speed 1605 rpm), 45 Hz (spindle speed 1806 rpm), to 50 Hz (spindle speed 2006 rpm).

This research is highly significant for students as a learning module for PLC and SCADA systems, specifically in controlling 3-phase motors. Future developments could involve pressing the UP or DOWN buttons on the HMI to adjust the spindle rotation or directly inputting a desired frequency, ranging from 0 to 50 Hz, on the HMI.

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