Design of control instrumentation system for setting the stripper position on DECY-13 Cyclotron

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Abstract.
This research aims to design a stripper positioning system with input in the form of angle values and outputs are the x, y coordinates of each stripper. This system consists of hardware and software. The hardware consists of Fx2424 Super PLC, micro-step driver, stepper motor and dc power supply. The software includes Super PLC programming for stepper motor motion using features of the i-TRILOGI program and LabView program for the user interface. The test results show that stripper A with a length of 85 mm, an input angle of 60 degrees, obtained x; y coordinates are 435; 193 mm. For stripper B with a length of 85 mm, an input angle of 240 degrees, obtained x; y coordinates are 400; 118 mm. For stripper C with a length of 85 mm, an input angle of 90 degrees, obtained x; y coordinates are 415; 75 mm. Overall test results show that the stripper position control system can be used to rotate and monitor the position of the stripper on the DECY-13 cyclotron.

1. Introduction
The Center for Science and Accelerator Technology (CSAT)-BATAN, is currently developing a proton cyclotron with 13 MeV energy, named DECY-13 (Development of Experimental Cyclotron in Yogyakarta 13 MeV) is used for radioisotope production [1]. DECY-13 Cyclotron specifications according to the design are Penning type ion sources capable of producing 100 µA beam currents in the central region, 1.275 Tesla magnetic field strength, 40 kVpp dee peak voltage, 77.60 MHz rf generator, 13 MeV proton energy and 50 µA current proton beam directed at the target [2]. A photograph of the DECY-13 cyclotron is shown in Figure 1 [3].
Figure 1. Photograph of DECY-13 cyclotron [3].

DECY-13 cyclotron has several subsystems, one of which is the extractor system. The extractor system functions to control the particle beam to be directed to the target system.

The principle of the stripper is to change the polarity of negative hydrogen ions, H\(^-\) to positive hydrogen ions, H\(^+\) through carbon foil placed on the stripper's arm. Carbon foil is able to absorb the negative charge of hydrogen atoms well and carbon also has a low level of radioactive residue [4]. The determination of the particle beam path has been carried out in a simulation using Opera 3D / Tosca software [5]. The position of the stripper is very important in determining the output of the particle beam produced by the cyclotron. In its development, the extractor system on the DECY13 cyclotron has not been equipped with a control instrumentation system (CIS) to adjust the position of the stripper.

To support the development of the DECY-13 cyclotron, it is necessary to design an instrumentation and control system for stripper positioning. The design of the instrumentation control system of the stripper position control aims to monitor and adjust the position of the stripper on the DECY-13 cyclotron using super PLC and LabView. It is hoped that the beam particle output to the target can be optimized.

2. Methodology

This system consists of hardware namely a stepper motor which is equipped with a micro-step driver as a stripper driver, Fx2424 Super PLC as the main control system and LabView program for the user interface. The software consists of super PLC programming for stepper motor motion using features in the i-TRiLOGI program. LabView communication with Super PLC is done serially via RS232. This CIS functions to regulate and monitor the position of the stripper. The input parameters are the angle and the output values of each stripper in the form of x, y coordinates.

2.1. System Design

The block diagram of the stripper positioning system design is shown in Figure 2.

Figure 2. Block diagram of a stripper positioning system.

Before making software, input/output addressing needs to be made on the PLC are shown in Table 1 [6].
Table 1. Input/output addressing on the PLC [6].

| Input/Output        | Interface         | Pin Super PLC FX2424 |
|---------------------|-------------------|----------------------|
| Driver Motor        | Digital Output    | Pin 5 & Pin 6        |
| Button Selector Stripper A | Digital Input   | Pin 1                |
| Button Selector Stripper B | Digital Input   | Pin 2                |
| Button Selector Stripper C | Digital Input   | Pin 3                |
| Button Selector Sudut 1°  | Digital Input   | Pin 4                |
| Button Selector Sudut 5°  | Digital Input   | Pin 5                |
| Button Selector Sudut 10° | Digital Input  | Pin 6                |
| Button Clockwise    | Digital Input    | Pin 7                |
| Button Anti Clockwise | Digital Input | Pin 8                |
| Button Count Up     | Digital Input    | Pin 9                |
| Button Count Down   | Digital Input    | Pin 10               |
| Button Home         | Digital Input    | Pin 11               |
| LCD                 | LCD Display Port | LCD Display Port     |
| Button Reset        | Digital Input    | Pin 12               |
| Button A            | Digital Input    | Pin 15               |
| Button B            | Digital Input    | Pin 16               |
| Button C            | Digital Input    | Pin 19               |
| Button D            | Digital Input    | Pin 18               |

2.2. Software Design

The main control program used Fx2424 super PLC with i-TRILOGI software. As the human-machine interface (HMI) for positioning strippers used NI LabView 2018 software. The system design steps are as follows:

1. The algorithm for stripper positioning system programming is shown in Figure 3.

![Figure 3. Algorithm for stripper position control system.](image)

2. Design of the HMI display for the stripper position control system shown in Figure 4.
2.3. **Hardware Design**

The hardware design of the stripper positioning system is built using Fx2424 PLC, micro-step driver, stepper motor and stripper. The wiring diagram for the input and output stripper positioning systems is shown in Figure 5.

2.3.1. **Fx2424 PLC Module**

Fx2424 PLC is a hardware module that functions to process data / signal input commands from the keypad as request input (setting demand), digital input, digital output, analog voltage input, analog voltage output and display on the LCD screen. An Fx2424 series PLC module is shown in Figure 6 [7].
PLC-F2424 specifications have 24 digital inputs, 24 digital outputs and 12 I/Os analogs built-in and can be expanded to 96 digital outputs and 96 digital outputs using the EXP1616R or EXP4040 expansion boards. The features of the PLC F2424 provide pulse width modulator facilities (PWM), stepper motor control, interrupt, encoder input, Real-Time Clock (RTC), PID control and output to the HMI (Human-Machine Interface) along with the LCD. PLC F2424 has 4 analog output channels (D/A), 0-5 V, 10 bits [7].

2.3.2. Stepper Motor and motor driver
Stepper motor is one type of dc motor that is controlled by digital pulses. The working principle of a stepper motor is to work by converting electronic pulses into discrete mechanical movements where the stepper motor moves based on the sequence of pulses given to the stepper motor [8]. The stepper motor used is 57J1854EC-1000 nema 23 full closed-loop hybrid stepper motor type and 2HSS57-KH hybrid step-servo motor driver type are shown respectively in Figures 7 and 8.

3. Result and Discussion,
3.1. Hardware manufacturer
The prototype of the instrumentation system for stripper position control shown in Figure 9. The stepper motor installation on the stripper system shown in Figure 10.
3.2. Software manufacture
Software to drive a stepper motor using Ladder diagrams and TBasic languages from the iTriLOGI program and LabView program to create the user-machine interface through a computer has been made. The results of the software design for turning the stepper motor shown in Figure 11 [11], and the simulation test results are shown in Figure 12.

![Figure 11. Ladder diagram of stepper motor motion [11].](image1)

![Figure 12. Simulation results of stepper motor motion](image2)

3.3. Test Results
The design results of the control instrumentation system for stripper position control in the form of HMI (Human Machine Interface) to arrange and display data in the form of stripper position coordinates in the path of the particle beam is shown in Figure 13.

![Figure 13. HMI of stripper control system](image3)

Description in Figure 13: Number 1, Functions of this block to connect HMI to Fx2424 PLC. Number 2, This block serves to write the length of the stripper arm used. Number 3, This block contains the angle value to change the position of the stripper. Number 4, This block contains the estimation point to position the stripper at a certain position. Several coordinate points for stripper positions have been simulated by Kudus, et al [5]. Number 5, this block contains the value of the position adjustment for each step and clockwise (cw) and counterclockwise (CCW) button.

In this block, the user can choose steps for 1 degree, 5 degrees or 10 degrees and change rotation of the stepper motor. Number 6, block used to display the x - y coordinate points of the stripper. When the coordinate point is 0 (zero) it means that the stripper is outside the path of the particle
beam. Number 7, this block contains an illustration of the stripper on the DECY-13 cyclotron and there is a home button and reset button. The home button functions to return the stripper to its original position, i.e., stripper A is at coordinates $x = 416$ mm and $y = 126$ mm. Reset button functions to reset the contents of the data memory address on the PLC and return the stripper to the initial position.

This experiment aims to determine the movement of the stripper and to determine the position of the coordinates of each stripper. Measurement of $x$-$y$ coordinates of the stripper position using a particle beam path image outside of the cyclotron area with the image size of 1:1 shown in Figure 14. Name tags for stripper arms A, B, and C are shown in Figure 15.

![Figure 14. x-y coordinate measurement of the stripper position](image1)

![Figure 15. Name tags of stripper A, B, C](image2)

Testing with a stripper arm length of 65 mm, the angle value is varied and carried out repeatedly. As a reference to determine the coordinates of the stripper A, B, C is stripper A. Retrieval of data with an angle range of 0 degrees to 40 degrees with a 5-degree angle interval is shown in Table 2. Test results for the $x$-$y$ coordinate of A, B, C stripper positions with 85 mm arm length with 10-degree angle intervals are shown in Tables 3, 4 and 5, respectively.

| Table 2. Test results of the $x$-$y$ coordinate |
|-----------------------------------------------|
| Sudut (derajat)  | koordinat | Panjang lengan (mm) |
|------------------|-----------|---------------------|
| 1                | 0         | 416 126             |
| 2                | 10        | 416 132             |
| 3                | 20        | 417 142             |
| 4                | 30        | 421 154             |
| 5                | 40        | 427 167             |

| Table 3. Test results of stripper A |
|-------------------------------------|
| No  | Sudut Stripper A (derajat) | X tertanpil (mm) | X terkukur (mm) | $\Delta X$ (mm) | error (%) | Y tertanpil (mm) | Y terkukur (mm) | $\Delta Y$ (mm) | error (%) |
|-----|-----------------------------|------------------|-----------------|-----------------|-----------|-----------------|-----------------|-----------------|-----------|
| 1   | 0                           | 396 399          | 3               | 0,75            | 126       | 126             | 0               | 0,00            |
| 2   | 10                          | 396 399          | 3               | 0,75            | 142       | 142             | 0               | 0,00            |
| 3   | 20                          | 397 400          | 3               | 0,75            | 152       | 150             | 2               | 1,33            |
| 4   | 30                          | 405 406          | 1               | 0,25            | 164       | 163             | 1               | 0,61            |
| 5   | 40                          | 411 413          | 2               | 0,48            | 177       | 176             | 1               | 0,57            |
| 6   | 50                          | 425 424          | 1               | 0,24            | 186       | 186             | 0               | 0,00            |
| 7   | 60                          | 435 435          | 0               | 0               | 193       | 196             | 3               | 1,53            |
| 29  | 280                         | 471 472          | 1               | 0,21            | 39        | 40              | 1               | 2,50            |
| 30  | 290                         | 459 461          | 2               | 0,43            | 46        | 49              | 3               | 6,12            |
| 31  | 300                         | 441 443          | 2               | 0,45            | 58        | 57              | 1               | 1,75            |
| 32  | 310                         | 433 435          | 2               | 0,46            | 66        | 64              | 2               | 3,13            |
| 33  | 320                         | 425 424          | 1               | 0,24            | 77        | 74              | 3               | 4,05            |
| 34  | 330                         | 416 416          | 0               | 0,00            | 85        | 85              | 0               | 0,00            |
| 35  | 340                         | 408 410          | 2               | 0,49            | 101       | 98              | 3               | 3,06            |
| 36  | 350                         | 405 406          | 1               | 0,25            | 111       | 112             | 1               | 0,89            |
| 37  | 360                         | 404 404          | 0               | 0,00            | 129       | 126             | 3               | 2,38            |
In Table 3, with a range of angles from 0 degrees to 360 degrees, the deviation by coordinates measured and computer displayed is ±3 mm. The average error monitoring of the stripper position between measured coordinates and those displayed on the system is 1.05% and the maximum error is 6.12%. In Table 4, the maximum deviation value of monitoring of the stripper position between the measured coordinate points and those displayed on the system is ±3 mm, the mean error monitoring of the stripper position between the measured coordinate points and those displayed on the system is 0.74% with a maximum error is 4.65%.

In Table 5, the maximum deviation value of monitoring the position of the stripper between the measured coordinate points and those displayed on the system is ±3 mm and the mean error of monitoring the position of the stripper positions between the measured coordinates and those displayed on the system is 1.12% with a maximum error is 6.98%. In this experiment the foil stripper size is 10 mm x 10 mm and the angle interval value is 10 degrees. The experimental results show that the value of the measurement deviation is from parallax error when reading the tool.

4. Conclusion
The instrumentation control system to adjust the position of the stripper has been successfully designed. This system can rotate and monitor the coordinate of the stripper position. The function test results show that stripper A, length of 85 mm, with a 60-degree input angle, obtained x-y coordinates are 435; 193 mm. For stripper B, length of 85 mm, with 240 degrees input angle, obtained x-y coordinates are 400; 118 mm. For stripper C, length of 85 mm, with 90 degrees input angle, obtained x-y coordinates are 415; 75 mm. Overall test results show that the stripper position control system can be used to adjust and monitor the position of the stripper on the DECY-13 Cyclotron.

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