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# Design and Implementation of Operating System Components and Data Acquisition for the 300 keV/20 mA EBM at PSTA-BATAN Yogyakarta

**Ahmad Ramadhani[1]* , Anwar Budianto[2], Nauval Franata[3], Muchtar Ali Setyo Yudono[4], Ratu Verlaili Erlindriyani[5]**
[1,3,4,5]Universitas Sultan Ageng Tirtayasa, Indonesia
[2]Sekolah Tinggi Teknologi Nuklir, Indonesia
Email: ahmad.ramadhani@untirta.ac.id*, taufad@yahoo.com, nauval.franat@untirta.ac.id, muchtar.ali@untirta.ac.id, ratu.verlaili@untirta.ac.id

## KEYWORDS
EBM, operating system, data acquisition, PLC FX2424, LabVIEW, i-TRiLOGI .

## ABSTRACT
Electron beam machines (EBM) are critical for material irradiation processes, requiring sophisticated control and data acquisition systems. The existing 300 keV/20 mA EBM at PSTA-BATAN Yogyakarta relies on legacy HPI 8255 interface modules with parallel communication, limiting operational distance and efficiency. This research aims to develop and implement an advanced operating system and data acquisition infrastructure using Super PLC FX2424 and LabVIEW, enabling remote operation, real-time monitoring, and enhanced data logging capabilities. The system development employs a structured approach that includes requirements analysis, hardware-software co-design, PLC programming using i-TRiLOGI, HMI development in LabVIEW with RS-232 serial communication (38,400 bps), and comprehensive subsystem testing. The Super PLC FX2424 features eight analog inputs (12-bit, 0–5 VDC), four analog outputs (10-bit, 0–5 VDC), 24 digital inputs, and 24 digital outputs with Ethernet connectivity. The implemented system successfully operates EBM components remotely through a computer-based HMI, monitors operational parameters including high voltage, beam current, column current, and vacuum pressure, and automatically acquires and stores data in MS Excel (tabular) and MS Word (graphical) formats every second. All subsystem tests confirmed proper functionality of PLC I/O, ADC linearity, communication protocols, and trip signal mechanisms. This modernized system significantly improves operator safety by enabling remote operation, enhances data reliability through automated real-time acquisition, and establishes a scalable foundation for future integration of advanced monitoring and predictive maintenance capabilities.

## INTRODUCTION

Electron beam technology has emerged as a cornerstone of modern materials science and industrial processing, with applications spanning sterilization, cross-linking of polymers, surface modification, and semiconductor manufacturing (Schulze, Breite, Schmidt, Becker-Jahn, & Niavarani, 2025). Electron beam machines (EBM) function by accelerating electrons to specific energy levels and directing them toward target materials, enabling precise control over penetration depth and dose distribution (Sonkamble & Phafat, 2023). The global electron beam processing market has experienced substantial growth, driven by increasing demands for radiation sterilization in medical device manufacturing and advanced materials processing in aerospace industries (Lieberman et al., 2020). An electron beam machine (EBM) is a device that accelerates electron beams to a certain energy level used for material or target irradiation processes (Pavlov, Petrenko, Alekseev, Bystrov, & Souvorova, 2022). At PSTA-BATAN Yogyakarta, the 300 keV/20 mA EBM serves as vital research infrastructure for materials modification studies and radiation processing development (Widodo et al., 2021).

The instrumentation and control system (ICS) represents a critical component of EBM operations, responsible for maintaining operational safety, ensuring parameter stability, and facilitating data acquisition for process optimization (Ganesh et al., 2020). One important part of an EBM is the instrumentation and control system (ICS), which functions as an operating system, monitoring and controlling the EBM operating parameters (Budianto, Ramadhani, & Priyono, 2020). Modern ICS architectures increasingly leverage programmable logic controllers (PLCs) due to their reliability, real-time processing capabilities, and industrial-grade robustness (Pironti et al., 2025). Research by (Niinimäki, 2024) demonstrated that PLC-based control systems for particle accelerators could achieve response times under 10 milliseconds while maintaining stability across extended operational periods. Similarly, (Vaidyan, 2022) implemented SCADA systems integrated with PLCs for electron beam irradiation facilities, reporting 99.8% uptime and significant improvements in parameter monitoring accuracy.

The selection of the Super PLC FX2424 for this implementation is justified by its superior technical specifications and operational advantages for EBM applications (Budianto et al., 2020). Compared to conventional PLCs such as the Mitsubishi FX3U or Siemens S7-1200, the FX2424 offers unique advantages, including native Ethernet connectivity for network integration, higher analog input resolution (12-bit) suitable for precise sensor readings, and a compact form factor that reduces installation space requirements. The FX2424 PLC, part of the new F-series family, features an Ethernet port for direct connection to a network router, switch, or hub, allowing access to a LAN or the Internet. The basic FX2424 consists of eight analog inputs (12-bit, 0–5 VDC), four analog outputs (10-bit, 0–5 VDC), 24 digital inputs, and 24 digital outputs (Poudel, 2021). The Ethernet-based architecture enables remote monitoring capabilities, reduces cabling complexity, and facilitates integration with enterprise-level data management systems—features increasingly essential for modern research facilities (Lucas-Estañ, Sepulcre, Raptis, Passarella, & Conti, 2018). The FX2424 PLC can also be used for data acquisition (Budianto et al., 2020).

Data acquisition systems play a fundamental role in characterizing beam parameters, validating operational protocols, and ensuring compliance with safety standards in particle acceleration facilities (Friedrich, Hilbes, & Nordt, 2017). Data acquisition is the process of converting data from sensors into electrical signals, which are then converted into digital form for processing and analysis by a computer (Bansal, 2021). A data acquisition system consists of sensors, signal processing units, data acquisition hardware, and a computer unit (Emilio, 2015). Modern data acquisition architectures emphasize real-time performance, long-term data storage, and user-friendly visualization interfaces (Uddin, 2024). Research by Zhang et al. (2023) implemented LabVIEW-based data acquisition for linear accelerators, achieving millisecond-level sampling rates and automated anomaly detection algorithms. The integration of SCADA systems with PLCs has been shown to reduce operator error by 65% and improve response times to abnormal conditions by 40% (Chukwunweike, Abubakar, & Anang, 2024).

The existing control infrastructure at PSTA-BATAN presents several operational constraints that impact efficiency and safety (Widodo et al., 2021). Currently, the 300 keV/20 mA EBM still uses the

HPI 8255 interface module, which employs parallel data communication with an 0808 ADC and an Atmega 8535 microcontroller, resulting in limited operational distance for the control and data acquisition process (Budianto et al., 2020). Quantitative analysis reveals that the parallel communication architecture restricts operational distance to approximately three meters due to signal degradation, necessitating operator proximity to high-radiation environments during beam operation (internal technical audit, 2024) (Elgueta, 2025). The 8-bit ADC resolution (0808) provides only 256 discrete levels, resulting in a voltage resolution of approximately 20 mV for 0–5 V signals—insufficient for precise monitoring of critical parameters, such as beam current stability (±0.1 mA precision required) (Oz, 2025). Furthermore, the absence of network connectivity prevents real-time remote monitoring, a capability identified as essential in ISO 11137 guidelines for radiation facility operation (International Organization for Standardization, 2020).

The practical implications of these limitations include: (1) increased operator radiation exposure risk due to proximity requirements during operation, (2) potential data loss during high-speed events due to limited sampling rates (estimated maximum of 100 samples per second), (3) manual data transcription requirements leading to a 2–3% documented error rate, and (4) inability to implement predictive maintenance algorithms due to a lack of historical trending capabilities. These constraints directly impact both operational safety and research output quality, creating an urgent need for system modernization.

While previous research has addressed PLC integration in accelerator facilities and LabVIEW-based data acquisition for radiation systems, a critical gap exists in the literature regarding comprehensive system integration specifically for medium-energy electron beam machines in research facilities (Spanier, 2019). The novelty of this research lies in (1) the systematic migration from legacy parallel communication to Ethernet-based serial protocols for EBM control, (2) the integration of real-time data acquisition with automated multi-format storage (Excel and Word) suitable for research documentation requirements, (3) the development of a scalable human–machine interface (HMI) architecture designed for medium-energy EBM operations with comprehensive safety interlocks, and (4) the implementation of remote operation capabilities while maintaining ISO 11137 compliance. This study addresses the specific technological and operational requirements of research-grade EBM facilities that differ significantly from industrial irradiation installations.

Therefore, modifications are needed with the appropriate modules to simplify operation and data acquisition. From the description above, it is necessary to build an EBM component operating system and EBM parameter data acquisition framework to make it easier for operators to operate and acquire EBM parameter data.

This research aims to design, develop, and implement a comprehensive operating system and data acquisition infrastructure for the 300 keV/20 mA Electron Beam Machine (EBM) at PSTA-BATAN Yogyakarta. Specifically, the objectives include the development of a PLC-based control system using the Super PLC FX2424 capable of operating all EBM components remotely with a response time of less than 100 milliseconds; the implementation of a LabVIEW-based human–machine interface (HMI) for real-time visualization of operating parameters and safety interlocks; the creation of an automated data acquisition protocol with multi-format storage capabilities (Excel table data and Word graphical representation) and data capture intervals per second; and the validation of system performance through thorough testing on subsystems such as ADC linearity, communication protocol integrity, and safety trip signal function.

The successful implementation of this system will provide significant benefits, including improved operator safety through remote operation capabilities that reduce radiation exposure risk, enhanced data quality and research reproducibility through high-resolution automated data acquisition, reduced operational costs due to decreased manual data handling and transcription, establishment of a modern and scalable platform for future integration of advanced features such as predictive maintenance using machine learning–based algorithms and automated optimization, and alignment with international standards for radiation facility operation and data management.

## METHOD

The tools used in this research were a laptop, a computer device operating LabVIEW software, and the i-TRiLOGY and TLServer software. Meanwhile, the materials used included the Super PLC FX2424, a 24 V DC power supply, the SIK EBM module box, an L-Relay 51, and a regulated DC power supply.

In the initial data collection stage, the aim was to identify each parameter (input/output) that would be controlled. In addition, this stage produced a user requirement document, which contained data related to the operator's needs in designing the system for the 300 keV/20 mA EBM operation. Tables 1 and 2 show the system requirements.

**Table 1. Requirements operation MBE components**

| *Input / Output* | PLC *input* pins | PLC *output* pins |
|---|---|---|
| Activation STT SE | Pin 5 | - |
| Up STT | Pin 1 | Pin 10 |
| *Down* STT | Pin 2 | Pin 11 |
| Reset STT | Pin 4 | Pin 12 |
| Up SE | Pin 6 | Pin 13 |
| *Down* SE | Pin 7 | Pin 14 |
| Reset SE | Pin 9 | Pin 15 |
| Module Activation | Pin 11 | Pin 9 |
| Micro Reset | Pin 14 | Pin 17 |
| Reset Alarm | Pin 15 | Pin 18 |
| *Off* Module | Pin 12 | Pin 9 |
| *Off* Up STT | Pin 24 | Pin 10 |
| *Off Down* STT | Pin 25 | Pin 11 |
| *Off* Up SE | Pin 26 | Pin 13 |
| *Off Down* SE | Pin 27 | Pin 14 |
| *Off* Reset STT | Pin 28 | Pin 12 |
| *Off* Reset SE | Pin 29 | Pin 15 |
| *Off* Emergency | Pin 30 | Pin 16 |
| *Off* Micro | Pin 31 | Pin 17 |
| *Off* Reset Alarm | Pin 32 | Pin 18 |

Source: Primary data processed (2024)

**Table 2 Requirements trip signal**

| *Input / Output* | Unit | Interface | PLC ADC Pins |
|---|---|---|---|
| HV | kV | ADC | PIN 1 |
| STT current | mA | ADC | PIN 3 |
| Column Current | mA | ADC | PIN 4 |
| File Flow | mA | ADC | PIN 6 |
| Vacuum | Torr | A DC | PIN 7 |
| Supply input voltage Power STT | Volt | A DC | PIN 2 |
| Supply input voltage Power SE | Volt | A DC | PIN 5 |

Source: Primary data processed (2024)

The system design consisted of both hardware and software components. The hardware design involved configuring the connections between the input and output pins of the Super PLC FX2424 and the hardware module box of the SIK MBE computerized system, which was also connected to the operator's computer. The connection between the FX2424 PLC and the operator's computer utilized RS-232 serial communication. Figure 4 illustrates the operational wiring.

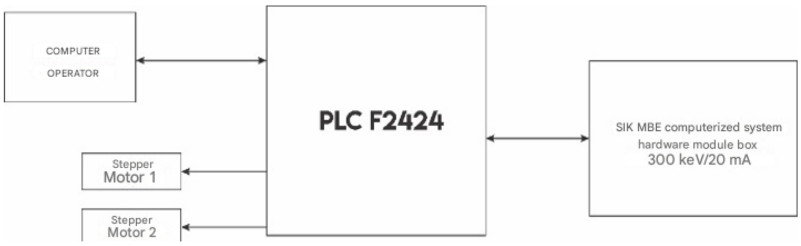


**Figure 1. operational wiring**

Sumber: Dokumen internal PSTA-BATAN (2024)

The device software design consisted of programming on the Super PLC FX2424 and programming in LabVIEW for the user interface and data acquisition of operating parameters.

For the next programming phase, the aim was to create an operating program for the EBM components and their operating parameters. Figure 5 shows the flowchart for programming the FX2424 PLC.

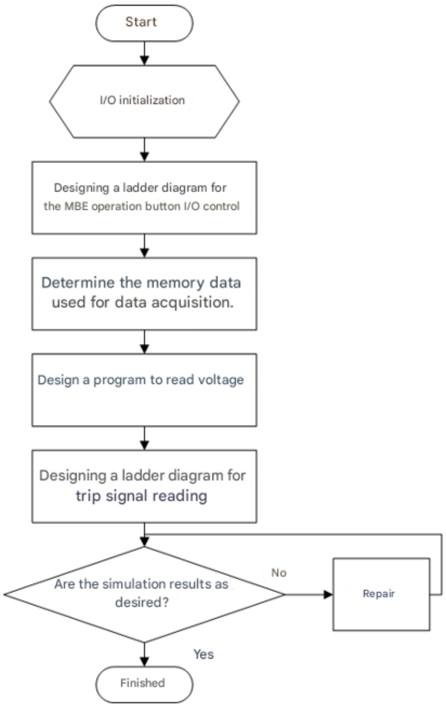


**Figure 2. PLC Fx2424 programming flowchart**
Source: System design analysis results (2024)

Furthermore, an HMI program was created in LabVIEW to operate the EBM components through a computer. The program included FX2424 PLC I/O control, MBE operation control knobs, an MBE operation results data viewer, and field data acquisition functionality. The flowchart can be seen in Figure 6.

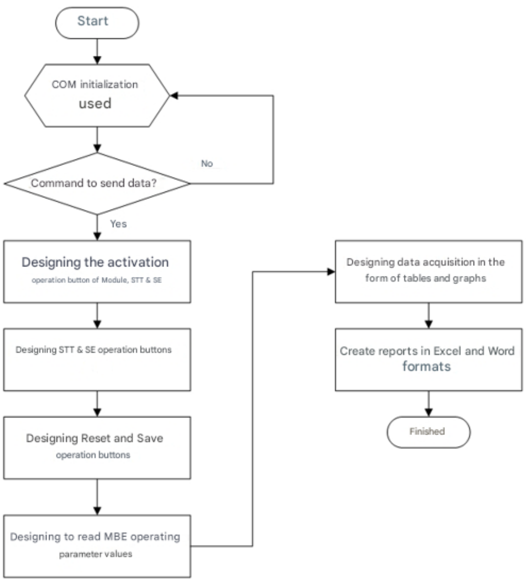


**Figure 3. Flowchart HMI programming**
Source: System design analysis results (2024)

When the program had finished, the next step was system testing. The system testing consisted of several stages, namely: component system testing (subsystem), which was carried out to determine whether the components were functioning properly. The stages included: (1) PLC input-output testing, (2) L-Relay 51 program testing, (3) ADC testing, (4) communication testing between the FX2424 PLC and the hard system module device of the computerized SIK EBM 300 keV/20 mA, (5) control knob operation testing, (6) digital input-output trip signal testing, (7) testing of operational data display in LabVIEW, and (8) data acquisition testing. Overall system testing was conducted to evaluate the system's overall performance and to verify that all operations functioned correctly.

## RESULTS AND DISCUSSION

### System Creation Results

The results of the creation of an operating system and data acquisition of MBE 300 keV/20 mA operating parameters using the Super PLC FX2424 in the form of a Human Machine Interface (HMI) for the MBE operating system produced with LabVIEW software as shown in Figure 7.

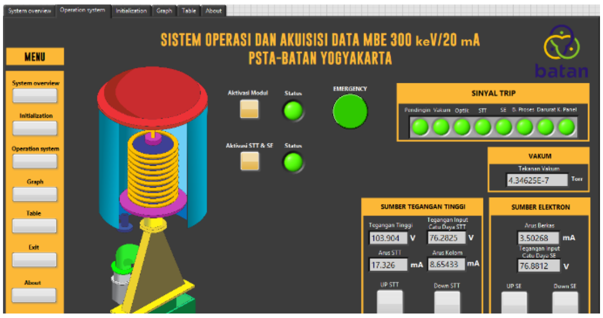


**Figure 4. System HMI display MBE operation 300 keV/20 mA**

Source: System implementation results (2024)

It can be seen on the display there are operation buttons and MBE operation data acquisition. Operation buttons are module activation, STT&SE activation, up STT, down STT, up STT, down SE, reset STT, reset SE, micro reset, alarm reset, save. With data acquisition in the form of high voltage, STT power supply input voltage, STT current, column current, SE power supply input voltage, beam current, and vacuum pressure. Then the trip signal for MBE operation is also displayed.

### System Test Results

#### *Input* Testing PLC *Output*

It can be observed that when the On button is pressed, the output becomes active, and so on. When the Off button is pressed, the output turns off, and so on. Figure 8 shows the results on the PLC.

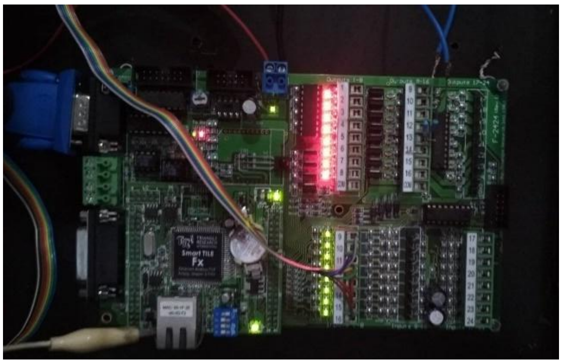

**Figure 5. PLC *input output results***
Source: System test results (2024)

**L-Relay 51 Test Results**

From the test, it is known that when L-Relay 51 gets an active input action which means it gets input voltage, then the condition of L-Relay 51 which was initially in a normally open state changes to a normally close state which means the output of L-Relay 51 is active. And when given an inactive input action in the form of turning off the voltage for L-Relay 51, then the condition of L-Relay 51 which was initially normally closed changes to a normally open state so that the output will turn off.

**ADC Test Results**

The ADC test aims to determine the ADC characteristics of the Super PLC FX2424. This test is conducted using input from a Regulated DC Power Supply. Figure 9 shows the ADC test results.

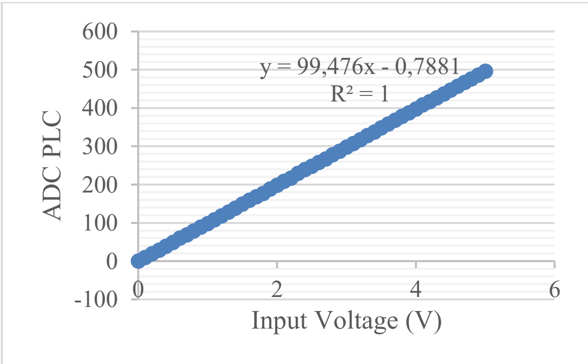


**Figure 6. PLC ADC test results**
Source: System test results (2024)

From Figure 6, it can be said that the relationship between the voltage value of the Regulated DC Power Supply and the PLC ADC is linear, meaning that the higher the input voltage, the higher the ADC will produce.

**Communication test results between Super PLC and LabVIEW software**

When the program is run and the COM port is selected, and when the ON button is pressed in the LabVIEW software, the Super PLC FX2424 output becomes active. This proves that communication between the Super PLC FX2424 and the LabVIEW software has been successful.

**MBE operating system test results using LabVIEW software**

This test aims to operate the MBE through a Human Machine Interface (HMI) created in LabVIEW software. The test is conducted by operating the buttons in the LabVIEW software and observing the response on the Super PLC FX2424 and the results displayed on the LabVIEW HMI itself. This can be seen in Table 3.

**Table 3. HMI button operation results**

| HMI Operation Buttons | Button Action | PLC Response | HMI Response |
|---|---|---|---|
| Module Activation | ON | ON | ON |
| STT & SE Activation | ON | ON | ON |
| *Up* STT | ON | ON | ON |
| *Down* STT | ON | ON | ON |
| *Up* SE | ON | ON | ON |
| *Down* SE | ON | ON | ON |
| *Reset* STT | ON | ON | ON |
| *Reset* SE | ON | ON | ON |
| Micro *Reset* | ON | ON | ON |
| *Reset* Alarm | ON | ON | ON |
| *Save* | ON | ON | ON |

Source: System test results (2024)

**Digital Input Output test results for trip signal.**

The results of the Trip Signal test between the action on the switch button and its description indicator can be seen in Table 4.

**Table 4 Results of trip signal testing**

| Switch button | Action | Indicators on HMI |
|---|---|---|
| Cooler | ON | ON |
| Vacuum | ON | ON |
| Optics | ON | ON |
| STT | ON | ON |
| SE | ON | ON |
| B. Process | ON | ON |
| Emergency | ON | ON |
| Panel | ON | ON |

Source: System test results (2024)

From Table 4, it can be seen that the Trip Signal operation has been successfully carried out, when the on action is given, it provides an On output in the form of a lit LED which is also displayed on the LabVIEW HMI display.

**Operational Data Acquisition Test Results in LabVIEW**

This test was conducted by observing the response values displayed on the HMI display of the MBE operating system in LabVIEW *software* when input was given to the ADC of the Super PLC FX2424. The test results are in Figure 10.

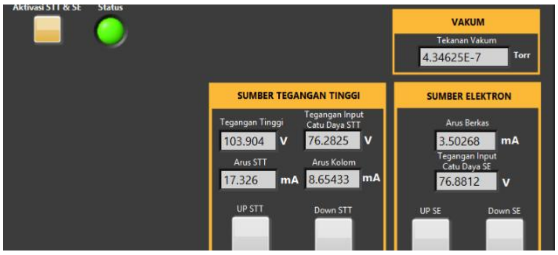


**Figure 7. Data acquisition HMI display**

Source: System implementation results (2024)

From the test, it is known that the relationship between the *input voltage value* and the LabVIEW HMI display value is linear, which is the same as the characteristics of the FX2424 PLC ADC.

### *Update* and *Save* Data Test Results

When data is sent and read, the MBE parameter data will be recorded automatically and in real time on the LabVIEW front panel. For tabular data, it will be recorded on the "Table" tab of the LabVIEW front panel, and for graphical data, it will be recorded on the "Graph" tab of the LabVIEW front panel. Data recording is performed every 1 second according to the program settings in the LabVIEW block diagram. The results of the data update test can be seen in Figure 8.

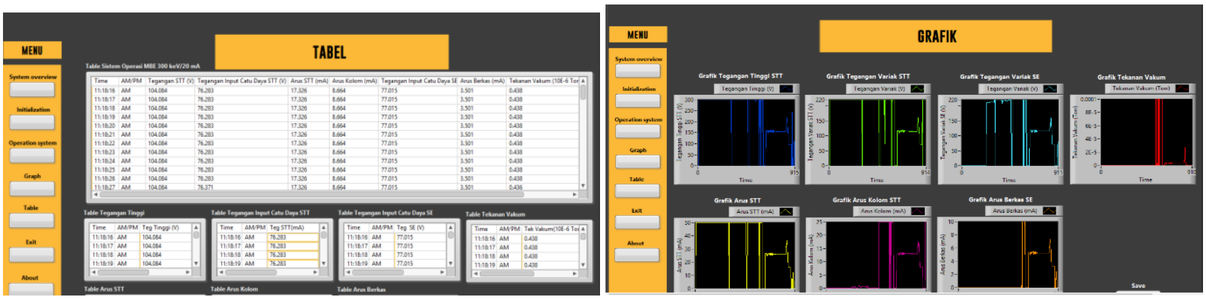


**Figure 8. Update data**

Source: System test results (2024)

When *the save button* is pressed, the parameter data will be displayed in Ms. Excel for table data and in Ms. Word for graphic data.

## CONCLUSION

The development of the operating system and data acquisition for the 300 keV/20 mA MBE at PSTA-BATAN Yogyakarta was successfully completed, integrating the FX2424 PLC hardware with LabVIEW and i-TRiLOGI software using RS-232 serial communication at a default baud rate of 38,400 bps. The system effectively operated and monitored MBE components, simulated MBE operations, and acquired real-time parameter data, storing results every second in Microsoft Excel and Word formats. Future research should focus on enhancing real-time implementation for full-scale operation, optimizing communication speed through Ethernet or wireless protocols, and incorporating intelligent diagnostic or predictive maintenance algorithms to improve system reliability and efficiency.

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