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Implementation of an automatic monitoring system using electromagnetic induction parameters to enhance hot forging quality

Gun Gun Maulana*, Abdurrahman Harits Martawireja, Fitria Suryatini
Department of Manufacturing Automation Engineering and Mechatronics, Politeknik Manufaktur Bandung, Bandung 40135, Indonesia
*Corresponding Author: gungun@polman-bandung.ac.id

Abstract

This research presents the implementation of an automatic monitoring system using electromagnetic induction parameters to enhance the quality of heating processes in hot forging industries. Efficient heating is essential in industrial applications, particularly during the production stage of hot forging. To ensure consistent product quality and optimize energy efficiency, accurate and responsive monitoring is required. The proposed system integrates electromagnetic induction sensors to capture, in real time, the physical characteristics of heated AISI 4140 Bolt M24 × 100 mm (±0.35 kg). Sensor data are processed using intelligent algorithms to identify critical parameters such as temperature, heat distribution, and optimal heating time. Based on these results, the system automatically adjusts heating parameters, thereby ensuring consistent product quality and improved energy efficiency. The results indicate that the system, supported by a Human–Machine Interface (HMI), Programmable Logic Controller (PLC), and infrared temperature sensors, was effectively implemented. It demonstrated real-time monitoring of process parameters with no detected errors, smooth data transfer between components, and reliable temperature display on the HMI with an average delay of only 1.1 seconds. This research provides an integrated solution to improve hot forging quality, reduce energy waste, and accelerate production cycles, contributing to more intelligent heating control systems for industrial applications.

Keywords:
Automation monitoring system, electromagnetic induction, HMI, infrared temperature sensor

1 Introduction

Modern manufacturing industries are increasingly facing challenges to enhance operational efficiency and product quality [1–4]. In industries that involve heating processes, such as metal, ceramic, or other thermal processing industries, precise control of heating parameters is crucial to achieving the desired product quality. Improving the quality of hot forging products not only impacts customer satisfaction but also optimizes energy usage and reduces production waste [5–7].

In forging an automatic monitoring system using electromagnetic induction, setting a clear temperature threshold is essential. For example, aluminum is hot forged above 400°C, while temperatures below 350°C enter the cold forging range, increasing the risk of cracks and tool damage. The system must use real-time sensors to detect when the temperature drops below this limit and trigger a warning or stop the process to maintain quality and safety. Generally, monitoring and control systems in heating processes still rely on conventional methods that are not always responsive to material variations, environmental conditions, or changes in production requirements. For instance, in the electromagnetic induction monitoring process at PT. Eastech Nusantara, conventional methods are still being used, which are not fast enough to detect changes or issues in process parameters. The shortcomings of the current monitoring process have led to time and resource losses before problems are identified. Additionally, data obtained from conventional monitoring has resulted in inconsistent data over time because certain monitoring parameters are difficult or even impossible to measure accurately manually, especially when there are rapidly fluctuating parameters [5–9]. This makes process analysis and planning more challenging. Another drawback of this system is that it requires operators to be in proximity to the operating equipment, increasing the risk of injury and health issues caused by exposure to electromagnetic radiation [10].

To address the problems outlined above, there is a need to develop a monitoring system that enables real-time measurement and analysis of process parameters related to electromagnetic processes [9,11]. This process will use sensors and actual monitoring technology to collect accurate data from various relevant aspects of electromagnetic operations. This system allows operators to continuously monitor and control process parameters during operation, enabling production technicians to take immediate action if abnormalities occur in the induction process or the induction product.

This research focuses on the implementation of an automatic monitoring system through electromagnetic induction parameters [12–15]. This technology offers advantages in obtaining accurate real-time data related to the physical characteristics of the material being heated [16,17]. By utilizing electromagnetic induction sensors [18], this research aims to develop a system capable of recognizing and optimizing heating parameters such as temperature, heat distribution, and heating time.

By integrating advanced sensor technology and intelligent algorithms [19,20], this research is expected to provide a more adaptive, efficient, and accurate solution for monitoring and controlling heating processes. The results of this study are expected to contribute significantly to improving the quality of hot forging products, reducing energy waste, and increasing operational efficiency in industries that rely on heating processes in their production.

2 Research methods

2.1 System architecture

The system architecture developed in this study is illustrated in Fig. 1. The working principle begins with initialization, where all components, including the Programmable Logic Controller (PLC), the Human-Machine Interface (HMI), temperature sensors, current sensors, induction heater, and pneumatic system, are activated and ready for use.

Next, the temperature sensors, current sensors, and infrared sensors measure the electromagnetic induction on the workpiece to be processed, and the data from the temperature and current sensors are sent to the PLC for processing. The HMI displays real-time data to the operator, including current temperature, electric current, and electromagnetic induction parameters. The PLC processes the sensor data and makes decisions based on the implemented automatic control algorithm. If the electromagnetic induction parameters or temperature do not meet the set limits, the PLC can issue instructions to correct or stop the process. If the PLC determines that the workpiece needs to be stopped or clamped more tightly, it sends instructions to the pneumatic system. The pneumatic cylinders control the clamping of the workpiece to ensure the correct position and stability during the process.

Next, the operator can interact with the system through the HMI interface. The HMI provides manual control and additional information as needed, as well as displays warnings or emergency messages when necessary.

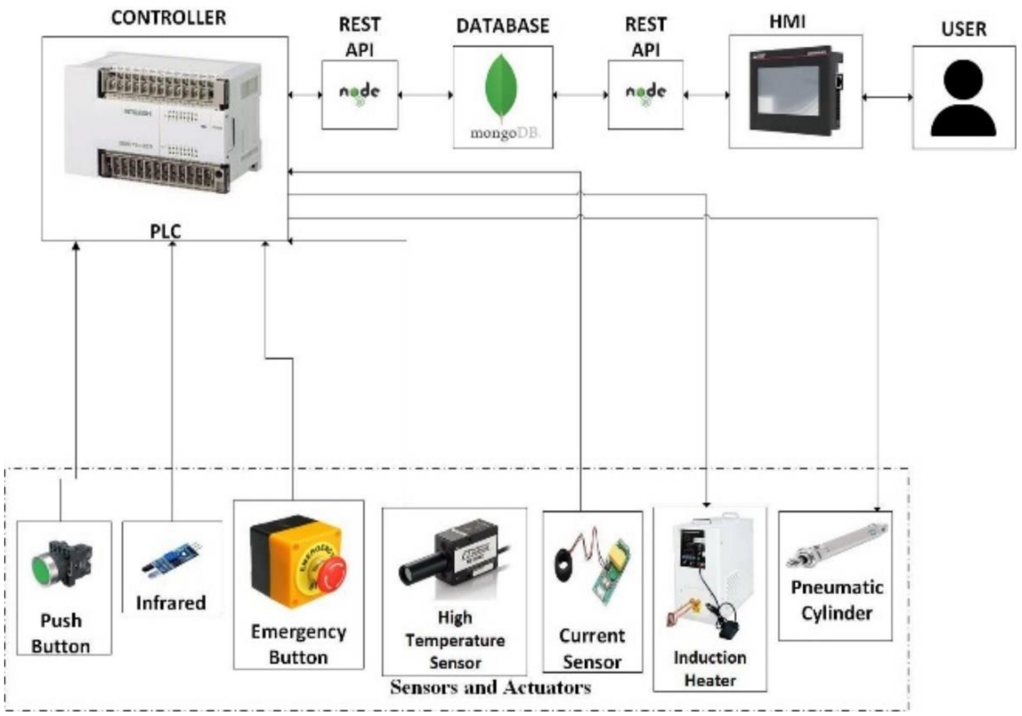


Fig. 1. System architecture

The system continuously monitors electromagnetic induction parameters, temperature, and other conditions during the hot forging process. The HMI provides real-time visualization to the operator, allowing for quick monitoring and decision-making. If the system detects an emergency condition, such as excessive temperature or pneumatic issues, the emergency system will be activated. The emergency system can shut down the process, reduce the temperature, or stop the movement of the pneumatic cylinders to prevent damage or hazards. Process data, including electromagnetic induction parameters, temperature, and control decisions, can be stored in a database for long-term analysis and maintenance. Finally, after the hot forging process is completed, the system notifies the operator through the HMI, and the workpiece can be released from the pneumatic cylinders.

2.2 System design

The system design, where the required components are as follows:

1. Infrared Sensor: Captures infrared radiation emitted by the object. This sensor uses a photodetector sensitive to the infrared spectrum. The infrared radiation received by the sensor is converted into an electrical signal.
2. Induction: Creates a rapidly oscillating or varying magnetic field. The inductor is connected to a high-power source that can provide a sufficiently large electric current.
3. Material: The object to be heated. The induction heating system is equipped with controls that allow the user to set parameters such as frequency, amplitude, and heating duration.
4. Pneumatics: Used to hold the workpiece securely during heating, keeping it stable and safe from workplace accidents. The working principle is that when the pneumatic system is activated to prepare the workpiece holding process, the pneumatic cylinders are set to move the gripper or clamping element to the correct position to hold the object.
5. HMI: The main component of the system to be developed. The HMI for monitoring electromagnetic induction parameters can be designed to provide a visual display and easily understandable information related to electromagnetic induction. The designed HMI will have features to display the actual values of key parameters, such as induction current, voltage, and frequency.
6. PLC: Executes complex control logic. This includes reading sensor data, making decisions based on certain parameter values, and issuing control commands.

3 Results and discussion

3.1 System implementation results

3.1.1 Induction machine display

Fig. 2 shows the display of the automatic induction monitoring system, where the process begins when the operator presses the push button to start the process. When the start button is pressed, a signal is sent to the PLC, which then activates the entire system.

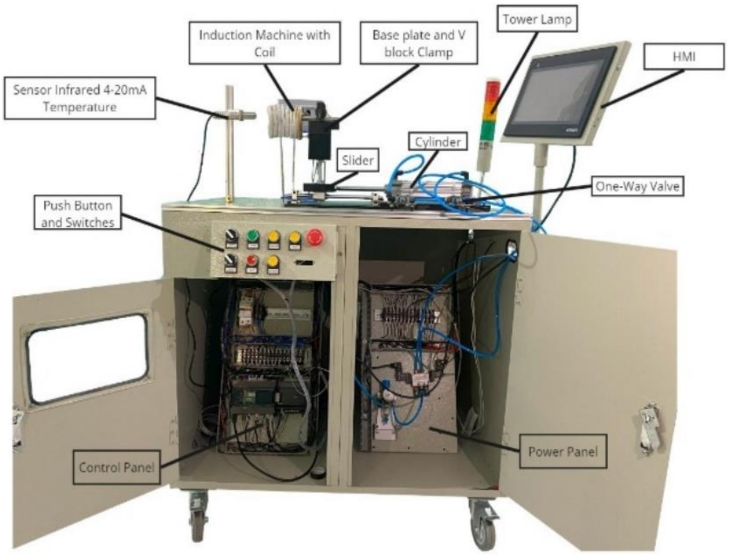


Fig. 2. Induction machine monitoring system display

The first step is to turn on the infrared temperature sensor, which starts detecting the workpiece temperature by measuring the emitted infrared radiation. This temperature data is then sent to the PLC for further processing. At the same time, the pneumatic cylinder is activated by the PLC to hold the workpiece in the correct position during the induction process. The pneumatic cylinder ensures that the workpiece remains stable and does not shift, allowing the heating to be conducted evenly and according to the requirements. During the process, the infrared temperature sensor continuously monitors the workpiece temperature and sends real-time temperature data to the PLC. The PLC is responsible for comparing the received temperature data with the set temperature limits.

HMI is used by the operator to monitor the system conditions in real-time. The HMI displays critical information such as the workpiece temperature, pneumatic cylinder status, and other process parameters. The operator can also use the HMI to adjust settings according to process needs. Once the heating process is complete or if the operator wants to stop the operation, the stop push button is pressed. Pressing the stop button sends a signal to the PLC to gradually turn off the induction heat source, stop the infrared temperature sensor, and deactivate the pneumatic cylinder, allowing the workpiece to be safely removed from the machine. In case of an emergency, the operator can press the emergency button. This button immediately halts all operations, shuts down the entire system, and activates a safe mode to prevent accidents or further damage. The system also includes an Andon system that serves as a warning system to notify the operator if there are any disturbances or hazardous conditions during the process.

3.1.2 HMI display

Fig. 3 shows the screen when users first access the HMI. Users are presented with a login screen that includes fields for entering a username and password. After successfully logging in, users can access the available features.


28/08/2024 15:01:12

User :

Fig. 3. Initial HMI display

On the far left, there is a Logout button that allows users to easily log out of their accounts. After logging in, users are directed to the main page containing the Main Menu. This menu displays several icons or buttons that guide users to various key functions of the HMI, such as system monitoring, device control, reports, and more. In the Main Menu, there is an option to access the Configuration Manager. This feature allows users with certain access rights to configure or manage system parameters, such as sensor settings, Set Time, network, and the overall system. The Configuration Manager interface displays a list of parameters with options to edit, save, or revert to the default settings.

Fig. 4 shows the HMI screen displaying the main dashboard that combines several key features. At the top, there is a temperature monitor that displays the current temperature with visual cues like graphs or dials, making it easier for users to track real-time conditions.


DASHBOARD USER: MANUAL 15:01:25 28/08/2024

COUNT 1

CURRENT TEMP(°c) 29.20

SET TEMP (°c) 233.00

SET TIME (s) 0

ELAPSE TIME (s) 0

REMAINING TIME (s) 0

HEATING MODE

Manual Mode 2024/08/28 15:01:07 T

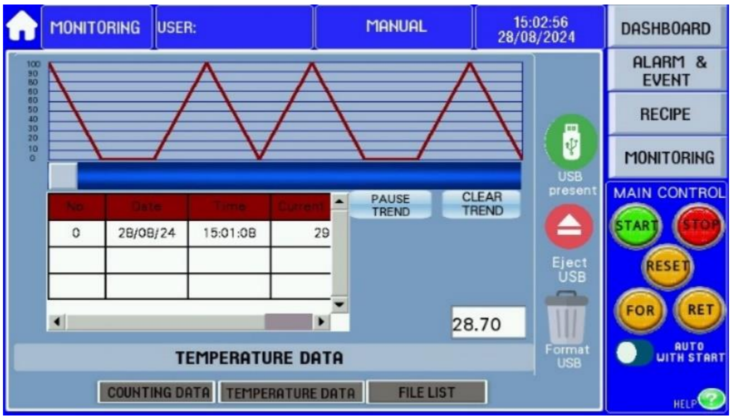
2 2024/08/28 15:01:07 Manua

1 2024/08/28 15:01:07 Timer

Fig. 4. HMI dashboard display

The Set Time feature allows users to set the machine's operation time or a specific process, with adjustable input options. The Cylinder Counting feature shows how many cycles or operations the cylinder has completed, helping to monitor usage duration or frequency. There are Run and Stop buttons to start or stop the machine, usually designed to be large and in contrasting colors for easy identification and access.

Fig. 5 shows the HMI screen for monitoring temperature graphs and data, presenting information visually and textually to facilitate monitoring and analysis. The main screen displays a dynamic graph illustrating temperature changes over time. This graph uses lines or curves that move in real-time, showing trends of rising or falling temperatures. The horizontal axis represents time, while the vertical axis represents temperature values. Below the graph, there is a table listing detailed temperature data. This table includes the measurement time, the temperature value at that moment, and possibly status indicators such as normal, high, or low. Users can quickly review data history and understand the temperature conditions that have occurred.


MONITORING USER: MANUAL 15:02:56 28/08/2024

No	Date	Time	Current
0	28/08/24	15:01:08	29

28.70

Fig. 5. HMI monitoring graph display

Fig. 6 shows the HMI screen for the recipe feature, which includes the name, type, ID, set time, and set temperature, organized for easy configuration and management of operation recipes. At the top of the screen, there are input fields or dropdown menus that allow users to select or enter the recipe name and desired operation type, making it easy to identify and choose the correct configuration. Each recipe has a unique ID number displayed alongside the name and type. This ID is used to specifically identify the recipe within the system, especially when searching or saving. At the bottom, users can set the operation time (Set Time) and temperature (Set Temp) for the selected recipe. These inputs are typically in the form of number fields or sliders, allowing users to easily enter the desired values. At the bottom of the screen, there are Upload and Download buttons.


RECIPE USER: MANUAL 15:02:40 28/08/2024

RECIPE 1

NAME	M16
No. ID	1
TYPE [M.........]	16
SET TIME [S]	12
SET TEMP [°C]	600.00
HEATING MODE	ONLY TIMER

Fig. 6. HMI recipe file display

3.2 Testing

3.2.1 Hardware testing

Based on the test results, the connection between the PLC, HMI, and temperature sensor was stable and effective. Temperature data was communicated accurately and in real-time from the sensor through the PLC to the HMI. The response time of the HMI and PLC was within the expected range, and there was no data loss during the testing process. The system demonstrated good reliability in managing connections and communication between devices, as shown in Table 1.

Table 1. Connection testing between the PLC, HMI, and temperature sensor

No	Test criteria	Test description	Test method	Test result	Average value	Conclusion
1	Physical connection (PLC-HMI)	Ensure the physical connection between the PLC and HMI functions without interruptions.	Inspection and connectivity test	Stable connection	N/A	The physical connection between PLC and HMI is functioning well and is stable.
2	Physical connection (PLC-Sensor)	Ensure the temperature sensor is correctly connected to the PLC and functioning properly.	Inspection and signal test	Signal received well	N/A	The temperature sensor is correctly connected to the PLC, and the signal is received well.
3	Data communication (PLC-HMI)	Ensure temperature data from the PLC is displayed in real-time on the HMI.	Observation on HMI	Accurate data	N/A	Data communication between the PLC and the HMI is smooth and accurate.
4	HMI response	Measure the HMI response time in displaying data from the PLC.	Response time measurement	1.3 seconds	1.3 seconds	The HMI response time is within the expected range.
5	PLC response	Measure the PLC response time in receiving data from the temperature sensor.	Response time measurement	0.9 seconds	0.9 seconds	The PLC response time is efficient and meets the specifications.
6	Data consistency	Ensure the consistency of temperature data received and displayed on the HMI during testing.	Repeated testing	Consistent	N/A	The temperature data received is consistent without data loss.

3.2.2 Temperature sensor performance testing

The test results indicate that the temperature sensor has high sensitivity, capable of detecting temperature changes as small as 0.1°C during the electromagnetic induction process. The sensor's measurement accuracy falls within an acceptable range, with a deviation of ±0.3°C compared to the reference thermometer. The sensor also responds quickly to temperature changes, with an average response time of 1.2 seconds. Additionally, the sensor demonstrates good consistency in temperature measurements under constant conditions. Overall, the tested temperature sensor is considered reliable and suitable for use in electromagnetic induction process monitoring applications, as shown in Table 2.

Table 2. Temperature sensor sensitivity and accuracy testing

No.	Test criteria	Test description	Test method	Test result	Average value	Conclusion
1	Sensor sensitivity	Measure the sensor's ability to detect small temperature changes during induction	Gradual temperature change test	Quick change detection	0.1°C	The sensor shows high sensitivity with minimal changes detected.
2	Measurement accuracy	Compare sensor data with a reference thermometer to measure accuracy	Simultaneous measurement with reference	Deviation < ±0.5°C	Deviation: ±0.3°C	The temperature sensor's accuracy is within an acceptable range.

3.2.3 User testing

The test results (Table 3) show that the HMI interface is easy for operators to use and understand. On average, operators can complete tasks within 35 seconds, with a low error rate of 1.5 errors per task. Operator satisfaction with the ease of use of the HMI is high, with an average score of 4.7 out of 5. The instructions and information presented on the HMI are also easy to understand, with an average score of 4.8 out of 5. Overall, the HMI interface has proven to be effective and user-friendly in supporting operator tasks.

Table 3. Usability and understanding testing of the HMI interface

No	Test criteria	Test description	Test method	Test result	Average value	Conclusion
1	Data display timing accuracy	Measure the time delay between receiving temperature data by the PLC and displaying it on the HMI	Response time measurement	1.1 seconds	1.1 seconds	The HMI displays the temperature data with minimal and acceptable delay.
2	Temperature data display accuracy	Compare the temperature data displayed on the HMI with the data from the PLC	Simultaneous testing	Accurate	N/A	The temperature data on the HMI matches the data received from the PLC.
3	Process status display accuracy	Measure the accuracy of the process status display on the HMI compared to the actual process conditions	Observation and verification	Accurate	N/A	The process status displayed on the HMI matches the actual process conditions.
4	Real-time consistency	Ensure that temperature data and process status are continuously updated without delay during the test	Continuous testing	Consistent	N/A	The HMI consistently updates data in real-time.

3.2.4 Data logging and reporting testing

3.2.5 Reporting and analysis

Fig. 7 shows that the system can continuously log temperature data and process status without any data loss. Data logging is performed consistently, with a frequency that matches the set interval, and no data is lost during the logging process. Additionally, data integrity is well maintained, without any corruption or errors. Overall, the system has proven to be effective at accurately and continuously logging.

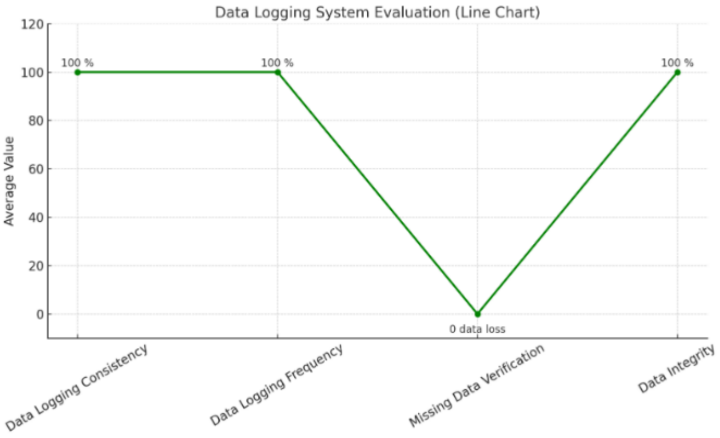


Fig. 7. Temperature data and process status logging testing

4 Conclusions

The results of this study confirm that the automated monitoring system, integrating HMI, PLC, and infrared temperature sensors within the electromagnetic induction process, was applied and functioned reliably. The system demonstrated real-time monitoring of temperature and process parameters with no detected errors, while effectively controlling the induction process according to specified requirements. Data transfer between the PLC and HMI was smooth, with an average display delay of only 1.1 seconds. The HMI provided operators with an intuitive and responsive interface, achieving high user satisfaction, with an average score of 4.7 out of 5 for ease of use and 4.8 out of 5 for clarity of displayed information. In addition, the system continuously recorded and stored temperature and process status data, with sensor accuracy showing a deviation of only ±0.3 °C compared to a reference thermometer. Overall, this study demonstrates that the implemented automated monitoring system can enhance the efficiency and reliability of the electromagnetic induction process, with a user-friendly interface and functionalities that support data-driven decision-making. Still, the system has not been tested with materials used by industry due to limitations of infrared temperature sensors.

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