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Research/Review

Analysis of Vacuum Pan Automation Performance Using Solenoid Valve at PT. Duta Sugar International

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Abstract: This research focuses on analyzing the performance of a vacuum pan automation system using solenoid valves at PT. Duta Sugar International as an effort to improve the efficiency and quality of refined sugar production. The vacuum pan is the main tool in the sugar crystallization process that functions to evaporate the sugar solution under low pressure. Problems faced in the manual system are temperature instability and high dependence on operators, which impact time inefficiency and decrease product quality. The purpose of this research is to design and analyze the implementation of an automatic control system based on a Distributed Control System (DCS) with the integration of solenoid valve actuators to optimize temperature stability and cooking process efficiency. The research method was carried out using qualitative and quantitative approaches through direct observation, technical interviews with the automation team, and supporting literature studies. The results showed that the automatic system was able to maintain a stable cooking temperature in the range of 78°C–85°C, lower and more efficient than the manual system which fluctuates between 90°C–100°C. In addition, cooking time was reduced by 10–15 minutes per cycle, and the crystallization process became more uniform with more efficient energy consumption. The results showed that the implementation of DCS-based automatic control with solenoid valves significantly improved operational stability, productivity, and energy efficiency. Thus, this automation system proved to be an effective solution for optimizing vacuum pan performance in the modern sugar industry.

Keywords: Distributed Control System; Industrial Automation; Solenoid Valve; Sugar Crystallization; Vacuum Pan.

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1. Introduction

PT. Duta Sugar International is a sugar processing company that supports agricultural productivity in Indonesia. PT. Duta Sugar International focuses on refined sugar processing, using imported raw sugar as the primary raw material. To achieve high productivity and improve production efficiency, the sugar cooking process is generally carried out using a vacuum pan, the primary equipment used to evaporate the sugar solution until crystals form. At PT. Duta Sugar International, the vacuum pan system initially used a manual method, relying on operators to regulate temperature, pressure, and fluid flow. This often led to temperature instability and inefficient cooking times, which impacted the quality of the sugar produced. Therefore, the development of a vacuum pan automation system using solenoid valves was undertaken as the object of this research.

Previously, manual control methods for vacuum pans had the advantage of flexible operator adjustments, but their weaknesses lay in inaccuracy and reliance on individual experience. Meanwhile, an automated approach based on a Distributed Control System (DCS) and solenoid valve actuators offers advantages in temperature stability, control precision, and production time efficiency. Based on field test data, the automated system is able to maintain the cooking temperature within the range of 78–85°C, compared to the manual system, which fluctuates between 90–100°C. Furthermore, cooking time is reduced by approximately 10–15 minutes per cycle, indicating increased energy efficiency and productivity.

However, implementing an automated system also presents its own challenges, such as susceptibility to software glitches, unresponsive solenoid valves, and air regulator failure. In industrial practice at PT. Duta Sugar International, the automation team implemented a corrective maintenance approach to address these issues. This demonstrates that while automated systems improve operational efficiency, reliability and maintainability remain key factors in their successful implementation.

The main problem addressed in this research is how to improve temperature stability and the efficiency of the sugar cooking process in a vacuum pan through the integration of an automated system based on solenoid valve actuators controlled from a DCS panel. This system is designed to automatically regulate the opening and closing of fluid flow based on a digital output signal, eliminating the need for error-prone manual intervention by operators. Furthermore, temperature stability and time efficiency were tested as indicators of system success.

The proposed solution to address the temperature stability and efficiency issues in the vacuum pan cooking process at PT. Duta Sugar International is to integrate a solenoid valve actuator-based automatic control system into the Distributed Control System (DCS) network. This system enables real-time process control through a digital output (DO) signal that precisely regulates the opening and closing of fluid valves according to the temperature and pressure parameters programmed into the system's setpoints. This allows for constant steam and cooking material flow rates, maintaining a stable temperature within the optimal range of 78–85°C and minimizing fluctuations that could affect the quality of the sugar crystals.

Furthermore, this integration is equipped with temperature and pressure sensors that provide direct feedback loops to the DCS, allowing the system to automatically adjust when sudden changes in operating conditions occur. Data collected from these sensors is analyzed by a logic controller to proportionally adjust the position of the solenoid valve, making the cooking process more efficient without requiring manual operator intervention. Implementing this system not only improves temperature stability but also reduces cooking time by an average of 10–15 minutes per cycle, directly increasing factory productivity.

2. Preliminaries or Related Work or Literature Review

Vacuum pan as a tool for making sugar

A vacuum pan is the primary equipment in the crystallization process in the sugar processing industry. This device evaporates sugar solutions under low pressure, allowing the evaporation process to occur at temperatures lower than the normal boiling point. This working principle maintains sugar quality by minimizing the risk of damage due to high temperatures and color degradation. Vacuum pans generally take the form of closed cylindrical vessels equipped with a heating system (calandria), a cooling system, and pressure control to maintain process stability. The application of a low-pressure heating system to a vacuum pan can increase evaporation efficiency and produce clearer, more homogeneous sugar crystals than conventional systems (Prajogo, 2023)

Figur 1. Vacuum pan.

In operation, the vacuum pan serves as the primary tool in the sugar crystallization process, where the sugar solution resulting from dissolving raw sugar is heated and evaporated under low-pressure conditions. The working principle is to reduce the air pressure in a closed vessel so that the boiling point of the sugar solution is lowered. This allows water evaporation to occur at a lower temperature without damaging the sugar quality. Hot steam is circulated through a heating section (calandria) below the vacuum pan to accelerate evaporation. During the process, the solution will reach a state of supersaturation, after which seed crystals are added to form sugar crystals. This evaporation and crystal growth process produces a thick, solid-liquid mixture called massecuite, which is then sent to a centrifuge unit to separate the crystals from the molasses.

Furthermore, the vacuum pan also plays a role in the factory's energy efficiency. Because it operates at low pressure, it requires less heat energy to achieve the same evaporation rate than conventional atmospheric pressure systems. In a modern industrial context like that of PT. Duta Sugar International, automatic control of temperature, pressure, and steam flow in the vacuum pan is crucial. By implementing a solenoid valve as an actuator in the automated system, the evaporation and crystallization processes can be precisely controlled through a Distributed Control System (DCS), resulting in more uniform sugar quality, shorter processing times, and higher energy efficiency.

In a modern industrial context like PT. Duta Sugar International, vacuum pan operation has transformed from a manual system to a fully automated system controlled by Distributed Control System (DCS) technology. This shift is part of the implementation of the Industry 4.0 concept, where the entire production process is integrated through a digital control system capable of monitoring, analyzing, and adjusting process variables in real time. The vacuum pan, a crucial unit in the process of crystallizing palm sap into sugar, can now be precisely controlled through temperature, pressure, and fluid flow sensors connected to the DCS system. Through continuously updated data, this system can control the supply of hot steam using automatic actuators such as solenoid valves, which open or close the steam line with high accuracy according to process requirements.

The primary advantage of this automation lies in the resulting operational stability and efficiency. Before the DCS system, human operators had to manually monitor changes in pressure and temperature, which often caused variations in sugar crystallization results due to delays or inaccuracies in parameter adjustments. With the integration of the DCS, any small fluctuations in pressure or temperature can be automatically corrected by the system without the need for human intervention. As a result, the cooking process is more stable, production times are shorter, and the quality of the resulting sugar crystals significantly improves because the ripeness of the sap can be consistently controlled throughout each production cycle.

Given these advantages, it can be concluded that the integration of a vacuum pan into a DCS-based automatic control system is not simply a technical innovation, but rather a strategic step towards industrial efficiency, reliability, and sustainability. The application of this technology demonstrates that modernizing control systems in the sugar industry can increase productivity by up to 20%, reduce energy consumption, and simultaneously support the industry's transformation into a smarter and more environmentally friendly digital era (Awulachew, 2025).

Solenoid Valve as an automatic actuator tool

An automatic solenoid valve is an electromechanical actuator component. Its primary function is to automatically regulate, open, or close fluid flow based on an electrical signal. It operates using electromagnetic force. When an electric current flows through the coil, a magnetic field is created that attracts the plunger. When the current is present, the plunger lifts, opening the fluid flow path. When the electric current is turned off, the magnetic field disappears, and a spring pushes the plunger back, thus blocking the fluid flow. In refrigeration systems or industrial control systems, solenoid valves play a crucial role in regulating the flow of liquid or vapor refrigerant, hot steam, or other process fluids according to temperature or pressure requirements controlled by a sensor or thermostat. Their operation is fully automated because they are connected to a control system (such as a thermostat or Distributed Control System/DCS) that disconnects and reconnects the electrical current based on process conditions. (Saleh, 2021)

Figure 2. Automatic Solenoid Valve.

In the context of this research, the solenoid valve plays a crucial role in maintaining temperature stability and the efficiency of the sugar crystallization process. When the temperature inside the vacuum pan exceeds a predetermined set point, the DCS system sends a signal to partially close the valve to reduce the steam supply. Conversely, if the temperature drops below the optimal limit, the solenoid valve opens to increase the heating steam flow. This automatic open-close cycle creates a closed-loop control system that maintains a stable cooking temperature within the range of 78–85°C, resulting in more uniform sugar crystal quality and increased energy efficiency. In addition to improving process stability, the use of a solenoid valve also minimizes manual operator intervention, which previously had the potential to cause setting errors and temperature fluctuations. However, the effectiveness of a solenoid valve is highly dependent on the speed of its electromagnetic response, the system's operating pressure, and the quality of the DCS output signal.

In addition to providing precise control over fluid flow, solenoid valves also offer significant advantages in terms of energy efficiency, response speed, and overall system reliability. This component operates on the principle of electromagnetism, where an electric current flowing through a coil generates a magnetic field that moves a plunger or iron core to open or close the valve. Because the system is electrically controlled and requires no direct mechanical intervention, solenoid valves are capable of very fast and repeatable responses with a high degree of accuracy. This makes them ideal for use in industrial systems that demand process stability and timeliness, such as the evaporation and crystallization processes in sugar mill vacuum pans.

Another advantage that makes solenoid valves widely used in automation systems is their energy efficiency. Compared to conventional manual or pneumatic valves, solenoid valves require only a small amount of electrical energy to activate their actuators. Furthermore, because they don't involve many moving parts, the risk of mechanical wear is minimized, resulting in a longer tool life. However, optimal solenoid valve performance depends heavily on several factors, including the design of the control system used, the system's operating pressure, and the quality of the air or steam supply flowing through the valve. If the air supply is dirty or the pressure is unstable, the response speed and accuracy of the valve opening can be disrupted, ultimately affecting the stability of the production process. Therefore, selecting the right type of solenoid valve is crucial and must be tailored to the system's operating conditions, including the operating pressure and temperature of the vacuum pan. For example, in systems with high steam pressure and extreme temperatures, solenoid valves made of heat-resistant materials and internal designs capable of withstanding thermal expansion are required. In the context of the modern sugar industry, the use of solenoid valves integrated with a Distributed Control System (DCS) has proven to provide optimal results. This integration enables automatic and coordinated control of the cooking process, where any changes in temperature, pressure, or vacuum levels can be compensated for in real time by the DCS. This results in a more stable cooking process, reduced energy consumption, and significantly increased system efficiency (Saleh, 2021).

Distributed Control System (DCS) as an Automatic Control System in Industrial Processes

A Distributed Control System (DCS) is an automated control system that functions to regulate, monitor, and optimize industrial processes in a distributed manner. Unlike a centralized control system, a DCS divides control functions into several interconnected local control units (LCUs) controlled by a central control center (Master Control Unit/MCU). Each LCU is responsible for controlling a specific part of the process, while the MCU coordinates the entire process in an integrated manner through a communication network such as a fieldbus or Profibus. This approach allows the system to continue operating stably and efficiently, even if one of the units experiences a failure (Setiawan, 2022).

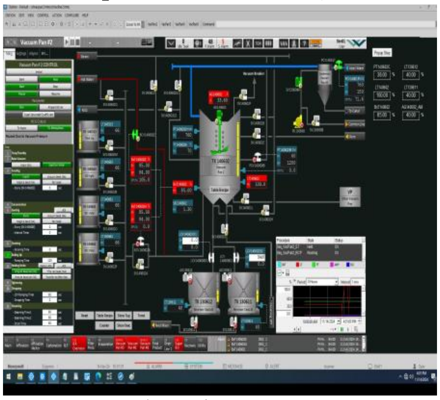

Figure 3. Distributed Control System (DCS).

The working principle of a DCS is based on the distribution of control functions across various control points within an industrial system. Each LCU receives input signals from sensors that measure process variables such as temperature, pressure, liquid level, or fluid flow. It then processes them using a control algorithm such as Proportional-Integral-Derivative (PID) to generate output signals to actuators, such as solenoid valves or pumps. All measurement data and control actions are sent to the MCU via an industrial communication network for real-time analysis, monitoring, and control. The DCS is also equipped with a Human Machine Interface (HMI) that visually displays process conditions and operating parameters so that operators can monitor or intervene when necessary (Santoso, 2018).

The primary use of a DCS in industry is to improve the efficiency, reliability, and safety of the production process. In the sugar industry, for example, a DCS is used to control the temperature and pressure in a vacuum pan during the sugar crystallization process, ensuring a stable temperature at the set point to maintain the quality of the sugar crystals. This system also allows for automatic regulation of the opening and closing of solenoid valves via digital output signals based on changes in temperature or pressure in the field. Thus, a DCS can reduce manual intervention, minimize human error, accelerate system response times, and save energy. The implementation of a DCS in a sugar industry automation system has been proven to significantly increase productivity and process recording accuracy, as the system operates in real time and is integrated with SCADA devices for remote monitoring (Setiawan, 2022).

With its ability to integrate various control devices, sensors, and actuators into a coordinated network, a Distributed Control System (DCS) has become the backbone of modern industrial automation systems. A DCS not only plays a role in regulating and controlling process variables such as temperature, pressure, and fluid flow, but also functions as a monitoring system, enabling comprehensive, real-time process oversight. Through the Human Machine Interface (HMI), operators can monitor system conditions, adjust parameters, and detect potential disturbances before they cause process failure. Furthermore, the system can be configured to run adaptive control logic, adapting to changing operating conditions without requiring manual intervention. This makes a DCS highly reliable in supporting the sustainability of industrial processes that require high precision and long-term operational stability.

The integration of digital control systems and real-time data processing in a DCS enables optimal energy efficiency and productivity. With centralized data analysis, the system can identify energy consumption patterns, detect performance anomalies, and provide automatic adjustment recommendations to improve process efficiency. In the sugar industry, such as at PT. Duta Sugar International, the implementation of a DCS has been proven to reduce temperature variations in vacuum pans, accelerate cooking times, and save up to 15% in heat energy per cycle. These advantages not only improve the quality of the final product but also extend the lifespan of the equipment because the system is able to maintain optimal machine operation. Thus, a DCS is not simply a control system, but rather an intelligent platform that integrates automation technology, data analytics, and energy efficiency to support the industry's transformation into a sustainable digital era.

In addition to being an automatic control system, a DCS also functions as an intelligent platform that integrates automation technology with industrial data analytics. This integration enables the implementation of the Industry 4.0 concept, where data from sensors and actuators can be used for decision-making based on artificial intelligence (AI) or machine learning. Through this integration, DCS not only plays a role in maintaining process stability but also becomes a strategic tool to support the industry's digital transformation toward an adaptive, efficient, and sustainable production system. Therefore, the implementation of DCS in the modern sugar industry, such as PT. Duta Sugar International, is not simply a technical innovation, but a strategic step toward energy efficiency, competitive advantage, and future industrial sustainability (Iqbal, 2025).

3. Proposed Method

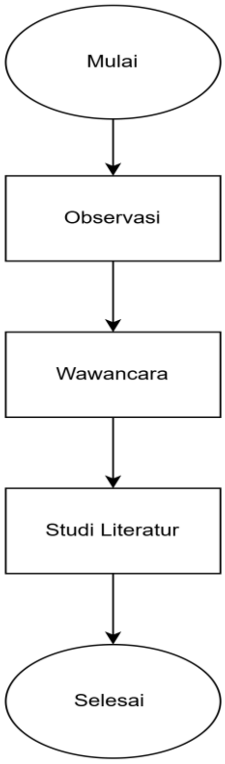

Figure 4. Research Stage Flow.

In the industrial practice research at PT. Duta Sugar International, this research was designed with an integrated qualitative and quantitative approach through systematic stages to obtain relevant data regarding the performance of vacuum pan automation using solenoid valves. The first stage of this research was direct observation in the field, namely in the vacuum pan process area of PT. Duta Sugar International. At this stage, observations were made on how the vacuum pan works in both manual and automatic modes. Researchers recorded the condition of the control system, fluid flow, and temperature and pressure stability during the cooking process. In addition, observations also included the identification of main components such as the DCS panel, junction box, and solenoid valve that acts as an actuator in the automation system. Through this stage, a comprehensive picture of the system structure, workflow, and potential technical obstacles that arise in its implementation was obtained.

The second stage was interviews, conducted with a team of experts from the automation and process divisions of PT. Duta Sugar International. The purpose of these interviews was to obtain technical information and practical experience regarding the design, testing, and maintenance of the vacuum pan automation system. Information obtained included temperature and pressure control parameters, the response of solenoid valve actuators to digital output signals from the DCS, and troubleshooting strategies in the event of operational disruptions. Through these interviews, researchers obtained empirical and technical data that served as references in analyzing the automation system's performance. The final stage was a literature review, which examined various references related to automatic control systems, the working principles of vacuum pans, and the use of solenoid valves as industrial actuators. This literature review strengthened the theoretical foundation of the research and compared the results of field observations with those of previous research. From this literature review, an understanding was gained of how the implementation of an automatic control system based on a Distributed Control System (DCS) can improve energy efficiency and temperature stability compared to manual systems. Thus, this research method, which combines qualitative and quantitative analysis, is able to produce a comprehensive understanding of the vacuum pan automation performance, both from a technical and operational perspective, and proves that the implementation of an automatic system makes a significant contribution to increasing productivity in the sugar industry.

4. Results and Discussion

Comparison of cooking temperatures on manual and automatic vacuum pans

Table 1. Comparative data of cooking temperature on vacuum pan

DAY	COOKING TEMPERATURE MANUAL 90°C-100°C	AUTOMATIC COOKING TEMPERTURE 78°C-85°C
MONDAY	93,5°C	84°C
TUESDAY	94,5°C	80,5°C
WEDNESDAY	94°C	85°C
THURSDAY	95°C	82°C
FRIDAY	98,5°C	83°C

Table 1 shows a comparison of cooking temperatures between the manual and automated systems in the vacuum pan process at PT. Duta Sugar International. The temperature data in the table above was collected every day at 9:00 a.m. In the manual system, cooking temperatures ranged from 90°C to 100°C, with a relatively high and fluctuating average value of 93.5°C on Mondays to 98.5°C on Fridays. Meanwhile, in the automated system, controlled using a solenoid valve through a Distributed Control System (DCS) network, cooking temperatures were maintained more stably, ranging from 78°C to 85°C, with an average of approximately 82.9°C.

These results indicate that the automated system has more precise control capabilities in maintaining temperature stability during the sugar crystallization process. When the temperature approaches the upper limit of the set point (85°C), the system automatically partially closes the solenoid valve to reduce the steam flow, while when the temperature drops below the lower limit (78°C), the valve will reopen to increase the hot steam supply. Control mechanism This closed-loop system not only improves energy efficiency but also reduces reliance on human operators, which previously caused temperature variations.

From a productivity perspective, temperature stability in an automated system directly impacts shorter cooking times and more uniform sugar crystals. Conversely, temperature fluctuations in a manual system can potentially lead to imperfect crystallization, higher energy consumption, and reduced production quality. Therefore, the data in the table confirms that the implementation of automation using solenoid valves in the vacuum pan has proven effective in improving process efficiency and sugar production quality at PT. Duta Sugar International.

Comparison Chart of Manual and Automatic Vacuum Pan Cooking

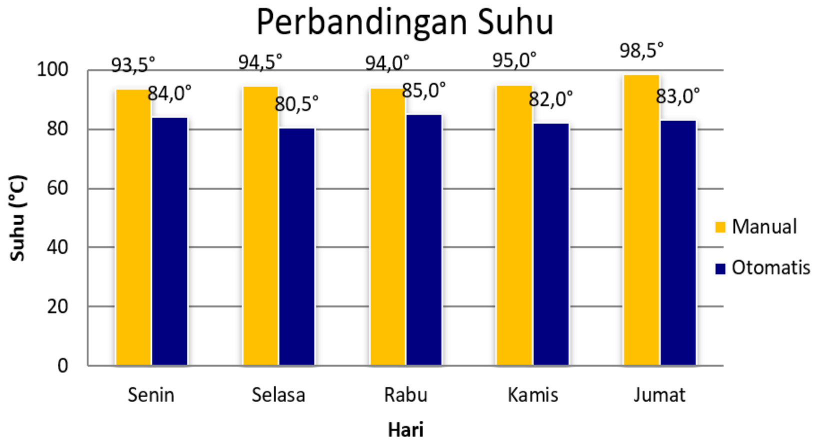

Figure 5. Comparison Chart of Cooking Temperatures on a Vacuum Pan.

The graph above shows a comparison of the cooking temperatures in the vacuum pan between the manual and automatic systems at PT. Duta Sugar International. The graph displays two colored bars: orange for the manual system and blue for the automatic system. Observations over five days of testing (Monday to Friday) show that the temperature in the manual system consistently exceeded that in the automatic system. The manual cooking temperature ranged from 93.5°C to 98.5°C, while the automatic system maintained a more stable temperature between 80.5°C and 85°C.

This significant difference indicates that the automatic system, with solenoid valve control, is capable of precisely regulating the steam supply through digital signals from the Distributed Control System (DCS). When the temperature in the vessel approaches the upper set point, the system automatically closes the valve to lower the temperature, and conversely, opens the valve when the temperature decreases. This results in optimal temperature stability for the sugar crystallization process, in contrast to the manual system, which relies heavily on operator experience and can potentially cause high temperature fluctuations.

Overall, this graph reinforces the data in Table 1, which shows that the use of an automated system not only stabilizes cooking temperatures but also improves energy efficiency and production quality. With temperature stability in the optimal range of 78°C–85°C, the evaporation process and sugar crystal formation are more uniform, cooking times are shorter, and energy consumption is reduced compared to manual methods. These results demonstrate the effectiveness of implementing a solenoid valve as an automatic actuator in the vacuum pan system at PT. Duta Sugar International.

The results of the study showed that the implementation of an automated system based on solenoid valves and DCS had a significant impact on the stability of the cooking process in the vacuum pan. Based on observations, the temperature in the automated system was maintained in the range of 78°C–85°C, much more stable than the manual system which fluctuated up to 100°C. This temperature stability directly impacted the sugar crystallization process, where crystals were formed with more uniform size, clearer color, and lower water content. In addition to improving product quality, the implementation of the automated system also reduced heat energy consumption by 10–15% per cycle.

5. Conclusions

Based on the results of research conducted on the performance analysis of vacuum pan automation using solenoid valves at PT. Duta Sugar International, it can be concluded that the implementation of an automatic control system based on a Distributed Control System (DCS) significantly improves temperature stability, time efficiency, and the quality of sugar production. The main research problem, namely how to improve temperature stability and efficiency of the sugar cooking process in the vacuum pan through the integration of solenoid valves as automatic actuators, has been answered through field testing of the system. The analysis results show that the automatic system is able to maintain a stable cooking temperature in the range of 78°C–85°C, lower and more efficient than the manual system, which fluctuates between 90°C–100°C. This increased temperature stability directly impacts more uniform sugar crystallization and improved energy efficiency.

In addition to improved temperature stability, the implementation of the automatic system also directly impacts time and energy efficiency. Observational data shows that cooking time is reduced by approximately 10–15 minutes per cycle compared to the manual method, meaning an increase in overall process productivity. This automation system also saves energy consumption by providing more precise and measurable steam supply regulation. Furthermore, the integration of the DCS and solenoid valve reduces reliance on human operators, thus minimizing the risk of human error. This results in more consistent and accurate control processes, even under continuous operation.

Overall, the research results demonstrate that implementing a DCS-based automatic control system with solenoid valve actuators is an effective solution for improving cooking process performance in vacuum pans in the sugar industry. This system not only positively impacts temperature stability and energy efficiency, but also improves crystallization quality and accelerates production times. Supported by an integrated digital monitoring and control system, the DCS plays a crucial role in realizing a modern, efficient, and sustainable industrial process. The successful implementation of this system at PT. Duta Sugar International is clear evidence that distributed control-based industrial automation can significantly contribute to increasing the competitiveness of the sugar manufacturing sector in Indonesia.

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