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[1]Samigulina Z.I.,
PhD, Professor, Associate Professor, ORCID ID: 0000-0002-5862-6415,
e-mail: z.samigulina@kbtu.kz
[2]Mukhangalieva M.A.,
Bachelor, ORCID ID: 0009-0002-0657-741X,
e-mail: m_mukhangalieva@kbtu.kz
[3]Uteyeva N.K.,
Bachelor, ORCID ID: 0009-0005-1582-1041,
e-mail: n_uteeva@kbtu.kz
[1]Kazakh-British Technical University,
Almaty, Kazakhstan

DEVELOPMENT OF AUTOMATED CONTROL SYSTEM FOR CEMENT PRODUCTION PROCESS

Abstract

This paper employs cutting-edge control strategies, including PID regulation, to manage the dynamic and time-sensitive processes inherent in cement manufacturing. The Honeywell C300 controller is utilized to implement a robust and scalable system capable of adapting to the demands of high temperatures, material flow variations, and operational disturbances. Mathematical modeling and simulation tools, such as MATLAB, are used to analyze the system's stability, as well as to obtain control parameters, allowing for predictive and adaptive management of crucial variables such as temperature and flow rate. This effort is important for more than just improving operational efficiency; it also contributes to sustainability by optimizing energy use and reducing waste. By integrating with worldwide initiatives to lessen the environmental effect of industrial processes, the system illustrates how automation may transform the cement manufacturing process. This article explores the control system's technological underpinnings, design techniques, and practical implementations, providing insights into its transformational potential.

Keywords: PID control, cement production, mathematical modeling, MATLAB, industrial automation, operational efficiency, scalable system, Honeywell C300 controller.

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Introduction

Kazakhstan's cement industry plays an important role in the national economy and contributes 6% to the overall gross domestic product. The sector has witnessed a sustained uptick, with cement production capacity utilization rising from 29.7% in 2015 to 40.6% in 2018. Following this growth bubble and in the backdrop of a yearly population growth of one per cent, the demand for cement production will continue to be strong. Technology up-gradation in the cement sector is most required [1]. The continuous increase in construction works and infrastructural development points to the strategic necessity of modernizing cement manufacturing processes.

Kazakhstan cement industry urgently needed this type of control system to do development. The focus of the project on efficiency and performance is timely due to the domestic cement industry producing more than 10 million tons of products a year and steady price growth (41.4% between 2015 and 2019) given by the Ministry of Trade of Kazakhstan. The combination of sustainability and energy efficiency will help the sector stay competitive while also meeting its environmental duties.

This initiative has practical applications such as enhancing product uniformity, lowering operating costs, and increasing cement plant efficiency.

Researchers investigated the current status of manufacturing facilities, how they operate, and the issues they confront in Kazakhstan's cement sector. Understanding these complications is critical for implementing automation systems capable of increasing production while reducing environmental impact. Rotary kilns are an essential aspect of cement manufacturing since they operate at high temperatures and under varied circumstances. Many researchers sought to improve these kilns and use waste heat for other purposes. Scientists investigated the possibility of using waste heat from cement rotary kilns for phosphogypsum calcination, an interesting path toward energy efficiency [2]. Forecasting future maintenance requirements is an essential part of cement production automation. Researchers investigated how utilizing predictions to solve problems might help industries perform a better job [3]. Predictive maintenance approaches may reduce downtime and save operating costs, therefore they are options to explore for control automation. It is critical to investigate the stability of systems that exhibit delays. A set of enhanced stability requirements for linear time-delay systems is created to aid in the construction of robust controllers for industrial applications.

Many books contain information on modern cement production systems, demonstrating the need for and importance of efficiency improvement and energy-saving measures. Also, some works are focused on comparative analysis of energy consumption CO2 emission during the production of clinker and recycled cement [6]. Automation of cement production requires monitoring and control of temperature, pressure, and flow-rate of materials. Mathematical modeling for rotary kilns has been developed and used as a mean of predictive control [7]. For the best control efforts, one must use PID (Proportional-Integral-Derivative) controller in the systems for automation. New methods have been presented for tuning PI/PID controllers for the non-oscillatory response of time-delayed systems [8]. Different methods of optimization for PID controllers in time-delay systems have also been reviewed, giving a good insight [9]. While reviewing issues about regulator optimization, research about the creation of a regulator based on fuzzy logic principles has also been considered [10]. Review of technical aspect of implementation of advanced controllers have been looked upon by IMC-PID design for integrating processes along with dead time [10]. In addition, a poor control performance is characterized of PID controllers using a parameter-space approach for linear systems with dead time [11]. Advanced control strategies for clinker production have been actively investigated to enhance energy efficiency, process stability, and product quality. In particular, Model Predictive Control (MPC) has been applied to rotary kilns and grate coolers to coordinate their operation and stabilize key process variables. The implementation of advanced process control in a real plant environment demonstrated a significant reduction in fuel and electricity consumption while maintaining clinker quality and overall process performance [13].

Further developments in intelligent control have introduced hybrid systems that combine conventional and humanoid intelligent control approaches for the clinker calcination process. Such systems employ steady-state detection and adaptive strategy selection to achieve smoother operation, reduced process fluctuations, and lower dependence on manual supervision, contributing to greater process stability and reduced labor requirements [14]. In addition, predictive control methods have been refined for temperature regulation in rotary kilns. The design of a Generalized Predictive Controller (GPC) based on an identified mathematical model of the kiln has shown improved accuracy and robustness compared to traditional PID controllers, maintaining optimal thermal conditions under varying industrial scenarios [15]. Recent research trends also integrate machine learning techniques into process control. By developing data-driven models that link operational parameters to clinker quality, nonlinear model predictive control (NMPC) systems have been designed to optimize kiln operation. These approaches demonstrate the ability to maintain process outputs within constraints while achieving significant improvements in energy efficiency and product quality [16].

The scientific novelty of this study lies in the integrated implementation and validation of a control system for a cement rotary kiln using the Honeywell C300 controller combined with simulation-based analysis in MATLAB. Unlike works that rely solely on theoretical modeling or purely industrial case studies, this research establishes a practical link between industrial control hardware and mathematical simulation tools, enabling systematic tuning, verification, and performance evaluation of the PID controller before and alongside industrial deployment. The proposed approach demonstrates how academic control design can be translated into a real distributed control system architecture, providing a reproducible framework for future enhancement with advanced strategies such as Model Predictive Control (MPC).

Material and methods

Description of the control plant

The control plant and technological processes of cement production. Production of cement involves the many stages. First, the cement raw materials go through the processes of extraction and grinding. Then, the raw mix is produced with the help of a system of drying and grinding. After this, the production process is thermal treatment in kilns. Through this process, clinker is produced. This clinker is the realization of the cement. Finally, the last important step is the process of grinding, which involves the clinkers which are combinations of distinctive cements for safeguarding gypsum as a result it is the process of setting info. In this project, the rotary cement kiln has been selected and used as the control plant in this study. Rotary kilns are used by manufacturers to heat solid materials to the desired temperature, which aids in chemical processes. This heating method requires precise timing. The time a solid material spends in the kiln is a design consideration that is largely influenced by diameter, length, rotating speed, and slope. Figure 1 depicts a detailed step-by-step flow of the cement production process using elongation technology

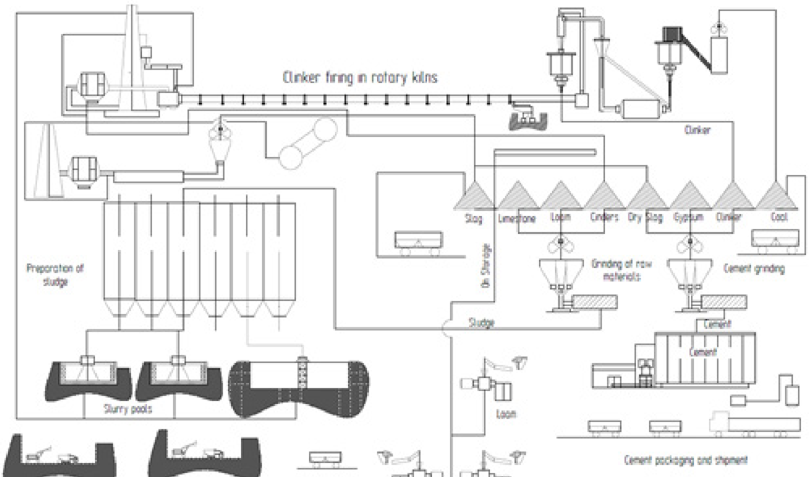


Figure 1 – Structural scheme of cement production process

The cement-making process starts with the extraction of limestone and loam from quarries. After extraction, these minerals are treated, combined with gypsum, slag, and other materials, and then ground. The confused mixture is then burnt in rotary kilns to yield clinker. The clinker is cooled and stored before going through another cycle of grinding to create a finished cement product. The final stage is to pack and deliver the cement. This picture depicts how each step links to the next. Temperature, pressure, and material flow are all managed during the production process. These metrics ensure maintaining quality control.

Some key parameters closely monitored during these processes are stage-wise temperatures (kiln operation, preheating tower, clinker cooling), grinding fineness and energy consumption. To form the clinker correctly, the temperature of the kiln must remain constant between 1400°C to 1500°C. To ensure proper circulation of gases within the system, pressure has to be managed efficiently, especially in the preheaters and precalciners, which helps alleviate energy usage.

Furthermore, control the particle size of the raw materials and the final ground cement. The clinker is usually ground to a fineness of about 300–500 m²/kg. The below table 1 with the specification of system parameters including, the temperature, pressure, etc. value and units.

Table 1 – Specification of system parameters

Process stage	Parameter	Value	Units
Kiln operation	Temperature	1400-1500	°C
Preheating tower	Temperature	850-900	°C
Clinker cooling	Output temperature	~100	°C
Clinker grinding	Particle size	10-50	microns
Energy consumption	Kiln	2.9-3.3	GJ/ton
Grinding mill	Electricity consumption	30-40	kWh/ton

This table is crucial for clearly outlining the operating parameters and their respective units of measurement.

Mathematical model of the control plant

In the building materials sector, there are several technical processes that need the management of complex multi-connected objects, and their control systems are interconnected. Multi-connected items have several inputs and outputs that communicate with one another. The rotary cement kiln is a very sophisticated piece of equipment used in industrial processes. The clinker-producing kiln employs a number of interconnected physical and chemical processes that take place concurrently across a vast area. One distinguishing aspect of rotary kilns is the time lag in the system's responsiveness to input changes. Large thermal systems typically suffer time delays due to sluggish heat transmission mechanisms and the length of time it takes for materials to go through the kiln. It makes it harder to operate the system since the current state is determined by both previous and present input. When there is a temporal delay in the system, the control design might cause instability. Time delays can be mathematically represented through the use of transfer functions and terms, which indicate that the response of the system was delayed exponentially. In rotary kilns, the delay may become substantial, and hence there is a need to consider this delay while deriving models and designing controllers. If we analyze a cement kiln as an multiconnected control object, we can identify the following significant control and controlled signals (Figure 2):

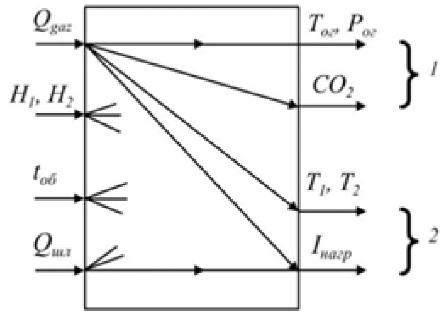


Figure 2 – Representation of a kiln as a model
of an multiconnected object

Where: Q_{gaz} is the amount of gas (fuel) supplied to the kiln, H_1, H_2 are the position of the smoke exhaust dampers, T_{or}, P_{or} are the temperature and pressure of the exhaust gases, CO_2 is the concentration of carbon dioxide in the exhaust gases, T_1, T_2 are the temperature of the material in the heating and calcination zone, $I_{нагр}$ is the load on the main kiln drive, $Q_{шл}$ is the amount of sludge supplied, $t_{об}$ is the kiln turnover time.

The control transfer function from the amount of gas supplied to the furnace (Qgaz) to the temperature of the exhaust gases (Тог) represents the mathematical model in this situation. This transfer function is given as follows [12]:

$$G_{Q_{gaz}-T_{og}}(S) = \frac{0.0098}{19.98s^2 + 5.423s + 1}e^{-s} \tag{1}$$

Converting given transfer function into the differential equation we get:

$$19.98\frac{d^2y(t)}{dt^2} + 5.423\frac{dy(t)}{dt} + y = 0.0098u(t-1) \tag{2}$$

To convert the transfer function into its state-space form use of MATLAB is needed, as this is a standard approach in control system design. The ss command in MATLAB allows for the transformation of the transfer function into the state-space form, with the state matrices A, B, C, and D representing the dynamic relationships between the states and inputs of the system. Matrix form is:

$$A = \begin{bmatrix} -0.2714 & -0.2002 \\ 0.25 & 0 \end{bmatrix}, B = \begin{bmatrix} 0.0625 \\ 0 \end{bmatrix}, C = [0 \quad 0.03139], D = [0] \tag{3}$$

The mathematical model for the rotary cement kiln was introduced, a complex multidimensional control plant. Due to the time-delay nature of the kiln process, special attention must be paid to how inputs affect the system over time. The transfer function provided describes the relationship between gas input and exhaust gas temperature.

The control objective for the rotary cement kiln can be formally stated within a standard feedback control framework. In this study, the controlled output is defined as the exhaust gas temperature $y(t) = T_{og}(t)$, which is a key indicator of the clinkerization process and must be maintained within a narrow operational range to ensure product quality. The control input is the fuel gas flow rate $u(t) = Q_{gaz}(t)$, which directly influences the thermal state of the kiln. The desired operating condition is represented by the reference signal $y_{ref}(t)$, corresponding to the optimal exhaust gas temperature for stable clinker formation. Accordingly, the control task is to design a feedback law that ensures asymptotic tracking of the reference, such that:

$$\lim_{t\to\infty}\left(y(t) - y_{ref}(t)\right) = 0 \tag{4}$$

while simultaneously minimizing transient performance indices such as overshoot, settling time, and excessive control effort, and respecting physical and safety constraints on both inputs and outputs. This formulation provides a consistent basis for the subsequent development of the PID controller and establishes a structured framework for future extension toward predictive or adaptive control strategies.

When controlling a system with characteristics like the rotary cement kiln, the choice between a PI and a PID controller can significantly impact performance. The PI controller, which includes Proportional and Integral actions, is generally simpler and focuses on reducing steady-state error. However, it may struggle with oscillations and stability in systems with time delay. On the other hand, the PID controller includes an additional Derivative action, which helps dampen oscillations and improve response time, making it more suitable for underdamped systems or systems with delay elements.

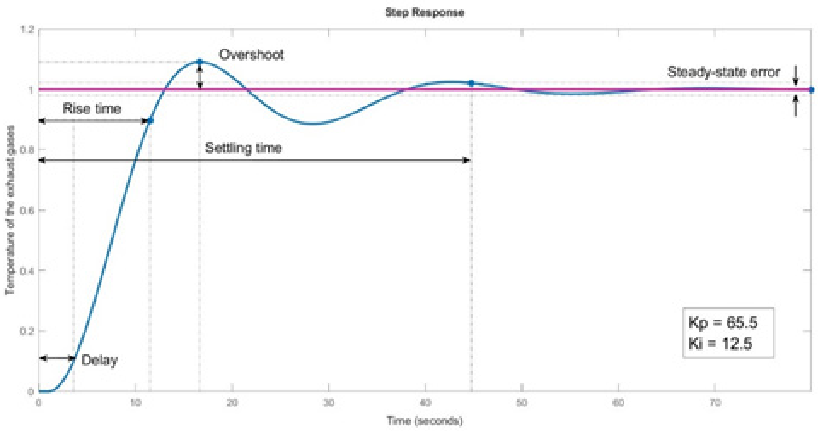
Using MATLAB's Autotuning for PID controllers, the step response plot for the PI and PID controllers was obtained. MATLAB's Autotuning feature provides an automated way to find initial PID parameters based on the system's response. This method is straightforward and uses an optimization algorithm to adjust the controller parameters.

Table 2 presents the dynamic response rise-time and settling-time overshoot generated by the PI and PID controllers.

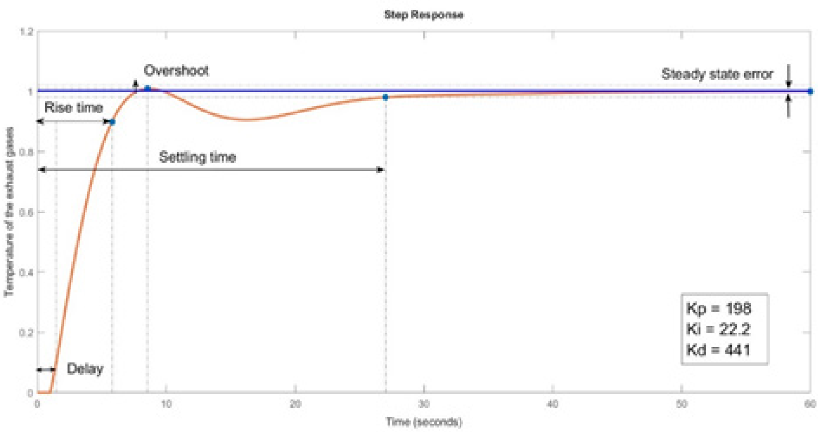
Table 2 – PI/PID controller performance

Characteristics	PI Controller	PID Controller
Settling time (sec)	44.7583	27.0291
Overshoot (%)	9.0668	0.8733
Rise time (sec)	7.9385	4.3537
Steady-state error	0	0

According to the resultant values, it is evident that the PID controller can generate the fastest rise time and settling time with the least overshoot. The desired characteristics of the system are obtained from these results i.e., PID is a better choice for controlling the rotary cement kiln. Documentation that analyses the module of Honeywell C300 controller.



(a) Step response of autotuned PI controller



(b) Step response of autotuned PID controller

Figure 3 – Development of the cement production control system:
(a) step response of autotuned PI controller; (b) Step response of autotuned PID controller

The graph above illustrates the step responses of the PI/PID controllers. The PI controller, while eliminating steady-state error, has a slower response and higher overshoot, making it less ideal for dynamic response control in this context. The PID controller achieves a faster rise time and lower settling time, with reduced overshoot compared to the PI controller.

Architecture of the Honeywell ecosystem: Control Designer, HMI web Designer, station.

The Honeywell C300 Controller is a high-performance compact process controller within the Experion PKS system, designed in the Series C form factor. This single-module unit integrates essential control functions, including a Control Processor, built-in I/O Link interfaces, and Fault Tolerant Ethernet (FTE) connectivity, which eliminates the need for additional plug-in modules. The C300 is engineered for demanding industrial applications, offering robust performance, streamlined integration, and high reliability within distributed control systems.

Another controller that is frequently used in process industries is Honeywell C200 Controller that is a chassis-based, modular process controller within the Experion Process Knowledge System (PKS). This controller is designed to support diverse process control applications through a range of plug-in modules, including those for the Control Processor, I/O Link Interface, and communications interfaces. The C200 controller is ideal for process industries that require modularity and flexibility in I/O and network configurations, making it suitable for varied and evolving control needs.

In the Table 3 shown comparison between C200 and C300 controllers.

Table 3 – C200 vs C300 controllers comparison

Feature	C200 Controller	C300 Controller
Controller Type	Chassis-based with plug-in modules for various functionalities.	Single-module, Series C form factor with integrated functionalities.
Redundancy	Achieved using two identically-equipped chassis with Redundancy Modules (RMs).	Built-in redundancy; only requires a second C300 controller and a redundancy cable.
I/O Link Interface	Requires an I/O Link Interface plug-in module to connect to PMIO hardware.	Two built-in I/O Link interfaces that support both PMIO and Series C I/O modules.
Memory	4 MB user memory	16 MB user memory
Communications Interface	Requires plug-in modules for Ethernet, FTE, and ControlNet connections.	Built-in Ethernet interface supporting both Ethernet and redundant FTE; no ControlNet support.
Network Requirements	Requires additional modules for Ethernet or FTE connections.	Functions as a node on an FTE network; supports standard Ethernet.
Peer-to-Peer Connections	Requires FTE Bridge to connect with other nodes.	Supports direct peer communication with other C300 controllers, C200 controllers (via FTE Bridge), and ACE nodes.
Data Capacity	Lower data handling and performance capabilities.	Higher data handling and performance, suitable for complex processes.
Price	$2,000 to $5,000	$6,000 to $11,000

The C300 controller was chosen due to its reliability, easy integration of the system, and processing capacity required for processes that are continuous and a must to have. For cement production, the C300 controller's built-in redundancy, flexible I/O support, higher memory capacity, and robust network capabilities provide a more reliable, scalable, and efficient solution compared to the C200. These features help ensure uninterrupted operations, adaptability to process requirements, and resilience in demanding industrial environments.

Table 4 shows the specification of the modules of the Honeywell C300 controller.

Table 4 – Specification of the modules and its functions

Module	Description of the module	Function
CC-PCNT01	C300 Controller Module	Executes control strategies and manages I/O communications within the Experion system.
CC-TCNT01	C300 Controller IOTA	Provides termination points for the C300 controller, facilitating connections for power, I/O, and network interfaces.
CC-PCF901	9-Port FTE Control Firewall Module	Acts as a network switch with firewall capabilities, supporting Fault Tolerant Ethernet (FTE) for robust networking.
CC-PWRR01	Redundant Power Supply Module	Supplies 24V DC power to the C300 controller and associated modules, supporting redundant configurations for high availability.
CC-PFB401	Profibus Communication Interface Module	Enables communication between the C300 controller and Profibus DP devices, facilitating integration with third-party equipment.
CC-PCIO31	Universal Input/Output Module	Offers 32 configurable channels for individually configuring AI, AO, DI and DO signal types, a true SOFT configuration.

The C300 series controllers manufactured by Honeywell are industrial automation devices designed to control technological processes at facilities with high reliability and performance requirements. The system architecture includes two controllers: C300_UNK and C300_UNK_2. The first controller, designated as C300_UNK, operates in simulation mode and is a virtual element of the system. It provides processing of input data coming from peripheral devices and sensors, as well as execution of control algorithms. The second controller, C300_UNK_2, is a real module to which sensors and actuators are physically connected.

The UIO-2_UNK (Figure 4) module as part of the C300_UNK_2 controller contains two active channels: channel 02 for pressure measurement and channel 17 for temperature measurement.

These channels process the analog input signals coming from the corresponding sensors and transmit the data for further processing. The C300_UNK virtual controller receives incoming data from the real C300_UNK_2 (Figure 5) controller and processes it, simulating the operation of the control system.

This separation of functions minimizes the load on the physical controller and provides redundancy of computing resources. The real UIO-2_UNK_2 module is used for data collection and primary preparation, while signal processing and calculation of control actions are performed in the virtual space of the C300_UNK controller. Such an organization of the control system allows for a flexible approach to configuration and testing, including modeling various scenarios of the technological process without interfering with the physical infrastructure of the facility.

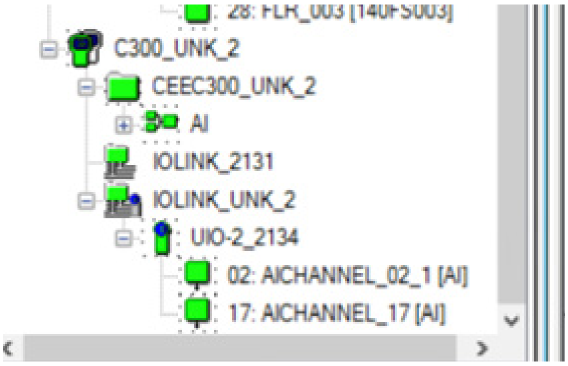


Figure 4 – UNK_2 real C300 controller with temperature/pressure sensors with control module

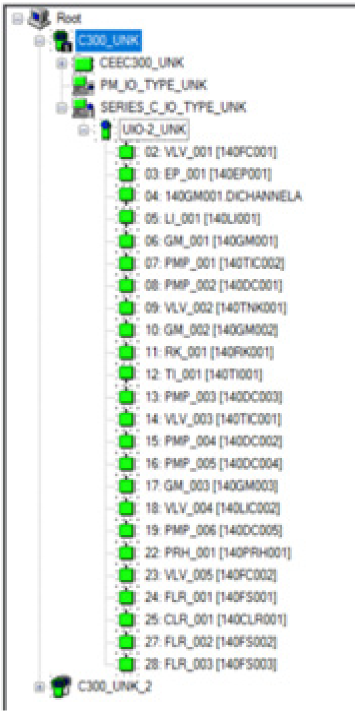


Figure 5 – UNK simulation C300 controller

Safety and health requirements in automated cement production

Based on «Industrial safety at hazardous production facilities» from January 31, 2006, No. 125 applies to organizations and enterprises whose activities are related to equipment operating at a pressure of more than 0.07 megapascals or at a temperature exceeding the boiling point of a liquid, mining, exploration, blasting, drilling for oil and gas, mining, mineral processing, underground operations, on the shelves of the seas and inland waters, industrial waste containing substances dangerous to human health and the environment, and so on, according to Article 3, Paragraphs 4,5,7,8,9. Let's consider the basic safety rules for the production and transportation of cement products.

Cement plants are subject to registration as CPS if they use: 1) rotary kilns; 2) equipment operating under pressure > 0.07 Mpa; 3) gas equipment; 4) storage systems for combustible materials. The equipment and control and measuring devices used in cement production must meet the requirements of explosion and dust protection in accordance with the zone class, while the level of automation of technological processes is determined based on an assessment of the explosion and fire hazard of production with mandatory equipment of automatic control systems and emergency protection. Rotary kilns must be equipped with emergency shutdown systems when critical operating parameters are exceeded (see Table 5), including automatic control systems for firing temperature, system pressure, and hazardous gases in the work area. All technological equipment, including silos for storing raw materials and finished products must be equipped with locking and alarm devices to prevent emergencies, while shut-off valves on pipelines must be clearly marked and placed in places accessible for maintenance.

The operation of imported equipment is allowed only if there is an expert opinion confirming its compliance with the requirements of the legislation of the Republic of Kazakhstan, and the commissioning of the equipment after major repairs is carried out under the supervision of responsible officials with mandatory commissioning and control tests. It is prohibited to operate technological equipment that does not comply with the declared climatic working conditions, as well as having technical malfunctions or non-compliance with industrial safety requirements, while all identified violations must be eliminated immediately with the equipment being repaired.

The temperature regime in the working areas should not exceed the established limits (45 ° C for indoor and 60 ° C for outdoor installations), while the external surfaces of the equipment and thermal insulation elements should be protected from heating to the temperature of spontaneous ignition of cement dust. After installation or repair, all pipelines are subject to mandatory pressure testing with the preparation of appropriate certificates, and pumping equipment must be equipped with interlocks to prevent dry operation and exceeding permissible operating parameters.

Repair work is allowed only after complete disconnection of equipment from energy sources, pressure relief from systems, installation of locks and posting warning signs «Do not turn on! People are working», while special attention should be paid to protecting fasteners from spontaneous loosening during operation. All wear-resistant parts must be designed to ensure their safe replacement without the use of additional means that pose a danger to personnel.

Table 5 – Criteria for classification as an DPF at a cement plant

Equipment/Process	Hazard criterion	DPF category
Rotating furnace	t > 115°C, working with combustible gases	II
Cyclone heat exchangers	Pressure > 0.07 MPa	III
Coal storage silos	Volume > 100 m3	III
Compressor units	Pressure > 0.3 MPa	II

Cement plants of hazard category II are required to develop an industrial safety declaration, which includes an analysis of the risks of accidents, calculation of their possible consequences and a plan of measures to reduce risks. The validity period of the declaration is 5 years with a mandatory annual adjustment calculation.

Results and discussion

The modeling and experiment findings were obtained using genuine industrial equipment at the Honeywell and KBTU JSC laboratories. The system design consists of two controllers: C300_UNK and C300_UNK_2. The C300_UNK controller runs in simulation mode and is a virtual component of the system. It processes input data from peripheral devices and sensors while also executing control algorithms. The C300_UNK_2 controller is a physical module that connects sensors and actuators. Separating these functions reduces the physical controller's strain while also providing computer resource redundancy. The actual UIO-2_UNK_2 module is utilized for data collecting and main preparation, while signal processing and control action computation take place in the C300_UNK controller's virtual environment.

Figure 6 shows a mnemonic scheme of a controlled plant, highlighting the key stages of the process such as quarrying of raw materials, crushing and mixing, and clinker formation. This includes the control of pumps, valves, mills, furnaces and other components. All these devices are controlled and monitored via the HMI interface, which displays process data such as percentage values, valve and pump status.

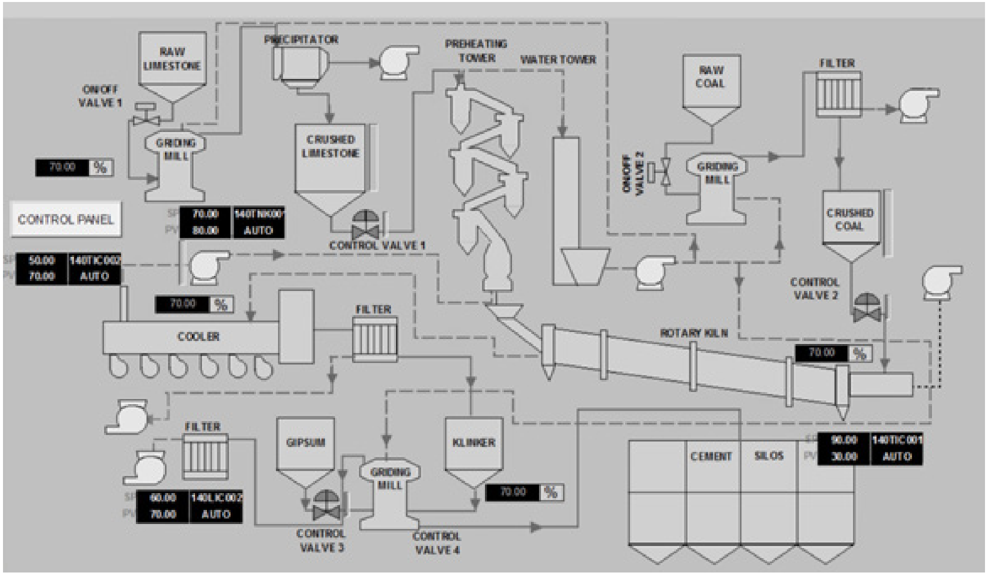


Figure 6 – Mnemonic scheme of the cement production control system

Figure 7 shows the control panel from which the operator can control the state of the system components. The following functions are available in the panel: manual/auto - allows you to manually control the condition of pumps and valves or switch the system to automatic mode; states - displays the status of pumps and valves or switch the system to automatic mode; states - displays the status of pumps and valves (e.g. on or off); trends – allows engineer to track current trends in system parameters such as pressure or temperature; start – button to start the process.

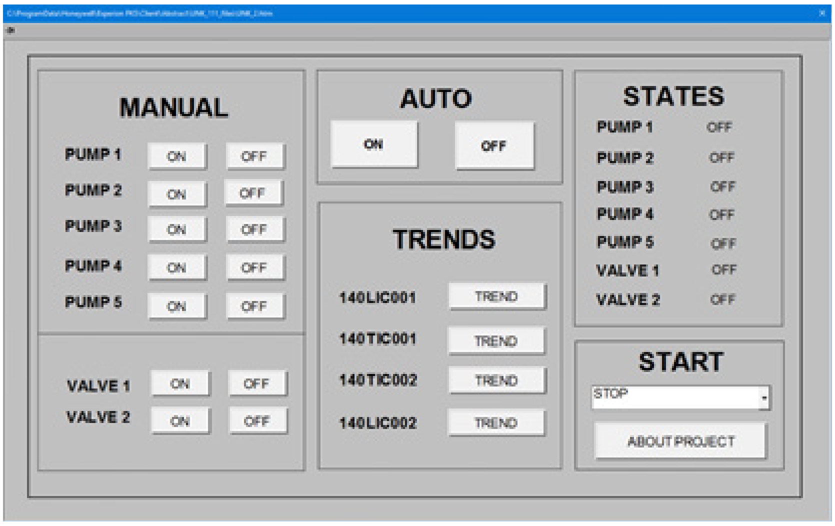


Figure 7 – Control panel of the cement production control system

The presented Figures demonstrate the integration of various controls and monitoring elements in the HMI system for cement production. Operators may successfully manage manufacturing operations using the control panel, automated mode, and parameter and status settings. These capabilities provide control, flexibility, and accuracy in the operation of the cement manufacturing automation system.

While the developed control system demonstrates stable operation and acceptable performance for regulating key process variables in the cement production process, several limitations can be identified. The implemented control strategy is based on a traditional PID regulator, which, although simple and reliable, has inherent drawbacks when applied to highly nonlinear, time-delayed, and multivariable processes such as rotary kilns. The PID controller relies on fixed tuning parameters and does not adapt to variations in process dynamics, raw material composition, or external disturbances. As a result, its performance may degrade under changing operating conditions, leading to suboptimal fuel usage, slower response to transients, and possible oscillations in temperature and pressure control loops. Moreover, the current system assumes linearized process behavior and does not explicitly account for strong cross-coupling effects between kiln zones, air flow, and material feed rates. This simplification limits control precision, especially under load fluctuations or transient startup conditions. The absence of adaptive or predictive capabilities restricts the system's ability to forecast future states or compensate for disturbances proactively. Additionally, while the Honeywell C300 controller provides robust hardware and redundancy, the implemented control logic remains deterministic and could benefit from data-driven or self-tuning algorithms.

Future improvements could focus on integrating adaptive control or model predictive control (MPC) strategies to enhance robustness against parameter variations and nonlinearities. Another promising direction is the incorporation of machine learning models for clinker quality prediction and dynamic model adaptation based on real-time data. Such approaches can enable nonlinear model predictive control (NMPC), which would optimize energy consumption while maintaining product quality. Furthermore, the use of fuzzy logic or neuro-fuzzy controllers could improve performance under uncertainty by combining heuristic knowledge with data-driven learning. Model predictive control (MPC) and adaptive control techniques offer several advantages for this type of industrial process. MPC introduces a predictive optimization framework that evaluates the future behaviour of the kiln over a prediction horizon and computes control actions that explicitly respect input, output, and rate constraints. This prevents operating limit violations, improves disturbance rejection, and produces smooth and coordinated actuator trajectories, which is particularly beneficial in high-inertia thermal systems. Moreover, MPC naturally handles multivariable systems and can coordinate fuel feed, air distribution, and cooler operation in a unified manner. Its cost function can be formulated to incorporate economic performance, such as minimisation of specific energy consumption, thus enabling true process-economic optimisation. Adaptive and nonlinear MPC extensions additionally allow the model to be updated online, maintaining high control accuracy even under variations in raw materials or process conditions.

From an implementation perspective, integrating MPC into the existing architecture can be achieved through a supervisory control layer running on an external industrial computing node connected to the Honeywell C300 via OPC or FTE communication. The predictive controller would operate at a slower supervisory sampling rate, generating optimal set-points for the lower-level PID loops which remain in place for fast safety-critical actuation. The digital twin configuration already established in the virtual C300 controller provides an ideal environment for model identification, controller synthesis, and offline validation before deployment. Following successful simulation, MPC can initially be introduced in advisory ("recommendation-only") mode and subsequently transitioned to active supervisory control, with automatic fallback to PID in case of communication loss or constraint violation.

In summary, while the current PID-based system provides a solid foundation for process automation in cement production, further research and development should be directed toward the adoption of intelligent, adaptive, and predictive control methods to achieve higher efficiency, reduced energy consumption, and improved process stability.

Conclusion

The effective implementation of an automated control system for the cement production process demonstrates the capabilities of industrial automation. By addressing challenges like quality control, resource utilization, and pollution control, it demonstrates the effectiveness of some automated controls in a formerly manual business. The solution is based on the dependable Honeywell C300 controller, a complex system with time delay, and mathematical model analysis resulting in a scalable, dependable, energy-efficient, and controlled system. The modeling and application of basic principles of automatic control theory, simulation with the help of MATLAB and PID control using different tuning approaches, has demonstrated the need for flexibility in managing cement manufacturing's dynamic and interrelated processes. The system can maintain stable operations in the presence of disturbances, achieving desired overshoot, settling time and rise time with zero steady-state error. Sensors and actuators have improved process visibility, enabling data-backed decision-making and looking ahead to assist maintenance. All in all, this project aims at the modernization of cement making via automation. The approaches in this regard are equally applicable for enhancing efficiency and sustainability through automation in other industries apart from cement manufacturing.

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[1]Самигулина З.И.,
PhD, профессор, доцент, ORCID ID: 0000-0002-5862-6415,
e-mail: z.samigulina@kbtu.kz
[2]Мухангалиева М.А.,
бакалавр, ORCID ID: 0009-0002-0657-741X,
e-mail: m_mukhangalieva@kbtu.kz
[3]Утеева Н.К.,
бакалавр, ORCID ID: 0009-0005-1582-1041,
e-mail: n_uteeva@kbtu.kz
[1]Қазақстан-Британ техниқалық университет,
Алматы қ., Қазақстан

ЦЕМЕНТ ӨНДІРУ ПРОЦЕСІН БАСҚАРУДЫҢ АВТОМАТТАНДЫРЫЛҒАН ЖҮЙЕСІН ЖАСАУ

Аңдатпа

Бұл жұмыста цемент өндірісіне тән динамикалық және уақытқа сезімтал үдерістерді басқару үшін алдыңғы қатарлы басқару стратегиялары, соның ішінде ПИД-реттеу қолданылады. Honeywell C300 контроллері жоғары температура, материалдар шығынының өзгеруі және өндірістік ауытқулар жағдайында жұмыс істей алатын сенімді әрі ауқымды жүйені іске асыру үшін пайдаланылады. Датчиктер мен атқарушы механизмдер нақты уақыт режимінде деректерді жинау және бүкіл өндірістік желі бойынша үздіксіз байланысты қамтамасыз ету мақсатында біріктірілген. Басқару параметрлерін дәл баптау үшін MATLAB сияқты математикалық модельдеу құралдары қолданылады, бұл температура, қысым және шығын секілді маңызды айнымалыларды болжамды және бейімделгіш басқаруға мүмкіндік береді. Жұмыстың маңыздылығы тек өндірістік тиімділікті арттырумен шектелмейді, сонымен қатар энергия тұтынуды оңтайландыру және қалдықтарды азайту арқылы тұрақты дамуға үлес қосады. Өнеркәсіптік операциялардың қоршаған ортаға әсерін төмендетуге бағытталған жаһандық бастамаларға сәйкес, бұл жүйе автоматтандырудың цемент өндірісі үдерісін түбегейлі жаңғырта алатынын көрсетеді. Мақалада басқару жүйесінің технологиялық негіздері, жобалау әдіснамалары және практикалық іске асырылу жолдары баяндалып, оның әлеуеті жан-жақты талданады.

Тірек сөздер: ПИД-реттеу, цемент өндірісі, математикалық модельдеу, MATLAB, өнеркәсіптік автоматтандыру, өндірістік тиімділік, масштабталатын жүйе, Honeywell C300 контроллері.

[1]Самигулина З.И.,
PhD, профессор, доцент, ORCID ID: 0000-0002-5862-6415,
e-mail: z.samigulina@kbtu.kz
[2]Мухангалиева М.А.,
бакалавр, ORCID ID: 0009-0002-0657-741X,
e-mail: m_mukhangalieva@kbtu.kz
[3]Утеева Н.К.,
бакалавр, ORCID ID: 0009-0005-1582-1041,
e-mail: n_uteeva@kbtu.kz

[1]Казахстанско-Британский технический университет,
Алматы, Казахстан

РАЗРАБОТКА АВТОМАТИЗИРОВАННОЙ СИСТЕМЫ УПРАВЛЕНИЯ ДЛЯ ПРОЦЕССА ПРОИЗВОДСТВА ЦЕМЕНТА

Аннотация

В этой работе используются передовые стратегии управления, включая ПИД-регулирование, для управления динамическими и чувствительными ко времени процессами, присущими производству цемента. Контроллер Honeywell C300 используется для реализации надежной и масштабируемой системы, способной адаптироваться к требованиям высоких температур, изменениям расхода материалов и эксплуатационным нарушениям. Датчики и исполнительные механизмы интегрированы для сбора данных в реальном времени и обеспечения бесперебойной связи по всей производственной линии. Инструменты математического моделирования, такие как MATLAB, используются для точной настройки параметров управления, что позволяет осуществлять прогнозное и адаптивное управление критическими переменными, такими как температура, давление и расход. Значимость этой работы выходит за рамки повышения эффективности работы, способствуя устойчивому развитию за счет оптимизации потребления энергии и минимизации отходов. Соответствуя глобальным усилиям по снижению воздействия промышленных операций на окружающую среду, система демонстрирует, как автоматизация может произвести революцию в процессе производства цемента. В этой статье излагаются технологические основы, методологии проектирования и практические реализации системы управления, предлагая понимание ее потенциала.

Ключевые слова: ПИД-регулирование, производство цемента, математическое моделирование, MATLAB, промышленная автоматизация, эксплуатационная эффективность, масштабируемая система, контроллер Honeywell C300.