Process optimisation solutions

Cement producers are driving to adapt in a constantly changing market - demand is increasing and the industry is facing a major push for sustainable production while dealing with cost pressures and workforce shifts. Basic control strategies are not enough and although regulatory control is adequate in terms of plant safety, it rarely achieves optimal control in terms of quality, nor does it operate in the most economical fashion. Machine learning and model predictive control are solving these challenges and more.

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Global cement producers are continuously working to drive production to adapt to a constantly changing market. Market demand is increasing due to growing populations, and urbanisation trends and market volatility are serving as the new normal. Green cement production is also taking off, emphasising sustainable, low-carbon production and decarbonisation.

Other trends include significant pressure on the industry to become more profitable along with a workforce skills gap, which requires training new and necessary skills to existing workers, filling the gaps after tenured employees leave and encouraging the next generation of workers to fill roles.

It is a lot for cement producers to deal with. And employing basic control strategies are no longer enough to keep up with the competition. Although regulatory control provides adequate control in terms of plant safety, it rarely achieves optimal control in terms of quality, nor does it operate in the most economic fashion.

Supervised machine learning and model predictive control (MPC) are major artificial intelligence (AI) techniques that can and are being used in the cement industry.

Process optimisation comes with inherent challenges. The process itself features multivariable characteristics and it can be difficult to measure the critical variables, especially in the case of a high degree of load disturbances. Moreover, the inertia of the process often obscures the understanding of the impacts of changes made by operators.

Meeting industry challenges

MPC can help by allowing operations to perform as close to the threshold as safely possible, maximising output and delivering results.

MPC uses a model of the process to predict how the process output variables will respond to changes in the process input variables and disturbances. In short, it shows the dynamic relationships between process outputs and inputs. The system predicts future values of the outputs by movement of all the inputs (manipulated variables and disturbance variables). Figure 1 illustrates these relationships.

Figure 1: model matrix

		CV 4th Stage Exit Temp	CV Tower O2	CV Kiln NOx	CV Tower CO	CV Kiln CO	CV Stage 1A Temp	CV Stage 1B Temp	CV Elbow Draft	CV Free Lime
MV	Calciner Coal Flow	K : 51.6 θ : 60 T : 324	K : -1.4 θ : 60 T : 90	K : 863 θ : 540 T : 360	K : 0.1 θ : 0 T : 5		K : 18.5 θ : 180 T : 156	K : 18.5 θ : 180 T : 156		
MV	Kiln Coal Flow	K : 63.5 θ : 0 T : 138		K : 3193 θ : 60 T : 900		K : 0.1 θ : 0 T : 5	K : 43 θ : 90 T : 90	K : 43 θ : 90 T : 90		
MV	ID Fan Speed	K : 1.7 θ : 180 T : 300	K : 0.12 θ : 60 T : 180		K : -0.03 θ : 60 T : 180	K : -0.03 θ : 60 T : 180	K : 4 θ : 180 T : 180	K : 4 θ : 180 T : 180	K : -0.1 θ : 30 T : 90	
MV	Kiln Speed	K : -58.7 θ : 180 T : 48	K : -1.85 θ : 180 T : 225	K : -2316 θ : 180 T : 180			K : -145 θ : 150 T : 216	K : -145 θ : 150 T : 216		
DV	Roller Mill ON		K : -0.37 θ : 30 T : 120				K : -12 θ : 180 T : 180	K : -12 θ : 180 T : 180	K : 0.22 θ : 0 T : 30	

Variable definitions

- *Controlled variables (CVs)*
  Process variables to maintain at a target or within a range (can be considered outputs).
- *Constrain variables (CCVs)*
  The state is forbidden to penetrate or may have physical limitations.
- *Manipulated variables (MVs)*
  A manipulated input is one that can be adjusted by the control system (or process operator).
- *Disturbance variables (DVs)*
  Disturbance variables (also called "load" variables) represent input variables that can cause the controlled variables to deviate.

MPC provides process stability while delivering peak performance since it finds optimal trade-offs operating closer to system specification limits while managing the process within constraints and safety margins. The built-in controller KPIs provide easy to understand views of control utilisation, time at constraints, model error and other key metrics to determine effectiveness of the control. Additional metrics for production, quality, energy usage and other factors can be easily configured to provide continuous measurements of the benefits derived from the application.

Operators can simply discover and pull business data from a common database and use the tools to easily guide users through data wrangling and discovery. Anomaly detection applications are trained on normal operating data to identify problematic unit operations or lines, be alerted on unusual operations and identify leading indicators before significant losses occur. The system offers clues to help prevent costly shutdowns or minimise unexpected performance deviations.

Let's take a look at three areas of a cement plant to understand how MPC is helping to increase throughput, lower fuel consumption and reduce energy intensity while providing better product quality in each area.

Process challenges by area

Blending

Within the blending process, unstable chemistry in raw materials can lead to unstable kiln operation. However, maintaining a stable process is not easily accomplished. Raw materials can vary widely and achieving the optimal ingredient ratio to reach production requirements can feel like a guessing game. The blending process is also traditionally controlled manually in several operations, creating even more variability dependent on the operator.

Machine learning, virtual online analysers and MPC can help stabilise the blending process by using precise models to help reduce variability caused by raw materials and chemistry ratios. In turn, this results in reduced blending costs, improved materials resource usage and better performance downstream.

Kiln

The reactions involved in kilns are still not well understood because of their complexity. Producers are working to maintain quality requirements of the clinker with minimum fuel consumption along with stabilising operations and a temperature profile along the kiln. Similar to the blending process, variability in raw material characteristics and complex dynamics also impact the process stability.

By implementing MPC, cement producers are seeing huge benefits in operations. Throughput is increasing along with improved product grades and heat recovery. Product variability is decreasing along with energy costs and emissions. Longer campaign runs and refractory life in kilns are also being seen.

"Model predictive control enables operations to increase efficiency by utilising existing equipment and systems to perform at their maximum potential through an advanced control strategy."

Customers using MPC to monitor kiln production are reporting the following typical results:

- increased throughput of between 2-4 per cent
- reduction in fuel consumption of 1-3 per cent
- reduction in power consumption of 1-3 per cent
- deviation free lime up to -50 per cent
- reducing NO_x emissions up to 20 per cent.

Grinding

Nearly 70 per cent of electrical energy in a cement plant is used for size reduction. This includes crushing and grinding of cement raw materials and clinker grinding. Cement producers are continuously working to maximise the productivity of grinding applications while keeping the fineness variability with the product specifications and reducing energy consumption. With a lack of reliable measurements of some key variables, operations lack optimisation.

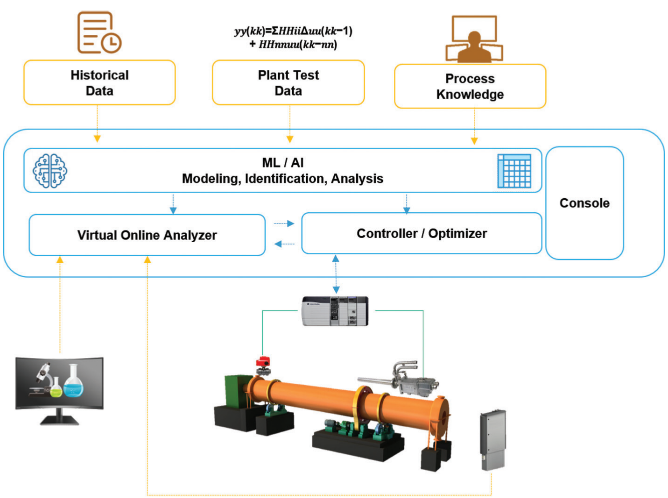

Figure 2: MPC cement architecture

Machine learning, virtual online analysers and MPC are helping cement companies reduce energy costs, increase throughput and reduce fineness variability, resulting in substantial gains. Throughput is increasing anywhere from 2-10 per cent and power consumption is decreasing by the same measure (2-10 per cent). Cement customers also saw a reduction in transition time for type changes, reduction of off-specification products by 20-30 per cent and reduced standard deviation for product residue/ Blaine by 20-30 per cent.

Anomaly detection

Anomaly detection using machine learning can be leveraged throughout a cement facility to provide additional oversight. It enables predictive strategies targeting any equipment that rotates or has concerns of failure or high maintenance costs. Improve maintenance dispatch timing to improve the return for every maintenance dollar spent.

Anomaly detection is useful for any equipment section that periodically goes wrong and provides operators early insight into developing issues with kiln wall ring formation or gas flow blockages, ball mill losses, or equipment failure concerns where there is not an existing history of identified failures. With anomaly detection, cement producers can gain advanced warning on detectable issues (measurement deviations) and resolve them to minimise periods of upset or poor performance.

If MPC is continuously driving good periods of plant performance to the highest levels, predictive analytics are identifying abnormalities. The two collaborate to increase plant profitability.

Conclusion

Understanding the relationship between variables and how they interact is key to the modelling of a process. Once these variables are identified, control can be achieved, predictably. It is like having the best operator on the job every minute of every day of the year.

MPC enables operations to increase efficiency by utilising existing equipment and systems to perform at their maximum potential through an advanced control strategy. This results in greater throughput at reduced energy costs per tonne – ultimately, increasing production, improving quality and reducing energy consumption and variability. ■