Thinking ahead

Ensuring stable and more beneficial operation of a cement plant with Expert Optimizer

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What can be done when the quality of the fuel burnt in a cement plant varies, but those tolerances may not be reflected in the final product? This is exactly the challenge faced when the goal is to use waste-based and other alternative fuels in such a process. The answer lies in adopting a predictive control strategy – a strategy that emulates that of a chess player by always thinking several moves ahead.

The cement production industry is a regional business in which the plants are owned by globally operating companies. Regional markets and differing legislation lead to diverse requirements within the production process: The production costs of cement depend strongly on the costs of fuel. The cement industry makes use of alternative or waste fuels to reduce these costs. These fuels range from used tires and carcass meal to the daily waste every single one of us produces. Hence, replacing fossil fuels with waste fuels significantly reduces the production costs. But this replacement also has its disadvantages. The variability of the quality of the waste fuels destabilizes the combustion process. Additionally, legislation regarding emissions is much stricter when the fuel in question is waste rather than coal. This leads to new challenges for the automation system to ensure that the quality of the cement can be sustained and to guarantee the legal operating limits.

ABB joined forces with a lead customer, the Lägerdorf plant of "Holcim Germany", in order to mitigate the negative effects of the AFRs (Alternative Fuels and Raw materials) in their calciner with the help of the most modern control technology available. The results were most satisfactory and stand as a showcase of a technical competence and customer orientation.

The process

The kiln process is schematically represented in 1.

Many different plant setups are common. The newer and more energy efficient of these have a preheater tower 1a with several cyclone stages 1c-f. The preheater extracts heat from the exhaust gas of the combustion downstream of the process. In the precalciner 1m, the decarbonization of the raw meal takes place ($CaCO_3 \rightarrow CaO + CO_2$). The heat used to drive the endothermic reaction is taken from the hot exhaust gases of the rotary kiln 1n and from the fuels burnt in the precalciner. From here, the decarbonized hot meal enters the rotary kiln 1n where the actual sintering of the clinker takes place.

The high variability of the alternative fuels used on the Holcim plant in Lägerdorf causes instabilities within the clinker burning process [1]. In this plant any changes in the degree of decarbonation of the meal entering the kiln will affect the quality of the clinker. Most notably, dips in the degree of decarbonation cannot be compensated by the rotary kiln due to its short length. Decarbonation of the hot meal is largely determined by the temperature in the precalciner. The relation between meal temperature and degree of decarbonation is shown in 2. In the described plant, up to 70 percent of the heat used within the clinker production process is generated by the combustion of fuels within the calciner.

As fuels transported by conveyor belts have a trasport delay of up to many minutes, they are not suitable for use as manipulated variables.

The nonlinear characteristic of the temperature versus degree of decarbonation shows that with increasing temperature, the benefit to the decarbonation is reduced and the process is therefore less energy efficient. In Lägerdorf, the kiln operators essentially try to keep the precalciner temperature high to ensure the required quality and therefore to stabilize the process [1]. At high precalciner temperatures, many additional problems occur. The high temperatures accelerate the wear of the refractory lining in the cyclones, increasing maintenance and repair activities. Additionally the meal grows more "sticky" and the risk of capital cyclone blockages increases considerably.

The R&D project

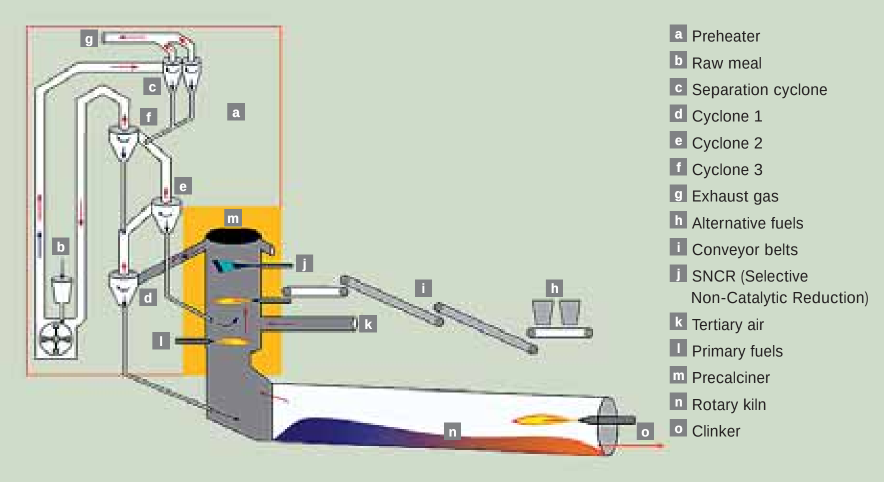
During the last two years, ABB has designed and deployed advanced process automation solutions and applications in different plants around the world. ABB is in constant contact with customers, seeking ways to improve current products to better meet their requirements. These automation systems are deployed using ABB's advanced process control system Expert Optimizer – a comprehensive engineering tool 3 that facilitates the development of generic control solutions for highly complex problems within the process automation industry [2]. Most installations have been implemented in blending, kilns, and grinding operations. Notably, 45 blending systems, 195 rotary kilns and 90 mills have been commissioned by the ABB team during the last 10 years.

The "precalciner control problem" had been a desired extension to ABB's control system portfolio for a long time, both on Holcim's and ABB's side. The necessary cooperation could therefore be swiftly established.

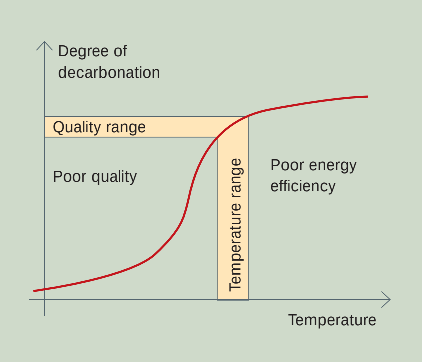
MPC as enabling technology

MPC (Model Predictive Control) is based on the "receding horizon" approach. A sequence of optimum actions extending into the future is calculated while incorporating the dynamics of the process 5. The first element of the optimal action se-

1 Schematic representation of the clinker production process at the Holcim plant in Lägerdorf, Germany



2 Relation between temperature and degree of decarbonation; the desired temperature and quality range are highlighted

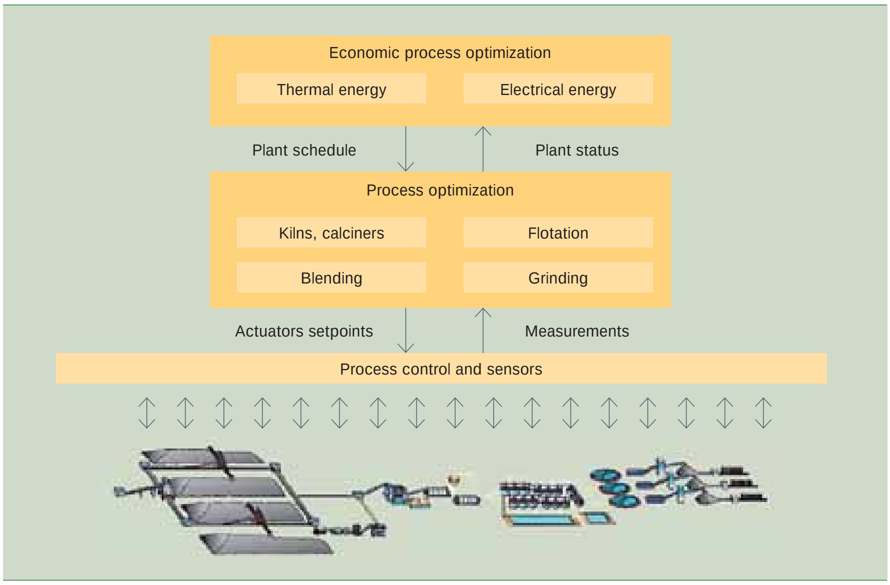


quence is transferred to the control system as the new actuator setpoint. If new measurements are available, the algorithm is repeated and a new sequence is calculated. Typically, this approach is comparable to the strategy of a chess player:

(i) The situation on the chess board is evaluated, ie the state of the process is measured and assessed
(ii) Future moves are considered, ie a mathematical algorithm calculates the optimal sequence of actions
(iii) The first move of the selected sequence is applied, ie a new setpoint is sent to the actuators.

This sequence is repeated after the opponent has made his move. An important advantage of such a system is that the mathematical algorithm can take limits and constraints into account when deriving the optimal control sequence. Analogously, the chess player has a restricted area in which to make his moves (the board) and has a limited range of moves (depending on the chessmen).

3 Expert Optimizer applications scope



4 Recordings of plant operations; temperature and target temperature a, input heat flow from combustion of alternative fuels b, coal feed rate c.

Expert Optimizer supports many different control technologies including MPC. However, it has not previously been used to control a calciner combustion process in the cement industry.

The control problem

The temperature in the precalciner is the main continuous indicator for the quality of the hot meal. It is therefore used as the main controlled variable. Furthermore combustion of the fuel must be guaranteed and therefore oxygen levels need to be maintained above predefined limits. Carbon monoxide exhaustion is legally regulated and may cause the system to trip if the limits are violated.

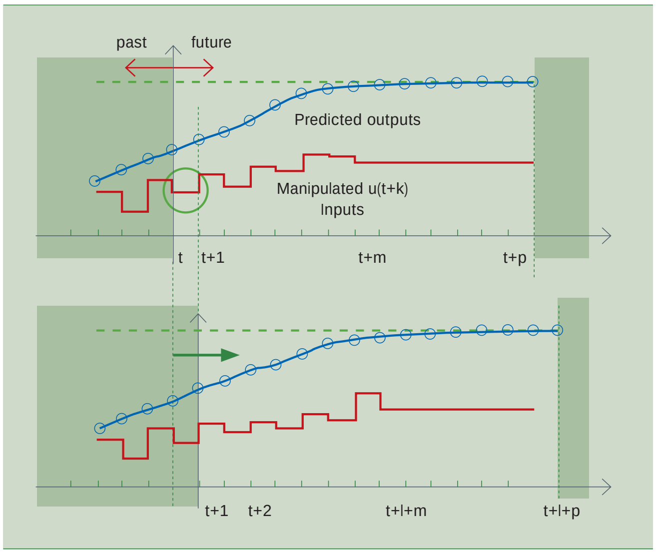
The primary fuels are used as manipulated variables. These are mainly coal, but in the specific case discussed here, a high quality waste fuel is used. In both cases this is transported pneumatically to the precalciner and forms the fastest available actuator of the system. Up to five other alternative fuels are used; these are transported to the precalciner by conveyor belts. As the transport delay of these fuels is up to many minutes, they are not suitable for use as manipulated variables.

The mathematical model

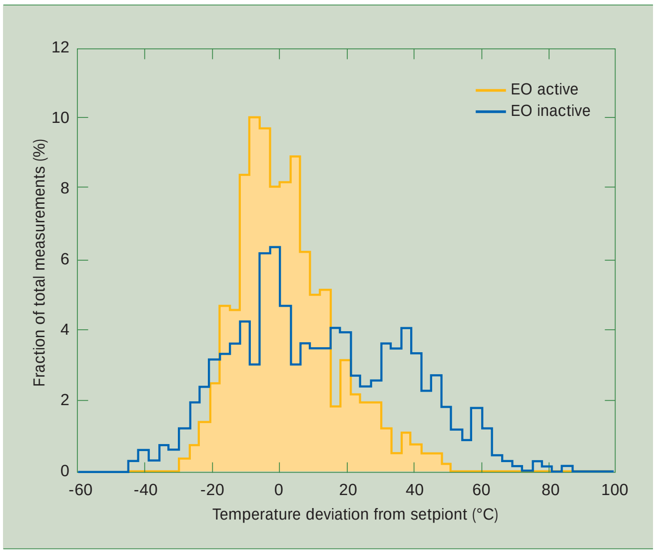
Part of the success of model predictive control in the process industry is related to the mathematical model being directly part of the control strategy. In general, the better this model describes the real process, the higher the expectations that can be placed on the performance of the controller. However, it is often also true that the more accurate the model is, the more sensitive the controller will be in reacting to uncertainty in the process. The uncertainty and variability of the process in this specific case is significant. For example, the calorific values of the alternative fuels change constantly depending on the composition of the originating waste, but the associated model parameters are updated only once a month.

The model essentially comprises two separate parts: the transport model

5 The main principle of MPC is based on the receding horizon. After each sampling instance, the considered future in the optimization algorithm is modified accordingly



6 Distribution of the temperature error for periods in automatic (Expert Optimizer, EO, active) and in manual control (EO inactive)



and a combustion model. The transport model is a series of unit time delays corresponding to the different transport delays of each of the fuel feeders. The combustion model consists of two parts:
i) a heat balance and
ii) an oxygen balance.

The heat balance considers any heat which is added or drawn from the precalciner. This includes fuel input, gas and air flows, meal feed rates and the decarbonation reaction (which consumes considerable heat). Varying meal composition also introduces a significant variation of the heat used for decarbonation. Usually these composition variations are considerably slower in relation to the thermal reaction and therefore can be captured in an adaptive bias term.

Similar ideas are used to formulate the oxygen balance.

Results

A recording of plant operations is shown in 4. Subplot 4a shows the temperature and the target temperature. 4b shows the input heat flow to the combustion model related to all of the alternative fuels. 4c shows the main manipulated variable, the coal feed rate.

To compare the performance of the controller with the performance of the operators, several periods were evaluated where comparable conditions were present. 6 shows the distribution of the temperature error.

The performance of the control system outperforms the operators. The temperature targets are better maintained and the variations from set-point are less. Obviously this does not imply the operator is superfluous; instead this person is occupied by other and more important tasks. This shows that a control system can support the overall task of the operator.

Conclusion

The controller successfully stabilizes the temperature at a given target and reduces the variability of the deviation from the target. This allows the system to be operated closer to the quality limit, which is more energy efficient and decreases the risk of downtime. By using the control system, less stable operating points with lower temperature targets can be achieved without risking insufficient product quality. The generally lower temperature reduces the risk of capital blockages of cyclones. Hence, the controller protects the equipment and increases uptime.

This project's success was strongly conditioned by the close collaboration between the teams of ABB and the customer's. Both groups contributed with their technical competence and goodwill, thereby guaranteeing the success of this project.

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See also

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