INCREASING
PRODUCTIVITY

BRUNO GODOY AND MICHAEL STALDER, ABB, SWITZERLAND, AND DERYA DERINYOL, BURSA CIMENTO, TURKEY, DEMONSTRATE HOW BURSA CIMENTO IN TURKEY INCREASED PRODUCTIVITY USING MODEL PREDICTIVE CONTROL WITH ABB'S EXPERT OPTIMISER.

The Bursa Cimento plant

ABB successfully commissioned a MPC-based solution for the cement kiln at Bursa Cimento plant in Turkey.

The Bursa Cimento plant is located near the city of Bursa in the Marmara region of Turkey. Bursa is one of the most populated cities in Turkey and an important industrial area.

Bursa Cimento operates two clinker lines and four cement grinding mills. The Expert Optimiser project was carried out on line 1 which consists of a 50 m rotary kiln with a 5-stage preheater and an in-line calciner, designed by Polysius and commissioned in 1996. The system is designed for a capacity of

2250 tpd. The kiln main burner is fired with coal dust, whereas the calciner burner also fires RDF (refuse-derived fuel) at a rate of about 4 tph. The kiln is followed by a grate cooler with 12 cooling fans.

The kiln is also equipped with a waste heat recovery plant (WHR) using exhaust gases to generate electricity.

Expert Optimiser project

Bursa Cimento was looking at improving the production and energy efficiency of its plant when ABB was approached to present their process optimisation system, Expert Optimiser.
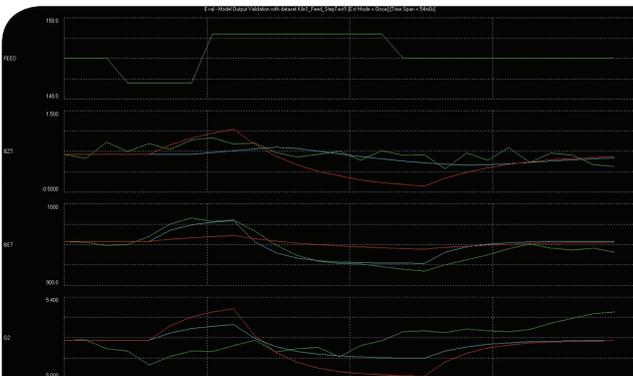
Figure 1. Bursa Cimento plant.

Figure 2. Plot of pre-configured model and final model versus actual data.
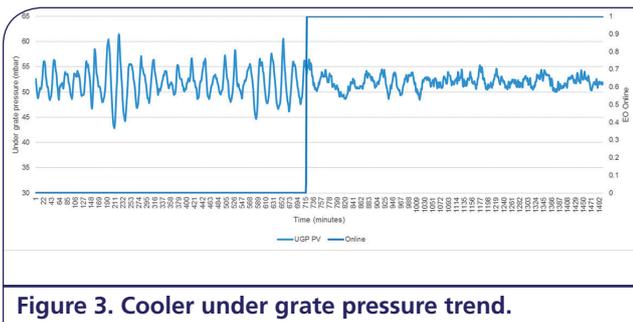

Figure 3. Cooler under grate pressure trend.

The collaboration was started with a site audit in October 2014. An ABB engineer visited the Bursa Cimento plant to study the process and evaluate the potential of applying Expert Optimiser to clinker line 1 and two cement mills. In the pyro processing area it was identified that Expert Optimiser would be able to improve the stability of the calciner temperature and the cooler operation with subsequent optimisation of the kiln production and energy consumption.

The potential improvements indicated by ABB convinced Bursa Cimento and the contract to implement Expert Optimiser was signed in September 2015.

In early 2016, two engineers from Bursa Cimento attended an Expert Optimiser training course to learn the essentials about the technology used in Expert Optimiser and ABB's approach to control and optimise a cement factory.

Commissioning of the system started end of February 2016. The resistance of the operators was minimal as the system quickly showed benefits, including improving little things that made the operators life easier. Utilisation factors higher than 90% were already achieved at the beginning of commissioning. ABB implemented Model Predictive Control (MPC) for the kiln[1] and the mills. The MPC approach and results from the project will be explained in more detail in the next chapters with focus on the pyro processing section.

MPC Technology
From a user perspective, the main components in an MPC are:
- The plant model.
- An objective function.
- A state estimator.
- An algorithm for solving constrained optimisation problems.

The following actions take place on a cyclic basis and are repeated with the user-defined sampling time, which is chosen with respect to the time scale of the controlled process:
- The actual state of the process is estimated from current and past measurements and from the state at previous sample(s) using Moving Horizon Estimation (MHE) method for state estimation. The estimated state x(k) is assumed to be an accurate approximation of the sometimes unmeasurable state in the true process. It is used as the starting point for the optimisation in the next step.
- The plant model can be used to predict the future trajectories of the plant outputs for a given sequence/trajectory of future control signals. Optimisation determines the future control signal such that the objective function is minimised. The optimisation may also account for constraints on the process inputs and the process outputs.
- Finally, the first instance for each calculated future control signal is applied to the process.

It is worth noting that normally the objective function is a weighted sum of deviations in the plant outputs and in the control signal increments. There may also be linear terms for minimisation or maximisation of certain variables.

Model Predictive Control applied

This section describes the practical implementation of MPC application for the cement kiln at Bursa Cement plant. It describes the modelling approach, how the objective functions is designed and how MHE is used to deliver a robust controller.

Model building

A good model is crucial first step for a successful application of MPC. Many MPC projects are deployed using data-driven, empirical models, where the user feeds data to an algorithm which derives the model from this data. One major drawback of applying this technique is the need for 'good' data. Good data means that the data sets contain as few unmeasured disturbances as possible and the process has been exited in a controlled manner. Producing good datasets for empirical model building can be a lengthy process and especially, for a cement kiln, hard to achieve as unmeasured disturbances are plenty.

To overcome this issue, ABB uses an approach with preconfigured models built with a graphical editor. These pre-configured models describe the relationship between the measured variables and manipulated variables using knowledge of the cement making process, experience of engineers and past projects and information acquired from the site audit and discussions with the process engineers.

The kiln model is divided into three major model blocks:

1. BZT model captures the relationship between the actuators (kiln feed, kiln fuel, air flow and kiln rotary speed) and the burning zone temperature of the kiln. Burning zone temperature is virtual measurement or a so-called soft sensor. The measurement is built with three direct measurement that indicate the burning zone temperature conditions:
    • Kiln motor current.
    • Pyrometer temperature.
    • Secondary air temperature.
2. BET model models a temperature in the pre-heater tower. BET is important as a measurement because it indicates what will happen to BZT when the material has moved through the system.
3. O_2 model describes the oxygen balance between air flow, fuels and kiln feed.

The ABB engineer will arrive on site with a model that is 85% ready to use. His job is then to validate the model and adjust the model parameters to fit site conditions using data from the plant. The tools allow the engineer to compare data to different models, e.g. with different model parameters. Figure 2 shows a plot with the pre-configured model and final (tuned) model versus a dataset acquired during commissioning. The figure shows that the initial model captures the basic relationship correctly. Getting from the initial model to the final model is a matter of adjusting model parameters, such as gains, lag times, dead times etc.

Model building happens decoupled from the runtime, so there is no danger of disturbing the control of already deployed MPC controller when tuning models.

Desired control behavior and objective function

The desired behavior for the kiln controller for Bursa factory is to maximise the kiln feed while keeping burning zone temperature and oxygen close to the setpoint. This behaviour is achieved by formulating following objective functions for the MPC problem:

● The object functions for burning zone temperature and oxygen are chosen such that the cost rises proportional to the deviation between setpoint and actual value:

$$Cost \propto (SP - PV)^2$$

● To maximise the kiln feed the objective function is selected such that the cost is inverse proportional to the kiln feed:

$$Cost \propto - Kiln\_Feed$$

An additional objective function is implemented for the kiln rotary speed. It is desired to operate close to ratio specified by the production engineer:

$$FeedSpeedRatio = \frac{100 * Kiln\ speed}{Kiln\ feed}$$

The objective function is of the same type as for burning zone temperature. The controller will compromise between setting the speed into the correct ratio with feed and achieving the correct burning zone temperature.

Moving Horizon Estimation (MHE) for model adaptation

A concern often mentioned applying MPC is that model will be obsolete after a short time and the controller will no longer deliver a good performance. There are multiple approaches how to tackle this issue, including 'engineered' calculations outside the MPC framework to adjust certain model parameters which will be continuously fed to the MPC or concepts such as Robust Model Predictive Control often referred to in the literature.

ABB has successfully applied an approach using the MHE and MPC framework where the MHE capabilities are used to automatically correct modeling errors.[1-2] This approach is also used in the MPC application for the cement kiln.
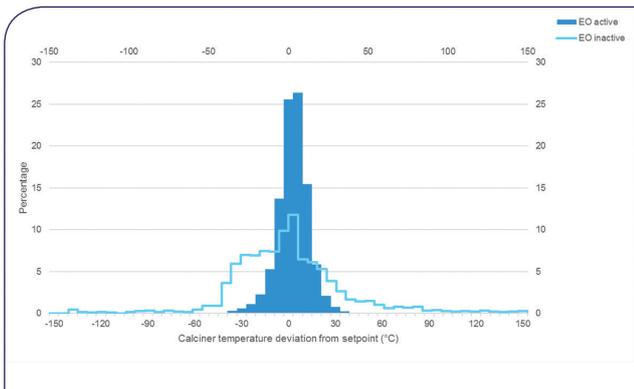
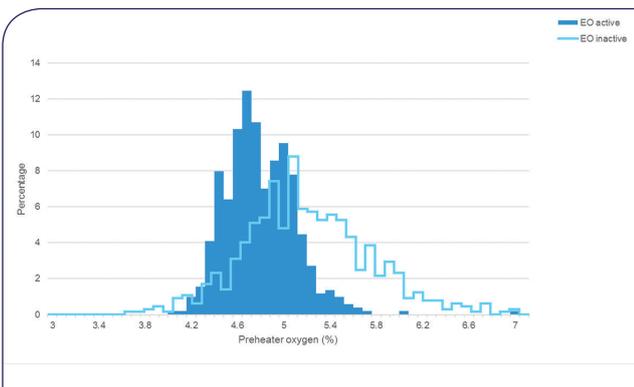**Figure 4. Calciner temperature control (minute values).**

Figure 5. Pre-heater oxygen distribution EO active and EO inactive (hourly values).

Table 1. **Average kiln feed and energy consumption. Typical values vs. April 2016.**

	Average Kiln Feed (tph)	Specific Energy Consumption (kcal/kg)	EO utilisation (%)
Typical (EO off)	152.0	870 – 880	
April 2016	155.8	850 – 860	> 95

Results

The stability of the kiln system has been improved since first day Expert Optimiser was set into automatic mode. Figure 3 shows the trend when Expert Optimiser was first switched into automatic mode. One can see that the under grate pressure in the cooler stabilised immediately. Bursa Cimento had issues operating the WHR plant, as the required minimum temperature of 340˚C could often not be ensured. After Expert Optimiser stabilised the cooler operation this problem vanished. This will improve the overall performance of the plant outside of the foreseen Expert Optimiser scope.

Similar improvement was achieved for the calciner temperature. Figure 4 indicates the control error distribution of the calciner temperature, showing that Expert Optimiser controls the temperature more tightly. Please note that this

statistic includes about 2 days of data when EO was inactive and about 20 days of data when Expert Optimiser was active. Good control of the calciner temperature is essential as it is important for the stability of entire pyro process. Stable calciner temperature ensures that the material is always well prepared before it enters the kiln. Large variations cannot be corrected anymore after that point.

Better process stability is the foundation for improving the productivity of the kiln. Figure 5 shows the distribution of hourly oxygen values for Expert Optimiser active and inactive. The figure clearly shows that with Expert Optimiser in control the oxygen is operated at a lower level which indicates that the process is operated more efficiently.

The same is supported by Table 1; both average kiln feed and thermal energy consumption are improved by 2 – 3% compared to typical values before Expert Optimiser was used. On 7 March, Expert Optimiser was first turned online. After initial tuning, Expert Optimiser was used almost continuously and utilisation of higher 95% has been reached since.

In general the results achieved follow the findings made during the site audit at the very beginning of the project.

Similar results have also been achieved for the two raw mills and cement mills by applying the same principles.

Conclusion

In this article, ABB and Bursa Cimento describe how an MPC-based solution for advanced kiln control has been implemented. The control strategy has been implemented with ABB's Expert Optimiser. The results achieved follow observations made during a site audit before the project and show improvements in the stability of the process and the performance of the kiln system.

This project shows that ABB's Expert Optimiser continues to produce value for its users. It depicts that the MPC-based approach can deliver results fast and consistently. 🌐

References

1. Konrad S. Stadler, Jan Poland, Eduardo Gallestey, Model predictive control of a rotary cement kiln, Control Engineering Practice Volume 19, January 2011.
2. Matthew J. Tenny and James B. Rawlings, Efficient Moving Horizon Estimation and Nonlinear Model Predictive Control, Proceedings of American Control Conference 2002, Anchorage, May 2002.