Auto-optimising the kiln

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Experienced operators and experts confirm that each rotary kiln for clinker production is individual. Thus automation and optimisation solutions require an individual approach for each kiln. The continuous need for adapting expert systems to the process changes have led to low success of those systems. Advanced and auto-optimising process control instead utilises powerful on-line data analysis software to develop individual kiln simulation models Non-linear Model Predictive Control (NMPC) for an optimised kiln operation. Smart data analysis and management technologies allow for an autonomous on-line re-calibration implemented in this unique software.

Over the last three decades expert systems represented the leading technology for process automation and optimisation of cement kilns. Firstly, plant experiences and results were often great, but after a while the hang-over was even greater. Since the control with fuzzy and rule-based expert systems requires manual re-programming to consider the changing process conditions, plant drift and changes in targets, the acceptance of these expert systems gradually vanished. As a consequence, three of four expert systems are currently running with significantly reduced functionalities. But most of them are even not in operation any more – with no intention for a re-start.

To re-inspire cement producers for optimising kiln control and to encounter the disadvantages of conventional expert systems, Powitec introduced the 'PiT Navigator' – an autonomous kiln control, based on self-learning and adaptive software plus optical information from the combustion and sintering zone. This development prompted David Haspel to comment: "the industry appears to have swapped 'expert systems' for 'optimising systems'".[1]

Contrary to expert systems with the frequent need for manual adjustments of the control strategy, the PiT Navigator is a self-calibrating and auto-optimising closed loop control software. As a consequence, extensive and expensive manual reconfigurations like for expert systems are not necessary any more.

Results achieved by the expert systems are rarely published in detail. On average the Powitec auto-optimiser enabled a 30-50 per cent stability improvement shortly after commissioning.

Based on this, in the average production volume (+3-7 per cent) as well as energy efficiency (+2-10 per cent) and clinker quality (up to 20 per cent) can be improved.

Along with this comes the long-lasting acceptance by kiln operators and plant experts, as the auto-optimiser is easy-to-use and reprogramming or reconfiguration is not necessary. This is why it achieves online-times of 80-100 per cent in various references.

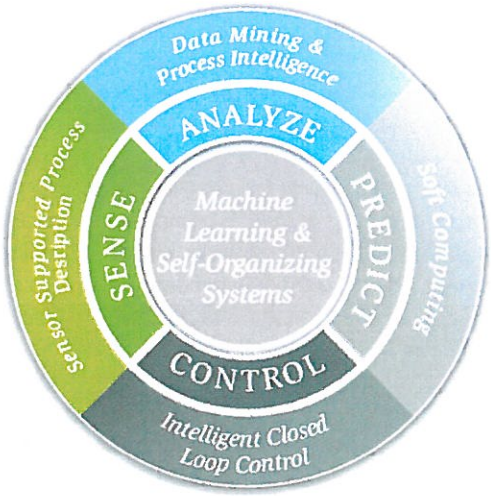
SAPC-approach

Clinker production is a complex, non-linear process with significant reaction times and inconsistent, permanently changing correlations. From a process control point of view, it is considered as a complex multi-dimensional optimisation task.

To cope with this, the auto-optimiser uses the Sense-Analyze-Predict-Control (SAPC) approach.

Sense: Only what is measured can be controlled! To control a rotary kiln, on-line information of the combustion atmosphere, flame behaviour, sintering zone data etc from inside the kiln are decisive. The auto-optimiser 'measures' the kiln interior with a self-developed powerful optical sensor especially designed for dusty kiln atmospheres:

By means of digital image processing of up to 80 per cent of the information considered in the NMPC is being generated – and also stored in a database. The PiT Navigator is the only integrated optimisation solutions utilising conventional process data and optical information for control purposes.



The Sense-Analyze-Predict-Control (SAPC) approach

Analyse: Process data are the most important resource for process optimisation. An increasing number of sensors digitally describe and measure the production, generating huge and complex set of data.

Via a DCS interface these data will constantly be read and analysed by the auto-optimiser. The more accurate and comprehensive the process data, the more precise the on-line simulation models can predict future development of essential process parameters.

Predict: With the on-line simulation models a prediction of decisive process variables is possible, eg free lime, kiln torque, etc. Based on the learned knowledge, the auto-optimiser predicts results with very high accuracy. Only after internal performance evaluation for alternative hypothetical control actions the auto-optimiser selects and accomplishes the control actions fulfilling the optimisation targets the best.

Control: The auto-optimiser integrates latest developments in the field of Computer Science and Digital Image Processing. Self-organising Neural Nets are combined with biologically inspired re-enforcement learning strategies and powerful software for picture analysis. In cooperation with the Technical University of Ilmenau, a leading institute in the field of Neuro-Informatics and Cognitive Robotics, the basis for the optimisation approach has been developed. The solutions are also applied for optimised mill control, for coal-fired power plants and waste combustion plants.

Auto-Optimising control

Neural Nets do not require programming, instead they are trained. Unlike expert systems which require human experts for configuration and update of systems software, the auto-optimiser itself becomes the expert, having the permanent urge to even further improve the already good control strategy. Hence it significantly reduces the dependency on highly qualified personnel to operate an expert system – as well as the commissioning efforts and the after-sale service costs.

There will be no programming of Fuzzy controllers or characteristic curves. This has major advantages:

1. Fuzzy controllers take a lot of time to programme and setting up. The PiT Navigator Software is typically set up within two to three weeks only. Lately the set up took less than two weeks on-site.
2. Fuzzy controllers only can be as good as the best expert having programmed it. Adaptive Neural Nets improve themselves fully, automatically, by learning over time.

Advanced closed-loop process control represents an embedded information-driven control solution, utilising objective statistics and algorithms to generate process knowledge out of complex historical and actual process data. Neural Nets come with the ability to adapt. The auto-optimiser generates new models every time new data correlations have to be considered. Usage of new coal type, changes in raw meal or even process upgrades do not require manual re-programming or re-parameterisation, the auto-optimiser adapts itself automatically.

This individual process knowledge is then stored in the PiT Navigator system database and is permanently available for further process control improvement via on-line process simulation models. These models can capture comprehensive experience of years of kiln operation.

If priorities in optimisation targets change, for example from energy efficiency to production or through government driven emission targets, the Neural-Net software receives new priorities with a few mouse clicks and will follow them. Fuzzy systems would have to be extensively reprogrammed by experts.

Any cement plant with a standard instrumentation regarding sensors, actuators and DCS is able to implement and operate this advanced process control. This auto-optimiser is also applicable to planetary cooler kilns, lime kilns, etc.

Advantages of auto-optimising control

- Personnel need: low additional load on plant personnel during commissioning and no additional load over life-time. The system is easy to use:
- Objective: mathematical statistical models do not rely on subjective expert knowledge. They learn from existing process data automatically and select the objectively best control strategy
- Adaptive: process models learn continuously and dynamically adjust control strategy
- Flexible: easy changes in process targets and its priorities without the need of re-programming. Automatic integration of additional process signals
- Fast: software commissioning to be accomplished without 2-3 man weeks on-site
- Complete: optical information from the sintering zone as well as non-linear correlations between process data is included
- Fault tolerance: the auto-optimiser is fault tolerant. If single measurements fail, the system will rely on the available measurement and not suffer a total breakdown
- Cost: total cost of ownership is low, as no permanent manual adjustment and re-programming is required

Latest results

Table 1 shows the results recently achieved by the advanced process controller at Cimpor Brasil in a comparison with PiT Navigator against manual operation.

Thus the auto-optimiser achieved:

- a more stabilised kiln operation in general (up to 36 per cent)
- an increase in clinker production volume of seven per cent
- an increase in energy efficiency of six per cent.

Table 1: results achieved at Cimpor Brasil cement plant
PiT Navigator Off (41 days) PiT Navigator on (28) days

Target	*Process value*	*PiT Navigator +/- absolute*	*PiT Navigator +/-relative (%)*
Stability	Standard deviation preheater exit temperature (°C)	-2.35	36.5
Stability	Standard deviation sintering zone temperature (°C)	-6.92	20.2
Stability	Standard deviation kiln drive torque (°C)	-0.08	12.9
Production	Raw meal feed (tph)	10.1	7.1
Energy	Specific energy input clinker (kcal/kg)	-56.6	6.0

Summary

The self-learning adaptive process controller is implemented very quickly, it adjusts itself automatically to changes and thus achieves very good results with online-times of constantly over 80 per cent without manual reprogramming.

Depending on the kiln capacity, this allows for an amortisation of some 3-4 months – and for any other kind of application, less than two years!

References

1. Haspel, D (2003) in *International Cement Review*, "Coming of age?" pp51