FROM VIRTUAL TO REALITY

Nikola Jovicic and Dieter Burgwinkel, KHD Humboldt Wedag, describe a new advanced raw mix quality control system.

Novoroscement OJSC is one of the most important cement producers in Russia, with three operating plants and a production capacity of more than 5.7 million tpy of high-quality cement.

In 2008, the Russian cement producer signed a major contract with KHD Humboldt Wedag for a new plant with a production capacity of 2 million tpy. The contract included engineering and equipment supply for a complete production line, from raw material crushing, through pyroprocessing, to cement loading and packing. Additionally, supervision services for erection and commissioning, as well as plant operation and training, were carried out by KHD.

The new dry process cement production line, Pervomaysky, was erected next to Novorossiysk in the southern region of Russia, achieving compliance with European and international environmental standards. KHD's scope of supply comprised the following:

- A marl crusher plant, designed for 800 tph.
- A raw material grinding system with a vertical roller mill (VRM), designed for 550 tph.
- A pyroprocessing line, with a daily production rate of 6000 tpd, consisting of the following equipment:
  - A two-string, four-stage preheater with a PYROCLON®-R calciner, a PYROTOP® compact mixing chamber, a tertiary air duct, and two calciner burners.
  - A PYRORAPID® rotary kiln of 5.2 m dia. x 65 m length with a PYRO-JET® burner.
  - A PYROFLOOR® PFC 751.
- Two grinding circuits, designed for 235 tph (at a fineness of 3200 cm^2/g acc. to Blaine), each consisting of the following machines:
  - A RP 20 – 170/180 roller press.
  - A type VS static V-Separator.
  - A 3.8 m dia. x 12.75 m ball mill.
  - A type SKS–Z dynamic separator.

Figure 1. Dry process cement production line at the Pervomaysky plant.

Figure 2. KHD ROMIX®-C v2.0 overview panel.

In line with the scope of supply, Novoroscement also ordered the delivery and installation of the following KHD solutions:

- A ROMIX® raw meal quality control system.
- A PRODUX® process control system.
- A PYROFLOOR® cooler control and process optimiser for a PYROFLOOR® clinker cooler.
- A SCANEX® kiln diagnostic system.

After successful erection, commissioning, and years of stable operation, KHD and Novoroscement decided to upgrade the existing ROMIX®-C controller to the latest version ROMIX®-C v2.0 (Figure 2), which offers model predictive control and an extended range of functions.

ROMIX® guarantees a uniform raw meal quality and facilitates the work of plant operators by improving information availability and analyses reproducibility. On top of that, ROMIX® helps to permanently reduce production costs. ROMIX®-C is part of the ROMIX® product family. The ROMIX® product family includes automatic samplers for raw meal and kiln meal, a pneumatic tube system for sample transport, laboratory equipment with a x-ray fluorescence analyser, and a cross-belt analyser. Moreover, the solution contains adaptive mixture controllers for the automatic control of weighfeeders. Specifically, the ROMIX® product family offers the following solutions:

- ROMIX®-S: fully-automatic, representative sampling for all products and intermediate products in the cement production.
- ROMIX®-T: sample dispatch (transport) by a pneumatic tube system to the laboratory.
- ROMIX®-P: manual or fully-automatic sample preparation for analyses.
- ROMIX®-A: sample analysing with x-ray spectrometers, cross-belt analysers, diffractometers (Rietveld), and laser granulometers, etc.
- ROMIX®-C: model predictive quality control, including statistical methods for permanent identification of raw material composition, plus embedded optimisation methods (e.g. for feed material cost reduction).

Virtual commissioning

In the course of the upgrade process, ROMIX®-C was installed, connected to the client's process control system, tested in various scenarios, and fine-tuned within a period of three days.

The objective of KHD's virtual pre-commissioning approach is to reduce the real commissioning effort for advanced process control systems, as well as minimising disturbances in the client's running process during the actual commissioning phase. A precondition for virtual commissioning is KHD's plant simulation SIMULEX® (Figure 3), which is used to implement and test core production

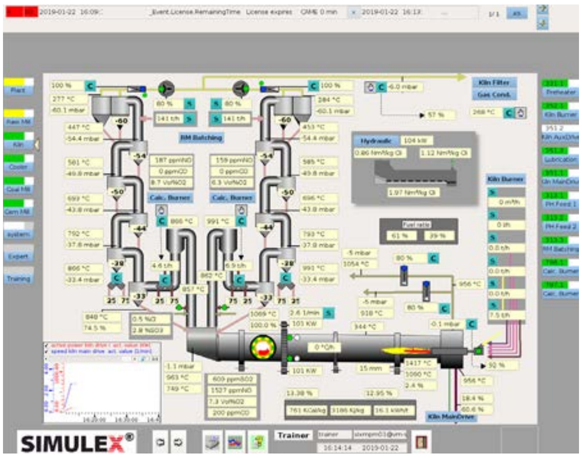

Figure 3. SIMULEX® cement plant simulator.

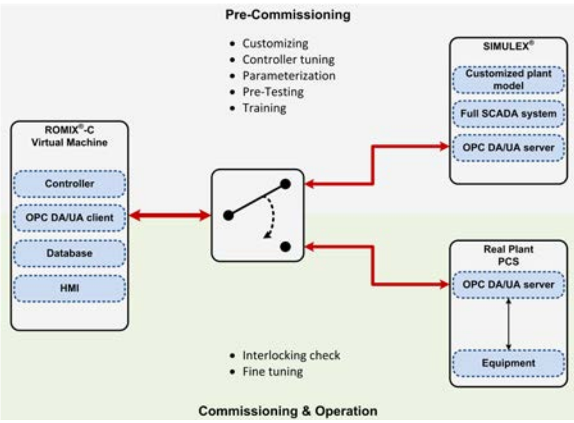

Figure 4. KHD virtual precommissioning advantages.

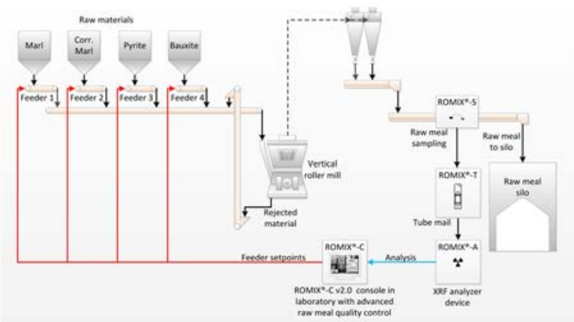

Figure 5. Schematic illustration of the raw material regulation circuit at the Pervomaysky plant.

metrics in a sandbox environment. This also covers aspects such as interlockings, system communication interfaces, and modularity. SIMULEX® was also very helpful during the development phase of new functions and control strategies for the new ROMIX®-C v2.0. ROMIX®-C v2.0 was tested continuously in SIMULEX®, which acted as a software-in-the-loop simulation tool (Figure 4). KHD's expertise in cement process and equipment, which is continuously incorporated into the development of SIMULEX®, enables the simulation to also evaluate other KHD automation solutions, such as MillExpert® or PyroExpert®.

KHD, in cooperation with the German VDZ Research Institute, started the development of SIMULEX® in 2001 to train cement plant operators in a virtual environment. Over the years, many improvements and individual plant configurations have been integrated into SIMULEX®. Today, the simulation allows a realistic reconstruction of the behaviour of a complete cement plant and is also able to interact with external control systems via open platform connections.

In retrospect, the development of ROMIX®-C v2.0 in combination with KHD's SIMULEX® enabled the automation department to test various control strategy functions that could only be designed thanks to multiple development iterations. This was only possible within a realistic test environment, such as SIMULEX®. With the help of this virtual yet realistic environment, it was possible to develop an ideal solution without constantly disturbing the client's production process. The optimisation of functions, as well as testing and software debugging, was performed during the various stages of development within the virtual environment. Thanks to this approach, the overall development time was significantly reduced and the final software quality, in regard to functionality correctness, greatly improved. This enables a shorter commissioning time and an increased acceptance amongst plant operators.

During the development of ROMIX®-C v2.0, KHD also focused on keeping the interface of the customer's process control system backwards-compatible. This allows KHD to upgrade from the legacy system to the newer version with minimal effort on both sides.

The raw meal regulation circuit

The raw meal composition is controlled by adjusting the feed ratios of the raw material feeder. Within an extended period, a control problem arises due to a raw material composition variation, which cannot be constantly measured in the feeding bins.

Figure 5 shows a simplified presentation of the components of the raw-meal control loop at the Pervomaysky plant. All components are withdrawn from the feed bins by weighfeeders and are fed via belt conveyors to the raw mill, where they are then ground into a uniform raw meal.

The raw meal is then stored in a homogenising silo, from where it is forwarded to the pyroprocessing part of the plant. The material is automatically sampled after leaving the raw mill. The samples are then split, collected, and mixed. Representative samples are taken from the collected material at intervals of 30 min. or 60 min. and are sent to the laboratory by the pneumatic tube conveyor system. After the sample has been prepared in the laboratory, it is then analysed in a x-ray spectrometer. The results of the analysis are automatically transferred to the ROMIX®-C system, which offers various interfaces to connect to the XRF or cross-belt analyser devices of different manufacturers.

The number of different raw materials used at the Pervomaysky plant varies based on the composition of the material supplied from different sources. In order to achieve the desired results with regard to lime saturation factor (LSF), silica ratio (SR), and alumina ratio (AR), controlling only the first three weighfeeders is mostly sufficient. As an additional aluminium corrective, bauxite is also used at the Pervomaysky plant and is added on demand. As a result of that, the client needed a quality controller that allows spontaneous switching

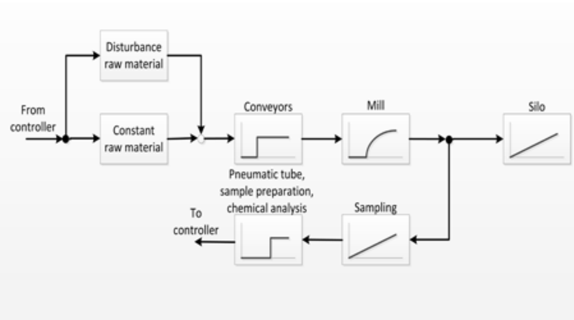

Figure 6. Dynamic behaviour of the raw meal grinding plant.

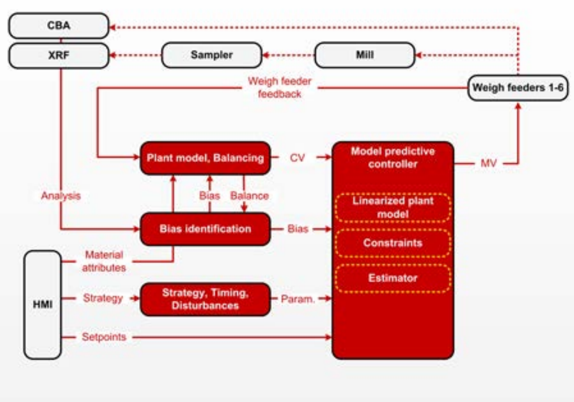

Figure 7. ROMIX®-C control structure.

between weighfeeders and respective materials in real-time during operation.

The internal process model

To ensure the real-time control of weighfeeder setpoints, the new ROMIX®-C uses an internal raw mixing process model that is adapted to the client's raw mill specification. Moreover, it considers all equipment between the weighfeeders and ROMIX®-C workstation. The controller must be adapted to the dynamic behaviour of the examined system, as this is crucial for the control quality. Dynamic behaviour depends on the conveyor, the measuring device, the sampling, the sampling preparation, and the mill's retention time.

All conveyors and pneumatic tubes are considered as transport routes and can experience transport delays, specifically at the sampling preparation or the x-ray unit. During a sample interval, the sampler collects a small portion of raw meal that is then stored inside a small bin. After the sampling interval is finished, the collected material is transported to the laboratory via ROMIX®-P, where it is prepared for analysis by mixing, fine grinding, and compacting. This way the samples are homogenised to achieve constant and more accurate test results.

The dynamic behaviour of the sample can be best described as an integrator, presenting the actual component balance of the current sample cycle, which is reset with each new sampling interval.

The mathematical description of the mill is more difficult. The varying grindability of the components is the reason for large differences in the dynamic behaviour from one plant to another. The mill can be described as a first order lag approximation, with additional time delay for material transfer through the mill. Therefore, new typical values must be determined for each plant. A simplified model of the raw meal grinding plant is shown in Figure 6. In the end, the material that passes the raw mill model is accumulated in a virtual silo or batch of configurable size and duration. The forecast of the composition of a cycle, a batch, or a silo is not only utilised for control, but is also important information for operators that can be accessed by the ROMIX®-C human machine interface (HMI).

The control concept

ROMIX®-C v2.0 is based on a model predictive control (MPC) concept that uses an internal process model and proven optimisation algorithms to reflect the correlations between manipulated variables (MV) and the process outputs (CV). MPC is an advanced method of process control that is designed to optimise the

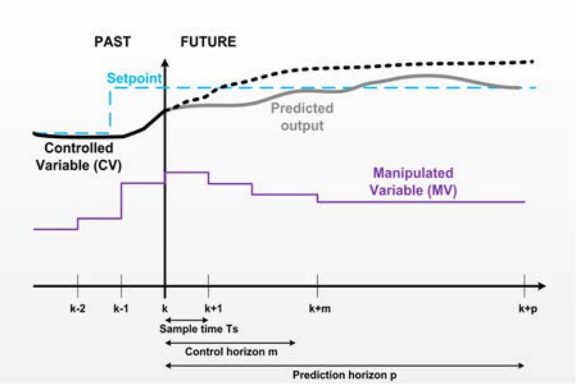

Figure 8. MPC controller behaviour time.

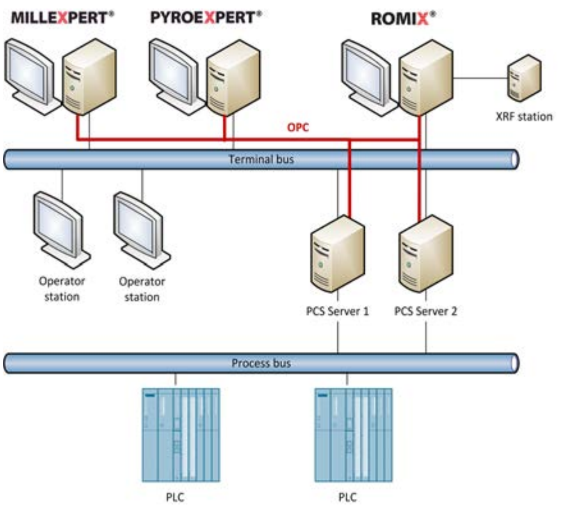

Figure 9. XPERT® in a process network.

process, while satisfying a set of constraints for MVs and CVs. As a result, the controller calculates new MVs in every sample to achieve the control targets in the desired way and with the desired accuracy.

The MVs are the weighfeeder setpoints. ROMIX®-C is able to control up to six weighfeeders simultaneously. The CVs are the common quality key performance indicators for raw meal: LSF, SR, and AR. The CVs can be complemented by two additional key performance indicators (e.g. MgO, SO_3, Cl), which are chosen on a project specific basis. All control targets can be prioritised by the client to meet individual production objectives.

The fundamental structure of a ROMIX®-C control is shown in Figure 7. The following three components work together in a ROMIX®-control system:

- The model predictive controller: based on a professional MPC toolbox, the ROMIX®-C MPC calculates future moves of MVs by solving the optimisation problem online. Therefore, it uses an explicit process model that is a light version of the more detailed internal process model. MVs can be constrained in their absolute value and the rate of change. The CVs can also be constrained and weighed based on control objectives.
- The internal process model with component balancing: the detailed process model is used to precisely calculate the situation inside the raw mill in real-time. Also, the balancing of the sample, batch, and silo are calculated here.
- Bias identification: the bias identification module is responsible for correcting the real-time values and balances generated by the internal process model. It compares the expected compositions with the results of the analyser and manipulates the internal model's parameters to adapt the internal results to the plant situation. It is fed with the analyses of the raw meal that periodically arrive from the sampler.

Based on the reduced model, constraints, control objectives, and weighings, the MPC's solver calculates new MVs at every sample interval. Therefore, it determines the future prediction of all CVs over a prediction horizon, depending on a future control sequence (Figure 8). Minimising the distance to the control targets and not violating the constraints on multiple MVs and CVs within the complete prediction horizon is the main objective of the MPC solver. Furthermore, the accuracy and aggressiveness of the controller can be adapted for each CV by individual weighing factors.

Due to the fact that the MPC's internal model is not an exact representation of the real process, the MPC approach incorporates a state estimator, which has the purpose of keeping internally-calculated plant outputs at or close to the real outputs. This is done by manipulating the internal states of the MPC, compensating the modelling error and ensuring a higher robustness and reliability of the controller.

All parameters of the MPC controller are determined and preconfigured during the virtual commissioning phase with a SIMULEX® model that reflects the client's system. This prevents disturbances of the real-time process during the actual commissioning.

The preconfigured parameters, and the high robustness of the internal process model and the pretested controller, made it possible to hand over the weighfeeder control to ROMIX®-C at the Pervomaysky plant immediately after the communication to the client's process control system (PCS) was established.

Thus, the subsequent tasks during the commissioning phase were only undertaken to demonstrate the differences between the provided control modes and for a final fine-tuning.

System architecture and coupling to the process network

A big advantage of the simple commissioning of the new ROMIX®-C at the Pervomaysky plant was that the system is set up as a virtual machine (VM) that runs as a service on an industrial workstation. The VM contains all essential software components to run the application. The workstation hosts the VM, as well as the remote support client and a remote HMI application. It is not mandatory for the HMI to be bound to the ROMIX®-C workstation, which itself often needs to be located close to the XRF device due to the direct coupling type. The HMI client can be installed on multiple PCSs, as long as they have a network connection to the ROMIX®-C workstation. For this purpose, the system has a comprehensive user and rights management system. This enables laboratory personnel to change parameters, plant operators to keep track of the current key performance indicators, and the quality manager to generate detailed ROMIX®-C protocols, all at the same time.

The existing IPC hardware of the former ROMIX®-C system at Pervomaysky was reused.

The connection to the client's PCS is done by OPC-DA or OPC-UA data access, if desired, in a redundant configuration that increases the availability of the system (Figure 9).

To back up a ROMIX®-C system, including connection settings, historical data archive, and all licenses, it is only necessary to perform a backup of the VM files hosted on the ROMIX®-C workstation. This enables the client to replace defective hardware and to set up the system on new hardware without the support of KHD.

At Pervomaysky, the system is connected to both PCS servers via a redundant OPC-DA link. The XRF analyser is connected via serial cable to the ROMIX®-C workstation. Next to the PCS' network connection, the client installed a network link with internet access. This can be used by KHD in case remote support is needed. Only the PCS link is forwarded to the VM. The hosting system is completely managed by the client and integrated into its network security concept.

Conclusion

After the successful commissioning of the new ROMIX®-C v2.0 system at the Pervomaysky plant, the owner (Novoroscement OJSC) certified that the ROMIX®-C v2.0 provides "new functionality for the automated performance control of the weighfeeders of the raw mill, depending on the chemical composition of raw meal control samples after the mill". Furthermore, Novoroscement stated that "regulation with the upgraded ROMIX®-C module enables desired accuracy at achieving setpoint values for LSF, SR, and AR for three component raw mixtures (marl, correction marl, pyrite), as well as LSF, SR, and AR modules for the four component raw mixture (marl, correction marl, pyrite, bauxite)". On top of that, the client highlighted the commendable features of the software, which offers several regulation strategies, and an intuitive user-friendly interface, as well as a convenient integrated data archive and reporting functions.

Delivering a completely pre-commissioned ROMIX®-C control software that was tested within SIMULEX® in a software-in-the-loop simulation environment was the key factor for the high acceptance of the client during commissioning and the subsequent installation phase.

The utilisation rate of ROMIX®-C v2.0 at the Pervomaysky plant was above 95% since commissioning. All control targets for LSF, SR, and AR were achieved with the desired accuracy, even with all parameters being determined during the virtual pre-commissioning phase. After one day of fine-tuning, the control accuracy was increased to an optimal level. The commissioning, fine-tuning, and testing of the new ROMIX®-C, including the training of Pervomaysky plant personnel, was completed within four days onsite.

To summarise, the new ROMIX®-C v2.0 offers clients the following advantages:

- Higher control quality due to continuous automatic compensation of raw material fluctuations.
- Higher robustness due to automatic model adaptation during run time.
- A model-based approach enables permanent, real-time control, deals with failures and fluctuations in the availability of analyses, and improves the handling of problematic conditions (e.g. weighfeeder failure).
- An increased scope of control targets and optimisation functions.
- Overall cost minimisation.
- Significant reduction of the commissioning effort thanks to a virtual precommissioning approach.
- Simplified backup and recovery strategies.
- Increased system security by embedding all system-relevant software components in the VM.
- A more intuitive and user-friendly interface. ■

About the authors

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