ADVANCED SYSTEM FOR TECHNOLOGICAL PROCESS CONTROL

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Abstract

Industrial furnaces belong to the basic thermal apparatuses for material processing in many industry branches. The model based predictive control is the most suitable control approach. Developed control system consists of three level hierarchies. At the optimization level optimal control trajectory and its responding controls are determined at the time of material charging. At the discharging time period the model is calibrated, and real process trajectory is determined. The difference of optimal and real control trajectory used for the control correction at the stabilization level. Process monitoring and control of individual loops are executed at the basic level. Control interval is set according the difference of optimal and actual process trajectory. The simulation model is based on the first principles and enables real time simulation. Optimal working point can be determined according selected performance criteria which includes technical, technological, economic and environmental indexes. Control system is visual promoted. Visual support enables internal view to the furnace and it is oriented on the extraction of critical process and equipment parameters. Developed model based on predictive control system was applied on the rotary furnace of magnesia sintering at SMZ Jelsava, Slovakia.

Keywords: Rotary furnace, predictive control, magnesia sintering, process optimization

Introduction:

Process control is principal approaches to increase process performance. Model-based predictive control (MPC) is an advanced method of process control. Mathematical models in MPC are generally intended to represent the behavior of the complex dynamical systems. In many raw materials beneficiation operations, the economic objectives can be translated into the maximization of throughput with suitable constraints on the product quality distribution. Optimum operation of granular materials thermal treatment is important for the economic recovery of the valuable substances, for energy efficiency, as well as from the point of view of pollution control. While controllers at the regulatory level are capable of controlling the process at the desired values of the process variables, a supervisory control system based on a process model will be required for optimization of the furnace operations. In the supervisory control system economic objective function is used for on-line optimization to determine the optimum set points for the controlled variables.

1. Predictive control:

Simple formulation in the time area, and from that also result simplicity in the implementation of restriction – input, output and states variables is the main advantage of the predictive control. Next important contribution of predictive control is simple application for the control of multidimensional systems and systems with a significant transport delay. Mathematical model is also used for the prediction of output behavior on a long time horizon. Main control problem is to keep required process output under fluctuated boundary conditions and operating conditions. The main factors influencing product quality are charge composition, processing temperature and processing time, sinter density, sinter composition, sintering temperature and sintering time. The sintered magnesia density is hard to measure online and cannot be controlled directly in these days. Therefore online measurable technological parameters with closed relations to the quality index were chosen so that the quality index control is realized indirectly.

There are two key issues about the control problem of quality index of furnace production. One is how to keep the furnace temperature distribution satisfying technical requirements under fluctuated boundary conditions and operating conditions, i.e. burning zone temperature, furnace tail temperature and residual oxygen content in combustion gases in their technically required ranges. The second is how to adjust the set point range of burning zone temperature so that the sinter quality may be kept under fluctuated boundary conditions and operating conditions.

On the supervisory level (Fig. 1) optimal process trajectory and the optimal control are determined. Optimal trajectory is characterized by corresponding indexes. In our case it is time of beginning of the calcination, time of beginning of the sintering and value of the maximal temperature.

The process control level includes material output, fuel volume, combustion air volume and flue gas volume to make the burning zone temperature, the furnace tail temperature, and the residual oxygen content in combustion gas to satisfy determined requirements. The measured quantities are fuel volume, combustion air volume, temperature of calcinations, sintering and cooling zone, flue gas temperature and composition. Individual controllers create basic loops controlling gas flow, combustion air flow, cooling air flow and material flow.

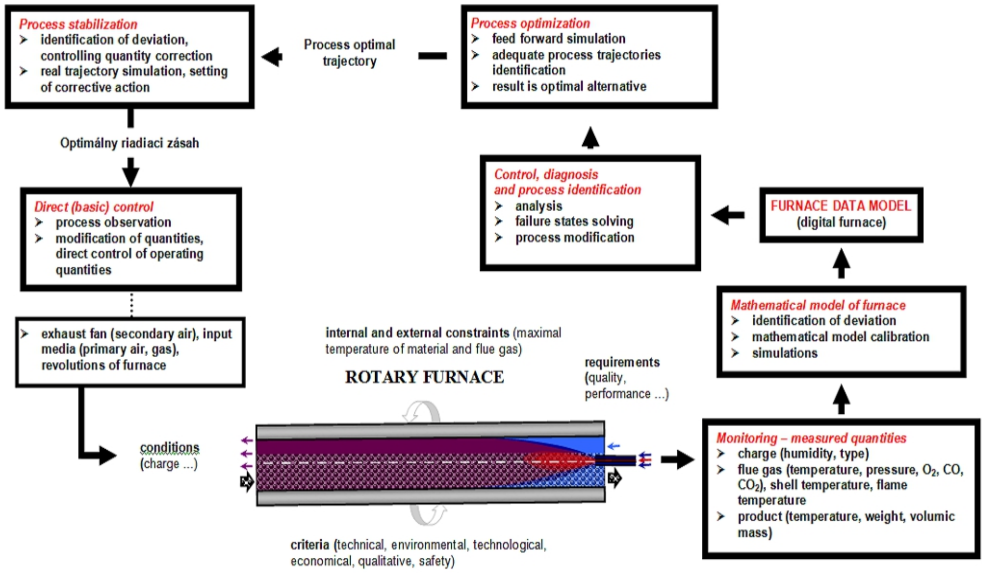

Fig. 1 Rotary furnace predictive control system

1.1 Criteria for the predictive control system

For the control system can be used criteria of quality, economic, technical, technologic and environmental influences. For determination of the optimal control this criteria are not effective due to limitations on the simulation time. For this reason internal criteria were determined.

On the Fig. 2 criteria position of some selected index is determined. By such away the selection of the optimal trajectory is reduced on the determination of the reference position of the critical point. The movement of the point to the right means worsening and the shift to the left means improving of the selected criteria. For the magnesia sintering in the rotary furnace the critical points are:

- begin of caustification,
- end of caustification,
- maximal sintering temperature,
- sintering time.

The optimal process trajectory for the change of critical points position is on Fig. 2.

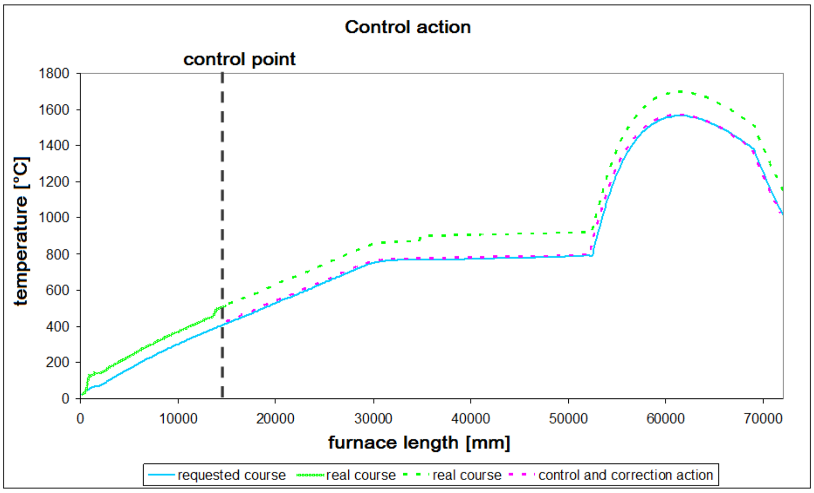

Fig. 2 Determined criterial position and control action

1.2 Control system strategy

The control problem is to keep density of the sintered magnesia under fluctuated boundary conditions and operating conditions. The principal factors influencing sinter density are sinter composition, sintering temperature and sintering time (Fig. 3). Sintered magnesia density is hard to measure online and cannot be controlled directly. Therefore online measurable technological parameters with closed relations to the quality index were chosen so that the quality index control is realized indirectly.

In the sintering process, normal range of sintering temperature of raw material depends upon its composition. Variations of components of raw material (Tab. 1, Fig. 4) require corresponding variations of sintering temperature.

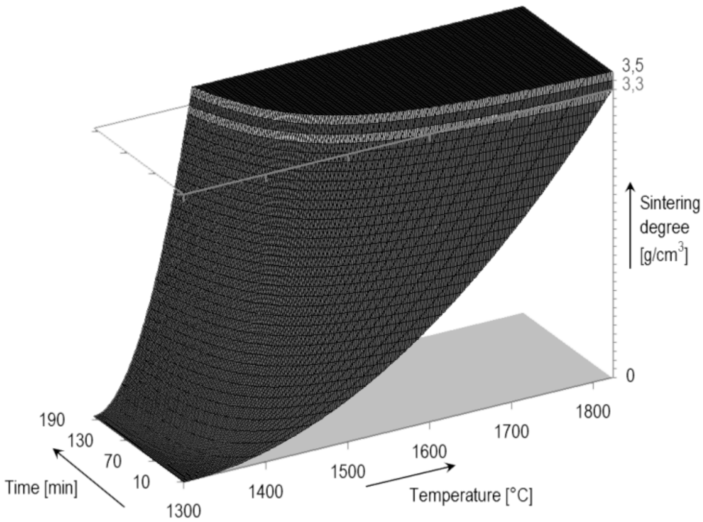

Fig. 3 Sinter quality - sintering temperature and sintering time relation

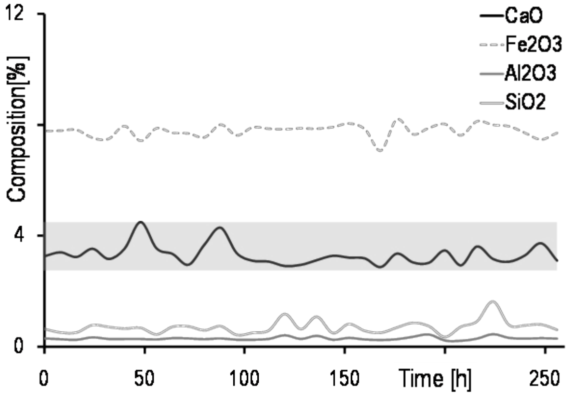

Fig. 4 Time behavior of the rotary furnace charge composition

Tab. 1 Compositions of concentrates

Concentrate	MgO (min %)	CaO (max %)	Fe_2O_3 (max %)	SiO_2 (max %)
K1 1-10	43,0	2,7	3,8	0,5
K1 10-40	43,5	2,2	3,8	0,4
K2 10-40	41,3	3,0	3,9	0,6

Inconsistency of real sintering temperature range with requirement of raw material will results in over burning or under burning, and sinter quality is not satisfactory (Fig. 5). Raw material composition, sintering temperature, and sintering time are the main factors influencing the sinter quality. Relation between sintering temperature and raw material composition is unknown function, which can be determined experimentally. Key issues about the control problem are quality index and furnace production rate. One is how to keep the furnace temperature distribution satisfying technical requirements under fluctuated boundary conditions and operating conditions, i.e. burning zone temperature, furnace tail temperature and residual oxygen content in combustion gases in their technically required ranges. The other is how to adjust burning zone temperature the set point range so, that the sinter quality may be kept under fluctuated boundary conditions and operating conditions.

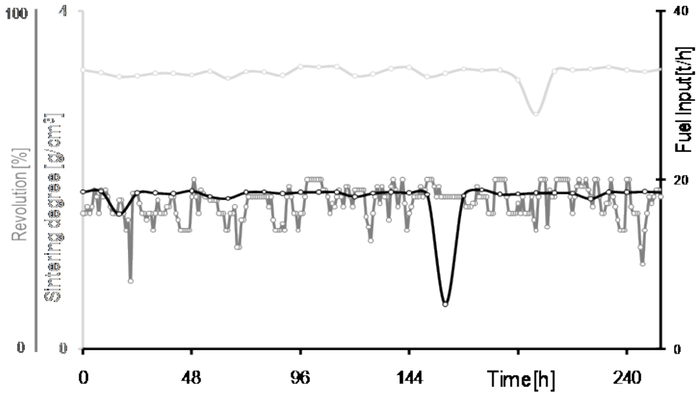

Fig. 5 Sinter quality

Designed supervisory control system consists of a supervisory level and a process control level (Fig. 6). Objective of the supervisory control system is to keep the production quality index under changed boundary conditions.

The process control level includes material output, fuel volume, combustion air volume and flue gas volume to make the burning zone temperature, the furnace tail temperature, and the residual oxygen content in combustion gas to satisfy determined requirements. The measured quantities are fuel volume, combustion air volume, temperature of calcinations, sintering and cooling zone, flue gas temperature and composition. Individual controllers create basic loops controlling gas flow, combustion air flow, cooling air flow and material flow.

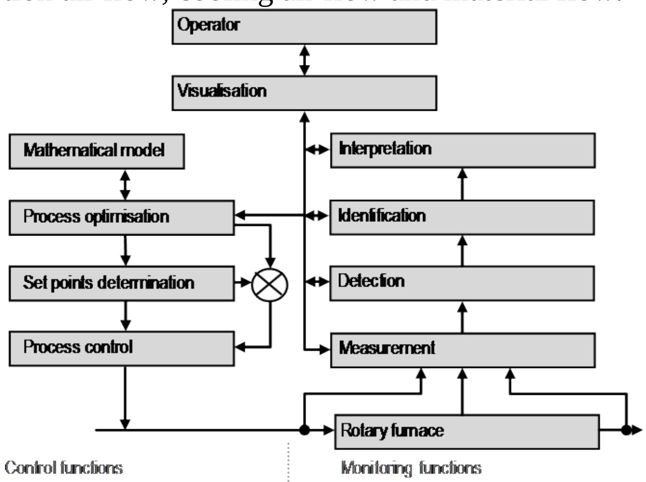

Fig. 6 Rotary furnace control system hierarchy

2. Results:

2.1 Supervisory level

At the supervisory level operator adjusts the set points range at the process level according the process state, production scheduling and production experiences. Due to unstable raw material composition and granulometry, components of raw material often change. The off line analysis data reach the operator with large time delay so that the operator cannot directly adjust the set points. As a result, single controllers cannot maintain satisfactory performance. In such a case, a human operator usually rectifies the output of the controllers based on the experience. Such interventions can adapt the variation of the operating conditions to a certain degree to sustain the quality of the product. To deal with such a problem, a furnace model is appended. When the offline analysis of components of raw material is known, the setting selector mechanism triggers the model to calculate the proper set point range. When the components of raw material are unknown, the compensation model is triggered to calculate the proper upper and lower limits of set point range (Fig. 7).

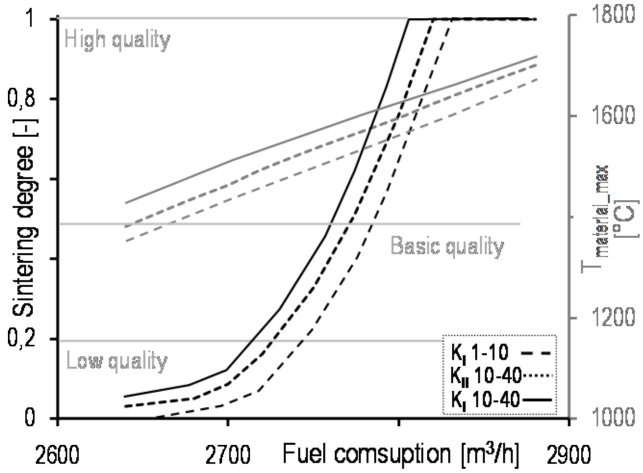

Fig. 7 Criterial quantities interdependency

Finding the optimal solution for selected criteria is very time consuming and cannot be effectively realized in the real time. Alternative solution is selection of adequate criterion on the process level. For magnesia sintering, maximal sintering temperature is adequate criterial quantity.

2.2 Process operation

The supervisory system estimates the variations of the furnace operating conditions and adjusts the set point range of material throughput accordingly. Set point adjustments should be made when the supervisory system make accurate judgment about the furnace operating conditions. Because of complexity and fluctuation of the furnace operating conditions, accurate judgment for current state usually needs long time, and the time span between two set points adjustments cannot be too short, otherwise a calculated immediate reward cannot reflect the real influence of the above adjustment upon the behavior and performance of the control system. After long term running, large characteristic changes of components of raw material and of furnace may appear. Under new operating conditions the previous optimal design might become invalid. This needs model correction and new optimal design to keep good performance of the control system for a long term period. In this case model calibration should be switched and with the corrected model improved furnace performance can be achieved, so that the control system has a strong adaptability for the long term running. Developed control system was applied on the rotary furnace No. 3 of SMZ Jelsava, a.s., Slovak Republic. Treated magnesite is of breuneric type. Its composition is: CaO (4-8%), SiO_2 (0,5-1,5 %), Fe_2O_3 (above 7,5%). Required sinter density is 3,25 – 3,35 g/cm^3. Furnace capacity is of 10,5 t/h. Furnace production rate is limited by the sintering temperature. Maximal sintering temperature is limited by the sinter fusion, and the lowest sintering temperature is limited by production of not sufficiently sintered material. Optimal trajectory for different charge quality is presented on Fig. 8 and Fig. 9.

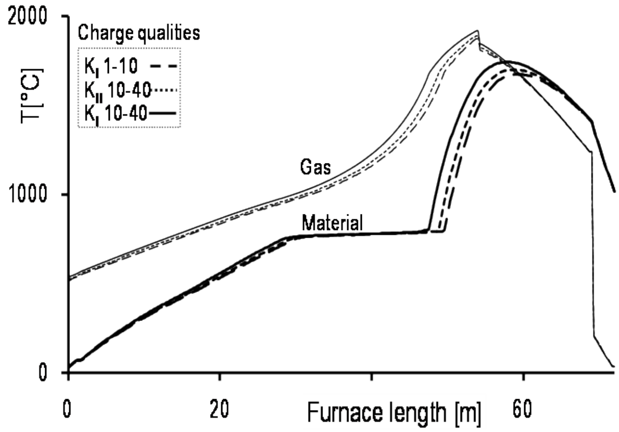

Fig. 8 Criterial quantities interdependency

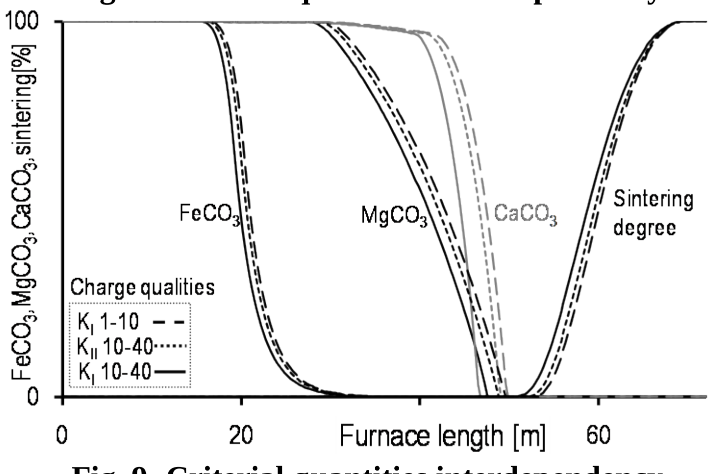

Fig. 9 Criterial quantities interdependency

3. Discussion:

Presented approach is new in the dimension of operations in the digital world. Developed rotary furnace supervisory control system was applied to control digital furnace which is equivalent to the productive furnace. Its equivalency was achieved by model calibration. By this approach many limitations of the classical control systems were removed. Economical contributions were estimated on the data from productional rotary furnace far of 8 %.

Further improvement is oriented on the increasing of adequacy to the real world and on the possibility to execute the whole simulations in the real time. Also development is focused on deepening and enlarging of existing system.

The application of the neuronal network on the optimization of the process trajectories will enable to use first principles mathematical model for real time simulation (Fig. 10).

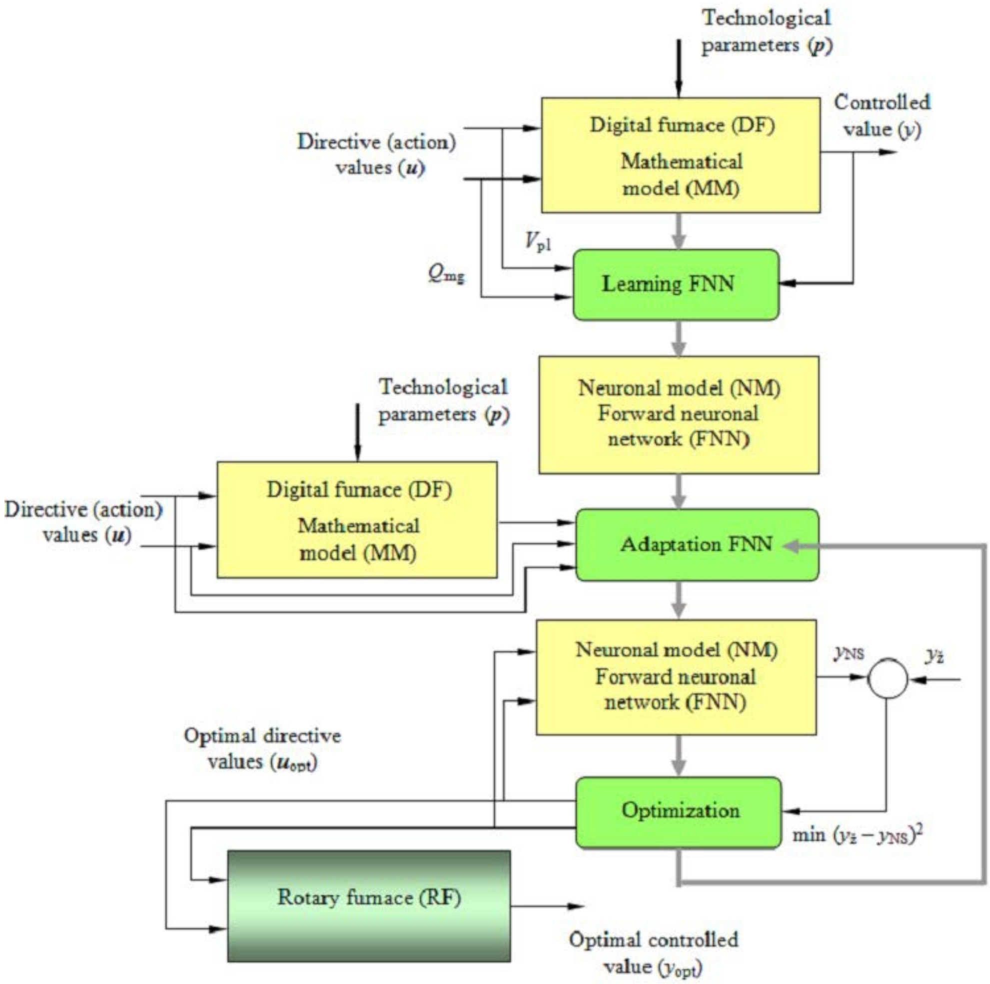

Fig. 10 Neuronal network application for the predictive control

Conclusion:

Operation of rotary furnaces for magnesia sintering is a difficult task and relies on experienced human operators observing the sintering status. The human-machine coordination is addressed when we design the rotary furnace control system, and the human intervention, and adjustment can be introduced. Except for the emergent operation conditions, that need urgent human operation for system safety, the fact is observed that human interventions to the automatic control system usually imply human's discontent to the performance of the control system when the variation of conditions occurs. From this idea supervisory control system was designed. The optimal operating conditions and adjustment of important controller set point parameters can be established gradually. Application of this strategy has shown that the adaptability and performance of the control system have been improved.

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