HYBRID MODEL-BASE PREDICTIVE AND PROPORTIONAL-INTEGRAL-DERIVATIVE TEMPERATURE CONTROL SYSTEM FOR LPCVD PROCESSES

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A hybrid Model-Base Predictive Control (MBPC) and Proportional-Integral-Derivative (PID) temperature control system is developed for LPCVD processes. The MBPC control algorithm is based on both multiple linear dynamic mathematical models and non-linear static mathematical models, which are derived from the closed-loop modeling control data by using the closed-loop identification method. The model-based predictive control (MBPC) methodology is used for developing a hybrid MBP+PID temperature control system (MBPTC) with a robust PID auto-tuner.

To provide a high quality temperature control system for LPCVD processes in a batch vertical thermal reactor, a new hybrid cascade control scheme is proposed (shown in Figure 1). It can be used to satisfy the different temperature control requirements that may include high temperature ramp rates with good dynamic temperature uniformity, fast stabilization with very small or without temperature overshoot, extremely small steady-state error band, lower heat budget, shorter down-time for controller parameter tuning and so on.

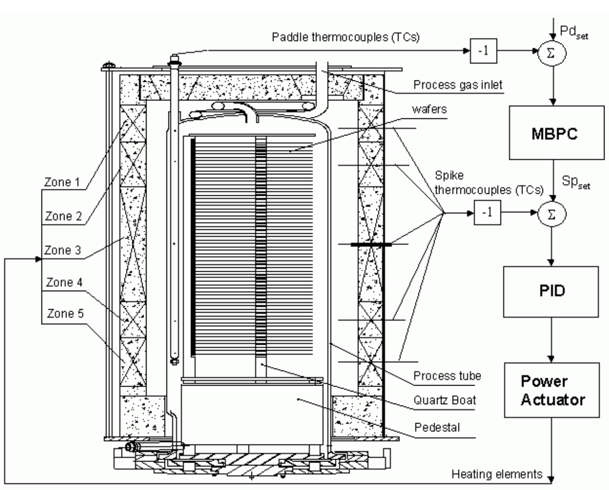

Figure 1 Hybrid Cascade Control Scheme of Vertical Thermal Reactor

The hybrid control scheme comprises two control loops: the inner control loop (PID) and the outer control loop (MBPC). The PID control loop with auto-tuner and anti-wind-up effects is used to control the heater power directly so that it can reject some disturbance and non-linearity from the electric heating coil. On the other hand, PID controller is also used for acquiring temperature data to build the models. The multiple linear dynamic mathematical models are off-line derived from the PID close-loop control data. Using linear models, constant predictive horizon and two embedded tuning parameters (Ku, Ks) in MBPC control law, the complex MBPC control algorithm is simplified. Based on the identified mathematical models, the outer MBPC control loop is used to generate the set points for the inner PID control loop so that the control margin of the whole temperature control system is enlarged.

By using the new hybrid control scheme, parameters tuning of the two control-loops are not strongly coupled. In other word, the control behavior (aggressive or sluggish) of the inner PID control loop has no seriously influence on the performance of the outer MBPC control loop because the control behavior of inner control loop is already incorporated in the mathematical models. Due to this reason, the PID parameter auto-tuner can be designed independently. Therefore, such a design fully uses the advantages (simple structure and design) of PID and overcomes its main disadvantage (difficult parameter tuning). In our case, the inner PID control loop can be thought of as a fast and generic power driver of the power actuator. And it also acts as an effective exciting signal generator for modeling, which simplifies the model identification procedure and makes the on-line modeling possible. Due to the use of inner PID loop, both the model order and predictive horizon can be dramatically decreased, which greatly simplifies the computing of MBPC. This is why in our new hybrid cascade control scheme a PID control loop is still adopted.

In order to provide a more flexible, stable and safe temperature control solution, the trajectory planners, fuzzy inference engine, control output limiters based on the static models, hardware failure detector and soft-sensors based on the dynamic models are also added to the outer MBPC control loop. Then by using only two intuitive tuning parameters (Ku and Ks) in the MBPC control loop, both the dynamic and static performances of the temperature control system can be easily controlled by the users.

Compared with the traditional temperature control methods used on the vertical reactors, the new hybrid control method has the following advantages:

- Accurate dynamic and static temperature control performances;
- Easy, less, intuitive or without parameters tuning;
- Soft-sensors based on the dynamic models computing ensure the batch processes safety;
- More advanced control technology can be easily implemented in the temperature control scheme to satisfy the more critical temperature requirements;
- More flexible controls possibilities.

Implementations of MBPTC on the ASM LPCVD vertical thermal reactors exhibit the significant benefits such as improved uniformity, high reliability, and stabilization-time reduction for the different LPCVD processes. Furthermore, the novel MBPTC control scheme can provide more wide temperature control solutions for the coming LPCVD processes.