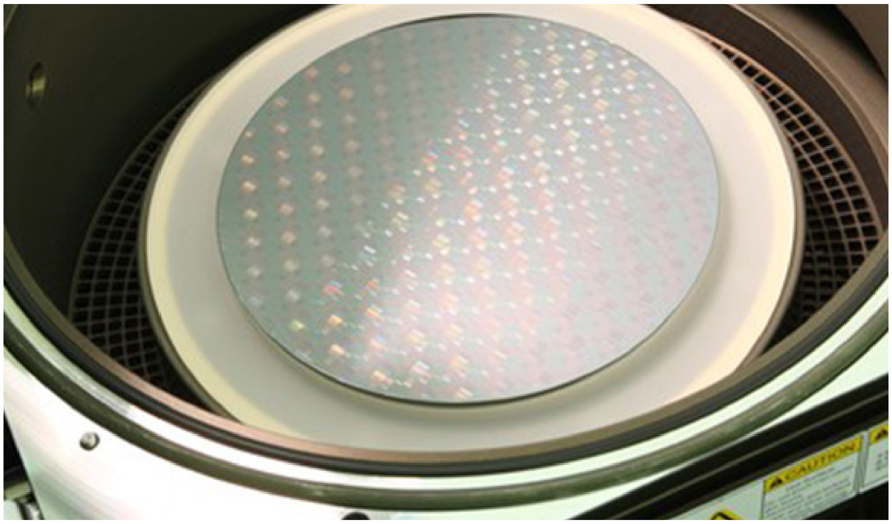
Model-Based versus PID Control



Challenge

To demonstrate the significant advantages of Model-Based Control (MBC) over standard PID control with regard to performance and robustness.

BACKGROUND

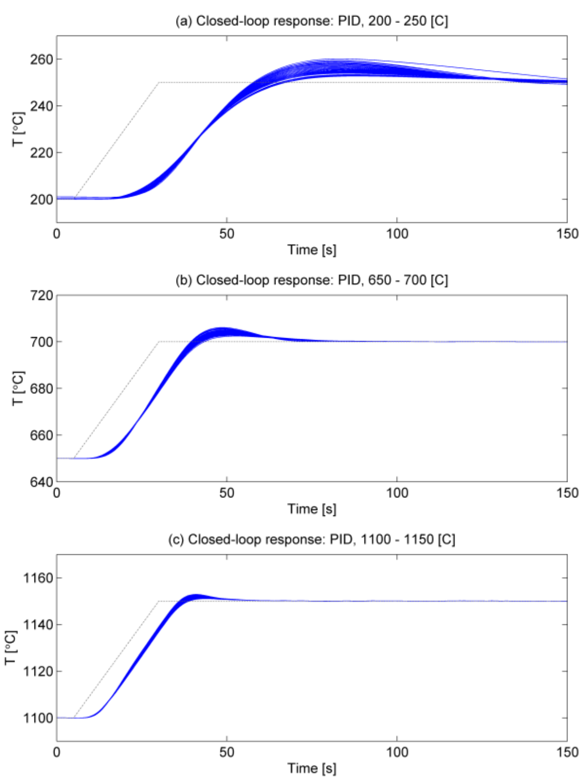
Many modern thermal processing systems involve temperature control of heated plates. Typically, these plates are heated by infrared radiation from hot filaments (including tungsten halogen lamps) and the temperature is measured using pyrometers. In many cases the temperature of the system is controlled using a Proportional-Integral-Derivative (PID) controller. However, there are applications where the temperature must be ramped up (or ramped down) rapidly while maintaining good temperature uniformity and with tight performance limits. In these cases, it may be difficult, or even impossible, to achieve the desired performance using PID controllers. In addition, the dynamic response of these systems typically changes considerably with operating conditions such as temperature, process gas composition, wafer emissivity, or wall emissivity (e.g., in systems where walls become coated during the deposition process). These changing operating conditions can make it difficult to tune a PID controller to achieve the desired performance over a broad range of operating conditions.

To improve performance in such situations, PID controllers are often gain-scheduled using different PID gains for different operating conditions. However, the limitations of PID control still apply, and gain-scheduling increases the amount of effort needed to tune the gains. Alternatively, even more complex controllers can be designed, such as Linear Quadratic Gaussian (LQG) controllers, but this requires the close involvement of an expert in the field of systems and control which is impractical in fabs.

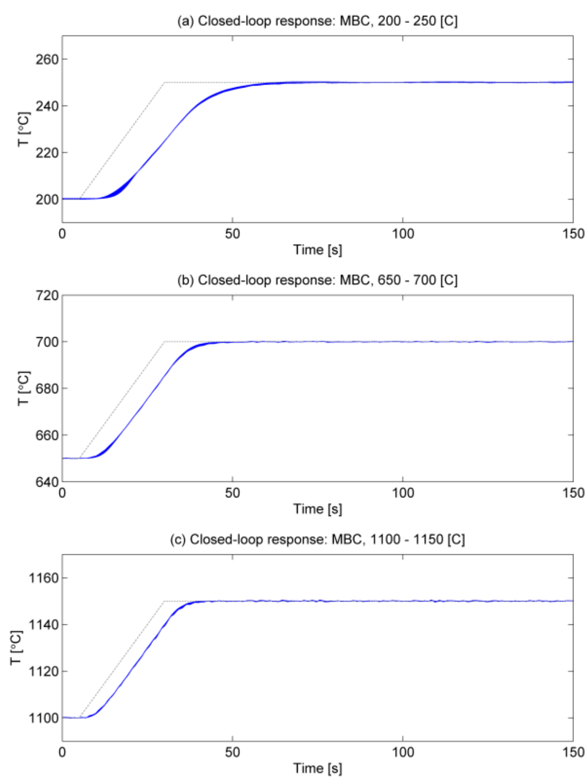
SOLUTION

SC Solutions has developed and refined a model-based control approach that can achieve good performance for a wide range of operating conditions. In this approach, e.g. for temperature control, a mathematical model of the relevant physics of the system is directly incorporated into the feedback controller. Thus, the controller incorporates knowledge of how the system dynamics change with the operating temperature.

Once the plant model is developed using information of the chamber geometry, material properties, etc., the controller design is relatively simple compared to an LQG controller. The design of the controller comes down to a few simple choices, such as the selection of the bandwidth of the desired closed-loop system. The set of graphs in the two figures below show the superior performance of the MBC controller compared to a standard PID controller for a heated plate.



PID Performance



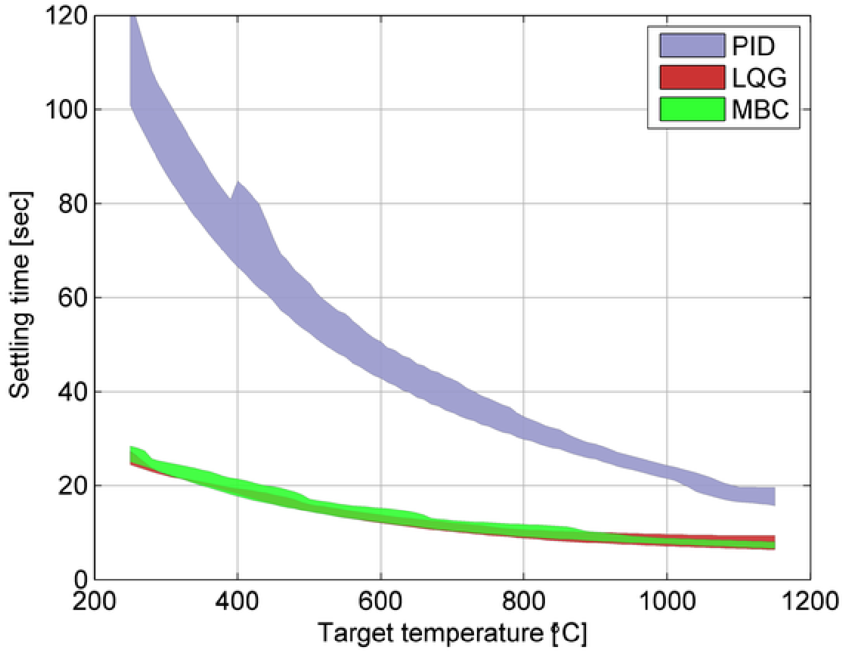
MBC Performance

In another simulation study, we compared the robustness and performance of this model-based controller to that of a gain-scheduled PID controller, as well as an LQG controller for a range of plate properties and operating conditions. In the set of graphs in the three figures shown below, the three control design methods are compared in terms of their ability to handle system modeling uncertainty, tracking performance (overshoot, settling time, etc.), and noise accommodation properties.

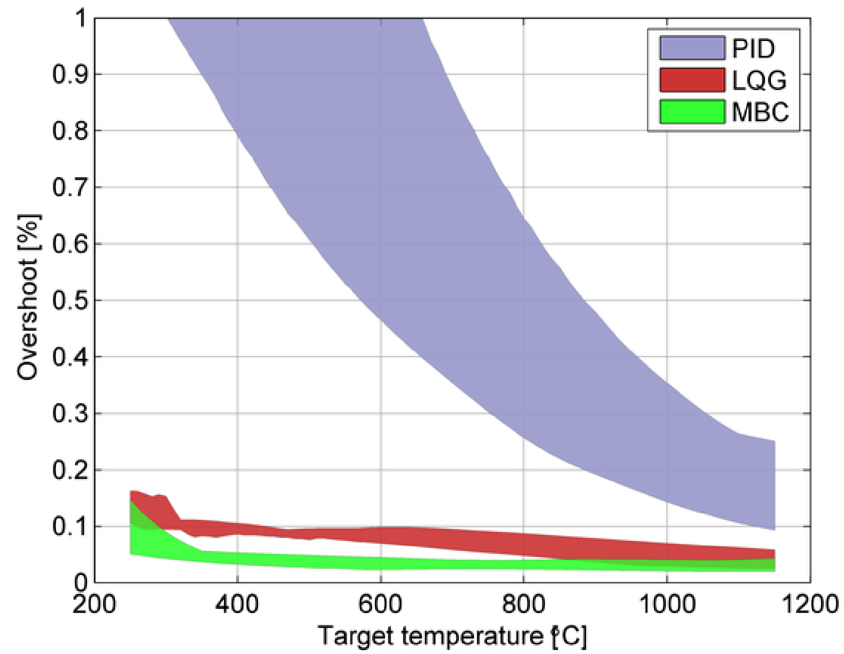
The simulation studies show that the model-based approach, as well as the LQG controller, yield significantly better performance and exhibit a much lower sensitivity to variation in system properties compared to a gain-scheduled PID controller, at the expense of a slight increase in noise sensitivity. The model-based controller has the added advantage of having a simpler and more intuitive design process than the more mathematically complex LQG controller.

When comparing Model-based Control (MBC) with standard Proportional-Integral-Derivative (PID) control, MBC has distinct benefits. This case study shows that in terms of performance, an MBC method outperforms a gain-scheduled PID controller in all performance areas such as overshoot, worst-case settling time, and robustness against

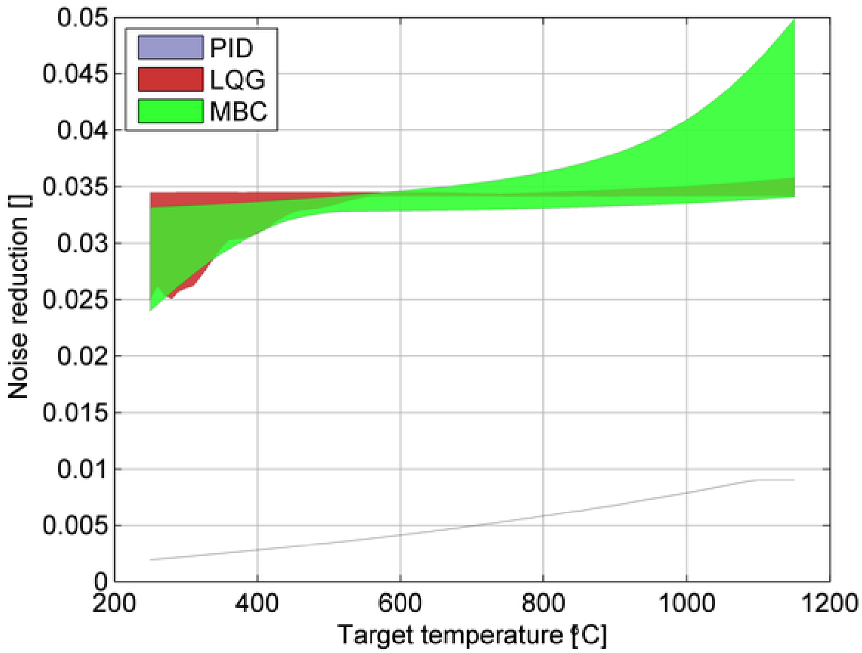
Comparison of PID (blue), LQG (red), and MBC (green) for different target temperatures



Settling times



Overshoot



Noise reduction

system variations, at the expense of a slight increase in sensitivity to sensor noise. The model-based controller provides similar results as those obtained with the more mathematically-complex LQG controller, but has the advantage of a simplified and more intuitive design, resulting in the possibility of more efficient implementation and maintenance in a production environment.

The process of tuning of an MBC reduces to adjusting a simple 'bandwidth' knob in order to achieve the desired performance for the specific application. The design of the controller changes from ad-hoc tuning to modeling the performance-relevant system dynamics. Once a control-relevant model is derived, tuning of the MBC is quite straightforward.

While tuning simplicity is desirable, the primary advantage of Model-based Control is the superior performance that is achieved, which is a very important competitive advantage for our customers in today's manufacturing environment.

More details regarding this comparison between MBC and PID are available in our publications. For further information, please contact us.