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Controller design for solar once-through boilers in direct steam generation line focus systems

J. F. Feldhoff, D. Trebing, T. Hirsch, L. Keller and R. Pitz-Paal (all DLR),
L. Valenzuela (CIEMAT-PSA)
Corresponding author: J. F. Feldhoff, jan.feldhoff@dlr.de, DLR Stuttgart, Germany

The DUKE project

The project's goal is to develop and demonstrate the direct steam generation (DSG) in once-through mode in parabolic troughs under real solar conditions and at a commercial scale. There are four project phases:

1) Upgrade of former DISS test facility
2) Component qualification
3) Dynamic response testing and model validation
4) Control design and demonstration

This poster deals with phase 4.

Control task and challenges

The main goal of control is to keep the loop outlet temperature constant. This can be done by manipulating the mass flow(s) into the loop. Difficulties arise by the following issues:

- Non-linear and non-minimum phase characteristics of overall system
- Slow and fast time variant parameters
- Long and varying time delay of inputs and outputs
- Limited accuracy of analytical transfer functions
- No buffer compared to DSG plants with recirculation mode

Design strategy

- Use simple control structures to allow easy application with little tuning effort
- Design from a large plant point of view with as few sensors as possible
- Design for maximum energy output, i.e. mass flow control by additional injection(s) instead of de-focusing
- Derive new design rules based on adaptive and internal model control ideas such that only step responses of the system are needed in advance

Easy-to-design PI controllers

Proportional-integral (PI) controllers are standard in industry and familiar to most engineers. Therefore, we use those controller types and provide design structures and rules that allow robust operation of the plant.
We recommend splitting the loop into two or three separate controllers in order to reduce reaction times (Fig. 1):
A: outlet temperature controlled by injection mass flow.
B: temperature before injection controlled by inlet mass flow.
Controller B can be significantly improved and robustness can be added, if a second injection in the evaporation section is introduced. The design of this injection control is then analogous to controller A.

The **main new features** compared to the state-of-the-art controllers [Valenzuela et al., DSG in solar boilers, Control Systems, IEEE, 24 (2), 2004] are:

- Adaptation of controller gain and integration time depending on load situation (inlet mass flow and irradiation) from pre-calculated design ('gain scheduling')
  → Significant improvement in controller performance
- Feedforward term especially in B considering the variation in incidence angle not only for current instance, but for upcoming delay period.
  → Significant improvement in morning and evening operation
- Feedforward terms only based on reliably measurable disturbances
- Non-minimum phase characteristics considered in controller design.
  → Significant improvement in disturbance rejection and robustness

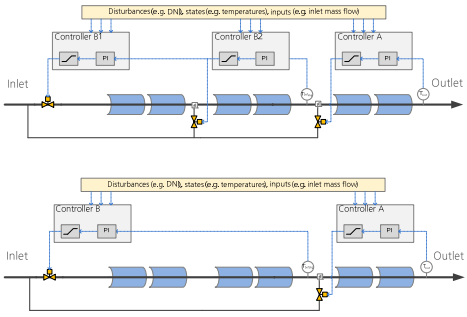

Fig. 1: Two variants of control loop splitting with one (bottom) and two (top) injections.

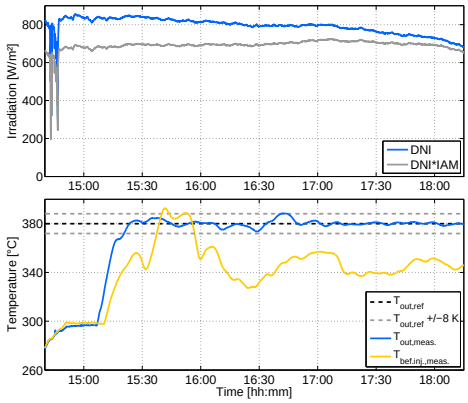

Fig. 2: Outlet temperature control by injection controller A, while various disturbances are imposed on the system, especially on temperature before injection (DISS test facility, experiment Sept. 5, 2014).

Conclusions and outlook

Easy-to-apply design rules have been developed for standard PI controllers. Only the knowledge of step responses (e.g. from simulations) is needed. Although working reliably, these controllers can further be improved by introducing more complex adaptation schemes and pre-filters. These schemes are currently being developed.

For more details, please contact the main author.

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