Controller Tests for Molten Salt Parabolic Trough Systems with Loop-Wise Control Valves

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Figure 1. EMSP Platform

Abstract

Concentrated Solar Power systems are used to generate thermal and electrical energy from solar radiation. Molten salt as a heat transfer medium offers the possibility of a higher temperature in the solar field and at the same time the use of direct energy storage. The Évora Molten Salt Platform (EMSP) is a research platform to study molten salt in the solar field on a precommercial scale (Figure 1). The use of molten salt requires to adapt control concepts used in thermal oil fields since the temperature rise over the loop and the loop length are different from those of thermal oil. One approach is to use automatic valves in each loop to individually control the loop outlet temperatures. This poster presents controller tests performed at molten salt loop of the EMSP in normal operation and start-up mode. Results are the basis for an individual loop flow control strategy.

Control System

Figure 2 shows the **normal operation control** scheme used for the tests at the EMSP. The actual error (e_T) is calculated from the measured outlet temperature ($T_{loop,out}$) and the setpoint temperature ($T_{loop,req}$). The error is used as the basis for the proportional-integral (PI) controller in the valve control section. This controller is used to calculate a delta for the change in valve opening (Δs_v) that would be required to reach the outlet temperature. Whereas this signal would be sent to the loop control valves in a multi-loop configuration, the opening in the simplified test setup directly serves as input to the mass flow PI controller. The controller determines the new required mass flow ($\Delta\dot{m}$), which is added to the base mass flow ($\dot{m}_{Base}$) and then used as controlled input to the EMSP control system. An anti-windup mechanism is employed to reduce the integral component of the controller as soon as the calculated output variable exceeds or falls below the maximum or minimum permissible valve opening or mass flow.

The purpose of the **startup controller** is to increase the temperature of the solar field from its current value to the specified design outlet temperature. The temperature gradient-based start-up concept is demonstrated by operating the EMSP collector loop with a fixed valve opening and varying HTF pumping power. Figure 3 depicts the configuration of the control structure utilized in the experimental tests. The temperature gradient within each control time step is determined by means of the equation 1, which serves as the basis for comparison with the temperature gradient setpoint ($\Delta T_{loop,req}$).

$$\Delta T_{loop} = \frac{2.75 \cdot \Delta T_{max} + 1.25 \cdot \Delta T_{mean}}{4} \quad (1)$$

ΔT_{max} represents the maximum and ΔT_{mean} the average calculated temperature gradient of all sensors within the loop. The resulting error (e_T) is employed to calculate a new mass flow ($\Delta\dot{m}$) in the PI controller. This new mass flow value is then added to the base mass flow ($\dot{m}_{Base}$). The controlled mass flow ($\dot{m}$) is provided as an input to the EMSP plant control, which subsequently sets the pumping speed accordingly.

Results Normal Operation

- 8 tests conducted under clear sky conditions to assess system control functionality
- Temperature controlled within specified range (489-492°C) with minimal deviation (RMSE: 0.18-0.19%) (Figure 4.)
- Similar tests under clear sky conditions were performed on other days, all resulting in RMSE values of 0.95°C or 0.18%.
- One instance with a temperature overshoot of 1.3°C was observed. This was immediately adjusted by the controller and the system moved back into the setpoint range.
- System performance indicates robust and stable operation

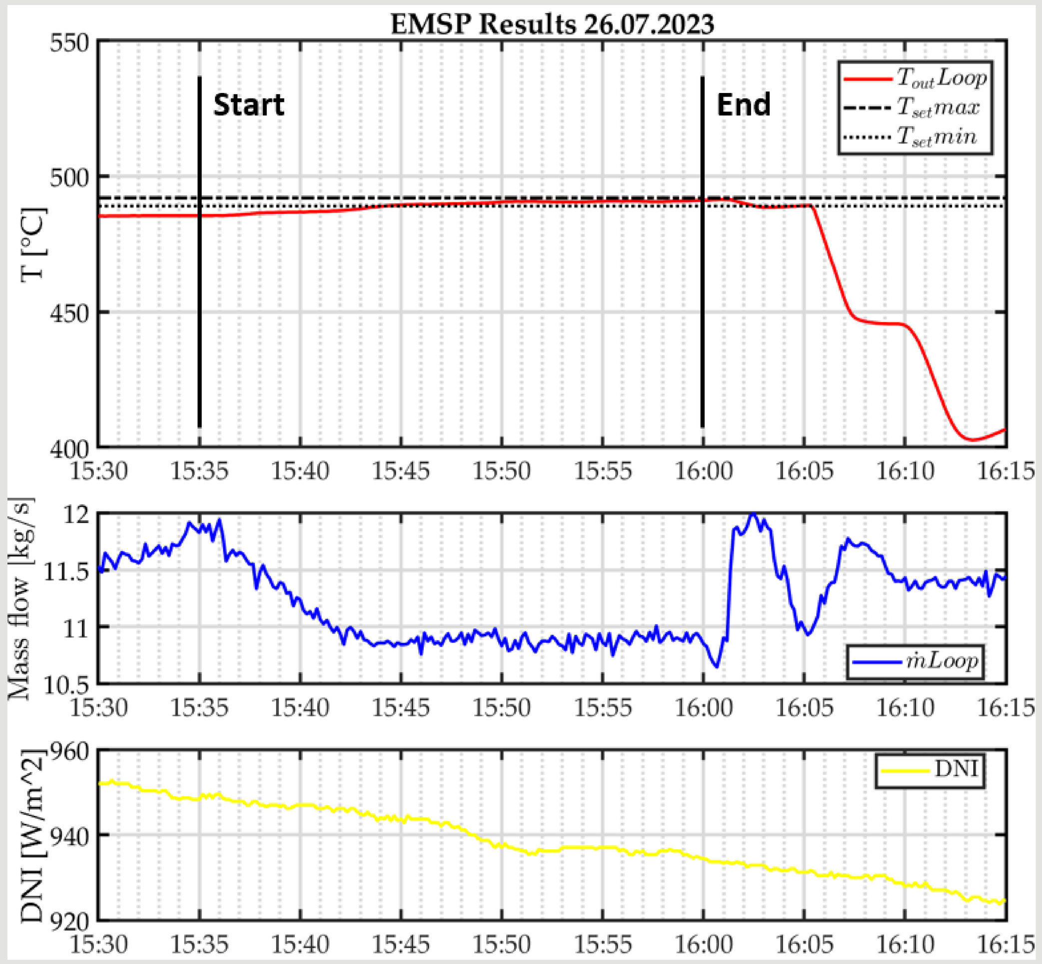

Figure 4. Exemplary control test for normal operation

Results Start-up

- The tests were carried out on 5 days.
- The objective is to achieve the set point for the outlet temperature (490°C) in the shortest possible time without significant overshoots. (Figure 5.)
- The most optimal results were achieved by adapting the temperature gradient setpoint value when approaching the end of the start-up phase.
- A standard temperature gradient setpoint of 10K/min is reduced to 4K/min as soon as an outlet temperature of 485°C is reached.
- On August 3, the system was started from 440°C and brought up to 490°C in approximately 25 minutes with a temperature gradient of 10K/min.
- As soon as the transition temperature of 485°C was reached, the gradient was reduced to 4K/min to prevent overshooting.
- The startup controller completed its operation at approximately 11:15, and the system transitioned to normal operating mode.
- Control is maintained until approximately 11:45, when the control system is deactivated, and an operator takes over.

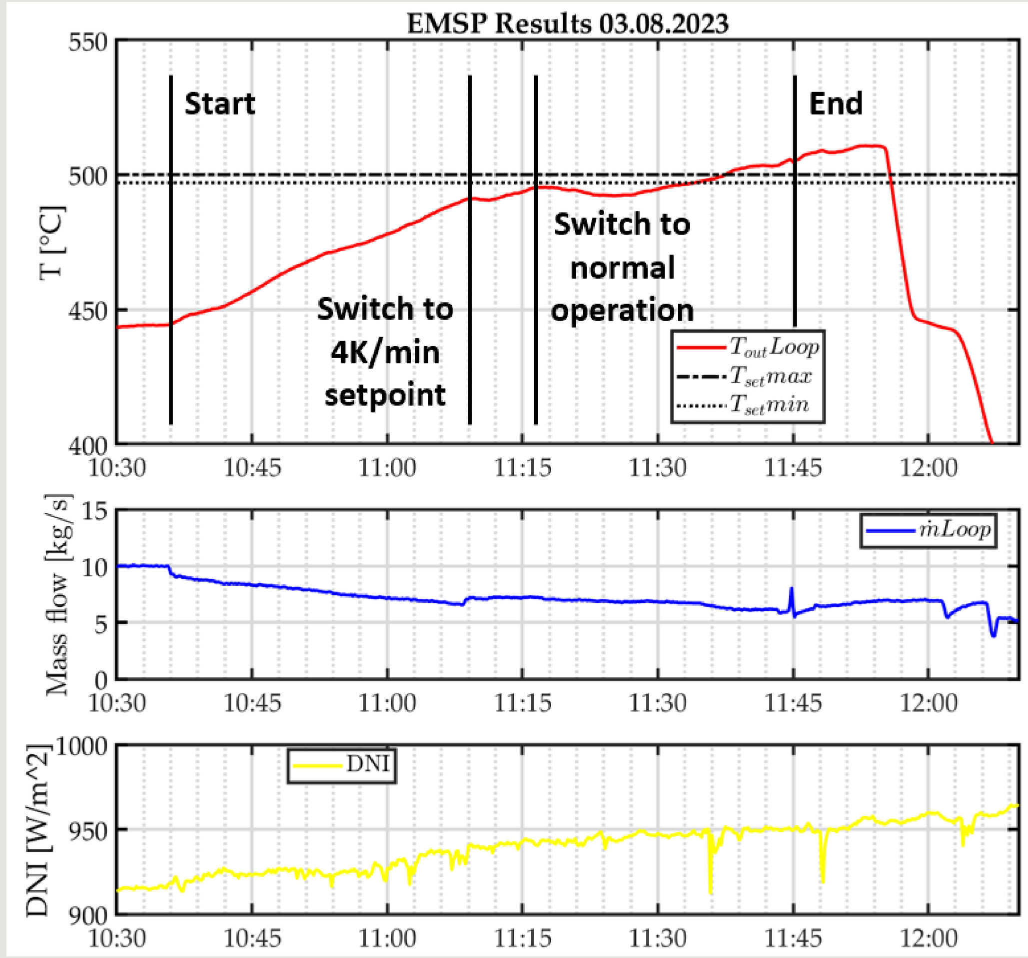

Figure 5. Control test for start-up

Results during cloudy situation

- The test began at 13:15 with normal operation and a setpoint temperature of 515°C. (Figure 6.)
- At around 13:40, cloud cover caused a significant drop in DNI, leading to a decrease in outlet temperature.
- The control system responded by reducing mass flow and initiating the start-up process.
- A brief period (13:40-13:50) with full DNI allowed the temperature to rise above setpoint.
- An important aspect of the test was to check whether the control system behaved stably under various conditions (13:40-14:30).
- The control system successfully adjusted mass flows to suit the situation, without becoming unstable or oscillating.
- During this period, the mass flow was calculated to bring it back to setpoint temperature as far as possible.
- A single test was conducted under transient conditions, specifically in the presence of cloud cover.
- It would be beneficial to perform additional tests under transient conditions to gain a more comprehensive understanding of the control system.

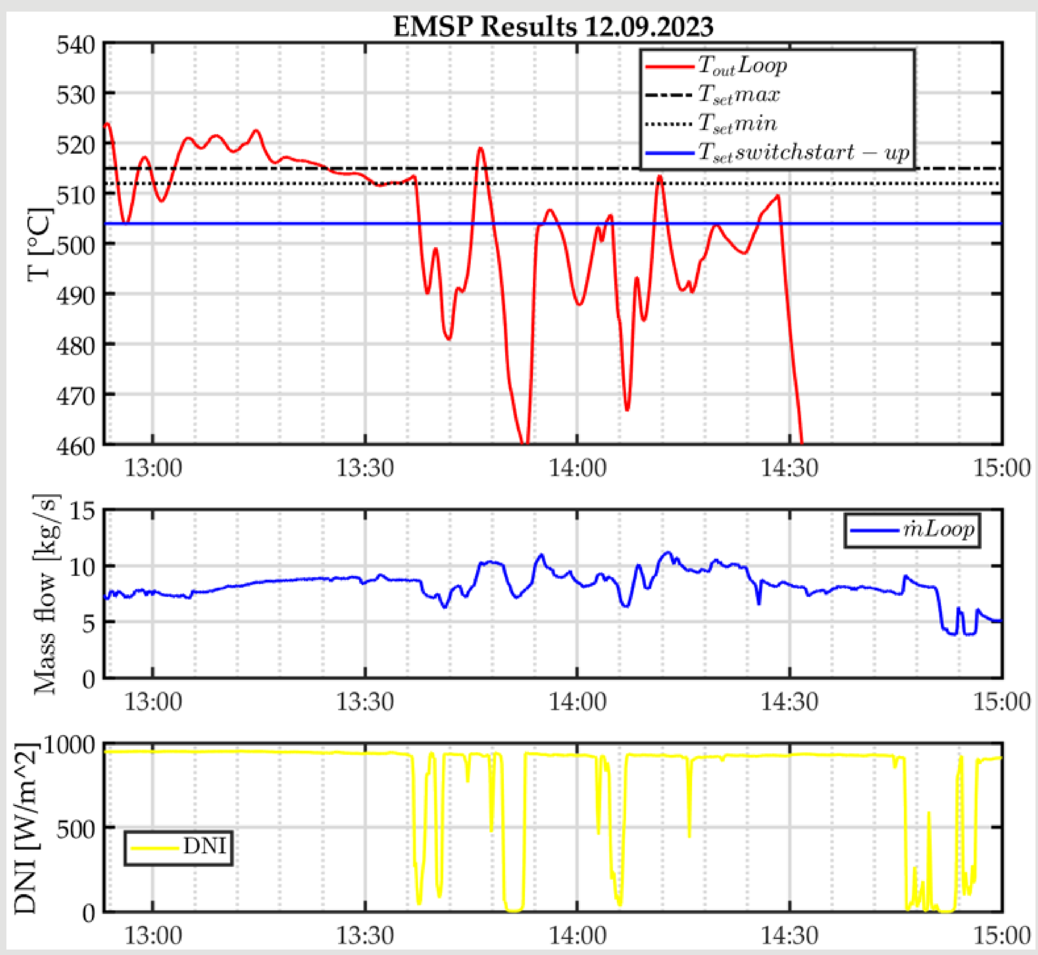

Figure 6. Controller during cloudy situation

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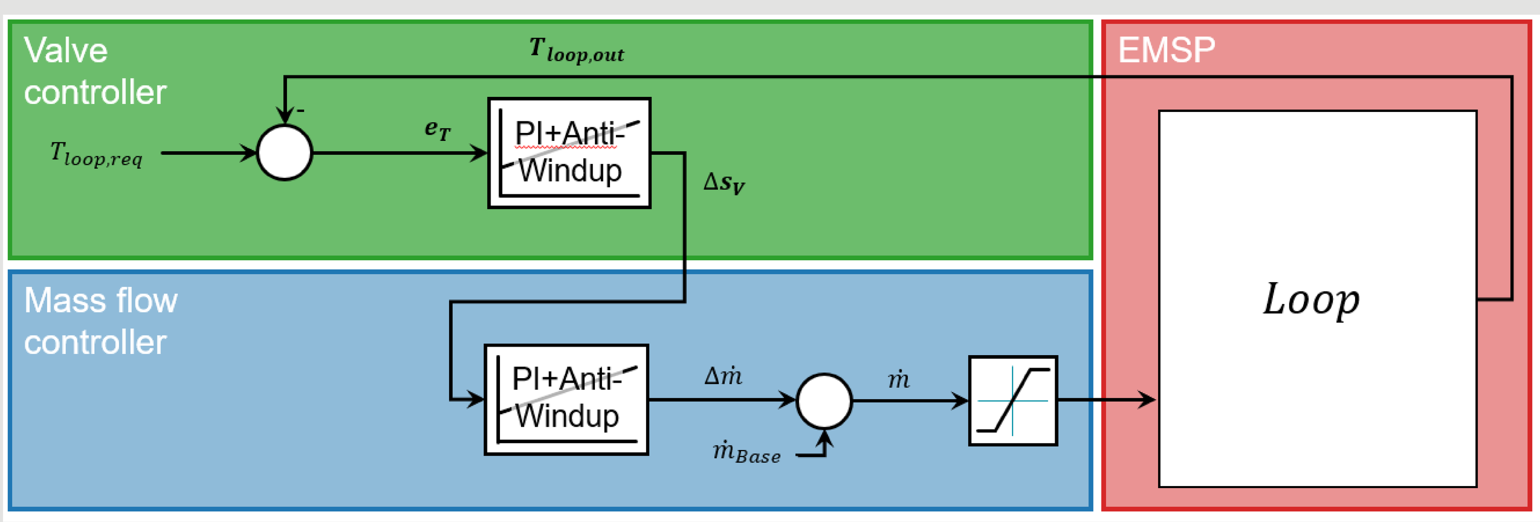

Figure 2. control concept for the normal operation

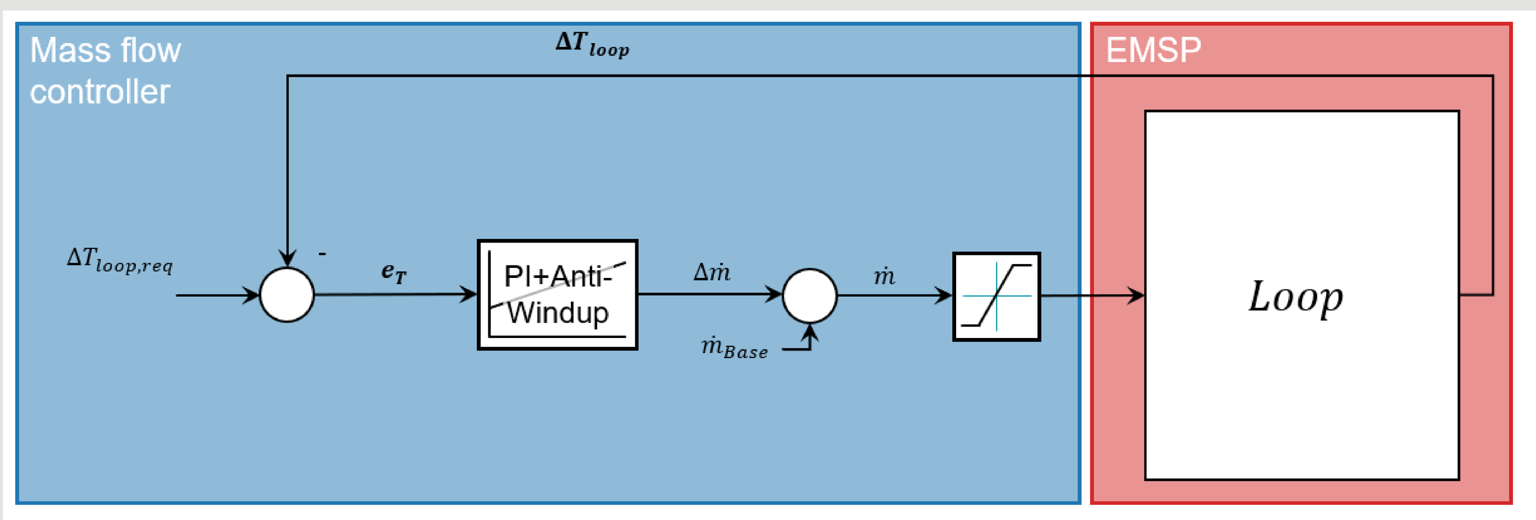

Figure 3. control concept for the start-up

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