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Milli-Kelvin Temperature Control using a Local Fluid Stream Heater

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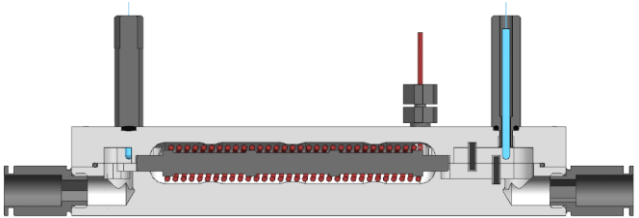
Date: 04-09-2018
Version: 0.1

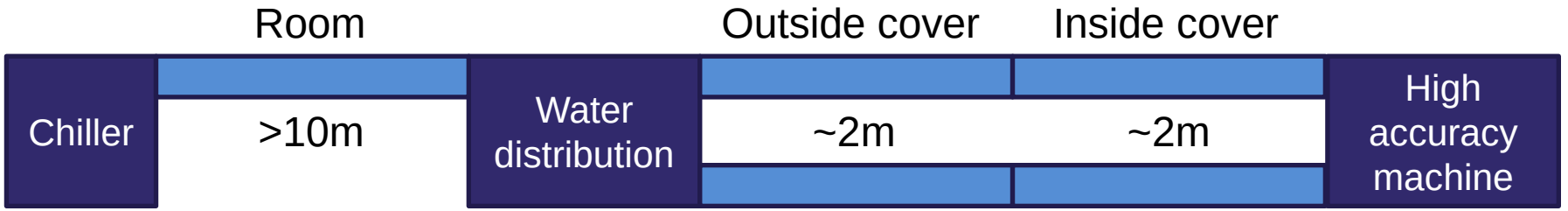


Outline

- Introduction
- Local Heater
- Local Heater Control – collocated control
- Local Heater Control – cascaded control
- Conclusions

Introduction

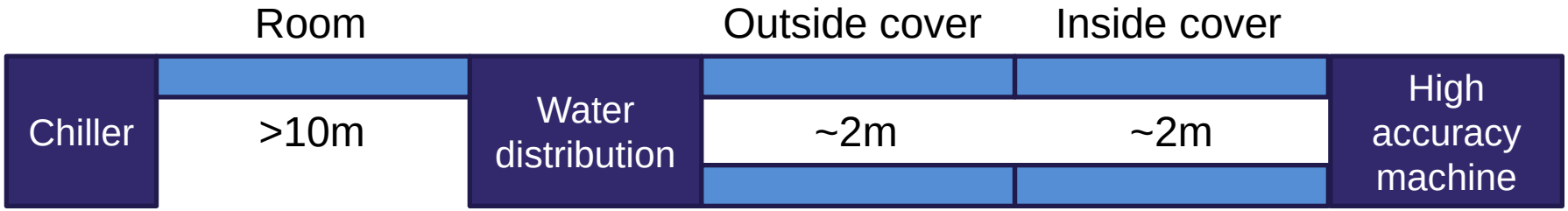
Temperature conditioning – conventional solution



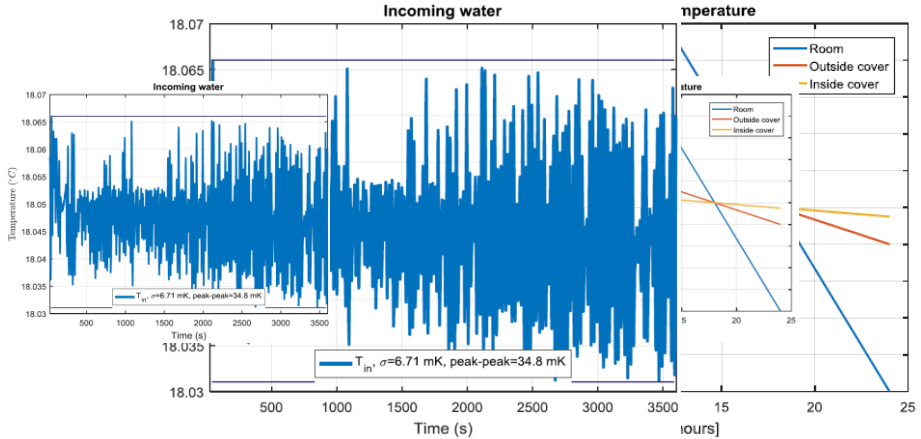
- Required temperature stability in the order of a few milli-Kelvin
- Temperature fluctuations cause
  - Machine drift
  - Deformation

  } Accuracy loss

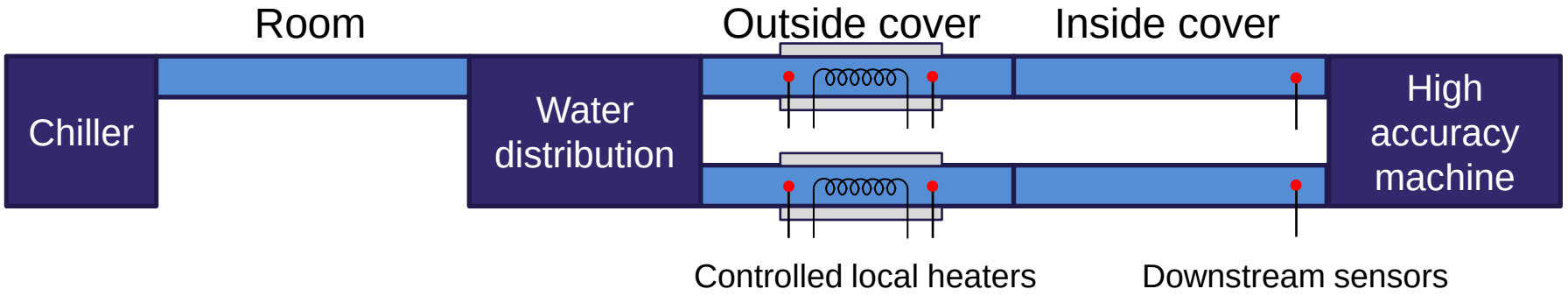
Temperature conditioning – conventional solution



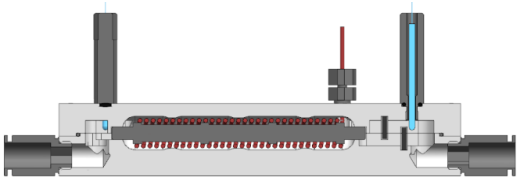
- Temperature fluctuations are due to:
  - Limited chiller temperature stability
  - Distance chiller – machine
    - Ambient variations
    - Heat loads
  - Fixed chiller setpoint



Temperature conditioning – proposed solution



- Need for improved thermal machine control
- Proposed solution: local heaters
  - Desire to place heaters as close as possible to machine
    - Limitations in space
  - Additional downstream sensors near machine



Local Heater

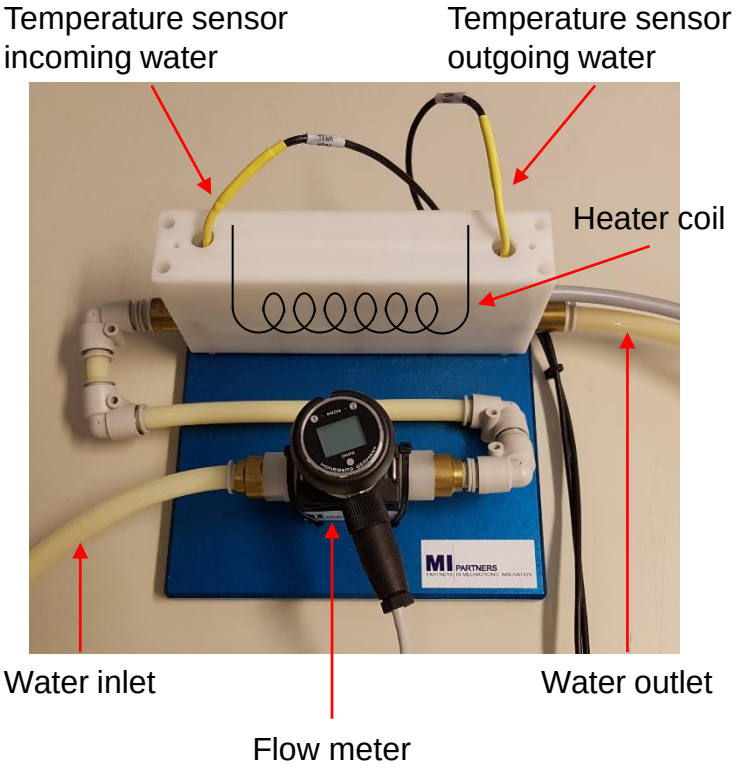
Local Heater Layout

Local heater development:

- Heating coil within cooling channel
- 2 NTC sensors to measure
  - Incoming water temperature
  - Outgoing water temperature
- Controller implementation in Matlab Simulink

Local heater can be used

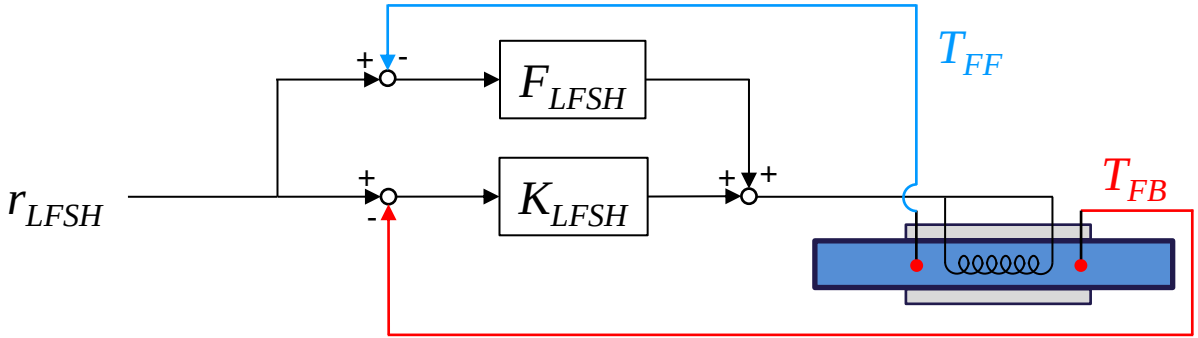
- to improve water temperature stability
- as thermal actuator
- for system identification



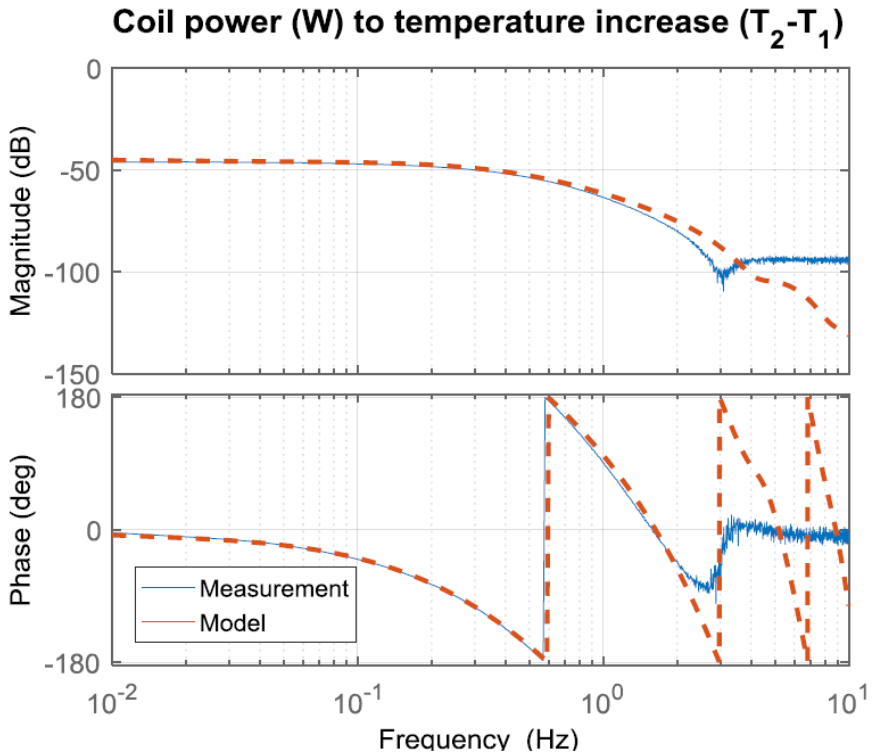
Local Heater Control – collocated control

Local Heater Control – collocated feedback

- Feedforward control
  - Uses incoming water temperature sensor
  - $Q_{FF} = \dot{m} \cdot c_p \cdot (r_{LFSH} - T_{FF})$
- Feedback control
  - Corrects for disturbances & FF mismatch



System Identification

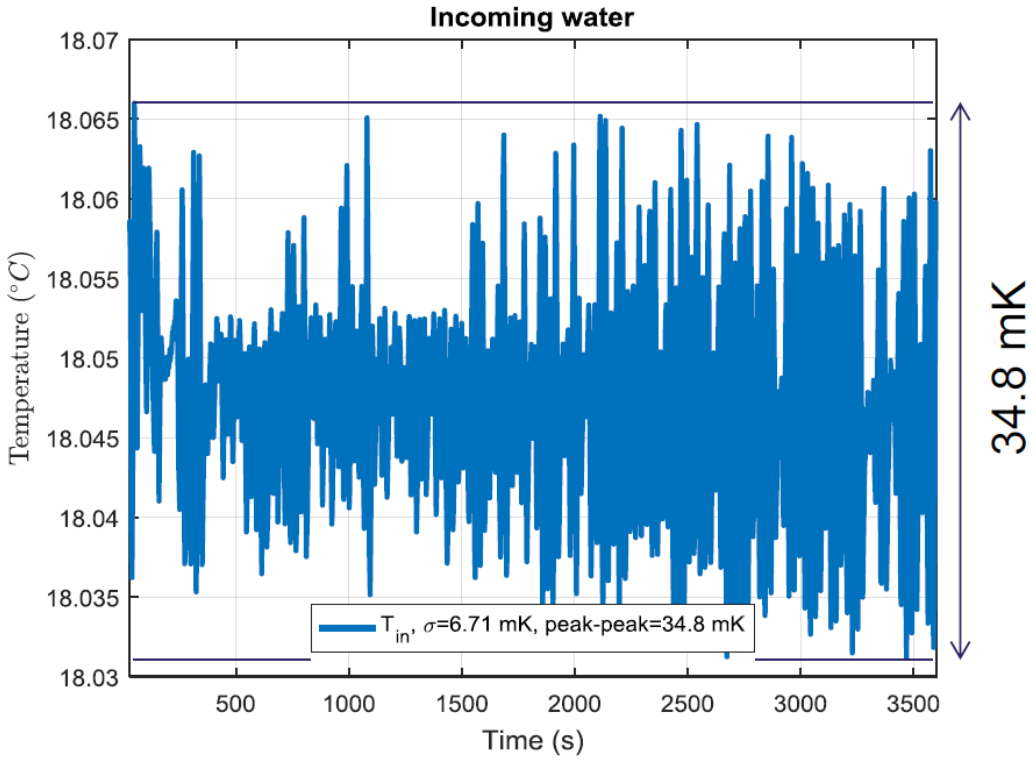


- Decent measurement up to ~3 Hz
- Low-frequency gain: 0.0056 K/W

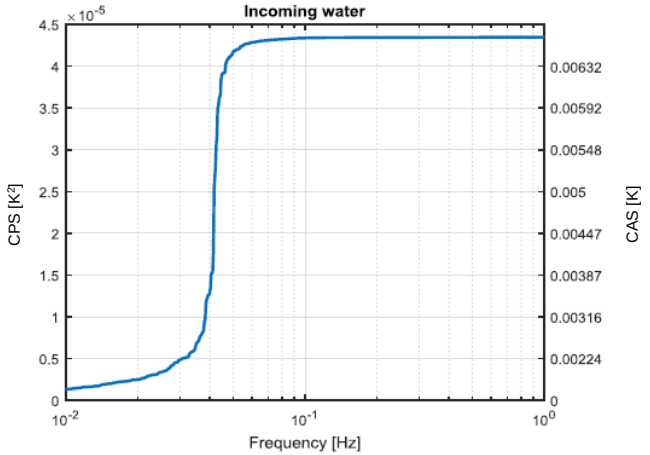
$$F_{LFSH} = \frac{1}{0.0056} = 178 \text{ W/K}$$

- Modelling to predict performance
- Model verified by measurement: Good match in relevant frequency area

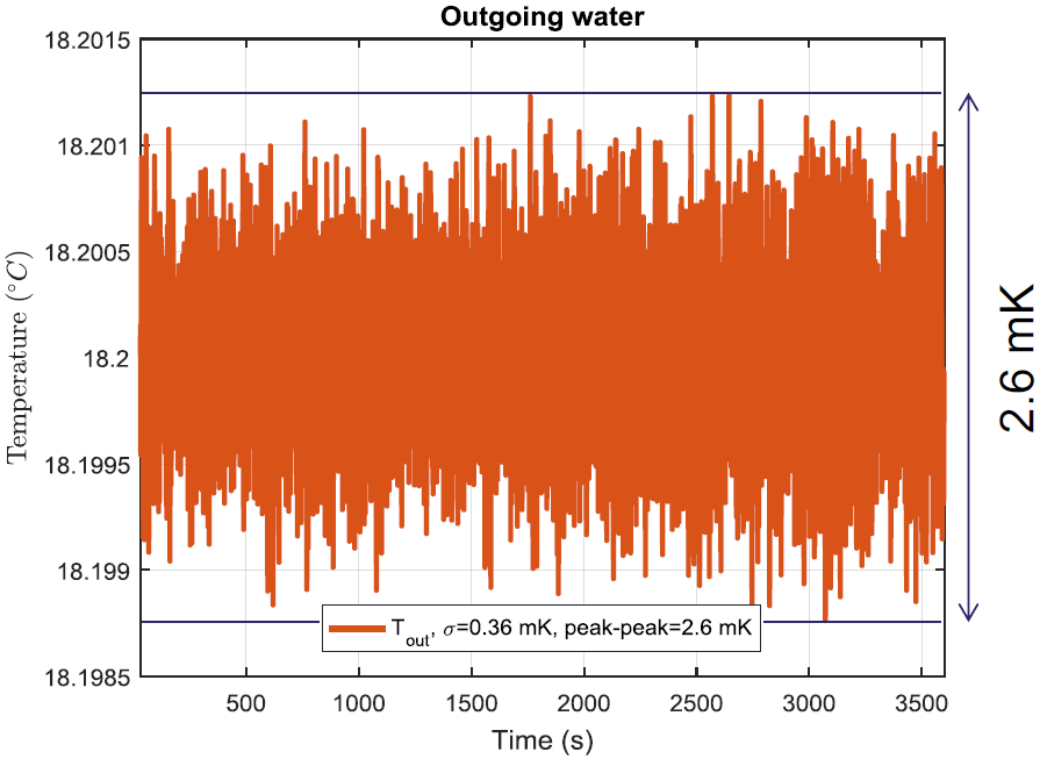
Results: Temperature stability incoming water



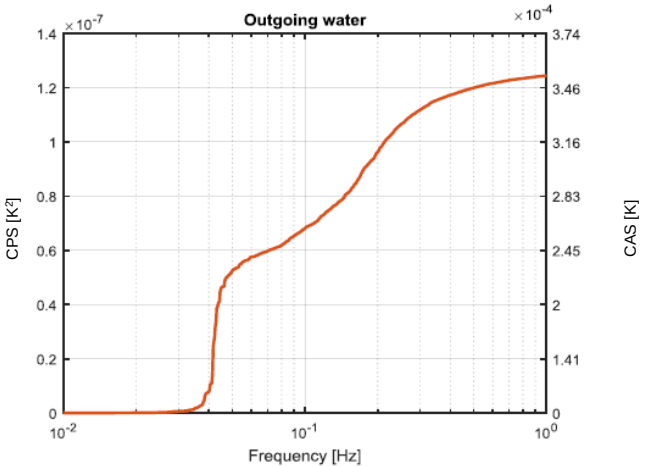
- Temperature stability incoming water: $\pm 3\sigma = \pm 20$ mK
- Main frequency content at 0.04 Hz (25 s) due to round trip time in water circuit.



Results: Temperature stability outgoing water

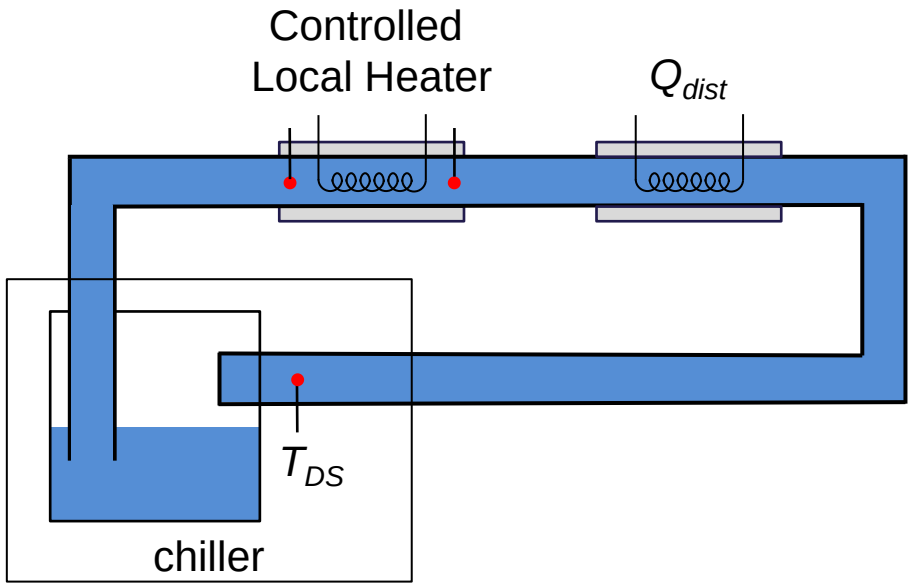


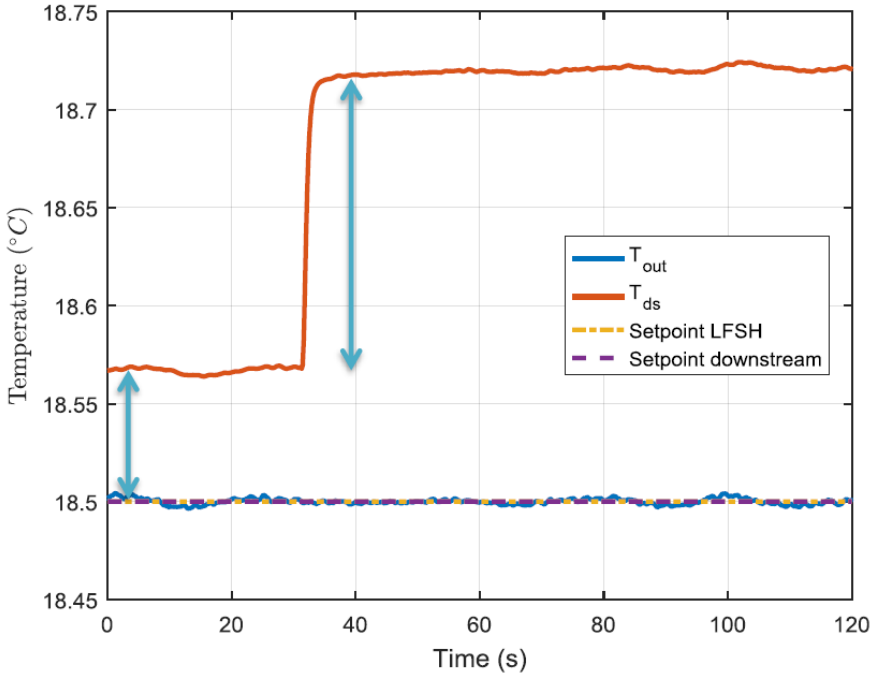
- Temperature stability incoming water: $\pm 3\sigma = \pm 1.1$ mK



Results: disturbance after heater

- 30 W disturbance in water stream

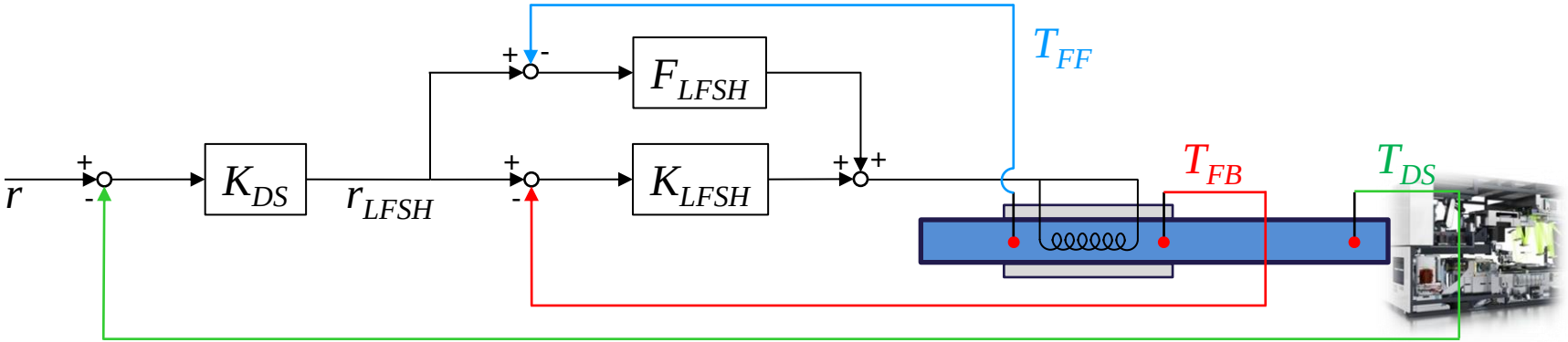




Local Heater Control – cascaded control

Local Heater Control – collocated feedback

- Performance desired at machine
- Often local heater can NOT be placed close to this location
- Ambient variations and local disturbances → drift and/or accuracy issues
- Additional sensor downstream to enable Cascaded Feedback Control



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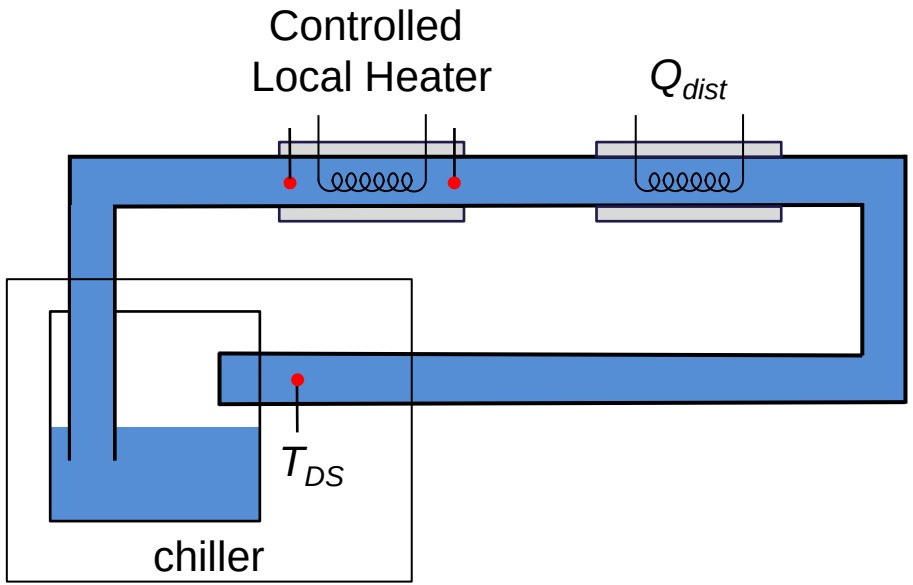

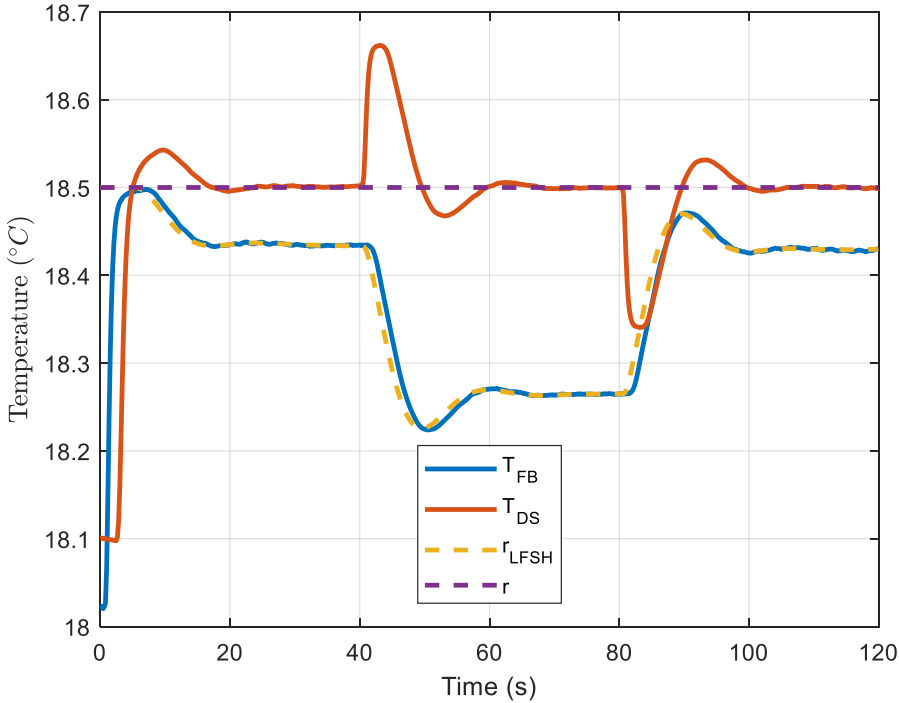

Conclusions

Conclusion

With controlled local heater:

- Improved temperature stability to milli-Kelvins (3σ = 1.08 mK)
- Relative fast response to disturbances compared to chiller

With additional downstream sensor:

- Compensation for slow ambient variations and local heat loads
- Effectively removes temperature offset at downstream sensor

Outlook:

- Compensation of local heat loads using multiple local heaters

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