# Advanced identification and control for thermal systems

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ADVANCED THERMAL CONTROL CONSORTIUM

Technische Universiteit **Eindhoven** University of Technology

# Advanced Identification and Control for Thermal Systems

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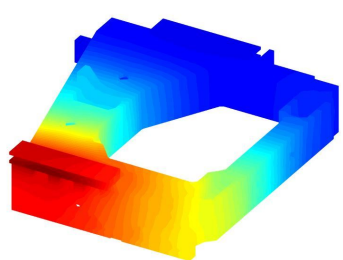
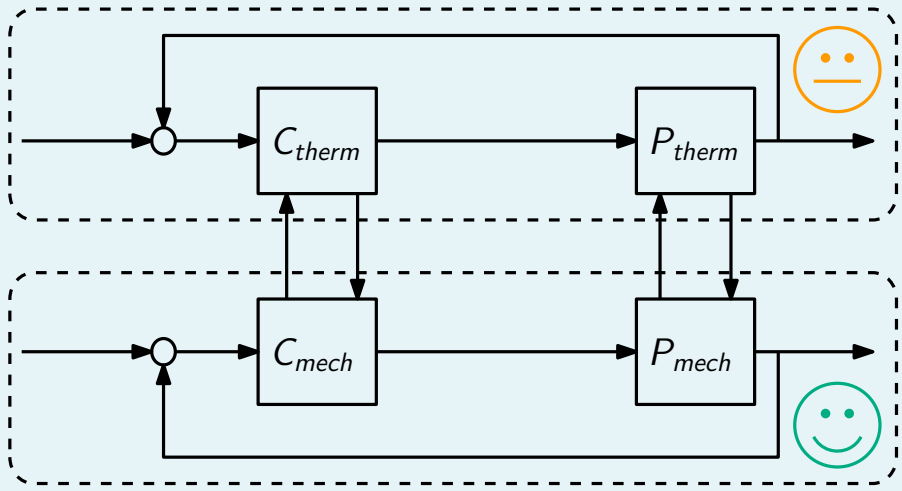
## Thermal Deformations

### Challenges:

- Accuracy: Deformation induced by thermal gradients
- Thermal control less developed compared to mechanical [1]

ThermoFisher SCIENTIFIC PHILIPS ATC ADVANCED THERMAL CONTROL CONSORTIUM ASML IBS Precision Engineering






### Modelling for thermal control:

- Error compensation [2]
- Active control
- (Non-)parametric modelling

## Next big step in FRF identification [3]

### Key challenges in system identificaiton:

$$Y(k) = G(e^{i\omega_k})U(k) + \underbrace{T(e^{i\omega_k})}_{\text{transient}} + V(k)$$

Transient dynamics

- Mechanical: $\mathcal{O}$(10 s)
- Thermal: $\mathcal{O}$(10 min)

### Proposed approach:

**Local Rational Method with Prescribed Poles (LRMP)**

Local window around a DFT bin $k$ such that locally

$$G(e^{i\omega_{k+r}}) = \sum_{b=1}^{Nb} \theta_{G_b} B_b(e^{i\omega_{k+r}})$$

$$T(e^{i\omega_{k+r}}) = \sum_{b=1}^{Nb} \theta_{T_b} B_b(e^{i\omega_{k+r}})$$

where $B_b(e^{i\omega_{k+r}})$ are (rational) basis functions

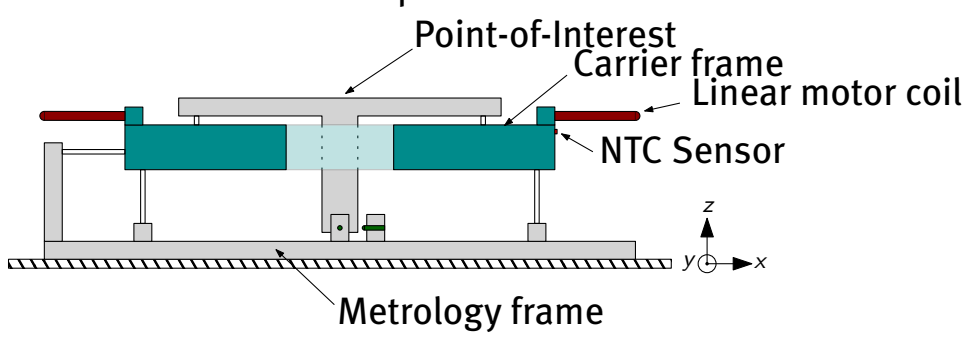
$$B_b(z) = \left(\frac{z\sqrt{1-|\zeta_n|^2}}{z-\zeta_n}\right) \prod_{k=0}^{n-1} \left(\frac{1-\bar{\zeta}_k z}{z-\zeta_k}\right)$$

where $\zeta = \{\zeta_0, \zeta_1, \ldots, \zeta_p\}$ are the pre-specified poles for the all-pass functions.

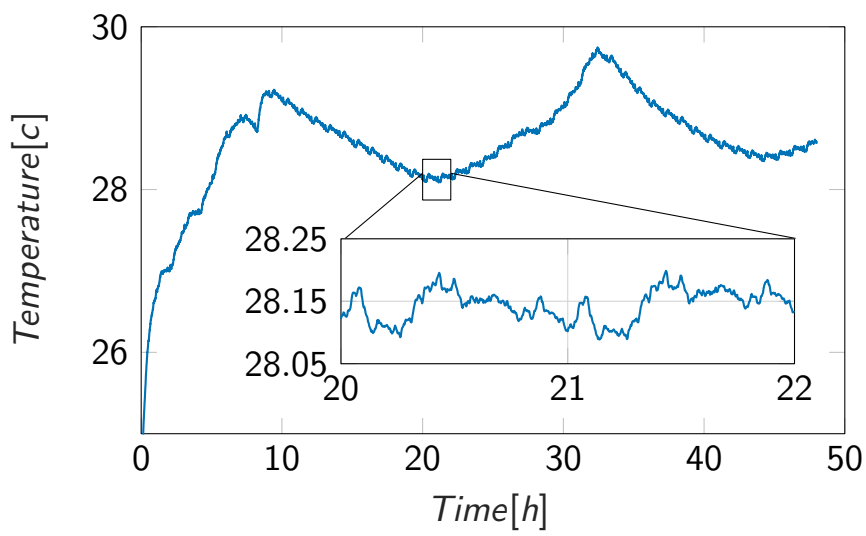
## Experimental setup

### Precision stage application (PSA)

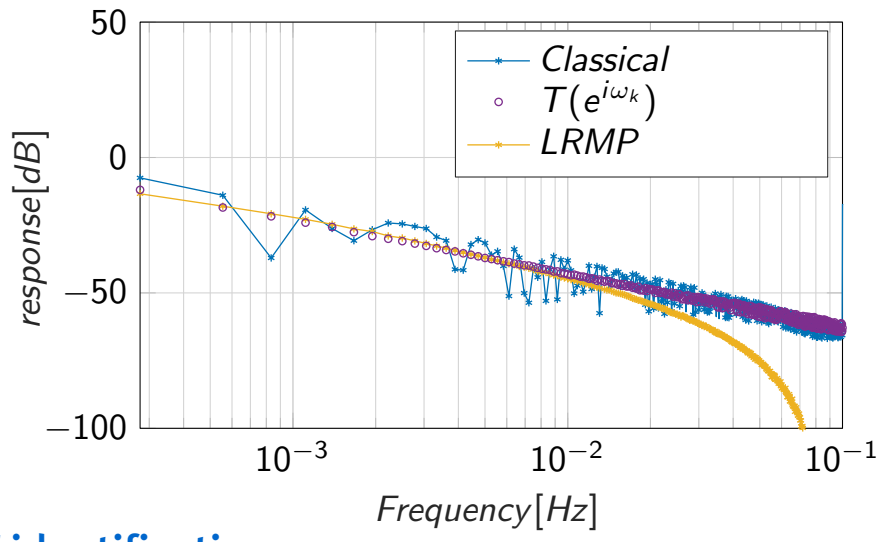
- Linear motor coil as heat source
- Multisine excitation with period of 1 hour




## Experimental results




### Strong transient response and environmental disturbance




### FRF identification:

1. Classical: Spectral analysis, large transient error
2. Transient estimation and removal
3. LRMP: Improved FRF estimation

### Future work:

- Error compensation and control [2]
- Inferential control [4]

## References

[1] Oomen, T. (2018). Advanced motion control for precision mechatronics: control, identification, and learning of complex systems. IEEJ Journal of Industry Applications, 7(2), 127-140.
[2] E. Evers, M. van de Wal, and T. Oomen. Synchronizing decentralized control loops for overall performance enhancement: A Youla framework applied to a wafer scanner. In IFAC 2017 Triennial World Congress, Toulouse, France, 2017
[3] E. Evers, B. de Jager, and T. Oomen, "Improved Local Rational Method by incorporating system knowledge: with application to mechanical and thermal dynamical systems," in 18th IFAC Symposium on System Identification (SYSID 2018), Stockholm, Sweden, 2018.
[4] J. Guo, "Positioning Performance Enhancement via Identication and Control of Thermal Dynamics: A MIMO Wafer Table Case Study," MSc Thesis, Eindhoven University of Technology, 2014.