TECHNISCHE UNIVERSITÄT DRESDEN

Fluidtechnik TU Dresden

Faculty of Mechanical Science and Engineering Institute of Fluid Power

Investigation of the Potential of Different Cooling System Structures for Machine Tools

11. IFK

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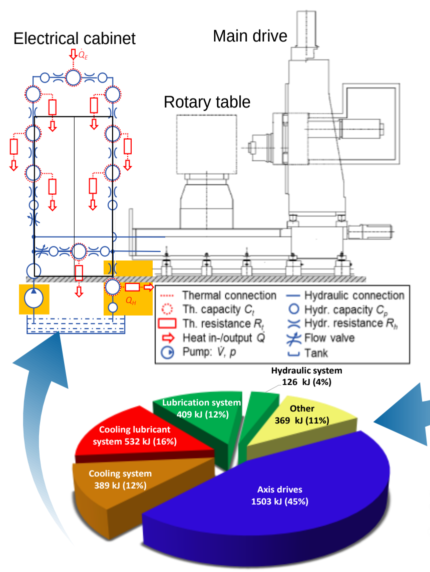
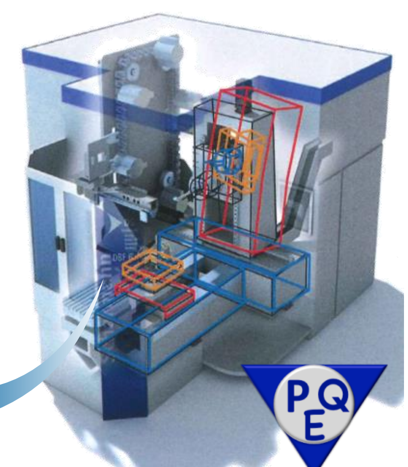
- Introduction
- Cooling system structure design
- System modelling and validation
- Potential analysis of cooling structures
- Summary & outlook





SFB/Transregio 96
Thermo-energetic Design of Machine Tools

Introduction

Motivation

– Production processes (energy losses) → thermal energy

– Different generated heat → temperature fluctuation

– Temperature variation → thermo-elastic deformation

– Displacement of TCP → reduction of machine accuracy

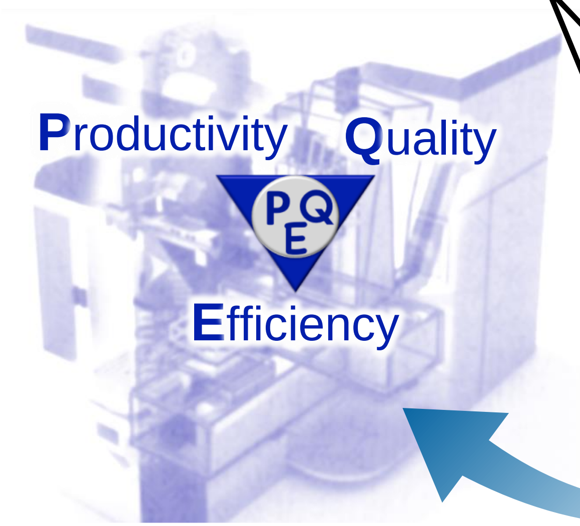
Challenges

– Thermal behavior of cooling systems → not analyzed in detail

– Energy demand of cooling system → inadequate information

– Previous projects → efficient components & control strategies

– Main goal → uniform temperature, minimal energy demand



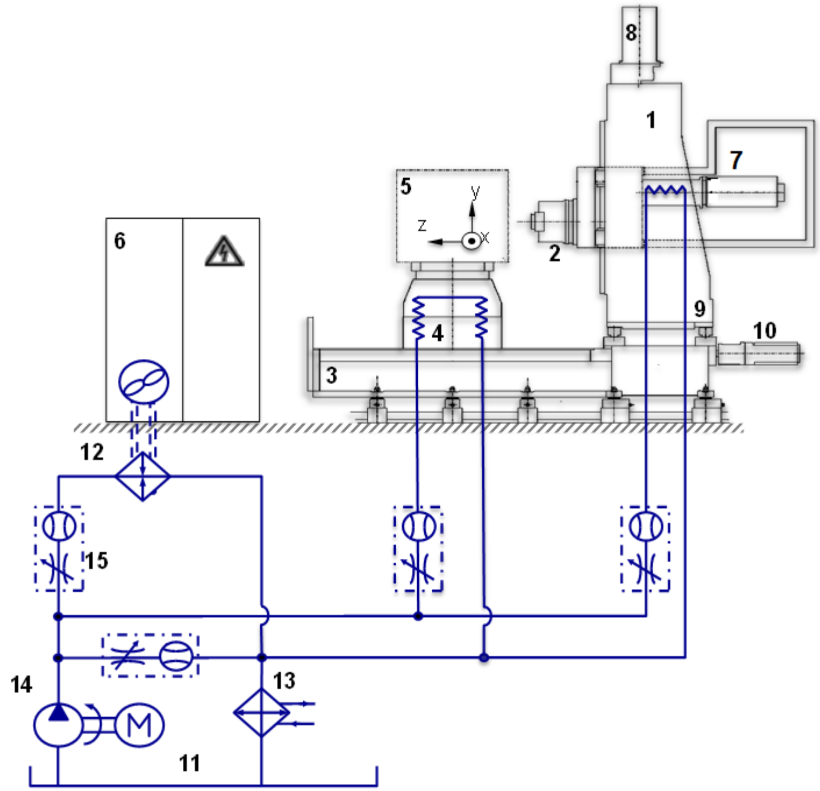
Thermo-energetic Design of Machine Tools

www.transregio96.de

Cooling system structure design

Cooling system of DBF630

- Cooling system cools three components
- Centrally fixed displacement pump
- Rotary table & main drive → cooled directly
- Cooling unit (heat sink) → in the return flow



1) Column	6) Ele. cabinet	11) Tank
2) Headstock	7) Main drive	12) Air-cooling cabinet
3) Bed	8) Y axis drive	13) Cooling unit
4) Rotary table	9) X axis drive	14) Fixed displacement pump
5) Workpiece	10) Z axis drive	15) Flow valve

Schematic representation of cooling system of DBF630

Cooling system structure design

<u>Cooling system of DBF630</u>

- Cooling system cools three components
- Centrally fixed displacement pump
- Rotary table & main drive → cooled directly
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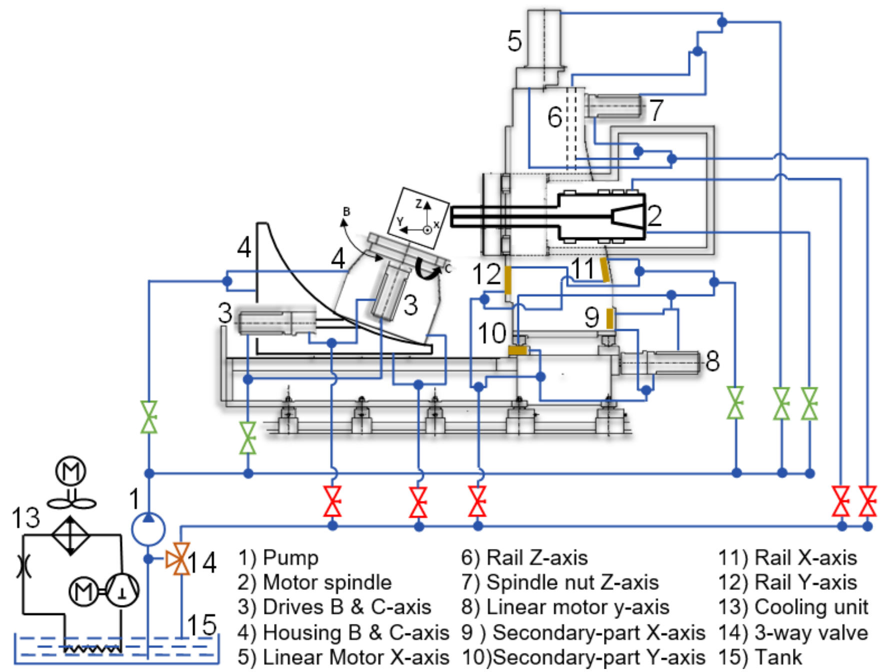
<u>Cooling system of DMU80</u>

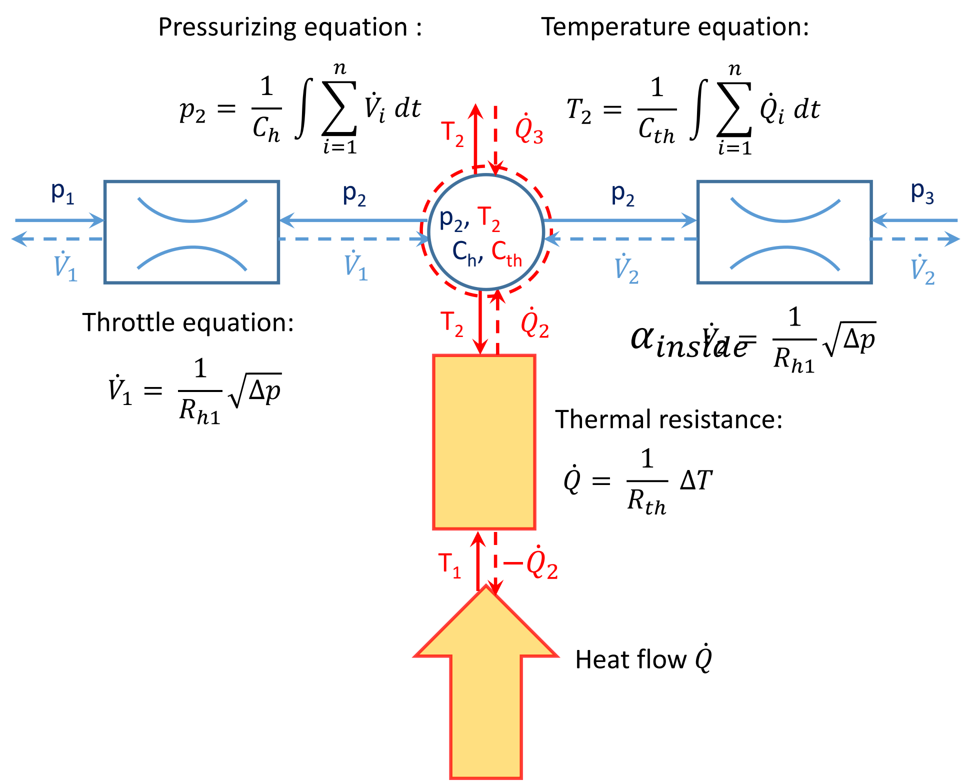
- Cooling systems cools 13 components
- Cooling unit (heat sink) → bypass cooling
- Electrical cabinet → separate cooling unit
- 3-Way valve → used as diverting valve



Schematic representation of cooling system of DMU80

System modelling and validation

- Methodology of the model development → thermo-hydraulic network modelling
- Hydraulic & thermodynamic domain → laws of electrical engineering (Kirchhoff's circuit)



Thermo-hydraulic network modelling

System modelling and validation

- Methodology of the model development → thermo-hydraulic network modelling
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- Heat transfer at the hoses is considered → α_{inside} $\alpha_{conduction}$

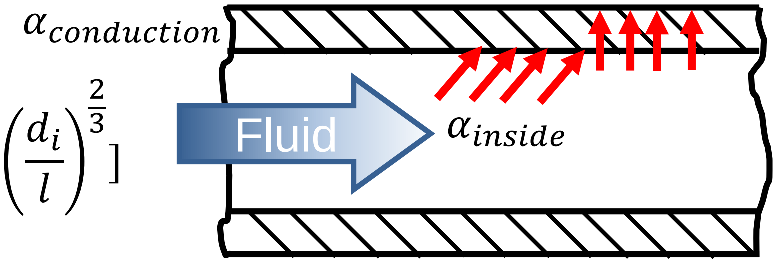
$$Re = \frac{D_H \cdot \dot{V}}{\nu \cdot A}$$

$$Pr = \frac{c_{fluid} \cdot \rho \cdot \nu}{\lambda_{fluid}}$$

$$Nu = 0.0235 \cdot (Re^{0.8} - 230) \cdot (1.8 \cdot Pr^{0.3} - 0.8) \cdot [1 + \left(\frac{d_i}{l}\right)^{\frac{2}{3}}]$$

$$\alpha_{inside} = \frac{\lambda_{fluid} \cdot Nu}{L} \quad Enforced\ convection$$

$$\alpha_{con.} = \frac{2 \cdot \lambda_{con.}}{d_o \cdot ln\left(\frac{d_o}{d_i}\right)} \quad for\ cylinder\ shape$$



Heat transfer mechanisms at the hose

System modelling and validation

- Methodology of the model development → thermo-hydraulic network modelling
- Hydraulic & thermodynamic domain → laws of electrical engineering (Kirchhoff's circuit)
- Heat transfer at the hoses is considered → α_{inside} $\alpha_{conduction}$ $\alpha_{outside}$

$$\beta = \frac{1}{T_\infty}$$

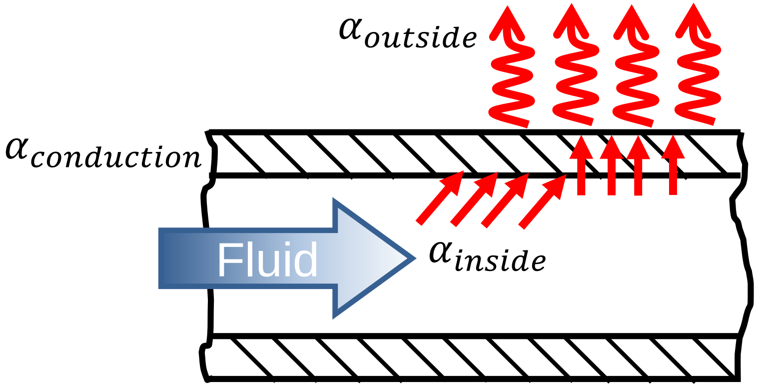
$$Gr = \frac{\beta \cdot g \cdot D^3 \cdot (T_w - T_\infty)}{\nu^2}$$

$$Ra = Gr \cdot Pr$$

$$Nu = \left[0.6 + \frac{0.387 \cdot Ra^{1/6}}{(1 + (0.559/Pr)^{9/16})^{8/27}}\right]^2 \; for\ 10^{-5} < Ra < 10^{12}$$

$$and\ 0 < Pr < \infty$$

$$\alpha_{outside} = \frac{\lambda_{air} \cdot Nu}{L}$$



Heat transfer mechanisms at the hose

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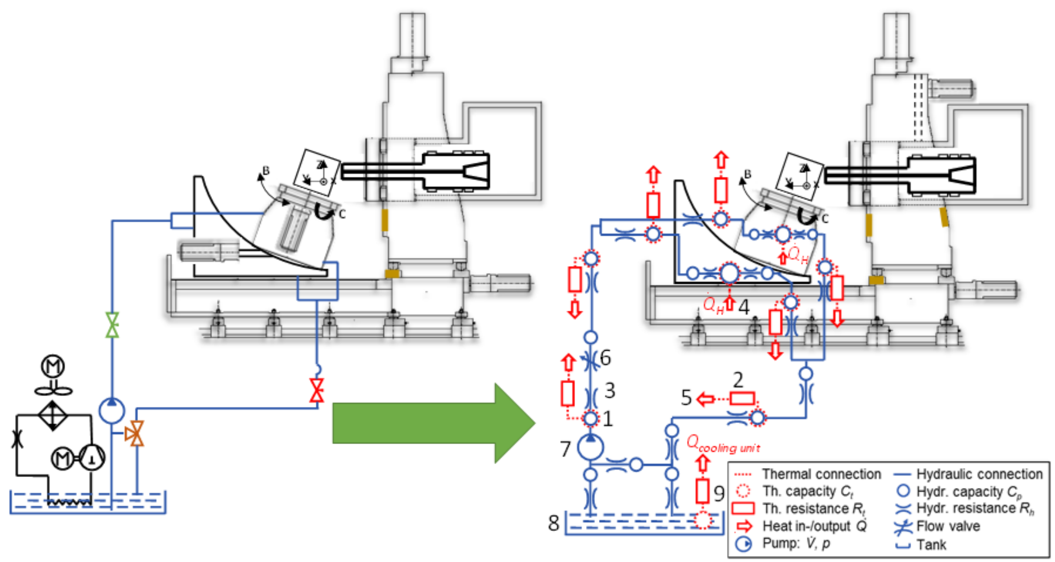
- Heat transfer at the hoses is considered → α_{inside} $\alpha_{conduction}$ $\alpha_{outside}$
- Developing Simulation model of the current cooling system

No.	Element	Parameter
1	Thermal or hydraulic capacity	Geometry of the connections
2	Thermal resistance	α_{inside} $\alpha_{outside}$, $\alpha_{con.}$ fluid properties, pipes properties, ambient properties
3	hydraulic resistance	Description form in the simulation software, $\alpha(Re), \zeta(Re)$, laminar resistance, $(\Delta p, Q)$ characteristic curve, reference measurement
4	Heat input	With aid of measurement is calculated by the equation (15)
5	Heat output	Calculated by forced convection, free convection and heat convection of the hoses, equations (5-14)
6	Flow valve	characteristic curve of the valve
7	Pump	Flow rate and system pressure
8	Tank	Tank capacity e.g. 15 l
9	Cooling unit	Data sheets of the cooling unit, e.g. cooling capacity 4.5 kW

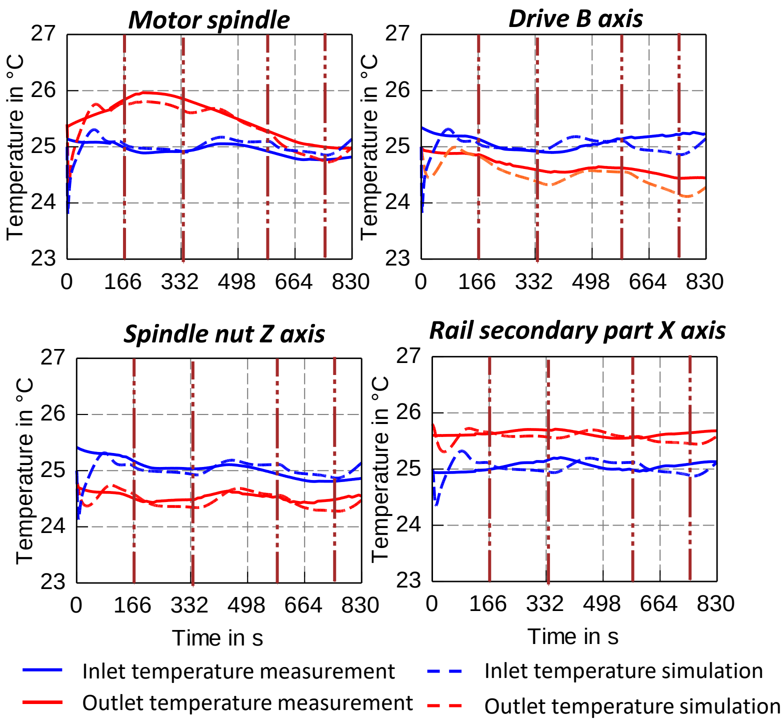
Model parameters for the simulation model

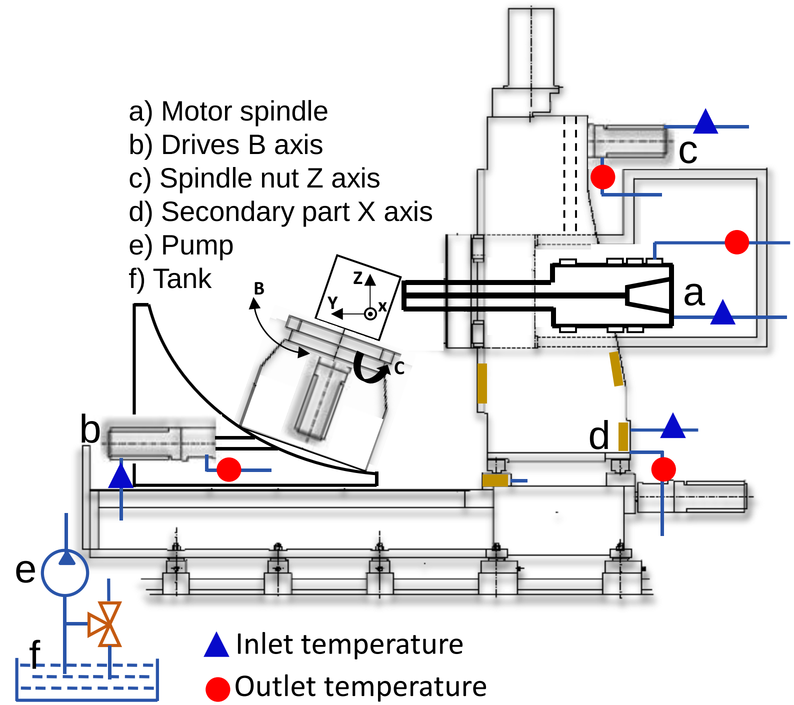


Model development of cooling system in the simulation software exemplified by DMU80

System modelling and validation

- ➢ Measurement on the machine tools → different operating processes
- ➢ Validation the simulation model → high accuracy of the thermal and hydraulic quantities





Comparison of temperature development simulation and measurement in the idle process of DMU80

System modelling and validation

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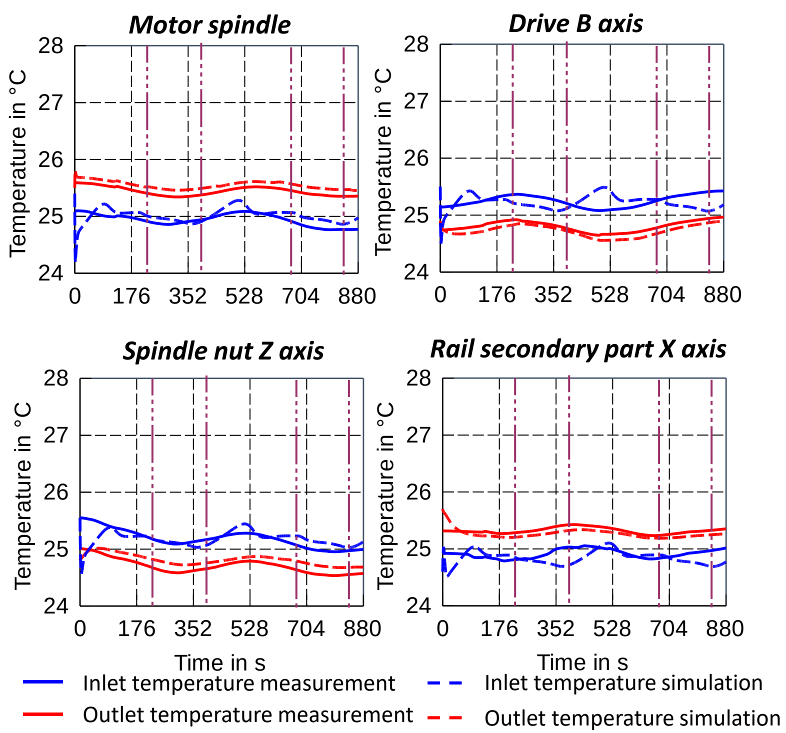
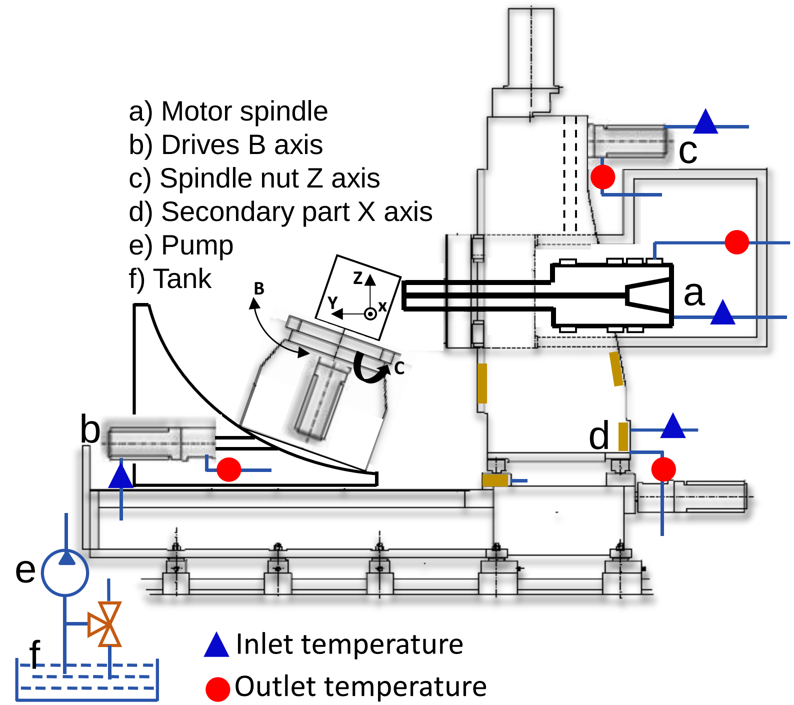
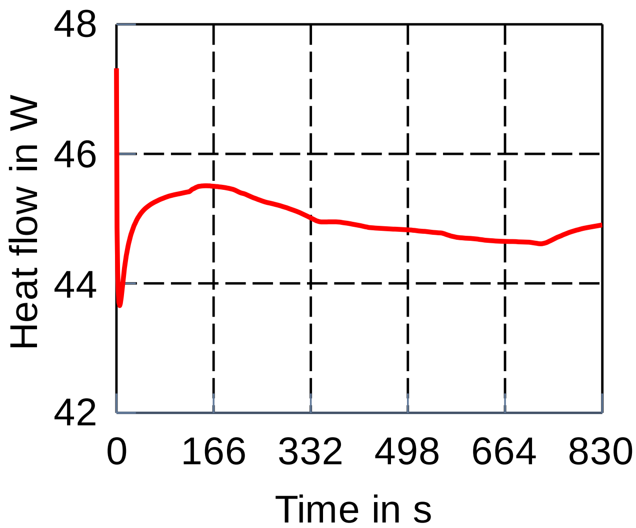




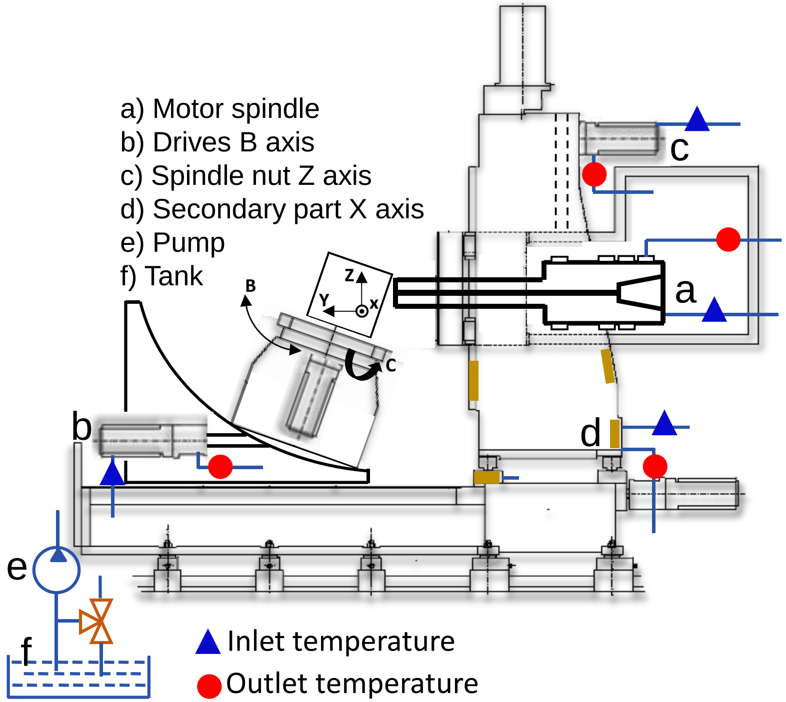
Comparison of temperature development simulation and measurement in the manufacturing process of DMU80

System modelling and validation

- Measurement on the machine tools → different operating processes
- Validation the simulation model → high accuracy of the thermal and hydraulic quantities
- Heat transport through the hydraulic pipe → 1% of cooling unit performance (4.5 kW)



Total heat transport through the hydraulic hoses of the DMU80

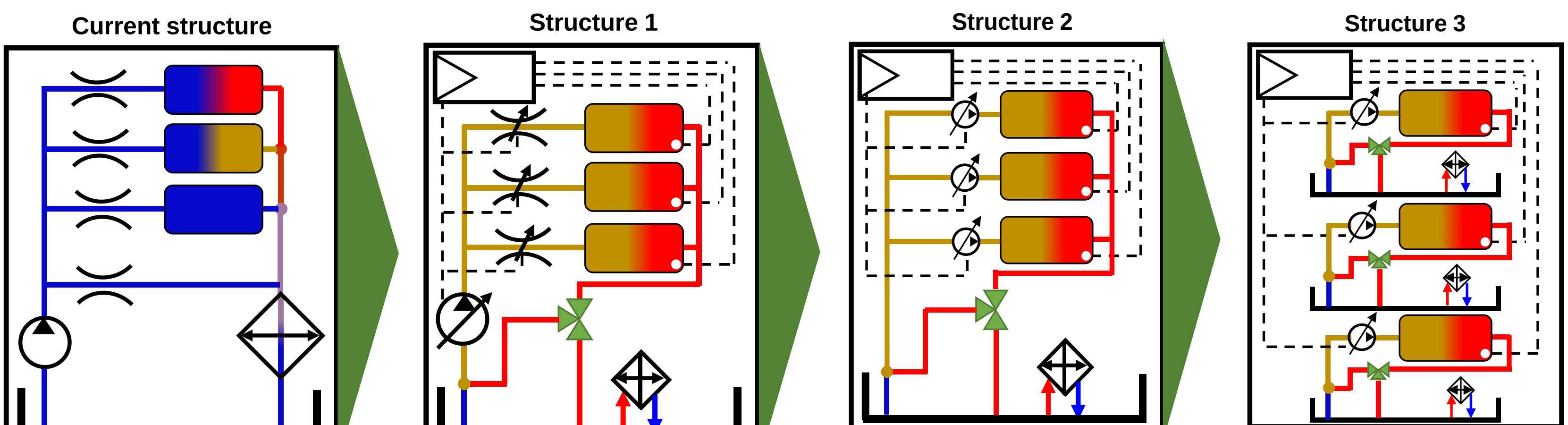


Potential analysis of cooling structures

Deficit of the current cooling system structures

- High energy consumption → 12% DBF630, 26% DMU80 /4,12/
- Investigation of cooling systems → ineffectively cooling
- Supplied cooling medium → does not match the component demand
- Pump performance → does not match to thermal load

Developing new cooling system structures



fixed drive unit with constant flow valves

central, variable speed drive unit with proportional valves

Decentralized, variable speed drive units without flow control valves

Decentralized, variable speed drive units, tanks and cooling units

Cold fluid — Hot fluid — Mixed fluid with predefined temperature

Potential analysis of cooling structures

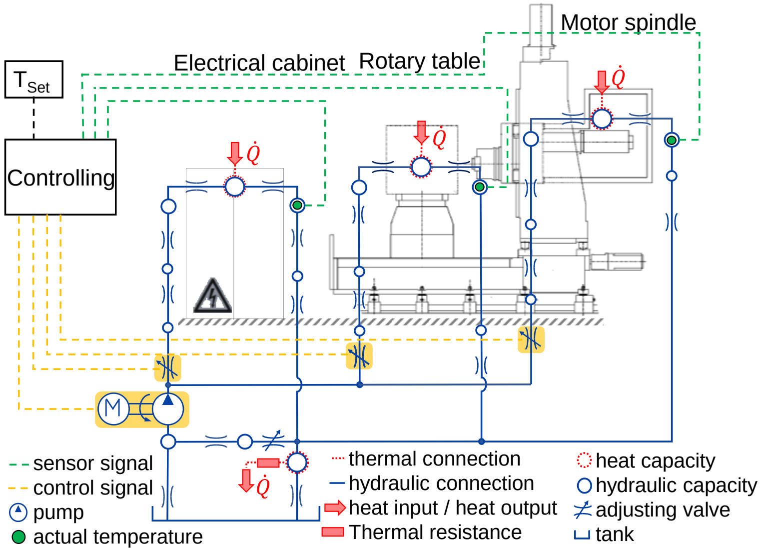
Design of the new cooling system structures

- Individually component-specific supply (pump or proportional valve)
  - Controlled cooling volume flow → minimizing energy demand
  - Precise temperature control → homogenous temperature field at the component
  - Reducing of displacement of TCP → enhance the machine accuracy
- The control compares T_{actual} with T_{set}

  → controlling of cooling volume flow
- Each component is supplied with a different

  demand-oriented cooling volume flow
- Inactive pump or valve → Component's temperature

  doesn't exceed predefined limits



Control strategy of structure 1

Potential analysis of cooling structures

Potential analysis structure 1, 2, 3

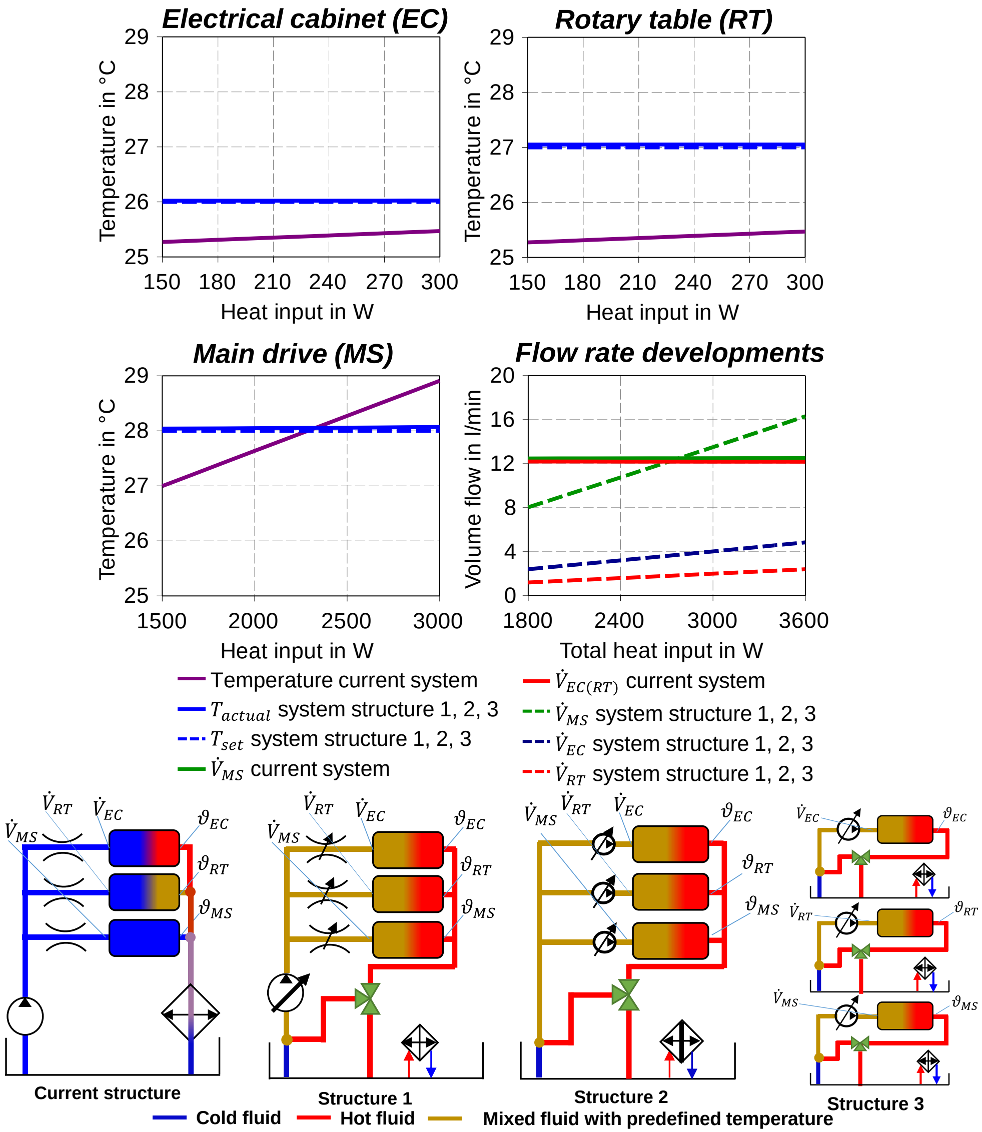
- Stationary behavior of cooling system
- Average equivalent heat flow

New cooling structures

- Different T_{set}
- T_{actual} constant
- Volume flow control
- Lower hydraulic power

Current cooling structures

- No T_{set} possible
- T_{acutal} depends from heat input
- Uncontrolled volume flow
- Higher hydraulic power



Simulation results of new cooling structures in comparison to the current cooling structure

Potential analysis of cooling structures

Potential analysis structure 1, 2, 3

- Stationary behavior of cooling system
- Average equivalent heat flow

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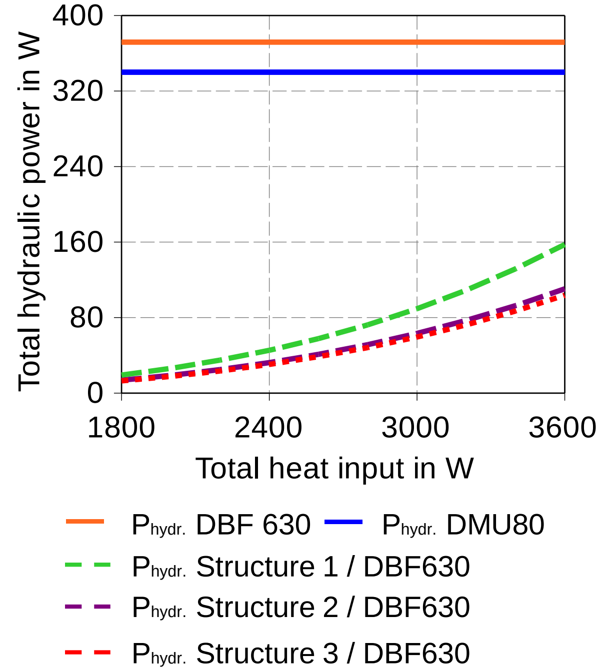
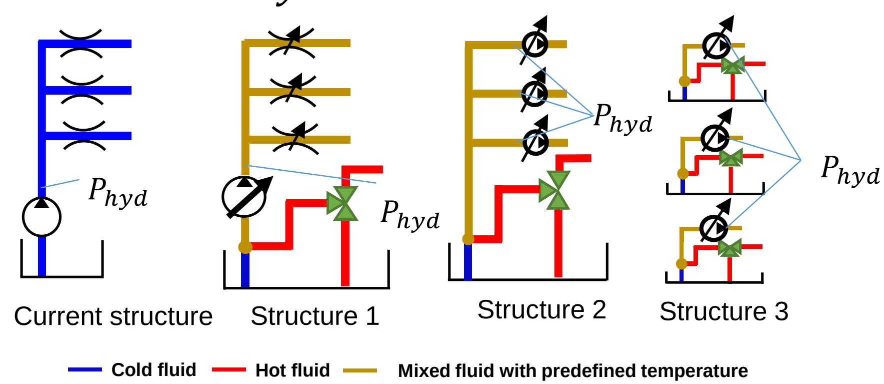


$$P_{hydraulic} = \dot{V} \cdot \Delta p$$



Comparison of the pumps performance in the current cooling structure and in the new cooling structures

Summary and outlook

Motivation and main goal

- Reducing of thermo-elastic deformation → enhancing of machine accuracy
- Demand-oriented cooling system → uniform temperature, minimal Energy demand

Deficits of current cooling structures

- Cooling systems → high energy consumption (12% to 26%)
- Non-matching supplied cooling medium → temperature fluctuation (ΔT= 3 to 5K)
- Fixed speed drive → high hydraulic energy

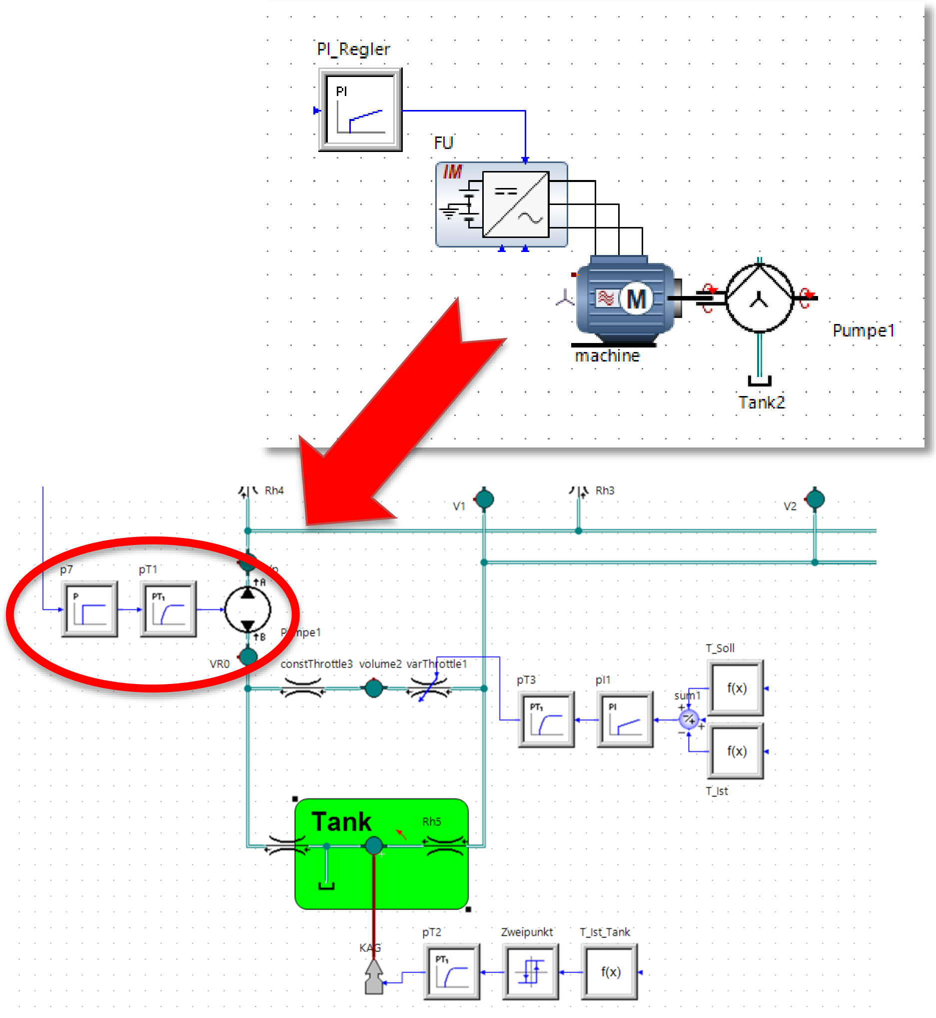
Benefits of new cooling structures

- Controlled cooling medium flow → minimization of energy demand
- Matching supplied cooling medium → temperature difference (ΔT= 0.2 to 0.4 K)
- Variable speed drive → lower hydraulic energy (53% to 70.5%)

Summary and outlook

Extension of simulation models

- E-Motor, Frequency converter, etc.
- Energetic evaluation of the overall system
- Calculation of efficiency
- Showing the energy flow paths



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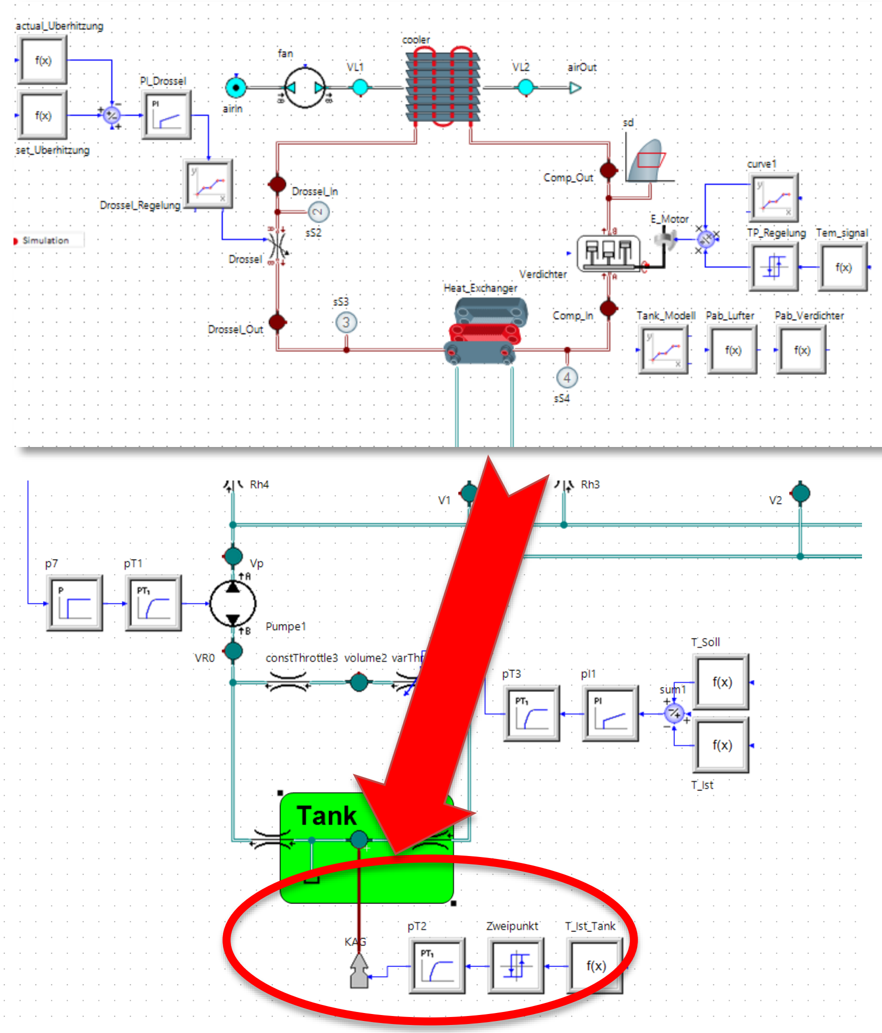

Summary and outlook

Extension of simulation models

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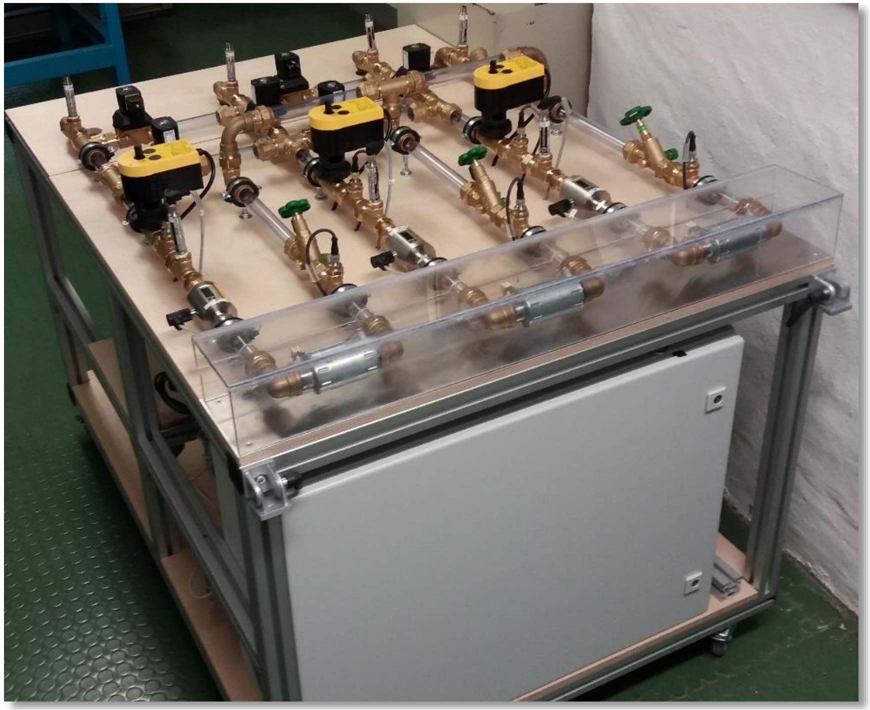
Development of a test rig

- Practice investigation of cooling structures
- Demonstrate the benefit of the structures
- Experimentally sound statement



Summary and outlook

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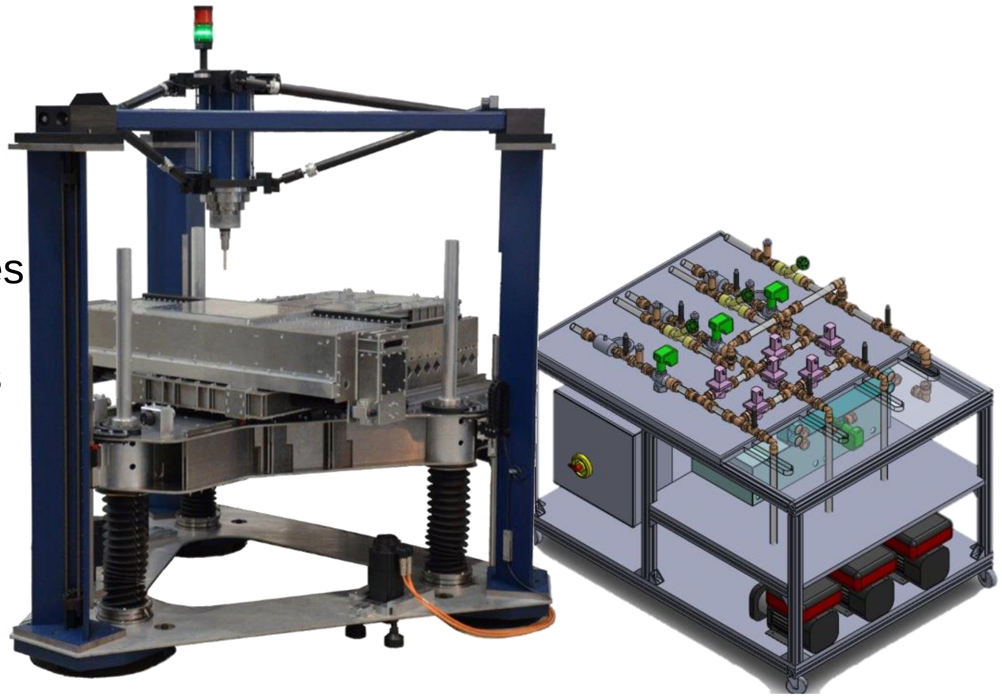
- Demonstrate the benefit of the structures
- Experimentally sound statement
- Coupling with a demonstration machine, measurement TCP displacement



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Thank you for your attention

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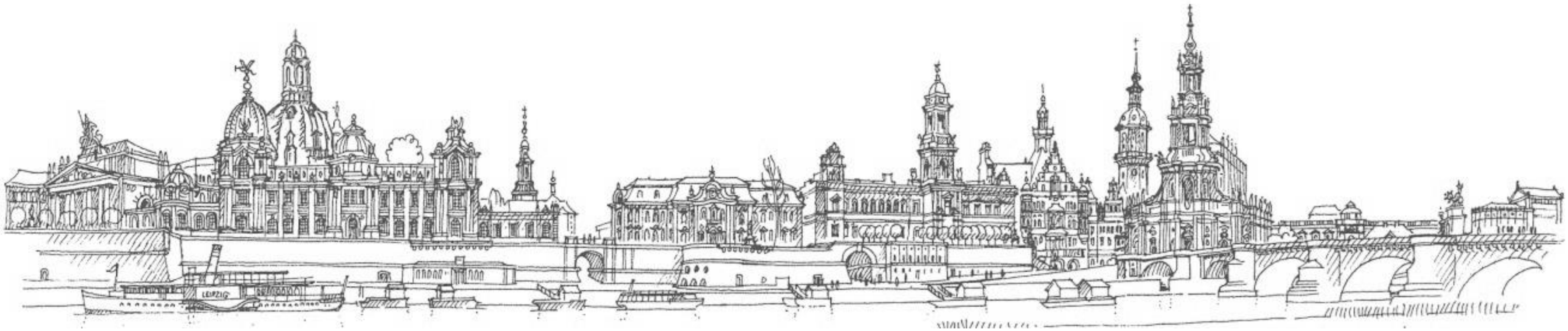

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