ICTIMT 2025

4th CIRP Sponsored International Conference on Thermal Issues in Machine Tools

17th – 19th June 2025, Zurich Switzerland

https://ictimt2025.ethz.ch

WELCOME

  

Zurich and especially ETH Zurich is the place of the International Conference on Thermal Issues in Machine Tools, ICTIMT 2025. This is the fourth edition of an ICTIMT Conference. The series was launched out of the SFB TR 96 funded by the German research foundation (DFG) by the involved scientists and as a forum to discuss findings and developed methods. After Dresden, Prague, Dresden now in Zurich, IWF and AMLZ of ETH Zurich and inspire feels greatly honoured with the opportunity to organize this conference. We cordially welcome you now to the 4th International Conference on Thermal Issues in Machine Tools. We have the honour and pride to present to you industries, our institutes, ETH Zurich and the wonderful city of Zurich, which is despite being not the capital the economic and cultural center of Switzerland. Zurich is embedded in the scenic landscape of the alps, which offers the possibility for impressive tours into the mountains. Managing the alpine countryside was and still is one of the important challenges of the Swiss population. Since centuries Swiss people carved holes into the mountains to connect to each other and by the way to create an infrastructure that enables to connect the north of Europe to the south. That is also where the industrialisation of Switzerland started and for what ETH Zürich was founded in 1855. The latest major step in this infrastructural master plan was the inauguration of the Gotthard Basistunnel in 2016, which was at that time with 57.1 km the longest tunnel of the world.
Switzerland today is a major manufacturing country, besides hosting also important banks. Having been the poorest country in Europe in the beginning of the 19th century Switzerland’s wealth is based on manufacturing. It is by that an archetype society for demonstrating the role of manufacturing for fulfilling sustainable development goals of the UNO. Thus, today comparing countries by value of produced machine tools per capita and year Switzerland leads by far. In a wider sense the region around the Alps is Europe’s machine tool area, within which approximately one fifth of the world’s machine tool production takes place, and Zurich is in its center. From here major machine tool companies as well as manufacturers of all different kinds of goods can easily be reached.
Thermal distortion and thermal errors in machine tools are the most frequent reasons for defective parts. When the knowledge- and technology transfer organisation inspire AG started to grow in 2002 and IWF of ETH Zürich restarted, the most urgent whish of Swiss machine tool manufacturers according to an industry survey was to develop means against thermal distortions of machines. CIRP colleague James Bryan stated, “whatever you design, it becomes a thermometer”. As thus the physics of heat transfer and thermal elongation is invincible, three different approaches remain: thermo-energetically optimized design, tempering of shop floors and machine tools and thermal compensation using the axes of the machine and as required auxiliary compensation axes with small strokes. The first is generally

recommended, whatever comes afterwards. Tempering is straight forward and therefore the most frequently applied method, but also the least sustainable one, as it consumes energy and / or requires startup time partly even with scrap production to reach the thermal equilibrium due to the inbuilt heat sources. Compensation especially while using the machine axes is the most elegant way for better accuracy, though only deterministic errors can be compensated, requiring machine tools with excellent repeatability. Thermal compensation replaces resource expenditure by a knowledge-based approach, which was the general guideline for the EU Horizon2020 program. Thermal compensation is one of the rare cases, where sustainability and increase of accuracy coincide. As a general outline compensation methods consist of three different functions and can thus be described with a morphological box: information supply by sensors and the CNC-program, control system based on a machine model and actuation like machine axes or auxiliary heat sources and sinks. The measurement of thermal displacements is a challenge as such, as they are superposed with large strokes of the machine tool. But also the isolation and identification of individual errors is a task to be solved. An important topic today is the influence of hollow spaces especially but not only the working area with the influences of process and process cooling. Modelling for compensation requires sufficient precise models that are capable to deliver correction data in real time. This is the domain of meta models, which today are frequently based on artificial intelligence (AI) in terms of self-learning compensation models. Physics supported AI in most cases provides the best tradeoff between effort and success.

All energy supplied to the machine tool ends in heat, also the intentionally provided energy to the process zone. The only exception is the tiny amount for the state change of the material. But understanding the heat conversion and flow in the process zone is of crucial importance for the correct setup of the respective process, for the wear of the tool, the process signature of the process onto the material and last but not least for the operation of the machine tool.

For both topical blocks machine and process CFD simulation becomes important and still suffers from the bad predictability of heat transfer coefficients to the machine body for the modelling of the machine and to the tool, workpiece and fluid for the simulation of the process behavior. Careful measurements are crucial technologies and, in most cases need to be supported by modelling and simulation because the accessibility of the process zone or the area of interaction is limited.

A vital role plays the cooperation between industry and academia in this topic. Providing understanding and exploring possible approaches is the domain of academia, implementation, integration of sensors and providing powerful interfaces to the control as well as long term experience under real conditions the one of the industry. To promote and deepen this collaboration is one of the most important goals of the ICTIMT 2025 conference. We are proud of a strong industrial participation despite the adversities of present times and very much appreciate the generous sponsoring of DMG Mori Ltd., Schneeberger AG, Kern Mikrotechnik GmbH, Swissmem, Agathon AG, GF Machining Solutions and inspire AG.

We would like to sincerely thank the speakers of the conference, the CIRP conformance committee, the scientific committee and all contributors to the conference.

Markus Bambach, Josef Mayr, Konrad Wegener
Conference Chairmen ICTIMT 2025 also on behalf of the local organizing committee

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Prof. Dr. Matej Sulitka	Czech Republic
Prof. Dr.-Ing. Matthias Weigold	Germany
Prof. Dr.-Ing. Michael Zäh	Germany

VENUE

ETH Zurich

In 1855, the Swiss Federal Institute of Technology (ETH) was founded mainly as a school for engineers, but also as a compensation to Zurich for not being the capital city of Switzerland. Between 1861 and 1864, the impressive main building was created by Gottfried Semper. Ever since it was first founded, ETH Zurich has been a driving force behind Swiss industry, whose innovative products and services are in demand worldwide. In the history of ETH, many well-known scientists and 21 Nobel prize winners are associated with this school. 21,400 students, including 4,180 doctoral students, from over 120 countries are matriculated in 16 departments of all technical and scientific disciplines

The City of Zurich

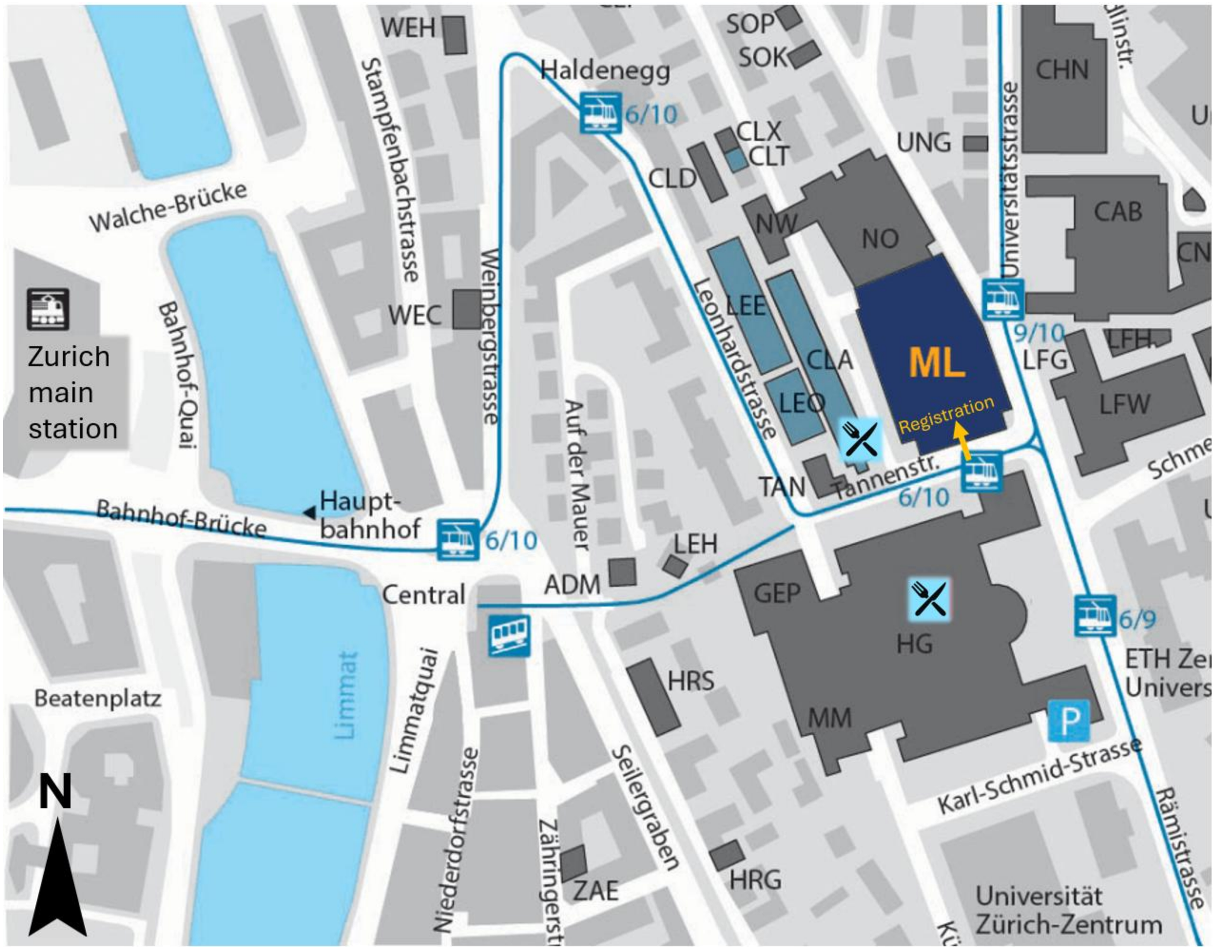
More than 2000 years ago Zurich was founded by the Romans as a fortress. Today Zurich has about 400'000 inhabitants and is the largest city in Switzerland. Zurich is the main town of a canton also named Zurich. The city has a picturesque downtown with many tourist attractions and is located at the end of the Lake of Zurich. Zurich is not only important for its universities but is also the commercial centre of Switzerland and a platform for international trade.

Switzerland

Switzerland is well known for its food (especially chocolate and cheese), skiing in Zermatt, Gstaad, St. Moritz and many other famous places in the alps, hiking in the Engadin or watching the mountain panorama out of the Glacier-Express train. Many famous places of interest are very close to Zurich and easy to reach by train. Enjoy some days before or after the conference at the Lake of Lucerne, on the Jungfraujoch, the Rheinfall of Schaffhausen or at many other beautiful landmarks.

Information and Directions

The conference will take place at the **ML building** of **ETH Zürich**, located at **Tannenstrasse 3, 8092 Zürich**.

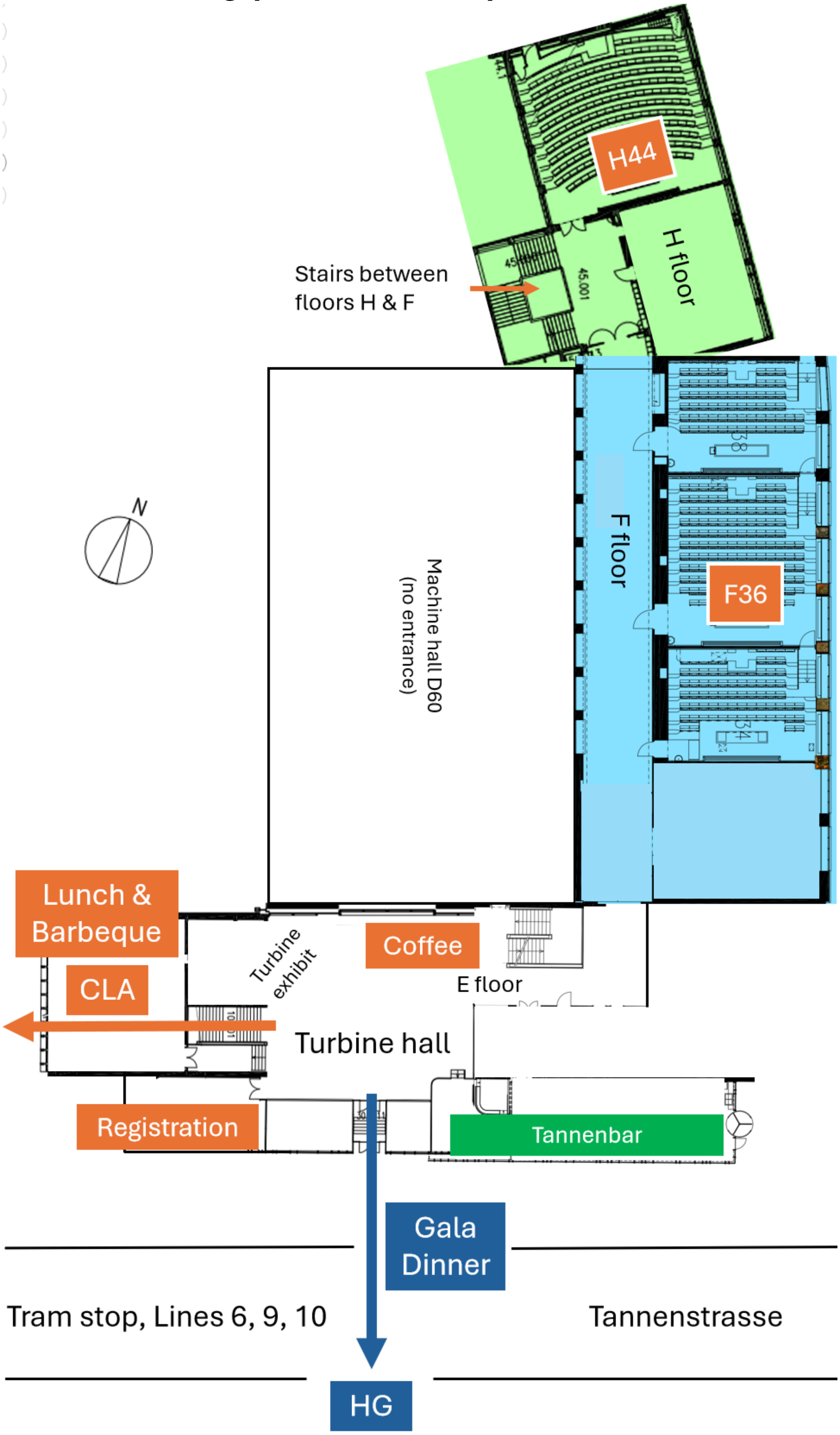


Getting there from Zürich Main Station (Zürich HB)

- By tram (Recommended)
  1. From Zürich HB (Main Station), take Tram Line 6 (direction *Zoo*) or 10 (direction *Zürich Flughafen)* from the Bahnhofplatz/HB stop.
  2. Ride 3 stops to ETH/Universitätsspital.
  3. From there, it's a 2-minute walk along Tannenstrasse to the ML building.
  4. The registration desk will be clearly marked at the building entrance.
- On foot (15 minutes)
  1. Exit the main station and head east across the Bahnhofbrücke.
  2. Follow Weinbergstrasse uphill until you reach the junction with Leonhardstrasse and then again uphill until you reach the Tannenstrasse.
  3. Turn left onto Tannenstrasse. The ML building will be on your left-hand side.

We recommend using public transport, as parking near ETH is limited.
We look forward to welcoming you at ETH Zürich!

Floorplan ML Building (Floors E, F & H)



CATERING

Lunch at Clausiusbar

Clausiusbar at ETH Zurich offers a modern dining experience with a focus on Asian-inspired cuisine. The menu features freshly prepared wok dishes, vibrant salads, and homemade lassis, catering to a variety of dietary preferences. Emphasizing sustainability, Clausiusbar also provides a range of vegetarian and vegan options. Guests can enjoy their meals in a relaxed atmosphere, with the option of dining on the terrace or taking food to go.

Location	Tannenstrasse 3, Zurich, CLA (D Floor), Adjacent to ML
When	Tuesday – Thursday 11:45 – 13:00
Cuisine	Asian. Wok specialties, vegan & vegetarian options
Menu Link	web.sv-restaurant.ch
How	Queue for your preferred menu and **mention the codeword "ICTIMT2025" at the checkout**. Drinks included.

Casual Barbeque Dinner at CLA Rooftop

Join us for a relaxed get-together on the CLA rooftop terrace, right next to the main building of ETH Zurich and just next to the iconic "Polyterrasse" with its breathtaking view over the city. During this rustic dinner we'll be serving freshly grilled Bratwürste (Sausages) with bread and beer, including pork-free and vegetarian/vegan alternatives – something for everyone! This is a perfect opportunity to unwind, enjoy good food and drinks, and connect with fellow participants in an informal atmosphere.

Location	Tannenstrasse 3, Zurich, CLA Rooftop (take elevator to K-floor)
When	Tuesday, starting from 17:30
Cuisine	Bratwurst & bread, pork-free and vegetarian/vegan alternatives
How	Just come by! No registration needed.

Conference Dinner at Dozentenfoyer

The ETH Faculty Restaurant “Dozentenfoyer” is located in the main building of ETH Zurich, which was built from 1858 to 1864 under Gustav Zeuner; the architect was Gottfried Semper, who was a professor of architecture at ETH Zurich at the time and one of the most important architectural writers and theorists of the age. The rooftop of the “Dozentenfoyer” is an ideal place for networking while watching the sunset at the end of a conference day.




Location	Rämistrasse 1, Zurich, ETH Main Building (take elevator to K-Floor)
When	Wednesday starting from 17:30
Homepage	ethz.ch/staffnet/en/service/events/dozentenfoyer.html

SESSION OVERVIEW

Time	Tuesday 17.06.2025 ML H44	Tuesday 17.06.2025 ML F36	Wednesday 18.06.2025 ML H44	Wednesday 18.06.2025 ML F36	Thursday 19.06.2025 ML H44
08:00	Registration and Coffee Opening	Registration and Coffee	Welcome and Coffee Keynote 3	Welcome and Coffee	Welcome and Coffee Keynote 6
09:00	Opening Keynote 1		Keynote 3 Keynote 4		Keynote 6 Keynote 7
10:00	Coffee Break Keynote 2	Coffee Break	Coffee Break PROC	Coffee Break SIM	Coffee Break COMP
11:00	Keynote 2 COMP Lunch	PROC Lunch	PROC Lunch	SIM Lunch	COMP Lunch
12:00	Lunch	Lunch	Lunch	Lunch	Lunch
13:00	EXP	PROC	AI	SIM	COMP
14:00	SIM	PROC	AI	SIM	COMP Keynote 8
15:00	Coffee Break SIM	Coffee Break EXP	Coffee Break AI	Coffee Break PROC	Keynote 8 Closing Remarks Coffee & Farewell
16:00	SIM	EXP	Keynote 5		Coffee & Farewell
17:00	Barbeque Dinner	Barbeque Dinner	Conference Dinner	Conference Dinner	
18:00	Barbeque Dinner	Barbeque Dinner	Conference Dinner	Conference Dinner	

AI	AI and Data-Driven Thermal Analysis
COMP	Thermal Error Compensation in Machine Tools
EXP	Experimental Methods and Measurement Techniques in Machine Tools
PROC	Process Integrated Thermal Behaviour in Manufacturing
SIM	Simulation Strategies and Digital Twins of Machine Tools

Tuesday 08:45 – 10:00: Opening and Keynote Session in ML H44

Session Chair: Markus Bambach

08:45 – 09:15	Markus Bambach Konrad Wegener	Opening Remarks and Welcome
09:15 – 10:00	Steffen Ihlenfeldt Lars Penter	Advancing Thermal Control in Machine Tools: The Role of Digital Twins

Tuesday 10:00 – 10:30: Coffee Break

Tuesday 10:30 – 11:15: Keynote Session in ML H44

Session Chair: Markus Bambach

10:30 – 11:15	Michael Klotz Frank Fiebelkorn	Investigation and influencing of the thermal behavior of grinding machines from a manufacturer's perspective

Tuesday Sessions 11:15 – 11:45

Session PROC in ML F36
Session Chair: Josef Mayr

11:15 – 11:45	Ayato Ishigaki, Daisuke Kono	Estimation of thermal boundary conditions in rotating bearing by data assimilation

Session COMP in ML H44
Session Chair: Konrad Wegener

11:15 – 11:45	Angelo Cescato, Filippo Monti	Thermal Effects and Compensation in EDM Machines

Tuesday 11:45 – 13:00: Lunch at Clausiusbar

Tuesday Sessions 13:00 – 15:00

Session PROC in ML F36
Session Chair: Konrad Wegener

13:00 – 13:30	Eckart Uhlmann, Mitchel Polte, Florian Triebel, Thomas Pache, Roland Binninger	Influence of thermoelectrically controlled temperature of spindle front bearings on the warm-up time after a spindle stop
13:30 – 14:00	Takumi Nagashima, Masaya Yokota, Shiho Takemura, Takanori Mori, Yoko Hirono, Yuji Imamiya, Teppei Maki, Yasuhiro Kakinuma	Liquid cooling system for tool steel coating on gears by directed energy deposition
14:00 – 14:30	Hui Liu, Markus Meurer, Thomas Bergs	Empirical and Simulation-Based Analysis of Heat Partition in Orthogonal Milling
14:30 – 15:00	Amirhossein Ranjbar, Mohammad Amirshirzad, Behzad Jabbaripour, Munish Gupta	Studies on Surface Integrity Parameters in the Turning of Hardened 1.6580 Steel under different cooling condition

Session EXP in ML H44
Session Chair: Steffen Ihlenfeldt

13:00 – 13:30	Álvaro Sáinz de la Maza García, Leonardo Sastoque Pinilla, Luis Norberto López de Lacalle Marcaide	Thermally induced volumetric error modelling on large-scale machining centre
13:30 – 14:00	Eri Tsuchiya, Shunsuke Ohmae, Daisuke Kono	Necessary Camera Calibration Accuracy for Vision-Based Thermal Error Measurement in Machine Tools

Session SIM in ML H44
Session Chair: Steffen Ihlenfeldt

14:00 – 14:30	Sebastian Lang, Marco Schneider, Lenny Rhiner, Markus Bambach	Overcoming Uncertainty with an Ensemble of Physical Models and Real-Time Measurements: Thermal Error Compensation using Kalman Filters in a Digital Twin
14:30 – 15:00	Daniel Spescha, Nino Ceresa, Mayra Hoppstädter	Model-Reduction-Based Temperature Field Reconstruction for Volumetric Error Compensation

Tuesday 15:00 – 15:30: Coffee Break

Tuesday Sessions 15:30 – 17:00

Session EXP in ML F36
Session Chair: Matej Sulitka

15:30 – 16:00	Michal Straka, Martin Mareš, Hyeok Kim, Otakar Horejš	Utility of radio transmission probes for identifying non-stationary thermal errors of high-performance spindle units
16:00 – 16:30	Morteza Dashtizadeh, Andrew Longstaff, Simon Fletcher	Effect of thermal changes on the squareness error between linear axes of machines tools
16:30 – 17:00	Gaurav Abhay Kulkarni, Rajeev Rajampeta, Steffen Strauss, Malte Langmack	Enhancing Thermal Precession of Coordinate Measuring Machine (CMM) through Feed Forward Correction for Shopfloor Metrology

Session SIM in ML H44
Session Chair: Josef Mayr

15:30 – 16:00	Roland Binninger, Hans-Fridtjof Pernau, Florian Triebel, Katrin Schmitt, Jürgen Wöllenstein	Simulation-based design of a thermoelectrically temperature-controlled motorized milling spindle
16:00 – 16:30	Immanuel Voigt, Welf-Guntram Drossel	Mixed-dimensional finite element modelling of passive thermal error compensation systems in machine tools
16:30 – 17:00	Meng Bai, Tao Tao, Hu Shi, Yingqiang Zheng	Modeling for thermal error of slant bed lathe based on error decomposition and differential equations

Wednesday 08:30 – 10:00: Keynote Sessions in ML H44

Session Chair: Konrad Wegener

08:30 – 09:15	Matej Sulitka, Martin Mareš, Otakar Horejš	The ways towards applications of Thermal Digital Twins
09:15 – 10:00	Philipp Klimant, Christian Naumann, Alexander Geist, Janine Glänzel	Ambient influences on thermal errors in machine tools: challenges, modelling and compensation

Wednesday 10:00 – 10:30: Coffee Break

Wednesday Sessions 10:30 – 11:45

Session SIM in ML F36

Session Chair: Matej Sulitka

10:30 – 11:00	Janine Glänzel, Alexander Geist, Christian Naumann, Steffen Ihlenfeldt, Steffen Brier, Joachim Regel, Martin Dix, Marc-André Dittrich, Matthias Brand, Denis Ulrich	Simulation-Based Approach of Thermal Effects Considering Coolant Application and Axis Movements in the Working Area Through a Coupled CFD Mode
11:00 – 11:30	Lars Penter, Steffen Schroeder, Matthias Brand, Steffen Ihlenfeldt	Hybrid thermal modeling approach for the early stages of the machine tool design process

Session PROC in ML H44

Session Chair: Konrad Wegener

10:30 – 11:00	Simon Winter, Tim Göttlich, Hui Liu, Thomas Bergs, Reinhold Kneer	Investigation of the influence of temporally and spatially resolved heat fluxes at the cutting edge on the maximum tool temperature during side milling
11:00 – 11:30	Anna Kibireva, Hui Liu, Markus Meurer, Thomas Bergs	Experimental and Simulative Investigation of Cutting Edge Geometry Effects on Surface Integrity in Turning of Inconel 718

Wednesday 11:45 – 13:00: Lunch at Clausiusbar

Wednesday Sessions 13:00 – 15:00

Session SIM in ML F36
Session Chair: Konrad Wegener

13:00 – 13:30	Satsuma Ando, Shun Tanaka Yuta Teshima Toru Kizaki Jun Morishita	Strategy for sensor placement to estimate thermal errors using temperature-sensitivity distribution based on a reduced-order model of machine tools
13:30 – 14:00	Pritam Bari, Holger Rudolph, Lars Penter, Steffen Ihlenfeldt	Comparisons of model order reduction techniques for efficient thermal simulations
14:00 – 14:30	Michelle Engert, Kim Torben Werkle, Hans-Christian Möhring	Finite element analysis of residual stress variations in prestressed fiber-reinforced polymer concrete induced by temperature changes
14:30 – 15:00	Darío Fernández Holger Rudolph Lars Penter Steffen Ihlenfeldt	Modeling and simulation of the thermal behavior of an electromechanical compact axle

Session AI in ML H44
Session Chair: Soichi Ibaraki

13:00 – 13:30	Sebastian Lang, Mario Zorzini, Markus Sprecher, Stephan Scholze, Markus Bambach	No Warm-Up Required: Initializing Time-Dependent Thermal Error Compensation Models for Machine Tools
13:30 – 14:00	Sergio G. Ferreira, Gorka Aguirre	Temperature field prediction and convection coefficient estimation from temperature data using PINNs
14:00 – 14:30	Yue Zheng, Guoqiang Fu, J.R.R. Mayer, Sen Mu, Sipei Zhu	Thermal Error Modeling in CNC Machine Tool Spindles Using Transfer Learning with GRU
14:30 – 15:00	Weiguo Gao, Junyan Xing, Lingtao Weng, Dawei Zhang, Yingjie Zheng, Kai Shi, Zheng Guo	Dynamic active temperature control method based on structure-specific heat dissipation-to-generation ratio matching

Wednesday 15:00 – 15:30: Coffee Break

Wednesday Sessions 15:30 – 16:30

Session PROC in ML F36
Session Chair: Réné Mayer

15:30 – 16:00	Lucas Brause, Sebastian Michel, Robert Schmidt, Dirk Biermann	Measurement and analysis of the thermal load during BTA deep hole drilling
16:00 – 16:30	Leonie Christine Kilian Patrick Fehn, Matthias Weigold	Design Measures for Enhancing Heat Conduction in CFRP Motor Spindle Components

Session AI in ML H44
Session Chair: Konrad Wegener

15:30 – 16:00	Guangyan Ge**,** Xuetao Wang Zhilin Zeng, Zhengchun Du	A Permutation Test-Based Method for Identifying Thermal Hysteresis Characteristics and Modeling Thermal Errors in Machine Tools

Wednesday 16:30 – 17:15: Keynote Session in ML H44

Session Chair: Konrad Wegener

16:30 – 17:15	Josef Mayr, Konrad Wegener, Petr Kaftan	Thermal aspects toward the fully compensated machine tool

Thursday 08:30 – 10:00: Keynote Sessions in ML H44

Session Chair: Christian Brecher

08:30 – 09:15	René Mayer	Indirect metrology of machine tool kinematic errors and application to thermal errors
09:15 – 10:00	Soichi Ibaraki	Self-calibration for on-machine probing

Thursday 10:00 – 10:30: Coffee Break

Thursday Sessions 10:30 – 11:45

Session COMP in ML H44
Session Chair: Steffen Ihlenfeldt

10:30 – 11:00	Christian Naumann, Philipp Klimant, Sebastian Lang, Lenny Rhiner, Josef Mayr, Markus Bambach, Konrad Wegener, Christoph Habersohn, Christoph Einspieler, Friedrich Bleicher	Geometric thermal error compensation using assembly submodels enhanced by adaptive learning control
11:00 – 11:30	Christoph Habersohn, Christoph Einspieler, Nikita Nobel, Friedrich Bleicher	Development and Integration of Temperature Measurement on a Machining Center for Precision Machining Used for a Data Driven Thermal Distortion Compensation Considering Real Production Conditions

Thursday 11:45 – 13:00: Lunch at Clausiusbar

Thursday Sessions 13:00 – 14:30

Session COMP in ML H44
Session Chair: Philipp Klimant

13:00 – 13:30	Fabian Axel Tripkewitz, Matthias Fritz, Matthias Weigold	Reducing thermally induced position and orientation errors of a precision machine tool's rotary axis due to rotation by using hydrostatic bearings
13:30 – 14:00	Tim Boye, Florian Sellmann	Practical Implementation of Complex Thermal Models on NC-Controls
14:00 – 14:30	Daniel Divisek, Petr Kaftan, Josef Mayr, Markus Bambach, Konrad Wegener	Extension of the Torque Limit Skip Method for Thermal Error Measurement

Thursday 14:30 – 15:45: Keynote and Closing Session in ML H44

Session Chair: Konrad Wegener

14:30 – 15:15	Christian Brecher, Stephan Neus, Ralph Klimaschka, Janis Schäfer Alexander Steinert	Advancing Sustainable Manufacturing: Multidimensional Optimization of the Thermal Behavior of Machine Tools
15:15 – 15:45	Konrad Wegener Markus Bambach	Closing Remarks

Thursday 15:45 – 17:00: Coffee and Farewell

KEYNOTE CONTRIBUTIONS

Steffen Ihlenfeldt and Lars Penter
TU Dresden, Institut für Werkzeugmaschinen und adaptive Steuerungen

Advancing Thermal Control in Machine Tools: The Role of Digital Twins

Tuesday 17.06.2025, 09:15 – 10:00 in ML H44

Thermal deviations are a leading cause of geometric error in machine tools and pose persistent challenges to high-precision manufacturing. This review explores how digital twins (DTs) have advanced thermal management through the integration of real-time data, simulation models, and adaptive control strategies. Recent developments in thermal digital twins are categorized as physics-based, datadriven, hybrid, or adaptive modeling approaches. Their contributions to thermal error prediction and compensation are highlighted. The emphasis is on model order reduction, machine learning integration, sensor technologies, and lifecycle-wide applications. Finally, we discuss open challenges such as model generalization, calibration robustness, and early-stage design integration to guide future research.

Michael Klotz and Frank Fiebelkorn
Fritz Studer AG

Investigation and influencing of the thermal behavior of grinding machines from a manufacturer's perspective

Tuesday 17.06.2025, 10:00 – 10:45 in ML H44

Thermally induced structural displacements are among the main causes of dimensional deviations in high-precision machining. Particularly in the grinding process, where tolerances in the micrometer range must often be maintained, the thermal stability of the machine tool significantly influences workpiece quality. This article addresses the investigation and targeted manipulation of the thermal behavior of universally applicable external and internal cylindrical grinding machines from the perspective of a machine manufacturer with many years of development experience.

During product development, various thermal analysis methods are used on real prototypes. A key investigation technique is the relative measurement of the so-called "thermal course." A defined test workpiece is machined at regular intervals over several hours to record the progressive dimensional deviations, particularly in diameter. These measurements serve as direct indicators of the thermo-mechanical deformation behavior of the overall system under operating conditions.

The particular challenge of grinding machines with flexible, universal application lies in the wide variety of workpieces to be machined: from delicate components with minimal contact surfaces and machining times in the range of seconds to large-scale workpieces with grinding times of over an hour. This process diversity results in highly divergent thermal loads, the effects of which on the machine structure must be analyzed and understood.

To identify thermally relevant influencing factors, comprehensive temperature monitoring of all significant heat sources (such as drive spindles, dressing systems, hydraulic units) and heat sinks (such as coolant returns, machine bed) is carried out during prototype testing. Continuous recording of temperature profiles allows us to determine thermally dominant components and their characteristic time delays in heat transfer.

In individual cases, the evaluation of machine behavior is supplemented by absolute displacement measurements between the workpiece, grinding tool, and dressing system. This complex method enables the direct quantification of thermally induced relative movements in the machining area, allowing the detection of the effects of everything from heat input to geometric deviations and their time-delayed behavior.

Based on these findings, machine-type-specific measures are being developed for the targeted control of heat input and heat dissipation. These include design optimizations, thermally decoupled assemblies, and active temperature control, as well as software-supported compensation strategies. The goal of these efforts is to quickly achieve and maintain thermal stability under fluctuating operating conditions. To achieve this, it is important to understand and master the influence of auxiliary systems, such as coolant temperature control, coolant preparation, and grinding mist extraction.

The lecture provides an insight into the practical application of engineering methods for analyzing thermal effects and demonstrates how robust, series-ready solutions can be developed to improve thermal stability and process reliability – regardless of the complexity and variance of the grinding processes used.

Matej Sulitka, Martin Mareš and Otakar Horejš
CTU Prague, Faculty of Mechanical Engineering

The ways towards applications of Thermal Digital Twins
Wednesday 18.06.2025, 08:30 – 09:15 in ML H44

The machine tool thermal behavior represents one of significant phenomena with an impact, in particular, on the machining accuracy. Prediction of machine tool thermo-mechanical behavior and minimization of thermal errors is a part of long-term research topics aimed at increasing the accuracy and reliability of machine tool operation. Increased availability of data and computing power for edge applications currently significantly expands the possibilities of deploying advanced digital models and digital twins for modeling, monitoring and compensation of machine tool thermal behavior and thermal errors.
RCMT has been systematically addressing the topic of thermal issues in machine tools for almost two decades. The keynote paper divides the use of thermal digital models and digital twins into three areas: pre-process, process and post-process applications. In the field of pre-process digital models, the procedures for creating and using advanced models are presented, e.g. for predicting the spindle thermal behavior, spindle cooling systems design, or cooling with process fluids. Process thermal digital twins for online compensation of thermal errors represent one of the means aiming at the vision of autonomous manufacturing systems. The challenges are mainly in hybrid combinations of data, FEM and transfer functions, AI and procedures for adaptive model modification using an on-machine artifact measurement system. The post-process thermal digital twin consists of the ability of updating and retraining the models used for follow-up production. Successful applications and challenges for further research are presented

Philipp Klimant, Christian Naumann, Alexander Geist and Janine Glänzel
Fraunhofer Institut für Werkzeugmaschinen und Umformtechnik

Ambient influences on thermal errors in machine tools: challenges, modelling and compensation

Wednesday 18.06.2025, 09:15 – 10:00 in ML H44

Thermally induced errors are one of the main factors contributing to positioning inaccuracies of cutting machine tools. The causes of these errors can be divided into machine-internal, process-related and external heat sources and sinks. Machine-internal are heat sources such as friction in guides and bearings, electrical losses in drives, waste heat from hydraulic and pneumatic units and the various cooling systems, which may act as both heat sources and heat sinks. Process-related are the friction from the cutting process, cutting fluid, the workpiece and chip nests. Ambient effects comprise the convection of ambient air, radiation e.g. from sunlight and conduction with the foundation.

Of these three causes, ambient effects pose a particular challenge, because these effects are slow, but large-scale and thus very strong. From the viewpoint of a machine tool manufacturer, ambient effects are difficult to control, because every machine tool they sell can be placed in a different environment, and also difficult to study, because a controlled change of ambient conditions is difficult to achieve without expensive infrastructure. There is also a secondary ambient component of free and forced convection within the workspace due to moving machine tool axes, cutting fluid usage and air/fog evacuation units.

This paper presents various methodologies to accurately and efficiently model ambient effects in simulation-based thermal machine tool studies. This includes a simplified method for categorizing natural convection based on the surface orientation, methods for obtaining localized heat transfer coefficients via computational fluid dynamics (CFD) simulations and for applying them in real-time to thermal FEM simulations and methods for modelling the complex conditions in the machine tool workspace during cutting operations.

The paper also presents some best practices for measuring ambient effects and for the parametrization of CFD simulation models. For a specific milling machine tool, various relevant load scenarios were simulated as well as measured and the results will be shown to demonstrate the efficacy of the simulation models and the scope of the ambient effects.

Aside from the mere study and modelling of ambient effects, their reduction or compensation will also be addressed. Different methods for predicting the environment-induced thermal error will be presented, including the use of data-driven black-box methods, transfer functions and simulation-based methods.

Josef Mayr, Konrad Wegener and Petr Kaftan
inspire AG
ETH Zurich, Institute for Machine Tools and Manufacturing

Thermal aspects toward the fully compensated machine tool
Wednesday 18.06.2025, 16:30 – 17:15 in ML H44

The thermal behaviour of machine tools is the greatest challenge of precision in manufacturing and counteracting it with a controlled environment swallows an immense amount of effort and energy. As thermal errors result from physics and physics is invincible, the solution must be generated from another principle as a workaround. The vision of a fully compensated machine tool intends to remove the thermal errors for machine tools that operate under normal shop floor conditions with the help of numerical control. Research in the field of machine tools at inspire AG and the Institute of Machine Tools and Manufacturing (IWF) at ETH Zurich is following the vision of the fully compensated machine tool. This keynote paper provides an overview of past and current work on how this vision is being pursued in the field of thermal issues in machine tools and related manufacturing systems. The paper concludes with a summary and assessment of the state of the art and provides an outlook on the challenges in thermal error research on the way towards the fully compensated machine tool by illustrating that up to now, not all thermal axis errors of machine tools can be measured in a sufficiently short time and be compensated by data driven models, and the physical models for predicting the thermal behaviour often do not achieve the required accuracy.

René Mayer
Ecole Polytechnique de Montreal, Department of Mechanical Engineering

Indirect metrology of machine tool kinematic errors and application to thermal errors
Thursday 19.06.2025, 08:30 – 09:15 in ML H44

Machining machines such as machine tools and industrial robots are required to achieve increasing levels of precision and to reliably achieve prescribed levels of precision despite adverse operational conditions. Although extensive and time-consuming direct measurement at the factory or at commissioning of a machine is justified for quality control and final adjustment, it is considered too costly and time-consuming to be regularly performed at the customer’s production facility. Hence the interest in indirect methods. Indirect methods are also particularly attractive for thermal error studies due to the potentially short measurement time. However, careful analysis of the measurement strategy and model are necessary to obtain meaningful results. The keynote will review key principles and then focus on the SAMBA (Scale and Master Ball Artefact) approach, using a calibrated scale reference and a set of nominally positioned master balls, and its application to thermal errors.

Soichi Ibaraki
Hiroshima University, Graduate School of Advanced Science and Engineering

Self-calibration for on-machine probing
Thursday 19.06.2025, 09:15 – 10:00 in ML H44

A major uncertainty contributor to the on-machine probing is linear axis geometric errors. We proposed a novel self-calibration scheme to separate the workpiece geometry and machine tool kinematic errors from the probed profiles. First, "classical" self-calibration schemes will be briefly reviewed, which are limited to either of the straightness, roundness, and 2D grid point positions, since they require the probed points being in a closed set, as the workpiece is rotated or translated.
Our work extends it to a free-form 2D geometry. A key idea is on the assumption that the machine tool's positioning error is in accordance with the rigid-body kinematic model. Its extension to the flatness measurement (probing in Z direction) will be also presented.
By performing the present self-calibration periodically, one may observe a long-term variation in machine tool geometric errors due to, e.g. thermal influence. Such an application to a long-term machine accuracy monitoring will be also presented.

Christian Brecher, Stephan Neus, Ralph Klimaschka, Janis Schäfer and Alexander Steinert
RWTH Aachen University, Laboratory for Machine Tools and Production Engineering

Advancing Sustainable Manufacturing: Multidimensional Optimization of the Thermal Behavior of Machine Tools
Thursday 19.06.2025, 14:30 – 15:15 in ML H44

To achieve the sustainable operation of machine tools, it is essential to address the optimization problem consisting of productivity, quality, and energy use. The thermal behavior significantly influences these parameters, thereby directly affecting sustainable machine operation. The Collaborative Research Center CRC/TRR96, funded by the German Research Foundation DFG, has proposed approaches to systematically tackle this conflict. Building on the foundational knowledge and transferring it into practical applications, control systems can effectively be developed and implemented. One such application is the model predictive control of active cooling systems in machine tools for compensation of thermoelastic displacements during operation, thus enhancing the machine accuracy. However, to optimally select the operating point of the active cooling system from the holistic sustainability perspective, it is crucial to consider the effects on all dimensions of the optimization problem. The design of a multivariable model predictive control is demonstrated using the example of the spindle cooling. The approach involves ex-tending the system modeling and developing of a sustainability index.

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IWF RESEARCH GROUPS

Group Thermal Simulation

Markus Bambach[1], Sebastian Lang[1,2], Lenny Rhiner[1,2], Marco Schneider[1], Max Keel[2], Petr Kaftan[2], Mario Zorzini[2], Josef Mayr[2]

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1 Introduction

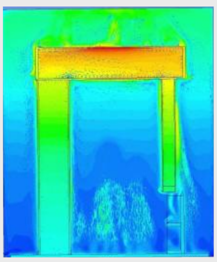
Thermally induced errors significantly affect the accuracy of machine tools (MTs). The research group is committed to advancing the precision of machine tools by comprehensively understanding, predicting, and compensating for these thermal errors. The goal is to improve accuracy and optimize energy consumption by compensating the impact of thermal fluctuations.

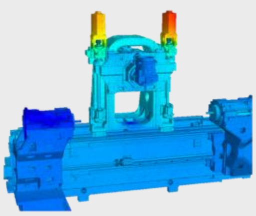
2 Precision Measurements

New measurement techniques for thermal errors in machine tools have been developed, allowing for precise, real-time monitoring of temperature-induced deviations. These innovations enhance error detection capabilities and improve the prediction and compensation for thermal effects, leading to greater accuracy and reliability in machine tool operations.

3 Simulation of Thermal Behavior

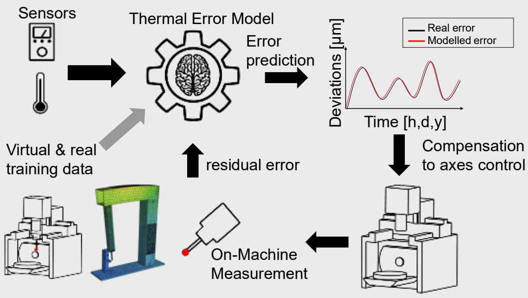
The research group has developed comprehensive simulations to model the complex dynamics of machine tools, employing FEM, CFD, and other advanced computational techniques. These simulations accurately capture the thermal and thermo-mechanical behavior of machine tools under varying operational conditions. By providing a detailed analysis of heat distribution, thermal deformation, and fluid dynamics, the simulations generate high-quality virtual training data essential for predicting thermal errors as well as generate insights to improve construction and energy efficiency.





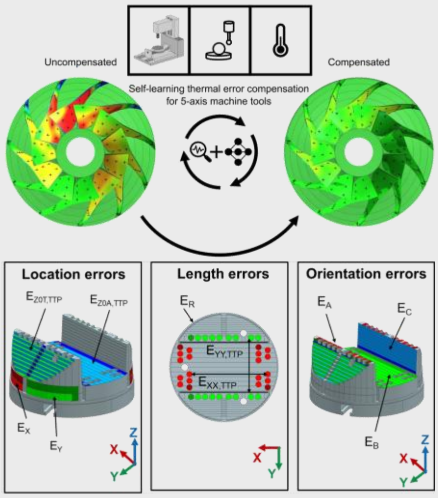
4 Thermal Error Model

Data-driven thermal error models are trained using experimentally measured and simulated thermal errors to accurately predict deviations in machine tools. This predictive capability allows for proactive error compensation, compensating the effects of thermal fluctuations and enhancing precision and performance across various operating conditions.



5 Compensation of Thermal Errors

The compensation of thermal error has been successfully demonstrated on test pieces and advanced engineering parts alike. The first figure below compares an uncompensated impeller to a thermally compensated one on the right. The compensated impeller demonstrates markedly better precision and quality, highlighting the effectiveness of the implemented error compensation strategies. The second figure below presents a test piece designed to assess location, length, and orientation errors, clearly illustrating the differences between a compensated and an uncompensated workpiece. This comparison effectively highlights the thermal errors, showcasing the impact of compensation strategies on reducing these deviations.



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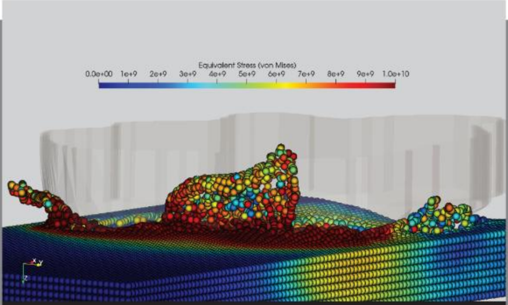
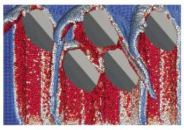


Meshfree Methods in Machining Simulation

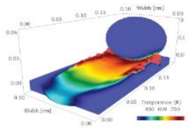
Cutting Simulation

Without mesh restrictions, particle methods accurately predict chip formation and other physical parameters.



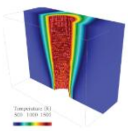
Tool development

Graphic Processing Unit (GPA) enhanced algorithms largerly shorten the computational time, and thus provide with possiblility of fast development of cutting tools.



Material Modeling

Through reduced simulation time, inverse parameter identification of constitutive model and friction model at extreme conditions can be achieved.



Laser Drilling

Based on the successful thermal modeling, optimization of process parameters can be achieved with higher efficiency.www

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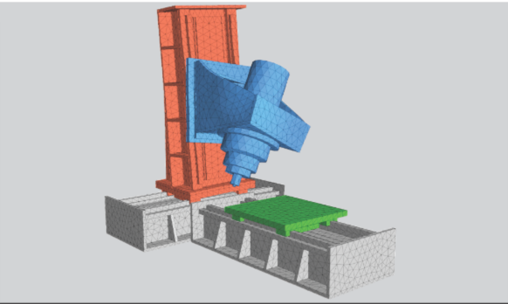
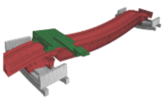


Machine Tool Analysis

Simulation - Optimization - Metrology

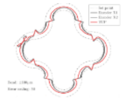
MORe Simulation Tool

Mechanical, mechatronic, thermal, and thermo-mechanical simulation of machine tools brought to the point.



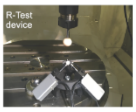
Static Optimization

Design and correction methods for high-precision machine tools under gravity loads.



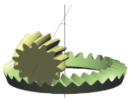
Dynamic Optimization

Optimal control parametrization and structure design for high-dynamics machine tools.



Machine Tool Testing

Measurement of precision and dynamics. Geometric, kinematic and dynamic testing of machine tools.



Face Gear Application

Development of software tools for parameter studies and laser ablation process development.

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Laser Ablation using Pulsed Laser Sources
Cutting tools
Advanced 5 – axis laser machining of tungsten carbide. Application: Manufacturing of micro milling tools.
Grinding tools
Quasi tangential laser profiling and conditioning. Application: Cubic Boron Nitride (CBN) - and Poly Cristalline Diamond (PKD) - composite grinding tools.
Surface adjustment
Micrometer-precise metal removal of large area by short pulsed laser processing. Application: Adjustment of a surface profile.
Parameter studies
Determination of laser-material interaction parameters and pump-probe experiments. Application: Process development.
Software development
Development of software tools for parameter studies and laser ablation process development.
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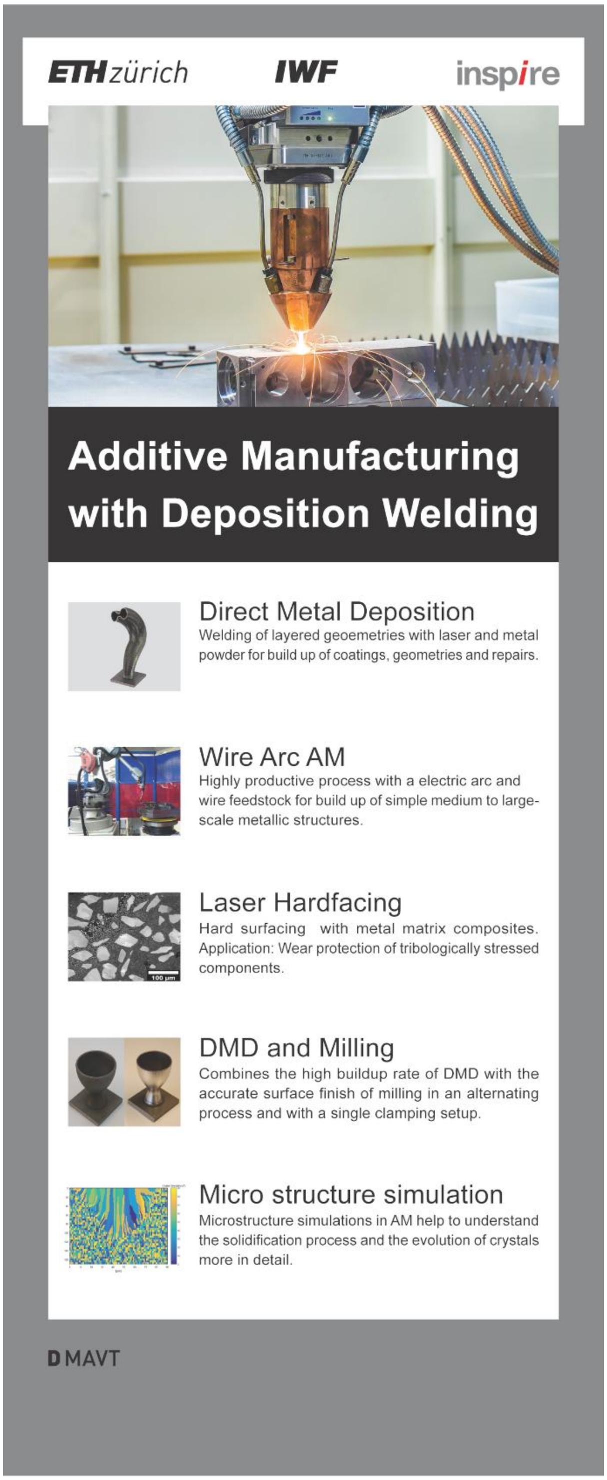
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Additive Manufacturing with Deposition Welding
Direct Metal Deposition
Welding of layered geoemetries with laser and metal powder for build up of coatings, geometries and repairs.
Wire Arc AM
Highly productive process with a electric arc and wire feedstock for build up of simple medium to large-scale metallic structures.
Laser Hardfacing
Hard surfacing with metal matrix composites. Application: Wear protection of tribologically stressed components.
DMD and Milling
Combines the high buildup rate of DMD with the accurate surface finish of milling in an alternating process and with a single clamping setup.
Micro structure simulation
Microstructure simulations in AM help to understand the solidification process and the evolution of crystals more in detail.
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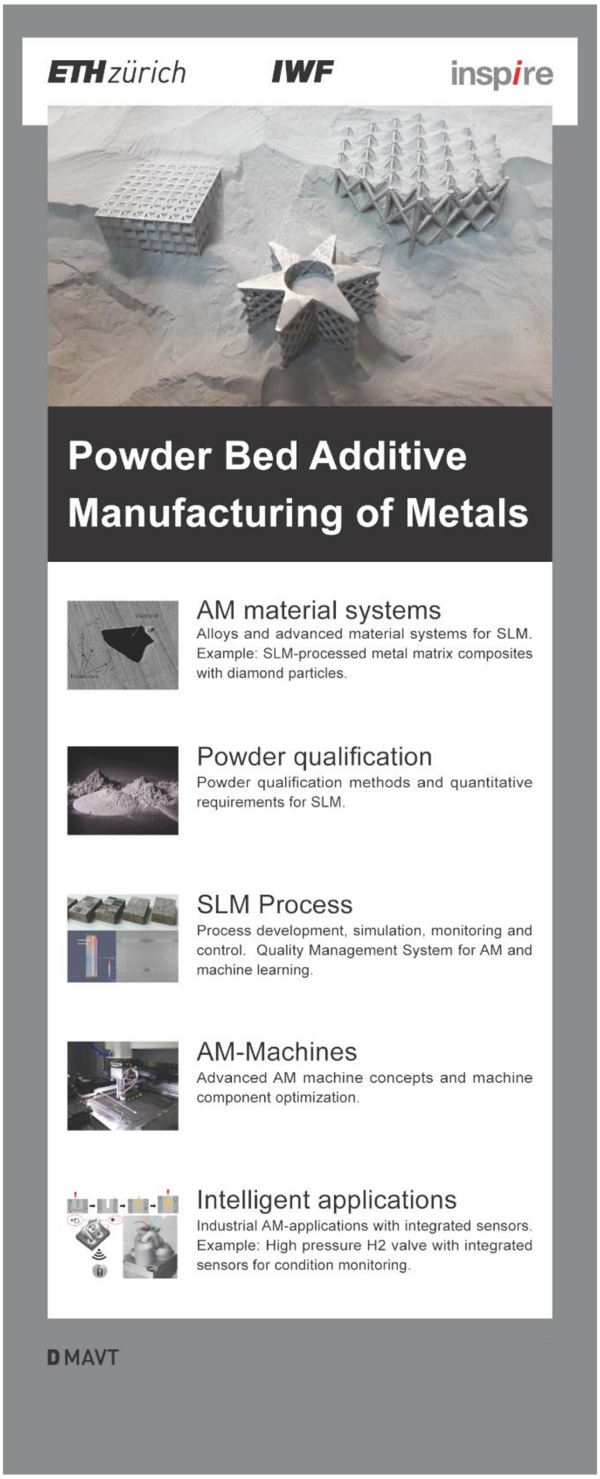
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Powder Bed Additive Manufacturing of Metals
AM material systems
Alloys and advanced material systems for SLM. Example: SLM-processed metal matrix composites with diamond particles.
Powder qualification
Powder qualification methods and quantitative requirements for SLM.
SLM Process
Process development, simulation, monitoring and control. Quality Management System for AM and machine learning.
AM-Machines
Advanced AM machine concepts and machine component optimization.
Intelligent applications
Industrial AM-applications with integrated sensors. Example: High pressure H2 valve with integrated sensors for condition monitoring.
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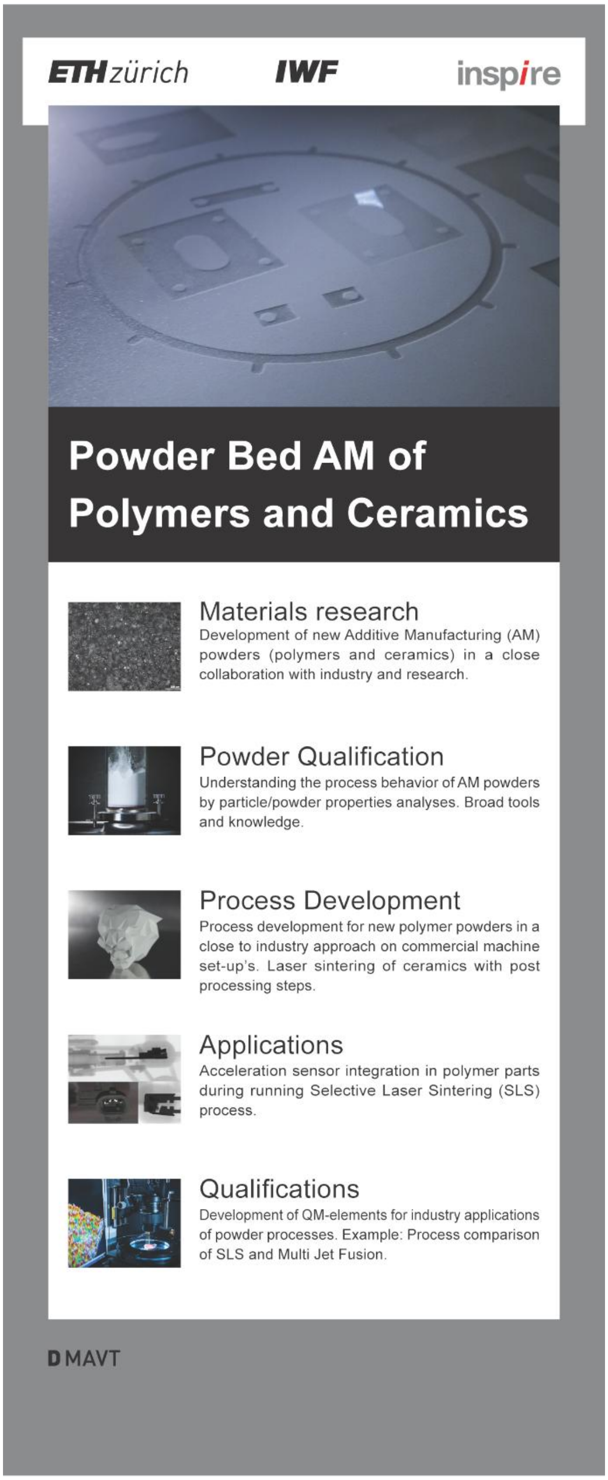
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Powder Bed AM of Polymers and Ceramics
Materials research
Development of new Additive Manufacturing (AM) powders (polymers and ceramics) in a close collaboration with industry and research.
Powder Qualification
Understanding the process behavior of AM powders by particle/powder properties analyses. Broad tools and knowledge.
Process Development
Process development for new polymer powders in a close to industry approach on commercial machine set-up's. Laser sintering of ceramics with post processing steps.
Applications
Acceleration sensor integration in polymer parts during running Selective Laser Sintering (SLS) process.
Qualifications
Development of QM-elements for industry applications of powder processes. Example: Process comparison of SLS and Multi Jet Fusion.
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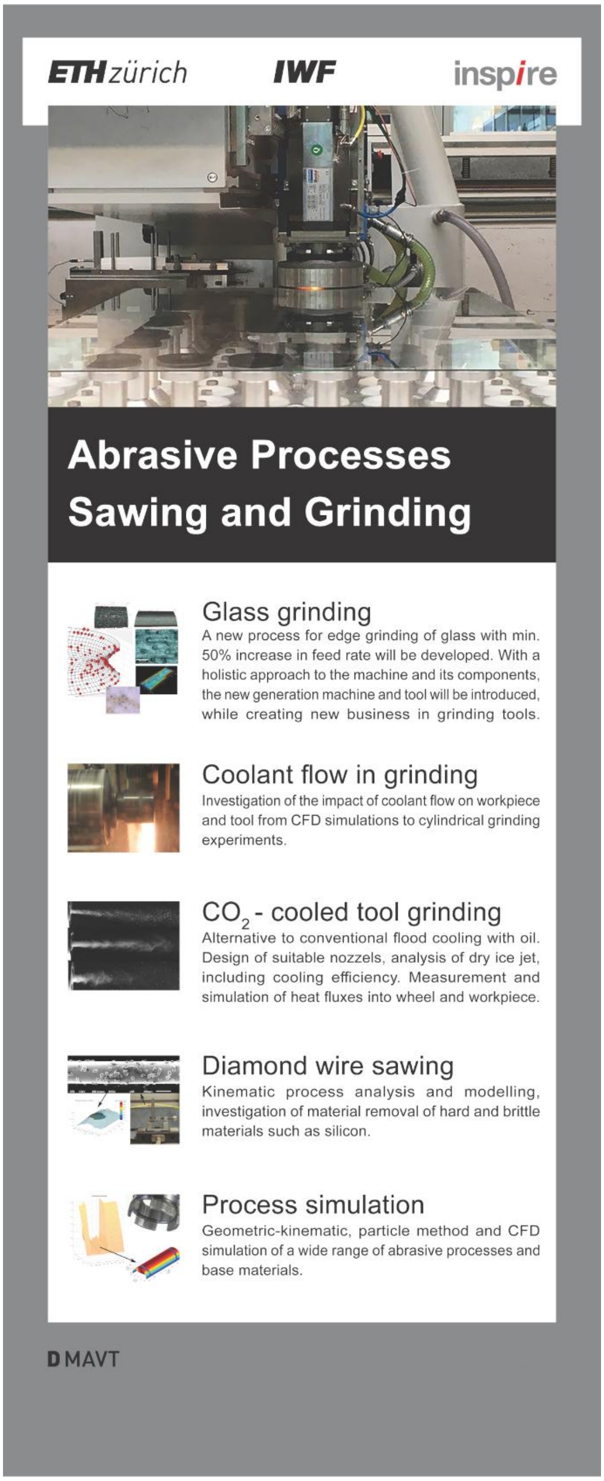
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Abrasive Processes
Sawing and Grinding
Glass grinding
A new process for edge grinding of glass with min. 50% increase in feed rate will be developed. With a holistic approach to the machine and its components, the new generation machine and tool will be introduced, while creating new business in grinding tools.
Coolant flow in grinding
Investigation of the impact of coolant flow on workpiece and tool from CFD simulations to cylindrical grinding experiments.
CO2 - cooled tool grinding
Alternative to conventional flood cooling with oil. Design of suitable nozzels, analysis of dry ice jet, including cooling efficiency. Measurement and simulation of heat fluxes into wheel and workpiece.
Diamond wire sawing
Kinematic process analysis and modelling, investigation of material removal of hard and brittle materials such as silicon.
Process simulation
Geometric-kinematic, particle method and CFD simulation of a wide range of abrasive processes and base materials.
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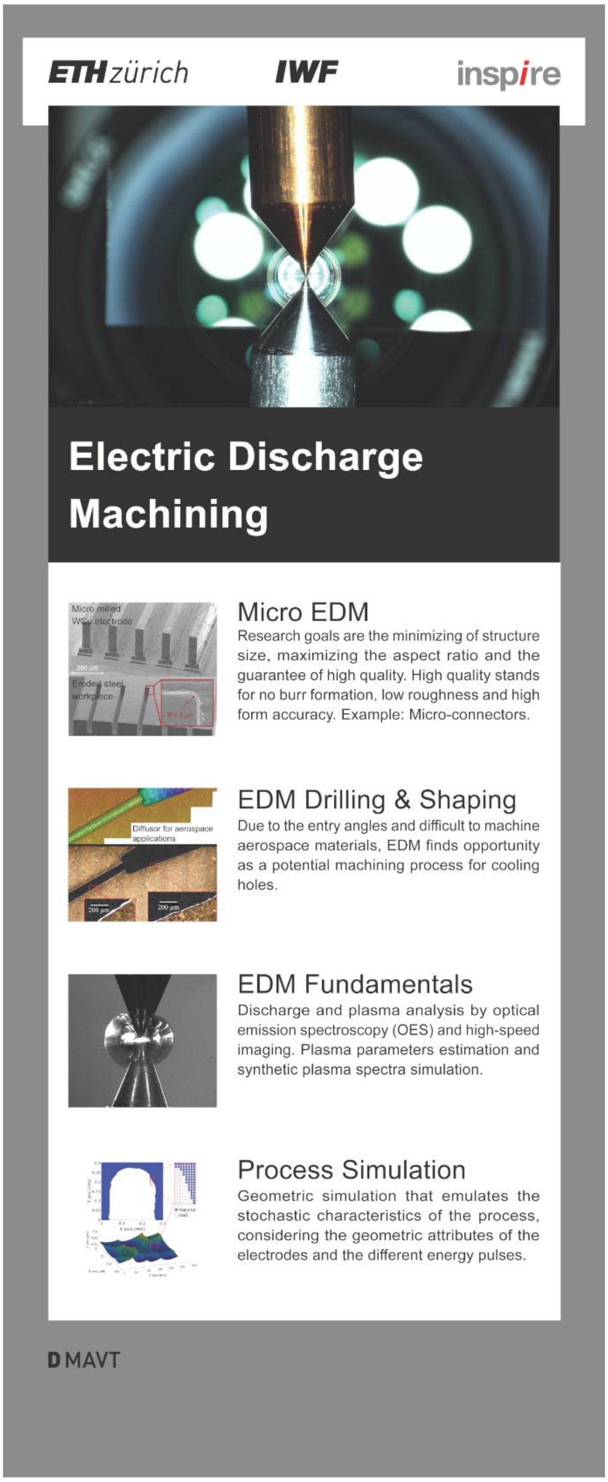
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Electric Discharge
Machining
Micro EDM
Research goals are the minimizing of structure size, maximizing the aspect ratio and the guarantee of high quality. High quality stands for no burr formation, low roughness and high form accuracy. Example: Micro-connectors.
EDM Drilling & Shaping
Due to the entry angles and difficult to machine aerospace materials, EDM finds opportunity as a potential machining process for cooling holes.
EDM Fundamentals
Discharge and plasma analysis by optical emission spectroscopy (OES) and high-speed imaging. Plasma parameters estimation and synthetic plasma spectra simulation.
Process Simulation
Geometric simulation that emulates the stochastic characteristics of the process, considering the geometric attributes of the electrodes and the different energy pulses.
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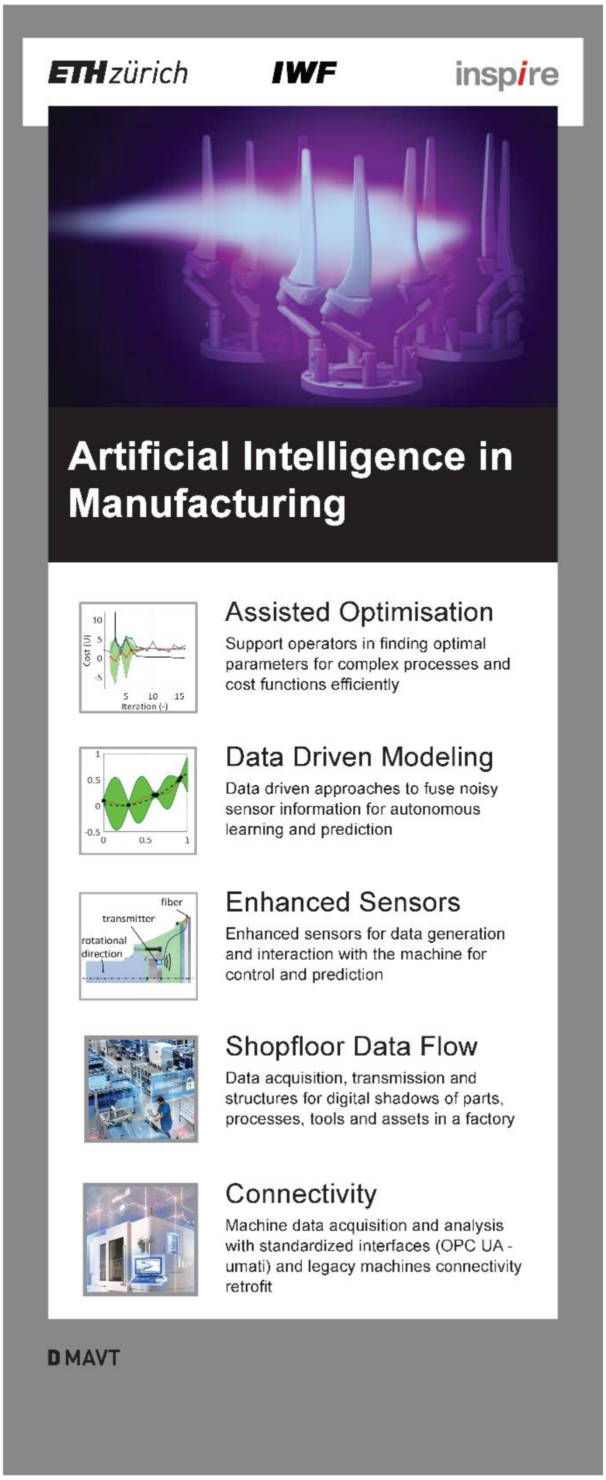

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