Using virtual reality (VR), objects can be regarded in a three-dimensional space. Thus, machine developments can be assessed and evaluated realistically in the early stages of development. The sooner changes are made to virtual prototypes, the lower the required cost.

We develop methods and tools for systematic design and optimization of parallel kinematics and machine structures, among others. Electromechanical drives for generating the main motion and feed motion are assemblies of machine tools, determining accuracy and productivity. Considering resource efficiency, need-based design of drives and structures gains more and more importance. This current trend is taken up in forming machines by using large servo-drives as main drives.

Increase in production accuracy and omitting cooling lubricants in dry processing are trends that place the focus of scientific research on thermal issues. Thermally robust machine designs and the compensation of thermally caused dislocations in machine tools are among the most significant tasks in this area.


FROM TECHNOLOGY TO MACHINE

The Department of Machine Tools conducts research on developing production systems, machines and components as well as their peripheral fields under the umbrella brand of resource-efficient production of the Fraunhofer Institute for Machine Tools and Forming Technology IWU. The focus especially lies on the increasing requirements concerning productivity, production accuracy, flexibility as well as energy and cost efficiency in developments in machine construction and plant engineering.

Reduction of the processing times and increase in production accuracy are vital for cost-effective manufacturing of tools in sheet and bulk metal forming, as well as for the highly productive mass production of powertrain components. The department focusses on the determination and implementation of these requirements for machine tools and their main assemblies. This includes higher accelerations and speeds of feed axes, increase in rotational speeds for high speed cutting and self-optimizing accuracy controls and reconfigurability.

High dynamics can be achieved by low moved masses. Weight savings are possible due to new design principles of the machine and also due to consistent application of lightweight construction, for example by using metal foams as construction materials for assemblies. In addition to preventive determination of properties by performing experimental investigations and FEM calculations, we also deal with simulation of motion and collision behavior of machines.
Core areas of expertise

We offer our know-how within the framework of research projects and as a service for machine manufacturers and operators in the following areas of expertise:

– Determination and optimization of structures for machine tools based on technological requirements
– Development of high performance components
– Metrological property analyses
– Simulation of the static, dynamic and thermal behavior of machines, assemblies, tools and workpieces
– Development of computer-assisted design tools for machine tools, considering mechanics, drives, control and processing
– Design and optimization of feed control
– Support in commissioning
– Experimental thermal analyses of machines in a thermocell
– Predictive maintenance of forming machines
– Economic assessment of production solutions
– Consulting, training, developing studies

1 3D pre form center
   Hexabend for bending tubes
2 Hydraulic highly dynamic short-stroke actuator
3 Large machining center for tool and mold making
One of our core competencies is the planning, development and commissioning of cutting machine tools. Here we consider the entire machine, including peripheral facilities such as handling, clamping technology and devices. Our main focus lies on manufacturing solutions for automotive engineering, especially for tool and mold making.

**Our services**

- Concept development of machine concepts
- Machine development
- Assembly development
- Reparation and realization of requirements and performance specifications
- Development of active principles considering the feasibility in real constructive solutions
- Drafts and detailed constructions with 3D-CAD-modeling and 2D-CAD-drawings, dimensioning of components/assemblies
- Functional demonstration of constructive solutions by animation, collision analysis, stiffness and accuracy analysis
- Specification (single-part drawings, assembly drawings, assembly descriptions, acceptance guidelines)
- Support in commissioning
- Conducting evaluations of economic efficiency

Our expertise makes us a competent partner for the mechanical engineering industry. In addition to investigating actual states, we develop and implement suggestions for optimization.

**Our competencies**

- Realization of innovative cutting technologies and hybrid processes
- Development of machine structures
- Versatile production systems
- Controlled electric and hydraulic drives
- Simulation of mechatronic feed and motion systems
- Development of control strategies
- Increase of process stability due to active dampers
- Preparation of chatter charts
- FEM-calculations and static, dynamic and thermal simulations while considering control
- Experimental determination of properties
- Condition monitoring
- Predictive maintenance

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CUTTING MACHINE TOOLS

1. High performance screw drive in CFK-metal hybrid design
2. Mobile 5-axes-machining unit for cutting of a rotor shaft
CORE COMPETENCY
MOBILE MACHINE

Mobility for a more efficient machine structure – Small transportable machines for large workpieces

In mechanical engineering, the components to be processed are becoming larger and larger. Examples include individual components consolidated into a monolithic component by integral construction, or wind power plants, cranes, forming tools as well as components of plant construction. Often these components require processing in local areas which demands 5-axis machining and highly precise execution. With conventional methods the workpiece has to be placed into large machining centers. This leads to extreme imbalances between theoretically required and available machine size, resulting in inefficient use of resources. It is more appropriate to process large workpieces with small mobile machines. Local and global mobility are the aims of this concept.

Local mobility

Smaller machine units are positioned locally at the places of the workpiece to be processed. Thus the machine dimension and the mass to be moved can be reduced to a minimum. Furthermore, this minimization results in efficiency increases by saving ancillary units and in a significant reduction of gray energy by substituting large machining centers.

Global mobility

Global mobility means transportability of the machine between different operation sites. Due to the smaller dimensions of the machine and its robustness, transportability is possible. This is especially interesting for maintenance applications. In addition to the reduction of logistics and the omission of the transport risks for high-investment workpieces, advantages include, above all, responsiveness to global maintenance tasks and considerably reduced downtimes of plants due to maintenance on site.

Within the framework of an integrated methodology for developing and configuring mobile machines, realistic solutions for fundamental machine concepts are developed. Additional developments include coupling strategies, approaches for coordinate allocation and corresponding processing strategies. Regarding the industrial use, tools are developed for the economic and energetic evaluation of mobile machine tools.

Potential for application

- Time savings by omitting workpiece disassembly due to integration of the mobile machine into available structure
- Opening up new possibilities in product development, especially by processing of integrated components
- Flexibility due to non-stationary machine structure
- Cost reduction by reducing logistics
- Time savings due to processing directly on site
In the area of Forming Machine Tools we offer our competencies of planning, development, design and property analysis of assemblies for forming machines or plants, including the corresponding handling equipment.

Our services

– Plant planning and concept development for press plants, including simulation of the part throughput and the possible yield
– Product development, design and project planning of selected assemblies of forming machines, for example structure components, main drives and auxiliary drives, automation technology
– Theoretical and experimental property analysis of the static and dynamic behavior of forming machines
– Analyses on energy consumption of plants, including individual assemblies
– Support or execution of machine acceptances, support for preparation of specifications
– Support and organization for constructing and commissioning selected assemblies

The numerical calculation, analysis and simulation of individual components up to complex machine structures and process flows become increasingly indispensable for the development of modern and competitive products. Our services in analyzing and simulating forming machine tools comprise project planning and testing in the development of machines as well as analysis of existing plants.

Our competencies

– Development and testing of prototypes
– Control design, modeling, simulation, control, diagnosis and maintenance of fluidic drives
– Project planning of electromechanical drive assemblies
– Calculations or simulations of static and dynamic behavior of assemblies
– Metrological analysis of forming machines (static and dynamic behavior)
– Analyzing energy efficiency of plants and machines

In order to verify simulation models machine analyses are executed. The advantages of analysis and simulation are as follows:
– Reduction of product development times
– Structural optimization
– Visualization of complex kinematic relationships, e.g. collision analysis
– Control design
– Predetermination of process flows
– Analysis of critical spots

1 Working space of a forming machine
2 Analysis of active dampers to increase process stability
3 Load tests on forming machines
Aim of our research and services for companies is the increase of static and dynamic stiffness of machine tools and the improvement of production accuracy, the determination of the static and dynamic parameters of forming machines and analysis of critical spots in faulty operations. Results of experimental analyses are compared with simulation models, and suggestions for improvement are developed.

Our competencies

- Experimental identification of static and dynamic behavior of machine tools and forming tools
- Assessment and optimization of static and dynamic machine behavior by analyzing critical spots and deducing improvement potentials
- Analysis of failure causes
- Calibration of machine tools and forming tools
- Realization of operational vibration analyses and acoustic examinations
- Process monitoring for cutting and forming
- Machine monitoring according to predictive, condition-based maintenance (condition monitoring)

Experimental analyses

In order to measure the structural behavior of machines and to identify critical spots and improvement potentials, experimental machine analyses have to be conducted with high-quality measuring equipment. Our extensive experience allows us to perform metrological investigations at the machine manufacturer's facilities or at the operator's company as well as at Fraunhofer IWU.

First results are available directly after the measurement. A detailed report and the presentation of results at the client's facilities are part of our service. Furthermore, the entire scope of machine and process monitoring can be covered metrologically. This results in extensive possibilities of integrative approaches for machine and process.

Experimental structure examination:
- Analysis of static and dynamic deformation behavior in case of excitation with impulse hammer or hydraulic exciter
- Calculation of dynamic resilience, mode of vibration and damping
- Determination of static machine parameters of hydraulic/mechanical forming machines with a laser tracker
- Determination of the load-bearing behavior and the deformation behavior of drive assemblies and frame assemblies

Operational vibration analyses and acoustic measurements:
- Signal analyses in case of oscillatory phenomena in processing (diagnosis of chatter vibrations)
- Run-up and mode order analyses
- Noise level measurement and sound source location

Machine and process measurement:
- Measurement and compensation of positioning accuracy, perpendicularity and circular deviation
- Thermal analysis/compensation of machine tools
- Quality measuring technology (circularity, roughness, dimensional accuracy, cutting edge measurement, geometry measurement)
Low simulation accuracy of temperature fields and displacements is no longer acceptable for modern machine tools. Thus, we carry out research to increase the production accuracy of machine tools under common temperature conditions by simulative and experimental analysis, feasible error corrections and constructive improvements.

**Our competencies**

- Experimental identification of temperature fields and their temporal change as well as resulting deformations and displacements of individual assemblies or absolute deviations
- Calculation of the thermo-elastic behavior of machine tools by improved modeling, especially by describing boundary conditions
- Evaluation and optimization of thermal dislocations of structural elements due to analysis of critical spots and deduction of improvement potentials
- Development of algorithms for control system-integrated compensation of thermally caused deformations and dislocations

Nowadays thermally caused displacements are dominant causes of errors in machining. Furthermore, there is an appropriate switching on and off of main and auxiliary drives as well as the reduction of cooling lubricants. Therefore the thermal equilibrium is permanently disturbed, which causes transient machine behavior.

A special method to analyze the thermal behavior has been developed based on a multitude of machine analyses. Employees of the Fraunhofer IWU carry out complex analyses concerning the thermal behavior in the thermocell at the institute in Chemnitz as well as individual analyses at machines respectively assemblies at the customers’ facilities as a service.

The influence of the ambient temperature and the temperature stratification in the shop floor are identified, as well as the temperature effects which result from the machine drives and direct machining of the workpieces (including hot chips) in the working space. The outcome is a mathematical model which characterizes the dislocation at the contact point, using temperatures at heat-sensitive points.

The following equipment is available for experimental analyses:

- Thermal cell to generate defined variable ambient conditions
- Multichannel measurement equipment with up to 100 measuring channels and selective measurements of dislocations and temperatures
- Extensive thermostable measuring rods made of invar-steel
- High-definition fast thermographic camera

1 Thermographic images
2 Machine in the thermal cell
As a consequence of increasing accuracy requirements in modern machine tool industry, a detection of thermally caused dislocations between tool and workpiece at various operating states and unsteady environmental influences is required to develop thermally tolerant machine tools. The knowledge of the influence of different thermal boundary conditions, especially the ambient temperature, on the accuracy behavior and the long-term stability of the machine is essential.

Fraunhofer IWU Chemnitz has comprehensive experimental testing facilities and long-term experience, which form a fundamental basis to conduct experimental analyses and can generate the foundations for exact modeling of thermal effects. A thermocell makes it possible to determine the influence of internal heat sources of a machine at constant ambient temperatures. Additionally, it makes it possible to define the determined thermal behavior of machines at systematically changing ambient temperatures.

Considering thermally caused deformations and displacements of the machines, including the thermal interaction with the environment, improved measures and methods of design and compensation are derived to minimize these effects.

The following objectives can be achieved using the thermocell and our metrological equipment:
- Determination of the thermal behavior under constant ambient conditions
- Analysis of the thermal behavior at change of ambient temperature
- Correction of deviations using control system-integrated methods
- Derivation of measures for design and material, based on knowledge of thermal behavior

Technical Data
- Outer dimension: 10.7 m x 7.5 m x 5.0 m
- Air conditioning:
  - Ambient air adjustable between 10 °C – 40 °C
  - Max. air speed < 0.4 m/s
  - Air exchange max. 20,000 m³ per hour
  - Humidity control between 35 % – 55 %
- Base plate:
  - Installation surface 8.15 m x 5.10 m
  - Temperature can be changed in two levels independently
  - 4 x 6 temperature probes integrated for regulation
  - Vibration-solated (12 air springs, electronically controlled)
If machines in production fail unexpectedly, unnecessary costs arise for the companies. If it was possible to know beforehand when a machine fails or when components break, a company could plan exactly when to maintain a machine or when to exchange a component. The best time to do this is when it fits best into the production plan. Such a predictive look into the future requires extensive information and specific expert knowledge. However, with current remote maintenance systems this can be realized neither technically nor economically.

**Cloud-based maintenance approach**

Informatization and linking of machines and plants could solve this problem. Especially those manufacturers can profit from this approach who want to offer services of maintenance to their international customers. By central administration of the recorded data and information within an in-house eMaintenance Cloud, completely new possibilities emerge for generating maintenance-related knowledge. By combining this data and information, an entirely new quantity is achieved in the prognosis of remaining service life. Co-simulation environments enable the integration of the most complex evaluation systems. For this purpose, problem-specific expert knowledge from third parties can be embedded.

The EU project iMAIN (intelligent maintenance) is coordinated by Fraunhofer IWU and involves eight partners from four European countries, developing the required IT infrastructure, special algorithms and models. Furthermore the project demonstrates the functionality using the example of sheet metal forming.

**Embedded condition monitoring**

The interdisciplinary approach for the pursuit of further knowledge on material load and component life is reflected in a broad strategy of instrumentation and data acquisition. A “multi-domain” approach is followed in capturing the physical processes and measured variables, sensors and additional plant process data – such as various data rates, formats and interfaces. Thus various sensor types (among others, MEMS, Wireless) can be integrated and numerous state functions can be detected, such as ram tilt in presses, the distribution of the pressing forces, temperature changes in bearings and guides, vibrations in drives and belts or the oil quality, air and energy consumption. A special focus lies on the first acquisition of a real load history of the complete frame structure in order to avoid fatigue fractures. Novel so-called virtual sensors are used here.

**Service-oriented business models**

Such a cooperative maintenance approach allows machine and plant manufacturers to extend their service-oriented business areas. A particular future focus lies on “information-for-x” models which offer the customers further guarantees of providing current plant information. Other product-service-models such as “pay for use” or “pay for performance” can also considerably reduce the economic risk for the system provider by applying cloud-based monitoring approaches.