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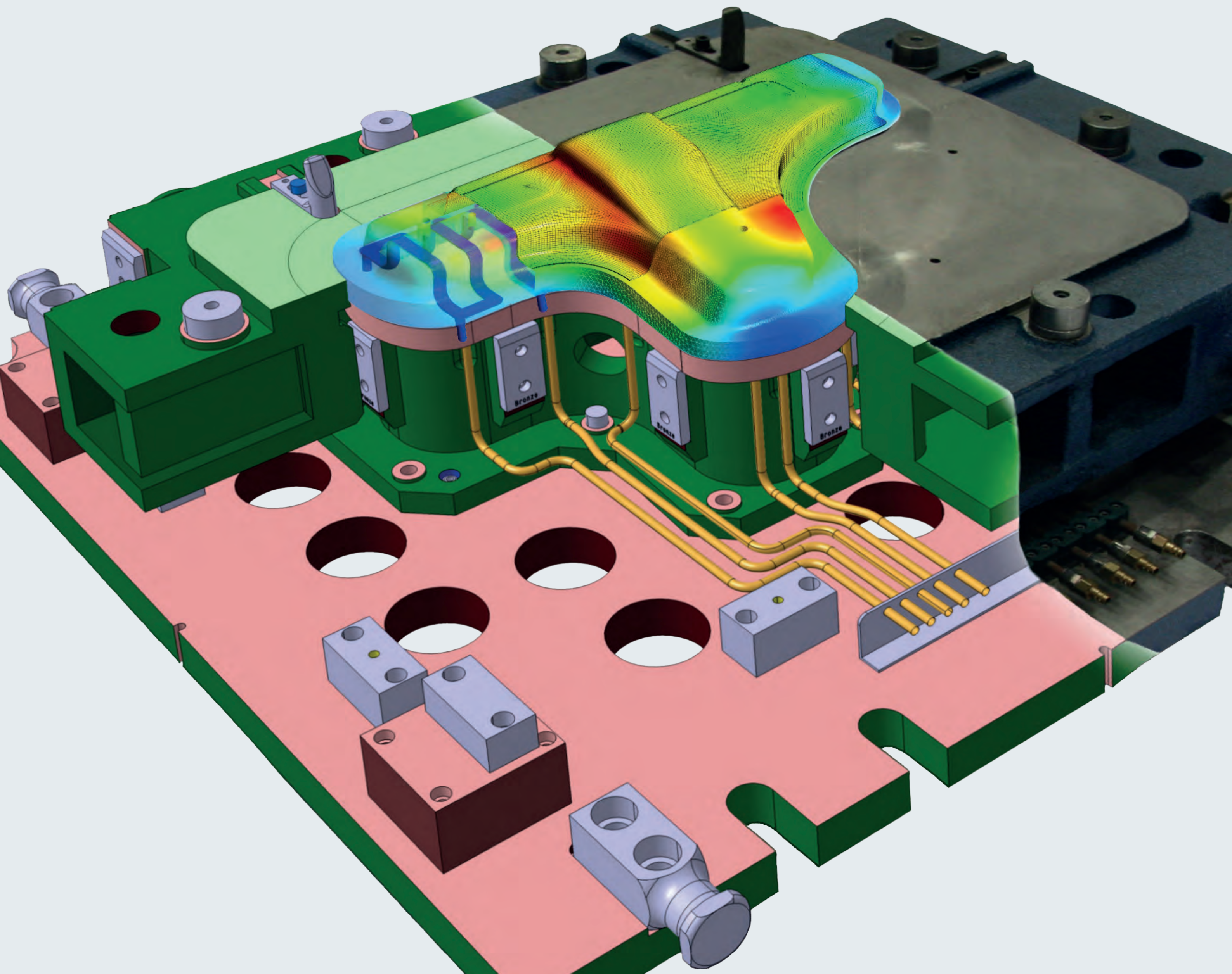
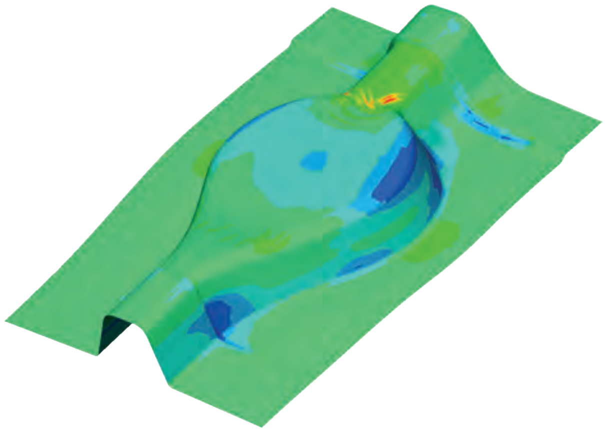
FRAUNHOFER INSTITUTE FOR MACHINE TOOLS AND FORMING TECHNOLOGY IWU

SIMULATION
IN FORMING TECHNOLOGY





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SIMULATION IN SHEET METAL FORMING

Simulation is an essential part of the development chain, especially as a tool for virtual product development in the automotive and the aerospace industries. The range of simulation applications has been extended more and more, also in developing and optimizing shaping processes. In sheet metal forming finite-element programs (FEM) can predict the geometries and properties of components, and they can also be optimized by specifically varying the process parameters and the tool shape.

Fraunhofer IWU conducts detailed simulations of sheet metal forming with a large variety of physical phenomena. The latter include the influence of springback as well as thermal effects, high speed effects and material fracture. The main objectives of sheet metal forming simulation consist in feasibility studies, robust tool and process design and the optimization of components and processes.

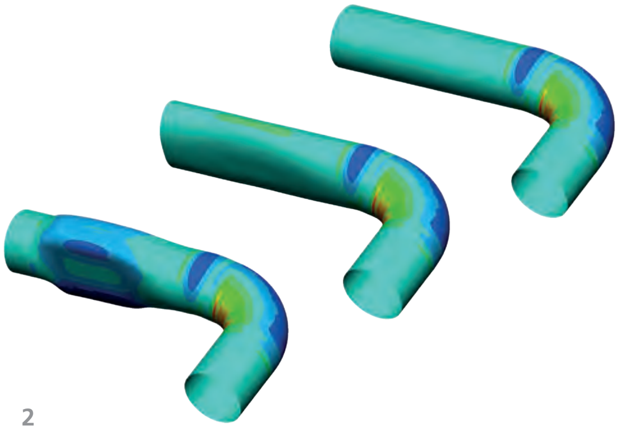
1 *Suspension strut support optimized for springback, used in automobiles*
2 *Simulation of process chain for a titanium exhaust component*
3 *Joining using electromagnetic pulse technology*

Detailed and exact investigations of shaping processes using FEM are based on
– Product geometries and installation spaces
– Process kinematics and process sequences
– Highly accurate material characteristics
– Exact characteristic values for process tribology.

Using sheet metal simulation we focus on investigating the following processes:
– Deep drawing/stretch drawing
– Bending/seaming
– Incremental sheet metal forming
– Roll forming
– Combined processes (thermal, dynamic)

The following software packages are used for development and analysis of processes: ABAQUS Standard/Explizit, ANSYS, PAM-STAMP, AutoForm, LS-Dyna, COPRA and DEFORM.
A computer cluster with 128 cores is available at our institute, solving complex simulation tasks within short computing times.

The results of these investigations form the basis for
– Tool design (geometry and load)
– Process design (process curves, process monitoring)
– Evaluation of component quality (geometrical deviation) and process stages
– Optimization of products and processes.



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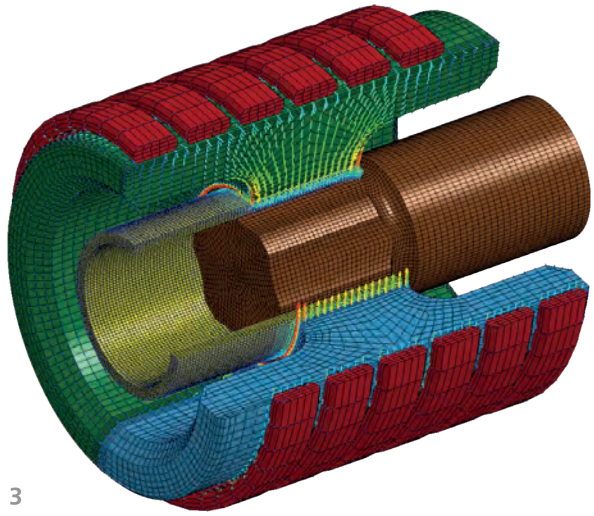

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SIMULATION OF HYDROFORMING AND ELECTROMAGNETIC PULSE TECHNOLOGY

In the field of sheet metal forming we also deal with further development and optimization of forming processes based on hydroforming and electromagnetic pulse technology. In particular, the processes include

– Hydroforming of tubes and profiles,
– Hydroforming of metal sheets and
– Gas generator processes for sheet metal forming.

Hydroforming uses gaseous and liquid media in the cold or hot state for forming. Forming simulation (FEM) is applied as a means to develop components and to conduct feasibility studies. Using FEM allows for realistic representations of hydroforming processes, including its processes such as bending and preforming. The simulation results are the basis for optimizing the process chain and the component properties. Our objective is the development of preforms, which are economic and optimized for the final function. Therefore we develop algorithms of optimization and complement them with practical results.

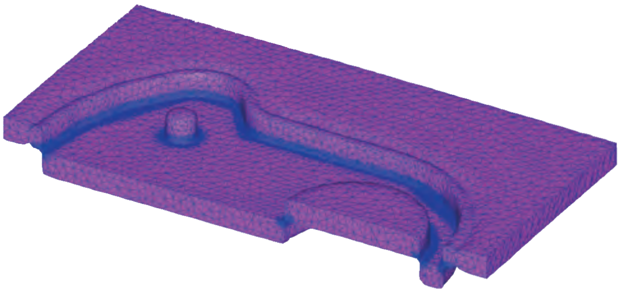
Based on forming simulation results we perform process design for the complete process chain. In this context, changing process variables such as material properties, material thickness, pressure and tribology are optimized in order to achieve a robust process window. Thus, the most suitable parameters (axial feeding and pressure increase) for component production are already known before tool manufacturing and tool testing takes place. So the expenditure for component prototyping can be minimized.

Forming processes based on electromagnetic pulse technology include the specific process of electromagnetic forming (EMF). This process uses the occurring interdependencies between conductive metallic materials and high-performance magnetic fields to cause specific deformations in the semi-finished products.

We examine the following process variants:
– Compression / expansion of tubes and hollow profiles
– Forming of flat or preformed metal sheets
– Cutting of profiles and metal sheets

Process simulation for these cases has to consider numerous physical phenomena. This includes mechanical material properties and fracture behavior at high forming speeds, electrical and magnetic material properties and how they are influenced by temperature. Due to the interdependencies between the physical effects a coupled simulation of structure, magnetic field, electric field and temperature is required in order to design the process as exactly as possible. We apply high-performance software packages to consider these phenomena.

The simulation of electromagnetic forming allows us to draw conclusions concerning the following aspects: processability, required boundary conditions regarding geometry and materials, the optimal parameters for process and tool design.



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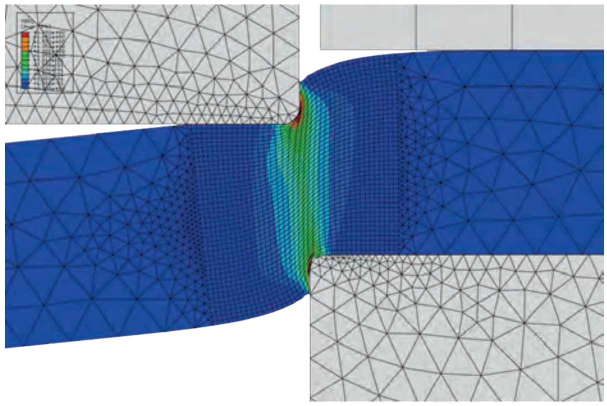

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SIMULATION OF CUTTING PROCESSES

Cutting processes are essential for preceding and subsequent processes within the process chain of sheet metal forming. By simulating cutting processes, effects on the process chain can be analyzed before testing the real part. Using FEM simulation we investigate and analyse the following conventional cutting processes and high speed cutting processes, among others:

– Shear cutting
– Fine blanking
– Profile cutting
– High speed impact cutting (HSIC)
– Cutting with electromagnetic impulses
– Cutting with gas generator processes

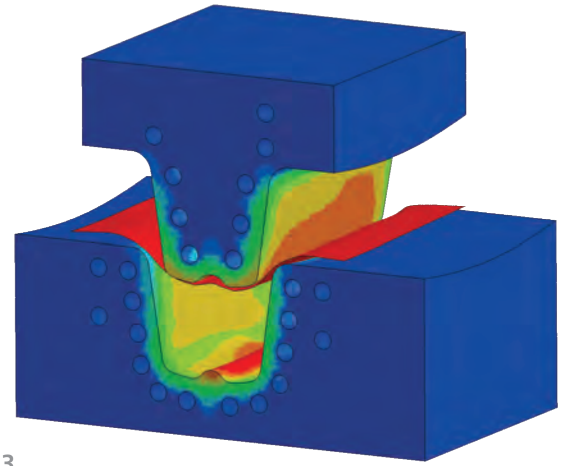
Numerous physical effects have to be considered, requiring coupled thermo-mechanical simulation while considering the deformation behavior as a function of strain rate and temperature, the complex fracture behavior and the highly dynamic process conditions. Active tool components and process requirements are designed according to quality requirements on the cut components as regards dimensional component stability, quality of fracture zone and component properties after the cut.

1 *3D fine blanking simulation*
2 *Cutting simulation*
3 *Press hardening with cooling channel structure*
4 *Hot metal gas forming of a crash box*

In the case of the cutting simulation, higher requirements are placed on the simulation environment of sheet metal forming. In conventional 3D sheet metal forming the blank is formed using shell elements. These have to be replaced by volume elements for the cutting simulation in order to achieve sufficient discretization across the cross-section of the metal sheet. Otherwise it cannot be ensured that an exact reproduction of the stress and deformation behavior in the cutting zone is obtained. This type of modeling results in a simulation that is significantly more detailed and requires more computation time.

In addition, an automated remeshing algorithm has to be considered to reduce distortions of the mesh as well as the numerical errors. Cutting of the material is realized in the FEM cutting simulation by applying fracture mechanisms (fracture criteria). Known mathematical approaches are used to describe material fracture according to Cockroft-Latham or Rice-Tracy. The required parameters are determined by using experimental tests. In order to save computation time, component symmetry has to be considered.

The temperature profile in the shearing zone of the material is important for correct predictions of the fracture behavior. The greatest part of the cutting work dissipates as heat. Thus a considerable heat input occurs during the cutting process.



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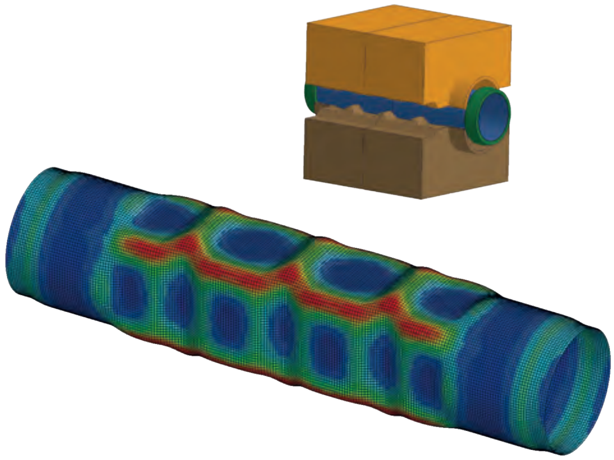

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SIMULATION OF THERMALLY ASSISTED FORMING PROCESSES

Temperature becomes more and more important as influencing variable and process parameter in technological developments of sheet metal forming. Improved forming properties of materials at higher temperatures are used in numerous technologies, for example in press hardening, which is well established in the automotive industry. When considering thermal processes, developers and engineers are faced with issues that absolutely require coupled simulation results.

The challenge of the computational analysis of these processes mainly consists in the fact that the coupled thermo-mechanical boundary conditions lead to a significantly more complex and more extensive numerical model. The thermal conditions in the tool, in the tool environment and the sheet material have to be considered.

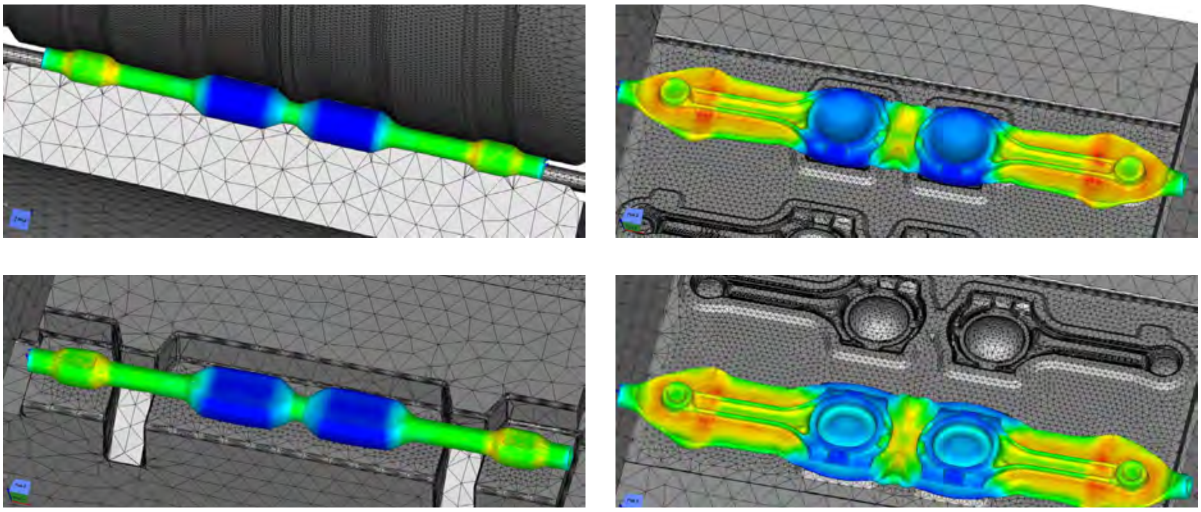
The analysis of the thermo-mechanical processes is based on thermal initial conditions. It requires taking into account cooling and heating strategies in the tool as well as specific temperature-dependent material models. The time scale for thermal processes is typically several orders of magnitude higher than the time scale for forming processes.

Our competence lies in realizing projects where thermal effects have a great influence on the forming process. Among others, this includes the following topics:

– Simulation of press hardening processes, i.e. deep drawing processes and processes based on active media
– Simulation, design and optimization of cooling channel concepts in tools, including simulation of fluid mechanics
– Simulation of thermal tool behavior in the course of several process cycles
– Simulation of superplastic forming processes

In particular, the simulation software LS-Dyna is used in addition to the programs ABAQUS, PAM-STAMP, AutoForm and ANSYS-CFX.

As a result of the analyses the user receives a highly detailed view on the thermo-mechanical interactions within the processes. Furthermore, the user obtains information on how to optimize technological processes. Thus, the application of simulation considerably reduces the variants of experiments in many cases. The optimization of thermal processes also increases energy efficiency and is oriented towards improved product quality.

1 

SIMULATION OF PROCESS CHAINS IN BULK METAL FORMING

The potentials of simulation are also used at Fraunhofer IWU in order to apply a holistic approach for investigating complete process chains of bulk metal forming – starting with the cutting of the blank, followed by heating and forming steps leading up to thermal postprocessing. Structural analyses can also be included as well as interactions between the forming process and the machine tool.

Our simulation studies focus on:
– Feasibility studies for new products
– Design and optimization of mass pre-distribution to reduce the use of raw materials
– Determination of the thermally stable state of tools in process stages
– Saving of process stages in order to reduce energy consumption and cost
– Manufacturing of material composites for lightweight construction
– Reducing or avoiding rework by cutting
– Integration of functions by combining components

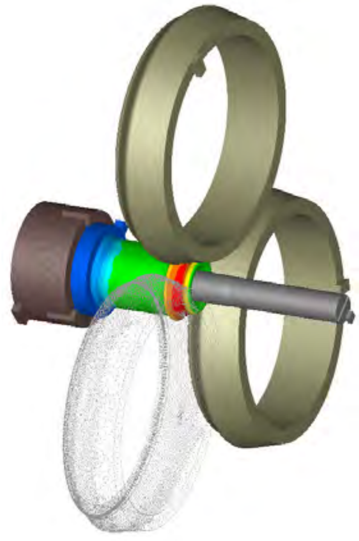
1 *Process chain for die forging of a conrod*
2 *Temperature development in spin extrusion*
3 *Effective strain in gear rolling*

In addition to simulation studies, we support our customers and give advice in decision making for introducing new forming processes and process chains.

In order to achieve simulation results as close to reality as possible, exact material parameters are essential. Thus we record hot flow curves and cold flow curves for new materials. These flow curves are directly integrated into the simulation. We mainly use the programs Forge and Simufact Forming for simulating process chains in bulk metal forming.

The results of the simulation studies are reflected in:
– Adaptation of component geometries to individual forming steps for minimizing tool load and wear
– Design and engineering of the tools
– Design of the process steps and adaptation of the process parameters
– Optimization of existing process chains
– Development and evaluation of new process chains

Due to constant further development of hardware and software we increasingly deal with the following topics in simulation:
– Combining forming process and adjustment of microstructure
– Including heat treatment into the process chain
– Combination of various processes to generate new product characteristics
– Forming of sheet metal structures into bulk metal components



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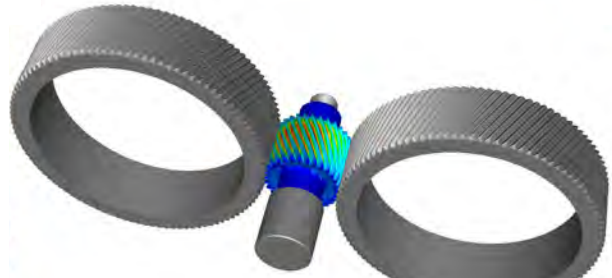

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SIMULATION OF INCREMENTAL BULK METAL FORMING PROCESSES

In incremental bulk metal forming processes the formed geometry is generated by repeated locally limited plastification of the workpiece. The local zone of plastification is moved along progressively in the workpiece according to the process kinematics. Thus incremental processes only need a fraction of the required forming force compared to forging or extrusion, for example. They are characterized by high flexibility due to the manufacturing of the geometry, which depends to some extent on the kinematics.

However, process and tool design are by far more complex than non-incremental processes. For this reason simulation is particularly valuable for designing processes and tools and for developing new processes and variants of incremental forming processes. We investigate the following processes, both by simulation and experimental investigation.

For shaft-shaped components and pre-distribution of mass:
– Cross wedge rolling, cross rolling with axial traverse speed
– Spin extrusion
– Rotary swaging, axial forming (also for manufacturing of hollow parts with simultaneous processing of inner and outer contours)

For manufacturing of gearings:
– Gear rolling
– Orbital forging

For manufacturing of ring-shaped components/preforms:
– Ring rolling
– Axial closed die rolling

In incremental processes the process kinematics has a strong influence on the formation of the geometry. Especially in the case of new developments and adjustments of machines, process simulations provide significant information on the process and its interactions with the machine. Thus solutions tailored for the specific manufacturing task can be tested in advance by virtual testing.

The focus of numerical simulation of incremental forming processes is on:
– Holistic approach for introducing and evaluating resource-efficient processes, for net-shape forming and pre-distribution of mass
– Development of new processes or optimization of existing processes
– Application of new materials (rare earth elements, materials relevant for medical applications, high-strength and high temperature resistant alloys)
– Evaluation of the rollability of rings and gearings
– Determination of stable process conditions
– Testing and optimization of tool geometry

This method of simulation allows for statements on the functioning of the tools considering the influence of kinematics or the feasibility of a product using existing machine technology. Furthermore it makes it possible to evaluate the thermal process control, tool load or component damage.

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Cover picture: Simulation of cooling down B-pillar base