Fraunhofer IWU

FRAUNHOFER INSTITUTE FOR MACHINE TOOLS AND FORMING TECHNOLOGY IWU

RESOURCE EFFICIENCY IN THE POWERTRAIN

ENGINEERING EXPERTISE FOR THE POWERTRAIN

A lot has been going on in the automobile business: cars need less material, are becoming more lightweight and consuming less gasoline. But, as we all know, the world's resources are limited and the need for energy and raw materials in countries like China, India and Russia is exploding. Production will have to make do with fewer raw materials if we also want to guarantee future prosperity.

This is the reason why the demands made of the future car are enormous: its production has to keep resource utilization down, it has to be environmentally friendly, consume a low level of fuel, keep air pollution to a minimum and repairs should also be infrequent. How can we meet this agenda?

The Fraunhofer-Gesellschaft has taken up the frontline theme of "Green Powertrain Technologies" at its various institutes for developing new, efficient and energy-saving technologies and subassemblies for the powertrain of today in tomorrow's drive systems. The Fraunhofer Institute for Machine Tools and Forming Technology IWU is coordinating the work of the Fraunhofer-Gesellschaft on this next-generation issue focusing on low power consumption by driving down friction, using lightweight materials and promoting sustainability.

The expertise available at the Fraunhofer IWU

The foremost concentration of our research and development work is coming up with and streamlining low-resource forming and metal-removing production technologies for manufacturing powertrain components. The powertrain has all of the components for generating and transmitting torque from the engine all the way to the wheel. This is the reason why it determines the efficiency and environmental impact of a car.

Our iconic solutions for continuous process chains include
- component design,
- calculation or experimental feasibility analyses,
- tool design and production,
- testing machining strategies and new materials, and
- producing prototypes and small lots.

Lightweight structures and the use of new materials have a major role to play in these considerations.

The prerequisite for setting up a low-energy and low-material manufacturing process for component parts is designing component parts in conformity with production requirements. For this purpose, we analyze
- how to shorten the process chain by combining near-net-shape forming and metal-removing finishing,
- material-reducing component part design,
- continuous dry processing,
- increasing processed stability and
- driving down the number of parts.

Beyond this, there is another reason for driving down resource utilization in component parts usage because coatings and surface structuring allow low-friction component operation. The Fraunhofer IWU focuses here on studying and advancing processes that can be used for producing tribologically optimum functional surfaces. They include laser structuring, electrochemical machining and band/stone finishing. One of the foremost jobs here is crafting and analyzing the tribological effectiveness and permanence of surfaces generated in this fashion.

FORMING PROCESSES

Hydroforming

Hydroforming has proven its worth over longer periods in industrial mass production of component parts in the direct automobile supply. The geometries it creates range from component parts for exhaust gas systems through camshafts, axle/steering systems right to engine mounts and entire structural concepts. In comparison to conventional forming technologies, hydroforming enables us to generate intricate component part geometries while achieving higher degrees of forming. Not only that, the forming mechanisms also enhance the final component part properties of accuracy, strength and rigidity.

In hydroforming, a workpiece is filled with a liquid or gaseous medium and formed into a specified tool contour under pressure. Using temperature as a process parameter is one option to increase the ductility and the associated form changing property of lightweight materials such as magnesium or aluminum, not to mention high-tensile steels (press hardening). Using hydroforming not only enables us to drive down the amount of energy and materials used, but also reduces the number of joining operations such as welding while using applications-streamlined forms and new design ideas.

Joining in the hydroforming process

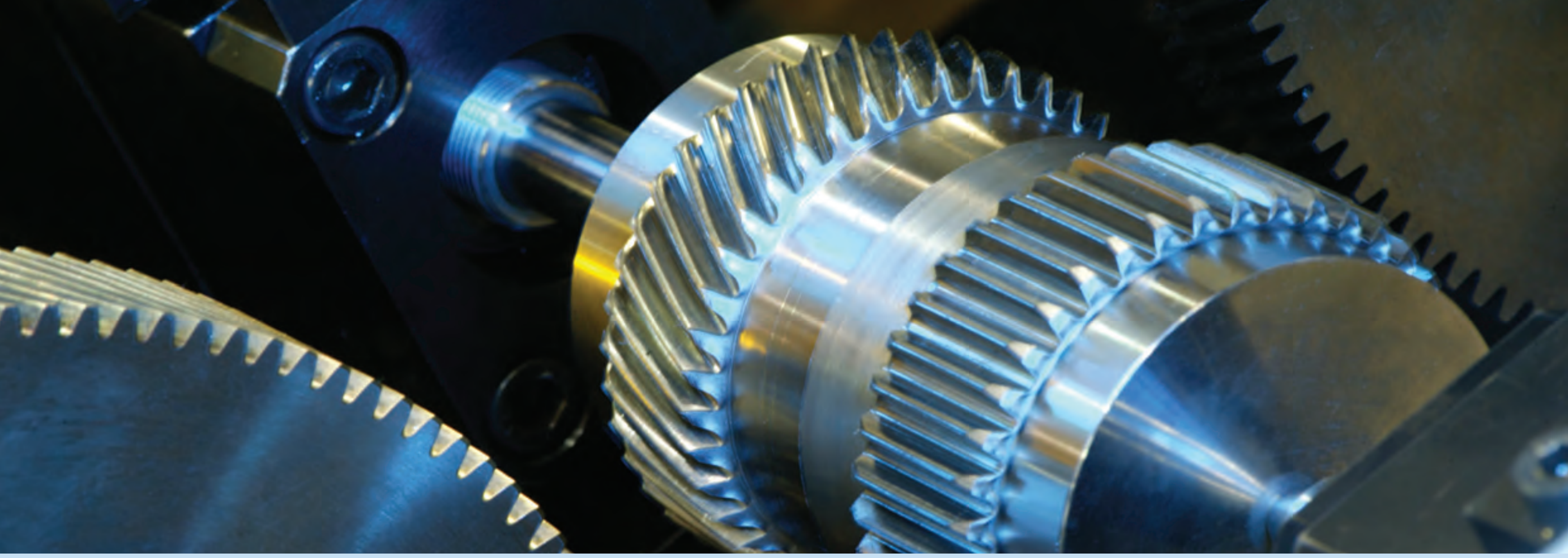
Hydroforming tube shaped semi-finished products makes it possible to join component parts with a profile actuated by both gravity and interlocking based upon a partial increase in the size of the component part. Integrating the joining operation into the forming process providing the final form enables us to produce high-precision and load-optimized subassemblies such as complete camshafts. These are mostly cold joining operations and they can be used to join a wide variety of material pairs with one another while preventing heat from entering into the subassembly.

Designing the joint with loads in mind by providing undercuts both in the radial and axial direction makes it possible to transfer very high torques and axial forces with relatively thin-walled hollow shafts. It is not only possible to join two hollow profiles. Other functional elements can also be integrated into the forming and joining operation such as gears, cams or bearings. Any final precision processing that may be necessary (generally only consisting of a grinding operation) is greatly reduced because of the high level of production accuracy of the combined forming and joining process.

Spin extrusion

Spin extrusion is an incremental pressure forming process for producing circular symmetric-axle hollow components from massive semi-finished products. The workpiece is mounted on the spindle of the tensioning unit and rotates along its longitudinal axis. It is formed through the kinematics of the tools, which means that it can be flexibly formed. The material drains opposite to the axial forward feed direction of the tools to form the bowl wall. This process can be carried out as cold, semi-warm or hot forming.

Spin extrusion is the preferred method whenever tube-shaped original forms are supposed to be produced in combinations of diameter/wall thickness that are not commercially available or if there are special precision requirements made of the wall thickness tolerance and correctness of the inside surfaces that go beyond tube standards. This expands the range of extruding in the direction of thick-wall forms by at least two times the ratio of length to diameter. Beyond this, it is very effective in producing component parts in proximity to the final contour. Finally, it is very useful in producing material-efficient component parts from cost-intensive or difficult-to-manufacture materials.



Cross rolling

Cross rolling is a process where initial shapes are reformed between wedge-shaped tools with a circular cross-section. The two halves of the tool simultaneously moving towards one another contain a negative form of the workpieces to be rolled. Radially infeeding the rolling wedges into the initial form and then de-laminating the material in the axial direction creates a recessed workpiece that is symmetric to rotation.

This process can be used both for producing shafts in proximity to the final contour and intermediate forming as mass distribution with drop forging. This technology makes it possible to produce the basic forms of hollow shafts. The benefits of cross rolling are to be found in a high degree of dimensional, shape and mass accuracy of the workpieces, material utilization of a higher quality than cutting production processes and the high level of tool life quantity.

Precision forging

This process makes it possible to produce highly stressed component parts in warm and semi-hot forming. Workpieces produced with precision forging have functional surfaces ready for installation and contours with a very high level of surface quality and tight tolerances. When precision forging the unmachined forged component will be forged in proximity to the final contour and without an exterior burr in a closed tool system with built-in hydraulically functioning system components. This forming stage is preceded by preliminary forming (such as transverse rolling or drop forging) that guarantees the optimum mass distribution ratio. The right mechanisms in complex forging tools can be used to intercept slight differences in mass when forging and they can be evened out in defined free spaces to compensate for volume. The focus and the assortment of precision-forged workpieces is primarily in the component parts of the powertrain.

Gear rolling

Standard or automatic transmissions are used in passenger cars to transmit the power delivered by the engine to the street through the wheels. Here, running gears transmit the required transmission ratios or the rotational speed of driven or drive shafts. More and more forming processes are competing with known metal-removing production methods in the economic and engineering race for effective gear profile manufacture. Forming production of running gears applying round tools in rolling processes offers a whole series of process benefits. For example, it allows cost- and energy-intensive subprocesses to be substituted in pre-production such as gear hobbing or subprocesses such as stability blasting. This not only brings about a reduction in the process chain, but also an increase in economic efficiency. Furthermore, enhanced final component part properties (load-bearing capacity, surface quality and minimum hardness distortion) are generated by the surface hardness caused by work-hardening and a fiber orientation adapted to the contour. The range of parts that can be rolled includes spur gears and worm gears, profiled hollow forms and a whole range of special profiles.

At Fraunhofer IWU, gear wheels with a tooth height factor of up to 2.8 could be realized.

CUTTING PROCESSES

Ultrasound-supported deep-hole drilling

Rolling out new and high-strength materials provides constant challenges for cutting procedures. The effective mechanisms of processes can be systematically influenced by superimposed energy forms with the aid of hybrid processes for metal-removing.

When drilling deep holes, the deeper the hole gets, the greater are problems in chip formation, chip conveyance, tool strain and process reliability. This is the reason why systematically coupling vibrations into the conventional production process provides one means of impacting the chip formation mechanism and therefore the length of the chip. A longitudinal natural frequency form of the tool is stimulated by piezoactuators to be able to make optimum use of the high frequencies (ranging between 20 and 40 kilohertz). Numerical simulation can be used to create a model for analyzing the impact of the ultrasound on tool strain and the chip formation process.

Superimposing ultrasound in chip removal (even under the more difficult conditions of minimum-quantity lubrication) enhances the process routine and this in turn has been proven to produce shorter chips. They are therefore easier to transport out of deep holes, thus reducing machining forces for higher time span volumes and longer tool service life.

Complete machining of rotation-symmetric component parts

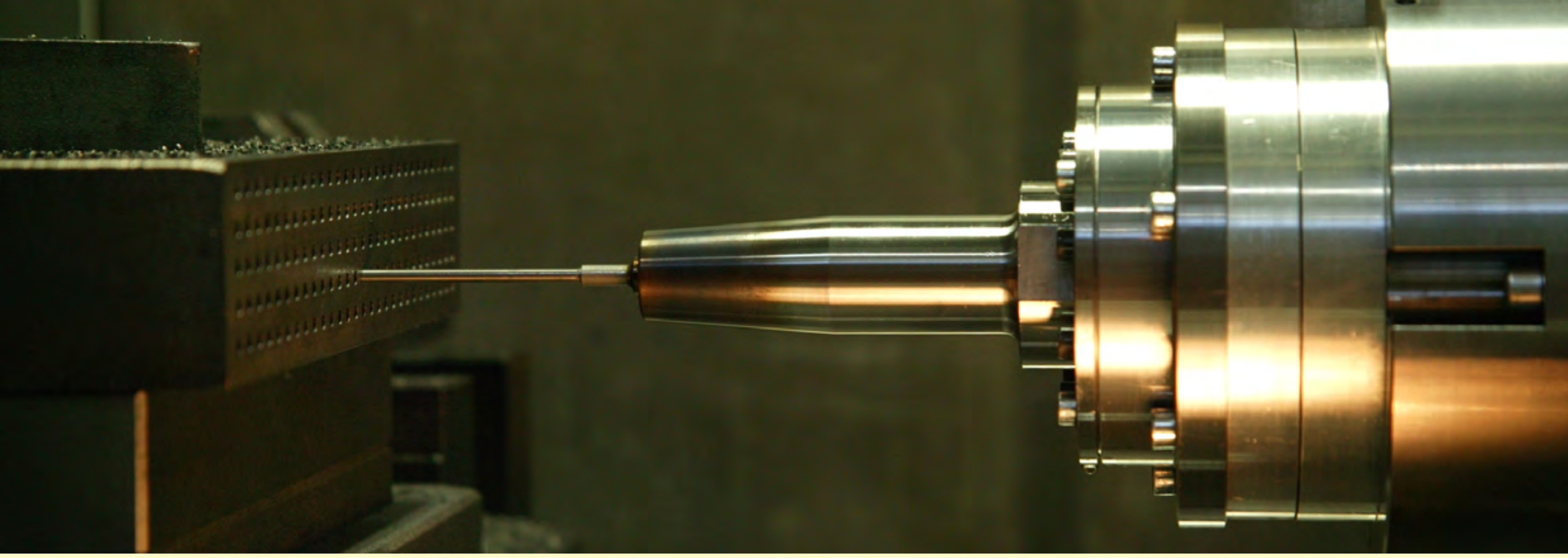
The metal-removing production of rotation-symmetric component parts makes high demands of the quality and productivity of these processes and the equipment used for them. This is the reason why efficient complete machining on turning centers/milling centers is one of the main missions of development. It includes integrating other metal-removing technologies in turning machines – such as hobbing.

Using this process in the turning working cycle has a significant economic impact due to substituting the additional (frequently external) working cycle. In addition, it can have a positive impact on quality features such as hobbing true running since hobbing takes place in one chucking operation such as turning. Furthermore, it can also improve the surface quality of the hobbing by intelligently laying out the order of machining within the complex working cycle. A final point is using forming processes such as burnishing or fixed rolling, but also grinding, honing and splicing.

When evaluating the efficiency of production processes, it makes sense to add the term of energy and ecological sustainability to the concept of economic efficiency. This is the reason why analyzing secondary processes has become an important area for development. It investigates the application of strategies of dry processing or minimum-quantity lubrication along with the options of alternative cooling methods such as using deep-cooled CO_2 or high-pressure cooling up to 300 bar.

High-speed grinding

High-speed grinding combines the benefits of a very high level of productivity with excellent production quality. Both of these factors can measurably reduce production costs. The first requirement made up of tools is greater strength due to higher cutting speeds which is the reason why it was previously only possible to carry out this process with super-hard cutting materials. However, advancements have enabled manufacturers to produce conventional abrasive wheels with reliable processes. This process can replace preliminary machining processes to shorten existing process chains and it reduces production capacities and minimizes throughput times. This means that there is less danger of damage to component parts from overheating when grinding due to thermal loads and it also overcompensates for higher tool costs. Finally, non-circular grinding and reducing the usage of cooling lubricants are also areas for development. Numerical simulations on the static, dynamic and thermal properties can be used to support the advancement of strategies for machining lightweight components.



Honing

Honing is a typical final machining process for drill holes because it makes it possible to maintain the tightest dimensional and shape tolerances while achieving almost any surface roughness required. Furthermore, it also produces excellent tribological surface properties with a surface morphology for this process in the form of a cross-furrow structure. This is not the only reason why honing has an important role to play in the powertrain, and its main area of application is cylinder bore, without forgetting connecting rod eyes and bearing channels that are also honed for the reasons mentioned above. Form honing using adaptronic tools makes it possible to compensate for the formation from operations with intentionally generated deviations from the form of the cylinder.

Furthermore, short stroke cylindrical surface honing (finishing) is used to smoothen surfaces when quality requirements are very high in applications such as machining rolling elements and gear shafts. It is also excellent for producing dominant waviness which improves the acoustic properties of bearing areas such as on crankshafts and improving the form and straightness state of highly precise cylinder surfaces.

The ultrasound-supported deep-hole drilling is, for example, applicable in the manufacture of crankshafts.

Hard milling

Milling hardened steel component parts and super-hard materials makes it possible both to reduce the process chain and to generate high-quality contours in terms of dimensional accuracy and surface quality. It also enhances productivity and economic efficiency more than the metal-removing processes with a geometrically undetermined blade.

The conventional method of external cylindrical grinding is applied to machining bearing seats in powertrains. Unfortunately, this process requires very large amounts of cooling lubricant, and these economical and ecological downsides indicate the need for added deliberations on the application of alternative processes. Orthogonal precision turn-milling is free of cooling lubricants, which is why it meets the quality requirements while eliminating the downsides mentioned above. Another advantage is the low speed of the workpiece with the eccentric bearing seats which is a benefit when using crankshafts. Normally, super-hard cutting materials are used and the model-supported analysis of chip and burr formation along with tool streamlining are also major features of this work. Unfortunately, massive hard metal components cannot be used in the powertrain due to the high level of density, so that terminally sprayed hard metal layers are an alternative, although conventional methods run up against certain limitations when machining parts with complex contoured geometries.

One economic machining option is milling thermally sprayed hard metals. The method and selection of tools should be laid out in accordance with the process to increase economic efficiency and flexibility. The hallmark of milling machining of hard metals is not only an end zone that is practically free of damage but also excellent surface qualities.

LIGHTWEIGHT POWERTRAIN COMPONENTS

Lightweight camshaft

The camshaft controls the intake and exhaust valves of an internal combustion motor that is necessary for the gas exchange in each cylinder. This is the reason why the cams have to have a high level of surface precision and be resistant to wear and tear. Camshafts are normally forged from full material and they are strain-resistant, although very heavy. This is the reason why the unmachined forged component has to be reworked.

The Fraunhofer IWU has come up with processes to make camshafts lighter and drive down the cost of the manufacturing process. Rejecting the previous camshaft design while using a tube-shaped semi-finished product and separately manufactured cams has led to build camshafts. Here, cams are connected to the basic tube body either positive or pressed. This model camshaft has low weight and its production requires little effort.

There was a major potential for reducing mass when applying hydroforming technology. The coated and nitrited camshaft are two new camshaft models based upon this manufacturing method. For manufacturing coated camshafts, the cams are formed from the tube in the hydroforming process where a hard metal coating provides the needed wear resistance. This camshaft model is even lighter and the production effort is on a low level. With the nitrited camshaft, the cams are also formed directly from the tube via hydroforming.

Then they are put through a thermal surface hardening process where super-hard steel is used to guarantee the needed surface hardness, sufficient effective hardening depth and sufficient formability in the hydroforming process. Using low-temperature processes (< 550 °C) such as gas and plasma nitrating minimizes the heat distortion from the hydroforming components caused by heat treatment. This type of camshaft has enabled us to reduce weight once again and the low level of production effort means that manufacturing also costs less. Other types of camshaft are in the development process.

Lightweight connecting rod

Connecting rods are dynamic engine components under a great deal of stress and the way they are designed is determined to a great extent by their vibration resistance and operational strength. The component parts of crankshaft, connecting rod, piston and piston pin form the engine's crank drive.

When weight is reduced in oscillating masses, this spells out smaller mass forces, which has a positive impact on dynamic motor properties, fuel consumption and mechanical strain in the crank drive. This is the reason why lighter crankshafts offer new ways to design the entire subassembly of the crank drive. The changed strain placed on the connecting rods holds the promise of new opportunities for lightweight connecting rod design and the general connecting rod design may be analyzed with a closed or open bridge between the small and large eye.

The Fraunhofer IWU has studied the static and dynamic properties of various connecting rods. FEM simulation calculations have indicated that the basic connecting rod model has a major potential for weight reduction. We used FEM calculations on the formation and strength analysis to ascertain theoretical component part properties on various new connecting rod designs and we were able to demonstrate mass reductions of as much as 50 percent as a result of this development. In other words, we were entirely successful at meeting the goal of manufacturing a component part with fatigue strength at maximum level of lightweight without boosting production costs. Furthermore, our vibration resistance tests on the service life of the connecting rod indicated that the connecting rod is sufficiently resilient to the requirements made by the engine. Finally, a lightweight connecting rod for passenger cars was produced as a prototype in combined projects and tested in the engine under test conditions in operation up to 30,000 driven kilometers.

Built crankshaft

The crankshaft was designed as a joined subassembly for next-generation lightweight crank operation to drive down mass, utilize new materials and reduce the amount of component parts dampening vibration on the engine. Some of the essential components are crankshaft cheeks designed as precision cutting components or forged cheek segments. High on the agenda was coming up with geometrical variants while special contoured elements (such as collars or offsettings) extend the length of the joint for the connection between the cheek and bearing, thus separating the thermal and geometric notches. This improves the component parts rigidity. The main and connecting rod bearing cheeks were made with precision cutting or of forged cheek segments with and without counterweights at a sheet metal thickness ranging from 11.5 to 12 millimeters.

Intricate joining of lightweight crank operation

We studied plans for hollow built crankshaft in various projects launching a whole series of different solutions for low- and high-load internal combustion engines. The benefits are to be found in reducing mass and friction power, a high level of flexibility with a modular approach and selecting the right materials for the appropriate strains by combining various materials and applying technological feasibility criteria.

Lightweight Gear Shaft

Gear shafts can be produced by applying various forming technologies and in combination with other production processes. Since shafts mainly have the job of transmitting torques while the core has to remain virtually unloaded, the specific mass can be reduced to 70 percent when using hollow shafts at almost the same torsion and flexural strength. In contrast, the prerequisite of producing design-enhanced shafts is matching the inner contour to the exterior shape, which requires new process routes that primarily incremental processes of massive forming are suited to with rolling tools.

Spin extrusion is a process that is suited to manufacturing hollow shafts. It can be combined with other forming and metal-removing processes that have comparable kinematics making it possible to lay out energy-efficient process chains for generating complex component part forms in the powertrain. Most of the projects we have launched to date are aimed at hollow shafts for lightweight passenger car transmissions where approximately 30 percent mass savings can be reached if a full shaft is replaced by a hollow shaft of the same diameter.

The basic form of gear shafts can also be manufactured extremely productively with transverse rolling at cycle times of 6-12 seconds at hot forming temperatures. The inside contour is produced during transverse rolling with the aid of controlled mandrils where the ends of the shafts are narrowed with CNC radial forging. The hollow shaft has to be put through a metal-removing process afterwards to form the surface and exterior contours such as gears. Finally, they are heat-treated and finished with hard processes.

Our Services

Process chain development

- market analysis
- process chain study
- process streamlining
- cost-to-benefit analysis
- coming up with production designs
- rough and precision planning for engineering processes
- technological dimensioning of processing machines
- recommendations for machine investments

Coming up with and analyzing machining strategies

- market analysis
- feasibility studies
- developing engineering
- outlining characteristic values for process
- outlining optimum machining strategies
- benchmarking CAD/CAM systems

Quality assurance

- photogrammetric recording of component parts and tool geometries
- measuring microcomponents with confocal microscopy and strip projection
- measuring machines and tools with laser trackers
- structural analysis with a scanning electron microscope
- high-speed camera

Editor
Fraunhofer Institute for
Machine Tools and Forming Technology IWU
Reichenhainer Strasse 88
09126 Chemnitz, Germany

Phone +49 371 5397-0
Fax +49 371 5397-1404
info@iwu.fraunhofer.de
www.iwu.fraunhofer.de

Director
Scientific Field Forming Technology and Joining
Prof. Dr.-Ing. Dirk Landgrebe

Main Department Sheet Metal Forming
Dipl.-Ing. Frank Schieck
Phone +49 371 5397-1202
frank.schieck@iwu.fraunhofer.de

Main Department Bulk Metal Forming
Dr.-Ing. Andreas Sterzing
Phone +49 371 5397-1221
andreas.sterzing@iwu.fraunhofer.de

Director
Scientific Field Machine Tools, Production Systems
and Machining
Prof. Dr.-Ing. Matthias Putz

Main Department Machining
Dipl.-Ing. Peter Blau
Phone +49 371 5397-1109
peter.blau@iwu.fraunhofer.de