Fraunhofer

IWU

FRAUNHOFER INSTITUTE FOR MACHINE TOOLS AND FORMING TECHNOLOGY IWU

HYBRID MACHINING PROCESSES IN CUTTING TECHNOLOGY

VIBRATION-SUPERIMPOSED MACHINING

Hybrid Machining Processes

Principle	Process Variants	Motivation for Application
Vibration-superimposed machining	drilling turning grinding	improvement of chip breaking
	EDM ECM	improvement of quality, productivity
Media-superimposed machining	high pressure cooling	improvement of chip breaking
	cryogenic cooling	increase in material removal rate
Machining with superimposed movement of the axis	scissors kinematics	increase in dynamics in die and mold making
	out-of-round machining by adaptronic form honing and form boring	improvement of the operating properties of engines

Machining of new high-strength materials places continuously increasing challenges on cutting technology. Using hybrid processes, existing technological process limits can be extended by combining additional sources of energy and conventional existing machining processes. In the above overview on hybrid processes the processes presented in this brochure are written in blue letters.

One possibility of vibration-superimposed machining is the excitation of the tool by using ultrasonic vibrations, in the axial direction (longitudinal vibrations) as well as in the circumferential direction (torsional vibrations). In addition to utilizing actuators developed by Fraunhofer IWU, there is also the possibility of using commercially available vibration actuators on a 5-axis machining center.

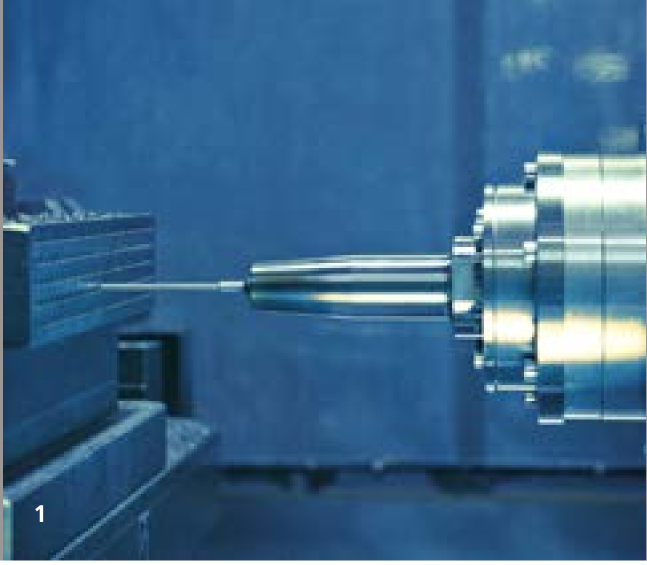
The objective of ultrasonic superposition is to improve chip breaking and chip removal in processes with geometrically defined and undefined cutting edges, thus increasing process reliability and productivity. Increase in quality and productivity can also be reached by electrochemical precision machining.

Ultrasonic-Assisted Drilling

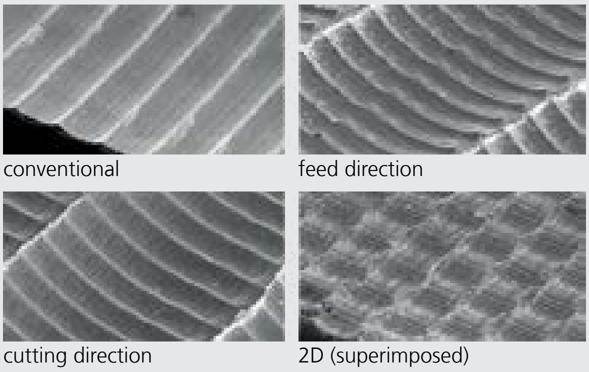
When producing deep bores, problems occur with increasing depth regarding long chips with poor breaking behavior, which leads to high tool load and low process reliability. Superposition of ultrasonic vibrations in deep hole drilling enables improved process cycles, even under the difficult conditions of minimum quantity lubrication. Thus, shorter chips are produced, resulting in easier chip removal from deep bores, reduced machining forces, higher material removal rates and longer tool life.

By activating the deep hole drill using piezo actuators, amplitudes of vibration in the micrometer range are generated at the cutting edge with operating frequencies between 20 kHz and 30 kHz. Especially in machining of high-strength and difficult-to-machine materials, which are currently often applied, this process can be used effectively.

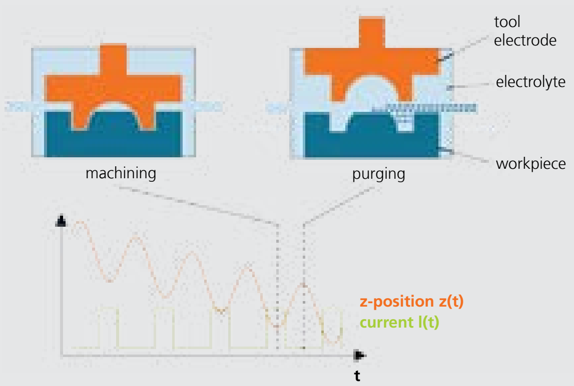
Further potentials can be opened up by the specific further development and optimization of the actuator technology as regards vibration direction and achievable vibration amplitudes as well as process development adjusted to the respective machining task.



Structures on the surface of the workpiece



Principle of ECM



Ultrasonic-Assisted Turning

In turning operations, it is possible to superimpose the cutting process by ultrasonic vibrations in different directions. The tool can be activated to vibrate in the feed direction or in the cutting direction. A combination of both vibration directions can also be realized. Here, short chips are produced and characteristic structures are generated on the surface of the workpiece. These effects are specifically adapted using the technological parameters such as vibration frequency, vibration amplitude, cutting speed and feed.

Thus, without an additional process step the tribological behavior can be influenced by specifically changing the surface structure.

Precise Electrochemical Machining

Current challenges in manufacturing of metal components include increasing requirements on precision, increasing material variety and the demand of developing economic and resource-efficient processes. Electrochemical machining (ECM) meets these requirements.

ECM is based on the principle of anode electrochemical dissolution. Precise electrochemical machining (PECM) is a hybrid manufacturing process combining conventional ECM with additional electrode vibration. The mechanical oscillation of the electrode is synchronized with electrical current pulses. This enables considerably improved localization of the material removal process and increase in precision compared to conventional electrochemical sinking. Surface roughness of up to Ra = 0.05 µm can be achieved as well as feed rates of up to 1 mm/min.

Since the tool electrode is not subject to process-related wear, PECM is used for series production of metal components. Mechanical properties of the material such as hardness and toughness have no influence on the removal process. For this reason, PECM is especially suitable for machining of difficult-to-cut materials such as Nickel-based alloys used for aircraft engine components. Further fields of application include tool making and medical engineering.

1 *Tool chuck with integrated piezo actuator*

2 *Precise electrochemical machining*

MEDIA-SUPERIMPOSED MACHINING

High Pressure Cooling

In grooving and cutting off but also in further turning processes as well as in drilling of materials with long chips, the application of high pressure plays an ever larger role. The objective of using high pressure cooling is to improve chip breaking behavior and to improve cooling of the machining zone.

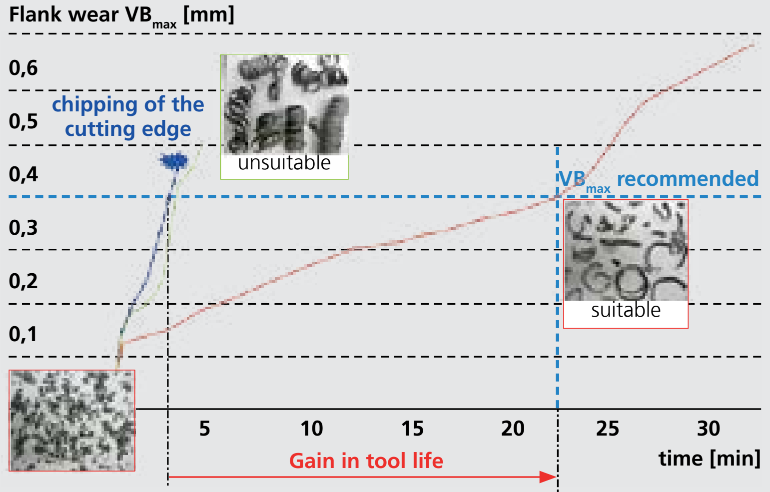
The most common application of high pressure cooling is the direct supply of the cooling lubricant jet between chip and rake face of the tool. The high pressure rake face flushing comes with two decisive advantages – improved chip breaking and higher machining parameters.

Due to the pressure applied by the cooling lubricant on the chips, the radius of chip curvature is reduced, and when exceeding the elongation at fracture, the chips are broken into little pieces. This way the chips can be easily removed from the active zone. Damage to the cutting edge and the produced workpiece surface due to long uncontrolled chips can be avoided by this method, and manufacturing of the components takes place reliably without expensive interruptions. In addition to the cutting edge geometry, the high pressure jet also acts as a chip breaker. Furthermore, shortening of the contact length takes place between cutting edge and chip, which results in reduced cutting forces and in a reduction of the thermal tool load.

Alternatively the high pressure jet can also be set between the flank face of the tool and the already machined workpiece surface. The coolant reaches the cutting edge much better, cools down the tool more intensely and causes reduced flank face wear. The cooling effect of this variant is higher than its influence on chip breaking.

Using specific application of cooling lubricant under high pressure, the following effects have been proven to be achieved:
– Improved chip breaking and chip control
– Increased cutting speeds and material removal rates
– Significantly increased tool life (by a factor of 7)
– Drastic shortening of machining times
– Higher productivity

Tool wear with different process parameters



Grooving in TiAl6V4, insert width 6 mm, grooving depth 10 mm, feed 0.1 mm/U

Conventional
v_c = 50 m/min, p = 40 bar

High pressure
v_c = 150 m/min, p = 150 bar

High pressure
v_c = 100 m/min, p = 150 bar

Moreover, possible increase in productivity results in savings in energy requirements. Important cost factors are the basic load of the machine tool and the supply of the cooling lubricant under high pressure. Increase in cutting speeds by using high pressure cooling, i.e. increasing the material removal rate, enables a reduction of the specific energy requirement, i.e. reduction of the proportion between applied energy and removed material volume.

Using flow simulation, the arrangement and the shape of the exit nozzles can be optimized, and these findings can be considered when solving individual problems.

Cryogenic Cooling

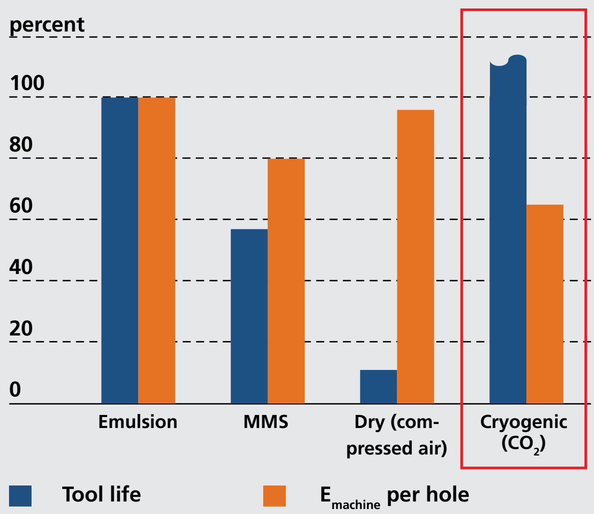
One alternative for high pressure cooling is process cooling using cryogenic media such as liquid Nitrogen or carbon dioxide. Cryogenic process cooling combines the advantages of dry machining with sufficient tool cooling.

Process potentials of cryogenic cooling are as follows:
- Specific cooling of the process zone
- Reduced thermal tool wear
- Residue-free cooling, thus possibility of dry machining
- Utilization of more productive technological parameters, thus increase in material removal rate
- Saving hazardous and polluting cooling lubricants

In cooling with liquid carbon dioxide (CO_2), its thermodynamic properties are used under various pressure conditions. At room temperature, the liquid CO_2 under pressure is brought to the opening of the cooling channel of the tool. Only when exiting from the tool, the pressure drops and expansion takes place, combined with a transformation of the state from solid to gaseous carbon dioxide. The medium cools down to -78 °C in this process. Subsequently the solid portion sublimates residue-free. Due to these properties, cryogenic cooling with CO_2 can be integrated into existing systems in a relatively easy way.

Tool life and energy consumption in drilling

(Q = 2,03 cm³/s, EN-GJL 250)



Fraunhofer IWU focuses on the following research topics:
- Investigation of the heat transfer in the cutting zone
- Development of suitable tools
- Process development
- Determination of the influence on machine components and their adaptation
- Flow investigations on a spindle test stand
- Development of integrative safety concepts
- Integration of lubrication media into the cryogenic cooling process
- Investigations of efficiency

3 Utilization of cryogenic cooling in milling of forming tools

4 Aerosol-dry lubrication with CO_2 cooling in turning

MACHINING WITH SUPERIMPOSED MOVEMENT OF THE AXIS

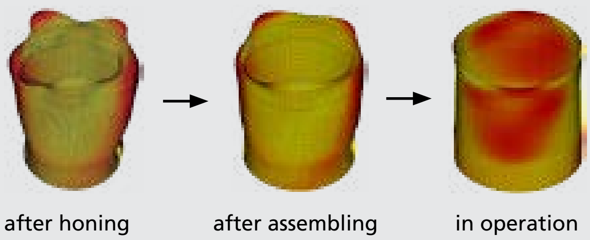
Machining with superimposed movement of the axis is a process approach using preventive out-of-round machining to compensate for bore deformations caused by production or function. In combustion engines, deviations from the cylinder shape substantially influence the tribological system of piston, piston ring and cylinder liner. The friction proportion of the piston group can amount to approx. half of the total engine friction. Therefore, reduction of friction in this area is especially important.

The adaptronic manufacturing processes developed at Fraunhofer IWU are based on uniaxial movement in form honing and multi-axial movements in form boring. The integrative process development includes machine, tool, process and measurement technology.

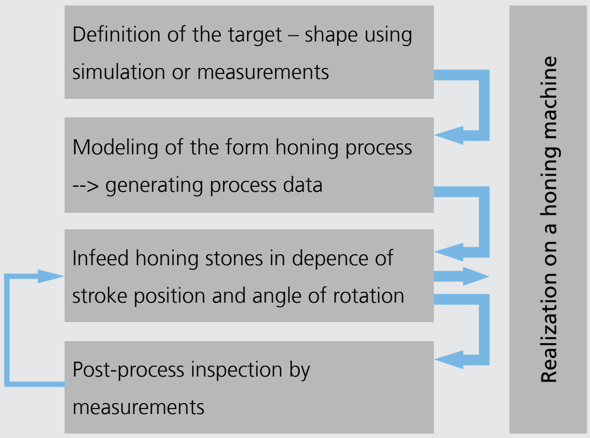
Form Honing

The developed adaptronic form honing tool has a basic tool body with the adaptronic cutting device consisting of piezo actuators, support bar and honing bar. By deflecting the actuators depending on stroke position and angle of rotation, infeed of the cutting edges takes place. The direction of the actuator movement and the infeed of the cutting edge

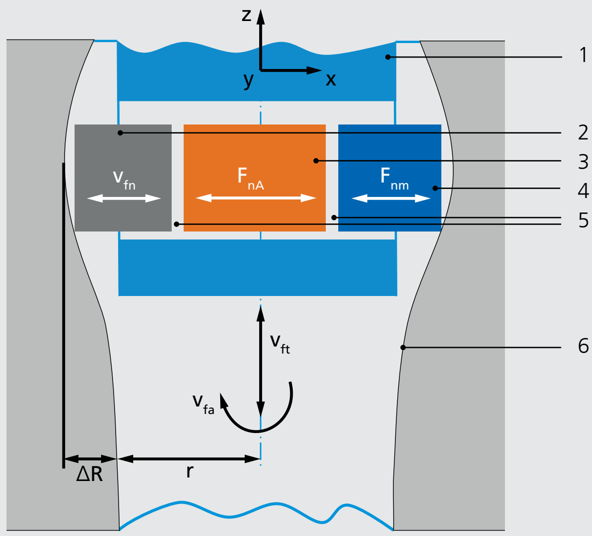
Form honing process



New process flow



Concept – new honing tool



1 tool body
2 honing stone
3 actuator package
4 support bar
5 interfaces
6 liner bore

is identical and ensures highest dynamics and minimum transmission losses. The process of adaptronic form honing has to be stopped when the desired bore shape is achieved. For this purpose process modeling was developed. Control of the machining result by shape measurement serves as determination of the machining quality and as output of a correcting matrix for process control. Form honing is realized by adapting the system-related hardware and software on a conventional single-spindle vertical honing machine.

The following results can be represented. The tool offers the degrees of freedom for producing radial shape deviations of up to 30 µm in relation to a bore diameter of 81 mm. In the area of constant contact conditions, shape accuracies of ≤ +/-2 µm were reached with the required roughness characteristics. Under laboratory conditions it could be proved that the productivity required for series production can be achieved by using the maximum potential of the actuators.

Form Boring

In contrast to conventional machining centers, in form boring the motor spindle is attached to a solid joint using a developed adaptive spindle holder. The solid joint realizes two rotational degrees of freedom and it is activated by eight piezo actuators which cause the tilting of the spindle and also the deflection of the cutting edge.

Preventive out-of-round machining of cylinder liners requires multiple radial cutting edge deflection per tool rotation of up to 50 µm at rpms of up to 6,000 rev/min. The technological challenges consist in managing the various deflection-related conditions of cutting edge contact as well as the development of control concepts depending on frequency and rpm.

5 *Adaptronic form honing tool*

Our Services

Development of Process Chains
– Market analysis
– Investigation of process chains
– Process optimization
– Cost-benefit calculation
– Development of manufacturing concepts
– Overall and detailed planning of technological processes
– Technological dimensioning of machining tools
– Recommendations on machine investments

Development and Evaluation of Machining Strategies
– Market analysis
– Feasibility studies
– Technology development
– Determination of process parameters
– Development of ideal machining strategies
– Benchmarking of CAD/CAM systems

Quality Assurance
– Photogrammetric geometry detection of components and tools
– Measuring of micro components by confocal microscopy and strip projection
– Machine measurement by laser-tracker
– Structural analysis by scanning electron microscope

Publishing Notes

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Photo title page: Milling tool with internal CO_2-snow jet cooling lubrication