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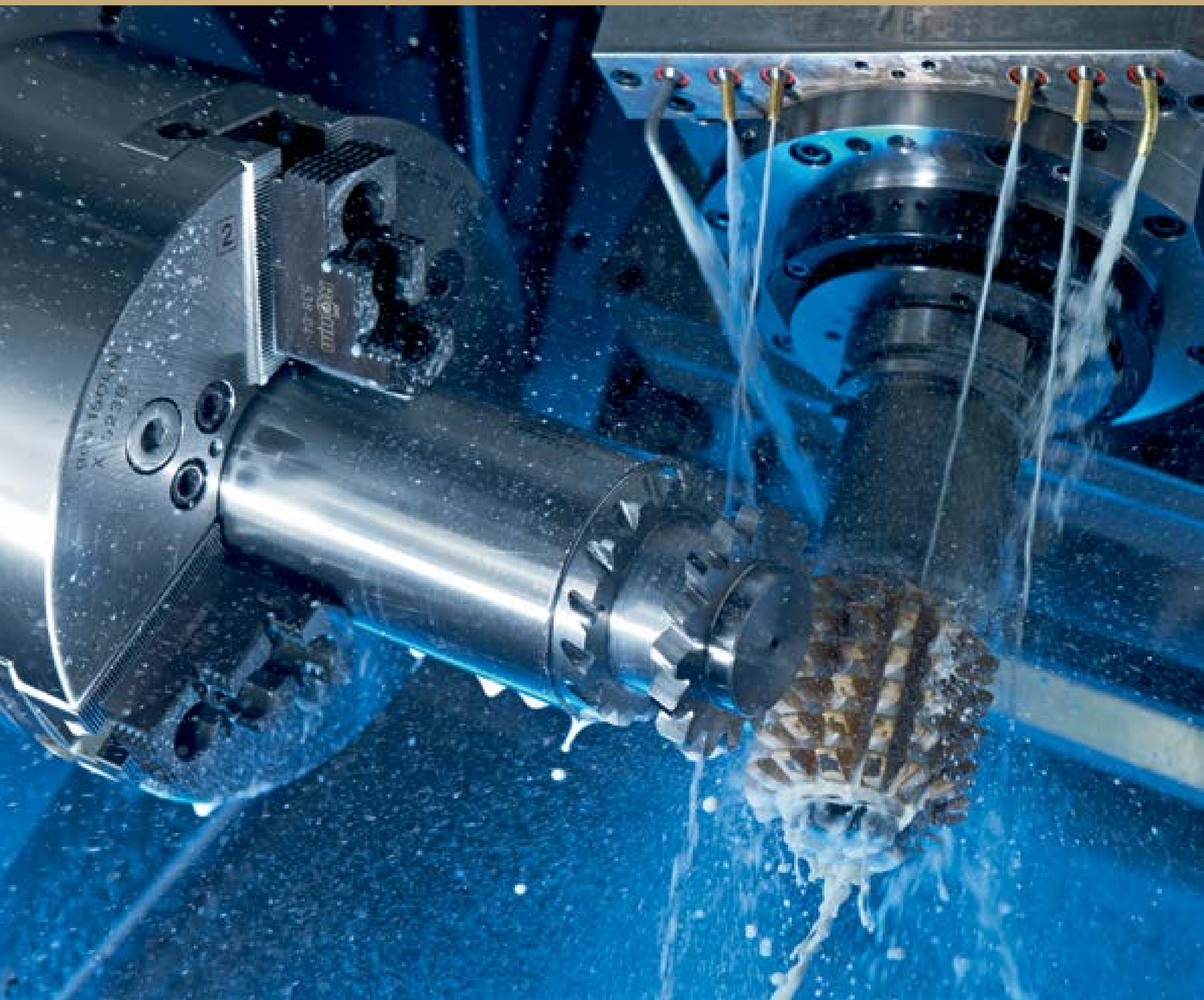
FRAUNHOFER INSTITUTE FOR MACHINE TOOLS AND FORMING TECHNOLOGIES IWU

COOLING LUBRICATION STRATEGIES IN MACHINING



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COOLING LUBRICATION – KNOW-HOW FOR MACHINING

Successful economic corporate development can only be realized if potentials for optimization regarding cost and machining times are determined early and are implemented into mechanical production. Efficient cooling lubrication during machining results in longer tool life and shorter machining times. In addition to increasing the performance level of numerous production processes, cooling lubricants can also contribute to an improved surface quality and they can support with part cleaning. Thus they allow higher cleanliness and also corrosion prevention of machine tool and workpiece.

Applying cooling lubricants effectively

The rising prices for resources and energy lead to increased requirements on the efficiency of production processes. In order to reduce energy and resource consumption in addition to cost, reduction and even avoiding of cooling lubricants is the objective. Minimum quantity lubrication and dry machining are interesting approaches compared to cooling lubrication by flooding. However, the use of these strategies always has to be regarded in association with the material to be cut. The users of cooling lubricants need more and more knowledge in order to effectively apply these media.

Although high-performance materials are cost-intensive, they rapidly gain importance due to their properties. In machining of heat-resistant steels and super alloys for the aerospace industry and energy technology, but also in automotive engineering, very high process temperatures may occur. The consequences are extreme tool wear, reduced cutting parameters, i.e. high machining times, cost and energy consumption. In order to meet the requirements for efficient machining of these high-performance materials, high temperature resistant cutting materials and coatings are required as well as suitable machine concepts, efficient cooling during the machining process and optimal cutting parameters. Conventional cooling processes often reach their limits in machining of such materials. Large temperature differences, e.g. due to full jet cooling in steel machining, increase the risk of a thermal shock in the tool. Minimum quantity lubrication or reduced quantity lubrication can achieve a good lubrication effect. However, the poor cooling effect causes increased tool wear. Furthermore the problematic chip breaking behavior of advanced materials cannot be positively influenced. In order to increase productivity, efficient cooling lubrication processes have to be utilized. For this purpose the adaptation of cooling lubrication strategies such as minimum quantity lubrication, high pressure cooling or cryogenic cooling, to the machining task is necessary to improve the performance of production processes.

Our competences

One research focus lies on developing production technologies that enable optimal use of cooling lubrication. All conventional cooling lubrication strategies with internal and external media supply are used for technological investigations, but also strategies such as aerosol dry lubrication, minimum quantity lubrication, cryogenic cooling or high pressure cooling are included. This makes it possible to conduct comparative investigations to determine potentials and to develop economically efficient production processes.

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HIGH PRESSURE COOLING

Alternative coolant concepts such as the use of high pressure cooling are a possible approach for machining processes where chips cannot run off freely due to the process or the workpiece, or where chips tend to stick together or where cooling cannot be omitted due to thermally caused problems during machining. In grooving and in cutting-off, but also in other turning processes or in drilling of long-chipping materials, the use of high pressure gains more and more importance. Today, influencing the process using a coolant pressure of 80 bar (to some extent up to 120 bar) is state-of-the-art in cutting of high-strength and long-chipping materials.

The most common application of high pressure cooling is the direct supply of the cooling lubricant jet between the chip and the rake face of the tool. High pressure rake face flushing causes better chip breaking and higher machining parameters. The chip is broken into small pieces due to the pressure the cooling lubricant applies to the chip. Thus the chips are easily removed from the cutting zone. This way damage to the cutting edge and to the generated workpiece surface, caused by long uncontrolled chips, can be avoided. Production of the components takes place reliably without cost-intensive interruptions. Alternatively, the high pressure jet can also be directed between the tool flank face and the already machined workpiece surface. The cooling lubricant reaches the cutting edge significantly better, the tool can be cooled more intensively and the flank wear is reduced.

Specific high pressure supply of coolant into the machining process enables improved process flow. This evidently influences the chip formation and also the chip breaking behavior of difficult-to-machine materials. Moreover, it results in reduced processing forces, higher material removal rates and longer tool life.

Our competences

In order to specifically optimize the machining process, it is important to understand the processes running in the active zone under high pressure cooling, wear and oscillation behavior of the tools, arising process temperatures and cutting forces, but also flow behavior of the cooling lubricants. In addition to numerical simulations of the cooling lubricant supply to the contact zone or to the determination of the thermal behavior of the components and tools, the wear behavior of tools is also investigated at Fraunhofer IWU in order to optimize the process and to achieve economic cutting parameters. Using numerical simulations on optimized flow design of the cooling lubricant supply, flow losses were reduced and the flow-rate of cooling lubricants was improved by approx. 10 percent. Pressures of up to a maximum of 270 bar are used for technological investigations on high performance machining. Thus tool life was increased by a factor of 7 when using high pressure cooling in grooving of TiAl6V4.

1 *Conventional cooling lubrication*

2 *Turning tool for high pressure cooling*

3 *Chip breaking with conventional cooling (left) and with high pressure cooling (right)*

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MINIMUM QUANTITY LUBRICATION AND REDUCED QUANTITY LUBRICATION

Minimum quantity lubrication (MQL) offers a feasible compromise between saving cooling lubricant and maintaining process reliability. The dosage of the lubricant amount is less than 50 ml/h for minimum quantity lubrication and more than 50 ml/h for reduced quantity lubrication. When changing the processes to MQL, the previous machining strategies, tool geometries and tool coatings as well as the machine concepts should be reconsidered and redesigned. Thus quality losses of the workpiece and increased tool wear are avoided. In particular when using MQL in manufacturing with high quality requirements, developments on alternative cooling principles are required in order to compensate for the loss or the reduction of the effect mechanisms of the cooling lubricant functions.

Generally when using minimum quantity lubrication or reduced quantity lubrication, the type of supply and the mixture preparation have to be distinguished since they influence the final result. The internal supply of the cooling lubricant through the tool to the contact zone is of special interest. The requirements on the system and on the machine tool differ significantly from those of external supply of cooling lubricant. In order to transport the lubricant to the cutting edge at high spindle speed, it is required to produce droplets with the smallest particle size and a narrow particle size distribution. Similar to the mode of action of a centrifuge, the precipitation of the particles on the wall of the cooling channel shall be kept as low as possible due to their inertia in order to reliably lubricate the cutting edge.

Aerosol dry lubrication (ADL)

Established methods such as MQL can reach their limits in machining of difficult-to-machine materials. For this reason, aerosol dry lubrication (ADL) has been developed in the past years. ADL uses very low lubricant amounts. Lubrication of the cutting zone occurs by a superfine aerosol with a lubricant particle size of approx. 0.1 µm. The required amount of oil lies between 5 and 15 ml/h, which is considerably below the amount of oil of MQL. By specifically lubricating the cutting zone, the friction between tool and workpiece is reduced. Thus, high temperatures are largely avoided.

Our competences

Based on systematic analyses of the actual state of manufacturing, the entire process is investigated regarding the potential use of ADL, MQL or reduced quantity lubrication. Furthermore, solution packages regarding process state detection, influencing of tribosystem and process temperature are developed and experimental investigations are conducted. The evaluation of the results is performed according to technical and economic criteria. For example, MQL can also be used for energy-efficient grinding. Using specifically developed grinding tools and thermally optimal machining strategies and targeted chip suction, machining can take place without damage to the thermal peripheral zone and while complying with the required accuracies. Thus, it is possible to perform complete dry machining within entire process chains.

DRY MACHINING

Dry machining is the most effective approach of combining machining with economic advantages and ecological objectives. The tendency towards highest increases in performance with strongly reduced energy consumption has led to promising tool developments and a general trend towards dry machining. It shall always be the preferred option when possible, considering the process (process reliability), the tool (high temperature wear resistance), the workpiece (dimensional accuracy, surface quality) and the machine tool (thermal behavior, machine accuracy).

Currently not all problems occurring when utilizing dry machining have been solved. Moreover, according to the state-of-the-art, the cooling lubricant cannot yet be completely omitted in all production processes. In processes with interrupted cut such as milling, dry machining can achieve high advantages in tool life since no thermal shock loads caused by cooling lubricants occur at the cutting edge. A change over to dry machining also depends on the situation of the machining task of each individual case. Specifically designed machine tools are required for economic dry machining in order to meet the requirements of dimensional stability under increased thermal loads.

While machining without any cooling lubricants is mostly suitable for series production using turning and milling processes, only first approaches exist for various drilling processes. The cutting zone is not freely accessible and the supporting cooling lubricant is omitted, which complicates chip removal, increases the thermal load on the drill and may impair the working result. The largest share of all machining operations is comprised by drilling with approx. 30 percent. Thus, it offers a very great savings potential which shall be further researched.

Our competences

Since numerous, often opposed factors have an effect on real production processes, general statements regarding the usability of dry machining are difficult to make. Fraunhofer IWU evaluates the specific production process while considering all boundary conditions. Using numerical simulation, optimal tool geometries and coating systems can be designed. Conducting experimental investigations helps validate the simulation results and determines suitable process parameters and strategies for dry machining.

1 *Turning with ADL*
2 *Dry milling of steel*

CRYOGENIC COOLING

Cryogenic process cooling combines the benefits of dry machining with sufficient cooling of the tool. Process potentials of cryogenic cooling include:

- Specific cooling of the process zone
- Reduced thermally caused tool wear
- Residue-free cooling, thus possibility of dry machining
- Utilization of more productive technological parameters, thus increase of material removal rate

Liquid nitrogen (LN_2) and liquid carbon dioxide (CO_2 or dry ice) are used for cooling of machining processes. Both gases have to be differentiated as regards the mechanisms of refrigeration. For this reason, different requirements need to be considered for their use as cooling media.

Liquid nitrogen, which is stored in insulated tanks, starts boiling at a temperature of -196 °C. Thus, considering this characteristic, nitrogen seems to be more suitable as a cooling medium compared to carbon dioxide. However, the low temperatures under atmospheric pressure are a problem for using liquid nitrogen as a cooling medium. On the one hand all supply lines have to be vacuum-insulated to avoid damages and losses. In addition, special tools with insulated supply lines have to be utilized. Machine components also need to be protected from the cold. On the other hand liquid nitrogen starts boiling at once when meeting the heated surface; then it vaporizes. Due to the insulating film forming from gaseous nitrogen, the cooling effect is reduced. However, when cooling with liquid carbon dioxide (CO_2), its thermo-dynamic properties at various pressure ratios are exploited. The liquid CO_2, which is under pressure, is transported to the cooling channel exits of the tool at room temperature. Only when exiting the tool, it expands due to the drop in pressure, combined with a phase transition to solid and gaseous carbon dioxide. The medium cools down to -78 °C. Subsequently, the solid portion sublimates residue-free. It is because of these properties that CO_2 cooling can be integrated into existing machine systems in a relatively uncomplicated manner.

Our competences

Our research focuses particularly on:

- Investigation of the heat transfer in the cutting zone
- Determination of the influence on machine components and development of suitable tools
- Flow investigations on a spindle test station
- Integration of lubrication media into the cryogenic cooling process
- Process developments and determination of optimal process parameters
- Analyses of economic efficiency
- Development of holistic safety concepts

The superiority of CO_2 cooling is evident, e.g. in drilling of gray iron with increased process parameters. Effects of CO_2 cooling can also be demonstrated in milling. For instance, in milling of cast iron the feed rates can be increased in so far that the machining time is reduced by approx. 15 percent and the tool wear is reduced by approx. 20 to 30 percent.

1 *Milling tool with CO2 cooling*

OUR SERVICES

Development of process chains
– Market analysis
– Investigation of process chain
– Process optimization
– Cost-benefit calculation
– Development of manufacturing concepts
– Rough and detail planning of technological processes
– Technological dimensioning of processing machines
– Recommendations on machine investments

Development and evaluation of machining strategies
– Market analysis
– Feasibility studies
– Technology development
– Development of characteristic process values
– Preparation of optimal machining strategies
– Benchmarking of CAD/CAM systems

Available software
– CAD systems: Inventor, Pro-Engineer, CATIA
– CAM systems: Tebis, GIB CAD&CAM
– Simulation software: MARC, ANSYS, DEFORM
– Computer-Fluid-Dynamics-Software (CFD)

Available cooling lubrication technology
– MQL single-channel system, Vogel and Lubrix
– MQL two-channel system, Bielomatik
– Aerosol dry lubrication with CO_2 cooling: Aerosol Master 4000 c, Rother
– CO_2 cooling system with MQL ChilAire EI 3120, CoolClean
– High pressure cooling system Jet Break N20 POMPES KPO 3509, Barthod Pompes

Available machine technology
– 5-axis hexapod milling machine Mikromat 6X HEXA
– 5-axis multifunctional machine Dynapod
– 5-axis milling machine DIGMA 850 HSC
– 4-axis horizontal machining center HEC 500D XXL
– 5-axis machining center HEC 630 X5
– 5-axis machining center DMU 210P
– CNC turning machine N20 with high pressure unit
– Turning-milling center GMX 250 linear
– Nagel VARIOHONE VSM 8-60 SV-NC
– Non-cylindrical grinding machine KEL-VARIA UR 175/1500
– Gear grinding machine Kapp KX 300P
– Jig grinding machine SkoE400
– Spindle test station for CO_2 cooling

Available measuring technology
– Coordinate measurement machine PRISMO7S-ACC (ZEISS)
– Various measuring devices for roughness and profiles
– Confocal microscope, ITO Uni Stuttgart
– White light interferometer, ITO Uni Stuttgart
– MikroCAD, GFM Teltow
– Scanning electron microscope, LEO Oberkochen
– EDX system, Oxford Instruments
– Touching measuring devices for roughness and profiles HOMMEL and Mitutoyo
– Dimensional measuring device F2002, HOMMEL
– Ultrasonic wall thickness measuring devices
– Profile projector PJ300
– Optical measurement technology by GOM
– Laser triangulation system Steinbichler T-Scan CS
– X-ray diffractometer Xstress 3000G2, Stresstech

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Cover picture: hobbing