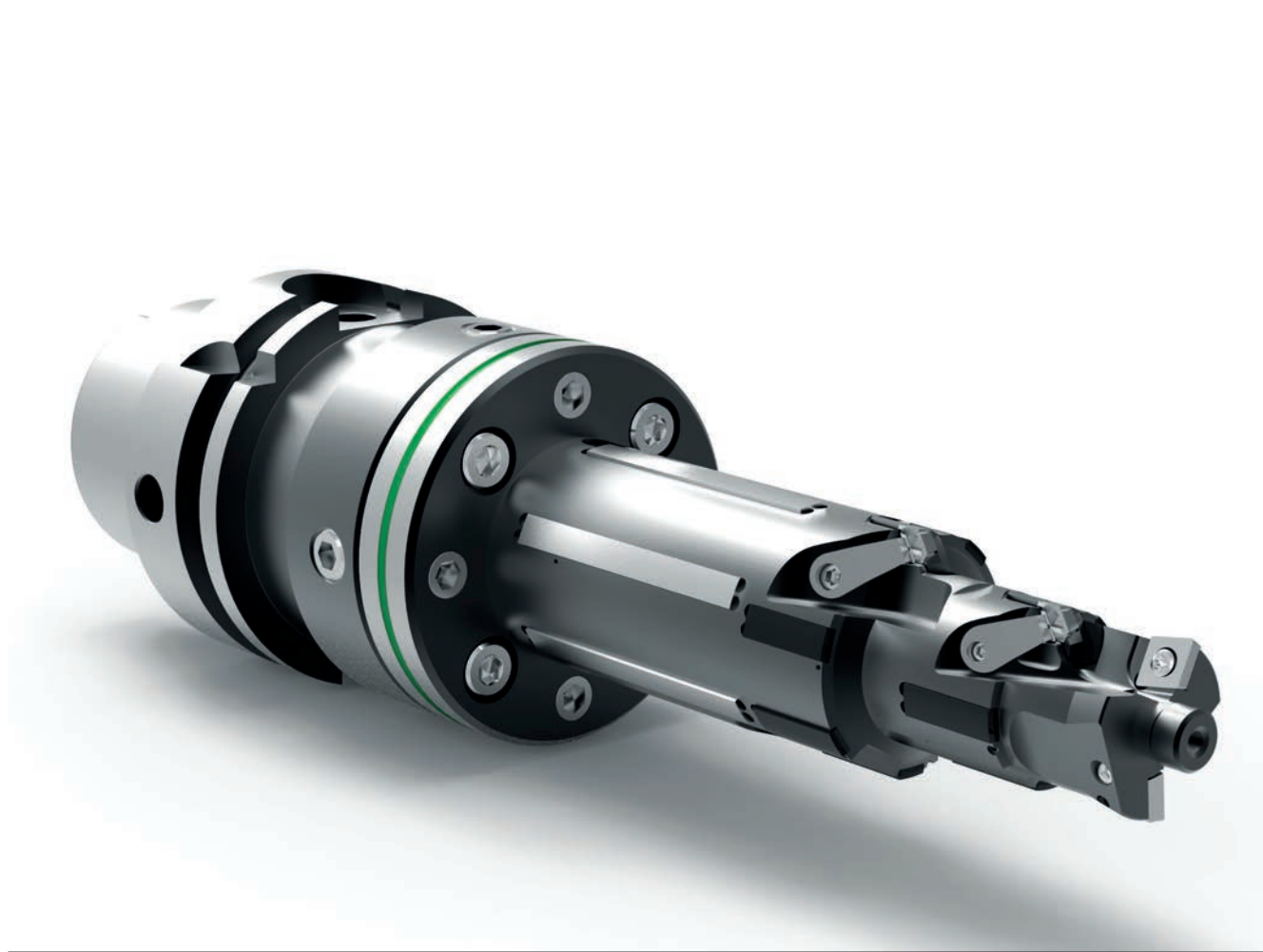

Successful series production with minimum quantity lubrication

03 | Minimum quantity lubrication



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Minimum quantity lubrication (MQL) is mature alternative to conventional cooling lubrication, particular in series production. It lowers production costs, investment costs and space requirements as well as reducing the impact on the environment. Different (and very much smaller quantities of) lubricating media and other systems are used for the supply of these media.

Different demands are also made in some cases on the machine tools, tools and tool holders for the minimum quantity lubrication as compared with wet machining. This article looks at the whole minimum quantity lubrication system as it can be successfully used particularly in series production.

Motivation Motivation

Minimum quantity lubrication can make a significant contribution to reducing costs in mechanical production. Costs for the conventional cooling lubrication in industrial-scale series production in the automotive industry typically lie between 8% and 16% (1). Apart from the cost reduction aspect, further reasons for the introduction of MQL are the growing number of environmental protection regulations and reduced impacts on the health of the employees.

In some cases, however, minimum quantity lubrication can also lead to a direct improvement in quality of the workpieces. Particularly during the precision machining of aluminium alloys and brass, machining with MQL results in a better surface finish compared with machining using conventional cooling lubrication with emulsion. Reasons for this are the better lubricating effect of the MQL media and the absence of any small particles that cannot be filtered out of the conventional cooling lubrication system.

For the same reasons (lubricating effect and higher purity of the medium), the use of MQL often also offers longer tool lives compared with machining using cooling lubricant. Machining with MQL also results in no thermal shock in the interrupted cut

which when using cooling lubricant can result in damage to the tool blade and in premature wear.

The possible savings offered by MQL result from lower investment costs compared with cooling lubricant systems (particularly when large central cooling lubricant systems can be avoided), lower media consumption, less maintenance and from significantly reduced energy costs for the cooling lubricant technology. Machining of transmission housing halves made from a cast aluminium alloy using MQL, for example, allowed roughly 20% to 25% of the energy costs to be saved during production (2). The monthly costs per machining centre for the cooling lubricant medium were thereby reduced from EUR 333 for the cooling lubricant machining to EUR 20 for the MQL machining.

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Media and supply systems

Media and supply systems for minimum quantity lubrication

MQL medium is the term used to refer to the oil/air mixture that is fed to the cutting point (3). By contrast with conventional cooling lubrication where the medium has a lubricating and cooling effect, the cooling effect (heat dissipation) with MQL is negligibly small. The oils used should have a good lubricating effect in order to limit the heat generation and temperatures by reducing the friction. Furthermore, they should have a high thermal stability, i.e. a high evaporation temperature and high flame point.

In practice, fatty alcohols and synthetic esters are widely used as MQL oil. Synthetic esters have a particularly high lubricating effect so that they reduce abrasive wear more effectively than fatty alcohols. Fatty alcohols are used when the focus is on the separating effect in order to avoid build-up edges. Both belong to water hazard class 1 or are classified as non-hazardous to water so that the environmental regulations to be satisfied for these oils are lower than for the normal water-miscible cooling lubricants. The oils used generally have a viscosity of between 20 and 50 mm²/s at 40°C.

The oil quantities required for MQL are dependent on the material to be machined and on the machining method. Figure 1 shows the oil requirement for different machining methods for cast aluminium alloys, taking the example of the machining of a cylinder head. The oil quantities consumed per hour are generally below 50 ml. In exceptional cases it is even possible to machine completely dry. The oil consumption for the final machining of the camshaft and the reaming of the injector bore, on the other hand, is relatively high because here guide pads of the tools have to be guided in the workpiece and therefore have to be well lubricated. For the machining of grey cast iron and steel, the oil consumption is generally lower than for cast aluminium alloys (Figures 2 and 3).

The compressed air consumption is dependent first and foremost on the flow resistance (in particular on the smallest cross-section of the feed channels) and the pressure. Two-channel systems are typically operated with 5 to 6 bar. With single-channel systems, the air pressure is frequently increased to

10 bar using a pressure booster, particularly for tools with small cooling channels.

Figure 1
Cylinder head, material AISi7

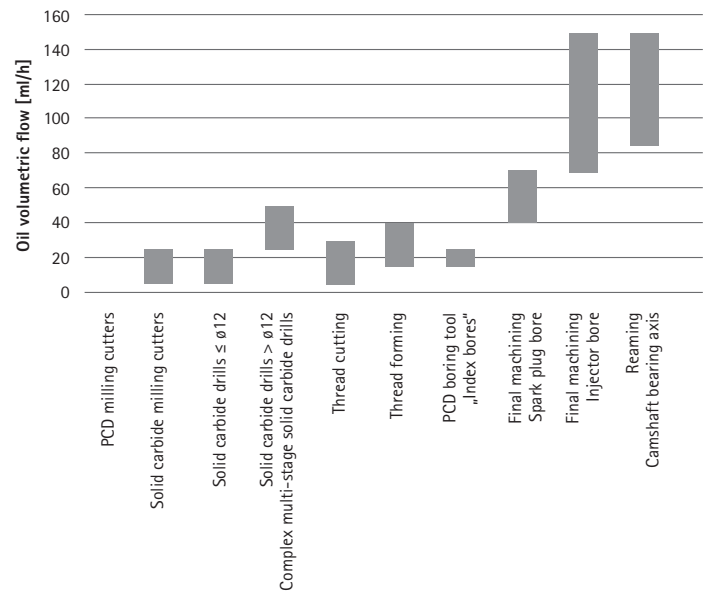
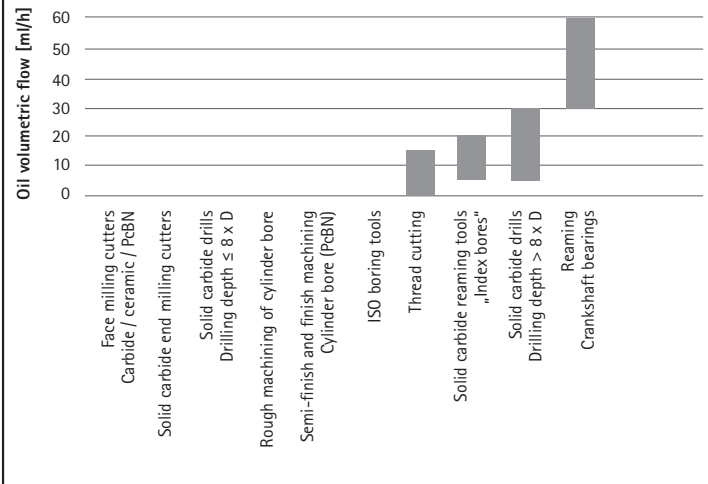
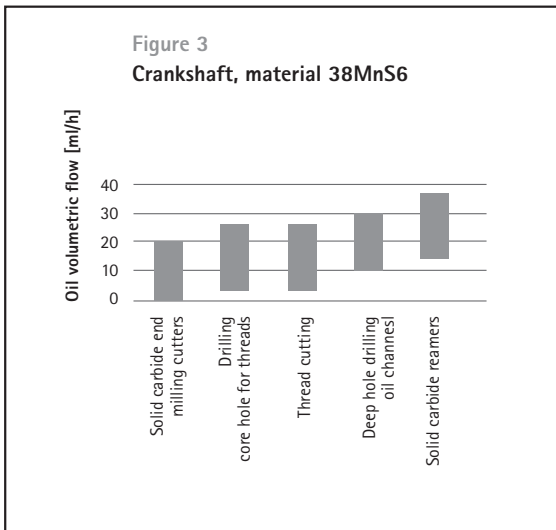


Figure 2
Crankcase, material GG30





A wide variety of demands are made on the MQL systems. The oil volumetric flow should be variable between 5 and 200 ml/h, depending on the process. Even small oil volumes have to be continuously and uniformly transported and be available at the tool outlet after a short reaction time (0.1 s) following the tool change or after starting/switching over in transfer units. The supplied oil volume should be as independent as possible of the operating time and temperature. The MQL system should permit an air volumetric flow of up to 1,000 standard litres per minute. The pressure losses in the MQL system up to the tool interface should be as low as possible and the system must have long-term resistance to the fatty alcohols and ester oils used.

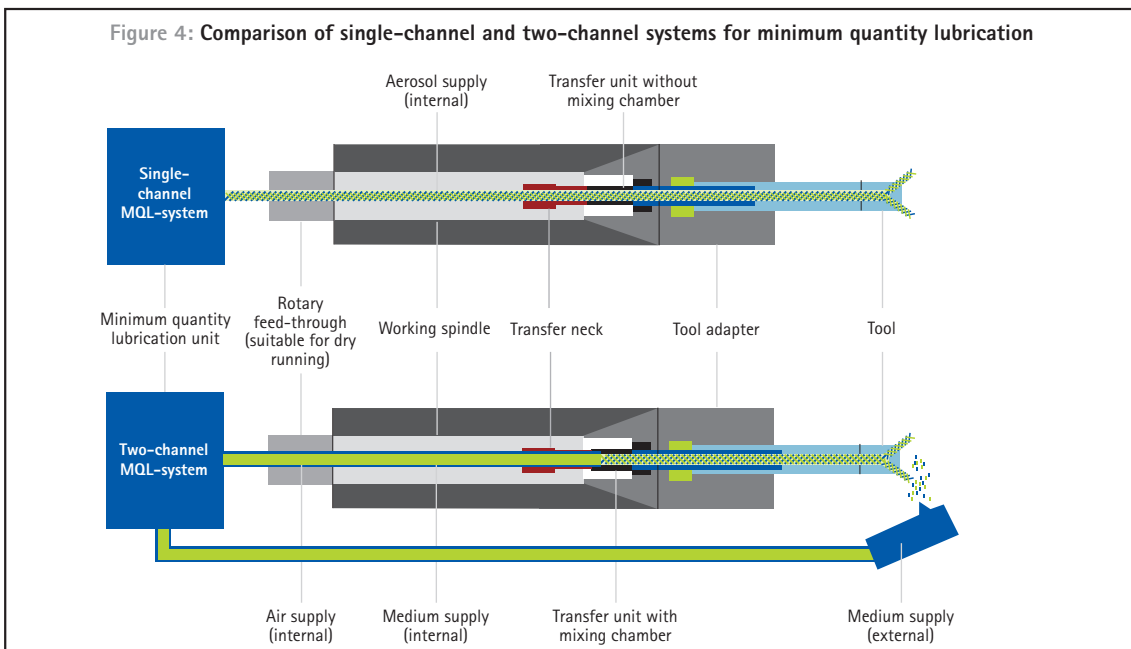
Different systems are generally used for the mixing of the MQL medium of oil and air and for the feed to the cutting point.

They can be divided into

- MQL systems with external feed,
- MQL systems with internal feed through the spindle and mixture formation outside the spindle (single-channel system, Figure 4, top) and
- MQL systems with internal feed through the spindle and mixture formation inside the spindle or tool holder (two-channel system, Figure 4, bottom).

In addition it must be possible to connect the MQL system to CNC and PLC systems. In some cases a multi-spindle supply by an MQL system and the automatic refilling of the storage tank is demanded. The possibility of reducing the oil volume to zero is also sometimes demanded so that pure compressed air can be used. This presupposes a rotary feed-through that can run dry.

MQL systems with external feed have the advantage that they can be more easily and less expensively retrofitted, and that no special tools are required. The adjustment possibilities for different tool diameters and lengths, however, are very limited or even non-existent. The majority of the MQL medium will generally not reach the cutting point. These systems



are therefore very rarely used in series production.

Single-channel and two-channel systems are widely used. They each have their specific advantages and disadvantages which are more or less significant, depending on the concrete application. Single-channel systems are less expensive and easier to integrate into the machine. Here the air and oil are mixed to form an aerosol outside the main spindle. This aerosol is transported into the tool. The transport of the MQL medium through angled channels and the supply of several spindles using one MQL system (in drill heads) is easier than with two-channel systems. The size of the oil droplets with single-channel systems is roughly 1 to 2 µm. The oil quantity supplied, however, is dependent on the speed and cannot be varied independently of the air volumetric flow. Precise, tool-specific metering of the oil quantity is therefore difficult. The viscosity and hence the temperature of the oil also influences the oil quantity with otherwise the same setting parameters. Temperature fluctuations in the production shop thus have a direct influence on the composition of the MQL medium.

With two-channel systems, air and oil are transported to the spindle nose in two different channels and only mixed at the spindle nose or in the tool holder. These two channels result in the higher installation costs and the difficulty of transporting the medium through angled channels and of supplying several spindles using one MQL system. On the other hand, a more precise and independent metering of the oil quantity is possible here. The optimum oil quantity can therefore be set for each tool. Ambient boundary conditions such as the temperature of the oil have practically no influence on the quantity of oil supplied.

MQL-compatible machine design

MQL-compatible machine design

A number of demands have to be taken into consideration for the MQL-compatible machine tool (4). The heat generated during the cutting process cannot be dissipated from the machine by the cooling lubricant. The vast majority of the heat is stored in the chips which should therefore be transported out of the machine as quickly as possible. Care must be taken that no accumulations of chips occur in the machine. The inside of the working chamber should

be as smooth as possible (for example, of unpainted stainless steel) and have steeply inclined or vertical walls. Horizontal surfaces, even pipework, on which chips could collect should be avoided, otherwise thermal distortion of the machine and dimensional errors can occur. An A axis is favourable in order to be able to tip out any chips lying on the clamping device after machining, or even to be able to carry out the whole machining operation upside down.

Linings can separate the precision-determining parts of the machine tool thermally from the machining chamber. The machining chamber should be effectively sealed to protect drive and guide elements and the tool magazine against metal dusts.

The chips can be transported out of the machine by a chip conveyor in the bottom of the machine or even by a chip extraction device. For the transport of the chips from the machine to central chip collection points there are special extraction systems with chip separators to which a larger number of machines can be connected so that the chips can be drawn off intermittently from the machines.

An extraction system with a suitable filter must always be installed to draw metal dusts, MQL medium and oil vapours out of the working chamber. This reduces cleaning work on the machine, lowers the risk of fires due to inflammable aerosols and ensures that the prescribed workplace limits are observed.

Metal dusts and chips typically adhere to the inside walls of the machining chamber so that an appropriate cleaning concept is indispensable. In some cases it is sufficient to clean the machines with a cloth or brush at the end of the shift. In other cases cleaning is carried out using low-pressure spray guns with water consumptions of between 1 and 2 litres per minute. Clean warm water or water with a cleaning emulsion is used here.

In many cases intensive machine cleaning using dry ice is necessary from time to time. In the case of severe soiling, cleaning with dry ice has to be carried out roughly every two weeks. In some cases, however, cleaning just once a year with dry ice is sufficient.

The determining factor for the amount of cleaning is the quantity of oil used during machining. The

degree of soiling of the machining chamber can be significantly influenced by strict process optimisation and minimisation of the amount of oil required. In one case, for example, it was possible to reduce the amount of oil for the industrial-scale complete machining of cylinder heads to approx. 7 ml per workpiece. During the complete machining of transmission cases, oil quantities of 1.5 ml and 0.3 Nm³ air per workpiece are achieved in some cases with a productive time of 3.3 minutes (5). Here, for example, the oil supply is switched off during rapid traverse movements in order not to consume oil unnecessarily. The material machined also influences the amount of cleaning required. The machine is more heavily soiled particularly when machining grey cast iron.

Systems for temperature compensation simplify the meeting of close tolerances, particularly of position tolerances. Temperature sensors are installed in machine components and/or in the clamping device for this. Scanning by proximity sensors positioned in the clamping device to compensate thermally related machine deformation is also possible. Often temperature compensation is not necessary at all if the position tolerances are not too tight and the raw parts are brought to shop temperature before machining. A modified process sequence can also significantly reduce thermally related position deviations at the workpiece (see below).

Clamping technology for MQL

Für die Bearbeitung mit MMS sollten spezielle MMS-Special MQL chucks should be used for machining with MQL. They differ from the chucks for conventional machining with cooling lubricant in particular through different coolant pipes and length adjustment screws. Further distinctions are necessary in order to meet the specific demands of the single-channel and two-channel systems. In both cases, there should be as few changes in cross-section in the flow channel as possible, and unavoidable changes in cross-section should be gradual. For single-channel systems, the flow cross-section for the MQL medium up to the entry to the tool shaft should be as large as possible in order to ensure that the cooling channels in the tool represent the smallest cross-section in the flow system.

Compared with the single-channel system, the flow cross-sections in the coolant transfer units and the length adjustment screws for two-channel systems are smaller. The reasons for this is that the flow velocity of the air has to be kept as high as possible in order to be able to ensure the transport of the oil which flows almost 100% as a thin film along the walls of the cooling channels in the tool.

The ratio between the cross-section in the length adjustment screw and the total cross-section of the outlets on the tool, the „MQL ratio“, should lie between 1 and 4. This is necessary in order to ensure a continuous, uniform oil supply at the tool outlet and for short reaction times. This means for different outlet cross-sections with various tools that different coolant transfer units and length adjustment screws have to be available for the adaptation to the tools in question (Figure 5).

For single-channel systems, one design for coolant transfer unit and length adjustment screw is sufficient. Here the flow cross-section does not have to be adapted to the tool (Figure 6). The considerably larger flow cross-sections compared with the two-channel technology can be clearly seen.

The transition between length adjustment screw and tool shank is typically conical in both cases. The Japanese Horkos Corp. has a patent which defines the transfer of an MQL medium via a „pipe-in-pipe“ system. The transfer systems used in industry today are based on this principle, which is why most sup-

Clamping
technology
for MQL

Figure 5: Geometric conditions in the chuck for two-channel technology

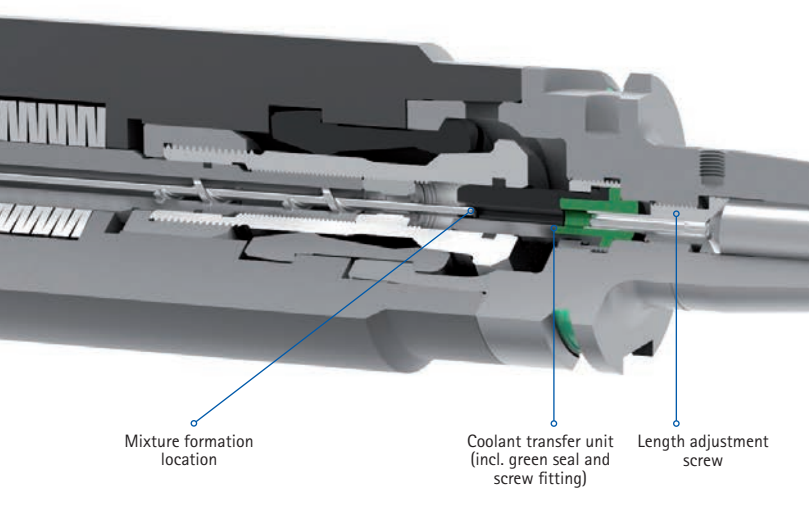
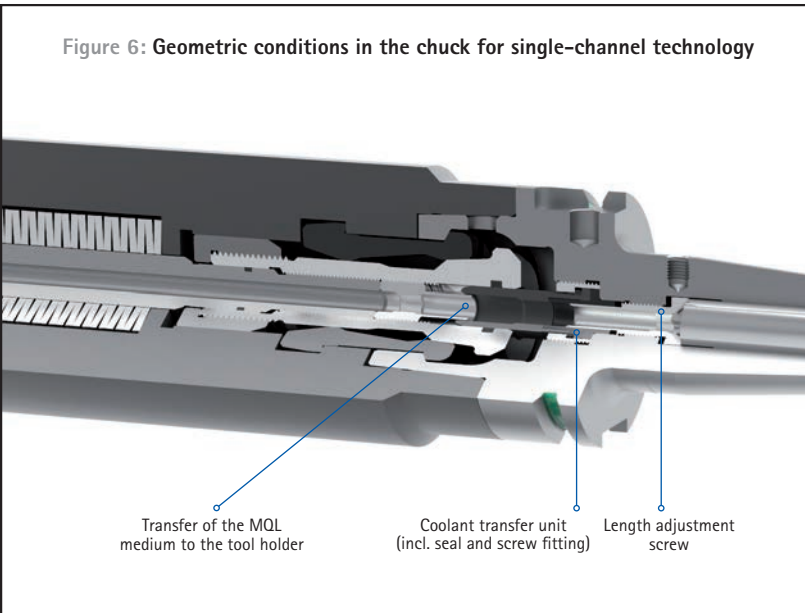


Figure 6: Geometric conditions in the chuck for single-channel technology



free passage in the cooling channels can be checked by spray tests in the tool manufacturer's works and for quality assurance in the tool preparation shop.

MQL-compatible process sequence

The heat input into the workpiece with the associated thermal expansions and the avoidance of chip accumulations in or in front of bores still to be machined play a major role for the sequence of the individual machining steps. Figure 9 shows one such example. If, after drilling into the solid material, the contour is first bored, a few chips collect at the bottom of the bore. During the subsequent thread forming, these result in a poor quality of the thread or even in tool breakage. A change in the machining sequence such that the thread is formed as the second step and then the contour is bored helps to overcome the problem.

MQL-compatible process sequence

pliers of tool holders and MQL transfer systems are correspondingly licensed. Alternative designs have not established themselves to date.

MQL-compatible tool design

MQL-compatible tool design

Adaptations to the tool geometry specifically for minimum quantity lubrication relate predominantly to the design of the cooling channels and the design of the chip discharge from the tool. In some cases the chip spaces are made slightly larger than for wet machining. The flutes are also polished in order to reduce the friction between chip and tool and hence allow the chip to be discharged more quickly. Drilling tools that are designed straight for wet machining are spiralised for MQL machining in order to simplify the chip transport (Figure 7). The improved chip discharge also minimises the heat input into the workpiece.

The cooling channels in the tool have to be designed such that an optimum feed of the MQL medium to the cutting point and, where necessary, to guide surfaces of tools guided inside the workpiece. The cooling channels should be machined burr-such that the flow resistance to all outlet openings is roughly the same. Longer flow paths therefore require slightly larger diameters. The outlets should be arranged more in radial direction and closer to the cutting point than in tools for wet machining (Figure 8). The

Figure 7: Improvement of the chip removal using spiralised drills

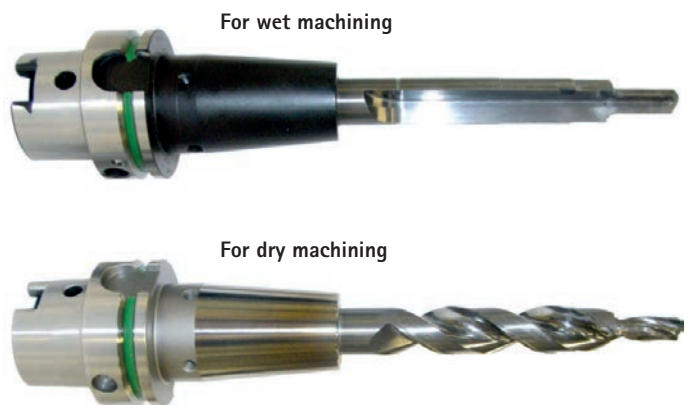
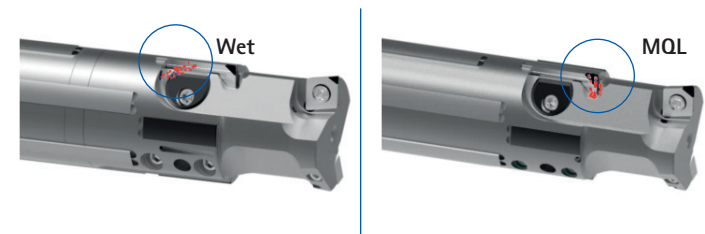


Figure 8: Arrangement of the outlet opening

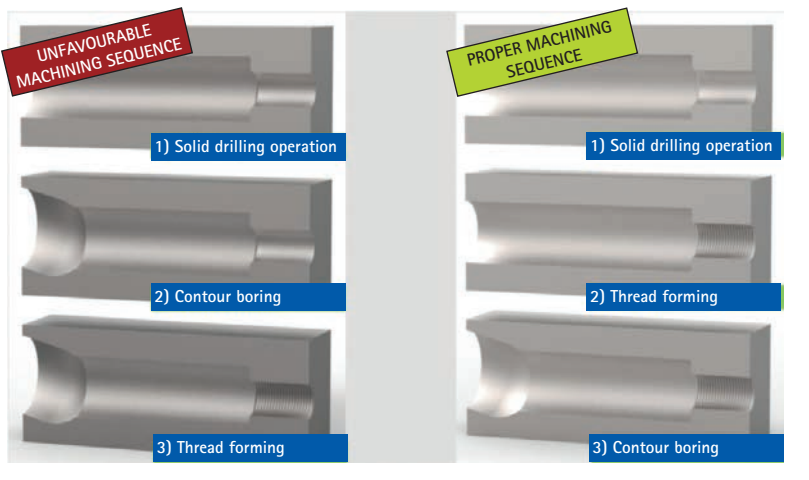


In order to minimise the effects of thermal expansion due to workpiece heating, machining operations with close tolerances should be carried out when the workpieces have not yet become warm. Machinings which cause a large heat input into the workpiece and which do not have such close tolerances should (if possible) be carried out at the end of the overall process. This is thus a reversal of the process sequence normally employed for wet machining where the precision machining is carried out at the end of the overall process.

edge is increased for MQL machining. As a result, the chips break shorter and slightly less heat is generated.

During aluminium machining with solid carbide tools, around 10 to 15% longer tool lives are typically achieved than for wet machining. For PCD tools the service life is slightly higher than for wet machining. Thread forming tools typically achieve at least twice the tool life compared with wet machining. 30 – 50% longer tool lives are achieved for the MQL machining of oil channels in crankshafts of spheroidal graphite cast iron and steel. In some cases even larger increases in tool life are documented for the machining of steel (6). The reasons for the reduced tool wear with minimum quantity lubrication are the better lubricating effect and the lower thermal shock compared with conventional cooling lubrication with emulsion.

Figure 9:
Optimisation of the machining sequence to reduce chip accumulation



If large volumes of material have to be removed from the materials and the release of intrinsic stresses is to be expected, this rough machining should be carried out first. After subsequent cooling (for example, in a workpiece buffer between two machine tools), precision machining is then carried out in a new clamping and subsequently the less precise machining steps.

Staff training

Apart from suitable tools, MQL systems, machines and well organised processes, well-trained employees are a basic prerequisite for the reliable achievement of the quoted tool lives. Many large companies carry out this training in their own company. Seminars can also be offered by the MQL tool suppliers.

Staff training

Only well-trained employees can react adequately to faults. They should not only know and be competent in their own duties for the use of minimum quantity lubrication, but should have a good general awareness of the various aspects of MQL.

During the fitting of tool and tool holder, for example, the correct choice of coolant tube and length adjustment screw is crucial for a good supply of the tool with MQL medium. This supply can be impaired, for example, by a tool shank not completely in contact with the length adjustment screw.

Possible faults during the machining operation can be

- A matt, cracked surface which indicates a problem with the oil supply,
- Scores in the surface (caused by the carrying of chips with the tool. This indicates a prob-

Cutting parameters and tool lives

Cutting parameters and tool lives with MQL

Apart from materials which are difficult to machine, such as titanium alloys and high-alloy steels, for example for turbochargers, similar or even the same cutting parameters can be used for MQL machining as for wet machining. In cast aluminium alloys the cutting speed should preferably not be lower than 200 to 250 m/min in order to avoid the formation of built-up edges. In some cases the feed per cutting

lem with the chip discharge which frequently can only be remedied by a tool modification in the manufacturer's works.),

- Tool breakage that can be caused, for example, by a poor oil supply during thread boring. Here it is necessary to check whether the MQL medium is reaching the outlet openings in the tool, or whether it is escaping elsewhere due to a leak in the tool holder.

Demands on the environment

A number of demands are also made on the area around the actual production system that are not as crucial with the conventional cooling lubrication as during MQL machining. The shop temperature should not exceed 35°C. It should not change by more than 10 K during the day and by more than 2 K within an hour. Direct sunlight on the machine, direct radiation of the shop heaters onto the machine and draughts should be avoided. Without the compensating effect of large quantities of cooling lubricant, these differences in temperature during MQL machining have a significant effect on the dimensional accuracy of the workpieces.

Even more important is a relatively constant temperature of the raw parts at the start of machining. When raw parts are delivered, they should be allowed a sufficient time in the production shop to reach shop temperature. Otherwise there are naturally large differences in temperature of the raw parts between the seasons with corresponding scatter of the manufacturing dimensions and higher costs for temperature compensation.

Demands
on the en-
vironment

Figure 10:

MAPAL programme for staff training on minimum quantity lubrication

Principles of minimum quantity lubrication

- What do we mean by MQL
- Definition of MQL
- Main differences between cooling lubricant and MQL

MQL feed systems

- Single-channel systems
- Two-channel systems

Principles of the design and configuration of machines, chip discharge systems, extraction, temperature compensation, MQL oils, air pressures

Clamping technology and transfer systems (coolant tubes and length adjustment screws)

Assembly of MQL tools

Principles of the tool design

- Cooling channels
- Chip space design

Process design with MQL

- Process sequences
- Oil quantities

MQL spray tests

- Static and dynamic spray tests

Identification and remedying of faults during the MQL process

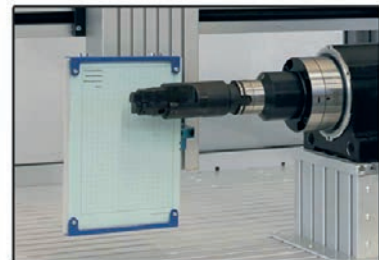
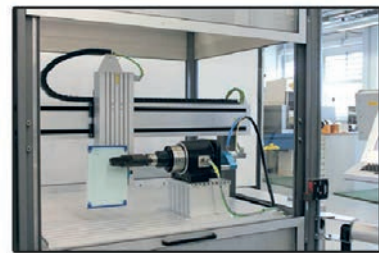
Summary

Summary

Minimum quantity lubrication allows investment and operating costs to be reduced. At the same time the impact on the environment and the exposure of the employees to cooling lubricant are reduced. With proper use, better workpiece qualities and longer service lives of the tools can be achieved in many cases. In order to take advantage of these benefits of MQL, the various components have to be perfectly matched to one another. Suitable MQL oils and MQL systems have to be selected. The tool machines must be designed to be MQL-compatible. Tool holders and cutting tools must be optimised for minimum

quantity lubrication. The process sequence for MQL is also different compared with wet machining. The changeover from wet machining to minimum quantity lubrication therefore involves a certain amount of effort. The advantages are so obvious, however, that numerous automotive manufacturers and their suppliers have equipped a large number of machines and production systems with minimum quantity lubrication instead of conventional cooling lubrication in the last ten years.

The Unitest-MQL performs spray tests and checks the reliable transport of the MQL medium to the blade



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