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Information

**Minimum quantity  
lubrication for machining  
operations**

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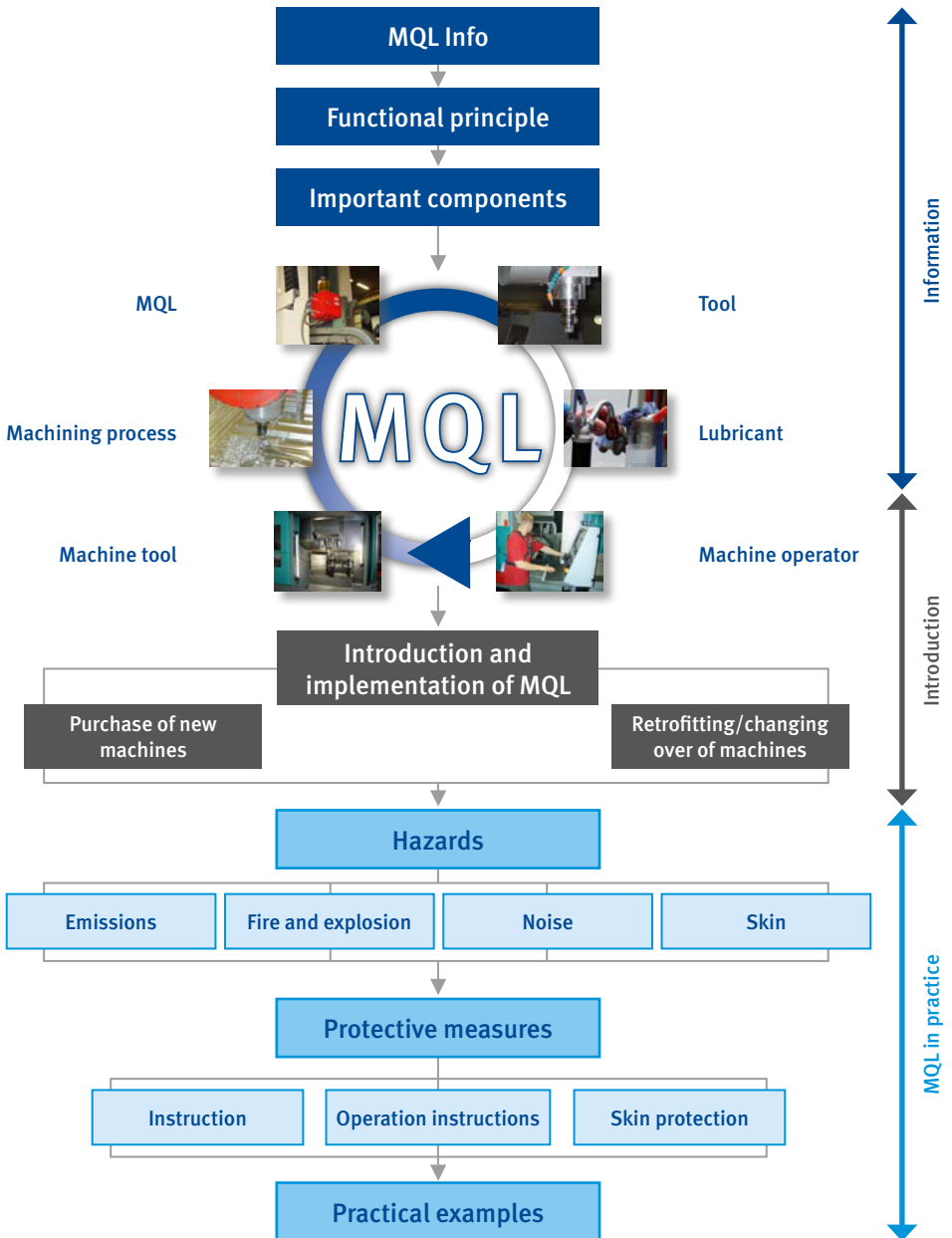
# **Minimum quantity lubrication for machining operations**

# Contents

	Page
<b>Foreword</b> .....	<b>8</b>
<b>1 The functional principle of MQL</b> .....	<b>10</b>
<b>2 Key components of minimum quantity lubrication – Getting it right</b> .....	<b>15</b>
2.1 Production processes with minimum quantity lubrication .....	15
2.2 Lubricants for minimum quantity lubrication .....	20
2.3 MQL systems for minimum quantity lubrication .....	26
2.4 Tools for minimum quantity lubrication .....	39
2.5 Machine tools for minimum quantity lubrication .....	41
2.5.1 Extraction systems for minimum quantity lubrication .....	45
2.5.2 Cleaning for minimum quantity lubrication .....	47
2.6 Qualified employees .....	50
<b>3 Introduction and implementation of minimum quantity lubrication</b> .....	<b>52</b>
3.1 General information for successful introduction .....	52
3.2 Purchase of new machines, retrofitting and changing over .....	53
3.2.1 Explanation of key terms .....	53
3.2.2 Purchase of new machines for MQL machining .....	55
3.2.3 Changing-over existing machines .....	56
3.3 Future prospects and development .....	57
<b>4 Hazards and protective measures</b> .....	<b>58</b>
4.1 Emissions in minimum quantity lubrication .....	58
4.2 Protection against fire and explosion .....	62
4.3 Noise .....	65
4.4 Skin protection .....	66
4.5 Instruction and operating instructions .....	67
4.6 Cleaning with minimum quantity lubrication .....	68

	Page
<b>5 Minimum quantity lubrication in practice</b> .....	<b>70</b>
5.1 Minimum quantity lubrication in small batch series and single piece production ..	70
5.2 Minimum quantity lubrication in large-batch, mass production .....	72
<b>Appendix 1 Operating instructions</b> .....	<b>74</b>
<b>Appendix 2 Sample of a cleaning schedule for machine tools with minimum quantity lubrication</b> .....	<b>75</b>
<b>Appendix 3 Check lists</b> .....	<b>76</b>
<b>Appendix 4 Documentation of instruction</b> .....	<b>79</b>
<b>Appendix 5 Directives, regulations and information</b> .....	<b>81</b>

# MQL: The first steps



**Information contains advice and recommendations intended to facilitate the practical application of regulations in a specific area or under specific circumstances.**



Information is primarily addressed to employers and is intended to aid them in implementing obligations with respect to statutory safety regulations and accident prevention regulations; the information also provides guidelines and ways of preventing occupational accidents, occupational diseases and work-related health hazards.

Employers who apply the recommendations contained in this Information, especially all exemplified possible solutions, can start from the fact that they will achieve the safety objectives required by the accident prevention regulations and rules. Other solutions are possible as long as health and safety can be guaranteed. To make the governmental work safety regulations more specific, the technical rules determined by the committees set up for that purpose shall preferentially be observed.

# Foreword

Minimum quantity lubrication (MQL) has increasingly found its way into the area of metal-cutting machining and, in many areas, has already been established as an alternative to conventional wet processing. In contrast to flood lubrication, minimum quantity lubrication uses only a few drops of lubrication (approx. 5 ml to 50 ml per hour) in machining.

Today, the enormous cost-saving potential resulting from doing almost entirely without metalworking fluids in machining production is recognised and implemented by many companies, primarily in the automotive industry. While in the early 1990s small applications (sawing, drilling) were done “dry”, today we are able to produce cylinder heads, crankcases, camshafts and numerous other components made of common materials – such as steel, cast iron and aluminium – using MQL in the framework of highly automated large volume production.

The advantages of this new technology are clear. With respect to occupational safety, MQL offers numerous advantages over water-mixed metalworking fluids. A major advantage is the substantially better compatibility concerning skin care.

Minimum quantity lubrication is a total-loss lubrication method rather than the circulated lubrication method used with emulsions. This means using new, clean lubricants that are fatty-alcohol or ester based. Additives against pollution, e.g. biocides and fungicides, are not necessary at all, since microbial growth is possible only in an aqueous phase. The extreme reduction of lubrication quantities results in nearly dry work pieces and chips. This greatly reduces health hazards caused by emissions of metalworking fluids in breathed-in air and on the skin of employees at their workplaces. Metalworking fluids do not spread throughout the area around the machine, thus making for a cleaner workplace.

Costs generated by conventional flood lubrication (e.g. maintenance, inspection, preparation and disposal of metalworking fluids) are no longer an issue with minimum quantity lubrication. The average percentages of these costs in the overall cost of wet processing are shown in Figure 1.



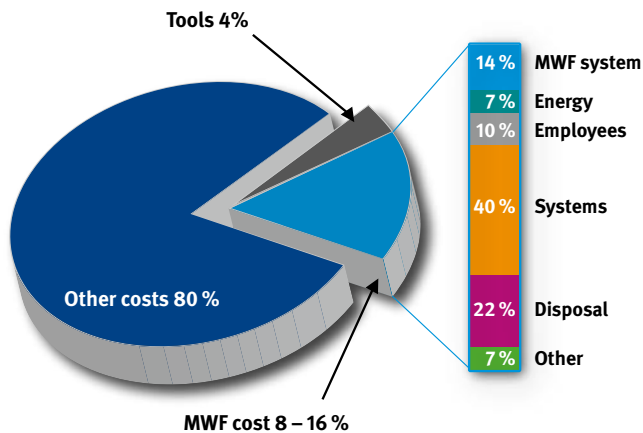


Figure 1 Metal working fluid costs in metal machining (source: Federal Statistical Office)

When cost analyses are carried out for new assemblies and systems, investments in metal-working fluid systems (containers, pipelines, pumps, filtration devices) play a major role. Furthermore, when minimum quantity lubrication is used, there are no costs for cleaning and drying the chips before their disposal or, as the case may be, cleaning the work pieces prior to subsequent processing. The exact percentage of metalworking fluid-specific costs is greatly dependent on the processing method, on the machinery, and on the specific building conditions.

The answer to the question “What is possible and what not?” is unequivocally “A great deal is possible” in view of the combinations of materials and production processes. The various topic sections in this Information provide the relevant technical background. The checklist at the end should help you estimate the scope of the task in your own company.

This Information is addressed to employers, safety officers, employees and master craftsmen in the manufacturing sectors of small and medium sized companies and large-scale operations. The reader is given an overview of the most important topics concerning the introduction and use of MQL. There is also help and information for ensuring safe working with minimum quantity lubrication that can be of assistance when instructing workers.

# 1 The functional principle of MQL

The enormous reduction in the quantity of lubricant compared to the circulated quantities of conventional metalworking fluid systems is the key feature of MQL. In contrast to conventional flood lubrication, minimum quantity lubrication uses only a few millilitres (ml) of lubrication per hour for the machining process.



Figure 2 “Central lubrication store” for minimum quantity lubrication



Figure 3 Lubrication requirement for a work shift using MQL

Minimum quantity lubrication today uses such precise metering that the lubricant is nearly completely used up. Typical dosage quantities range from 5 ml to 50 ml per process hour (tool cutting time).

The extreme reduction in lubricant quantities results in nearly dry work pieces and chips. Losses due to evaporation and wastage, which may be considerable with emulsion lubrication (depending on the work piece being processed), are inconsequential with MQL. This greatly reduces health hazards due to emissions of metalworking fluids on the skin and in the breathed-in air of employees at their workplaces.

The cost-inflating factors of conventional flood lubrication are done away with when MQL is used. This results in:

- Reduction of metalworking fluid quantities in use
- Decrease in the work required for monitoring and metalworking fluid maintenance
- No need to prepare and dispose of used metalworking fluids
- Decrease in the work required for cleaning the processed pieces and
- Easy recycling of the nearly dry chips due to less oil soiling.

Lubricant is supplied by means of a minimum quantity lubrication system (MQL system). Application of a targeted supply of lubricant directly at the point of use lubricates the contact surfaces between tool, work piece and chip. The lubricant is either applied from outside as an aerosol using compressed air or it is “shot” at the tool in the form of droplets.

Another possibility is internal lubricant feed through the rotating machine tool spindle and the inner channels of the tool. Figure 4 shows the basic differences between external and internal feed.

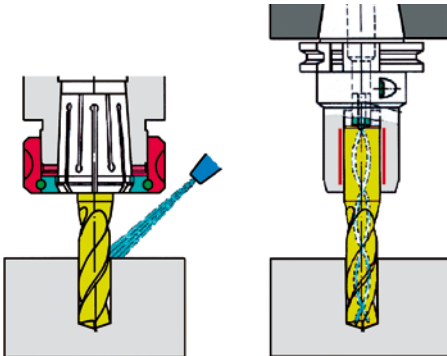


Figure 4 External and internal lubrication feed



Figure 5 External feed via nozzles

### External feed for standard processes

MQL systems for external feeds are suitable for retrofitting machine tools because the required spray nozzles can be easily installed on the spindle head. This system is especially suitable for simple standard processes, e.g. sawing, drilling, milling and turning.

This type of lubricant supply, however, is limited by the different tool lengths and diameters as well as by limited accessibility to the tool cutting edge, e.g. when deep hole drilling. Table 1 lists the main advantages and disadvantages of external lubrication.

External feed	
Advantages	Disadvantages
<ul style="list-style-type: none"><li>• Simple adaptation</li><li>• Low investment costs</li><li>• Little work required to retrofit conventional machine tools</li><li>• Rapid response characteristics</li><li>• No special tools required</li></ul>	<ul style="list-style-type: none"><li>• Limited adjustment options for the nozzles due to different tool lengths and diameters</li><li>• Possible shadowing effects of the spray jet when machining</li><li>• Possible shadowing effects of the spray jet when machining</li></ul>

Table 1 Use of minimum quantity lubrication with external feed

### Internal feed for demanding processes

Using MQL systems with internal feeds enables precise aerosol supply directly to the contact point through the tool. The lubricant is continually available at the critical points during the entire processing sequence. This makes it possible to drill very deep holes and use very high cutting speeds. Because the medium has to be fed through the machine spindle, converting to this system may be costly.

Some systems can be controlled directly by the machine tool control system; lubrication system settings for the required oil quantity and compressed air values can then be performed automatically when there is a tool change. For these lubrication systems in automated production, setting system parameters manually is not required. Table 2 provides an overview of the advantages and disadvantages of internal feed.

Internal feed	
Advantages	Disadvantages
<ul style="list-style-type: none"> <li>• Optimal lubrication at the cutting point (for each tool, even for inaccessible points)</li> <li>• No scattering or spray losses (see external feed)</li> <li>• Optimised lubricant quantity for each tool</li> </ul>	<ul style="list-style-type: none"> <li>• Special tools required</li> <li>• High investment costs</li> <li>• Suitability of the machine is required</li> </ul>

Table 2 Use of minimum quantity lubrication with internal feed

**Definitions:**

A definition of minimum quantity lubrication has not yet been specified in standards and guidelines. Based on numerous publications, the following definition has been established in practice:

**Minimum quantity lubrication (MQL)**

An average of not more than 50 ml of lubricant is used per processing hour and tool for the machining process. For certain operations, however, the process may well use more than 150 ml/h for short intervals, e.g. with tools having a diameter of > 40 mm.

A term often used is “minimum quantity cooling lubrication” (MQCL).

**Reduced quantity lubrication (RQL)**

This refers to reducing the circulation quantity of today’s metalworking fluid systems through the targeted supply of lesser quantities of metalworking fluids (up to 2 litres per processing hour). Reduced quantity lubrication is therefore not total-loss lubrication.

An example of reduced quantity lubrication is supplying metalworking fluids via shoe-shaped nozzles when grinding; the quantity of metalworking fluid can be reduced by up to 90 % compared to conventional processing.

**Dry processing**

This term was defined several years before the development of minimum quantity lubrication and refers to dry chips, tools and components during processing. The key factor here is the percentage of metalworking fluid on the chips (less than 2 % adhering to the chip means that it is “dry”).

In practice, up to 80 ml of metalworking fluid per hour can be used to achieve “dry” chips. Therefore, the term “dry processing” also includes minimum quantity lubrication.

Dry processing often also refers to processes that are completely dry (no lubricants). In this context, the added indication “Dry processing using minimum quantity lubrication” can clear up many uncertainties.

## 2 Key components of minimum quantity lubrication – Getting it right

Every company interested in introducing minimum quantity lubrication asks the question “How can we best implement it in our production processes?” Often initial tests and experiences with this new technology are already available.

For the seamless introduction and implementation of minimum quantity lubrication in the production processes it is vital to have comprehensive information about core elements in advance. Figure 6 shows the core elements for successfully introducing MQL.



Figure 6 Core elements for successfully introducing minimum quantity lubrication

Reliable process machining is achieved when the lubricant, tool, metering device and machine are all suitable for minimum quantity lubrication and optimally adjusted to each other. The more these elements are compatible with each other the better. It is also important that the conditions be properly applied to the machining process by the qualified machine operator. The individual core elements are described below.

### 2.1 Production processes with minimum quantity lubrication

In addition to cooling and lubricating the machining point, the job of the metalworking fluid in conventional wet processing is to transport the chips away from the cutting zone. Thus, the best suited machining processes for minimum quantity lubrication are primarily those in which lubrication is the most important factor. In Figure 7 the quantity requirement for metalworking fluids is shown as a function of the different machining processes.

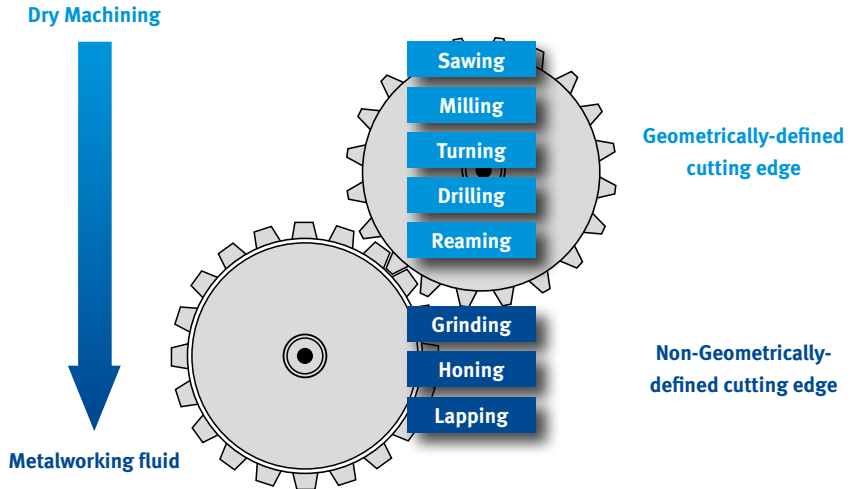


Figure 7 Metalworking fluid requirement as a function of machining process

Processing with geometrically defined cutting edges, such as milling, turning or drilling, can today be easily implemented with minimum quantity lubrication. The implementation is more difficult for processes with increasingly non-geometrically defined tool cutting edges, where the cooling and flushing effect of the metalworking fluid has a considerable influence on the machining process. Processes such as grinding are not yet economically feasible with minimum quantity lubrication.

In practice there is a broad range of machining materials which can be processed with minimum quantity lubrication. To ensure a successful start with the new technology, machining standard materials is recommended.

Machining cast materials with minimum quantity lubrication is particularly effective, since the graphite component in grey cast iron also acts as a gliding and lubrication component (e.g. GG 25- GGG 40). Likewise, non-ferrous metals (e.g. aluminium with up to 1% Si) and steel materials up to 800 N/mm<sup>2</sup> tensile strength (e.g. free-cutting steel, quenched and tempered steel CK 45) can also be cut. But even difficult-to-cut materials can be machined with minimum quantity lubrication if the process is optimally designed (example: X90CrMoV18).



A continually updated materials-processing matrix from research projects and working groups shows that today there are a great many and diverse areas of application for dry processing and minimum quantity lubrication (see Table 3).

Material  Process	Aluminium		Steel		Cast
	Cast alloy	Forged alloy	High-alloy steels, rolling bearing steel	Free-cutting steel, quenched and tempered steel	GG20 – GGG70
Drilling	MQL	MQL	MQL	Dry	Dry
Reaming	MQL	MQL	MQL	MQL	MQL
Thread cutting	MQL	MQL	MQL	MQL	MQL
Thread rolling	MQL	MQL	MQL	MQL	MQL
Deep drilling	MQL	MQL		MQL	MQL
Milling	Dry	MQL	Dry	Dry	Dry
Turning	MQL/dry	MQL/dry	Dry	Dry	Dry
Hobbing			Dry	Dry	Dry
Sawing	MQL	MQL	MQL	MQL	MQL
Broaching			MQL	MQL/dry	Dry

**Table 3** Areas of application for minimum quantity lubrication and dry processing  
(source: WBK Karlsruhe)

An overview by the University of Dortmund ISF (Department of Machining Technology), offers a very good orientation to the technological degree of difficulty of the different machining processes.

Sector	Work pieces	Material	Processes	Motivation
Automotive suppliers	Throttle housings	GD-ALSi12Cu4	Milling, Drilling, Reaming	Reduction of component costs by 8 %
Printing machine manufacturers	Drilled and tapped strips	Ck45	Milling, Drilling, Threading, Reaming	Shortening the process time: 10.49 min < 7.32 min
Automotive manufacturers	Gears Car gearboxes	Case-hardening steel 20MoCr4	Shaping	Environmental protection Reduction of component costs by approx. 5 %
Electronic components	Connector elements, < 1 cm <sup>3</sup>	Brass	Drilling, Milling	High drag-out of cutting oils
Pneumatic cylinders	Connector	Al die cast GD-ZnAl4Cu1	Tapping and grooving	Pollution of the machine environment, metalworking fluid cost savings, less maintenance and cleaning work, higher cutting values
Tool and die construction	Tools	Tool steels	Milling and turning	80 % reduction of maintenance and cleaning work, better surface quality, shorter processing times
Aviation	Aircraft integral components	Al forged alloy	Milling	Environmental protection Pollution of the machine environment, low procurement costs of machines
Power plant manufacturers	Turbine blades	X22CrMoV 12.1, CrNi steels	Milling	Flood lubrication unreliable, tool life tripled

**Table 4** Examples of areas of application with production processes and motivation

Within the framework of the project called “Forschung für die Produktion von Morgen” (“Research for tomorrow’s production”) sponsored by the German Ministry of Education and Research (BMBF), several production areas in companies were converted to minimum quantity lubrication.

Especially small and medium-sized companies (SMC) were sponsored; due to cost and capacity reasons, they are seldom able to carry out their own research. The interested companies were informed about the possibilities and limits of dry processing and given support in its practical use.

The detailed final report contains many examples from diverse production areas with results and descriptions of the procedures when introducing minimum quantity lubrication (page 80 ff. of the report).

The report can be downloaded at [www.trockenbearbeitung.de](http://www.trockenbearbeitung.de) by using the link “Bericht zum Verbundprojekt Technologienetz Trockenbearbeitung”.

Similar to wet processing, certain basic requirements for trouble-free metal machining have to be met. An optimally adjusted process (just as for wet processing) is the first obligation, i.e.

- No built-up edges due to slow cutting speeds,
- No juddering,
- No underachievement of the minimum values specified by the tool manufacturer for X and Y axis feeds,
- No exceeding the maximum depth of the cutting edge or of the maximum feed.

Experience shows that the processes with high feed, high cutting speed and short dwell times of the tool work best with minimum quantity lubrication. The materials can often be machined with considerably higher cutting parameters in comparison to wet processing.

Independent of the general requirements, the consideration of each specific processing situation is recommended. For this it is necessary to develop company-related know-how for getting along with this new technology. Also, an on-site visit by suppliers (tools, MQL system, lubricant, etc.) facilitates optimal adaptation and system parameter settings.

## 2.2 Lubricants for minimum quantity lubrication

### Lubricant properties for minimum quantity lubrication

Minimum quantity lubrication is total-loss lubrication. The lubricant in use is often subject to high thermal and mechanical loads and is applied to the work zone in the form of mists and aerosols. The user should therefore ensure that only toxicologically harmless lubricants are used.

For fault-free, low-emission metal machining when using minimum quantity lubrication, lubricants with very good lubricity and a high thermal rating are best. In industrial manufacturing, synthetic ester oils and fatty alcohols with favourable vaporisation behaviour and a high flash point are used.

**Synthetic esters** are preferable for all machining processes in which the lubricating effect between tool, the work piece and separation from the chips is of prime importance. (Prevention of abrasive wear) Examples of this are threading, drilling, reaming and turning.

**Synthetic esters** have the advantage that, despite low viscosity, they have a high boiling point and flash point. This means that much less vapour is emitted in the workspace compared to conventional mineral oils. In addition to these properties, ester oils exhibit very good biodegradability, and owing to their low toxicity are rated as Water Pollution Category 1 (WPC 1) or “non-hazardous to water”.

Compared to ester oils, **fatty alcohols** have a lower flash point at the same viscosity. In contrast to ester oils, they offer less lubricity.

**Fatty alcohols** are preferred for machining processes in which the separation effect rather than the lubricating effect is of prime importance (avoidance of built-up edges). An example of this is the machining of non-ferrous metals.

Fatty alcohols have very good biodegradability, are toxicologically harmless, and likewise are rated as non-hazardous to water (nhw) or Water Pollution Category 1 (WPC 1).

	Esters	Fatty alcohols
Vaporisation *	slow	fast
MQL – residual amount on work piece	low	“dry”
Lubricating effect	high	low
Flash point *	high	low
Water Pollution Category	nhw/1	nhw/1

\* based on the same viscosity

Table 5 Basic differences between esters and fatty alcohols

Experience deriving from industrial use shows that the choice of lubricant should be process and application-specific.

When choosing a suitable MQL lubricant, the user should take into account the criteria below.

### **Low-emission lubricants**

The following guide values have proven useful in selecting a low-emission lubricant.

Viscosity at 40 °C DIN 51562 Part 1	Flashpoint CoC DIN EN ISO 2592	Evaporation losses at 250 °C acc. to Noack DIN 51581 Part 1
> 10 mm <sup>2</sup> /s	> 150 °C	< 65 %

Table 6 Guide values for selecting a low-emission lubricant  
(source: BGIA workbook “Measuring hazardous substances, category 6”)

### **Smell**

The smell of the lubricant is not inconsequential. Spraying the lubricant can cause the smell to be intensified.

### **Sprayability**

The lubricant should spray easily and, especially with 1-channel systems, be able to produce a stabile aerosol (oil-air mixture).

### ***Additives***

The additives should be adjusted to the processing requirements, particularly when processing non-ferrous metals and difficult-to-cut steels.

### ***Residues on machine parts***

Despite minimum spray amounts and the use of extraction devices, lubricants may leave residues on work pieces and machine parts. The lubricant should not resinate and should be easy to clean off if necessary.

### ***Viscosity range***

Practical experience shows that the best results with lubricants (ester or fatty alcohol) are achieved at a viscosity range of 15 to 50 mm<sup>2</sup>/s and in some cases up to 100 mm<sup>2</sup>/s at 40 °C.

Upper viscosity limits should be discussed with the MQL system manufacturer (check device suitability for sprayability). In general the MQL system and lubricant should be compatible with each other.

### ***Lubricant change***

Before a new lubricant is used, the system should be completely drained and flushed. The flushing process should be performed with the new lubricant.

### ***Corrosion protection***

A check should be made as to whether the thin MQL residual film on the workpiece after machining offers corrosion protection that meets the requirements or whether additional corrosion protection is necessary.

### ***Unsuitable lubricants for minimum quantity lubrication***

The following products have proven not to be suitable for minimum quantity lubrication and should therefore not be used:

#### ***Natural oils and greases***

Esters (rape seed oil, etc.) have the disadvantage that they are very prone to oxidation. They tend to gum up machine elements.

***Water-miscible metalworking fluids and their concentrates***

These products may contain biocides and thus can be found in the spray aerosols.

***Lubricants with additives containing organic chlorine or zinc***

Due to high process-related machining temperatures encountered when using minimum quantity lubrication, reaction products harmful to health may result.

***Lubricants with mandatory marking***

(Orange hazard symbol in compliance with the hazardous substances ordinance)

These products have a hazard potential level that is already high.

***Mineral oil-based products with high aromatic compound content***

(> 3 ppm benzo[a]pyrene in the metalworking fluid)

Polycyclic aromatic compounds have a carcinogenic potential.

More information on the topic of lubricants for minimum quantity lubrication can be found in the BGIA workbook “Measuring hazardous substances, category 6”.

**Application examples for minimum quantity lubrication technology**

The following table shows a few application examples in which esters and fatty alcohols are used.

Component	Material	Process	Tool type and dimensions	Cutting parameters	Tool life	Medium, chem. base, Viscosity 40°C
Camshaft	16MnCr5	Centering	D = 6,3 x 20	N = 500 min <sup>-1</sup> Vf = 50 mm/min	1 200 centres	Fatty alcohol Visc: 10 – 20 mm <sup>2</sup> /s
Camshaft	16MnCr5	Drilling	Stepped drill D = 6,8 x 10 x 28,5	N = 2 800 min <sup>-1</sup> Vf = 50,4 mm/min	2 400 holes	Fatty alcohol Visc: 10 – 20 mm <sup>2</sup> /s
Camshaft	16MnCr5	Reaming	D = 7 H8	N = 690 min <sup>-1</sup> Vf = 152 mm/min	1 200 operations	Fatty alcohol Visc: 10 – 20 mm <sup>2</sup> /s
Crankshaft	38MnVS5	Drilling	HSS-Drill D = 14,5 mm	N = 330 min <sup>-1</sup> Vf = 52,8 mm/min	500 holes	Fatty alcohol Visc: 20 mm <sup>2</sup> /s
Crankshaft	38MnVS5	Countersinking	HSS-countersink 90°	N = 90 min <sup>-1</sup> Vf = 5,2 mm/min	960 operations	Fatty alcohol Visc: 20 mm <sup>2</sup> /s
Crankshaft	38MnVS5	Threading	Tap M16 x 1,5	N = 90 min <sup>-1</sup> Vf = 135 mm/min	500 threads	Fatty alcohol Visc: 20 mm <sup>2</sup> /s
Cylinder head	Al Si 7 Mg	Sawing	Band saw		> 2 000 cuts	Fatty alcohol Visc: 10 – 30 mm <sup>2</sup> /s
Cylinder head	Al Si 7 Mg	Milling	Surface mill		Approx. 6 000	Fatty alcohol Visc: 10 – 30 mm <sup>2</sup> /s
Universal joints	CK 45	Drilling (Impact drilling)	HSS-Drill D = 14 mm	N = 200 min <sup>-1</sup> Vf = 40 mm/min	100 – 150 holes	Synthetic ester Visc: 20 – 30 mm <sup>2</sup> /s



Component	Material	Process	Tool type and dimensions	Cutting parameters	Tool life	Medium, chem. base, Viscosity 40°C
Drive shaft	20MoCr4	Rolling DIN profile	Rolling tools		40 – 50-thousand	Synthetic ester Visc: 20 – 35 mm <sup>2</sup> /s
Cylinder head	Al Si 10 Mg	Milling	End mill	N = 4 000 min <sup>-1</sup> Vf = 1 200 mm/min	Approx. 105 000	Synthetic ester Visc: 30 mm <sup>2</sup> /s
Cylinder head	Al Si 10 Mg	Milling	Surface mill		Approx. 3 500	Synthetic ester Visc: 50 mm <sup>2</sup> /s
Cylinder head	Al Si 10 Mg	Sawing	Surface mill		Approx. 4 500	Synthetic ester Visc: 50 mm <sup>2</sup> /s
Connecting rod		Thread grooving	Thread grooving M16 x 1,5	N = 190 min <sup>-1</sup> Vf = 285 mm/min	1 500 Threads	Synthetic ester Visc: 10 mm <sup>2</sup> /s
Crankcase	Al Si9 Cu3	Deep hole drilling	Deep hole drill		5 000 holes	Synthetic ester Visc: 40 – 50 mm <sup>2</sup> /s

Table 7 Areas of use for esters and fatty alcohols in series manufacturing

## 2.3 MQL systems for minimum quantity lubrication

### General requirements

The main task of the MQL systems is the targeted supply of an appropriate lubricant to the contact point of the tool (cutting edge). A number of different devices for various requirements are available for this purpose.

For single-purpose machines, e.g. broaching, sawing and shaping, simple, manually controllable MQL devices with internal and external feeds with different functional modes are normally used. They are usually systems with pressure tanks and metering pumps.

Modern flexible production systems require very demanding MQL device technology. For this purpose, complex MQL systems have been developed that have integrated components for regulation, control and monitoring.

Depending on the accessibility to the cutting edge, different requirements apply to the devices in use. For this reason, a differentiation is made between external and internal feed of the lubrication medium, which makes a noticeable difference to the cost of the device technology.

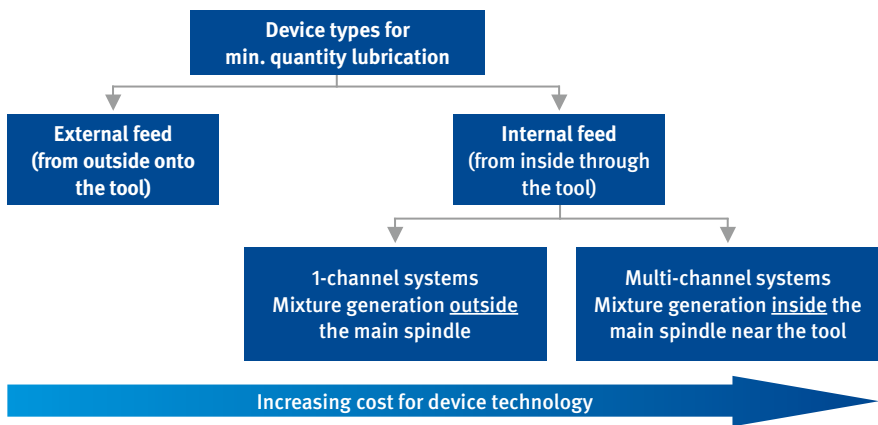


Figure 8 Device types for minimum quantity lubrication

In the case of external feed, the lubricant is applied by means of spray nozzles around the circumference of the tool. This system is especially suitable for entrance-level implementation for standard processes (turning, milling, drilling).

With internal feed, the lubricant is transported through the spindle system of the machine and through the channels in the tool to the machining point. This system is used primarily when flexible processing centres and new machinery are in use as well as with high-speed cutting (HSC).

The different device technologies and their purposes, as well as advantages and disadvantages, are described below.

**Minimum quantity lubrication systems for external feed**

Devices for external feed transport the lubricant and the separate atomisation air to near the contact point. This takes place in a coaxial or parallel pipework packet. At the end of the pipes, the lubricant is atomised with a spray nozzle and fed to the tool as an aerosol from outside.

Low cost, simple retrofitting and the option of deploying conventional tools are the key advantages of these systems. However, all of these systems have disadvantages that limit their use owing to the principle involved. The nozzles have to be manually adjusted or adjusted via supplementary positioning axes to the tool; there are also losses due to dispersion and shadowing effects.

The most important areas of application use machine tools with a low level of flexibility and involve sawing, milling, broaching, shaping, drilling and threading processes.



Figure 9 External lubricant feed via nozzles

The key differences in the device technology has to do with lubricant transportation. There are two technologies in use.

### Devices with metering pumps

The lubricant is transported by a pneumatic micro-pump. Lubricant dosage is regulated by means of the stroke and frequency of the pump plunger.

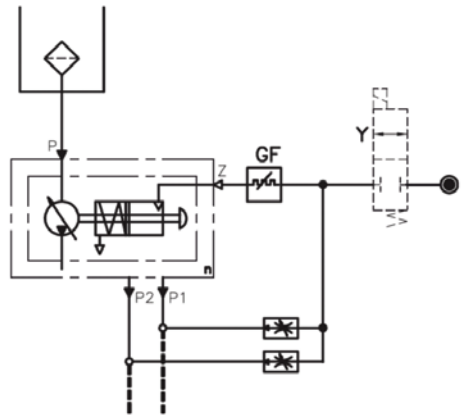


Figure 10 Device types with metering pumps

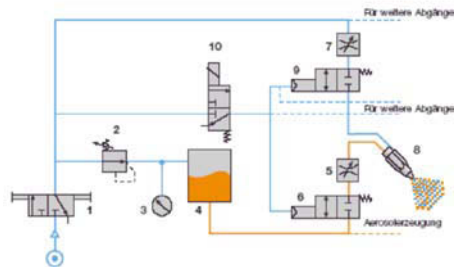
Besides the exact dosage volume settings, this device should be secured against unauthorised adjustment; it should also have sufficient container volumes and complete accessories (nozzles, containers, replenishing unit).

The key advantages of the micro-pump system are the exact dosage volume settings and modular design, which, in addition to the decentral assembly of the pump elements, makes it possible to install nearly any number of pump elements.

Disadvantages are the pulsating lubricant stream and the wear to moving parts.

### Devices with pressure tank

The lubricant tank is pressurised. Lubricant is forced out of the tank with pressure. Metering is done with supply pressure settings and with throttle elements in the pipework for air and oil atomisation.



- |                             |                       |
|-----------------------------|-----------------------|
| 1 Manual adjustment         | 6 2/2 switching valve |
| 2 Pressure regulating valve | 7 Throttle            |
| 3 Manometer                 | 8 Spray nozzle        |
| 4 Oil tank                  | 9 2/2 switching valve |
| 5 Oil adjustment screw      | 10 Solenoid valve     |

Figure 11 Devices with pressure tanks

To guarantee optimum use of these systems, it should be possible to adjust tank pressure, atomisation air, and oil quantity separately.

A design that is as modular as possible with several outputs that can be individually connected and regulated as well as complete accessories (nozzles, tanks, replenishing unit) are advantageous.

In contrast to the micro pump systems, the most important advantages of these systems are the uniform lubrication stream and the lack of moving parts subject to wear.

Systems with pressure tanks also have disadvantages. Precise adjustment of the oil dosage volume is possible only to a limited degree and the number of outputs is limited.

### Targeted bombardment with oil droplets

This external MQL system shoots single droplets of lubricant at the machining contact point via a high-speed valve. There can be a distance of up to 800 mm between valve and tool without air mixing in or atomisation taking place.

This metering principle makes it possible (especially with fast rotating tools or work pieces, e.g. on lathes) to break through the boundary-layer air that builds up during the turning movement.

The lubricant drop hits the precise point where it is required. In addition to fixed high-speed valves, pivotable high-speed valves align automatically to the work piece.

The external system can also be combined with a two-channel system with internal lubricant feed and a control device. It is mainly used in this combination for lubricating very small tools without internal cooling channels.

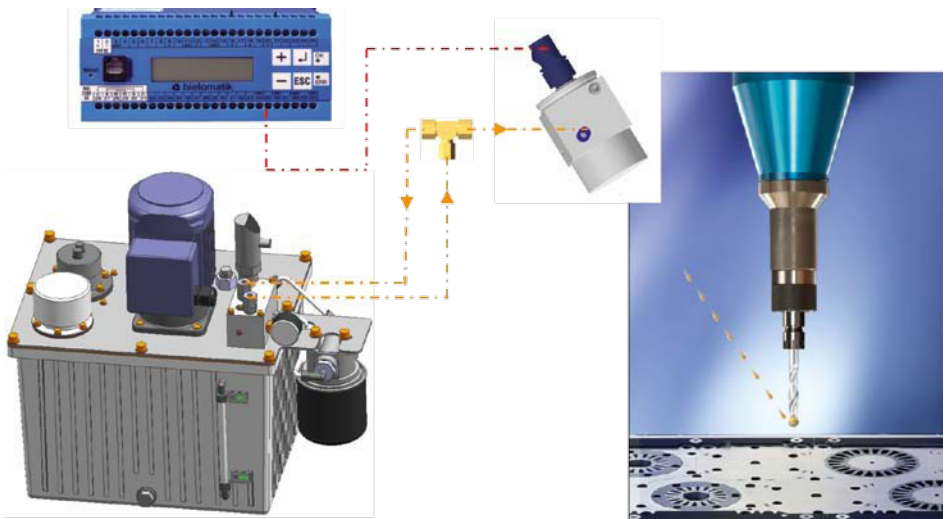


Figure 12 External system with lubricant droplet bombardment at the point of contact

### **Minimum quantity lubrication systems for internal feed**

Internal feed devices enable direct supply of the lubricant to the cutting zone. The lubricant must be transported through the spindle, tool revolver or similar and through the inner cooling channels of the tool.

The design of these machine components therefore has a considerable influence on the functioning of minimum quantity lubrication and in some cases requires optimisation of the overall system. The lubrication is continually available at the critical points during the entire processing sequence. This makes it possible to perform very deep hole drilling at very high cutting speeds reliably.

In contrast to devices for external feed, no adjustment of the feed nozzles is necessary and there is very little loss due to dispersion. The settings for oil and air amounts can be performed with the machine control system.

Conversions and retrofitting involve a certain amount of work and usually high cost; this should be checked on a case-by-case basis. Criteria for this are the remaining life of the machine tools, the production programme with unit numbers (series or single-piece production) as well as the feasibility of using existing machine tool components.

Internal feed of the medium is preferred when external feed is either no longer sufficient, for example when drilling with large L-D ratios, or when machine productivity is to be increased to achieve shorter machining times. Areas of application are all production processes with geometrically defined cutting edges, machines with a high degree of flexibility, and multi-spindles.

Common to all MQL systems is the use of vapour or aerosols, consisting of a gaseous and a liquid phase. The MQL systems on the market for internal feed differ in the number of required channels in the rotating chuck and spindles and where the aerosol is generated. Depending on where the vapour is generated, there are two common modes of action (Figure 13).

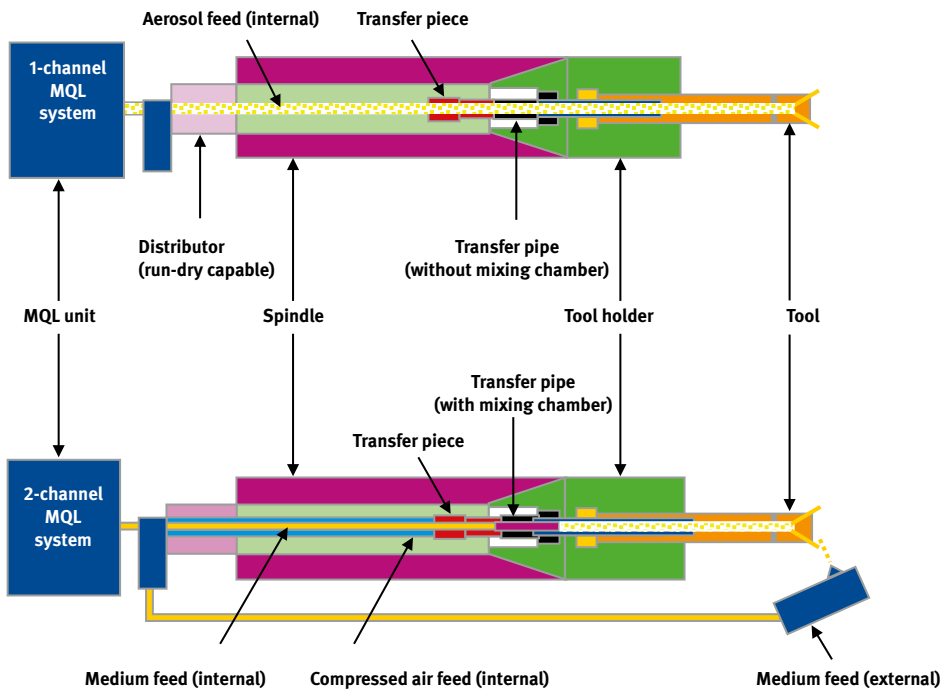


Figure 13 Comparison of 1-channel and 2-channel systems

In 1-channel systems the aerosol is generated in the tank, i.e. before entering the spindle. In 2-channel systems the two media are fed separately through the spindle and then mixed when they exit the spindle to produce the aerosol directly in front of the tool.

### 1-channel devices

“Minimum quantity lubrication with internal medium feed” is based on supplying the air-lubricant mixture through the machining tool. The lubricant aerosol in these systems is usually created with the aid of compressed air.



Investigations of different MQL systems clearly show that in 1-channel systems atomisation using the venturi principle is the most effective and offers process-reliable operation. Designed on this principle, a higher quality aerosol (approx.  $0.5\ \mu\text{m}$  to  $2\ \mu\text{m}$ ) is generated and reaches the cutting point with nearly no loss. Further supplies to the cutting point are via components of the machine tool (rotary chuck, spindle, tool holder, tool).

A functionally reliable device contains different components for adjustment and monitoring. Simple devices (see Figure 14) use manual adjustments for air and oil, a flow rate gauge and pressure gauge for visual inspection as well as pressure switches and fill level switches for monitoring purposes.

Devices for flexible production systems are connected by a field bus interface to the machine control system. Settings for process parameters are controlled directly from the NC program.

Comprehensive accessories consisting of ball valves, external spray nozzles and replenishing units complete the equipment.

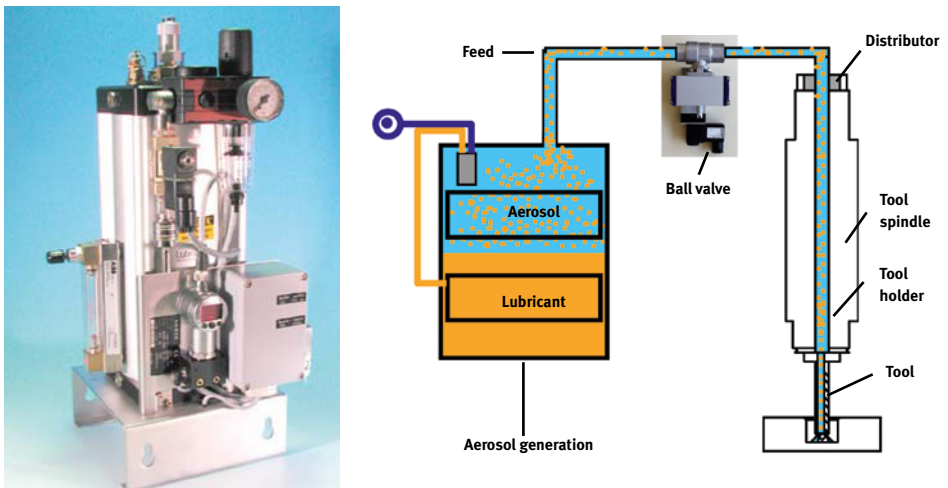


Figure 14 MQL systems (1-channel) for internal feed

## 2-channel systems

### Function

In 2-channel systems, lubricant and air are transported separately through two channels through the tool spindle to the tool holder, where the required mixture is created in a pipe nozzle. The separate supply of the two media in the spindle is by means of a lance located in the centre of the tool spindle.

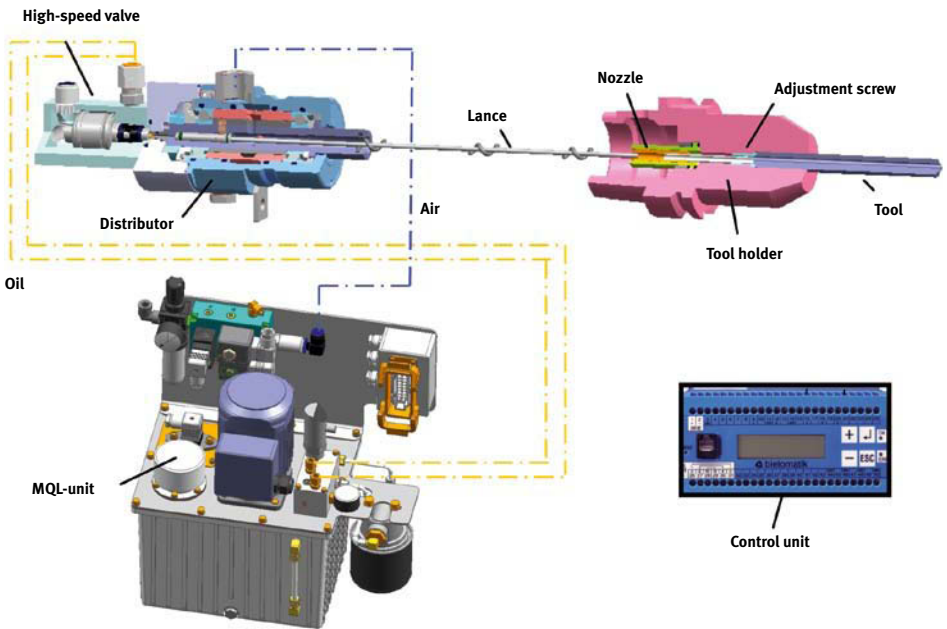


Figure 15 The 2-channel system

The MQL unit transports the lubricant to the high-speed valve, which precisely meters the process-dependent optimum lubricant quantity and conveys it to the 2-channel rotary chuck. The lubricant is transported through the internal channel of the lance while the air is supplied via the external ring channel between lance and spindle.

The front end of the lance projects into the mixing chamber of the pipe nozzle, from where the thus created oil-air mixture is fed to the tool. The pipe nozzle pressed into the standardised cooling agent pipe consists of a mixing chamber and a pipe piece, which is cut to length for the design.

The control device is responsible for actuating and monitoring the system. Selecting the various tool parameters is done via the M-functions or ProfiBus. Optionally, an external high-speed valve can be connected to this system.

**Advantages of the 2-channel system**

The lance suppresses centrifugal effects and thereby demulsification in the spindle. Consequently, spindle rpm can be greatly increased, and a continuous, precise dosage can be easily and reliably adjusted to the machining parameters. Due to the separate feed of air and oil, soiling of the spindle and interfaces is more easily prevented.

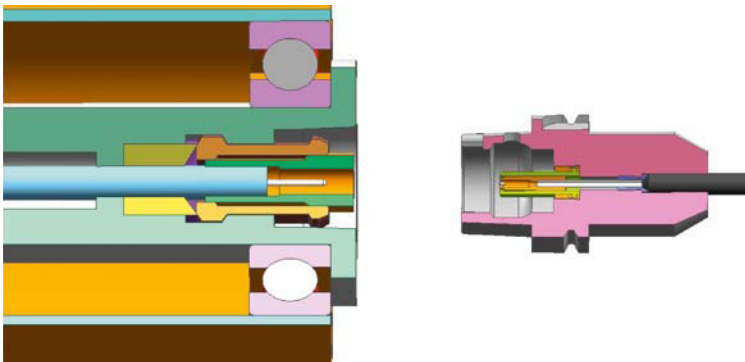


Figure 16 Tool spindle with integrated lance and tool holder for the 2-channel system

Also, making use of the capillary effect of the lance enables very fast tool changes. The response time of the 2-channel system is about 0.1 sec.

With this short response time there are no additional time delays such as when changing tools.

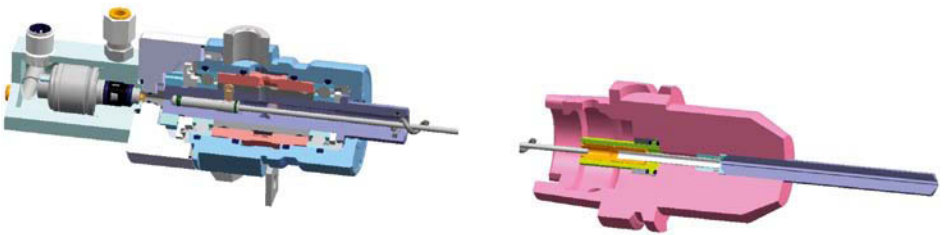


Figure 17 Components of the machine tool axle without spindle for the 2-channel system

The inclusion of a relief valve rapidly reduces pressure in the tool. This prevents subsequent fluid loss.

### Installation on the machine

### Structure of a 2-channel system

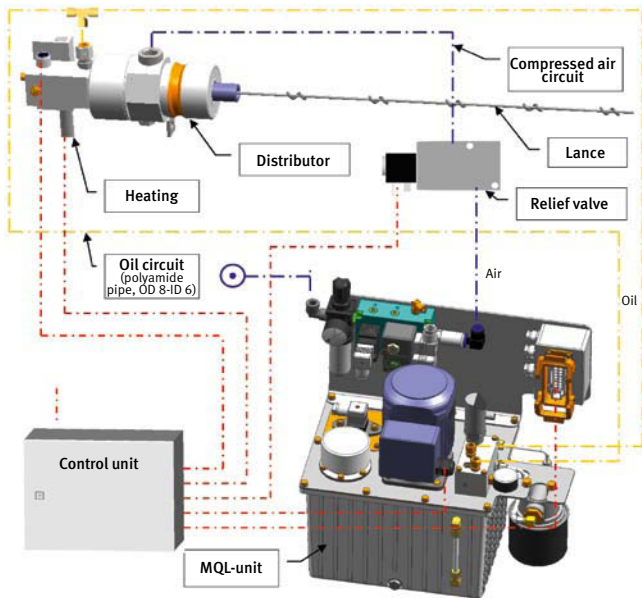


Figure 18 Installation of a 2-channel system

The installation of a 2-channel rotary chuck is almost like the installation of a 1-channel rotary chuck. The only difference is the lance which is installed at the same time.

**Comparison of the most important properties**

The two systems differ in the way the medium is fed as well as how and where the mixing takes place.

1-Channel System	2-Channel System
<ul style="list-style-type: none"> <li>• Oil feed conditionally dependent on RPM</li> <li>• Oil quantity dependent on air flow</li> <li>• In by-pass operation, reaction time almost identical to 2-channel technology</li> <li>• Air pressure &gt; 4 bar necessary</li> <li>• Feed through complicated channels (e.g. milling head, tool revolver) sometimes possible</li> <li>• No wear to components (maintenance-free)</li> <li>• Lubricant viscosities up to 50 mm<sup>2</sup>/s can be used</li> <li>• Simple routing of aerosol stream to multiple spindles possible</li> <li>• Standard tool holder for internal fluid feed possible</li> </ul>	<ul style="list-style-type: none"> <li>• Oil feed independent of RPM</li> <li>• Oil quantity almost independent of air flow</li> <li>• Very fast reaction time</li> <li>• Air pressure &gt; 4 bar necessary</li> <li>• Feed through complicated channels (e.g. milling head, tool revolver) difficult</li> <li>• Component wear (e.g. pump and valve parts)</li> <li>• Lubricant viscosities up to 100 mm<sup>2</sup>/s can be used</li> <li>• Supplying multiple spindles from one unit very complicated</li> <li>• HSK (Hollow taper shank) with MWF pipe, nozzle and plastic piping necessary</li> </ul>

Table 8 Comparison of 1-channel and 2-channel systems

**Application areas for MQL systems**

Owing to the physical properties of the two systems, there are overlapping areas of application.

When choosing an appropriate system, the basic conditions of machine tools, tools, and processes must be taken into account.

1-Channel System	2-Channel System
<ul style="list-style-type: none"> <li>• <math>N_{max}</math> ca. 30 000 1/min</li> <li>• Fluid channel diameter preferably <math>\geq \varnothing 0,5</math> mm</li> <li>• Transfer lines, multispindle, machining centres with frequent tool changes, provided process known, lathes</li> <li>• Switching over from wet to dry possible</li> <li>• Up to 200 ml per hour possible</li> </ul>	<ul style="list-style-type: none"> <li>• <math>N_{max}</math> ca. 40 000 1/min</li> <li>• Fluid channel diameter <math>&lt; \varnothing 0,5</math> mm possible</li> <li>• Machining centres with frequent tool changes</li> <li>• Tools with large lubricant requirements</li> <li>• <math>&gt; 400</math> ml per hour possible</li> </ul>

Table 9 Areas of application of 1-channel and 2-channel systems

### MQL system checklist

Of great importance for reliable operation and for emissions is guaranteeing the continuous, uninterrupted feed of the lubricant to the cutting point. Thus, for lubricant feed and metering, only safe systems that meet the requirements below should be used:

- Parameter settings, e.g. quantity and pressure, according to default values and dependent on process, material, and machining parameters possible.
- Exact and vibration-resistant adjustment of the nozzle(s) relative to the contact zone possible.
- Monitoring of MQL operation (e.g. fill level, media transport and compressed air) possible.
- Spray pattern of the nozzle
  - Specification of appropriate system adjustment values for minimising vapour formation.
  - Targeted wetting (specification of nozzle spray patterns).
- Specification of the viscosity range (specified by the system) at 40 °C.
- Guaranteed no-loss media transport to the nozzle transfer point or tool (no leakage).
- Components and seals resistant to the media in use checked on a case-by-case basis.
- Smallest setting for achieving dry work pieces and chips (quantity  $< 10$  ml/h) possible.
- Continuous feed of the lubricant medium guaranteed (no pulsing or interruptions).
- Fast response and media availability at the machining point even after long standstills.
- Low noise development ( $< 75$  dB [A]).

## 2.4 Tools for minimum quantity lubrication

Machining with minimum quantity lubrication uses extremely small amounts of lubricant. This is why continuous supply of the medium to the contact point is of overriding importance. The tool is a vital system element.

For minimum quantity lubrication, conventional systems are often of limited suitability. The tools used in wet machining frequently continue to be used. When this happens, the limitations concerning tool efficiency soon become apparent. Especially for processes with high heat development and high cutting speeds, MQL-compatible tools are a basic prerequisite for efficient machining.

On one hand, dry machining and minimum quantity lubrication are based on reduced heat development and on the other, on rapid heat dissipation via the chips. MQL-compatible tools are optimised to these requirements with respect to cutting materials and tool geometry. Modern HPC drilling tools are characterised by high-performance materials, MQL-compatible coatings and geometries that assist chip removal and combat overheating.



Figure 19 Tools for minimum quantity lubrication

MQL-compatible coating facilitates chip removal and increases process reliability. Friction between chip and cutting face is reduced due to the thermally insulating hard material layers and polished tool surfaces. For optimising the lubricant supply, tools with elliptical cooling channels that increase the cross section of the cooling channel are also available.

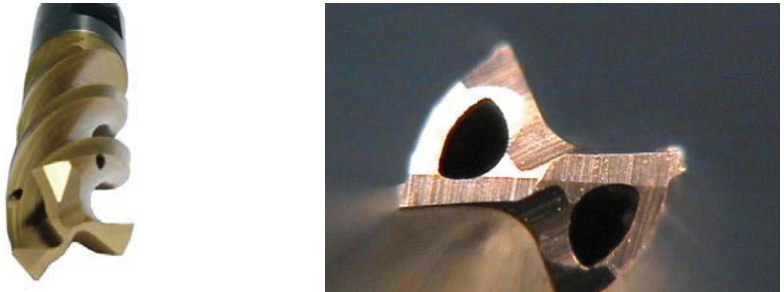


Figure 20 Tools with coating and elliptical cooling channels

Many tool manufacturers have extensive know-how in this area and offer a large selection of MQL-compatible tools. For selecting the right tool for the required process, the material-specific and tool-specific cutting parameters (e.g. feed, cutting speed) specified by the tool manufacturer are to be observed.

A central aspect of trouble-free operation with internal feed is the geometric shape of the tool shaft. To guarantee optimal lubricant feed, the machine-to-tool adapter interface should be a closed system; machine and adapter should also be compatible and adjusted to each other. The junction area between shaft and spindle must be perfectly sealed in order to prevent the lubricant from escaping to the clamping area of the chuck or the interior of the machine. Blind spots that could lead to accumulations are to be avoided.



## 2.5 Machine tools for minimum quantity lubrication

For machine tools that operate with minimum quantity lubrication, fast and complete removal of chips and metal dust from the workspace is of utmost importance. In contrast to wet machining, in which work pieces, chips and the workroom of the machine are effectively cooled by the metal working fluid, the heat situation in minimum quantity lubrication or dry processing should be taken into consideration. Chip accumulation and residues in the work area (e.g. on the work pieces and machining equipment) should be avoided as far as possible. Increased thermal distortion can cause dimensional inaccuracies as well as shape and alignment errors on the work piece.



Figure 21 Inner view of an MQL machine tool



Figure 22 Motor housing production

The basis for optimal chip disposal is workspace layout. The utilization of gravity for disposal of the chips has proven in practice to be of great benefit. The chips should fall unhindered onto steeply inclined metal sheets and via large openings on to the chip conveyor. Projecting edges and horizontal surfaces should be avoided.



Figure 23 Using gravity for chip removal, steep metal sheet



Figure 24 Large area openings in the chip conveyor

Position of the work piece is also vital for good chip removal. A suspended work piece is ideal, e.g. for a vertical lathe. A good alternative for machining centres is the use of work piece pivot axles. After being machined, the work piece can be suspended so that the chips fall from the work piece and equipment.

Fast and complete disposal of chips and metal dust is a major contribution to safety with respect to fire protection. The removal of chips via the chip conveyor and extraction is monitored by the machine control system. If there is a failure in the chip removal (e.g. chip conveyor) or extraction system, the machine must not continue to be operated.

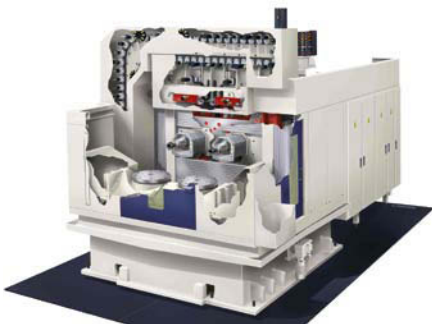


Figure 25 MQL machining centre



Figure 26 Gearbox housing production

The dry-compatible machine tool is equipped with mechanical and electrical interfaces for installation of MQL systems. The machine tool control system should have a connection option for the MQL system. For tool holders, it is important that dry-machining-compatible tools are also able to use internal lubricant feed.

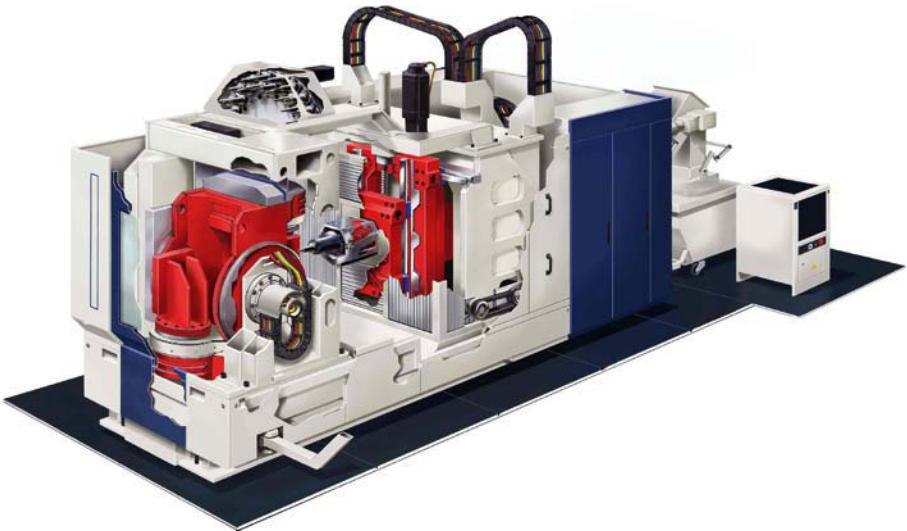


Figure 27 Overall installation with chip conveyor and extraction system for MQL machining

To be ready for minimum quantity lubrication and dry machining, the workspace of a machine tool should have the following features:

- Workroom panelling that is steeply inclined (at least 35 ° to the ground).
- Smooth, unpainted surfaces (e.g. made of stainless steel) for better sliding of the chips.
- No pipelines, edges or horizontal surfaces if possible on which chips and dust can accumulate (for screws, fillister-head screws are advisable).
- Careful sealing-off of the workspace so that no dust can get to sensitive parts of the drive and guide elements of the machine.

- Thermal isolation of the inside panelling to the machine frame to prevent thermal bridges.
- Continuous chip removal, e.g. with a chip conveyor.
- Equipped with an extraction system.

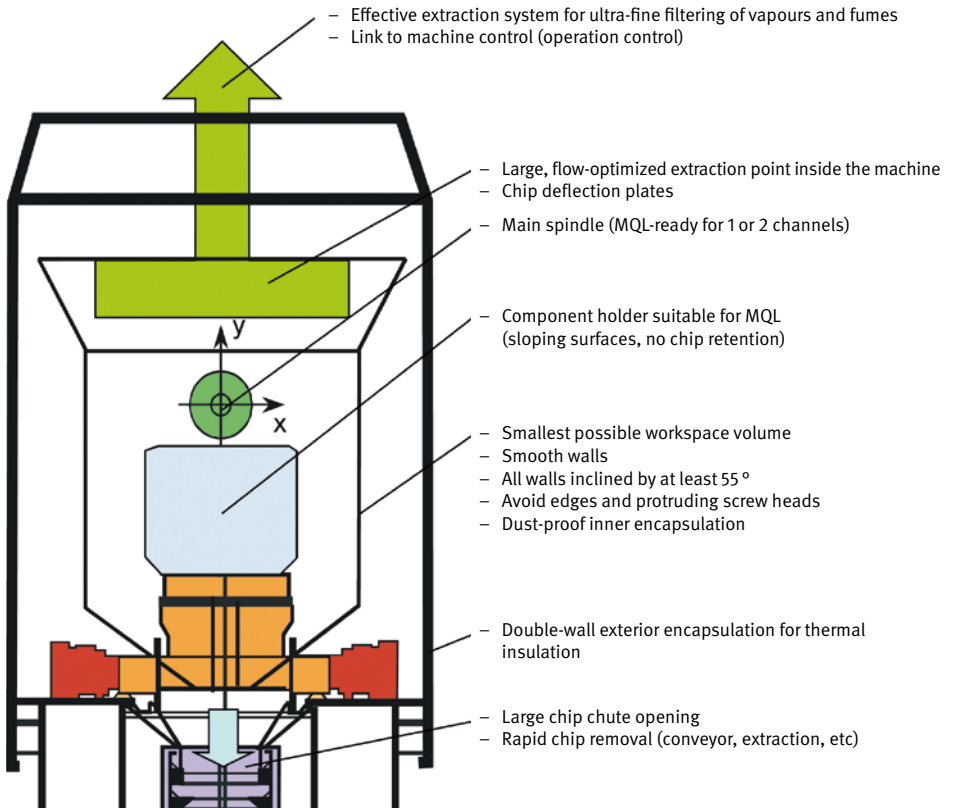


Figure 28 General requirements for dry-compatible machine tools

### 2.5.1 Extraction systems for minimum quantity lubrication

The efficient disposal of the emissions created inside the machine tool has proven to be very beneficial in MQL. Continuous extraction of lubricant vapours, aerosols and metal dust from the workspace has the following advantages:

- Measures for complying with workplace threshold values (MWF aerosols and vapours, dust)
- Minimises fire and explosion hazards
- Reduces cleaning work and improves machine cleanliness.

This decreases downtime, increases process reliability and contributes to the well-being of employees.

In contrast to wet machining, MQL extraction systems must not only remove and dispose of metalworking fluid mists and aerosols but also effectively remove and dispose of metal dust from inside the machine room. It is therefore necessary to ensure that the machine control system monitors the extraction system. The machine is switched off in the event of faults and extraction system failure.

There should be a slight negative pressure inside the machine encapsulation so that there is an inward flow through openings. The extraction rate should be adjusted so that no emissions escape when the doors are opened or through unavoidable openings (work piece supply, pallet changer, tool changer, chip conveyor).

On the other hand, the extraction rate must be high enough to ensure that flammable mixtures of lubricant emissions and metal dust are dependably prevented from forming. Further, the flow speed in the extraction pipework should be high enough to prevent dust accumulations from forming (as a rule, flow rate  $> 20$  m/s). This can be guaranteed with a flow monitor inside the extraction pipe.

If the flow rate is too high at the extraction point, there is the risk that the chip protection screen in front of the extraction opening gets clogged with chips. The separation of dust from large chips should therefore take place inside the machine. This can be done by installing a deflector plate and droplet separator (metal sheet, sieve).



Figure 29 Clogged chip screen



Figure 30 Deflector plate over extraction point

### **Special extraction systems for minimum quantity lubrication**

As opposed to the conventional extraction principle in wet machining (air extraction through an opening in the upper part of the machine), new concepts are used in minimum quantity lubrication in order to increase the effectiveness of extraction performance. Thus some machine manufacturers offer extraction that is near the machining point. Extraction openings are incorporated into the spindle head and thus extraction takes place very near to the cutting zone.

Experience shows that extraction systems that extract downward via the chip conveyor prove to be efficient. Well-placed air curtains along the inner wall of the machine have a cleaning effect and improve chip removal. This largely prevents caking and crusting of metal chips on surfaces.



Figure 31 Extraction via chip conveyor



Figure 32 Chip conveyor as extraction position

When extraction is from below, care must be taken that no secondary air is drawn in. For example, the chip conveyor should be sealed from the machine base. Another advantage of extraction via the chip conveyor are the long distances involved and the opportunity for hot chips to cool down. This prevents hot chips from entering the filter area of the extraction system.

Selection of the optimal separation system depends a great deal on the machine conditions during machining. Depending on the metalworking fluid vapours, aerosols and metal dust in the workspace, the manufacturer should be consulted before selecting an effective high-performance separating system. Ideally, the extracted air should be vented into the open. However, the applicable threshold values of the Technical Instructions on Air Quality Control are to be observed (TI Air) for extracted air.

### 2.5.2 Cleaning and minimum quantity lubrication

When operating machine tools with minimum quantity lubrication, particularly stubborn pollution may occur. Micro dust, chips and oil collect as a sticky layer of dirt in the workspace. Especially the graphite dust released from the machining of cast iron and forged parts can make machines very dirty. As a result, machine tools should be cleaned regularly.



Figure 33 Chip accumulation in corners and edges



Figure 34 Sticky residues inside the machine

It is advisable to define cleaning cycles and cleaning procedures based on the degree of pollution, the machining process, and material, e.g. graphite dust from cast iron or forged parts.

In this connection it is helpful to consult the maintenance and servicing intervals information in the operating instructions of the machine tool.

In practice, cleaning schedules in which the necessary cleaning cycles, cleaning procedures and cleaning agents are defined have proven to be useful. Complete information about cleaning, cleaning procedures as well as creating maintenance and cleaning procedures can be found in Section 5.6. A model cleaning schedule is given in Appendix 2.





Figure 35 Cleaning with a low pressure device

Company:	<b>Cleaning schedule</b>	No.:
Work area:		Date:
Workplace:		
Machine no.:		
<b>Cleaning of pollution and accumulations inside the machine tool</b>		
1. Purpose:	Cleaning inside the machine (metal dust and oil deposits) according to the maintenance and cleaning intervals.	
2. Application:	For machine tools operated with minimum quantity lubrication.	
2.1 Slightly polluted systems:	Execution with an interruption in production (end of shift).	
2.1.1 Cleaning agent:	Cloth or brush	
2.1.2 Execution:	a) Remove chip accumulations and swarf on horizontal surfaces and projecting parts. b) Remove moist residues and deposits on the inner walls of the machine and have the chip conveyor carry them away. c) Check extraction point of the machine. Clean chip screens (prevent clogging).	
2.2 Medium-to-heavy pollution of systems:	Execution with an interruption in production.	
2.2.1 Cleaning agent:	Cleaning with low pressure devices (pressure: 3 to 7.5 bar).	
2.2.2 Execution:	Clean off deposits on surface of machine interior with water jet and lance. Possibly add a cleaning emulsion to improve cleaning and add corrosion protection (read supplier information).	
2.3 Heavily polluted systems (stubborn soiling, caking):	Execution with an interruption in production.	
2.3.1 Cleaning agent:	Jet cleaning with dry ice	
2.3.2 Execution:	Use compressed air to shoot frozen CO <sub>2</sub> pellets the size of rice grains onto the surface to be cleaned. Dislodge the brittle layer of pollution from the surface. Remove the pollution with the chip conveyor.	

Figure 36 Cleaning schedule

Depending on the degree of pollution, the following types of cleaning are used in minimum quantity lubrication:

### Manual cleaning

It is often sufficient to clean the machine regularly with a cloth or brush at the end of the shift. Functional elements (e.g. optical sensors, monitoring systems, visual protection panes, tensioning devices and extraction openings) should be integrated into the cleaning concept.

### Cleaning with low pressure devices\* (be careful with pre-coating systems!)

For heavy pollution, it is advisable to use low pressure devices (pressure: 3 bar to 7.5 bar; water consumption 1 to 1.8 l/min; water temperature: up to 95 °C) for machine cleaning. The surface is cleaned with a hot water lance. Adding a cleaning emulsion provides corrosion protection. Environmentally-friendly cleaning can also be carried out without additives.

*\* Caution Extraction systems with lime powder as filter medium (pre-coating system) may experience clogging and gumming in the filter caused by moisture. Before use, it is obligatory to read the operating instructions and/or consult with the manufacturer.*

### **Jet cleaning with dry ice**

For very stubborn dirt, a CO<sub>2</sub> jet cleaner can be used. Using compressed air as the propellant, frozen CO<sub>2</sub> pellets the size of rice grains are shot onto the surface to be cleaned. This dislodges the embrittled layer of dirt from the surface. Because the CO<sub>2</sub> pellets become completely gaseous (CO<sub>2</sub>), there is no jet residue; only the pollution has to be disposed of.

A disadvantage of this type of cleaning is the high noise level. Also, it is necessary for employees to wear appropriate personal protective equipment (ear protection and protective suit). In small, poorly ventilated spaces there is the danger of concentrated CO<sub>2</sub> accumulation. It is therefore mandatory to comply with the requirements of the rule “Einsatz von Feuerlöschanlagen mit sauerstoffverdrängenden Gasen” (BGR 134).

Not advisable:

- High-pressure cleaners, because micro chips and dust can be forced through seals and passages, which may cause machine damage.
- Solvent-based cleaning agents, because they may cause fire and explosion hazards. Above all, it is very important to ensure that no solvents are introduced into the MQL system.
- Cleaning with compressed air (dust clouds, noise).

Further information on the subject of cleaning and cleaning procedures is available in the Internet at: [www.cleantool.org](http://www.cleantool.org)

## **2.6 Qualified employees**

Qualified and motivated employees are vital to the successful launching of new technologies. With the help of training and informational events, employees should be made familiar with the new technology early on.

The regular exchange of information provides the platform for employees to share their know-how with co-workers and to define and solve problems with qualified specialists (disseminator sessions). Setting-up “dry islands” in wet-machining production areas can also be useful. This allows employees to learn about the new technology on-site and to follow the internal implementation.

Practice shows that the opportunity of exchanging information and experience helps to support employees in the effective implementation and contributes to minimise time-consuming trials.



Figure 37 Machine operator at the control panel

# 3 Introduction and implementation of minimum quantity lubrication

## 3.1 General information for successful introduction

If it is clear which dry machining processes can be performed in the company, the implementation of minimum quantity lubrication can start. It must then be decided whether the implementation will be done on existing machines or with new investments.

Regardless of whether conversion of existing equipment or new plant is chosen with integrated minimum quantity lubrication as part of process chain, both options have one important aspect in common. The precise coordination of the individual system elements with the overall system is crucial to success. From the data base to the tool inserts, all relevant elements must fit and be compatible with each other.

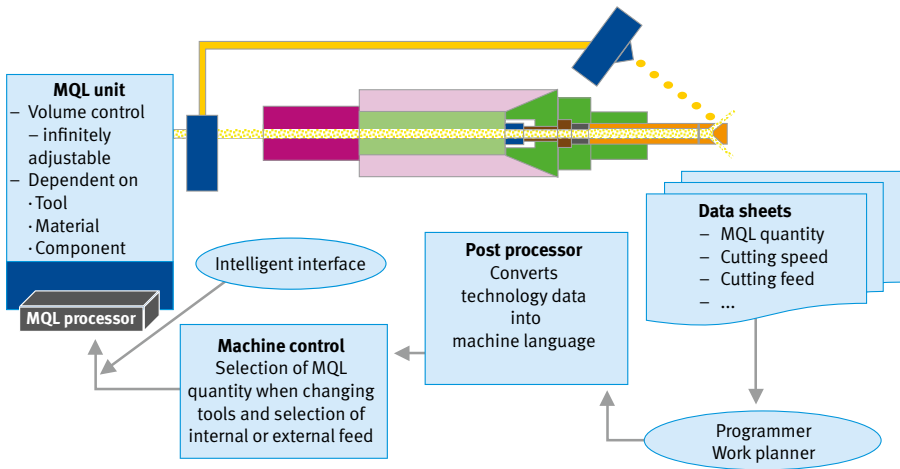


Figure 38 Everything compatible, from tool inserts to the programmer

From programming to tool tips (MQL device, connectors, interfaces, tool adapters, tools), the system elements have to be adjusted to the workflow.

The more these elements are compatible with each other the better.

A high level of element compatibility requires taking the relevant interfaces in the overall concept into account. The definition and compatibility of the interfaces is often a joint task of machine manufacturers and tool manufacturers.

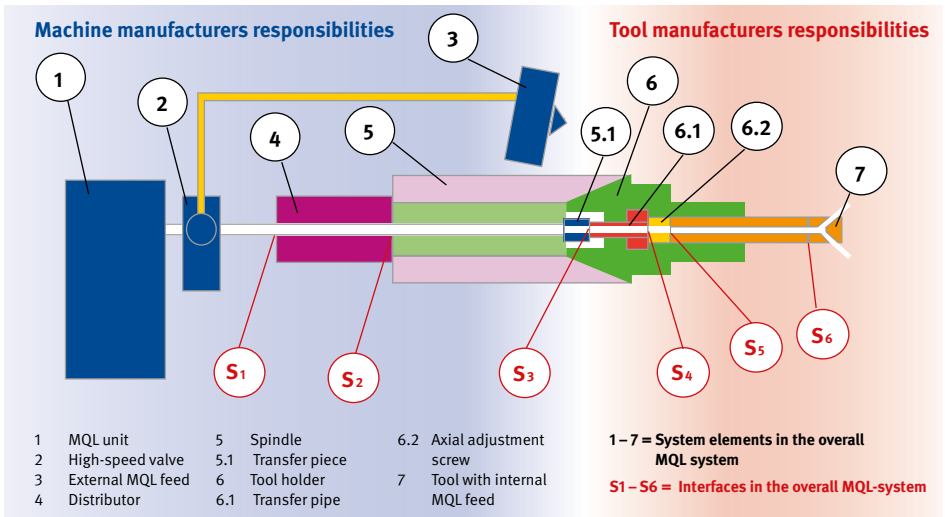


Figure 39 System elements, interfaces, responsibilities

### 3.2 Purchase of new machines, retrofitting and changing over

If retrofitting or changing over, fundamental points of the European Machine Directive must be taken into consideration. These are described below.

#### 3.2.1 Explanation of key terms

##### CE marking

The manufacturer of a finished machine is obliged to provide written compliance of the product (EC Declaration of Conformity) with the requirements of all relevant European directives (e.g. Machine Directive, EMC Directive). The manufacturer confirms that the machine meets the essential safety requirements and thereby the requirements for fire and explosion prevention and protection as well. This is made visible by applying the CE marking to the machine.

### **Risk assessment**

In the context of the *CE marking*, the manufacturer is obliged to submit a risk assessment of all hazards emanating from the machine. It must include all hazards and the corresponding countermeasures likely to occur during the lifetime of the machine from assembly to decommissioning.

### **Intended use**

The operating instructions must include, among other things, a description of the *intended use* of the machine. The *intended use* describes the purpose for which the machine was designed and for which it may be used (regarding the modes of operation intended by the manufacturer). It is therefore recommended to carefully consider the *intended use* and to decide whether it covers the planned use of the machine.

### **Substantial change**

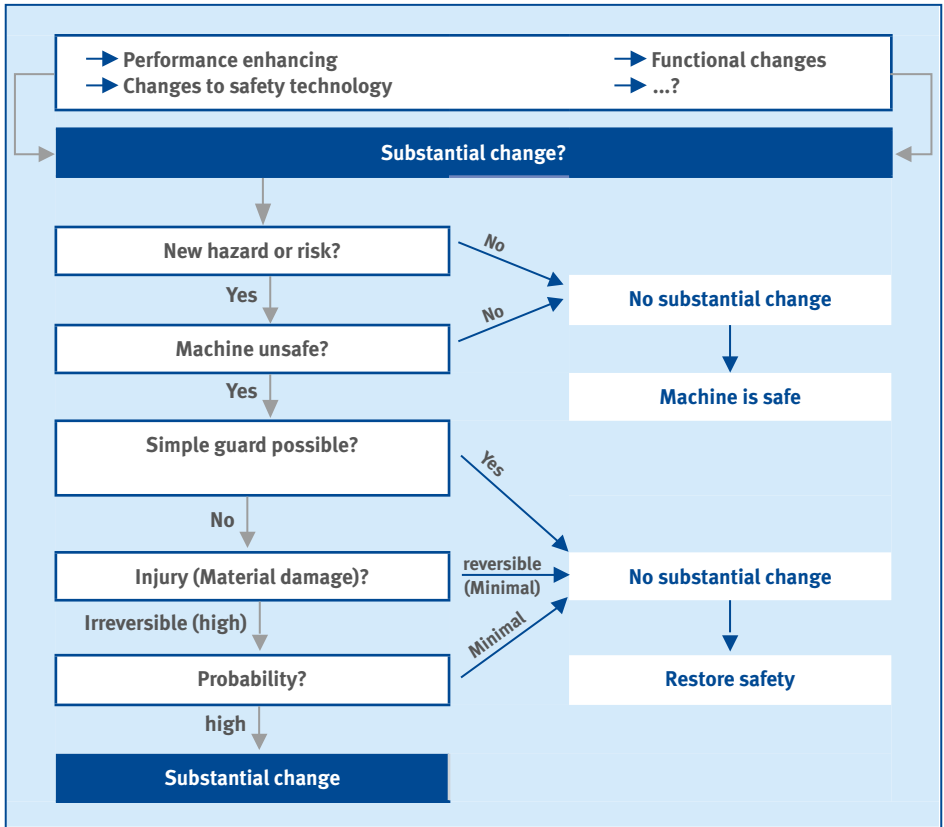
A change to the machine is considered “substantial” if it leads to increased risk requiring a new safety concept on the machine (see the following figure). If the machine has been “substantially changed”, it will be rated as a new machine, a corresponding EC Declaration of Conformity will be issued and the machine will receive an appropriate CE marking. Thus anyone who adds or modifies a machine in a substantial way is, as far as the EC Machine Directive is concerned, acting like a manufacturer and must re-declare the conformity of the modified machine with all of the relevant European directives (e.g. Machinery Directive, EMC Directive). Important: This applies also to so-called old machines, meaning machines which were placed on the market according to old regulations before the Machine Directive went into effect in 1993 and were not yet CE marked.

There is no legal definition for the term “*substantial change*”. The performed changes must be checked on a case-by-case basis to determine whether the intended changes are “substantial”. The following figure is intended to assist anyone planning a conversion to determine whether it is a *substantial change*.

#### **3.2.2 Purchase of new machines for MQL machining**

When purchasing new machines, the user should be convinced that their operation is within the scope of the intended use. Based on the operating instructions and/or after consulting with the manufacturer, it should be clarified that the machine is suitable for MQL applications. Add-on equipment may be necessary. As a rule, the add-on equipment will constitute an extraction system. To ensure that the overall system conforms to the Machinery Directive,

## Substantial change of a machine



consisting of machine and extraction system\*, the following will be helpful:

- The machine is ordered with the extraction system. The manufacturer is responsible for the conformity of the overall system and machine extraction system and takes care of the CE marking.

\* This approach using the example of the extraction system applies in principle also to all other auxiliary equipment of the machine that may be necessary for MQL machining

- The user would like to purchase the extraction system separately from another manufacturer or connect it to an existing extraction system. In this case, the user orders a machine that is not yet ready for use but is in principle suitable. The machine in this form is usable only for machining without extraction. The CE Declaration of Conformity is delivered with the machine and the CE marking affixed to the machine. In the operating instructions the manufacturer states the conditions under which MQL machining is possible and which parameters (e.g. volume flow, air change rate) need to be adhered to. Furthermore, the manufacturer provides an exact interface description in the documentation about how to connect the extraction system. With the specified extraction system, the user/operator of the machine can then properly use the machine for MQL machining. The extraction system can be provided either as a component of the building, or individually with CE marking or as free-standing equipment (also with CE marking). In all cases it must be guaranteed that extraction functions reliably for MQL machining. This can be accomplished by, for example, short maintenance intervals for the extraction system, by connecting a fault monitor, or with concentration monitoring in the emergency stop circuit of the machine.

### 3.2.3 Changing-over existing machines

Changing-over existing machines to minimum quantity lubrication ranges from simple retrofitting of metering devices to changes in the machine control system. Every change to the machine should be checked to determine whether hazard risks are increased, e.g. whether a possibly greater machining speed for MQL could cause additional risks due to fine abrasion; modification of the machine control system may affect safety-relevant functions. Consequently, for each change to the machine the question arises whether a “substantial change” is involved (as described in Section 3.2.1). The approach described below is recommended.

#### **Commission the changeover**

If the changeover is performed by a subcontractor, it is imperative that the contractor be informed of the topic “substantial change”. The contractor should be requested to check and confirm whether the changeover will involve a substantial change. Or it should be contractually agreed in advance that the contractor takes responsibility for the conformity of the changed-over machine concerning the relevant European Directives. In this way the commissioning party can avoid assuming responsibility for the conformity, the CE marking, and issuing the EC Declaration of Conformity. This is especially recommended for the more costly changeover to minimum quantity lubrication with internal feed.



### **Changing over by the company concerned**

If the company undertakes the changeover to minimum quantity lubrication itself, it should be done with the help of a risk assessment, perhaps in cooperation with the manufacturer or a test body (Grundsatz: Aufgabenbereiche der Prüf- und Zertifizierungsstellen im BG-Prüfzert; English version: principle: task areas of the test and certification bodies in the BG-PRÜFZERT [BGG 903]) to determine whether there is increased risk. The flowchart in Clause 3.2.1 should help you establish whether there is substantial change. If there is a substantial change, the user is legally considered the manufacturer, must re-declare the conformity, and must provide the changed-over machine with the CE marking. DIN EN ISO 14 121 provides help for the risk assessment.

### **3.3 Future prospects and development**

In practice, demanding production processes (HSC machining) for large-scale mass production have been implemented using process-reliable MQL. For this to be the case it is important that the elements are optimally adjusted to each other. A key objective for the user is to keep the MQL process “easy” to use and initiate. The selected NC program contains all information (optimal interface parameters, lubricant quantity and feed, tool etc.) for the smooth running of the process.

A standard for defining the relevant programs and processes is currently being worked out by a steering committee of industrial companies. This steering committee is composed of experts from companies which have already implemented minimum quantity lubrication in their own production or which, as suppliers, have many years of production system experience in using this technology. The objective of the standardisation is to adapt all commonly used MQL systems to the production process through defined configurations.

# 4 Hazards and protective measures

## 4.1 Emissions in minimum quantity lubrication

Metal machining with minimum quantity lubrication is generally viewed as a low-emission process. This trend is also confirmed by studies which were carried out in the framework of a special measurement program at workstations with minimum quantity lubrication.

Exposures (dust, MWF aerosols and vapours) were measured around machine tools in production areas. The surveys included personal measurements as well as stationary measurements on control panels and inside the workspace of the machine (see Figures 40 and 41).



Figure 40 Determining the carbon monoxide concentration with a direct-reading measuring device



Figure 41 Stationary exposure measurements as well as personal measurements at the control desk

When machining materials with minimum quantity lubrication on machine tools in production areas, MWF vapours and aerosols have turned out to be exposure factors. In all measurements, the formerly valid workplace threshold value for MWFs (prior threshold value: 10 mg/m<sup>3</sup> air; state-of-the-art) was maintained. The measured concentrations in the working areas were so minimal that more than 95 % of the measured values were easily less than half of the threshold value.

Decomposition products and pyrolyzates, e.g. formaldehyde, were only found in traces in a few cases. Also the measured dust concentrations were far below the permitted workplace threshold values for the “respiratory fraction” (workplace threshold values: 3 mg/m<sup>3</sup> air) and for the inhalable fraction (10 mg/m<sup>3</sup> air).

The tendency that significantly fewer emissions are created by minimum quantity lubrication than in wet machining was confirmed by the following comparative measurements.

On a lathe set up for machining revolver nuts made of steel (Ck 45), the emissions produced were measured for both flood lubrication and minimum quantity lubrication. Besides measurements on persons, the concentrations of MWF aerosols and vapours were ascertained by isokinetic measurements of the air extracted from the machine. The results are shown in Figure 43.



Figure 42 Machined revolver nut and unworked piece; material: CK 45

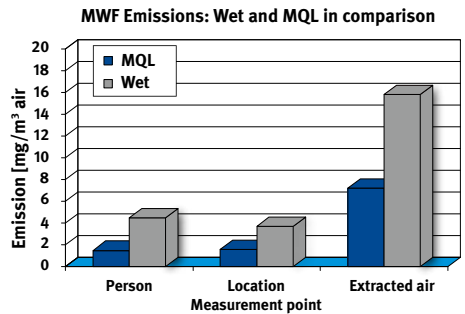


Figure 43 A comparison of emissions in wet machining and minimum quantity lubrication machining

Significantly higher emissions were measured on persons, at the control panel of the machine as well as in the extraction stream of the machine when wet machining than when minimum quantity lubrication was used. The MQL extraction stream emissions in particular were less than half of the measured flood lubrication values.

### Test bench trials

In general, the rule of thumb that applies to successful machining with minimum quantity lubrication also applies to emissions: the better the system is harmonised, the fewer the emissions.

The results of the following test bench trials illustrate how much impact some factors can have on emissions.

Here machining tests were carried out using internal feed minimum quantity lubrication when drilling (see Figures 44 and 45). The tests were done under realistic conditions with variations of the cutting parameters and materials (steel, aluminium and cast iron). The emissions of different lubricants could be ascertained and compared during machining in the interior of the test bench housing directly at the point of origin under reproducible conditions.



Figure 44 Test bench for determining emissions in the interior



Figure 45 High-speed spindle with internal feed (30,000 rpm)

### Lubricants: Quality and viscosity

Below are the measured aerosol and vapour emissions for different ester oils under realistic conditions (feed speed:  $V_f = 800 \text{ mm/min}$ ); see Figure 46.

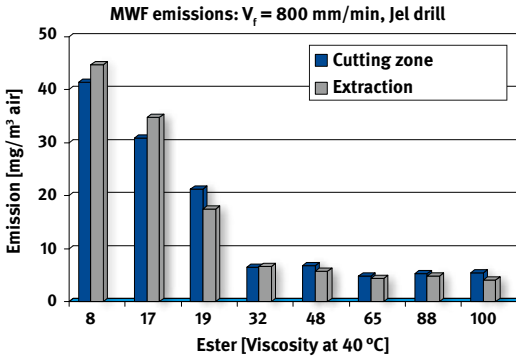


Figure 46 Aerosol and vapour emissions at the machining point

During the machining tests, a great deal of mist formation resulted especially with thin, low-viscosity lubricants ( $< 10$  mm<sup>2</sup>/s at 40 °C). In contrast, high-viscosity media (viscosity greater than 20 mm<sup>2</sup>/s at 40 °C) had significantly lower emission values.

Very thin low-viscosity lubricants with a low flash point ( $< 100$  °C) are often used in minimum quantity lubrication. They should evaporate without leaving residues after machining. To be able to evaluate the emission behaviour of this lubricant, a with very low viscosity (3 mm<sup>2</sup>/s at 40 °C) sample was tested against other media. The results of these tests are shown in Figure 47.

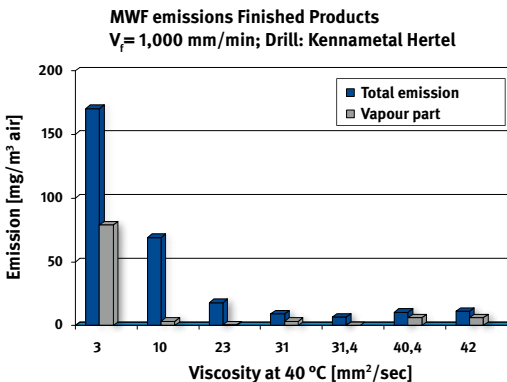


Figure 47 Emission behaviour of different lubricants with different viscosities; feed: 1,000 mm/min.

The low-viscosity oils often produce a great deal of fumes and mist even under low load. They produce considerably more emissions than conventional products; the high proportion of vapours is particularly striking. The high emissions when using such products may impact workplace conditions negatively. Consequently, high-viscosity products with high flash points (> 150 °C) should be used.

As guideline values and quality criteria for selecting low-emission lubricants, flash point and evaporation losses according to Noack at 250 °C are tried and proven (see Table 6).

Viscosity at 40 °C DIN 51 562 Part 1	Flashpoint CoC DIN EN ISO 2592	Evaporation losses at 250 °C acc. to Noack DIN 51 581 Part 1
> 10 mm <sup>2</sup> /s	> 150 °C	< 65 %

**Table 6** Guide values for selecting a low-emission lubricant  
(source: BGIA workbook “Measuring hazardous substances, category 6”)

The selection of a high-quality and rather high-viscosity lubricant as well as optimum machining parameters lower emissions when machining metals with minimum quantity lubrication.

More information on the topic of emissions in minimum quantity lubrication machining is available in the closing report of the project “Gefährdungsbeurteilung bei der Trockenbearbeitung metallischer Werkstoffe” (“Hazard assessment in dry machining metallic materials”) (detailed) as well as in the engineering committee information sheet “Emissionsarme Metallbearbeitung mit Minimalmengenschmierung” (“Low-emission metal machining with minimum quantity lubrication”). Both documents are available as downloads at [www.bghm.de](http://www.bghm.de).

## 4.2 Protection against fire and explosion

For minimum quantity lubrication, fire and explosion risks are primarily determined by the quantities of flammable metal chips and dust. When using a lubricant with a high flash point of 150 °C and the generally low consumption quantities involved (maximum 100 ml/hour), there is normally no risk of explosive vapour/air mixtures occurring. Even the mist formation resulting from the spraying process itself does not form a hazardous explosive atmosphere.

Based on experience, there is an increased fire hazard in areas where large quantities of flammable metal chips and dust are generated which accumulate inside the machine. With regard to the risk of explosion, accumulations of flammable metal dust with particle sizes of  $< 500 \mu\text{m}$  are relevant. Deposited flammable dust may cause hazardous explosive dust/air mixtures if stirred up.

Especially with “light” metal dusts (aluminium, magnesium), attention should be given not only to the dust in the machine (type, amount, and material) but also to the ease with which it can be stirred up. Besides the interior of the capsulated system, attention should also be given to the pipelines and the filter area of the extraction system, where fine dust can be separated and stirred up. If fine, dry metallic dusts are cleaned-off or stirred up due to system design, an explosion hazard may result under certain circumstances.

In practice minimum quantity lubrication is deployed almost exclusively in processes with geometrically-defined cutting edges (turning, milling, drilling). These machining processes primarily generate coarse-grained chips. Furthermore, the MQL medium in use often causes the conglomeration of metallic dusts and this, in turn, hinders flurrying. A cloggy and sticky mass of metallic dust and lubricant may often also be found in the filters.



Figure 48 Sticky mass in the machine interior



Figure 49 Caking on the panels

In the framework of a research project, metallic residues from systems in mass production using minimum quantity lubrication were investigated for their composition and reactivity. The selected samples from inside the machine consisted of aluminium, steel and cast iron alloys. These samples were not explosive, since the agglutination was significant and the proportion of small ignitable particles was very small.

To reduce the risk of fire, lubricants with a flash point of at least 150 °C should be used. Accumulations of coarse chips and quantities of dust inside the machine should also be avoided. By continuous removal of metallic residues via chip conveyor and by regular cleaning, the risk of fire can, in most cases, be reduced to insignificance.

Also important is that the work area with combustible metal chips should be a no smoking zone, since the heat of a cigarette thrown into the chips container may be sufficient to ignite a fire.



Figure 50 Covered and marked aluminium chip containers



Figure 51 Burning cigarette butt in the chip container

The use of effective extraction reduces the fine dust inside the machine. Extraction systems constructed with effective measures against fire and explosion hazards and which ensure safe operation should be given preference.

According to the European Machinery Directive (98/37/EC), machine manufacturers must take fire and explosion hazard into account in the operating instructions and describe whether and under which conditions the machine can be operated as specified.

To ensure that the extraction system works properly, regular cleaning of the panels and sieves should be carried out and the extraction volume flow monitored. In addition, extraction system maintenance should be performed regularly based on the intervals specified in the



operating instructions (according to the BG rule “Arbeitsplatzlüftung – Lufttechnische Maßnahmen” [BGR 121] at least once a year). Particular attention should be given to the filter and extraction point.

Further information on the topic of fire and explosion hazard is available in Information „Brand- und Explosionsschutz an Werkzeugmaschinen“ (BGI/GUV-I 719), English version: „Machine Tool Fire and Explosion - Prevention and Protection“ (BGI/GUV-I 719 E).

### **4.3 Noise**

Investigations in the manufacturing sector have shown that the noise generated by minimum quantity lubrication is comparable to that in wet machining. An optimally harmonised system guarantees low-noise metal machining. Loud noises (screeching and rattling) during the machining process are often an indication of insufficient lubricant feed or inappropriate tool or cutting parameters.

As opposed to wet machining, cleaning with compressed air is largely unnecessary because the work pieces are dry and nearly chip-free in minimum quantity lubrication machining.

The use of compressed air for cleaning parts – aside from the high noise level and stirring up dust and chips – also means additional costs for providing compressed air and consequently should not be used.

If the use of compressed air is unavoidable for technical reasons, noise-suppressing compressed air nozzles should be used. Information about using noise-suppressing compressed air nozzles and multi-hole nozzles is available in:

Noise protection worksheet LSA 05-351 “Geräuschminderung an pneumatischen Anlagen; Geräuschgeminderte Druckluftdüsen; Marktübersicht, Schallpegel, Blaskraft und Luftverbrauch aus Labormessungen” (BGI 680).

#### 4.4 Skin protection

With respect to occupational safety, MQL offers advantages over water-miscible MWFs because it is less harmful to skin. Instead of emulsions, only small amounts of clean ester-based or fatty-alcohol-based lubricants are used in machining. In contrast to emulsions, there is no need for system cleaners, biocides and fungicides that are harmful to skin and health, since microbial growth is only possible in aqueous phases.

Ester oils and fatty alcohols can, however, have a degreasing and therefore drying effect over the long term. Skin protection measures are thus required if there is long and intensive skin contact with the lubricants in minimum quantity lubrication.

Also when cleaning the machine, skin protection measures are required if special cleaning agents are used.

If direct skin contact with the lubricants is unavoidable, skin protection measures should be performed accordingly.

- Prepare a skin protection plan (skin protection plan B for non-water miscible metalworking fluids in accordance with Information “Hautschutz in Metallbetrieben” [BGI 658]).
- Avoid skin contact by using auxiliary tools.
- Protect at-risk skin areas with protective clothing (see rule “Benutzung von Schutzkleidung” [BGR/GUV-R 189]).
- Provided work is not on rotating machines, use durable protective gloves (see rule “Benutzung von Schutzhandschuhen” [BGR/GUV-R 195]).
- Provide skin protection, skin cleaning and skin-care agents.
- Train employees to use skin protection agents.

In most cases, ester-based or fatty-alcohol-based lubricants are used. When this is the case, skin protection plan B for non-water miscible metalworking fluids is recommended (see Information “Hautschutz in Metallbetrieben” [BGI 658]). For special lubricants, the details in the safety data sheet may be helpful for preparing an appropriate skin protection plan.

The employees should be instructed on the hazards as well as its purpose and use of skin protection in MQL; this should be done prior to working with the system as well as on a regular basis. Making instructions available on-site in the work area has proven simple and effective.

## 4.5 Instruction and operating instructions

The introduction of minimum quantity lubrication requires a certain amount of flexibility from the employees. Many habits stemming from wet machining often make the changeover to the new technology difficult. In contrast to flood lubrication, the lubricant spray jet in external feed is often “invisible” and has a different odour. Added to that is the operation of an external MQL system and differences in cleaning the machine. On the other hand, many tasks are no longer required (e.g. the maintenance, servicing, preservation and disposal of the used emulsion).

It is thus vital that employees receive instruction on the purpose and use of the individual systems (machine tool, MQL systems etc.) and are familiarized with hazards and peculiarities before beginning work with minimum quantity lubrication. Instruction contributes to reducing fears and reservations of the “new” and gives employees confidence in using the new technology.

The following points should be taken into consideration when instructing employees on minimum quantity lubrication:

- If there is intensive skin contact with lubricants: train employees to use skin protection agents in accordance with the skin protection plan.
- With open machines and hot chips that fly around: wear protective goggles.
- When removing work pieces with a temperature of  $> 50\text{ }^{\circ}\text{C}$ : protect against burns.
- For cleaning work: wear appropriate personal protective equipment and, if necessary, use a skin protection agent in accordance with the skin protection plan.

Instructions are usually verbal and take place at the place of work. Instruction should include precise information about hazards, hazardous situations and protective measures, correct behaviour when working with the machine tool, and safe operation of the machine tool and its work materials. What to do in the event of accidents and unexpected malfunctions should also be part of the instructions. Effective instruction at the machine tool should include theoretical matters and hands-on practical advice. Talking, discussing and direct participation of the employees is more effective than any lecture.

If servicing work or conversions are carried out, the supervisor must prepare accordingly so that the participating employees receive appropriate special instruction.

Instruction is to be given prior to work and repeated routinely, for example if there are changes in the job portfolio or if it appears that the effect of the instruction has worn off (negligence, close calls and the like). It is recommended that instruction is carried out at least once a year, the key points recorded with date as evidence of instruction, and the protocol signed by the employees. A sample sheet showing a documentation of instruction is given in Appendix 2.

Training using the operating instructions on-site in the work area is simple and effective. Operating instructions contain simple information about hazards, protective measures and rules of behaviour in an easy-to-understand form. Furthermore, the instructions contain information about how to behave in dangerous situations and first aid measures. The operating instructions can be used as a guide when instructing and should be kept at a suitable location in the working area. Sample operating instructions are shown in Appendix 1.

#### **4.6 Cleaning with minimum quantity lubrication**

Machine tools should be cleaned regularly for the following reasons:

- To minimise the risk of fire by disposing of accumulations of adhering metal chips and oil in the machine.
- To keep the machine in a good functional state (optical sensors, monitoring systems, visual inspection panels, tensioning devices).
- To ensure component quality with respect to production tolerances and surface quality.

Cleaning schedules should be created defining the necessary cleaning cycles, cleaning procedures and cleaning agents.

Cleaning cycles and the type of cleaning procedures are to be defined based on the following criteria:

- The pollution degree as a function of the machining process and material, e.g. cast iron or forged parts which create graphite dust.
- Specifications in the operating instructions of the machine tool according to the maintenance and servicing intervals.

The cleaning schedule (cleaning intervals and type of cleaning) should be individually adapted to the machining process. The extraction point should always be included in machine cleaning. Particularly important is that chip screens are not caked and clogged with swarf.

A sample cleaning schedule is shown in Appendix 2.

It must also be ensured that cleaning work is performed only by instructed persons and that they use appropriate personal protective equipment as specified in the operating instructions. The person given the job of cleaning should have received appropriate special instruction.

The protective measures for handling tenside-based cleaning agents and dry ice pellets described in the operating instructions are to be adhered to in particular.

See also:

- Rule “Benutzung von Schutzhandschuhen” (BGR/GUV-R 195)
- Rule “Benutzung von Augen- und Gesichtsschutz” (BGR/GUV-R 192)
- DIN EN 374 „Schutzhandschuhe gegen Chemikalien und Mikroorganismen“  
(English version: „Protective gloves against chemicals and micro-organisms”)
- DIN EN 420 „Schutzhandschuhe - Allgemeine Anforderungen und Prüfverfahren“  
(English version: „Protective gloves. General requirements and test methods”).

When using cleaning agents and water-based cleaners, the information of the manufacturer/ supplier must be observed in order to avoid acute skin injuries caused by overdoses (safety data sheet, product information).

# 5 Minimum quantity lubrication in practice

## 5.1 Minimum quantity lubrication in small batch series and single piece production

In the workshop area of small and medium-sized companies there are many possibilities for introducing MQL technology. Retrofitting and converting to minimum quantity lubrication has proven possible for most open stand-alone machines using geometrically-defined cutting edges for sawing, milling, drilling and turning.



Figure 52 Sawing with minimum quantity lubrication



Figure 53 External lubricant feed in milling

When sawing metals, lubricant feed with minimum quantity lubrication is considered state-of-the-art in many sectors. The new technology has even proven its worth with pillar drills, which earlier were operated with “oil can lubrication”. Thanks to continuous lubricant feed through an MQL metering device, the operator’s hands can stay out of danger zones such as rotating tools.

For infrequently used machines that are inactive for days or weeks, a machine conversion is advantageous. In the summer months, emulsions in machines tend to “go-off” if inactive for a long time or if not cared for and this may result in bacteriological attack, foul odours and health hazards to employees. In minimum quantity lubrication, however, clean lubricant is used and stays good for long periods of time.



Figure 54 Emulsion in the MWF tank;  
service life six months



Figure 55 Clean lubricant with MQL system

A precondition for the successful conversion of machine tools to MQL is ensuring the fast and complete removal of chips from the working zone. To guarantee dependable workflow, the chips in the MQL process have to be transported away from the device and machine, a task performed by the MWF in conventional processes. Chip accumulation and residues in the work area (e.g. on the work pieces and machining equipment) should be avoided as far as possible.

Ideally, minimum quantity lubrication is introduced when new machines designed for dry machining are purchased; in that case, chip disposal is no problem. Information about the features of dry-compatible machines can be found in Section 3.5 (Machine tools for minimum quantity lubrication).

There are also many examples from diverse production areas with results and descriptions of the procedures when introducing the minimum quantity lubrication in a detailed final report (page 80 ff. of the report).

The report can be downloaded at [www.trockenbearbeitung.de](http://www.trockenbearbeitung.de) by using the link “Bericht zum Verbundprojekt Technologienetz Trockenbearbeitung”.

## 5.2 Minimum quantity lubrication in large-batch, mass production

In the automobile industry, MQL technology is introduced when new production systems are purchased, e.g. transfer lines or production lines. In many areas of highly automated large batch mass production, minimum quantity lubrication is already being used in the manufacture of clutch and transmission casings, aluminium cylinder heads, and turbo-charger turbine wheels.

To reduce the weight of motor vehicles, Daimler AG has been manufacturing aluminium rear wheel carriers on the world's first flexibly-linked installation comprising of machining centres for dry machining in large-batch mass production since 2003.



Figure 56 Mercedes E and SL model rear wheel carriers



Figure 57 Mercedes E and SL models rear axle

In three-shift operation, a total of eight machining centres are loaded and unloaded by four robots and approximately 1,400 pairs of rear wheel carriers are produced a day for the Mercedes E and SL models. With a cycle time of about six minutes, the wheel carriers are produced in three setups and 27 operations (22 tools, 25 tool changes) per machine. For wheel carrier production it has been possible to reduce lubricant consumption to about 1 ml per part.



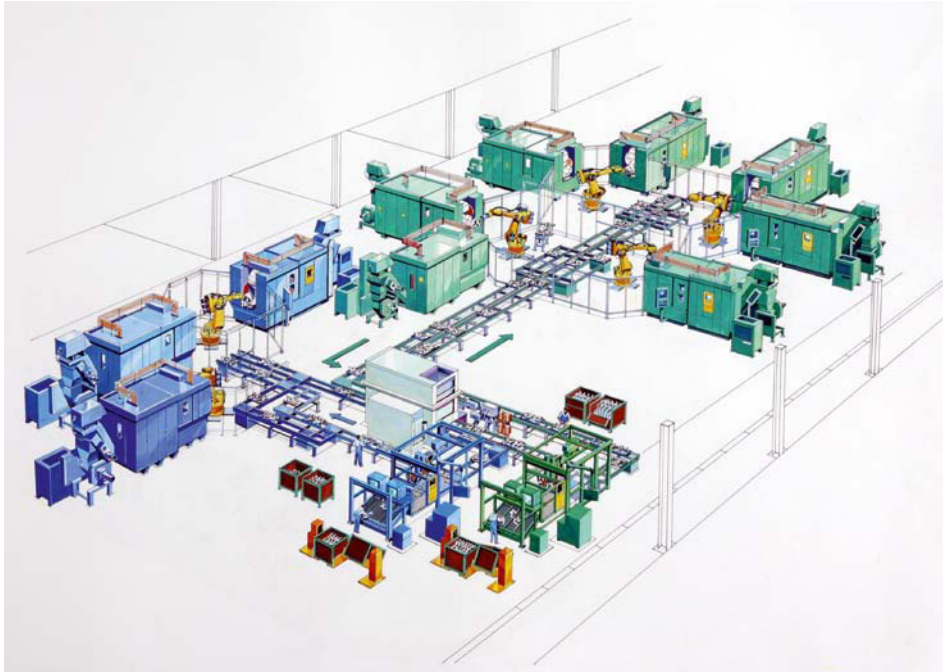


Figure 58 Linked plant for large-batch mass production of rear wheel carriers for the Mercedes E and SL models

Experience with this new technology demonstrates that MQL will become a permanent feature of large-batch manufacturing.

# Appendix 1

## Operating instructions

Company:  
Insert name of company here

### Operating instructions acc. to GefStoffV § 14

#### 1. Scope

Handling of non-water miscible lubricants for minimum quantity lubrication with mechanical machining

Department: \_\_\_\_\_ Workplace: \_\_\_\_\_

#### 2. Name of hazardous substance

Product name: \_\_\_\_\_

#### 3. Hazards for man and environment

- Intensive skin contact leads to degreasing, dehydration and irritation of the skin as pre-stage to skin diseases.
- Even minor skin injuries, e.g. by metal particles, increase the risk of a skin disease when in contact with lubricant.
- Skin contact may cause allergic reactions to constituents of lubricant.
- Blowing compressed air on skin or clothing wetted with lubricant damages the skin.
- Inhalation of lubricant vapour may cause irritation of the respiratory tract.
- Prior to start of work, breaks or after end of work protective measures in accordance with the skin protection plan shall be carried out.

#### 4. Protective measures and rules of behaviour



- Switch on extraction system prior to start of work.
- Avoid skin contact as far as possible, i.e.:
  - Use clean textile or paper towels for drying the skin,
  - Do not put polluted rags in your clothes.
- Do not eat, drink, smoke at the workplace and do not keep food there.
- Avoid skin contact during cleaning with solvents or wear protective gloves.

#### 5. Behaviour during failure and in case of danger

Emergency call 112



- Inform responsible superiors in case of breakdown of the extraction system or other malfunctions.
- Inform responsible superiors if special odors, discolorations of the lubricant occur
- Take up spilled lubricant e.g. with paper towels or bonding agents.

#### 6. Behaviour in case of accidents – First Aid

Emergency call 112



- Inform first aiders and responsible superiors.
- Have even minor injuries treated by the first aider.
- Notify skin reactions (e.g. redness, rough skin, itching, burning, blisters, danders, fissures) to the responsible superior

#### 7. Maintenance, disposal

- Rags, towels and binding agents soaked with lubricant should only be collected in non-flammable, closable, specially marked containers
- Person responsible for disposal \_\_\_\_\_

Date: \_\_\_\_\_

Signature: \_\_\_\_\_

# Appendix 2

## Sample of a cleaning schedule for machine tools with minimum quantity lubrication

Company:	<b>Cleaning schedule</b>	No.: Date:
Work area: Workplace: Machine no.:		
<b>Cleaning of pollution and accumulations inside the machine tool</b>		
1. Purpose:	Cleaning inside the machine (metal dust and oil deposits) according to the maintenance and cleaning intervals.	
2. Application:	For machine tools operated with minimum quantity lubrication.	
2.1 Slightly polluted systems:	Execution with an interruption in production (end of shift).	
2.1.1 Cleaning agent:	Cloth or brush	
2.1.2 Execution:	<ul style="list-style-type: none"> <li>a) Remove chip accumulations and swarf on horizontal surfaces and projecting parts.</li> <li>b) Remove moist residues and deposits on the inner walls of the machine and have the chip conveyor carry them away.</li> <li>c) Check extraction point of the machine. Clean chip screens (prevent clogging).</li> </ul>	
2.2 Medium-to-heavy pollution of systems:	Execution with an interruption in production.	
2.2.1 Cleaning agent:	Cleaning with low pressure devices (pressure: 3 to 7.5 bar).	
2.2.2 Execution:	Clean off deposits on surface of machine interior with water jet and lance. Possibly add a cleaning emulsion to improve cleaning and add corrosion protection (read supplier information).	
2.3 Heavily polluted systems (stubborn soiling, caking):	Execution with an interruption in production.	
2.3.1 Cleaning agent:	Jet cleaning with dry ice	
2.3.2 Execution:	<p>Use compressed air to shoot frozen CO<sub>2</sub> pellets the size of rice grains onto the surface to be cleaned. Dislodge the brittle layer of pollution from the surface. Remove the pollution with the chip conveyor.</p> <p>Important:</p> <ul style="list-style-type: none"> <li>– Very noisy; Wear ear protection.</li> <li>– Work only with protective clothing/protective suit.</li> <li>– Do no work in small, poorly ventilated spaces: Danger of CO<sub>2</sub> accumulation!</li> </ul>	
Name:	Signature:	

# Appendix 3

## Check lists

Suitable lubricants	OK
<b>Guide values for selecting low-emission lubricants</b>	
Viscosity at 40 °C (DIN 51562 Part 1):	> 10 mm <sup>2</sup> /s (cst.)
Flash point (CoC) (DIN EN ISO 2592):	> 150 °C
Noack evaporation loss at 250 °C (DIN 51581 Part 1):	< 65 %
<b>Information about lubrication in use (manufacturer):</b>	
Operating instructions	
Safety data sheet	
Product information	
<b>Not recommended:</b>	
<ul style="list-style-type: none"> <li>Water-based MWFs and their concentrates</li> </ul>	
<ul style="list-style-type: none"> <li>Lubricants with additives containing organic chlorine or zinc</li> </ul>	
<ul style="list-style-type: none"> <li>Marked lubricants (orange symbol in compliance with hazardous substances ordinance)</li> </ul>	
<ul style="list-style-type: none"> <li>Products based on mineral oils with a high content of aromatic compounds (&gt; 3 ppm benzo[a]pyrene or DMSO extract &gt; 2; safety data sheet or manufacturer)</li> </ul>	
<ul style="list-style-type: none"> <li>Esters (rape seed oil, etc.): Ageing, gummed on guides and components</li> </ul>	
<ul style="list-style-type: none"> <li>Lubricants with a strong odour.</li> </ul>	

Precision metering devices	OK
Guarantee continuous lubricant feed (no stalling, interruptions, leakages).	
Fast response characteristics and media availability at the machining point even after long standstills (lubricant at machining point after max. 0.5 seconds).	
Able to monitor minimum quantity lubrication functioning (e.g. fill level, media transport and compressed air).	
Able to set parameters (e.g. quantity and pressure) based on default values and dependent on process, material and machining parameters.	
Effective spray pattern of nozzle (for external feed): <ul style="list-style-type: none"> <li>• Detail of appropriate system adjustments to minimise mist formation,</li> <li>• Able to target wetting (specification of the nozzle spray pattern).</li> </ul>	
Specification of the viscosity range at 40 °C of usable lubricants in the system;	
Lubricant and metering device adjusted to each other (compatible);	
Components and seals resistant to the media in use (to be checked on a case-by-case basis).	
Low operating noise (< 75 dB [A]).	

Dry-machining-compatible machine tools	OK
Machine panelling that is steeply inclined (at least 35 ° to the ground)	
Smooth surfaces (ideally made of stainless steel) so that chips slide off easily	
As few pipelines, edges or horizontal surfaces as possible on which chips and dust can accumulate (for screws, oval-head screws are advisable)	
Careful sealing off of the workroom (no dust if possible on sensitive parts, such as drive and guide elements of the machine).	
Thermal insulation of the machine panelling to the machine itself (no thermal bridges if possible) with lowest tolerances possible.	
Continuous chip removal, e.g. with a chip conveyor.	
Equipped with an extraction system.	
Cleaning schedule with cleaning cycles and cleaning procedures depending on the degree of pollution, machining process and material.	
Tip: Heed the specifications in the operating instructions of the machine tool concerning the maintenance and servicing intervals.	

The right tools	OK
Use suitable tools for MQL machining (coating, geometry).	OK
Observe the cutting parameters recommended by the tool manufacturer (e.g. tool feed, cutting speed).	

# Appendix 4

## Documentation of instruction

**Documentation of instruction**  
(§ 4 par. 1 of the accident prevention regulations “Principles of prevention” [BGV/GUV-V A1] and/or § 12 Work safety act)

Company: \_\_\_\_\_

Department: \_\_\_\_\_

Supervisor (master craftsman): \_\_\_\_\_

Date of instruction: \_\_\_\_\_

Instruction before starting work

Repeated instruction (at least annually)

Subject: \_\_\_\_\_

Key words: \_\_\_\_\_

Participants:	Signature:

\_\_\_\_\_  
Place, date

\_\_\_\_\_  
Signature of the instructor

### Documentation of instruction – Example

(§ 4 par. 1 of the accident prevention regulations “Principles of prevention” [BGV/GUV-V A1] and/or § 12 Work safety act)

Company: Anybody and Sons

Department: Sheet metal processing

Supervisor (master craftsman):: Mr Huber

Date of instruction: DD.MM.VV

Subject: Working on eccentric press

Keywords: Make sure hand protection measures are observed; prevent misuse by removing mode selection switch; use gloves; observe operating instructions; use ear protection; use lifting gear for heavy parts.

Participants:	Signature:

\_\_\_\_\_  
Place, date

\_\_\_\_\_  
Signature of the instructor



# Appendix 5

## Directives, regulations and information

In the following, the pertinent directives and regulations which are to be observed are listed:

### 1. Acts, Ordinances and Technical Regulations

Available from:

Book shops and internet, e.g. [www.gesetze-im-internet.de](http://www.gesetze-im-internet.de), [www.baua.de](http://www.baua.de)

Arbeitsschutzgesetz (ArbSchG), (English version: Occupational Health and Safety Act),

Betriebsicherheitsverordnung (BetrSichV), (English version: „Ordinance on Industrial Safety and Health),

Ordinance on preventive occupational medical care,

Gefahrstoffverordnung (GefStoffV), (English version: Hazardous Substances Ordinance with associated technical rules for hazardous substances, especially),

TRGS 401 “Gefährdung durch Hautkontakt – Ermittlung, Beurteilung, Maßnahmen”,

TRGS 402 “Ermitteln und Beurteilen der Gefährdungen bei Tätigkeiten mit Gefahrstoffen: Inhalative Exposition”,

TRGS 555 “Betriebsanweisung und Information der Beschäftigten”,

TRGS 900 “Arbeitsplatzgrenzwerte”.

### 2. Regulations, rules and information for occupational safety and health

Available from:

To be obtained from your responsible insurer and [www.dguv.de/publikationen](http://www.dguv.de/publikationen)

#### **Accident prevention regulations:**

“Grundsätze der Prävention” (BGV/GUV-V A1),

“Sicherheits- und Gesundheitsschutzkennzeichnung am Arbeitsplatz” (BGV/GUV-V A8).

**Rules:**

- “Grundsätze der Prävention” (BGR/GUV-R A1),
- “Arbeitsplatzlüftung – Lufttechnische Maßnahmen” (BGR 121),
- “Einsatz von Feuerlöschanlagen mit sauerstoffverdrängenden Gasen” (BGR 134),
- “Benutzung von Schutzkleidung” (BGR/GUV-R 189),
- “Benutzung von Atemschutzgeräten” (BGR/GUV-R 190),
- “Benutzung von Augen- und Gesichtsschutz” (BGR/GUV-R 192),
- “Einsatz von Schutzhandschuhen” (BGR/GUV-R 195).

**Informations:**

- “Hautschutz in Metallbetrieben” (BGI 658),
- Lärmschutz-Arbeitsblatt LSA 05-351 „Geräuschminderung an pneumatischen Anlagen; Geräuschgeminderte Druckluftdüsen; Marktübersicht, Schallpegel, Blaskraft und Luftverbrauch aus Labormessungen“ (BGI 680),
- “Brand- und Explosionsschutz an Werkzeugmaschinen” (BGI/GUV-I 719).

**Principles:**

- “Aufgabenbereiche der Prüf- und Zertifizierungsstellen im BG-Prüfzert”;
- English version: “Task areas of the test and certification bodies in the BG-Prüfzert” [BGG 903])

### 3. Standards

Available from:

Beuth Verlag GmbH, Burggrafenstraße 6, 10787 Berlin

- |                     |  |
|---------------------|--|
| DIN 51 562-1        | Viskosimetrie; Messung der kinematischen Viskosität mit dem Ubbelohde-Viskosimeter, Teil 1: Bauform und Durchführung der Messung (English version: Viscometry; measurement of kinematic viscosity by means of the Ubbelohde viscometer), Part 1: Viscometer specification and measurement procedure, |
| DIN EN 374          | Schutzhandschuhe gegen Chemikalien und Mikroorganismen (English version: Protective gloves against chemicals and micro-organisms),   |
| DIN EN 420          | Schutzhandschuhe - Allgemeine Anforderungen und Prüfverfahren (English version: Protective gloves. General requirements and test methods),   |
| DIN EN ISO 14 121-1 | Sicherheit von Maschinen - Risikobeurteilung Teil 1: Leitsätze (Englisch version: Safety of machinery – Risk assessment – Part 1: Principles),   |
| DIN EN ISO 2592     | Mineralölerzeugnisse; Bestimmung des Flamm- und Brennpunktes; Verfahren mit offenem Tiegel nach Cleveland (English version: Petroleum products – Determination of flash and fire points – Cleveland open cup method).  |

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