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Deutsche Gesetzliche Unfallversicherung
Fachausschuss
Maschinenbau, Fertigungssysteme, Stahlbau

Machine Tool Fire and Explosion Prevention and Protection

The trend of using non water-soluble, flammable metalworking fluids (MWF) brings the topic of fire and explosion protection and prevention for machine tools to the fore. Depending on the type of machining, violent flame ejections may occur in the machine surroundings due to the ignition of the MWF-air mixture in the interior of the machine. Even though the majority of such fires turned out without serious damages, in some individual cases insufficient safety measures resulted in a total burn down of the workshop and damages running into millions. In the following, a possible protection concept and measures for the protection of employees against fire and explosion hazards when using machine tools are described. In order to prepare the hazard evaluation, the Annex contains „The recurrent theme“ and check lists for guidance.

Contents

1 Selection of low-emission MWF

By selecting low-emission metalworking fluids (MWF), aerosols and vapours in the interior of the machine can be reduced. Low-emission metalworking fluids are characterized by the following properties:

- formulated with low-evaporation mineral oils or
- synthetic esters and/or special liquids
- addition of anti-mist additives

Figure 1: Flame ejections [6]

It is principally recommended to select the MWF with the lowest vaporization losses (according to Noack procedure at 250°C), the highest flash point and if possible the highest viscosity required by the machining process.

Investigations show that increasing the temperature of an MWF by 10 °C, results in the doubling of aerosol formations. If the MWF temperature is successfully monitored and kept at low temperature by suitable measures, misting behaviour can be significantly improved. This can be achieved by:

- sufficient quantitys of WMF
- sufficient flooding of the cutting zone
- baffle plates for improved coolding
- general cooling

Besides the vaporization and misting behavior of the MWF, the following technical safety characteristics are relevant for the evaluation of the explosion risk:

- Lower explosion threshold in g/m^3,
- Maximum explosion pressure in bar (g),
- Maximum pressure increase, expressed by the K_P value in bar X m/s.

For MWF aerosols, the following values for the above characteristics are given in technical literature [1,2,3,4]:

Lower explosion threshold	25 g/m³	-	60 g/m³
Max. explosion pressure	7,2 bar	-	7,7 bar
K_P-value	75 bar·m/s	-	103 bar·m/s

(The explosion pressures and K_P values are determined experimentally and are maximum values).

In practice, the introduction of tramp oils and residues such as

- machine cleaning and care products,
- cleaning agents and solvents on workpieces,
- tramp oils etc.

into the metalworking fluid circuit of the machine tool should therefore be avoided as far as possible (information on MWF care, see VDI 3397 Sheet 2, BGR 143). A possibility of reducing the above hazards is the use of compatible multi-functional oils (see VDI 3035).

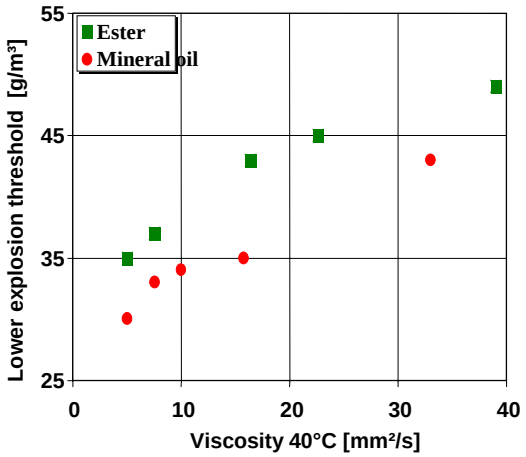

Figure 2: Lower explosion thresholds of WMF-emissions [3]

2 Measures against hot surfaces and "other ignition sources"

In most cases, machine fires during operation are started by an incandescent chip, a grinding spark or an overheated tool. Therefore, reliable and adequate cooling of the machining zone should be provided by the MWF.

The MWF circuit should be dimensioned (pipe cross-sections, storage tank, pumps etc.) so that a sufficient quantity of MWF is available to flood the cutting zone at all times and for every tool. For information on the design of the MWF circuit see VDI 3035, VDI 3397 Sheet 1. Measures for best possible flooding are e.g.:

- Cutting fluid flooding at low pressure (2 to 4 bar),
- Flushing (abrasive tools etc.) with 30 l/min at high pressure (up to 100 bar),
- Extinguishing of sparks with an additional MWF supply at the points of generation (lower nozzle during grinding).

The shape of the flushing nozzle (pressure, nozzle geometry and correct setting) is also relevant for the cooling effect and the degree of atomization. Flooding with large quantities and low pressures in the close vicinity of the tool is advantageous. By the installation of additional nozzles and their arrangement as "MWF rinsing curtains", mist volumes can be further minimized. It is necessary to correctly adjust and direct the nozzles towards the workpiece/cutting zone area.

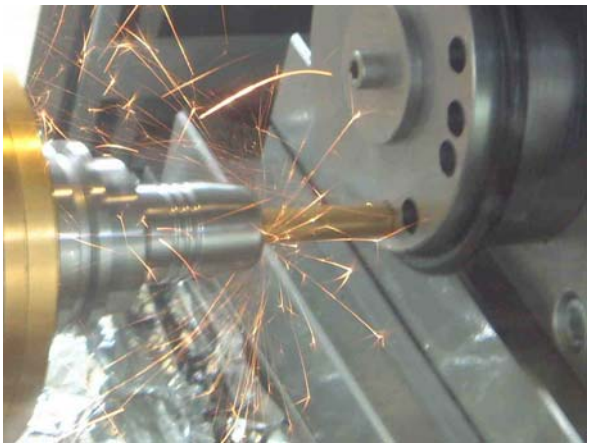

Figure 3: Ignition sparks during drilling [6]

For monitoring the MWF supply, switches for high and low pressure or flow control devices or monitoring of the pump motor currents are mainly used.

Generally, tools should be checked for their condition and be exchanged when their service life specified by the manufacturer has elapsed. By means of process monitoring, the above situations affecting safety due to tool wear can be recognized.

3 Engineering design measures: machine tool

In case of an ignition of the WMF-air mixture and during fires, flames and hot gases may escape from the machine tool. In order to reduce the hazards by flames and hot gases for the operator and the surrounding, door labyrinths are installed in the area around the machine tool doors.

If parallel loading and machining is possible at the setting point of the pallet exchanger, the loading area should be separated from the working area with a flame retarding design.

Unavoidable openings such as workpiece openings should be carefully sealed, e.g. by flaps or sliders, which only release during a workpiece change. The vision panels consist of polycarbonate and are positively fitted (DIN EN 12415).

The optimum information exchange between the control systems of the machine tool, the extraction unit and the automatic extinguishing system is the basis for the safe operation of the overall system.

It should only be possilbe to start the machine, if:

- the extraction and chip removal systems are ON
- door is locked with guard locking
- the extinguishing system is ready to operate

Indicated failures should be automatically notified and cleared without delay. Only then, may the system be started.

4 Extraction systems

In order to reduce enrichment of the flammable and possibly explosive MWF emissions inside the machine tool and in the immediate surroundings, they are captured, extracted and separated by extraction systems.

In general, systems for the extraction of flammable air impurities and explosive mxtures should be made of conductive or dischargeable electrostatic materials and should be earthed.

If a separator/pre-separator is used, it should be designed as ignition source free type, i.e. no moving parts or electric equipment with surface temperatures above the ignition temperature are on the intake gas side within the separator. The extraction fan is on the air intake side.

To avoid MWF aerosols and vapours escaping, low pressure must be maintained inside the enclosure. The air motion should always be directed towards the machining room and not vice versa.

The extraction point (connector) in the machine interior should be designed so that no coarser particles, metalworking fluid and chips can get into the extraction system and accumulate in the pipes. This is achieved if the following criteria are taken into account:

- Extraction point as far away as possible from the machining zone,
- Avoid lateral flows at the extraction point,
- Consideration of the arrangement of MWF nozzles, nozzle placing, main atomization direction and chip flight when selecting the extraction point,
- Baffle plates or mechanical pre-separators additionally avoid the introduction of MWF aerosols and chips into the extraction circuit,
- The air velocity at the extraction point should be as low as possible (< 8 m/s).

Ducting should be non-inflammable and should not be electrostatically chargeable (ensure that ducting is earthed, if possible, no use of folded spiral-seam ducts).

Ducting should be routed so that no introduced or condensed MWF can accumulate inside (avoid cavities and uneven ducting).

For the interior control of the ducting (oil deposits and chip accumulations) control/inspection hatches should be installed at required intervals.

If there is a risk of flames entering the piping and ducting and propagating to other areas, rapid-action shut-off valves have to be used. If a fire occurs in the machine tool, the shut-off valve immediately closes in order to protect the piping, ducting and extraction system.

Figure 4: Pressure control [6]

The precondition for the start of the machine is an operating extraction system maintaining the minimum volume flow/extracted air flow specified by the machine manufacturer (control e.g. by means of pressure or flow controls). If the required extraction rate is not achieved or in case of failure, the machine must be stopped.

5 Pressure relief devices

The pressure relief device (valve) has the purpose of releasing excess pressure generated by the ignition of a mixture to the machine's surroundings.

The pressure relief valve is usually installed in the cover of the machine tool. It is intended to relieve pressure as quickly and directly as possible and to direct flames and hot combustion gases into safe areas and thus reduce the risk to machine operators.

The response pressure of pressure relief devices for opening should be very low (e.g. < 5mbar). The device only opens briefly and shuts back closed.

When a MWF/air mixture ignites, long jets of flame may escape from the pressure relief device which pose a hazard to the surroundings of the machine. As a result, no flammable materials (wooden crates, insulation, etc.) should be located above the pressure relief valve.

Figure 5: Jets of flame [6]

A more detailed design including transfer to common pressure relief devices may be carried out according to research report VDW 3002 „Explosion pressure relief of metal cutting machine tools “[5].

6 Extinguishing of machine fires

If the operation of a machine tool involves a high risk of fire, integrated fire alarm and extinguishing systems must be installed (DIN EN 13478). Here, the order should be as follows:

- Manual extinguishing system,
- Fire alarm system in combination with a manually operated extinguishing system,
- Fire alarm system in combination with an automatic extinguishing system.

In practice, the implementation ranges from a fixed fire extinguisher with corresponding piping to a fire alarm system coupled to an automatic extinguishing system.

The choice of the extinguishing method and the integrated fire alarm and extinguishing systems used for machine tools depends on the degree of potential hazard to persons, property and the environment.

In case of a existing high risk of personal injury, heavy damage to assets and the environment, and even of hazards of subsequent metal fire (e. g. magnesium), the fast detection and the fast extinguishing of a fire by automatic fire extinguishing systems is essential.

6.1 Extinguishing agent

Extinguishing agents for fires of flammable metalworking fluids can be:

- Extinguishing gases, e.g. oxygen displacing gases like CO2, N2, inert gases and their mixtures.
- Water (using water atomizing technology / water misting technology)
- Foam
- Powders of fire classes ABC or BC (oil fires correspond to fire class B)

Attention:

If carbon dioxide is used as the extinguishing agent, health hazards have to be anticipated at concentrations of 5 per cent by volume or more. Concentrations of more than 8 per cent by volume can pose a danger to life (see also BGR 134).

Metal fires (Mg, Al, Ti) cannot be extinguished with extinguishing agents of fire classes A, B and C! At present, powder extinguishing agents of fire class D exist for the fighting of metal fires. Suitability for the extinguishing of metal fires must be proven for all other extinguishing agents.

Design and construction criteria for extinguishing systems are e.g. published by VdS Schadenverhütung GmbH, (see www.vds.de).

The planning and installation of the fire extinguishing system should be done by a specialist company, if possible, in collaboration with the machine tool manufacturer.

Further information on requirements for alarming and delay are contained in the corresponding regulations (e.g. BGR 134, BGI 888).

7 Protective measures in the machine surroundings

In order to avoid propagation of a machine fire to its surroundings and personal injury during a fire or extinguishing, general rules of behaviour in case of fire and general rules of preventive fire protection must be observed (see also information BGI 560). This includes:

- Reduction of combustible substances near to the machine (flammable materials, cardboard, oil)
- Provision of a sufficient number of manual fire extinguishers at the workplace (BGR 133)
- Enforcing smoking prohibition
- Keeping emergency exits, escape and rescue routes free

- Behaviour in the case of fire: rescue chain, emergency calls, fire service

To reduce fire hazards, there should be as few combustible materials in the immediate vicinicty of a machine tool as possible.

Packing materials or oil-soaked cleaning rags should, under no circumstances, be stored in the immediate vicinity. Regular emptying and cleaning of oil pans and gratings (provide drains, use oil extractors) and the disposal of cardboard boxes and oil-soaked rags significantly reduces fire hazards.

Used and soiled cleaning materials should be kept in non-flammable, closed containers.

Figure 6: Ignition sources in the chip container [6]

Furthermore, the chip containers should be emtied regularly in order to reduce the fire hazard and prevent possible self-ignition. The oberservance of a general ban on smoking is indispensable in these areas.

8 Instructions - Behaviour of workers in case of fire

For activities at machine tools using flammable metalworing fluids, aspects concerning fire and explosions portection should also be addressed within the framework of the training and it should be pointed out to the following hazards:

- Hazard of backfire when opening the machine door after a fire
- Wearing of oil soaked clothing: increased fire hazard in case of backfire (wicking-effect)
- Flame ejection at machine tool door gaps and openings
- Hazard of suffocation in confined spaces due to fire smoke and fumes
- Hazard of suffocation due to extinguishing gas carbon dioxide (from 5 Vol. %)
- Do not touch machine subsequent to a fire: possibly live, hot

In principle, the instruction includes briefing on the function, operation and handling of installed safety devices, such as e. g. extinguishing systems.

Leaflet

The expert committee „Mechanical engineering, manufacturing systems, steel construction“ (Fachausschuss “Maschinenbau Fertigungs-systeme, Stahlbau) has worked out a leaflet which describes in detail the measures against fire and explosion hazards during operation of machine tools.

The leaflet contains information on the evaluation of hazards caused by fire and explosions. Checklists and sample operating instructions are available as assistance in the execution of the hazard evaluation and the implementation of protective measures.

This leaflet is addressed to employers and provides information which the manufacturer may also take into account when placing a machine tool on the market in order to comply with the requirements of the Machinery Directive concerning fire and explosion prevention and protection (Annex 1 No. 1.5.6 and 1.5.7).

The leaflet may be ordered at fach@bgmet.de.

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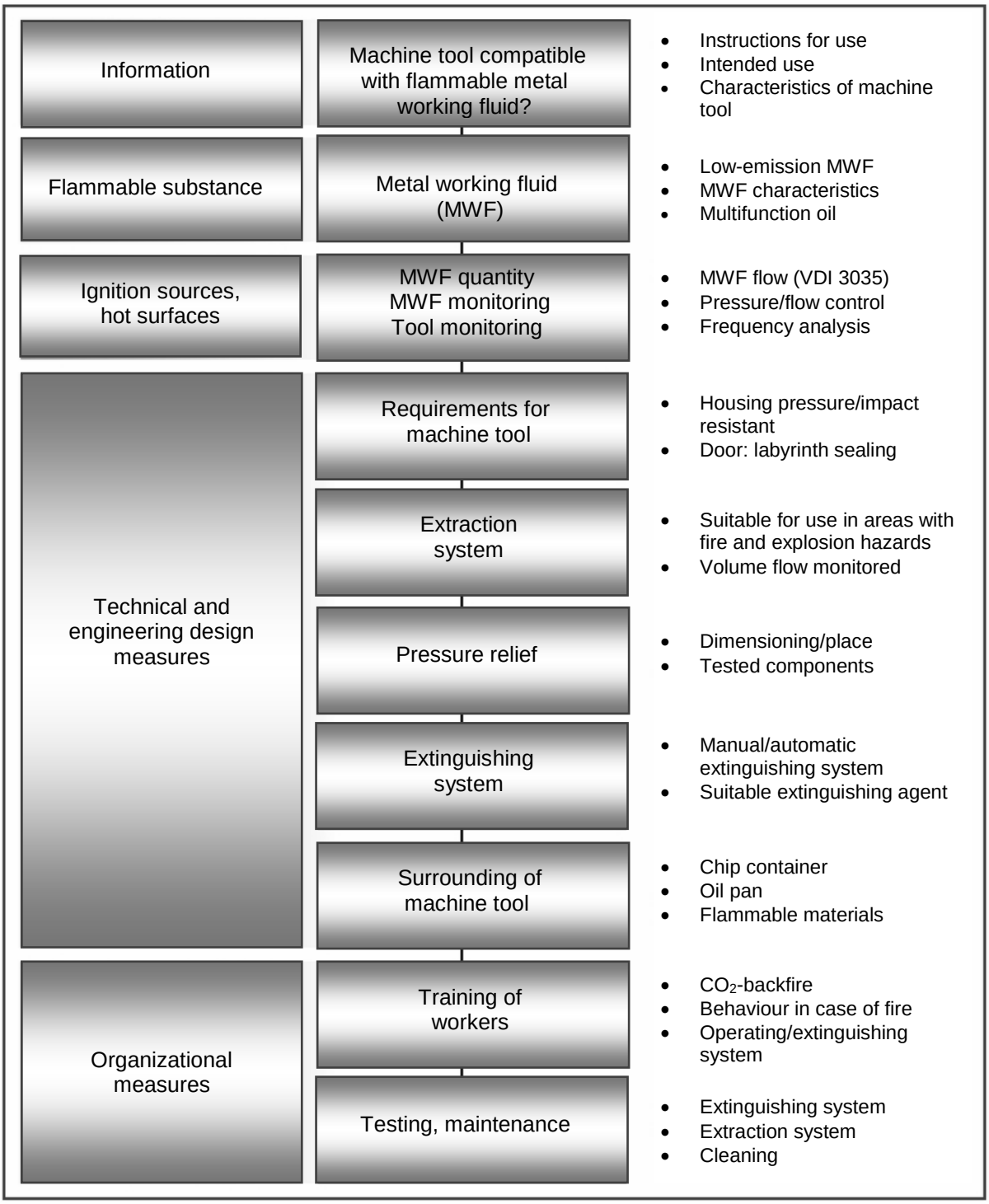

Figure. 1: „The recurring theme“: procedure for the hazard evaluation

Tendency	Viscosity grade acc. to DIN 51519 (ISO 3448:1992)	Viscosity at 40°C acc. to DIN 51562	Flashpoint acc. to ISO 2592 (CoC)	Evaporation losses at 250°C acc. to DIN 51581-1, 2 (Noack procedure)	Examples of machining processes
Decreasing fire and explosion hazard	ISO VG 5	4,14 - 5,06 mm²/s	> 120 °C	< 85 %	Honing, reaming
	ISO VG 7	6,12 - 7,48 mm²/s	> 145 °C	< 80 %	Grinding
	ISO VG 10	9 - 11 mm²/s	> 155 °C	< 60 %	Deep hole drilling
	ISO VG 15	13,5 - 16,5 mm²/s	> 190 °C	< 25 %	Turning, milling
	ISO VG 22	19,8 - 24,2 mm²/s	> 200 °C	< 15 %	Drilling
	ISO VG 32	28,8 - 35,2 mm²/s	> 210 °C	< 13 %	Threading Thread rolling
	ISO VG 46	41,4 - 50,6 mm²/s	> 220 °C	< 11 %	Broaching

Table 1: Characteristics of non-water soluble metal working fluids

Annex: „The recurring theme“, check lists: Measures at machine tools with flammable metal working fluids

Machine tool	Yes	No
Machine tool suitable for neat oil machining (non water-soluble MWF)?		
Oil machining dealt with in the “Technical documentation”?		
Extinguishing system present?		
Extraction system present?		
Extinguishing system deactivated when machining room door open?		
Machining room door stays locked during machining and emergency stop?		
Machining room door not lockable when the machine is open and switched-off?		
No oil pool formation in the machining area, drive room or handling area?		
No oil pool formation in the area outside the machine (oil pan regularly emptied)?		
Sufficient pressure resistance of guarding?		
Pressure relief device present?		
Door labyrinths resistant to outbreak of flames?		
Other openings (e.g. loading and unloading openings, gaps) in the operating area covered?		
If applicable, extinguishing hole present?		
Transparent screens made of polycarbonate undamaged (see DIN EN 12 415,VDW 0209)?		
Transparent screens positively fitted (not with rubber edging)?		
Alarm device present? optical		
acoustic		
Marking: Information signs, CO_2 hazard warnings, extinguishing system?		

Machine tool: Control system (example)	Yes	No
Start of machine:		
• Extraction system on/chip removal on		
• Door interlocked (with guard locking)		
• Extinguishing system ready to operate (optical and thermal sensors, activation)		
• MWF supply monitored		
Extinguishing process:		
• For CO_2: If applicable, activation delay set (BGR 134)		
• Extraction system off		
• MWF supply off		
• Extinguishing system ready to operate		
• Doors interlocked (with guard locking)		
• Alarm device (optical/acoustic) active		
• Machine drive off		
Opening of the door:		
• Extinguishing system inactive		
• MWF supply off		
• Machining process safely stopped		
• Extraction system: If applicable, keep in mind short overrun!		

Pressure relief device	Yes	No
Route flames and hot gases into safe areas		
Installation in the cover areas		
Provide pressure relief area: ~ 0.1 m^2/m^3 work room (see VDW 3002)		
Reliable opening at minimal excess pressure (<< 5 mbar)		
Reliable closing subsequent to pressure relief		
Suitability as protective device verified by the manufacturer (e.g. test)		
No flammable materials (wooden crates, insulation materials) in the danger zone around the pressure relief device		
Danger zone warning signs around the pressure relief device		

Extraction system	Yes	No
Extraction system suitable for neat oil machining? (Instructions for use/technical documentation) e.g.: • Design free of ignition sources		
• Arc-free fan drive on the intake side		
• System and ducting earthed		
Air flow monitored (pressure, flow controls)? • Extraction starts when machine starts		
• Flow too low: signal indication, machine tool failure indication		
Extraction capacity adjusted via throttle valve/speed control		
Extraction system integrated into extinguishing concept: • Provides sufficient quantity of extinguishing agent in extraction system and separator		
• If applicable, extinguishing nozzle and fire detection in separator		
• Consider fan overrun		
Ducting: • Slightly inclined without depressions (if applicable, provide MWF drain)		
• Provide inspection holes/control openings		
• Regular inspection for deposits, if necessary, cleaning		
For ducting system: Prevention of fire propagation, e.g. by means of • Flame arresters (in pipes and in the machining area)		
• Shut-off valves (at the machine tool)		
Effective pre-separation at the machine outlet, e.g. by means of baffle plates, pre-separators		
Regular maintenance of system and ducting: Maintenance schedule (Instruction handbook)		
In case of fire: Interruption/extraction by means of • Fan motor-brake (reduction of overrun)		
• Automatic shut-off valve		

Metalworking fluids	Yes	No
Low-emission metalworking fluid used?		
1: Observe characteristics, e.g. in the safety data sheet, product information		
Example: For MWF with a viscosity of 4.1 [mm/min at 40 °C] • Flash point > 120 °C (see Table 1) • Noack evaporation losses [250 °C] < 85 % (see Table 1)		
2: MWF with anti-mist additives (consider filterability)		
MWF compatible with hydraulic oils, slideway oils (multi-functional oil)?		
Sufficient quantity of MWF (MWF circuit, storage tank) during machining (see VDI 3035)?		
No drag-in of large quantities of:		
• Cleaning agents and solvents (on workpiece/part) into the MWF circuit		
• Hydraulic oil into the MWF circuit		
MWF supply: • Monitored? (pressure or flow controls)		
• Sufficient cooling quantity, MWF nozzles?		
• MWF nozzles arranged in the best possible way?		
Avoid considerable temperature increase of the MWF • Increase of MWF temperature by 10 °C = doubling of misting		
• MWF temperature monitored?		
• Possibility of cooling: e.g. baffle plates, MWF container used sufficiently large?		

Extinguishing system	Yes	No
Use suitable extinguishing agent (consider fire class)		
Attention: • For extinguishing gases, e.g. carbon dioxide (CO_2) consider danger to personnel (see BGR 134, BGI 888)		
• For metal fires (magnesium, aluminium, titanium): only use suitable extinguishing agents, e.g. fire class D!		
• For powder extinguishers: considerable material damage in the interior of the machine tool possible		
Provide a sufficient quantity of extinguishing agent: • Also consider extraction system, chip conveyer, holes ….		
• Consider flow-off losses (e.g. overrun, extraction …)		
Extinguishing system: • Planning and installation: By a specialist company, possibly in agreement with the manufacturer		
• Components, planning and installation: consider the state-of-the-art (e.g. VdS Directives.)		
• Planning and installation: Demand approval test and approval protocol		
• Positioning: No adverse effects by pressure or flame propagation		
• Electrical supply and control system independent of machine tool		
• Interlocking of the extinguishing gas supply during setting and maintenance work (non-electrical or electrical shut-off devices, see BGR 134, BGI 888)		
• Regular checking of extinguishing agent tanks fill-levels: e.g. pressure controls, weighing devices		
• Gas extinguishing system: Provide sufficient pressure relief options		
• Considerable material and environmental damage, personnel injuries: Automatic extinguishing systems!		
Fire detection and extinguishing: • Use optical and/or thermal fire detection elements		
• Fire detection elements: Consider the state-of-the-art (e.g. VdS Directives)		
• Optical sensors: – consider suitability (e.g. MWF mist) – keep clean (e.g. by air purging)		
• Thermal sensors: – fire detection slower than with optical sensors		
• Extinguishing nozzles: – suitable for the relevant extinguishing agent – consider arrangement: if possible, do not direct towards door labyrinths		
Extinguishing hole and machining area door in case of fire: • Only to be opened by fire service and specially instructed persons		
Regular testing of the extinguishing system (see BGR 134)		

Instruction	Yes	No
Function and handling of the machine tool and the extinguishing system in case of fire		
Optical sensors: Avoid light flashes (lighters, welding)		
Special hazards (NEVER!): • Opening of the machine door in the event of a fire in the interior: Hazard of backfire		
• Wearing oil soaked clothing: Fire hazard (wicking) in case of backfire		
In the case of fires or explosions (BGI/GUV-I 560): • When the alarm activates: Leave the danger zone immediately		
• Use escape and rescue routes		
• Search for help: Fire service, emergency telephone numbers		
Hazards during ignition of the MWF mixture: • Violent flame ejections at pressure relief devices/ subsequent fires possible		
• Flame ejection at machine tool door gaps and openings		
• Extinguishing agent CO_2 : Hazard of suffocation (above 5 % CO_2 volume in air)		
• During extinguishing process: Ejection of flames in the door area		
• Hazard of suffocation in confined spaces due to fire smoke and fumes		
• Do not touch machine components subsequent to fire: Possibly live (electric shock) and hot (burns)		
Reduce fire hazard – Preventive measures • Regular emptying of chip container to avoid self-ignition		
• Regular emptying of machine tool oil pans (extract oil)		
• No combustible materials (cardboard/carton/oil-soaked rags) in the vicinity of the machine tool		
• General smoking prohibition: No cigarette ends in chip containers/oil pans		