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Fluid elements in machine tools

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ABSTRACT

Fluids play a major role for production machinery and serve for very different tasks as lubricating, tempering, cleaning, transmitting force and energy. Due to maintenance requirements and the environmental impact their utilization is under discussion and alternatives are looked for. In this paper an overview of the latest research activities in the field of fluid elements in machine tools is presented. The topic of the paper includes an overview of the fluids used in machine tools, the usage of fluidic elements, supply and treatment units, and their influence on machine tools performance. A link to fluid media on energy efficiency is given. Research challenges in order to increase the performance of machine tools are discussed. The paper excludes metal working fluids, which have been treated in Brinksmeier et al. [33].
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1. Introduction

Fluid elements are used in machine tools for many and very different applications as lubricating, tempering, cleaning, transmitting force and energy, sealing, and fire extinguishing with vulnerable devices. In general fluids are supplied in circuits through the machine tool, which can be subdivided in:

- pneumatic circuits, often designed as open loop circuits,
- hydraulic circuits,
- lubrication circuits,
- process fluid circuits,
- cooling or tempering circuits,
- cleaning circuits, and
- fluidic circuits used for special applications.

Fluids in machine tools are enabler for the main process as for example in hydraulic presses and electric discharge machine tools. Beside this fluidic media are required to perform many of the auxiliary tasks on machine tools. The fluids used in machine tools are as widespread as the tasks they have to fulfill and thus different are their physical and chemical properties. Pure media are rarely used. Usually the used fluids consist of one main component which is mixed with additives to adjust the chemical and physical properties, to increase the performance and or to become an eligible fluid for fulfilling the task foreseen. In Fig. 1 an illustrative example of fluidic systems in a metal cutting machine tool is shown. Here four fluidic circuits are installed. Illustratively shown is that each circuit is used for special tasks, having different requirements to the fluid.

In metal forming machine tools hydraulic circuits are often used to perform force transmission as with pressurised fluids high forces can be exerted in limited spaces. In Fig. 2 the hydraulic circuit of a deep drawing press is illustrated.

Fluidic elements are further used to increase the performance of machine tools and the process. Metal working fluids are not considered in this paper as an overview is given in Ref. [33]. Precision machine tools are equipped with aero- and hydrostatic guideways due to their low friction and excellent damping.

For layout of fluidic circuit, computational fluid dynamics (CFD) is used frequently. Solving the Navier–Stokes equations in space and time discretised models is still costly. Therefore, often just single isolated fluidic machine elements are considered in computations. Meta models developed, both derived from detailed computation models and from measurements, describing the

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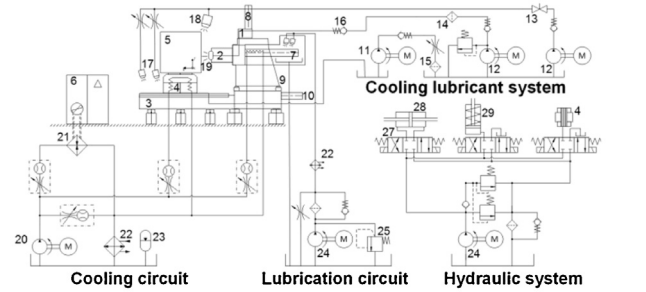

1 Column
2 Headstock
3 Bed
4 Rotary table
5 Workpiece
6 Electrical Cabinet
7 Main drive
8 Y-axis drive (spindle)
9 X-axis drive (spindle)
10 Y-axis drive (table)
11 Centrifugal pump
12 Submersible pump
13 Shut off valve
14 In-line filter
15 Belt filter
16 Check valve
17 Nozzles for flushing
18 Nozzles for external coolant supply
19 Internal coolant supply (through the tool)
20 Cooling unit
21 Air-cooling cabinet
22 Coolant device
23 Accumulator
24 Fixed displacement pump
25 Pressure relief valves
26 Nozzles (cooling headstock, lubrication (e.g main drive))
27 Directional control valves
28 Tool (clamping/release)
29 Break (at standstill)

Fig. 1. Simplified representation of the relevant fluid power systems in a milling centre [101,242].

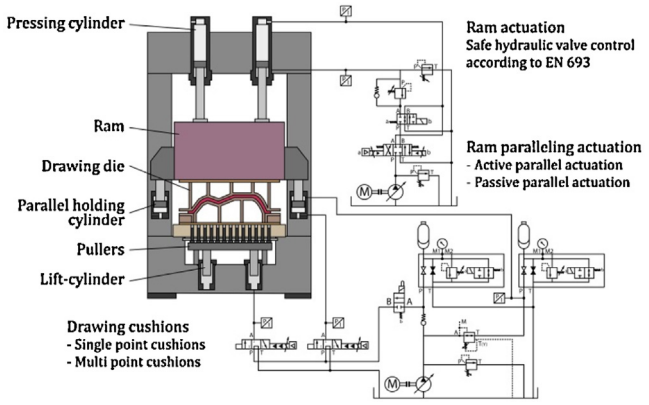

Fig. 2. Simplified hydraulic circuit diagram of a hydraulic deep drawing press with tool, according to Ref. [71].

behaviour of the fluidic machine elements in their interaction with the surrounding machine tool structure. Fluid elements are further discussed in specialized machine tool topics by:

- Bryan [34]: International status of thermal error research,
- Neugebauer et al. [181]: Mechatronic systems for machine tools,
- Abele et al. [2]: Machine tool spindle units,
- Altintas et al. [8]: Machine tool feed drives,
- Duflou et al. [65]: Towards energy and resource efficient manufacturing: a processes and systems approach,
- Mayr et al. [166]: Thermal issues in machine tools,
- Brinksmeier et al. [33]: Metalworking fluids-mechanism and performance,
- Möhring et al. [172]: Materials in machine tool structures.

With the upcoming discussions on energy efficiency of machine tools in the early 21st century, the lossy fluid elements of machine tools became regarded as critical. Therefore researchers think about replacing fluid elements in machine tools increasingly by more energy efficient elements.

Especially the influence of the environment is crucial. On one hand the environment itself, e.g. temperature fluctuations, dust, mist etc., influences the performance of fluid elements on machine tools and on the other hand the environment is influenced by fluids from the machine tool, e.g. by leakage, by oil mist, by aerosols used for cooling and lubricating means.

In Section 2 of this paper fluids used on machine tools are discussed. Their chemical and physical properties are presented. Section 3 gives an overview of the applications and function of fluids. The supply of fluidic media and their treatment is discussed in Section 4. In Section 5 the influence of fluids on machine tools is investigated. The research activities in the field of energy efficiency and thermal behaviour of machine tools are presented in Section 6. With a conclusion and outlook of open issues and future research activities the paper closes.

2. Types of fluidic media for machine tools

The different types of fluidic media used in machine tools depend on their applications and functions. Also non supported fluids, like the environmental air, are influencing the performance of machine tools. The base fluids are usually treated before usage in machine tools, e.g. compressed air is dried and filtered or oil is added for lubrication means. The media in machine tool applications can be gaseous or liquids, which is not a unique classification as some fluids change their state of aggregation during usage, e.g. liquids in heat pipes.

2.1. Base fluids

Base fluids in machine tools are mineral oils, synthetic oils, esters, biodegradable oils, and water. Leaks in the hydraulic system cause intermixture of the hydraulic oil with the cutting fluid. It is therefore important that the different media used in the machine tool are compatible. The hydraulic oil and the cutting fluid have to be compatible to avoid a short term replacement of the metal working fluid due to contamination or even vice versa. In Ref. [156] it is reported that due to leakage up to four times a year the volume of the hydraulic oil enters the cutting fluid circuit.

The hydraulic oil circuit in some machine tool applications is further used for lubrication means e.g. for the guideways. The measures in reducing the amount of media in machine tool, to reduce the circuit auxiliary units like filters and pumps, is often limited by extreme requirements on the fluid. In milling machines horizontal guideways are often lubricated with G 68 and HG 68 [125] slideway oils. For inclined and vertical axes guideways G 220 and HG 220 slideway oils are commonly used. In roller guide ways also grease is often used for lubrication. Common used grease in machine tool applications are of K2K class [156] in accordance to Ref. [54]. To guideway lubrication oils often anti-sticking additives, such as extreme pressure (EP) additives, and anti-wear additives (AW) are added.

The largest volumetric amount of fluids used in machine tool applications, apart from metalworking fluids, are hydraulic fluids, followed by guideway oils and gear oils. An investigation on hydraulic systems of machine tools in 1995 [156] in Germany showed that the working pressure range of 80% of all machines is between 50 and 100 bar. The relatively low pressure in hydraulic systems of metal cutting machine tools is installed to avoid chatter marks occurred by circuit vibration caused by the compressibility of the fluid at higher pressure. The hydraulic system of 13% of the investigated machine tools work in the range between 100 and 150 bar and just 7% work in higher pressure ranges. The investigation further shows that two types of hydraulic oils with viscosity grades of ISO VG 32 and 46 in accordance to Ref. [57] are dominant:

- HM, in accordance to EN ISO 6743-4 [56], which are oils with additive to increase the corrosion protection, reducing aging and avoid seizing in mixed operation. These oils are still often described as HLP in accordance to Ref. [55]. H indicates hydrostatic hydraulic systems, L stands for lubricants, industrial oils and related products and P specifies modification with extreme pressure additives.
- HLPD, which are oils with additives increasing the corrosion protection, reducing aging and deterging features. HLPD is a non-standardized common term. Compared to HLP fluids HLPD are oils with detergent/dispersant (DD) additives.

Hydraulic oils for machine tools are detergent and disperse oils absorbing small amounts of waste and water and are not

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