Retrofit unit for cryogenic process cooling

written by **Thomas Götz** and **Andreas Gebhardt,**
Fraunhofer Institute for Manufacturing Engineering and Automation IPA

The use of carbon dioxide as a cooling medium can significantly improve the economic efficiency of machining. For the simple retrofitting of cryogenic cooling technology in existing machines, *MHT GmbH Merz & Haag* and *Fraunhofer IPA* have developed and successfully tested a new solution.

In the machining process, tool and workpiece are subjected to high mechanical loads, whereby the mechanical energy applied for chip formation is almost entirely converted into heat in the shear and friction zone *(figure 1)*. Only about 75 % of the resulting heat flows are dissipated with the chip, while the remaining approx. 25 % are introduced into the cutting tool or the workpiece. On the one hand, this thermal load leads to an intense heating of the workpieces, which is associated with a corresponding expansion of the latter. In addition, the high temperatures cause signs of wear on the cutting tool, such as mechanical abrasion, diffusion processes or scaling. These effects have a negative impact on the machining quality and machining accuracy of the workpieces as well as the tool life. *(Klocke und König 2008; Lang 2012)*

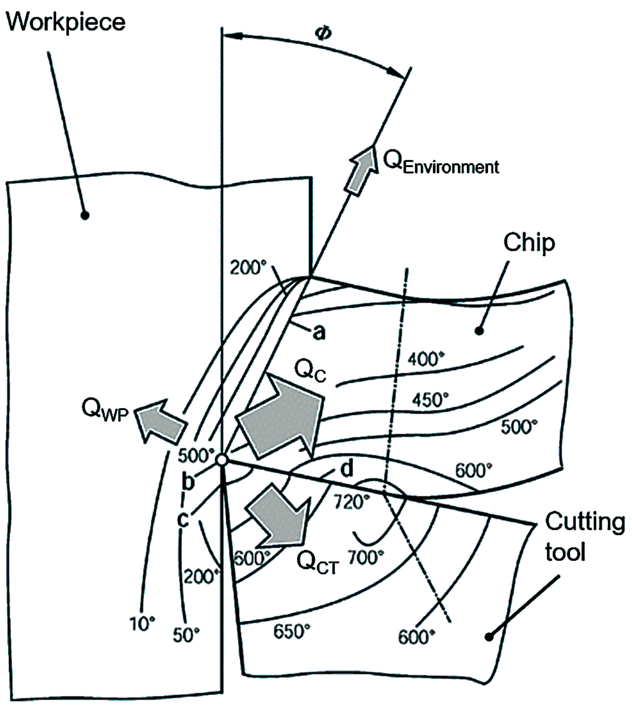

figure 1:
Energy conversion and heat during machining
(Kühn et al. 2018)

Cooling strategies in machining technology

Cooling lubricants are typically used to avoid or reduce a temperature load in the machining process whereby cutting tools and workpiece are usually flooded with the cooling lubricants. This cooling strategy, known as wet machining, does not only allow the removal of the process heat from the tool-workpiece contact point by cooling, but also a reduction of frictional heat by lubrication. Cooling lubricants thus contribute to a high level of performance in a wide range of machining processes. *(Lang 2012)*

Alongside the technological advantages associated with the use of cooling lubricants, however, they pose a not insignificant risk to people and the environment. For example, cooling lubricant components such as bactericides and fungicides can trigger illnesses in the event of contact or aspiration. In addition, leakage and drag-out losses, washing water or the disposal of used cooling lubricants lead to pollution of soil, water and air. Legislators have therefore imposed strict regulations on the handling and disposal of cooling lubricants. For the industry, these requirements involve, apart from a high level of responsibility towards their employees, a high financial burden as well (e.g. disposal costs). *(Klocke und König 2008; Koch 2015)*

One approach to completely avoid the use of cooling lubricants is the so-called dry machining, in which either limited air cooling is realized or completely without cooling. In dry machining, the coatings of the used cutting tools are therefore of particular importance, with the aid of which the thermal load on the cutting materials is to be reduced and adhesion and friction processes between the cutting tool and the workpiece are to be reduced, too. Disadvantages of dry machining include, among others, higher heat generation in the process, which can have a negative effect on dimensional accuracy, and the elimination of chip removal by cooling lubricants.

If the lubricating effect of cooling lubricants cannot be completely dispensed with, minimum quantity lubrication can also be used during machining. With this cooling method, an aerosol of air and lubricant is fed to the cutting point. *(Lang 2012)*

Another alternative to conventional cooling lubrication concepts is cryogenic process cooling *(figure 2)*. Here, media with extremely low temperatures are used for cooling. Typical cryogenic media are liquefied gases such as hydrogen (boiling point 20.268 K = -252.882° C) and nitrogen (boiling point 77.35 K = -195.80°C), but also carbon dioxide snow (sublimation point 194.5 K = -78.5°C). *(Klocke 2017)*

Major drawbacks of using hydrogen and nitrogen in machining are the complex storage, feeding and insulation technology. For example, liquid nitrogen boils under atmospheric pressure, which is why vacuum-insulated containers must be used for storage. *(Klocke 2017; Awiszus et al. 2020)*

In comparison, carbon dioxide (CO_2) is much easier to handle as a cooling medium because CO_2 is in liquid form at room temperature and under high pressures. This property allows the liquid CO_2 to be fed through a pipeline to the machining site under a pressure of 6MPa without insulation. *(Klocke 2017; Awiszus et al. 2020)*

At the time of discharge, an abrupt pressure drop affects the liquid CO_2, which subsequently expands to a mixture of solid (45 %) and gaseous (55 %) states. The solid phase of the mixture is also referred to as dry ice and has a significantly higher cooling capacity as compared to the gaseous phase. *(Klocke 2017)*

The carbon dioxide does not form harmful vapors and mists that can be inhaled with the air, so there is no health risk for the operator. Also, the cleaning of the workpieces or the disposal of the chips is simple. The workpieces remain dry and are not contaminated with oils and greases, which means that a final cleaning of the workpieces is largely unnecessary.

Feeding strategies of cryogenic cooling

In the case of cryogenic feeding strategies, a fundamental distinction can be made between cryogenic flood cooling and cryogenic internal cooling *(figure 3)*.

In cryogenic flood cooling, the machining point is flooded with the cryogenic cooling medium from the outside. Although this feeding strategy is simple to implement, it is also associated with some disadvantages. On the one hand, the cooling medium does not reach the cutting edge of the tool sufficiently, and on the other hand, there is a high consumption of the cooling medium required. In comparison, cryogenic internal cooling achieves a significantly higher cooling capacity, since the cooling medium is fed directly to the machining point. In addition, the consumption of the cooling medium can be significantly reduced with this feeding strategy. *(Lang 2012)*

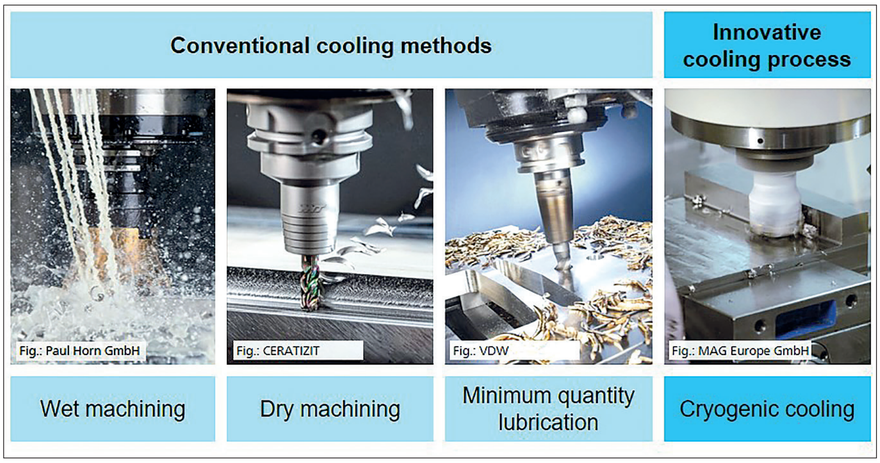

figure 2:
Cooling lubrication processes in machining production
(after Lang 2012)

Systems currently available on the market for cryogenic internal cooling use the concept of feeding the cooling medium through the motor spindle by means of a rotary feedthrough. However, this concept is associated with an increased risk of unwanted cooling of machine components, which in turn can lead to inaccuracies in the production or greater wear. In addition, the required modification of the motor spindle is complex and cost-intensive. *(Volz und Abele 2019)*

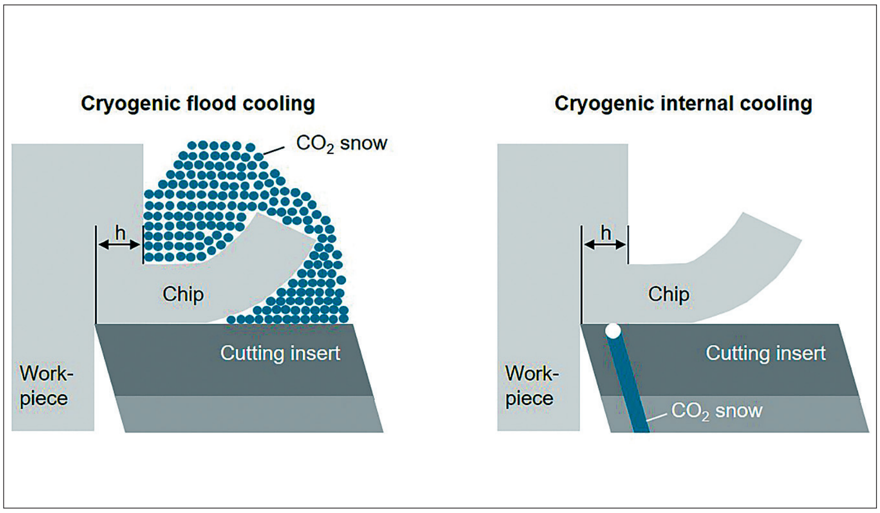

figure 3:
Feeding strategies of cryogenic cooling
(Lang 2012)

Retrofit unit for cryogenic cooling

Due to the existing disadvantages of a coolant supply through the motor spindle, the use of the IKZ medium distributor of *MHT GmbH* for cryogenic machining using CO_2 was investigated as part of a joint project between *MHT GmbH Merz & Haag* and the *Fraunhofer Institute for Manufacturing Engineering and Automation IPA*. The medium distributor is an independent system for internal cooling (IKZ), consisting of the components spindle attachment, IKM annular body and IKM tool holder *(figure 4)*. The system is characterized by the fact that it can be retrofitted in existing machines at low cost and without great effort.

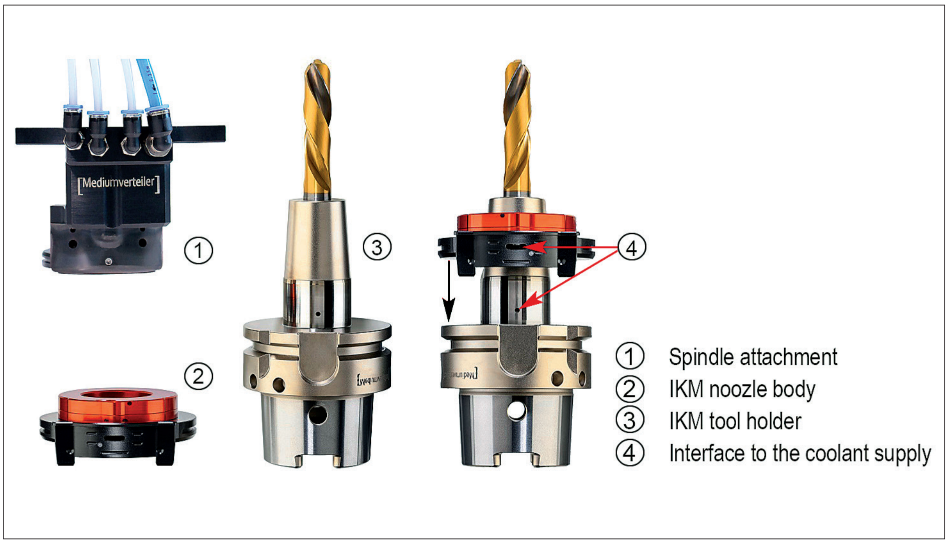

figure 4: IKM- medium distributor

A control system was also developed for actuating the solenoid valve, in which the feed is carried out via freely definable machine parameters. The machine parameters are provided by the machine control used, a Siemens Sinumerik 840d CNC control, via an OPC UA server, queried with the aid of the Node-RED development tool and transmitted as a trigger signal to an industrially suited, freely programmable PLC of the CONTROLLINO type. The PLC uses the trigger signals to open or close the solenoid valve so that the liquid CO_2 can be fed to the machining point through the cooling channel of the cutting tool. In the future, the control system will make it possible to implement a speed-, tool- or material-dependent coolant supply.

Within the project, liquid CO_2 was supplied from immersion tube bottles using a high-pressure hose via the spindle attachment, whereby the feed could be controlled via a solenoid valve, which was interposed immediately in front of the spindle attachment.

As soon as the solenoid valve was opened, the liquid CO_2 got into the internally cooled cutting tool via the interfaces on the ring body and the tool holder and expanded to CO_2 snow when exiting the cooling channel. Extensive research has shown that the MHT system, which is actually designed for MQL or compressed air, also seems suitable for cryogenic cooling.

Summary and outlook

Within the scope of the joint project, a retrofit unit based on MHT medium distribution for cryogenic process cooling was developed and successfully tested. Further future research is needed to observe the effects of the CO_2 cooling medium on the tightness at the interfaces over a longer period of time. In addition, further extensive tests on cryogenic machining should be carried out. Here, the focus should be primarily on the evaluation of tool life and surface quality under variation of cutting tools, materials, contact widths, speeds as well as the CO_2 volume flow. The knowledge gained from this should be used to implement an intelligent control system.

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