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Detailed information on energy research

Energy-efficient finishing in mechanical engineering

Vehicle manufacturers testing minimum quantity lubrication for precision machining engine components

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When producing machine components, the grinding stage is a production process with comparatively low energy efficiency. Up to 90% of the energy deployed is released as frictional heat. Large amounts of lubricants and coolants flood the workpieces and tools to cool them. The supply of coolants and their processing require enormous expenditure, including in terms of the energy. Researchers from industry and science have therefore jointly developed new processes that produce significant savings potential with minimum lubrication.

Turning, milling and drilling enable blanks to be transformed into machine components. These production processes are already used with minimum quantity lubrication (MQL) in mass production. Subsequent precision machining of the workpiece removes any remaining dimensional deviations and rough edges. This often requires, however, a grinding process in which until now it has not been possible to provide minimum quantity lubrication at an industrial scale. Rather, the current state of technology requires flood cooling and lubrication. The expenditure required for feeding, processing and cooling the cooling lubrication is considerable. The energy required considerably exceeds that required for the actual grinding process and can amount to 80% of the overall requirement in this work step.
Using Volkswagen AG's camshaft production at its Salzgitter factory as an example, the researchers and developers have for the first time developed a mass production grinding process with minimum quantity lubrication. Between 5,000 and 7,000 litres of coolant had to be circulated for this purpose per hour until now. The non-rounded contours of the workpieces, the large contact lengths in the concave flank areas, the considerable hardness of the induction-hardened chromium steels and the required precision of the components already complicate the process during

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the wet machining. If, according to the project partners, the camshafts can be ground with minimum quantity lubrication, the success ought to be transferable to other components and production processes. At the beginning of the project it was felt that there was a realistic chance of halving the energy deployed during this process stage.

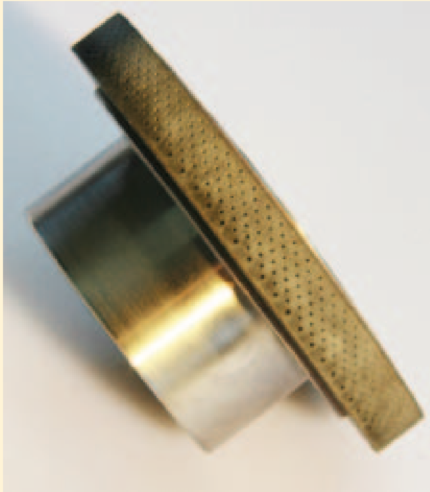
The problem of frictional heat

During the drilling and milling processes, a precise and sharp cutting edge cuts the stock from the workpiece like a knife peeling apples. Abrasive grains, on the other hand, grind grooves into the material with geometrically undefined cutting edges. In addition to chip formation, they create elastic and plastic deformations, buckling and compaction. That is why the frictional heat released during grinding exceeds that produced during drilling work by around two orders of magnitude in relation to the material removed. By way of calculation, that is sufficient to melt a multiple of the metal removed. This heat has to be securely removed since "grinding burn", which is a change in the metallurgical structure caused by overheating, could, together with thermally applied internal tensile stresses in the workpiece, make it unusable. The grinding tool can also suffer damage.

From flooding to minimum quantities

The coolant in optimised flood cooling removes more than half the heat. The chips remove another quarter. Because the grinding wheel and the environment also absorb heat, less than 15% remains in the workpiece. At the same time the coolant removes the chips, provides corrosion protection and tempers and cleans the machine.

With minimum quantity lubrication, the lubricant can no longer provide all these functions because only a few millilitres are added to the machine per hour. The researchers therefore faced the task of optimising the grinding machine, abrasive body and lubricant feed so that no more frictional heat is created than can be removed via the tool and chips without damage. It was also important to prevent flying sparks and to ensure that the chips are completely extracted.



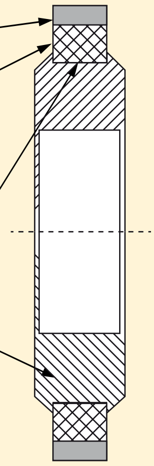


Fig. 1 *Grinding wheel with microstructured coating. Source: Fraunhofer IWU*

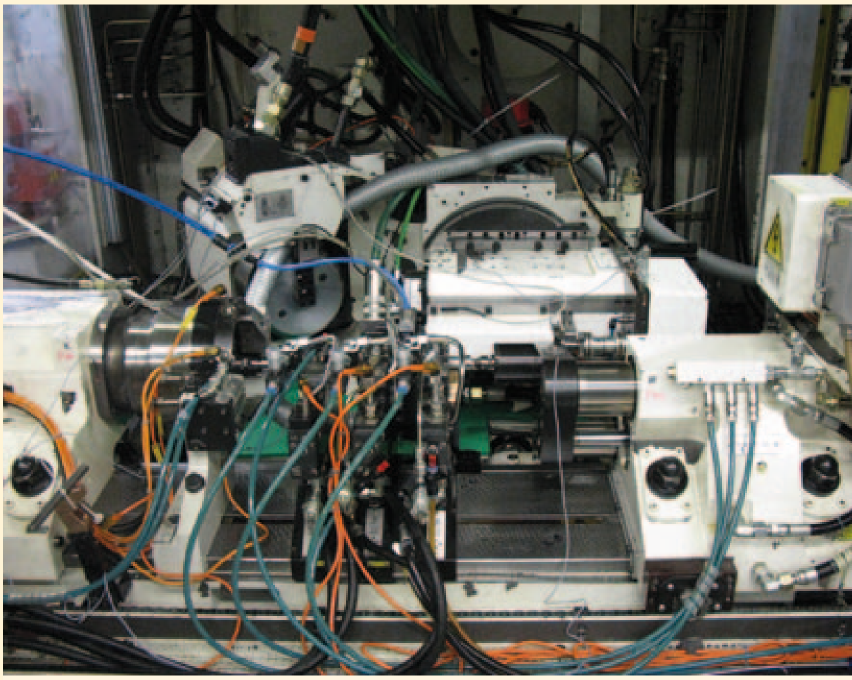


Fig. 2 *Test rig: Grinding with minimum quantity lubrication. Source: Volkswagen AG*

Grinding wheels – the coating is decisive

For the grinding wheel this resulted in a series of somewhat contradictory optimisation goals: it had to be able to withstand heat loads, dissipate heat easily and, in particular, generate as little frictional heat as possible.

The researchers used boron nitride (CBN) as the grinding media, which is ceramic-bound in the abrasive coating. Consisting of individual segments, the abrasive coating is bonded to the steel body. With the first test samples heat built up in the adhesive gap between the coating and the body so that segments flaked off. The researchers were able to solve this problem by designing the coating as a monolithic ring, increasing the ability of the abrasive coating to absorb heat by adding a ceramic intermediate layer and using an adhesive with greater thermal conductivity.

The surface structure of the coating considerably influences the extent to which the frictional heat can be minimised and dissipated. Pores in the coating on the one hand supply the cooling lubricant and on the other ensure that the hot chips are removed. The researchers quickly realised that they could only achieve the necessary porosity of the abrasive body by specifically generating microstructures. They achieved the best results with a lasered hole structure that provides a high porosity but only reduces the abrasive coating by 5%.

An abrasive coating with very good cutting properties was deliberately chosen for the tests. In addition, the lasered microstructure reduced the heating effect to such an extent that it should also be possible to grind the cams at production pace without thermal damage.

Lubricated and encapsulated

Because only small amounts of lubricant are used, it is particularly important that the lubricant is supplied to the grinding gap between the grinding wheel and the workpiece in a targeted and carefully dosed manner. For this purpose the scientists optimised a dual-channel spray system that adds the compressed air and lubricant separately from each other and first mixes

Fig. 3 *Three-cylinder camshaft rough, three-cylinder camshaft smoothed and a four-cylinder camshaft smoothed.*
Source: Volkswagen AG

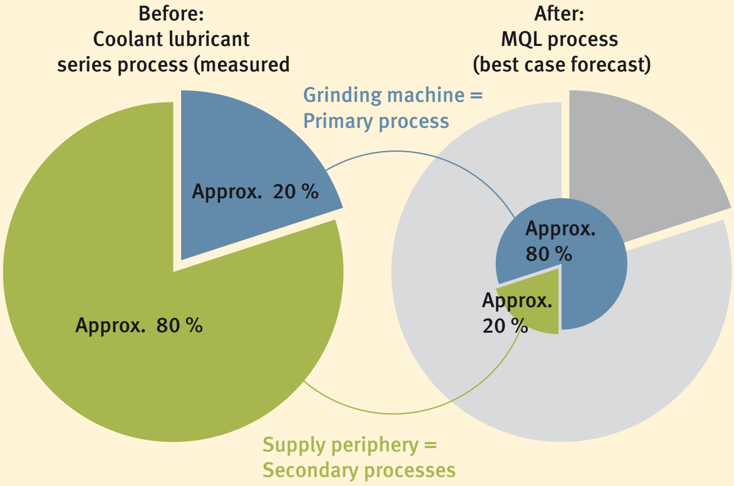


Fig. 4 *Energy savings in the best case forecast.*
Source: Volkswagen AG

them in the nozzle head. This enables both volume flows to be optimally matched with one another. A hood was used to optimise the flow conditions and prevent any hazards to people and the machine caused by flying sparks. An integrated extractor removes the hot chips quickly and effectively from the workspace.

Test case: Grinding camshafts

Following exhaustive testing on workpiece dummies, a standard cam grinder was re-equipped for grinding tests on a real camshaft. In addition to the encapsulation on the wheelhead, the nozzle head for feeding the lubricant and the extractor unit, the scientists also installed comprehensive measuring equipment. This provided process data such as the radial and tangential forces, the temperatures on the grinding wheel and camshaft as well as the real power of the grinding spindle. The use of a high-speed camera enabled the flow conditions to be observed within the encapsulation around the nozzle head, the grinding gap and the extractor.

After the grinding process, the researchers checked the quality of the ground cams and, by means of a non-destructive magnetic measurement procedure (Barkhausen noise), checked the workpiece for possible thermal damage.
However, the long-term suitability of the process components involved and the calibration values still need to be verified in lifetime tests.

Energy savings and more

Volkswagen's diesel camshaft production in Salzgitter alone produces around two million camshafts per year. For supplying and removing cooling lubricant, around 2.4 kWh of electrical energy are required on average per camshaft. With estimated energy savings of 50%, this equates to a reduction of around 2,400,000 kWh, which corresponds to almost 300,000 euros. However, these estimates are on the conservative side. In a “best case” forecast, the energy costs compared with flooding lubrication could be reduced to 20% of the overall costs.
A cost analysis has shown that there is considerable potential for cost savings not just in terms of the energy but also in regard to the investment and maintenance costs for the cooling lubricant (procurement, servicing and disposal). This is slightly offset by the low additional costs (compressed air and MQL oil) for the new technology. However, with less than 4 cents per camshaft, the additional operating costs for the energy and cooling lubricant used in minimum quantity lubrication are negligible.

Mass production as goal

By 2018, Volkswagen is looking to improve its environmental key performance indicators by 25% compared with 2010. These key performance indicators include the energy and water consumption, the amount of waste and the CO_2 emissions, whereby the conversion of metal-cutting production processes to dry machining or the use of minimum quantity lubrication technology at the Salzgitter site provide important building blocks in this regard.
This step has already been taken on a mass production scale with many of the machining processes in the drivetrain production. In Volkswagen's new cutting production lines at Salzgitter, cooling lubricants are now only used on a large scale for grinding and honing. The results from the investigations on camshaft grinding with minimum quantity lubrication now offer an opportunity to eliminate another area of previous uncharted processing territory.
In conjunction with the Junker tool making company, Volkswagen is now considering starting pilot production under series conditions. Here the remaining risks for series production, for example the long-term behaviour of the chip transport from the contact zone, will be assessed and correspondingly adapted machine concepts tested. Such a pilot process would enable further experience to be gained under series conditions before it is decided whether the new production technology can be transferred at a mass production scale to further products or sites.

Industry focussing on energy costs

Industry accounts for around 25% of the total final energy consumption in Germany. The sharp rise in energy prices during recent years has led to a clearly perceptible coupling of production costs and CO_2 emissions. At Volkswagen's Salzgitter plant, for example, the electrical energy costs for machining processes for the first time exceeded the tool costs in 2006. This trend has continued until today. The focus on reducing costs has therefore shifted from the tool costs to the energy costs. In future this will have a substantial impact on the product and planning assumptions made by companies.

The research project has shown that minimum quantity lubrication is also possible with grinding processes at an industrial mass production scale. In addition to the camshaft grinding of individual cams, additional potential for using MQL is seen in the cylindrical grinding of gear shafts. However, individual tests and pre-trials will be required before it can be implemented. In machine manufacturing, grinding processes are also used in the production of crankshafts. Given the specific conditions that prevail in this area, a comparatively high annual savings potential in terms of the energy consumption can be expected. If the costs for the process oil and emulsion are added that currently apply each year, it is clear that grinding with minimum quantity lubrication would provide considerable savings potential in this sector alone. In order to fully tap this potential, the results must be transferred to other grinding operations. However, the potential grinding processes must first of all be thoroughly analysed on an individual basis in terms of their suitability, whereby the following factors should be viewed as positive aspects:

- *High-performance grinding process with high stock removal rates*
- *Cooling lubricant is not used for secondary functions in addition to cooling and lubrication (e.g. centreless grinding),*
- *Small dimensions (diameter ‹ 1.0 mm)*
- *Use of ceramic-bound CBN as the grinding media*

Nevertheless, individual tests and pre-trials will be required before the results can be transferred to other grinding operations.

Project participants

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- **Scientific monitoring:** Fraunhofer Institute for Machine Tools and Forming Technology IWU, Chemnitz, Germany

Literature (in German)

- Volkswagen AG, Salzgitter; biolomatik Leuze GmbH u. Co. KG, Neuffen; Diamant Gesellschaft Tesch GmbH, Ludwigsburg; Erwin Junker Maschinenfabrik GmbH, Nordrach (Hrsg.): Energieeffiziente Feinbearbeitung mit geometrisch unbestimmter Schneide und Minimalmengenschmierung. Abschlussbericht. FKZ 0327839A-D. Dez. 2012. 71 S.

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