NACHHALTIGwirtschaften
konkret

FORSCHUNGSFORUM
3/2006

# INNOVATIVE COOLANT LUBRICANT SYSTEMS IN METAL CUTTING

OPTIMIZATION OF
HIGH SPEED CUTTING PROCESSES

IMPROVEMENT OF ENVIRONMENTAL
AND OCCUPATIONAL SAFETY


bmvit
Austrian Federal Ministry for Transport,
Innovation and Technology

TOPIC

# APPROACHES TO SUSTAINABLE OPTIMIZATION OF HIGH SPEED CUTTING TECHNOLOGIES

Photo: Profactor Produktionsforschungs GmbH

**High-speed cutting (HSC)** is an innovative machining process used in the metal working industries today. In this process, cutting speeds and feed rates are much higher than in conventional processes. On account of the high cutting speed, the forces acting in HSC processes are reduced by up to 30%. In addition to a longer tool life, the process also has advantages in the machining of complicated work pieces. Environmental benefits result from an improved surface quality, which in many cases makes additional stages of surface treatment unnecessary. Processes using the HSC technology almost attain the quality of finely ground surfaces.

As in conventional machining, cutting by means of HSC technology also requires **cooling lubricants**. Estimates suggest that in Austria some 7,000 tons of oils and emulsion concentrates per year are being consumed in metal cutting processes. The overwhelming part of the cooling lubricants is petroleum-derived; renewable raw materials are hardly used. A considerable proportion of the lubricant is misted in the process and, on account of the heat generated in the cutting process, evaporates and is thus discharged into the ambient air. On account of their complex composition, cooling lubricants are classified as hazardous substances. In 2001, threshold limit values for cooling lubricant mist at the workplace were first introduced in Austria. Reducing environmental problems and the burden on employees through cooling lubricants, requires expensive investment in filtering and ventilation equipment at workplaces and causes high operating costs.

The only sustainable approach to solving these problems consists in avoiding as far as possible the formation of lubricant mist in the cutting process. One method, which has already been successfully used in practice, consists in **minimum cooling lubrication (MCL)**; compared to conventional flood lubrication the quantities of lubricant needed is considerably reduced here. The amount of lubricant applied to the tool-work piece interface is reduced to such an extent that it is consumed in the process and recovery of excess lubricant can be omitted. This also avoids the necessity of cleaning, pumps, and maintenance work. A new approach (hardly tested, so far) to minimum cooling lubrication uses an oil-in-water emulsion made from renewable raw materials.

The innovative technologies – HSC and minimum cooling lubrication – are still at an early stage of practical application in industry. At present, appropriate machining strategies in HSC processes still have to be developed experimentally for each individual work piece. The diffusion of this ecologically sound technology requires further experience from practice as well as model processes that make systematic use of this experience gained in experiments.

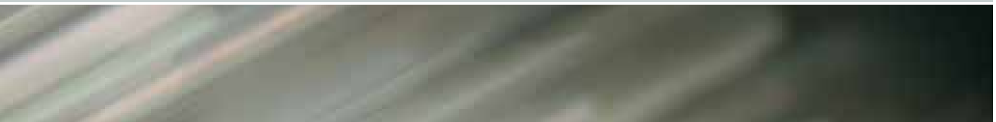
Two research projects within the **"Factory of Tomorrow"** subprogram aimed to optimize these technologies. In line with sustainable development the projects considered not only the requirements of the production process, but also focused on environmental and occupational safety.

While the first project developed a process model, demonstrating the manifold interrelations between technological requirements and the impacts on humans and the environment, the follow-up project further advanced optimization and tested the process in practice using real-life applications in various enterprises.

**Project 1**
**Entwicklung eines ganzheitlichen Vorgehensmodells zur Berücksichtigung von Aspekten des ArbeitnehmerInnen- und Umweltschutzes bei der Gestaltung von HSC-Prozessen**
Profactor Produktionsforschungs GmbH, Steyr 2002

**Project 2**
**Bio-Minimum-Lubrication**
Profactor Produktionsforschungs GmbH, Agatex Feinchemie GmbH, Steyr 2005

*The projects presented in this "Forschungsforum" have been realized within the "Factory of Tomorrow" subprogram. In 1999, the Austrian Federal Ministry of Transport, Innovation and Technology (bmvit) launched the "Sustainable Development" research and technology program, which aimed to effectively support a sustainable economy through research. Various research and development projects as well as demonstration and diffusion measures, which give new impetus to innovation in Austria's economy have since been supported within the scope of a number of subprograms.*
*The "Factory of Tomorrow" subprogram aims to encourage trend-setting pilot projects in the field of sustainable technology development. Model examples include innovative manufacturing processes, future-oriented products or exemplary enterprises.*




PROJECT

# HOLISTIC MODEL FOR THE DESIGN OF HSC PROCESSES

This project aimed to develop a systematic approach to the design and optimization of HSC processes in metal cutting. In addition to classic factors such as machining time, quality, and cost of the production process, investigations focused on occupational safety and environmental protection. Optimization of the process was realized in close cooperation with PIESSLINGER, a metal working company, and used a concrete aluminum component. Large numbers of this component have already successfully been produced for quite some time using HSC technology and minimum cooling lubrication.

The most important expectations at Piesslinger company referred to an improvement of working conditions with a view to indoor air quality and climate, noise and ergonomics, the increase in value of residue material such as aluminum chips, savings in cooling lubricant consumption in line with resource efficiency as well as an improved productivity and product quality.

**The project consisted of the following steps:**

- Experts' workshop ascertaining the actual state of affairs and definition of objectives
- Development of a model of the process
- Planning and implementation of milling tests in the Profactor laboratory
- Planning and implementation of aerosol measurements in the laboratory
- Survey among employees by means of a questionnaire
- Workshop for employees: Presentation of test results and definition of a reference workplace
- Implementation of the planned measures
- Workshop for the evaluation of the experience from practice and identification of further need for action

## RESULTS FROM THE MILLING TESTS

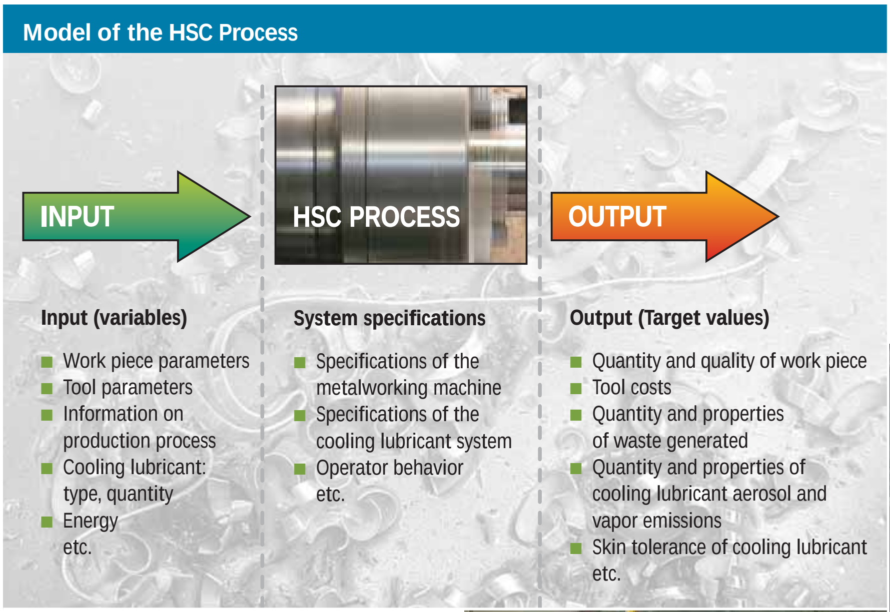
For the purpose of technological optimization, researchers performed milling tests in the laboratory using a reference work piece (a decorative aluminum part for coffee machines) and used varying key parameters for each test series. A total of 31 parameter combinations have been analyzed in the tests.

The milling tests identified, for each scenario, a favorable combination of tool coating and cooling lubricant system (MCL with optimized oil application and MCL using emulsion, respectively), which can reduce lubricant consumption.

Conventional machining of a component usually consumes approx.1 liter of lubricant (oil) per work shift. This corresponds to a lubricant consumption of 6.6 ml/min. **A change in the following parameters and an appropriate combination of parameters, respectively can reduce lubricant consumption by up to 75%:**

- Tool coating
- Correct adjustment of spray nozzles
- Increased feed rates (from f=4000 to f=5000)
- Type of cooling lubricant

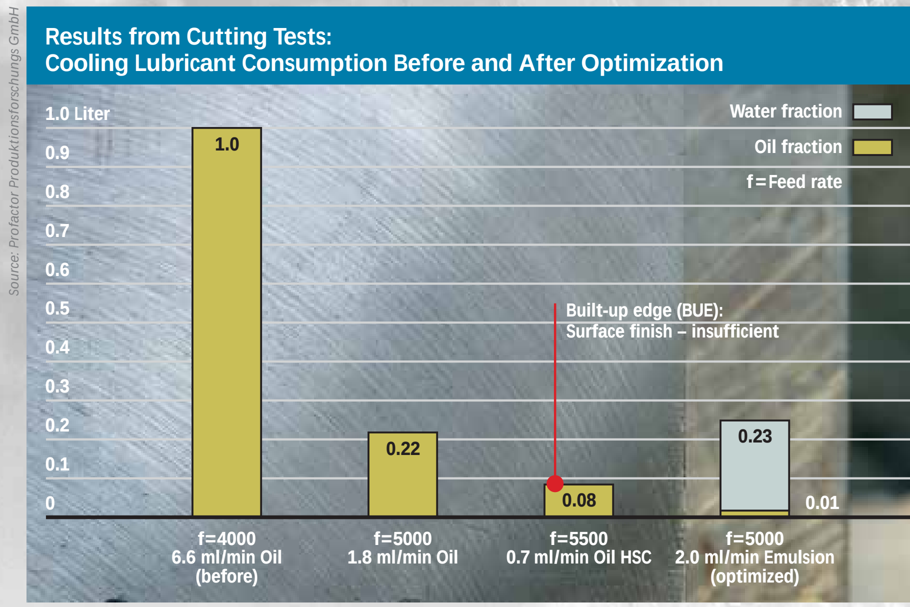
Especially the use of emulsion-based minimum cooling lubricants (6% oil, 94% water) can reduce lubricant consumption considerably. Also, tests using this system resulted in an improved surface finish. Recycling of the residue materials generated in the process (aluminum chips) strongly depends




Source: Profactor Produktionsforschungs GmbH

Photo: Profactor Produktionsforschungs GmbH

Photo: Profactor Produktionsforschungs GmbH




*The milling tests used increased feed rates and reduced the quantity of cooling lubricant. It has been shown that increased feed rates permit a substantial reduction of lubricant. An impairment of quality occurred only when lubricant was reduced to 0.7 ml/min. Using emulsion reduces the proportion of oil to only 0.01 ml/min.*

on the degree of soiling. Therefore, reducing the quantity of cooling lubricants has a positive effect on the quality of the aluminum chips. A shift from oil-based minimum lubrication to emulsion-based cooling lubricants further reduces impurities because most of the water evaporates during or after the milling process.

As the work piece and the material are virtually dry after machining with minimum lubrication, the cooling lubricant used in the process must have been discharged into the ambient air in the form of aerosol and vapor. The researchers measured the emissions discharged into the ambient air in the laboratory using a cascade impactor and ascertained the correlation between aerosol formation and the type of cooling lubricant method and the quantity of lubricant applied. Both systems (oil and emulsion) clearly showed a clear correlation between the amount of cooling lubricant used and aerosol concentration in the drawing-off air of the machine tool.

As minimum cooling lubricant systems use compressed air for atomization, misting levels tend to be higher than in conventional flood systems. However, this effect can be compensated by a consistent minimization of cooling lubricant consumption. In addition, an improved nozzle design for a more targeted application of the lubricant will probably solve this problem.

## IMPLEMENTATION

A sustainable optimization of industrial processes requires a holistic view of the system as a whole as well as the integration of employees' know-how and experience. The project involved all relevant actors in the planning and design of processes and work places. Employees participated in discussing the laboratory results and identified advantages and disadvantages of the two systems tested in the laboratory (minimum lubrication with optimized oil delivery and minimum lubrication using an emulsion). **The project participants then designed a reference workplace incorporating the measures below:**

- Shift from oil-based MCL to emulsion
- Increased feed rates
- Improved lighting in quality assurance
- Improved ergonomics
- Improved communication after work shifts
- Clear responsibilities in filter maintenance
- Elimination of organizational shortcomings

The most important modification of the production process consists in the shift to emulsion-based minimum cooling lubrication. Experience has shown that machining with higher feed rates following the laboratory test results, combined with minimum lubrication is feasible in practice. In addition to a reduction of lubricant consumption, the process afforded an improved surface finish and, simultaneously, an equally long tool life.

The chips and machined work pieces are virtually dry and hardly fouled by oil. This facilitates cleaning and quality assurance and also improves recyclability of residue material. Overall, machine operators welcomed all the implemented measures.

Measurements have shown a reduction of mist emissions from approx. 10 mg/m$^3$ to 0.6 mg/ m$^3$. A prerequisite for this improvement is that the emulsion application rate is strictly maintained at 2 ml/min. Improved indoor air quality has been noticed and appreciated by employees.

Problems in the process were associated with the emulsion delivery system: It was not possible to ensure stable adjustment of the twin nozzle in the requisite control range. A permanent shift to emulsion-based lubrication therefore requires the implementation of an specialized delivery system. The follow-up project therefore aimed to develop an improved pump-nozzle system for the minimum cooling lubrication method.

P R O J E C T

# BIO-MINIMUM-LUBRICATION


Photo: Profactor Produktionsforschungs GmbH

■ The goal of this project consisted in the development of an appropriate system for "Bio-Minimum-Lubrication" using an oil-in-water emulsion from renewable raw materials. The project was realized by Profactor in cooperation with Agatex Feinchemie GmbH and TPS Technische Produkte.

The **profile of specifications required for the minimum cooling lubrication system** had been developed by the project team in cooperation with representatives of various participating enterprises (Protan Produktionstechnik, Josef Haidlmair Werkzeugbau, and VA Tech Mechatronics). The profile comprises the production technology, chemical and physical properties of the cooling lubricant, dosing and delivery, occupational and environmental safety as well as availability of raw materials. Desired metal working processes include milling with a focus on HSC, turning, tapping and threading, reaming, drilling, sawing and, subsequently, also punching / blanking and drawing. Possible materials include nonferrous metals (copper, bronze), (stainless) steel, composite materials (e.g. copper and steel), sintered metals, plastics, and aluminum.

A study on the availability of domestic raw materials yielded positive results. The researchers examined the potential growing area and yields for oil crops using rape, sunflower, soybean, winter pumpkin, St. Mary thistle, false flax (Camelina sativa), and safflower (saffron thistle) as potential crops.
The additional potential growing area amounts to some 100,000 hectares of rotational fallow land. Taking into account crop succession, some 25% of this area could be used for the cultivation of oil crops. This corresponds to a potential yield of 62,000 tons of oil.
In addition, the researchers ascertained the production capacity, rate of utilization, and technical equipment of Austrian oil mills.

Photo: Profactor Produktionsforschungs GmbH

## LABORATORY TESTS

First the laboratory at Agatex developed 20 different emulsifier/lubricant combinations and tested their properties. Two pilot products were used in the subsequent practical tests of the pump-nozzle system. Of the three delivery systems tested by Profactor a commercially available system was selected and adapted with a view to flexibility and optimum adjustability.

The tests in the machining laboratory aimed to model the production processes used by the project partners as precisely as possible and to identify optimized cutting and cooling lubricant parameters. Target values referred to technological and economic aspects as well as to lubricant consumption and emission levels. 35 spraying tests used varying pressure conditions for the application of cooling lubricant and air supply. The researchers used two types of emulsion, oil, and different mixture ratios of the emulsions. Pressure conditions and the composition of the lubricant proved to be the main determining factors for aerosol concentration. The variants using emulsions yielded positive results, both, concerning consumption and with a view to emissions.

The subsequent milling tests examined three practice-oriented applications for minimum cooling lubrication with different work piece materials (brass - milling, sintered steel - thread molding, and C45 - milling). While the brass cutting tests focused on measuring emission levels, the objective of the second test series examined the feasibility of the minimum cooling lubricant system with emulsions in drilling and thread molding, respectively. In the third test series, various geometric shapes were cut out of a steel block.
The test aimed to examine mist formation and wear of the cutter head.

In general, the laboratory tests have shown that the new emulsion-based minimum cooling lubricant system causes lower emission levels compared to conventional flood lubrication, but also compared to oil-based minimum cooling lubrication. Tool wear, surface finish of the components, dimensional accuracy, and cutting parameters are comparable with those of other systems. It was, however, not possible to examine tool life in these laboratory tests.

>>

PROJECT

# TESTING IN PRACTICE AND PERSPECTIVES


Photo: Profactor Produktionsforschungs GmbH

Two enterprises – Protan Produktionstechnik and Josef Haidlmair Werkzeugtechnik – used the minimum cooling lubricant system developed in project 2 in practical applications. They tried particularly delicate applications in order to identify the limitations and problems of the technology. They worked in deep cavities to investigate chip removal and cooling lubricant delivery in hard to access spots. Weak points were associated, amongst others, with an increased susceptibility to corrosion of whetted surfaces and with shorter tool life.

As far as emissions are concerned, the trials yielded some rather promising results. At Protan for instance, the use of an emulsion-based cooling lubricant system (in long-hole drilling on a gear ring) reduced the overall aerosol concentration from initially 16.22 mg/m$^3$ (flood lubrication) to 1.88 mg/m$^3$. This corresponds to a reduction of emissions by approx. 90%.

Experience from practice has shown that the chemical, physical, and technological properties of the cooling lubricants have to be adapted to the individual processes through careful selection of additives. There is still need for further development in the field of nozzle systems because suitable solutions are technologically relatively complex and expensive. Solutions are also required for inherent weak points of minimum lubrication systems such as poor chip removal.

Overall, the research projects have demonstrated the great potential for development of emulsion-based minimum cooling lubricant systems using renewable raw materials. The research results constitute an important basis for further diffusion of the new technologies. The project partners Agatex Feinchemie GmbH and TPS Technische Produkte are now in a position to further optimize “Bio-Minimum-Lubrication” on the basis of experience gained so far.

FIGURES/DATA/FACTS

## PROJECT PARTNERS

**Project 1**
**Entwicklung eines ganzheitlichen Vorgehensmodells zur Berücksichtigung von Aspekten des ArbeitnehmerInnen- und Umweltschutzes bei der Gestaltung von HSC-Prozessen**
Profactor Produktionsforschungs GmbH, Steyr 2002
www.profactor.at

**Project 2**
**Bio-Minimum-Lubrication**
Profactor Produktionsforschungs GmbH, Agatex Feinchemie GmbH, Steyr 2005

## INFORMATION PUBLICATIONS

The final reports on the abovementioned studies have been published in issues 16/2005 and 23/2006 of the bmvit series “Reports on Energy and Environment Research” and are available from:
www.NachhaltigWirtschaften.at

PROJEKTFABRIK
A-1180 Vienna, Währinger Straße 121/3
versand@projektfabrik.at


Photo: Profactor Produktionsforschungs GmbH

## FORSCHUNGSFORUM in the Internet:

http://www www.NachhaltigWirtschaften.at

in German and English

You will find a complete list of all publications of the series *”Reports on Energy and Environment Research“* by the bmvit with order form on the HOMEPAGE: www.NachhaltigWirtschaften.at

FORSCHUNGSFORUM *provides information on selected projects within a bmvit program focusing on “Sustainable Development”. Published by the Austrian Federal Ministry for Transport, Innovation and Technology (bmvit), Division for Energy and Environment Technologies; Director: Dipl. Ing. M. Paula; Renngasse 5, A-1010 Vienna, Austria; Photos and diagrams: Profactor Produktionsforschungs GmbH, W. Bledl/SunSquare Kautzky, Projektfabrik. Editors: Projektfabrik, Währingerstrasse 121/3, A-1180 Vienna, Austria. Layout: Grafik Design Wolfgang Bledl, gdwb@council.net. Printed by: AV-Druck GmbH, Faradaygasse 6, A-1030 Vienna, Austria*

FORSCHUNGSFORUM is published four times a year and is available for free from: Projektfabrik, A-1180 Vienna, Währinger Straße 121/3, versand@projektfabrik.at

**P.b.b. Erscheinungsort Wien, Verlagspostamt A-1010 Wien.**