BULETINUL Universităţii Petrol – Gaze din Ploieşti	Vol. LIX No. 3/2007	17 - 24	Seria Tehnică

Consequences of Cooling and Lubrication Strategy on Gear Milling Process Efficiency

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Abstract

One of the main sources of environmental pollution during the machining processes is the huge amount of supplied cutting fluids. To avoid the problems caused by the use of cutting fluids, considerable progress has been made in the last years in the field of near-dry machining. The conversion from conventional processes to minimal quantity lubrication methods demands new tasks classification in the tribological system in order to guarantee the process safety and product quality. The present paper gives an overview on some requirements considered for a successful application of minimal quantity lubrication into industrial practice. Its second part is focused on technological effects of significant reductions of cooling lubricants by near dry techniques application to gear milling.

Key words: *Green Manufacturing (GM), Near-Dry Machining (NDM), Minimal Quantity Lubrication (MQL), Dry cutting (DC), Gear Milling*

Introduction

The manufacturing industry is one of the main roots of environmental pollution. Therefore, to reduce the environmental impact of manufacturing industry becomes an important topic for all manufacturers. During actual period an advanced manufacturing mode – Green manufacturing - is critically required for sustainable development process (Fig.1).

Fig.1. Environment protection and cost saving by green manufacturing

Green manufacturing is a modern manufacturing strategy, which is imperative for the 21st century manufacturing industry, integrating all the issues of manufacturing. Its ultimate goal is to reduce and to minimize environmental impact and resource consumption during a product life

cycle, which includes design, processing, production, packaging, transport, the use of the product and its disposal [2].

In this sense modern machining processes face continuous cost pressures and high quality expectations. To remain competitive a company must continually identify cost reduction opportunities in production, exploit economic opportunities, and continuously improve production processes. The key technologies that represent cost saving opportunities related the cooling lubrication and simultaneously improves the overall performance of cutting operations are dry cutting (DC) and minimal quantity lubrication (MQL).

Near dry-cutting as a part of green manufacturing

During the machining processes the cutting fluid is one of the main sources of environmental pollution. How to minimize the environmental impact of manufacturing systems related to cutting fluids is one of the important issues in the field of GM. Different types of cutting fluids employed in the manufacturing process have different impacts on the environment. The three objectives of quality, cost, and environmental impact are the critical factors, which should be integrated into cutting fluids selection for GM [2].

Machining technologies have been continuously developed aiming at getting the higher productivity and precision in manufacturing processes. Cutting fluids have been widely used to achieve these purposes, their action of cooling and lubrication, and to play a significant role in successful machining operations. Concerning the environmental issues, such ozone layer depletion, the global warming effects, and environmental pollution, it has nowadays raised the importance of environmentally friendly manufacturing. To avoid the above mentioned problems, caused by cutting fluids, considerable progress has been made in the last years in the field of dry and near-dry machining. In particular, MQL machining has been accepted as a representative near-dry application because of its environmentally friendly characteristics. The large number of studies has demonstrated that it can prove the satisfactory outcome in many practical machining operations [3].

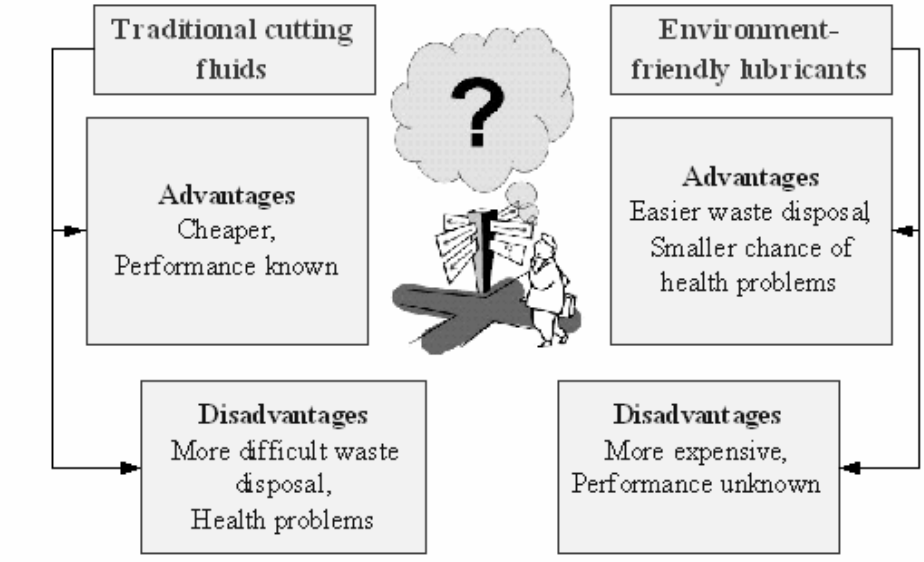


Fig.2. Cutting fluids selection

A cutting lubricant for MQL should be selected not only on the basis of its primary characteristics (cutting performance) but also by reason of its secondary characteristics, such as biodegradability, oxidation stability, storage stability, and water-soil-air pollution (Fig.2.).

Although the tribological action of a very small amount of lubricant is certainly of great significance in MQL machining, it should be also considered the relationship between MQL cutting performance and the tribological behavior of lubricants.

The conventional use of coolants/lubricants costs a lot of money and is hazardous to health and the environment. As mentioned before it could avoid this by introducing clean manufacturing technology. This allows at the same time the increasing of process productivity, thus securing itself the competitive advantages of tomorrow.

Technical features of MQL and NDM in the practice

The principal feature of near-dry machining with MQL is the replacement of the flood coolant with a very small amount of mineral or synthetic oil, which is applied directly and in a precisely dosed manner at the cutting point. With the introduction of this residual-free consumption lubricant, the manufacturing costs will decrease considerably, because the high costs for the preparation and removal of emulsion can be avoided. In addition, the costly health and environmental problems associated with the use of coolant lubricants are avoided as well.

Cooling the work piece with emulsion is replaced with a strong reduction in heat from friction due to effective lubrication of the cutting area. Depending on the type of processing, is consumed between 6 and 100 ml/processing hour of the corresponding lubricant. The considerably improved lubrication of the machining area creates the possibility to operate the tools at much higher cutting speeds and feed rates. In this way it is not only possible to obtain an enormous increase in productivity, but also longer tool service lives and better surface quality of the products. The dry chips can then be recycled without incurring large cleaning expenses.

Principally, every cutting and non-cutting process is convertible from closed circuit cooling with coolant lubricant to dry machining or minimal quantity lubrication. Due to the flexibility of techniques, there are suitable individual solutions for a wide variety of manufacturing processes.

Some of the main manufacturing processes, which were successfully made "near-dry", are: turning, milling, high speed milling, boring, deep drilling, tapping, grinding, drill finishing with single and multiple edge cutting tools. The accomplishing of cutting processes with dry cutting and/or MQL in practice is shown in figure 3.

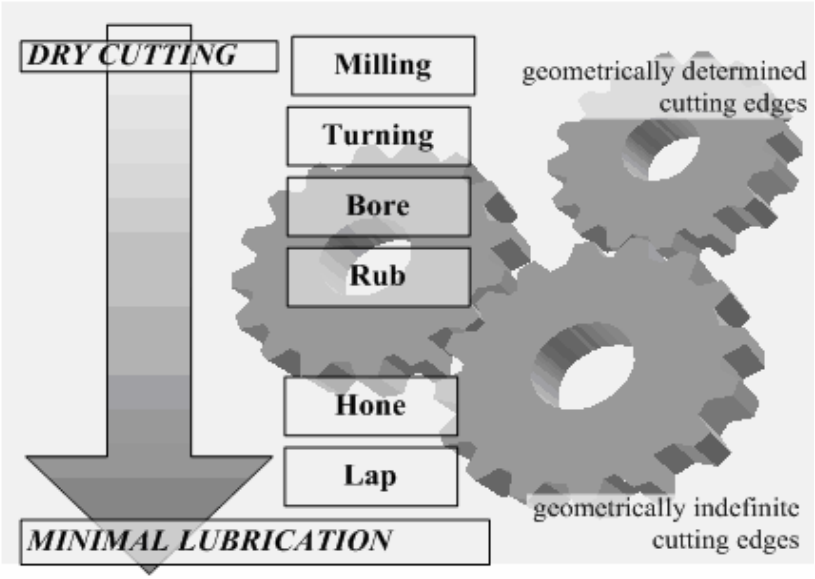


Fig.3. Cutting process accomplishing with ecological methods

Table1. Application of MQL and DC on several machine tools

Type of machine tool	MQL / Dry Cutting
Conventional machine tools	■
Individual CNC machine	◪
CNC centre	◧
CNC flexible cells	◪
Flexible lines	◧

■ very suitable □ not suitable

There are various MQL systems, which are suitable for use with a wide variety of equipment in order to create a competent, individually optimized solution (Table1.).
They allow extensively the conversion of manufacturing processes from flood cutting to near-dry technique, whether for a processing center, for conventional or CNC-controlled tool machine. In order to appreciate the efficiency of near-dry techniques' application several technological tests have been done with recording of the essential effects.

Some of them are: machining results (geometrical surface quality, precision), effectiveness of manufacture (wear tools), cutting forces and energy consumption, temperature of work piece and tool as well, process safety (edge-holding property, chips breaking, chips shape), pollutant emissions, vibrations level of tool/ work piece/ and machine tool and process productivity (minimum essential operating time).

Experiments and industrial practice show the advantages of near-dry techniques in comparison with the classical flood cooling methods, like: higher machining performance (higher cutting speeds), better surface finish thanks to lower (friction-induced) temperature, long tool life, mainly when high-frequency machining is involved. Small investment and operating cost suggest an amortization periods of less than one year. Application of the MQL technique and the DC hasn't only the economical advantages, but it is also an ecological-friendly alternative for the classical lubrication method [3].

The lubricant is consumed during the machining process and no residue is left on the work pieces or chips. Thus, there is no disposal of lubricant residues, and it is necessary no degreasing of parts and chips. It should be also mentioned the greater safety and environmental hygiene at the workplace by no mist, clean air to breath. The studies and researches have are also proved the fact that despite the emissions by MQL the application of this lubrication method hasn't any pollutant effect, even DC is an ideal process from ecological point of view.

MQL is an achievement-oriented technology, which takes over the lubrication task with mechanical manufacturing processes within modern machine tools and by it the conventional lubricants replaced. The friction forces between work piece, splinters and tool are reduced clearly due to the lubricating film. In addition the isolating lubricant film causes a better heat dissipation of the cutting area by the splinters and it also plays the role of anticorrosion protection. Detailed studies of the subject of the cutting fluids' use show clearly that it is essential to re-think the manufacturing processes.

Nowadays it must be accorded equal consideration to ecological aspects - researchers and individual companies have the responsibility for developing and implementing innovative environment-friendly manufacturing processes. As part of this effort, coolant-free metal cutting methods are being devised and implemented in factories not only to improve the process results and to protect the environment, but also to improve the company image.

Developments and future trends

A change in environmental awareness and increasing cost pressures on industrial enterprises have led to a critical consideration of conventional cooling lubricants used in most machining processes. The environmental requirements are mainly considered as a necessity, which generates additional design constraints and increases the costs. In an approach like this, environmental assessments are carried out late in the product development process. Efficient cutting manufacturing - economically and environmental compatibly through minimum quantity lubrication and dry cutting is one of the most current measures for the rationalization of cutting metalworking and it offers on a short or long-term basis the introduction of dry cutting.

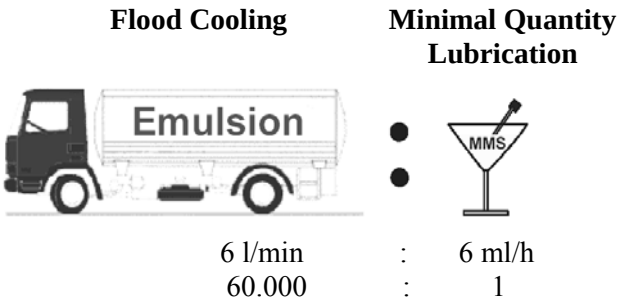


Fig.4. Comparison of the lubricant needs to FC and MQL

Besides an improvement in the efficiency of the production process, such a technology change makes a contribution to the protection of labor and the environment. The reduction of substantial exposure to lubricants at the work place (Fig.4.) raises job satisfaction and improves the work results at the same time.

Furthermore, an enterprise can use economically-friendly production processes for advertising purposes, which leads to a better image in the market. Analyzing and understanding the cutting process mechanisms is a key issue in developing an economical and safe dry machining process. Beyond the adoption of this new machining technology, the construction of machine tools and their peripheral equipment must also be considered. The results for a large variety of work piece materials and common production methods are essential to prove the superiority of this innovative machining technology [4].

Implementation of dry machining can't be accomplished by simple turning off the lubricant supply. In fact, the coolant performs several important functions, which, in its absence, must be taken over by other components in the machining process. Cooling lubricants reduce the friction, and thus the generation of heat, and dissipate the generated heat. In addition, lubricants are responsible for a variety of secondary functions, like the transport of chips as well the cleaning of tools, work pieces and fixtures.

Process efficiency by MQL

The reduction of cooling lubricants in the modern cutting-technologies of Dry Cutting and Minimal Quantity Lubrication has led to significant advancements in machining technology. Today many machining processes and work piece materials are produced by applying modern cutting tools and coating, adapted tools design and machining strategies, as well as optimized machine tools.
These high-performance system components ensure economic and highly productive processes, slightly reducing the production time of flood cutting process and improving the work piece quality significantly [5]. Dry cutting, mainly applied in high-volume, large-scale industries, like automotive manufacturing, still require special solutions. It is envisioned that the increasing number of industrial applications and the research activities in the field of DC and MQL will support and it results in the expansion of these modern high-performance technologies to small and medium-sized manufacturers [6].
Modern machining technologies like Dry Cutting and Minimal Quantity Lubrication have driven enormous cutting tool developments over the past decade. Wear and heat resistant cutting materials and coating were, and still are, the key to high-performance machining. Currently, the

improvement appears to be limited by sintering-process technology. The investigations on a laboratory scale are focusing on the development of cutting materials with nano-structures, whose properties will exceed those of currently available cemented carbides.

Minimal lubrication techniques to gear milling

The flood coolant cutting is still far common with hobs. Particularly in small-batch manufacturing with small numbers of items and in the gear machining from middle to large gear wheel modules with cemented carbides tools the flood coolant cutting is not to be excluded. The positive effects and the tools the available let no doubt about the sense of the flood lubrication cutting arise for many years.
The advantages of the cooling lubricant application with hobs result from the following points: simple management, very good cooling efficiency, service life-extending influence, simple splinter transport. Apart from the incontestable advantages of flood lubrication, also the substantial disadvantages (high handling costs, human-harmful, environmental-harmful) are to be regarded with a possible employment.
The advantages of flood lubrication can't compensate their disadvantages, so that MQCL technology is a favorable alternative also to hobs. In this case changes arise regarding the size of the working forces, temperatures and in wear characteristics in relation to the full jet technology primarily, while all sizes remain constant. Researches presented in this paper were concentrated on the technical evaluation and the effect of these above mentioned parameters.

Wear of the hob

The complete instrumentation were supervised within the attempt program: the development of the work piece and tool temperature before and after milling, the force behavior, the wear characteristics of the assigned tools, the behavior of the tooth wide as measure for the tooth thickness of the gear wheels and the behavior of further teeth deviations.

The tool life of the hob has a decisive influence on the economic effectiveness of the cutting process. It was used during the experimental investigations a tool from Mo5Co5 with TiN - coating. The results are represented in the figure 5 and they show that with the employment of the minimum lubrication technology obtained favorable wear/ tool life, which are attributed causally to the outstanding lubricating action of the assigned lubricant.

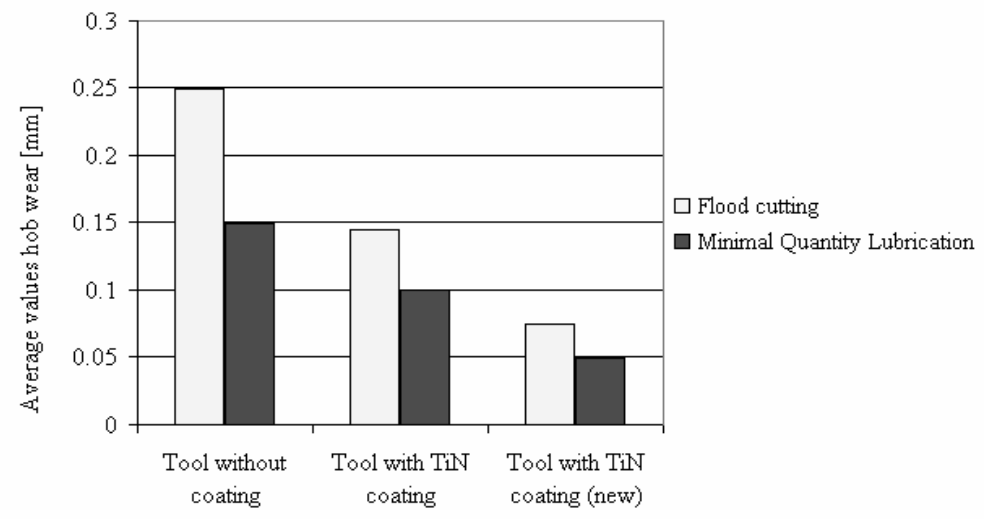
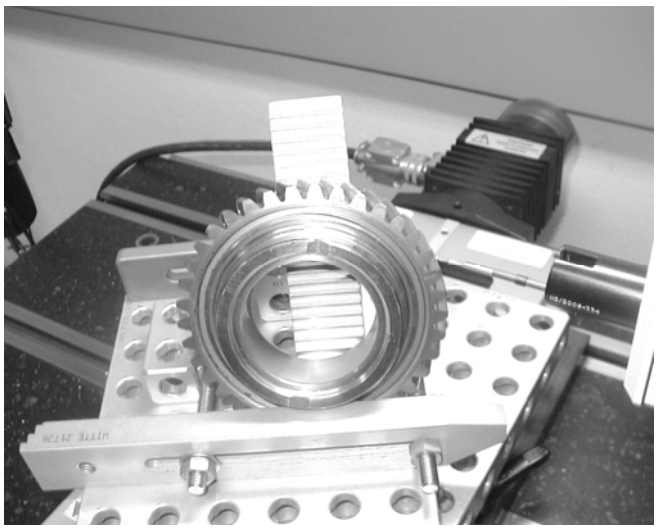


Fig.5. Average values of the hob's wear

To comparison purposes dry cutting was also use. Here a very unfavorable employment behavior showed up. After cutting of few work pieces the attempt had to be broken off. The wear effect by the hob reveals itself by the upward gradient of the machine cutting forces and the temperatures.

Surface Quality



With increasing, in particular abrasive wear it is added as a rule that with the gear milling process in the effect place an increased supplemental work must be carried out.
This leads both to a rise of the shear forces and to the increase of the temperature in the effect place and concomitantly at the cutting edge and at the work piece. The effect of the temperature higher with the DC and/or the MQL on the quality of gear teeth is shown in the figure 7.

Fig.6. Measuring of the tooth surface roughness

A comparison of the roughness values of damage-free milled teeth profiles of the standard attempt gear wheel furnished the result represented in the diagram 5 for the employment of the FC, MQL, MQC and the DC for a generally coated hob (Fig.7.). This comparison is for the MQL very satisfyingly. The wear-conditioned changes in the hob cutting edges (cutting edge not-alignment) convert themselves due to geometrical conditions with hobs directly in teeth deviations.

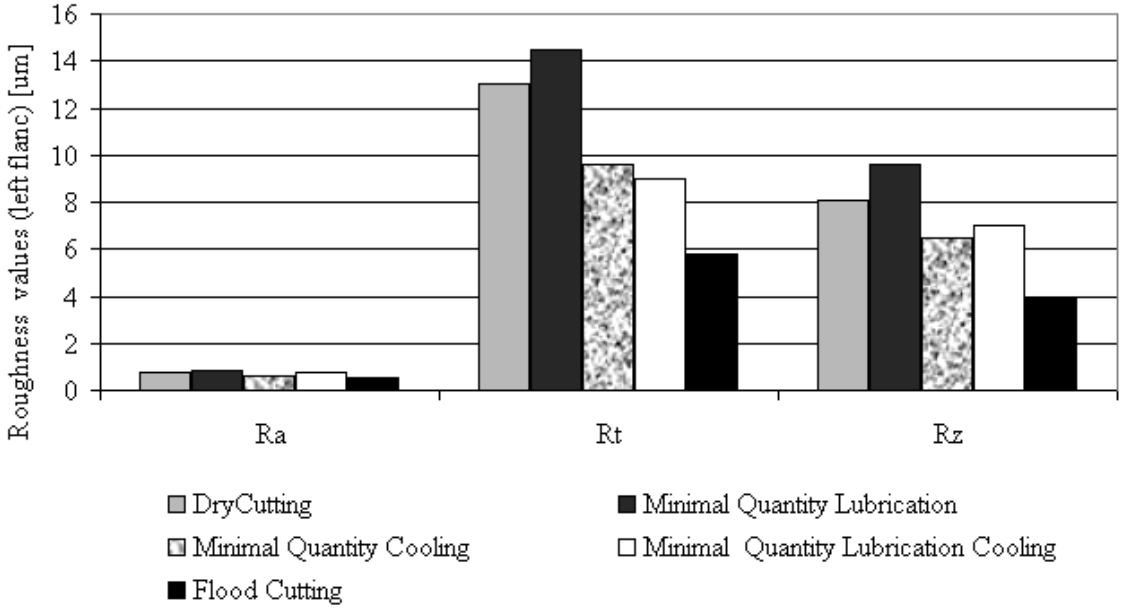


Fig.7. Measured roughness values

Conclusions

Practical experiences show the fact that it can do in numerous cases without the use of lubricant completely or with a small quantity of lubricants and so a higher economy can avoid industrial safety-technical and environmentally referred problems. In addition the possibilities and borders of the employment of the dry cutting or the minimum quantity lubrication, with almost dry splinters result, it must admit too.
The conventional use of coolants and lubricants loads the environment pollution and it costs the money with a rising tendency. With same productivity clean production technologies are a competition advantage for tomorrow. The use of dry cutting and also of the minimum quantity lubrication by the gear milling offers possibilities for increasing of efficiency. These result from: the elimination of the lubricant as conditioned wastes, the reduction of lubricants conditioned costs, the increase of the cutting power, the optimization of the process chain, improvement of the operational environmental situation.

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Efectele selecției strategiei de ungere şi răcire asupra eficienței procesului de frezare a roților dințate

Rezumat

În cadrul acestei lucrări sunt prezentare câteva din cerințele care trebuie considerate în vederea implementării cu succes în practică a tehnicii de aşchiere cu ungere şi răcire minimală. A doua parte a lucrării este concentrată asupra efectelor tehnologice pe care le are aplicarea tehnicilor ecologice de aşchiere în cazul frezării roților dințate.