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Application of Minimal Quantity Lubrication in Gear Hobbing

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The results of investigations on application of Minimal Quantity Lubrication (MQL) in gear hobbing are presented in the paper. The experimental stand which allows measurements of cutting forces, F_c , is described. Experiments were carried out for MQL and flood cooling. The influence of the fluid supply methods on tool wear and cutting forces is presented in the paper. The influence of the different workpiece materials is presented, too. The investigations have proved that the using of the MQL method is by all means justified. The results indicate that the hob wear rate is similar for the MQL and for conventional flood cooling. This is also confirmed by the measurements of cutting forces, which values are comparable for both methods.

 $\mathit{Keywords}:$ Gear hobbing, cutting forces, tool wear, cutting fluid, MQL

1. Introduction

Cutting fluids are widely used in machining processes. Their application leads, among others, to longer tool life, better surface finish, and lower cutting forces. Despite the above-mentioned advantages their application in cutting processes more and more frequently is regarded as unwanted. High purchase and maintenance costs, environmental problems and detrimental effect on human health are the main disadvantages of cutting fluid application [1–3]. On the other hand application of dry cutting is often limited due to high cutting temperatures generated, which shortens tool life significantly or even makes application of particular tool materials impossible.

The disadvantages connected with flood cutting fluid supply or dry cutting can be significantly reduced by application of the so called Minimal Quantity Lubrication (MQL) method, which means supplying cutting fluid as a mist directly into cutting zone with a flow rate not higher than 50 ml/hour. This fluid supply method can also contribute to better working conditions for machine operators and fewer environmental threats (when combined with good ventilation equipment). Consequently, from the point of view of the business and ecology, this method seems to be competitive.

Many publications describe application of MQL in various machining operations. The investigations indicate that the results are sometimes similar to that obtained for conventional flood cooling and much better than that obtained for dry cutting [4–10]. That means that such a small quantity of lubricant is enough for efficient lubrication of tool/workpiece interface. The reduction of tool life is caused by a lack of cooling action which increases cutting temperatures in comparison with flood fluid supply.

Hobbing is the one of the most popular methods of gear making, but no results on using MQL method in this machining operation were found. Because hobbing is different from majority of cutting operations in terms of chip formation, cutting edge loads and uneven wear distribution on the hobbing cutter's teeth so that it is not possible to adopt directly investigation results from another cutting methods for hobbing. The investigation presented in this paper has been carried out to find the influence of the cutting fluid supply mode on the hobbing process.

2. Experiments

The main aim of investigations described below was to check possibility to apply MQL method in gear hobbing process.

For this reason tool life tests were carried out with measurements of tool flank wear in some time intervals. During these tests cutting force measurements were carried out to compare efficiency of fluid application in both fluid supply methods investigated.

Fig. 1 shows the scheme of the experimental stand for measuring of the cutting forces during gear hobbing on the ZFC 20 type hobbing machine.

Cutting force, F_c , was measured by means of a 9321B, one-component KISTLER dynamometer, operating with a 5011B KISTLER charge amplifier. The dynamometer has been placed in the special holder fixed as the work arbour. The measured signals were recorded and processed using the special computer program [11, 12].

Fig. 2 shows the example of cutting force, F_c , changes during one revolution of hob. A very high differences of cutting forces are observed caused by uneven loading of particular cutting edges. For further processing a maximal cutting force was taken as a representative, ct. Fig. 2.

Spur gears were made of two different materials - normalized 0.45%C carbon steel and alloys steel 42CrMo4 and were machined with a hobbing cutter made of HS6-5-2 high speed steel. For both workmaterials two cutting fluid supply methods were applied – MQL and conventional flood cooling. Cutting conditions are presented in Tab. 1.

For this test the following cutting parameters were applied: depth of cut $a_p = 6.6 \text{ mm}$, axial feed f = 0.5 mm/rev, cutting speed $v_c = 34 \text{ m/min}$.

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Figure 1 Experimental stand for gear hobbing:1) gear, 2) dynamometer, 3) charge amplifier, 4) data acquisition card , 5) computer



Figure 2 Example signal of cutting force

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Table 1 Cutting conditions			
Tool	Cutting parameters	Spur gear	Fluid sup-
			ply
hobbing cutter NMFc-3/20 ° B', HS6-5-2 (HSS) module m=3	cutting speed – $v_c=34$ m/min axial feed – $f=0.5$ mm/rev depth of cut – $a_p=6.6$ mm up milling	C45 (carbon steel) 18÷20HRC	flood cooling
			MQL
		42CrMo4 (alloy steel) 18÷20HRC	flood cooling
			MQL

 Table 1 Cutting conditions

The experimental stand shown in Figure 1 was equipped with a single nozzle oil–mist generator Micro–Jet Type MKS–G 100. The lubricant MICRO 3000 was supplied at the rate of 25 ml per hour. In flood cooling an oil was used which was supplied at the rate of 10 l per minute.

Each hobbing test was carried out for 72 minutes and tool wear was measured at specified in Figure 5 intervals. The tool wear was measured on the Carl Zeiss Jena workshop microscope, equipped with a special holder for fixing the hobbing cutter in a precisely defined repeatable position [11]. The typical form of flank wear land of the hob tooth is shown in Fig. 3. The largest wear land width was observed in the corner region, on the enter side of tooth described as VB_{cen} . The photograph of the actual hob wear land is shown in Fig. 4.



Figure 3 Flank wear distribution on the hob tooth

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Figure 4 Actual hob flank wear land

3. Experimental results

Experimental results of hob wear changes vs. cutting time are presented in Figs 5 and 6. Fig. 5 shows the magnitudes of the maximum VB_{cen} wear land width on the subsequent hob teeth for conventional flood cooling and for the MQL method for carbon steel workmaterial. In Fig. 6 such results are shown for alloy steel. From these diagrams a variable distribution of wear land width on subsequent tool teeth is visible caused by uneven cutting edge load during tooth space generation. Typically, the maximum wear is concentrated on a one tooth – No. 12 for C45 and No. 13 for 42CrMo4.



Figure 5 VB_{cen} wear land width on subsequent hob teeth when C45 carbon steel was cut with a) conventional flood cooling, and b) MQL fluid supply



Figure 6 VB_{cen} wear land width on subsequent hob teeth when 42CrMo4 alloy steel was cut with a) conventional flood cooling, and b) MQL fluid supply

It can be seen from these Figs that wear land width increases with cutting time. It can also be noticed that for both workmaterials tool wear occurred when hobbing with conventional flood cooling is lower than that obtained for cutting with MQL method. In the first case maximum tool wear reached the magnitude of 0.36 mm while in the second case this value was over 0.5mm after the same cutting time.

Comparing tool wear changes when hobbing 42CrMo4 alloy steel it could be seen that for flood cooling there are only slight differences in tool wear distribution. After 72 minutes of cutting the maximum tool wear difference is only 0.05 mm.

Comparison of efficiency of MQL fluid supply method for both workmaterials investigated shows that much higher difference of tool wear is obtained (cf. Figs 5 and 6). The difference of tool wear after 72 minutes of cutting exceeded 0.20mm

The above observations are proved in Fig. 7 where the changes of maximum VB_{cen} wear land in time for both workmaterials investigated, cut with application of two cutting fluid supply methods, are presented. For carbon steel tool wear vs. cutting time curves (Fig. 7b) showed similar inclination which proves good lubrication action of MQL, sufficient to keep cutting temperatures low and allow cutting without excessive tool wear.



Figure 7 Changes of maximum flank wear vs. time for MQL and flood cooling (FC): a) C45, b) $42\mathrm{CrMo4}$



Figure 8 Changes of cutting force vs. time for MQL and flood cooling (FC): a) C45, b) 42CrMo4

The comparison of tool wear inclination curves obtained for 42CrMo4 alloy steel shows much sharper increase of tool wear when MQL method was applied. This is visible especially for higher tool wear magnitudes. It may indicate that, for this workmaterial, lubrication of tool/workpiece interface is not sufficient when flank wear increases.

The measurements of cutting forces, F_c , carried out during hobbing confirmed above conclusions. The results of these measurements are shown in Figure 8. It can be seen from this Figure that there are much lower differences in forces observed between flood cooling and MQL in hobbing of carbon steel than in case of alloy steel cutting. Also, higher cutting forces observed for alloy steel indicate that the normal stresses at tool/workmaterial interface may be significantly higher, making access of lubricating mist in MQL method to the contact zone difficult.

4. Conclusion

The investigations have proved that the application of the MQL method in hobbing is justified. The results indicate that the course of hob wear rate is similar for the MQL and for conventional flood cooling. This is also confirmed by the measurements of cutting forces. As the hobbing time progressed, values of cutting forces are comparable for both methods. These observations were more visible for hobbing carbon steel. The results should be verified in further tests. The basic research should be concerned on the influence of the modification of the MQL parameters (number and direction of the nozzles, different air pressures, different fluids, different fluid rates, etc.) on the hob wear. Also, efficiency of MQL method of fluid supply should be checked for higher hob wears, and for finishing cutting with low cutting depths.

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