Gear Hobbing Without Coolant

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Introduction

For environmental and economic reasons, the use of coolant in machining processes is increasingly being questioned. Rising coolant prices and disposal costs, as well as strains on workers and the environment, have fueled the debate. The use of coolant has given rise to a highly technical system for handling coolant in the machine (cooling, filtering) and protecting the environment (filter, oil-mist collector). In this area the latest cutting materials—used with or without coolant—have great potential for making the metal-removal process more economical. The natural progression to completely dry machining has decisive advantages for hobbing.

	ADVANTAGES	DISADVANTAGES
FINISHING	Reduced machine time/increased tool life/improved quality	
MACHINE	Chip flushing	Filtration unit Refrigerator Fire Extinguisher Pumps and hoses
CUTTING OIL		Purchase cost Disposal cost Monitoring cost
ENVIRONMENT		Health risk Environmental hazard Contaminated chips
PROCESS		Additional part washing

Fig. 1 — Consequences of using cutting oil.

The Coolant

Coolants serve many purposes in metal removal. With their help, the workpiece and tool are cooled, wear is reduced and chips are flushed out of the machine. But there are essential disadvantages: the substantially increased cost of the machine because of the need to process and circulate the coolant, the cost of protecting the environment from oil mist, the costs of purchasing and disposing of the coolant, the cost of disposing of the contaminated chips and the strain on workers and the environment caused by coolant in all its forms.

In Europe, the purchase price of coolant today is about $2,060 per cubic meter of oil and $185 per cubic meter of emulsion. To those prices add disposal costs in the range of $76 per cubic meter of used oil and $185 per cubic meter of emulsion, as well as disposal costs of about $6/ton for chips. These figures are valid at the moment, but we have to assume that they will skyrocket in the near future. A thorough examination of the subject can be found in the 1993 addresses to the Aachen Machine Tool Kolloquium (Ref. 2).

Since hobbing usually precedes heat treating, the use of coolant during metal removal also necessitates an additional wash operation. Fig. 1 clearly shows that the disadvantages of using coolant outweigh the advantages. Nonetheless, economic and technical considerations will not allow coolant to be abandoned in the immediate future.

The Tool

Elimination of coolant has far-reaching effects on the machine, tool and process. The tool must withstand the thermal and mechanical stresses of the process and still be economical; that is, it must allow large batch sizes with consistent workpiece surface quality. In this regard, modern cutting materials, such as carbide or cermet with suitable carbide coatings, open completely new perspectives.

Fig. 2 shows the progress that has been achieved in steel cutting speeds over the past few years because of improvements in cutting materials. Today, coated carbides and cutting ceramics allow speeds that are many times greater than the cutting speeds possible with classic tools or high-speed steels. For example, cutting ceramics allow cutting speeds of about 2,000 m/min. At the same time, the improved cutting materials have increased tool life, so that in the final analysis these new tools offer a substantial economic advantage in spite of their high cost.

The Machine

The machine design must be adapted to the new requirements of the coolant-free process. First the thermal load of the entire machine changes. According to Koenig, Severt and Berthold ("Cutting Without Coolant," Ref. 4), 75% of process heat is removed by the chips. Since there is no coolant to wash them away, the chips must be removed from the process in the most direct way possible so that the heat they contain is transferred out of the machine quickly. Furthermore, the use of modern cutting materials requires a different performance profile from the machine. Increased speeds and power are both necessary.

Fig. 3 shows the design of a modern hobbing machine that meets these requirements. Integrating the chip conveyor in the machine bed satisfies the requirement that the chips be centrifuged away from the process directly to the chip conveyor below. In addition, putting the chip conveyor at the center of the machine allows the side walls to be substantially steeper than they could be if the chip conveyor were built onto the side. In this way the chips take the shortest possible route out of the machine.

The table is driven by a compound, preloaded gear train that allows maximum speeds of up to 450 rpm. The hob head is equipped with a heavy duty drive that offers maximum speeds of 3000 rpm with a drive power of 18kW. With a maximum hob diameter of 90 mm, these result in a cutting speed of 850 m/min. These performance data—in comparison with the technology data used in current practice—leave sufficient reserves for further increases beyond the performance potential of today's cutting materials.

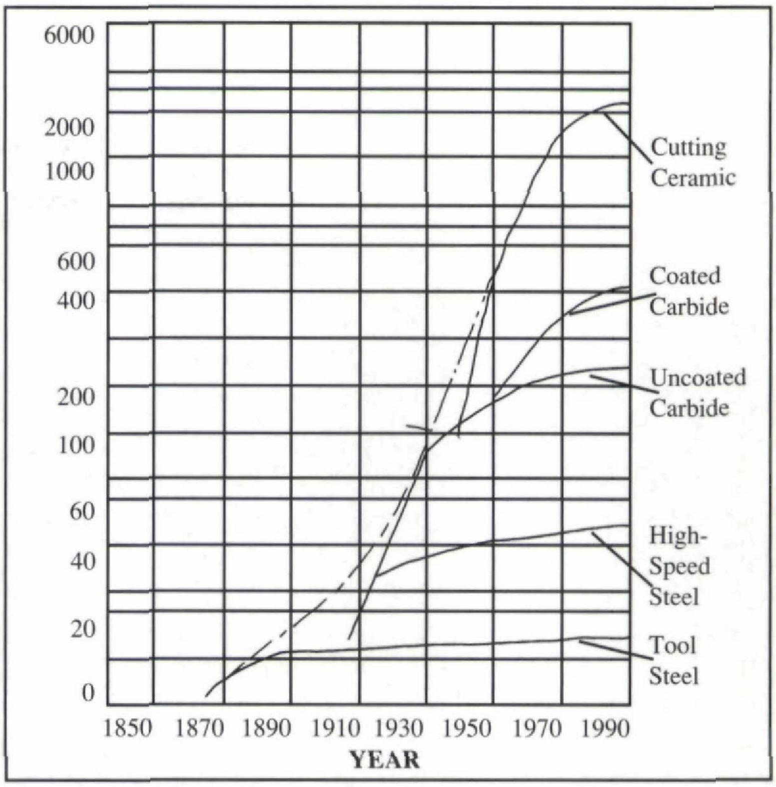

Fig. 2 — Development of Cutting Speed for Steels (See Ref. 1).

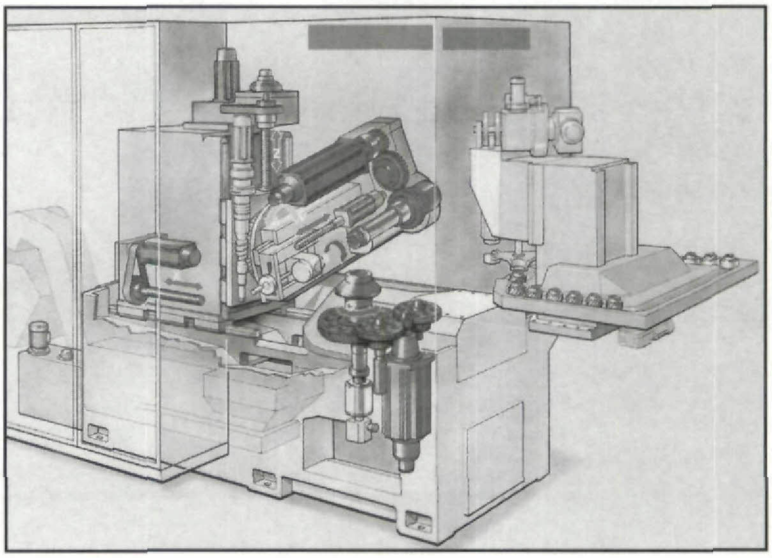

Fig. 3 — Concept Hobbing Machine for High-Speed Machining.

Since these enormously high cutting speeds reduce machining times to less than 10 seconds (depending on the workpiece), part change has to be considered an integral aspect of the basic machine design. For that reason, a conveyor system for part load/unload is integrated with the machine. Part change is so closely combined with workpiece clamping that the entire process is complete in about 2 seconds.

Fig. 4 shows the prototype of the newly

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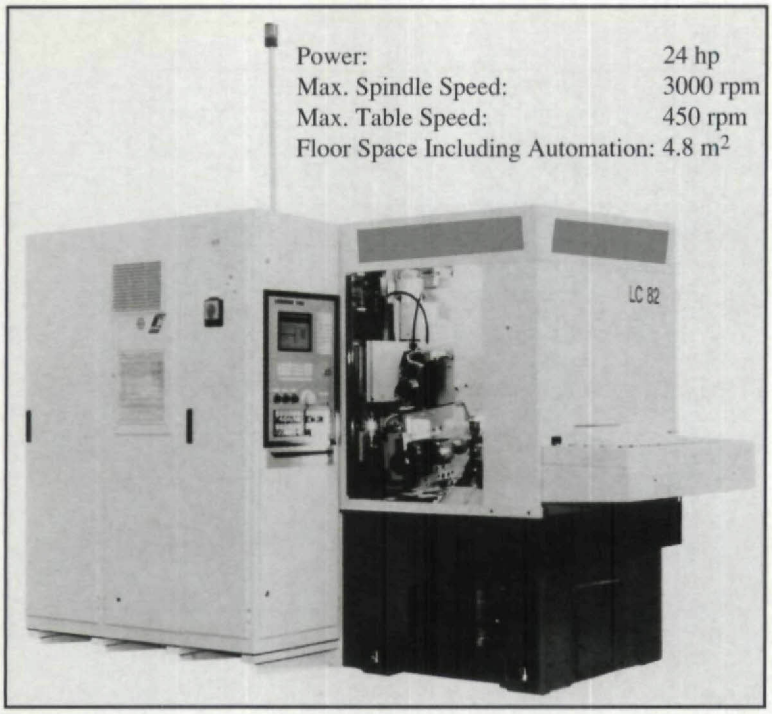

Fig. 4 — Hobbing Machine for High-Speed Machining.

Work Example: Speed Gear

Part Data:			
No. of Teeth	31		
Module (DP)	2 mm (12.7)		
Helix Angle	32° RH		
Face Width	18 mm (.71")		
Cutting Depth	5.8 mm (.23")		
Hob Data:			
Material	**HSS**	**CARBIDE**	**CERMET**
No. of Starts	3	1	1
No. of Gashes	30	30	30
Hob Diameter in mm (")	90 (3.5)	90 (3.5)	90 (3.5)
Hob Length in mm (")	70 (2.75)	70 (2.75)	70 (2.75)
Technology:	**HSS**	**CARBIDE**	**CERMET**
Coolant	Oil	None	None
Speed in m/min. (sfm)	120 (393)	450 (1475)	600 (1970)
Hob rpm	424	1590	2120
Axial feed in mm/tr. (ipr)	3 (.12)	4.5 (.18)	4.5 (.18)
Cutting time in sec.	25	14	10
Load/unload in sec.	3	3	3
Time per part in sec.	**28**	**17**	13
Costs: (Guide Values)	**HSS**	**CARBIDE**	**CERMET**
Hob Cost in $	2200	3500	5250
No. of Resharpenings	3	3	3
Cost/Resharpening in $	350	35	350
Parts/Resharpening	5400	6700	6700*
Tool Costs/Part in $	**0.15**	**0.17**	**0.24**
Machine Costs/Hour in $	75	75	75
MC-Costs per Part in $	**0.58**	**0.35**	**0.27**
Total Costs per Part in $	**0.73**	**0.52**	**0.51**

*Assumed

Fig. 5 — Hobbing without coolant (Cost/Performance Comparison).

developed heavy-duty hobbing machine and lists its fundamental technical performance characteristics.

In addition to the associated technological requirements, the current push toward "lean" manufacturing was taken into account. The internal functions of the machine were simplified as much as possible, and the electrical and mechanical designs were closely integrated. In this way, a production-ready machine was developed. Installation at the customer's plant is limited to setting it up and plugging it in. And the entire machine—including integrated automation—has a footprint of less than 5 m².

Machining Examples

For one of the test cuts, a gear that is typically used as a drive gear in passenger car transmissions was selected. The workpiece data are shown in Fig. 5.

The table shows the time that can be saved by using dry cutting with carbide or cermet tools rather than conventional wet cutting with HSS hobs.

The use of TiN-coated HSS hobs with coolant is considered the current state of the art. At cutting speeds of 120 m/min. with a feed of 3 mm/rev., the machining time is 25 seconds. TiN-coated carbide tools, used with a cutting speed of 350 m/min., make it possible to reduce the machining time to 17 seconds and eliminate the use of coolant. A further reduction to 10 seconds machining time is achieved with the use of cermet hobs. This process is also carried out without coolant. In all, there is an improvement of the overall machining time from 28 to 13 seconds; that is, today's standard value is reduced by more than half, or in other words, the capacity of the machine is more than doubled. With relation to hobbing, this increase in performance directly reduced piece costs by 15–25% before the savings from the elimination of coolant is taken into account. To be complete, our rough analysis of productivity increases would also have to include a recalculation of the steps in gear manufacturing such as extrusion molding (See "Cold Impact Forming of Geared Workpieces," Ref. 6). Simply switching hobs has the additional advantage of increasing the flexibility of the hobbing process.

Along with purely time-related issues, the targeted workpiece quality plays an essential role in assessment of the process. Fig. 6 shows the profile and lead measurements of a drive gear. The workpiece was cut with a TiN-coated cermet hob using the machining data given in the right-hand column of Fig. 5. The profiles of the left and right flanks are identical, showing that the process is stable. The same conclusion can be drawn from the leads, on which the feed marks show up as ripples about 16 µm in size because of the high feed rate. Influences on the leads and face width resulting from the increased workpiece temperatures associated with dry cutting can be corrected through suitable compensation strategies. The tooth-space measurement (Fig. 7) shows outstanding values for tooth-spacing error (DIN quality 4–5). The cumulative tooth-spacing error is also good (DIN quality 6–7), though it was affected by the excessive runout of the gear.

In summary, excellent machining results were achieved simultaneously with the enormous reduction in time from 28 to 13 seconds. This dry-cutting process is compatible with subsequent heat treatment and hard gear finishing (honing) or with an alternative finishing process, such as shaving and hardening.

For another test, a steering pinion was hobbed. Fig. 8 shows the steering pinion along with workpiece and technology data. The main hurdle with this workpiece is the need for smooth operation, which is hindered by large feed marks. For economic reasons, of course, the feed rate should be as high as possible. Derived from practical experimentation, the metal-removal rates in Fig. 8 represent a compromise between these opposing requirements. The steering pinion was machined with a TiN-coated, single-start carbide hob with 11 gashes and a diameter of 45 mm. Once again, no coolant was used.

Using the technological possibilities provided by dry cutting with carbide hobs reduces machining time by 50% compared to conventional machining with HSS hobs.

Fig. 9 documents the machining results in the form of profile and lead measurement. The small deviations on the profiles are due to the quality of the hob. The lead tracing shows ripples of about 2 µm caused by feed marks. The jump that can be seen on the lower part of the right flank was caused by a change in cutting force that resulted from a change in the workpiece diameter in this area.

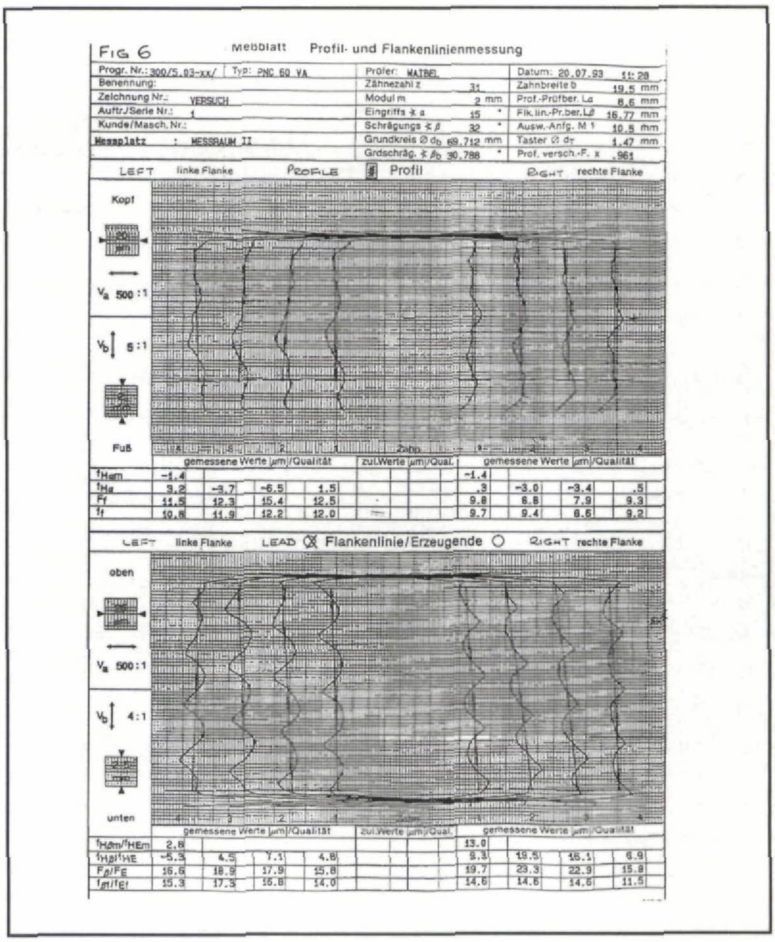

Fig. 6 — Profile and lead measurements of drive gear.

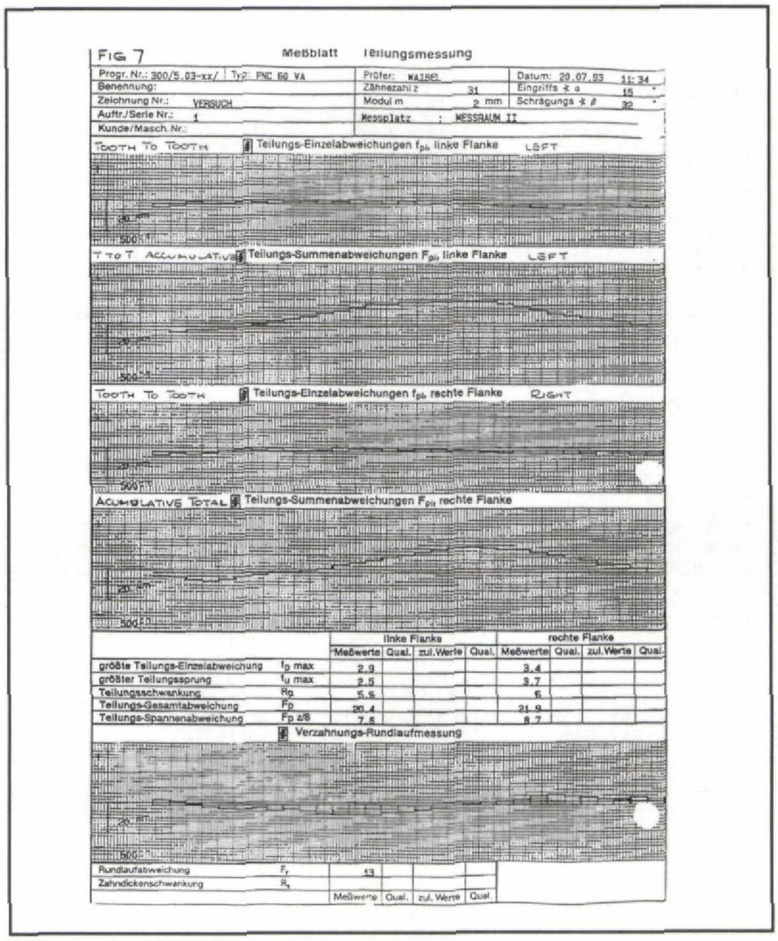

Fig. 7 — Tooth spacing error measurement.

Work Example: Steering Pinion		
Part Data:		
No. of Teeth	8	
Module (DP)	1.95 mm (20)	
Helix Angle	13.67° RH	
Face Width	26 mm (1.02")	
Cutting Depth	3.2 mm (.13")	
Hob Data:		
Material	**HSS**	**CARBIDE**
No. of Starts	1	1
No. of Gashes	11	11
Hob Diameter in mm (")	45 (1.75)	45 (1.75)
Hob Length in mm (")	100 (4)	100 (4)
Technology:	**HSS**	**CARBIDE**
Coolant	Oil	None
Speed in m/min. (sfm)	107 (360)	250 (820)
Hob rpm	760	1800
Axial feed in mm/tr. (ipr)	0.9 (0.35)	0.9 (0.35)
Cutting time in sec.	38	16
Load/unload in sec.	6	6
Time per part in sec.	**44**	**22**
Costs: (Guide Values)	**HSS**	**CARBIDE**
Hob Cost in $	600	2200
No. of Resharpenings	8	20
Cost/Resharpening in $	100	200
Parts/Resharpening	2700	2400
Tool Costs per Part in $	**0.06**	**0.12**
Machine Costs/Hour in $	75	75
MC-Costs per Part in $	**0.82**	**0.46**
Total Costs per Part in $	**0.88**	**0.58**

Fig. 8 — Hobbing without coolant (Cost/Performance Comparison).

The steering pinion has all the properties required for trouble-free actuation. Once again, using carbide hobs without coolant has direct economic advantages through shortened machining times as well as indirect advantages through the elimination of coolant.

Summary

For ecological and economic reasons, the use of coolants in production has been at the center of debate for some time. The advantages and disadvantages are well known, and there have already been numerous attempts to develop economical dry cutting methods. Improvements in tools and the incorporation of dry-cutting requirements in a suitable machine design have established the prerequisites for eliminating coolant from the hobbing process. This elimination leads to other process advantages, which in direct comparisons have already yielded considerable economic advantages in favor of dry cutting. The positive ecological balance results in still more pluses, which also show up as cost reductions. ■

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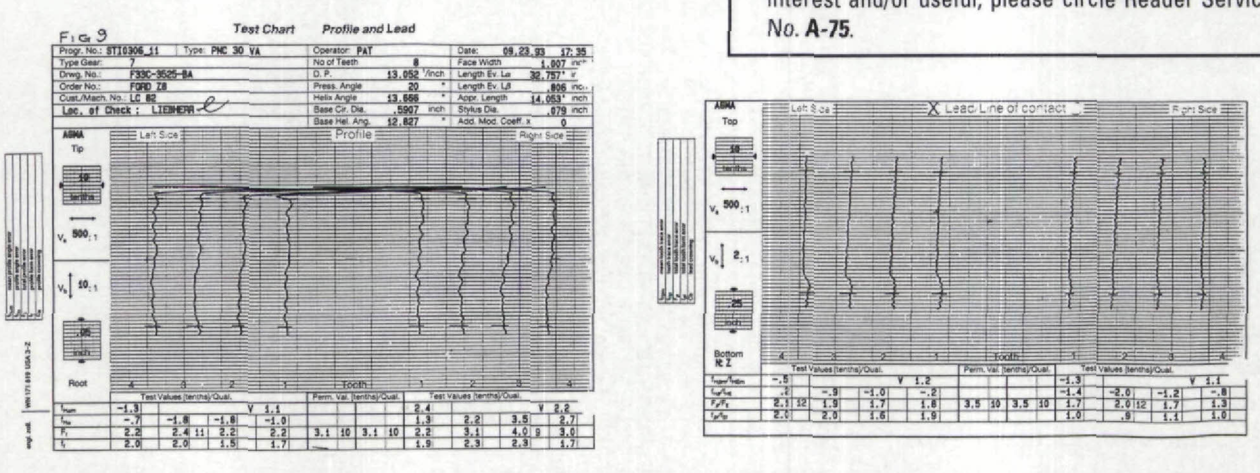

Fig. 9 — Profile and lead measurements.