New Innovations in Hobbing — Part I

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Prior to the introduction of titanium nitride to the cutting tool industry in the early 1980s, there was very little progress in the general application of hobbing in the gear cutting industry. The productivity gains realized with this new type of coating initiated a very active time of advancement in the gear manufacturing process.

The purpose of this article is to give the reader a general understanding of some of the latest technology in hob design as well as its application. This is not to say that the article is meant to be all-inclusive. There are sure to be recent advancements and ideas in development that are not covered.

Any company that wishes to take full advantage of the latest advancements should contact its hob manufacturer to obtain the necessary help and direction for each application.

One of the biggest driving factors in the development of new processing for gears has been the promotion in this industry of continual improvement. In virtually all levels of design and manufacturing today, the philosophy of continual improvement has led to some rather abstract solutions to specific problems. The first thing that must be agreed on is the elimination of any boundaries that may have been established in prior years.

To help organize the subject matter in this article, a number of key topics have been identified. Each area will be covered in detail. The topics include

- Analytical Evaluation
- Materials
- New Tool Configurations
- Coatings
- Accuracy Improvements
- Dry Hobbing

We should begin by discussing the effects of changing individual features of a hob's design. Greater detail will be offered later in this article; it is only noted at this time to help explain the logic that helped set the direction of some changes and improvement.

Changing Individual Features of Hobs

The first area to explore is the effect of the number of gashes in the hob. Fig. 1 demonstrates that by changing the number of gashes from 10 to 20, the number of cutting edges producing the form doubles. This in turn reduces the chip load, thus increasing the tool life. It also improves the form accuracy by reducing the height of the generating flats.

Another approach is to increase the feed and keep the load constant. Increasing the feed reduces the machining cost.

The next variable to consider is the number of threads in the hob. In some respects, this can be compared to changing the number of gashes. The equivalent number of gashes can be thought of as the number of gashes divided by the number of threads. For example, Fig. 2 shows the effect of changing from a one-thread hob to a three-thread hob, keeping all other variables the same. Although four-gash hobs are uncommon, the effect is very similar. Both the chip load and quality are affected as before.

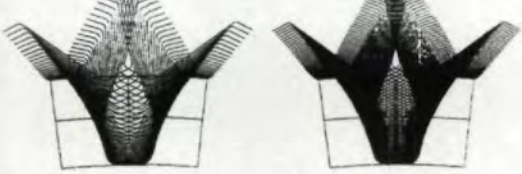

Fig. 1 1-Thread, 10 Gashes 1-Thread, 20 Gashes

One final area to examine in relation to the generating process is the effect of the number of teeth in the part. While this is not necessarily an item that is controlled by the hob design, it is important to see the resulting effect and determine what one might do to offset that effect. In Fig. 3, it is easy to see the impact on chip load, form generation and generating flats when comparing a tooth generated on a 10-tooth part with one generated on a 50-tooth part. Notice specifically the difference in the fillet produced and the amount of "sweeping" or generating that takes place on the 10-tooth part.

The gear manufacturer must realize that the objective in successfully applying the following concepts is to reduce the total manufacturing cost of the gear being evaluated. Shown in Fig. 4, the total manufacturing cost is the summation of the tool cost and the machining cost. To simply concentrate on only one of these factors may result in settling for a cost figure that does not represent the optimum machining rate. As you will see in some of the examples to follow, there are cases where it might be wise to sacrifice tool life to achieve greater gains in reducing the machining cost.

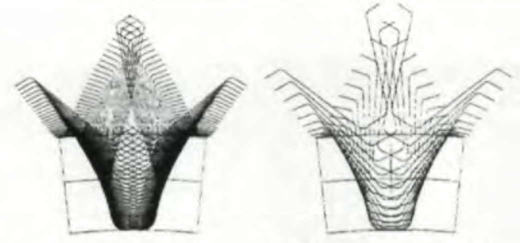

Fig. 2 1-Thread, 10 Gashes 3-Threads, 10 Gashes

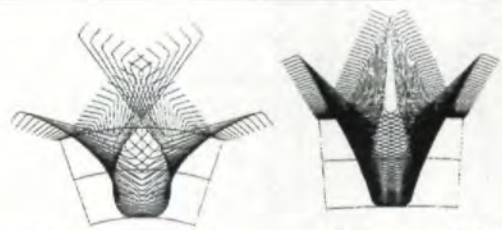

Fig. 3 1-Thread, 10 Gashes, 10 Teeth 3-Threads, 10 Gashes, 50 Teeth

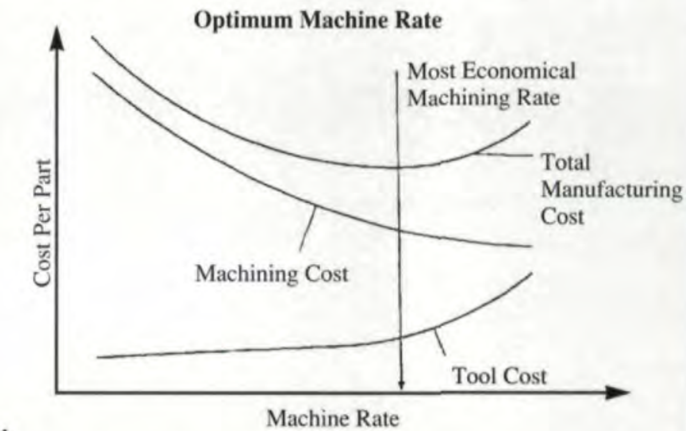

Fig. 4

Analytical Evaluation

While there have been many ways to evaluate the performance of an existing application or to predict the results of a new one, one of the systems being used more and more is the comparison of lineal inches cut per hob tooth. With this system, when one knows the hob parameters and part specifications and utilizes life factors that have been developed historically, it is possible to estimate tool life with a certain degree of accuracy.

The first step is to calculate the number of usable teeth in the hob. To do this, it is necessary to determine the usable length of the hob with the following formula:

Usable Length = $HL - HB - NCP - RZ - GZ/2$

where:

HL = Hob Length

HB = Hub Length (total of both sides)

NCP = Normal Circular Pitch

PA = Pressure Angle

RZ = Roughing Zone

$= \sqrt{(\text{part o.d.} - \text{part wd}) \cdot \text{part wd}}$

GZ = Generating Zone

$= (2 \cdot \text{part addendum})/\tan \text{PA}$

Usable number of teeth = (Usable length/NCP) • number of gashes

Once the usable number of teeth has been calculated, the information shown below can be used to determine the total number of lineal inches (or number of parts) that can be cut per sharpening.

Life Factors at recommended speeds in soft steel

- Uncoated tool—80 lineal inches/tooth
- TiN-coated tool—125 lineal inches/tooth
- Disposable hob—250 lineal inches/tooth

The following example demonstrates how this system can be used:

Hob:	3.00 OD	8.00 length	12 gashes
	10 NDP	.314157 NCP	.125 hubs
Part:	40 teeth	4.2 OD	Spur
	.225 WD	.100 ADD	.75 Face

Usable length = 8.0 – .25 – .314 – .946 – .275 = 6.215"

Usable number of teeth = (6.215/.314) • 12 = 238 teeth

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Table 1–Disposition of Allowances, Clearances & Tolerances

HOB DATA	CONVENTIONAL	DISPOSABLE
Diameter	3.5	2.0
Length	7.5	7.5
Number of Threads	4	3
Class	A	A
Material	CPM M53	CPM REX76
Coating	TiN	TiN
CYCLE DATA		
Feed Rate	0.090	0.06
Feed Scallop Depth	0.0002	0.0002
Cutting SFM	300	400
Cutting RPM	327	765
Floor-to-Floor Time (min.)	0.38	0.25

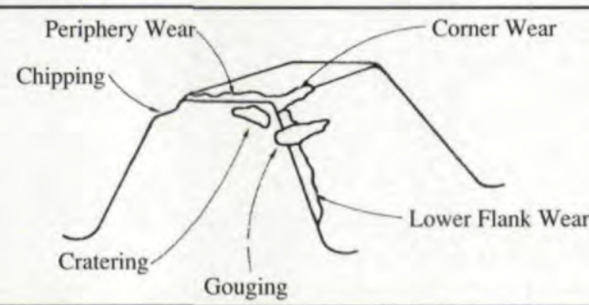

Fig. 5

Micro-chipping | Chipping Caused by Shear Stress | Chipping of Complete Tool Tip | Chipping of Complete Tool Tip | First Peel-back | Catastrophic Failure

Fig. 6

For a TiN-coated tool (125 lineal inches/tooth):

Life/Sharpening = 29,750 lineal inches
= 990 parts

Knowing the usable length of this hob is 6.215", it is possible to calculate the shift per piece.

6.215"/990 parts = .0063"/part

The goal of any of the proposed changes is to reduce the total cost of manufacturing the gear. One area that has been investigated recently is the effect of the outside diameter of the hob being used. In order to keep the cost of the tool low and reduce the approach and overrun dimensions, the designer tries to keep the diameter of the hob as small as possible. The small diameter also allows the hobbing machine to run at higher hob rpms while keeping the surface footage constant. Because of the timed relationship between the hob and the part, it should be obvious that the higher the rpm of the hob, the faster the gear will be produced. In some cases, as shown in Table 1, the use of premium steels, justified by lower material requirements, can also lead to gains in speed with the higher sfm.

Historically, a trade-off always has been required when determining the best possible diameter of the hob. While there are certain advantages to reducing the diameter, the main disadvantage is the reduction in number of sharpenings if the number of gashes is held constant. More recently, however, there has been a new approach to this design compromise. Normally an optimum diameter exists that may be considerably different from those suggested in the past. This will be discussed in greater detail later.

The field of wear analysis may have been somewhat misunderstood in the past. All too often, a wear problem is not noticed until catastrophic failure has taken place. In these cases, it is quite possible that the primary mode of failure is no longer recognizable. To establish some common ground, please refer to Fig. 5, which shows the different types of wear.

Earlier evaluations of the best solution to a specific wear problem may have been, in some cases, exactly opposite of what was correct. For example, the usual correction for an excessive flank-wear problem is to upgrade the substrate steel to a premium grade with increased wear resistance. With today's methods of evaluation, we attempt to review the wear performance as it progresses, leading up to the final failure. When this is done and the tool is investigated under a microscope, we may find that, in fact, the primary mode of failure is premature edge chipping. In that case, the solution may be a steel that has tougher characteristics. This method of evaluation may seem to be quite time-consuming, but if the manufacturer is able to determine the best material for a given application, the time is well spent. In Fig. 6, the progression of this type of wear is shown. Here you can see the wear take the following sequence:

- microchipping
- face chipping caused by shear stress
- chipping of complete tooth tip
- first evidence of peel-back
- catastrophic failure.

New Tool Configurations

The solutions of today's problems often take a direction or configuration that we would not have considered before because of self-imposed boundaries or limits. These limits must not be allowed to interfere with the thought process required to reach acceptable solutions to these new application challenges.

There is a definite compromise in the design of hobs when considering the diameter and the number of gashes versus the number of sharpenings available. In the past, the emphasis has been on achieving the maximum number of sharpenings because this reduced the tool cost per piece. More recently, it has become apparent that when considering the total cost to maintain a hob, a better solution might be to have a tool that is either smaller in diameter or the same diameter with more gashes. While this reduces the number of sharpenings, it also reduces the cost to maintain each hob.

Fig. 7 shows a comparison of the same hob with the only difference being the number of gashes. In this case the design changes from 14 gashes to 24. Because of this, the amount of life also changes from .365" to .132". Now considering the explanation of the advantages in increasing the number of gashes given earlier, it should be clear that there is certainly an optimum number of gashes for a given application. This optimum can change depending on the manufacturer's goal. For example, if the goal is simply to improve the life of the tool, the feed would be kept constant, thus reducing the chip load with the higher number of gashes and in turn reducing the amount of wear for a given number of lineal inches cut. Within these limits, it is possible to calculate the total cost for each number of gashes and arrive at the lowest or "optimum" cost. Table 2 is a spreadsheet that has been developed to make this evaluation quite simple. While the equations for this spreadsheet are not given here, they are available upon request.

Now consider the same application with the goal changed to increased productivity. This will be accomplished by increasing the feed relative to the increase in number of gashes. By drawing on the information regarding the reduced chip thickness with the higher number of gashes, an argument can be developed that it should be possible to increase the feed of a hob with the higher number of gashes to a point where the chip thickness remains constant. In this case, the amount of wear for a given number of lineal inches cut will stay constant even though the feed is increased. Now if we go through the same exercise as in the previous example, we can find the optimum number of gashes for this new set of criteria, which may not be the same as in the previous example (see Table 3). One possibility must be considered at this point. Not all applications have the potential to increase the feed for a number of reasons. One is machine limitations; another is a maximum feed scallop height due to finish requirements or stock allowances for finishing operations. In these cases, the limit can be included

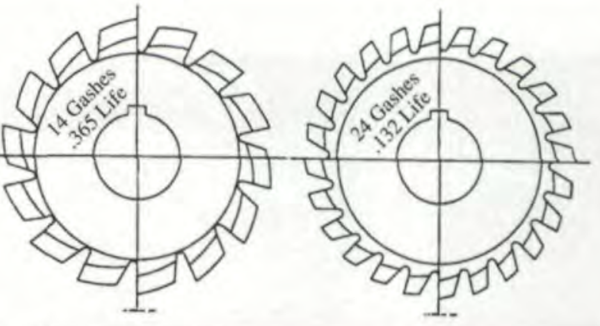

Fig. 7

Table 2—Hob Productive Performance Analysis—Constant Feed

EXAMPLE: Determine tool cost and machining cost per part for possible designs, assuming the hob is run at the same feed and speed as the conventional hob. The increase in the number of gashes is used to reduce chip load, thereby allowing the hob to cut more lineal inches for the same amount of wear.

NUMBER OF GASHES	14	16	18	20	22	24	26	28	32	35
Increase in # gashes	0.0%	14.3%	28.6%	42.9%	57.1%	71.4%	85.7%	100.0%	128.6%	150.0%
Usable tool length	0.326	0.259	0.208	0.169	0.138	0.112	0.090	0.074	0.045	0.031
Decrease in length	0.0%	20.6%	36.2%	48.2%	57.7%	65.6%	72.4%	77.3%	86.2%	90.5%
# of hob sharpenings	32	25	20	16	13	11	9	7	4	3
# of hob uses	33	26	21	17	14	12	10	8	5	4
Lin. inch cut per tooth	82.7	94.5	106.3	118.2	130.0	141.8	153.6	165.4	189.1	206.8
# of usable teeth	325	371	417	464	510	557	603	649	742	812
Lineal inch/hob (x1000)	886	912	932	932	928	947	926	859	702	671
Lineal inches per part	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.8
# of parts cut per hob	42570	43807	44781	44755	44597	45492	44492	41280	33698	32250
# of parts per hob use	1290	1685	2132	2633	3186	3791	4449	5160	6740	8062
Hob price	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600
Sharpen & recoat costs	$1600	$1250	$1000	$800	$650	$550	$450	$350	$200	$150
Cost to buy, maintain hob	$2200	$1850	$1600	$1400	$1250	$1150	$1050	$950	$800	$750
Tool cost/part	$0.052	$0.042	$0.036	$0.031	$0.028	$0.025	$0.024	$0.023	$0.024	$0.023
Tool cost/lin. inch	$0.002	$0.002	$0.002	$0.002	$0.001	$0.001	$0.001	$0.001	$0.001	$0.001
Hob RPM	360.1	360.1	360.1	360.1	360.1	360.1	360.1	360.1	360.1	360.1
Axial feed rate (IPR)	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
Chip load factor	.0286	.0250	.0222	.0200	.0182	.0167	.0154	.0143	.0125	.0114
Scallop depth at O.D.	.00079	.00079	.00079	.00079	.00079	.00079	.00079	.00079	.00079	.00079
Scallop depth on flank	.00027	.00027	.00027	.00027	.00027	.00027	.00027	.00027	.00027	.00027
Cutting cycle (minutes)	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
Load & unload (minutes)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Floor to floor (minutes)	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Total up-time (hr)	56.4	56.4	56.4	56.4	56.4	56.4	56.4	56.4	56.4	56.4
# parts per hob use	1290	1685	2132	2633	3186	3791	4449	5160	6740	8062
# of hob changes	8	6	5	4	3	3	2	2	1	1
Hob change time (minutes)	25	25	25	25	25	25	25	25	25	25
Total down-time (hr)	3.3	2.5	2.1	1.7	1.3	1.3	0.8	0.8	0.4	0.4
Total production hours	59.8	58.9	58.5	58.1	57.7	57.7	57.3	57.3	56.9	56.9
Total production costs	$1494	$1474	$1463	$1453	$1442	$1442	$1432	$1432	$1421	$1421
Machining cost/part	$0.149	$0.147	$0.146	$0.145	$0.144	$0.144	$0.143	$0.143	$0.142	$0.142
Tool cost/part	$0.05	$0.04	$0.04	$0.03	$0.03	$0.03	$0.02	$0.02	$0.02	$0.02
Machining cost/part	$0.15	$0.15	$0.15	$0.15	$0.14	$0.14	$0.14	$0.14	$0.14	$0.14
Total cost/part	$0.20	$0.19	$0.18	$0.18	$0.17	$0.17	$0.17	$0.17	$0.17	$0.17

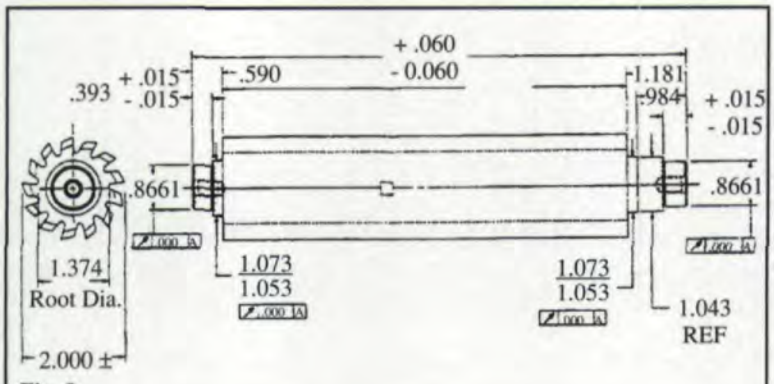

Fig. 8

Table 3—Hob Productive Performance Analysis—Increasing Feed

EXAMPLE: Determine tool cost and machining cost per part for possible designs, assuming the hob is run at a feed rate increased by the percent increase in number of gashes. The lineal inches cut per hob tooth will remain constant. The chip load factor will also remain constant. The feed rate remains constant after the scallop height reaches 0.0005

NUMBER OF GASHES	14	16	18	20	22	24	26	28	32	35
Increase in # gashes	0.0%	14.3%	28.6%	42.9%	57.1%	71.4%	85.7%	100.0%	128.6%	150.0%
Usable tool length	0.326	0.259	0.208	0.169	0.138	0.112	0.090	0.074	0.045	0.031
Decrease in length	0.0%	20.6%	36.2%	48.2%	57.7%	65.6%	72.4%	77.3%	86.2%	90.5%
# of hob sharpenings	32	25	20	16	13	11	9	7	4	3
# of hob uses	33	26	21	17	14	12	10	8	5	4
Lin. inch cut per tooth	82.7	82.7	82.7	82.7	82.7	82.7	82.7	82.7	82.7	82.7
# of usable teeth	325	371	417	464	510	557	603	649	742	812
Lineal inch/hob (x1000)	886	798	725	652	591	552	499	430	307	269
Lineal inches per part	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.8
# of parts cut per hob	42570	38331	34830	31329	28380	26537	23957	20640	14743	12900
# of parts per hob use	1290	1474	1659	1843	2027	2211	2396	2580	2949	3225
Hob price	*$600*	*$600*	*$600*	*$600*	*$600*	*$600*	*$600*	*$600*	*$600*	*$600*
Sharpen & recoat costs	$1600	$1250	$1000	$800	$650	$550	$450	$350	$200	$150
Cost to buy, maintain hob	$2200	$1850	$1600	$1400	$1250	$1150	$1050	$950	$800	$750
Tool cost/part	$0.052	$0.048	$0.046	$0.045	$0.044	$0.043	$0.044	$0.046	$0.054	$0.058
Tool cost/lin. inch	$0.002	$0.002	$0.002	$0.002	$0.002	$0.002	$0.002	$0.002	$0.003	$0.003
Hob RPM	360.1	360.1	360.1	360.1	360.1	360.1	360.1	360.1	360.1	360.1
Axial feed rate (IPR)	0.100	0.114	0.129	0.143	0.143	0.143	0.143	0.143	0.143	0.143
Chip load factor	.0286	.0286	.0286	.0286	.0260	.0238	.0220	.0204	.0179	.0163
Scallop depth at O.D.	.00079	.00103	.00131	.00161	.00161	.00161	.00161	.00161	.00161	.00161
Scallop depth on flank	.00027	.00035	.00045	.00055	.00055	.00055	.00055	.00055	.00055	.00055
Cutting cycle (minutes)	0.24	0.21	0.19	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Load & unload (minutes)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Floor-to-floor (minutes)	0.34	0.31	0.29	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Total up-time (hr)	56.4	51.5	47.6	44.5	44.5	44.5	44.5	44.5	44.5	44.5
# parts per hob use	1290	1474	1659	1843	2027	2211	2396	2580	2949	3225
# of hob changes	8	7	6	5	5	5	4	4	3	3
Hob change time (minutes)	25	25	25	25	25	25	25	25	25	25
Total down-time (hr)	3.3	2.9	2.5	2.1	2.1	2.1	1.7	1.7	1.3	1.3
Total production hours	59.8	54.6	50.1	46.6	46.6	46.6	46.2	46.2	45.8	45.8
Total production costs	$1494	$1360	$1253	$1165	$1165	$1165	$1154	$1154	$1144	$1144
Machining cost/part	$0.149	$0.136	$0.125	$0.116	$0.116	$0.116	$0.115	$0.115	$0.114	$0.114
Tool cost/part	$0.05	$0.05	$0.05	$0.04	$0.04	$0.04	$0.04	$0.05	$0.05	$0.06
Machining cost/part	$0.15	$0.14	$0.13	$0.12	$0.12	$0.12	$0.12	$0.12	$0.11	$0.11
Total cost per part	$0.20	$0.18	$0.17	$0.16	$0.16	$0.16	$0.16	$0.16	$0.17	$0.17

in the evaluation, which then gives the best-fit solution for the given criteria.

Another item that must be taken into consideration is the ability of the end user to sharpen the new tool. If there are limitations on the number of gashes set by index plate availability on the sharpener, the final result may have to be compromised slightly.

Many times the factors that will reduce the machining cost will actually increase the tool cost. In many cases the ratio of machine cost to tool cost may be as high as 20 to 1. In these cases the reduction of machining cost by increasing the feeds and speeds, for example, will more than offset the possible increase in tool cost because of accelerated wear.

To continue this concept to the next level, consider the possibility of either reducing the diameter of the hob or increasing the number of gashes to a point that there is no sharpenable life in the tool. This is, in fact, a disposable hob that is not intended to be sharpened. While each method of obtaining a non-sharpenable tool (reducing diameter, increasing gashes) has its benefits, the method that has been most successful recently is the diameter reduction method. A sketch of a typical disposable hob is shown in Fig. 8. The diameter in this case has been reduced to the point where there is no longer any room for a bore, so a quick-change shank design was developed.

Disposable hobs offer the following quality benefits:

- Uniform part size
- Less accuracy variation
- No arbor runout effects on accuracy
- Reduced cutting forces due to low feed, *high rpm cutting*
- Improved productivity without the need for a higher number of threads.

They also offer the following process benefits:

- Productivity gain due to small-diameter tool
- Quick-change tool
- No tool resharpening
- Tool is coated on all surfaces at all times
- No arbor maintenance
- Tool stays on machine longer
- Reduced tool inventory
- Reduced tool damage at changeover.

The success of this type of tool is dependent, of course, on its proper application and the full utilization of its benefits. In order to do this, the hobbing machine must be capable of hob speeds in the range of 2,000 rpms for high-speed steel hobs. This approach is one of the latest examples of application optimization through joint efforts of machine builders and tool manufacturers. ■

Editor's note: *Part II of this article, which will cover accuracy improvement, materials, coatings and dry hobbing, will appear in the next issue.*

Acknowledgement: *This article was first presented at the SME Gear Processing and Manufacturing Clinic, April 1994, Indianapolis, IN.*