

## Working Conditions

Since the hob performance depends on a large number of variables, which many times are interacting with each other, it's practically impossible to give exact informations on the cutting speed, on the work-piece in feed movement, on the shifting value and on the work-piece number that can be done in a particular operation.

Chances are so vast that it is not possible nowadays to formulate a mathematic law which fixes the fundamental cutting parameters, and it is therefore necessary to limit ourselves to general considerations which may orient the user toward a primary choice of the working conditions, which will have to be later ameliorated with a series of practical trials.

First we have to decide which is the best method to define a hob's performance.

It is not correct to consider only the number of hobbled pieces for each re-sharpening, since work-pieces might have more or less teeth, or they might have a large or narrow face width. It is instead more correct to talk about the length of the teeth which is performed at each re-sharpening. However, even this index is not complete, due to the fact the gear can be cut with a short hob or a long one, or even with a hob with many of few cutting edges. It's therefore appropriate to introduce the concept of the hob's number of teeth involved in the cut in order to formulate the performance index:

**K**= length of the teeth cut by each tooth of the hob

The formulas here reported are valid if considering the following notes.

$Z$  = number of teeth on the gear.

$L$  = width of the gear's hobbled face width

$\beta$  = angle of the gear's helix

$L$  = total length of the gear's teeth (in meters)

$L_p$  = total length of  $p$  gears' teeth (in meters)

$b_1$  = Hob's usable length

$f_{os}$  = Hob's axial pace

$l_o$  = Number of cutting edges on the hob

$N_z$  = Total number of hob's teeth involved in the cut

$$L = \frac{Z \cdot l}{1000 \cdot \cos \beta} \quad ; \quad L_p = p \cdot L = \frac{p \cdot Z \cdot l}{1000 \cdot \cos \beta}$$

$$N_z = i_o \cdot \frac{b_1}{t_{os}} \quad ; \quad K = \frac{L_p}{N_z} = \frac{p \cdot Z \cdot l \cdot t_{os}}{1000 \cdot i_{os} \cdot \cos \beta \cdot b_1}$$

The performance coefficient  $K$  is measured in meters per tooth and should range between 4 to 5 meters/tooth in order for the hob's performance to be considered a good one.

Of course it must be clear that such a defined performance is only one of many criteria which might be chosen to estimate the convenience of a determinate set of working conditions. It's often very common, for example, the choice of favouring the cutting speed increase and therefore the cutting time reduction instead of a hob's good mechanical performance.

In any case, if a certain result required from a hob is inferior to what expected, the working conditions have to be modified by progressively reducing the cutting speed and the feed for workpiece revolution, and by eventually increasing the shifting value.

One must keep in mind that a too much high cutting speed increases wearing by means of abrasion on the tooth flanks, while a too much strong in feed movement tends to increase the formation of crater. The wear exam might give useful indications on how to modify the working conditions.

If considering the previously explained criterion, it might be worthed to verify how hobs are being used in the factory. Performances which are far inferior to 4 m/tooth need a more thorough analysis.

It is also important to notice that before calculating K's value it is necessary to fix the wear value that needs to be reached before substituting the hob. It is indeed clear that if we keep the hob working until the wear reaches high levels we can hob more pieces thus increasing K, but at the end we will be able to sharpen the hob only a few times. Therefore the hob's cost for each work-piece produced (or for each meter of hobbing performed) will increase.

Today hobs with various coverings are generally used, and it is therefore possible to give an overall indication of what can be the granted wear. We can rely on the following values:

- For modules ranging from 1 to 2 mm : max wear = 0,20 mm
- For modules ranging from 3 to 4 mm : max wear = 0,25 mm
- For modules ranging from 5 to 6 mm : max wear = 0,30 mm

It is important to remember that such a criterion used to evaluate the hob's performance is only one of the parameters which influence the total cost of the produced gear. Other elements which need to be considered are: the hob's cost, the hobbing time, and auxiliary costs (sharpening, lubricating coolants ,working materials).

Another option which the user must take into consideration is the *number of passes*. Up until now we have discussed as if the hob would finish the work-piece in one single pass, but it's often common to make a first roughing pass and a second finishing pass. This system is nowadays facilitated by the fact that the two passes working conditions are easily programmed and the whole cycle can be managed with the numeric control.

The two passes are particularly used when an accurately refined gear is to be obtained, which can be then used without any further finishing operations. Moreover, they can be used when particular difficulties are encountered in the shaving operation, so that it is preferable to start with a roughed piece which owns limited errors. Another case where accurately hobbled pieces are required is for example when honing is involved.

The stock removal which is normally left for the second pass depends on the module. For modules ranging from 1.5 to 3.5 mm, the stock removal on each flank may vary from 0.3 to 0.5 mm.

### Cutting speed

Over the last few years, significant progress has been made in many areas that involve gear hobbing; machines have become more efficient, more rigid and more capable of enduring intense stress; the numeric control units that manage these machines are fast and able to control all cutting parameters; tools have become more accurate in quality and above-all they are manufactured in better quality steels than those that were once used.

Thanks to these developments it's now possible to reach cutting speed which were really unthinkable until recent times.

Unfortunately it is not possible to give precise indication of cutting speeds here since there are too many variables involved.

Just think of the combination of steels that must be machined and of the many cutting materials that are available on the market today, the influence that the chip thickness has on the operation and the geometrical characteristics of the hob.

Some may prefer to reduce cutting times without giving particular importance to poor tool performance. Others prefer to manufacture the largest number of pieces possible with hob, not being particularly interested in reducing cutting times.

Programmes for any PC are now available to determine the best working condition for the job at hand by simply entering the basic technical data.

For the moment, however, to clarify the subject of cutting speed, we will just examine some examples which may serve as a basis upon which to carry out further trials.

The examples that follow refer to gears with modules between 1,5 and 3 mm.

1)- Gear made of steel with  $R = 600 - 700 \text{ N/mm}^2$ . Latest generation of CNC hobbing machine, hob in M35 steel (or ASP 30) recoated with TiAlN also in the cutting face:

**$V_t = 100 - 120 \text{ m/min}$ .**

2)- Same as in example 1) without coating on the cutting face after resharpening:  **$V_t = 90 - 100 \text{ m/min}$ .**

3)- Gear made of hardened steel with  $R = 1000 - 1100 \text{ N/mm}^2$ , latest generation of CNC hobbing machine, hob in M35 (or ASP30) steel recoated with TiAlN also in the cutting face:  **$V_t = 60 - 80 \text{ m/min}$ .**

4)- Gear made of steel with  $R = 600 - 700 \text{ N/mm}^2$ . Latest generation of CNC hobbing machine, hob made in superalloy steel and recoated with TiAlN:  **$V_t = 140 - 170 \text{ m/min}$ .**

5)- For the first three examples if the hobbing machine is a conventional non CNC type but is in good condition, the cutting speed must be reduced by 10-15 %.

6)- When hobbing gear with above 3 mm, the greater the module of the gear, the more the cutting speed must be reduced.

The above examples refer to cutting operation with hobs in high speed steel. Carbide hobs, however, must be examined separately.

This type of hob may be conveniently used only in certain circumstances, that is only if the manufacturer has a modern hobbing machine which is particularly rigid and which has been constructed for high speed revolution.

When manufacturing gears that are made steel with a resistance of  $600 - 700 \text{ N/mm}^2$  it is possible to reach cutting speeds of above 300 m/min.

In order to summarise the data on cutting speeds and to give to manufacturers a better idea, the following table has been provided.

This data must be used, however, with precaution. As you may in fact notice there are differences between the values given in the table below and the values indicated in the examples above.

Table N°1 in fact shows general data where, for example, the type of machine and the type of coating have not been taken into account.

Table N°1 – Possible cutting speeds

Steel resistance ( $\text{N/mm}^2$ )	Velocità di taglio in m/min		
	High speed steel with coolant	Carbide Dry cutting	Carbide with coolant
600	120	320	305
700	110	290	280
800	100	270	240
900	85	240	200
1000	70	210	180
1100	60	180	160

another important consideration which, unfortunately, complicates yet further the matter of cutting speeds is that we must evaluate how the material of the workpiece react to being cut since the resistance of the steel alone is not a sufficient parameter.

In fact, based on the chemical composition, two different steels may react very differently to being cut even if they have the same level of resistance.

In the table N°2, the most commonly used steels have been indicated and they have been divided in term of their machinability. Clearly if a particular steel has a poor level of machinability, it is necessary to lower the working conditions, and the cutting speed, accordingly.

Table N°2 Machinability of steels

<i>Machinability of steels</i>		
Good	Acceptable	Difficult
16 Mn Cr 5	42 Cr Mo 4	30 Cr Ni Mo 8
20 Cr Cr 5	17 Cr Ni Mo 6	14 Ni Cr 14
15 Cr 3	18 Cr Ni 8	36 Ni Cr 6
34 Cr 4	CK 45	34 Cr Ni Mo 6 V
CK 15 (fino 35)	C60	30 Cr Mo V 9 V
30 Mn 5	Cf 70	40 Ni Cr Mo 7
15 Cr Ni 6	28 Ni Cr Mo 4	
20 Mo Cr 4	37 Mn Si 5	
21 Ni Cr Mo 2		

### Feed and chip thickness

In hobbing, the feed of the hob is indicated for each workpiece revolution. Where :

- $N$  = Number of revolution per minute of the hob
- $N_g$  = Number of revolution per minute of the workpiece
- $Z_0$  = Number of threads of the hob
- $Z$  = Number of gear teeth
- $A'$  = Feed of the hob per minute
- $F_a$  = Feed of the hob per workpiece revolution

The following formula applies :

$$N_g = \frac{N \cdot Z_0}{Z} \quad ; \quad f_a = \frac{A'}{N_g} \quad ; \quad f_a = \frac{A' \cdot Z}{N \cdot Z_0}$$

The feed per devolution also depends on many factors such as the material that is being cut, the material of the tool, the number of gashes of the hob, the accuracy that the manufacturer wishes t obtain on the workpiece, the state of the hobbing machine (in particular in terms of his rigidity) and so on.

It is, however, untrue that the lover the feed per workpiece evolution, the lower the level of the wear.

There is in fact an empirical relation between the chip thickness and the speed which wear propagates as shows in figure N°1.

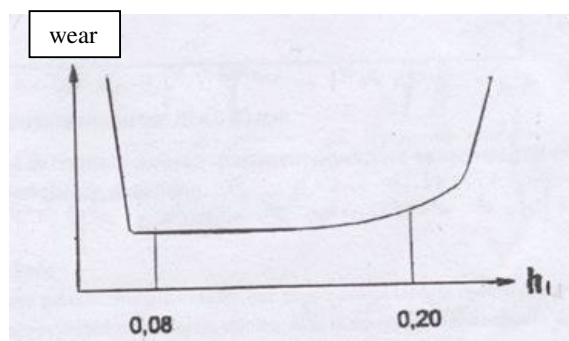


Fig.N°1

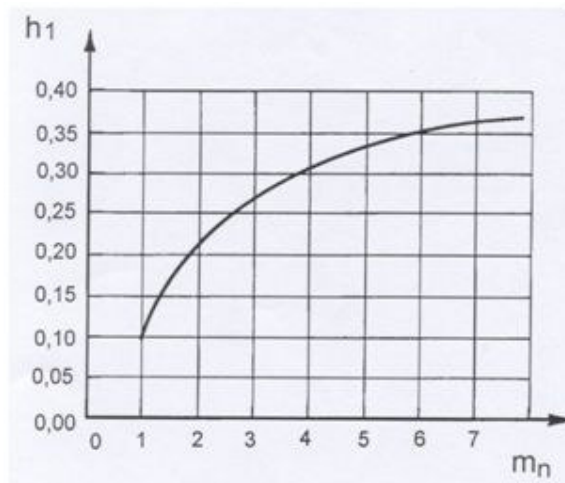
The chip thickness may be calculated precisely by using the formula of Hoffmeister which we be examined shortly.

It is therefore very important not to go beyond the advised chip thickness, firstly to avoid the formation of premature wear and secondly to avoid premature tooth breakage.

The maximum chip thickness depends very much on the module. It is possible to consider that for module on 1 to 3,5 mm the following applies:  $0,10 \leq h_1 \leq 0,30$ , whilst for module between 3,5 and 6 mm we have  $0,30 \leq h_1 \leq 0,35$ .

For example, if we consider a module around 2 mm the maximum chip thickness is about 0,25 mm.

To calculate  $h_1$  in relation to  $m_n$  it is in any case possible to use the chart shown in figure N°2.



**Fig. N°2**

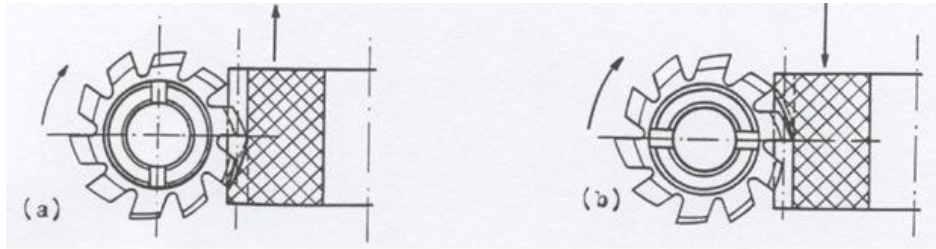
The maximum chip thickness also depends, however, on the type of steel being machined, on the material from which tool is made and on the type of operation (whether it is wet or dry).

Therefore the maximum thickness, for maximum module, as listed above must be modified according to table N°3.

Table N°3 – Maximum chip thickness

Resistance of steel $N/mm^2$	Maximum chip thickness (mm)			
	High speed steel and carbide. Wet cutting. (min. thickness)	High speed steel Wet cutting (Max thickness)	Carbide Wet cutting (max thickness)	Carbide Dry cutting (max thickness)
600	0	0,35	0,18	0,10
700	0	0,32	0,17	0,10
800	0	0,29	0,16	0,10
900	0	0,26	0,15	0,10
1000	0	0,23	0,14	0,10
1100	0	0,20	0,14	0,10

As with milling, it is possible to distinguish between two types of feed in gear hobbing : climb cutting and conventional cutting. (see figure N°3).



**Fig. N°3**

With climb cutting (fig. 3a), the thickness of the chip grows from zero to its maximum value, and it takes on the form of a prolonged comma.

This is why the hob cutting edges, at the beginning of the cutting operation, tend to run over the surface of the workpiece before cutting into the chip.

This causes the hob to wear quickly, the material being cut becomes work-hardened, which may be particularly damaging for those gears that must be finished by shaving, and lastly a kind of embankment forms on the back of the tooth which makes the machined surface lumpy.

For all of these reasons climb cutting does not allow for the use of particularly high speeds. The only advantage is that the cutting force drives the table in such a way as to avoid any backlash. The feed is therefore more regular.

Conventional cutting, however, tend to push the table in the same direction as the feed (see fig.N°3b). The table feed is therefore potentially jumpy.

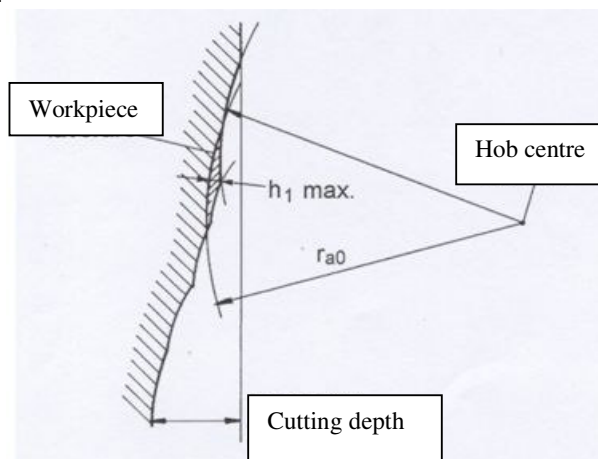
This inconvenience is, however, no longer a problem nowadays since here are technical solution which automatically recover backlash in the kinetic chain.

Modern hobbing machines, and especially where hob and workpiece rotation is driven by independent motors that are managed by numeric control unit, have overcome this difficulty.

With the conventional cutting method, the chip is cut from its largest part and the form of the chip is therefore that of a shorter comma, with this method, the performance of the hob is better.

The Hoffmeister formula

The famous Hoffmeister formula is fairly complicated to apply even though nowadays it has been made a lot easier with the aid of computerised programmes. Both the formula which calculates the maximum chip thickness given a certain feed per workpiece revolution and the reverse formula which calculates the feed per workpiece revolution given a certain chip thickness are useful. The meaning of maximum chip head thickness  $h_1$  is shown in figure N°4.



**Fig.N°4**

Calculation of the maximum chip thickness

$$h_{1\max} = 4,9 \cdot m_n \cdot Z_2^{(9,25 \cdot 10^{-3} \cdot \beta_2 - 0,542)} \cdot e^{-0,015 \cdot (\beta_2 + x_p)} \cdot \left(\frac{f_a}{m_n}\right)^{0,511} \cdot \left(\frac{d_{a0}}{2 \cdot m_n}\right)^{(-8,25 \cdot 10^3 \cdot \beta_2 - 0,225)} \cdot \left(\frac{i_0}{Z_0}\right)^{0,877} \cdot \left(\frac{h}{m_n}\right)^{0,319}$$

Calculation of the feed per workpiece revolution

$$f_a = h_1^{1,9569} \cdot 0,0446 \cdot m_n^{(-1,6145 \cdot 10^{-2} \cdot \beta - 0,7730)} \cdot Z_2^{(-1,8102 \cdot 10^{-2} \cdot \beta + 1,0607)} \cdot e^{0,0294 \cdot \beta} \cdot \left(\frac{d_{a0}}{2}\right)^{(1,6145 \cdot 10^{-2} \cdot \beta + 0,4403)} \cdot \left(\frac{i_0}{Z_0}\right)^{1,7162} \cdot h^{-0,6243} \cdot e^{0,0294 \cdot x_p}$$

Interesting considerations can be made on the Hoffmeister formula which gives the value of the feed per workpiece revolution in relation to the other parameters, especially if we examine the different elements involved graphically.

In the table N°4 the various factors that influence this calculation are listed.

Table N°4

Factors	Value	Figure	Comments
$F_{h1}$	$h_1^{1,9569}$	N°5	We can see that the influence of the chip thickness $h_1$ is strong; $F_{h1}$ basically varies roughly in proportion of $h_1$ squared
$F_m$	$0,0446 \cdot m_n^{(-1,6145 \cdot 10^{-2} \cdot \beta - 0,7730)}$	N°6	Here it's clear that as the module $m_n$ increases, the $F_m$ factor decreases in an exponential manner; this means that to obtain the same chip thickness, the other condition must remain unvaried whilst the feed must be much lower. Furthermore the influence of $\beta$ is insignificant.
$F_{Z2}$	$Z_2^{(-1,8102 \cdot 10^{-2} \cdot \beta - 1,0607)}$	N°7	There is almost a linear relation between the number of gear teeth $Z_2$ and the $F_{Z2}$ factor. This means that with the same chip thickness and with a larger number of teeth, it's possible to have a higher feed per workpiece revolution $\beta$ is insignificant.
$F_d$	$\left(\frac{d_0}{2}\right)^{(-1,6145 \cdot 10^{-2} \cdot \beta + 0,4403)}$	N°8	Also in this case the influence of $\beta$ is marginal, but with an increase of the hob outside diameter there is a significant increase in feed per workpiece revolution

$F_{i_0/Z_0}$	$\left(\frac{i_0}{Z_0}\right)^{1,7162}$	N°9	<i>The number of gashes and the number of start of the hob play an important part here. It can be clearly observed that to increase the feed, it is necessary to reduce the number of starts <math>i_0</math> and to increase the number of gashes <math>Z_0</math>.</i>
$F_{h/x_p}$	$h^{-0,6243} \cdot e^{0,0294 \cdot x_p}$	N°10	<i>The <math>X_p</math> correction factor does not have much influence, but the total tooth depth <math>h</math> (or better the cutting depth) is extremely important. The total tooth depth is practically proportional to the module. This is another factor which confirm that when the module increases, the feed per workpiece devolution must be reduced.</i>

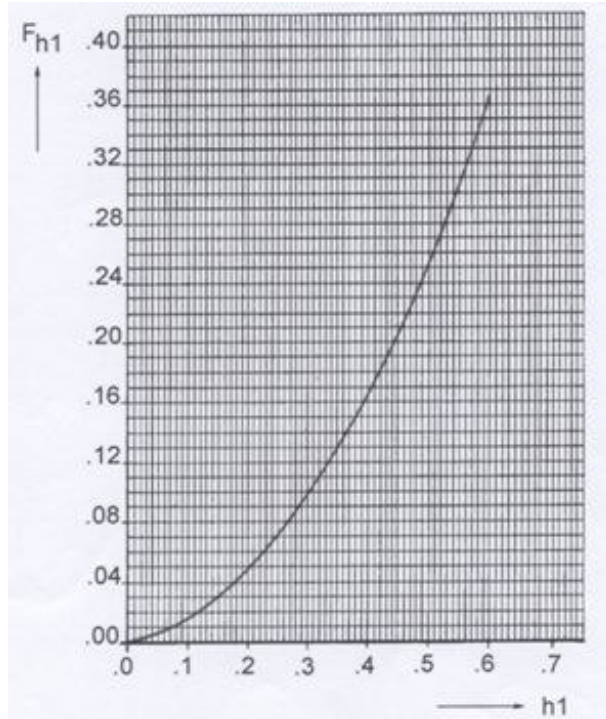
In this formula the two parameters which are interdependent are the feed workpiece revolution  $f_a$  and the chip thickness  $h_1$ . These parameters must be found.

All others parameters are in certain sense already fixed in that they are geometrical elements of the hob or of the gear.

To determine working condition we must choose the maximum chip thickness and from this value calculate the feed per workpiece revolution that would be acceptable.

It is in fact the chip thickness which determine the level of pressure that is placed on the hob tooth and is an indication therefore of whether the hob might be subject to a premature breakage.

If, in the other hand, the feed for workpiece revolution is already known, for example if it is a fixed value for a certain type of production, it is possible to check whether the chip thickness is within the acceptable limits or not.



**Fig. N°5**



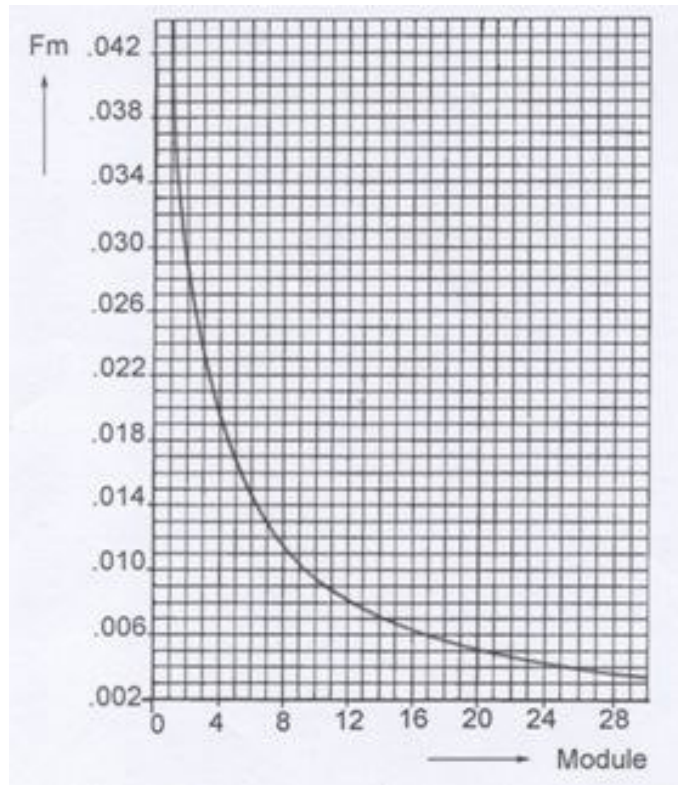


Fig. N°6

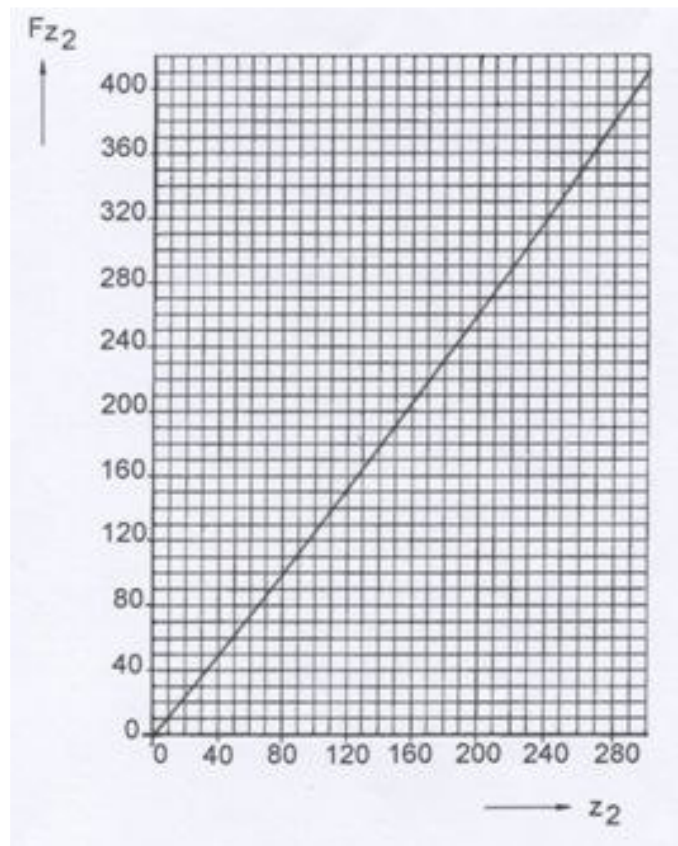


Fig. N°7

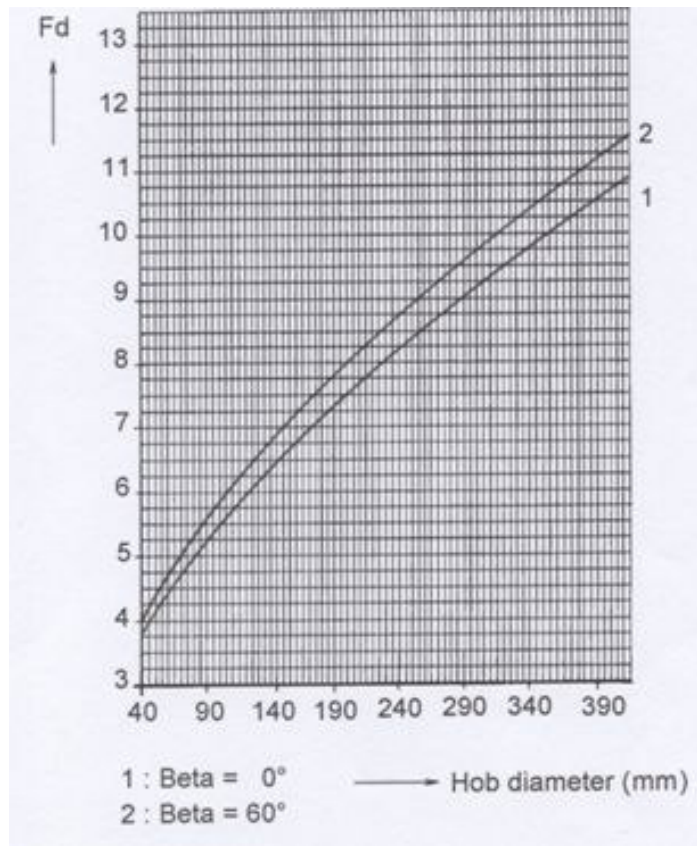


Fig. N°8

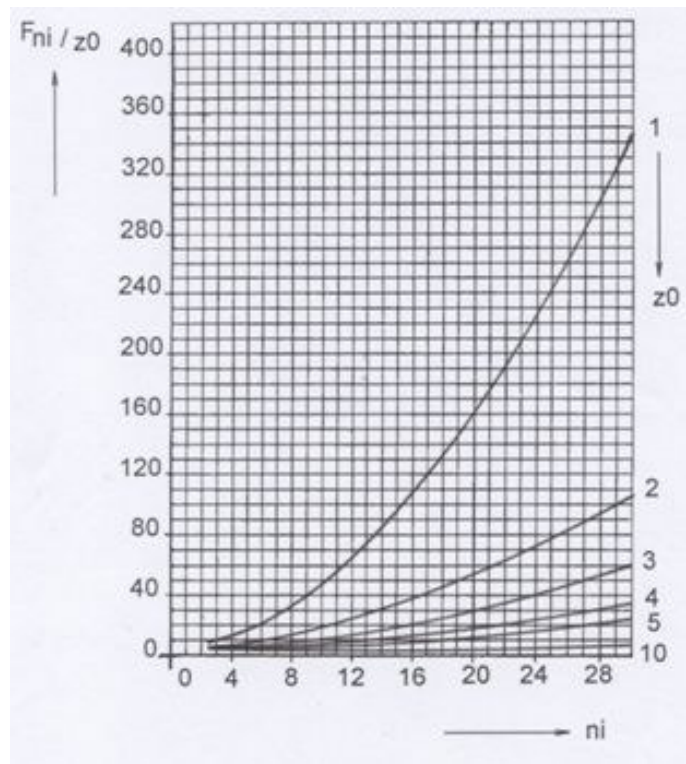
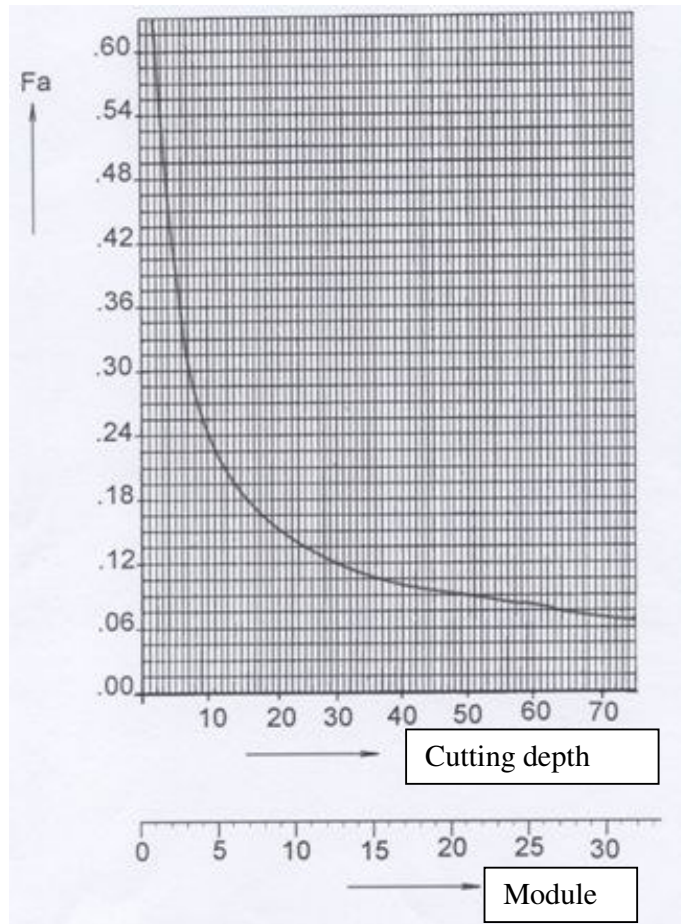


Fig.N°9



**Fig.N°10**

As a general rule the feed must be reduced as the number of starts of the hob increases. However, the limits of the feed are basically:

- *Profile and lead accuracy of the gear;*
- *Physical resistance of the hob teeth to breakage;*
- *The rigidity of the hobbing machine*

For gear which have a module less than 3 mm the following feeds per workpiece revolution may be advisable in optimum conditions and when working steel with a resistance  $R = 600 - 700 \text{ N/mm}^2$ .

- Hob with 1 start = 4 to 6 mm/revolution
- Hob with 2 starts = 3,5 to 4,5 mm/revolution
- Hob with 3 starts = 2,5 to 3,5 mm/revolution
- Hob with 4 starts = 2,0 to 3,0 mm/revolution
- Hob with 5 starts = 2,0 to 2,5 mm/revolution

It's important to remember that these values are purely indicative and that in any case it's necessary to check the maximum chip thickness, the accuracy of the gear produced and the resistance of the hob itself according to its state of wear in relation to the steel being worked.

For example, feeds with a value like those proposed in the case of hob with 1 start are rarely used since they produce significant lead errors (groove marks) especially when the hob has limited outside diameter.

In general profile and lead errors should not be above 15 – 20 microns.

### Shifting

After having machined one or more workpieces, the hob is moved by a certain amount in an axial direction; this movement is called shifting.

The axial movement is made in order to fully exploit the hob, that is to distribute wear along the whole of its length.

The problem of determining the optimum entity of shifting is not easy to resolve and is normally based on a series of practical trials in order to find out which shifting value gives the most uniform distribution of wear.

Different methods of shifting have been tried and tested for decades; the one which gives the best result today seems to be the following.

Carry out an initial series of shifting movements by dividing the whole stroke possible into more sections of an important entity, for example 10 mm, obtaining the intervals  $\overline{P_1P_2}; \overline{P_2P_3}; \dots; \overline{P_{n-1}P_n}$ .

Return to initial position  $P_1$  and shift a space of a limited value  $x$  (for example 0,05–0,2 mm). and the shift to the points  $P_2 + x$ ;  $P_3 + x$  .....  $P_{n-1} + x$ .

Repeat the procedure  $i$  times until  $P_1 + \sum x_i$  coincide with  $P_2$  in succession

Coincide with  $P_2$  in succession  $P_2 + \sum x_i$  with  $P_3$  ect. (see fig.N°11).

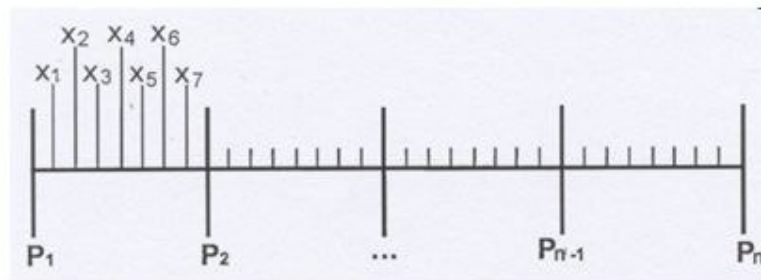


Fig: N°11

The overall result will be best possible providing that the interval  $x$  is that which generate the same level of wear across all teeth. In fact shifting movements of a greater entity, from  $P_1$  to  $P_2$  to  $P_n$  is important to keeps the temperature of the cutting edges low which is to the advantage of tool life.

Modern Numeric Control machines include shifting in their software options.

In older hobbing machines it is therefore easier to shift the hob after each gear cut or after one or more spindles of more workpieces.

The value to assign to “traditional-type” shifting may be calculated with the following

formula:  $S_h = \frac{2 \cdot m}{i_o}$  where:

$S_h$  = valore dello shifting in mm

$m$  = modulo

$i_o$  = numero dei taglienti del creatore

Lastly it's necessary to consider the shifting direction which may be in the same direction or in the opposite direction to that of the workpiece rotation (see fig.N°12).

*Shifting in the opposite direction*

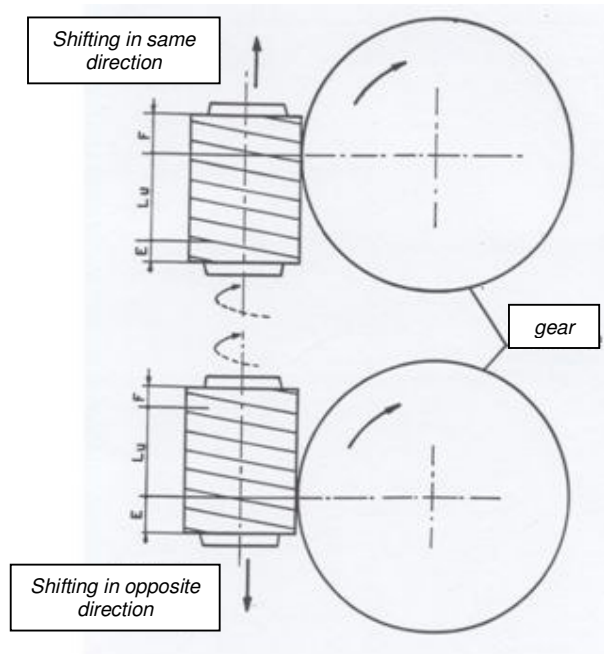
In this case the teeth that finish the gear have cutting edges that are not yet worn and therefore the gear produced has a good quality. Subsequently these finishing teeth are shifted to the roughing area A.

The hob wears more quickly, however, with this method.

#### *Shifting in the same direction*

The teeth that finish the gear are the same that previously roughed the gear area A and therefore the finish quality of the gear is worse.

The hob, however, wears less quickly. This method is used more frequently since any hobbing imperfection may be corrected in the subsequent shaving or grinding operations.



**Fig.N°12**

The reasoning behind shifting also changes according to whether we are dealing with large or small batch production.

In mass production where the rhythm in production is structured around two or three shifts, the hob is normally replaced at the end of a shift or at the beginning of the next one.

It is necessary to determine the shifting value both in terms of entity and frequency so that the hob will have completed the set number of strokes by the end of the shift.

In other words, it is necessary to avoid replacing a hob when it is in the middle of the shifting.

For small batch production where it is necessary to mount and dismount the hob in the machine numerous times before it needs resharpening, it is opportune to use the appropriate diagram where the position of the hob when dismantled is shown as well as the shifting direction, the number of strokes and the number of workpieces cut and any other data regarding the shifting operation.

Regular wear along the whole length of the hob may only be guaranteed in this manner.

#### Setting up the hob

The hob must be positioned correctly in the machine if it is to be properly, that is completely, exploited.



Often hobs may be found in workshops which have teeth at the extremities that have not worked. This means that there have been losses in term of overall hob performance and the cost of the gear produced increases.

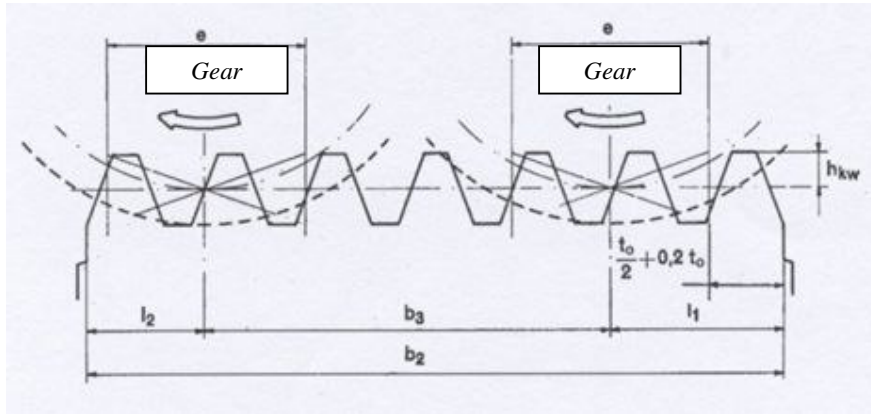
With reference of figure N°13, the hob will be fully exploited along its whole length if the total shifting has a value  $b_3$ , which is well estimated by the equation  $b_3 = b_2 - (l_1 + l_2)$  where the minimum positioning at the beginning of machining measured along the hob axis is given by  $l_1$  :

$$l_1 = \frac{h_{k1}}{\operatorname{tg} \alpha_2} + \frac{t_0}{2} + 0,2 \cdot t_0$$

Where  $t_0$  is the axial pitch of the hob teeth.

While the minimum positioning at the end of machining measured along the hob axis is given by  $l_2$  :

$$l_2 = \frac{h_{k1}}{\operatorname{tg} \alpha_2} + 0,2 \cdot t_0$$



**Fig. N°13**