Nomenclature of the hob's parts

In figure No.1 the different parts that make up a hob are shown. Some of these parts will be dealt with in more detail in other chapters whilst, for others, a short comment is sufficient.

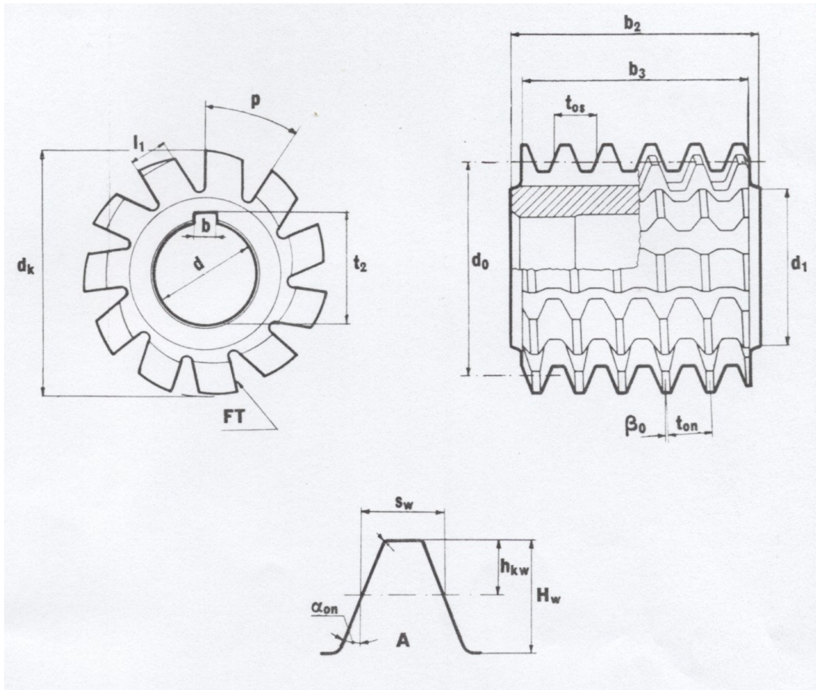

Figure No.1

Normal and axial pitches

One of the parameters which distinguishes a hob is the module. In general it corresponds to the module of the gear to be cut but this is not always the case. Later on we will see that it is possible to hob a gear with a certain nominal module using a hob that has a different one. Basically the module of a gear and therefore that of the hob is a value which is selected in a conventional manner. The definition of a gear module is:

m = Dp : Z

that is the module is obtained by dividing the pitch diameter of the gear by the number of teeth. The module is therefore not an a-dimensional number but it is measured in millimetres. This fact is often forgotten by many.

The module can also be considered as the diametral pitch. In fact, as we have just seen, it is precisely a length which is obtained by dividing the pitch diameter in as many segments as the number of teeth of the gear.

The Americans in fact tend to indicate the module with the name Diametral Pitch (DP) and they measure it in inches.

When we say, for example, that a gear has a Diametral Pitch of 16 (DP 16), it means that it has a module equal to a sixteenth of an inch i.e. 25,4/16 = 1,5875 mm.

By multiplying the module by Π (Pi i.e. 3,14159..), the normal pitch is obtained $\mathbf{t_{on}}$ which is the pitch measured in the direction perpendicular to the thread helix.

The normal pitch is the distance between two identical points of two consecutive teeth in the direction perpendicular to the thread.

In figure No.2 the axial pitch is also indicated $\mathbf{t_{os}}$. This is the pitch which is measured in the direction of the hob axis.

The relation between the two pitches is:

$$\mathbf{t_{on} = t_{os} \bullet \cos\beta}$$

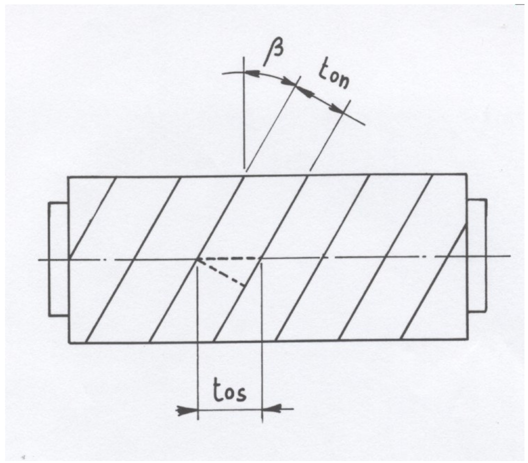

Figure No.2

Normal and axial pressure angles

Another element which strongly characterises the hob is the pressure angle which generally corresponds to the nominal pressure angle of the gear.
In the hob, it is simply the inclination of the tooth flank as illustrated in figure No.3.
As with the module, this value on the hob may differ from the nominal value.
The inclination changes according to the section of the tooth in question. Therefore the normal pressure angle α_{on} measured on a section perpendicular to the direction of the thread and the axial pressure angle α_{os} measured on an axial section of the hob are easily distinguished.
With reference to figure No.2, the normal and axial pressure angles are measured in the corresponding sections in which the relative pitches are also measured.
The relation that links the two pressure angles is:

$$\tan\alpha_{os} = \frac{\tan\alpha_{on}}{\cos\beta}$$

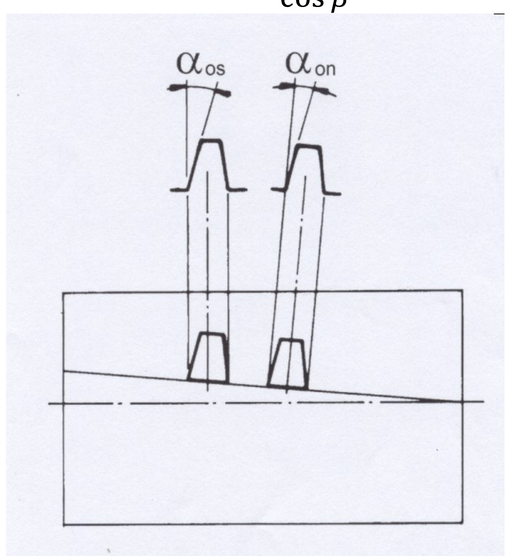

Figure No.3

Helix angle

The helix angle β , or thread angle, is measured on the pitch diameter of the hob and therefore it depends on this value. It also depends, however, on the number of threads (on the number of starts). This value must always be etched on the hob as the inclination of the hob clamping head in relation to the workpiece axis is set according to this value. In other words it is necessary to know the value of the helix angle to set the hobbing machine up properly.
It is calculated by the following formula:

$$\sin\beta = \frac{t_{on}\cdot f}{\Pi\cdot d_o} \quad \text{or} \quad \tan\beta = \frac{t_{os}\cdot f}{\Pi\cdot d_o}$$

The helix angle increases as the pitch and consequently the module increase, it increases as the diameter decreases and, as previously mentioned, it increases as the number of threads increases.
The direction of the helix is quite important however.
While cutting, the hob exerts a force S in the direction of the teeth; if we consider a helicoidal gear with an inclination of the helix β_0 , the force S has a tangential effect in the direction of movement of the gear. This force will have the value:

$$S_1 = S\cdot\sin\beta_0$$

It is advisable that the direction of this force is always opposite to the direction of revolution of the gear.
If the helix angle of the gear were higher than 15 – 20° and the force had the same direction as the revolution of the gear, the tangential force could drag the gear and reduce the contact between the hob teeth and the gear in the kinematic chain that commands the movement of the gear itself.
In this case machining would be jumpy and, apart from the poor quality of the gear, the hob teeth would be in great danger of breaking.
In order to avoid this type of inconvenience, which is relatively uncommon with modern CNC machinery, the helix direction of the hob is chosen in agreement with the helix direction of the gear.
Therefore a hob with a right hand helix for gears with a right hand helix and a hob with a left hand helix for gears with a left hand helix.
This rule may be ignored for helix angles under 15 – 20°.
In figure No.4 the directions of the tangential forces during cutting are shown.

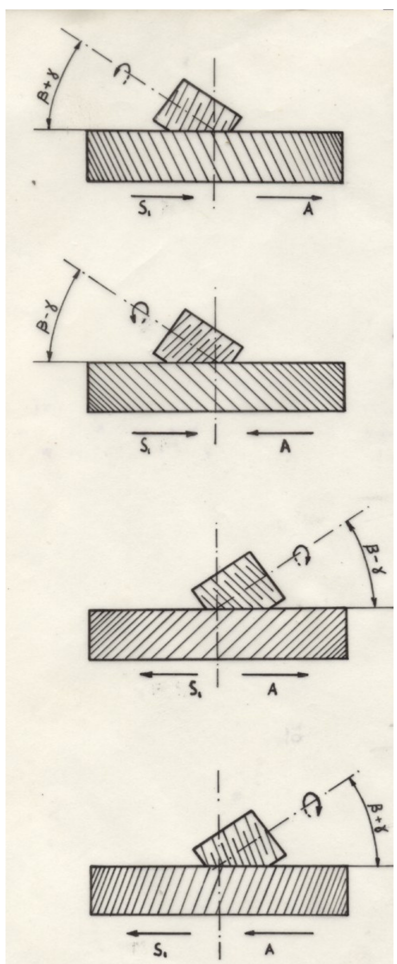

Figure No.4

Gashes
Gashes are basically serrations which cut the threads either in an axial direction, as indicated in figure No.5a, or in the direction perpendicular to the thread as in figure No.5b.

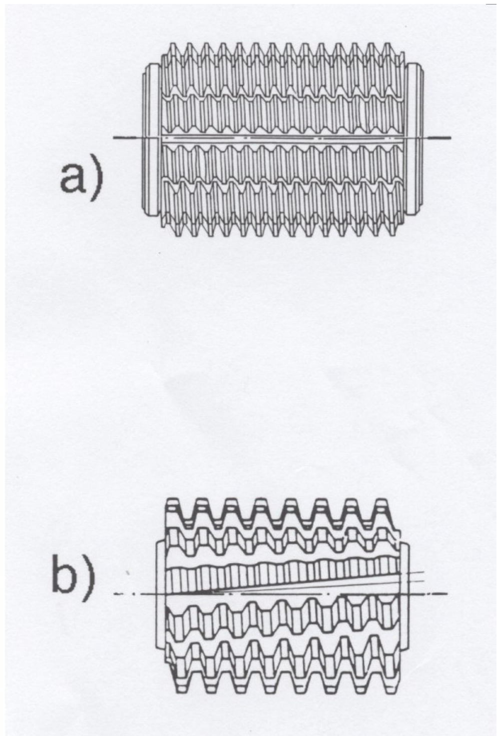

Figure No.5 a. & b.

From a theoretical point of view, it would be better to cut the gashes perpendicularly to the thread. In practice, however, it is possible to tolerate gashes in an axial direction up to a helix angle of around 4° – 5°. This facilitates both hob manufacturing and resharpening.
If the helix angle is higher than about 5° it is better to cut the gashes perpendicularly to the thread.
As we will see later on, however, this is not always possible especially when dealing with inserted blade hobs (even though these are slowing dying out) as for manufacturing reasons these must always have gashes in an axial direction.
Furthermore not all gear manufacturers have a resharpening machine which is able to resharpen helicoidal gashes.
With helicoidal gashes it is extremely important to know the value of the axial pitch of the helix of the gashes as this value is fundamental for setting up the resharpening machine properly.
Where P_a is the value of the axial pitch of the gashes, the following relation exists:

$$P_a = \frac{\Pi \cdot d_o}{tg\beta}$$

It is necessary to underline forcefully that an error in the spiral of the gashes has notable repercussions on the accuracy of the cut gear.
In fact, because of the tooth tip relief, the outside diameter of the hob itself becomes tapered.

Number of gashes

The hob designer must choose the number of gashes on the basis of many considerations including the end quality of the gear and the working conditions that are to be used.

The number of gashes depends very much on the hob diameter and on the number of starts. If, for example, we consider a hob with one start, each time the hob revolves, one gear tooth is hobbed. All of the hob teeth therefore contribute to forming the gear tooth and it is therefore logical that if the hob has a lot of gashes, the quality of the finished gear will be better and the cutting force that each tooth withstands will be lessened.

If the hob has 2 starts, only half of the gashes will be involved in forming a tooth and therefore the cutting force will be greater and the accuracy of the profile will be worse.

Obviously these concepts have been thoroughly studied and are expressed with often very complex mathematical formulae. In other parts of this book they will be discussed in more detail.

Nowadays the tendency is to design hobs with a larger number of gashes than in the past as the feed speed is higher and consequently hobbing time is reduced. It is clear that if the number of gashes is increased, the length of the tooth decreases and it is possible to carry out a smaller number of resharpenings. In total, therefore, less pieces will be hobbed and the cost of the hob per gear produced will increase.

This concept has led to the design of disposable hobs.

The number of gashes is increased until the length of the tooth is such that the tool can only be used once, that is the hob will not be resharpened. This type of hob drastically reduces hobbing time but the cost of the tool per gear produced increases notably.

Today, the cost of hobbing time is far more important than the cost of the tool per se. There are certain limits, however, which must be taken into consideration when choosing the number of gashes.

This matter will be examined in further detail when working conditions are discussed.

Cutting face

The gash determines the cutting face by intersecting the thread. The cutting face is nearly always radial, that is the rake angle is zero degrees. In very exceptional cases only, the angle may be positive while in a special type of hob known as the skiving hob, it is negative.

To obtain positive or negative rake angles, it is necessary to resharpen the hob with a grinding wheel that is positioned out of axis by a distance that depends both on the rake angle itself and on the hob diameter as per the formula:

$$tg\beta = \frac{2 \cdot u}{D}$$

considering that positioning the grinding wheel under centre will produce a positive rake angle whereas positioning it above centre will generate a negative rake angle.

Other important elements of the gash are: the tooth back angle (gash angle or chip removal angle), the radius of the bottom of the gash and the gash depth itself, see figure No.6.

Rather than hobbing accuracy, these elements influence the cutting efficiency of the tool. In fact if these values are not suitable, the chip will not be freely expelled through the vane between two teeth and, in extreme cases, it may result in chips building up at the bottom of the gash causing blockage and consequent breakage of the tooth.

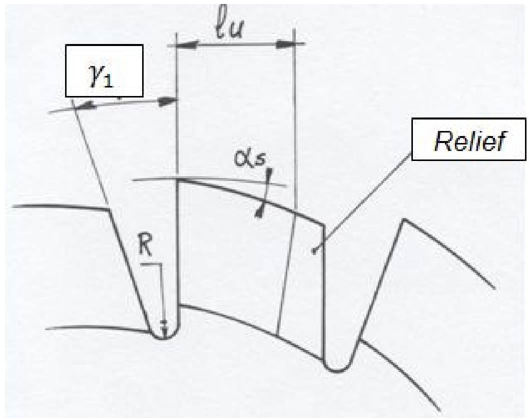

Figure No.6

Indeed, the curve that forms the vane between one tooth and another must always be continuous without any uneven interruptions that could prevent the free flow of chips. The breakage of hob teeth caused by chip blockage is not a rare occurrence and it may occur if the hob has a high number of gashes as the size of the vane is also consequently smaller.

<u>*Tip and side relief*</u>
To work properly, the cutting edge of each hob tooth must have adequate relief in order to avoid the part immediately behind the cutting edge interfering with the surface of the cut gear.
Tip relief is really the relief of the whole tooth profile and it is part of a particular curve known as the Archimedean spiral.
A curved relief like this is used in order to guarantee the continuity of the tooth profile when the tool is resharpened.
In fact the hob can also be considered a constant profile form milling cutter.
As the resharpening plane is nearly always designed to be radial (rake angle = 0°), the cutting profile lies on a plane that passes through the hob axis and the Archimedean spiral should guarantee that the profiles that are on this perpendicular section are constant.
In reality this is not the case: the curve that would guarantee this from a mathematical point of view is the logarithmic spiral. The Archimedean spiral, however, is easier to produce and it is nearly perfectly the same as the logarithmic spiral in the areas where it is normally used.

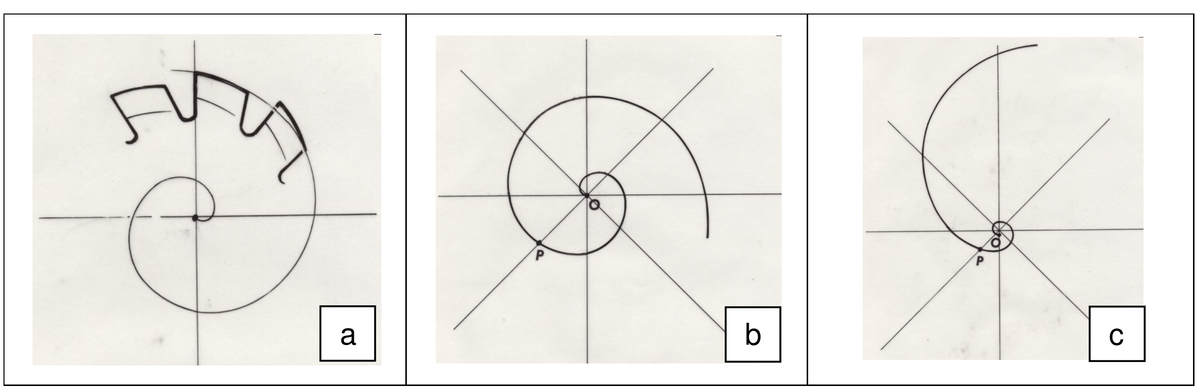

Figure No. 7 a., b. & c.

The mathematical definitions of the two spirals are the following:

Archimedean spiral. If a half line rotates around a fixed point O while one of its points P moves away from O in segments that are proportional to the angles at which the half line has rotated, the point P describes the Archimedean spiral. Its equation in polar co-ordinates is:

$$\rho = a \cdot \varphi$$

Logarithmic spiral. If a half line rotates around a fixed point O and a point P moves onto it in a way that the natural logarithm of the distance from O is proportional to the angle at which the half line has rotated, point P describes a logarithmic spiral. Its equation in polar co-ordinates is:

$$\log \rho = a \cdot \varphi$$

The side relief value depends on the tip relief value and on the pressure angle.
Where α_f is side relief

α_s is tip relief

α_{on} is the normal pressure angle

the formula is:

$$tg\,\alpha_f = tg\,\alpha_k \cdot tg\,\alpha_{on}$$

This formula is expressed graphically in the diagram in figure No.8

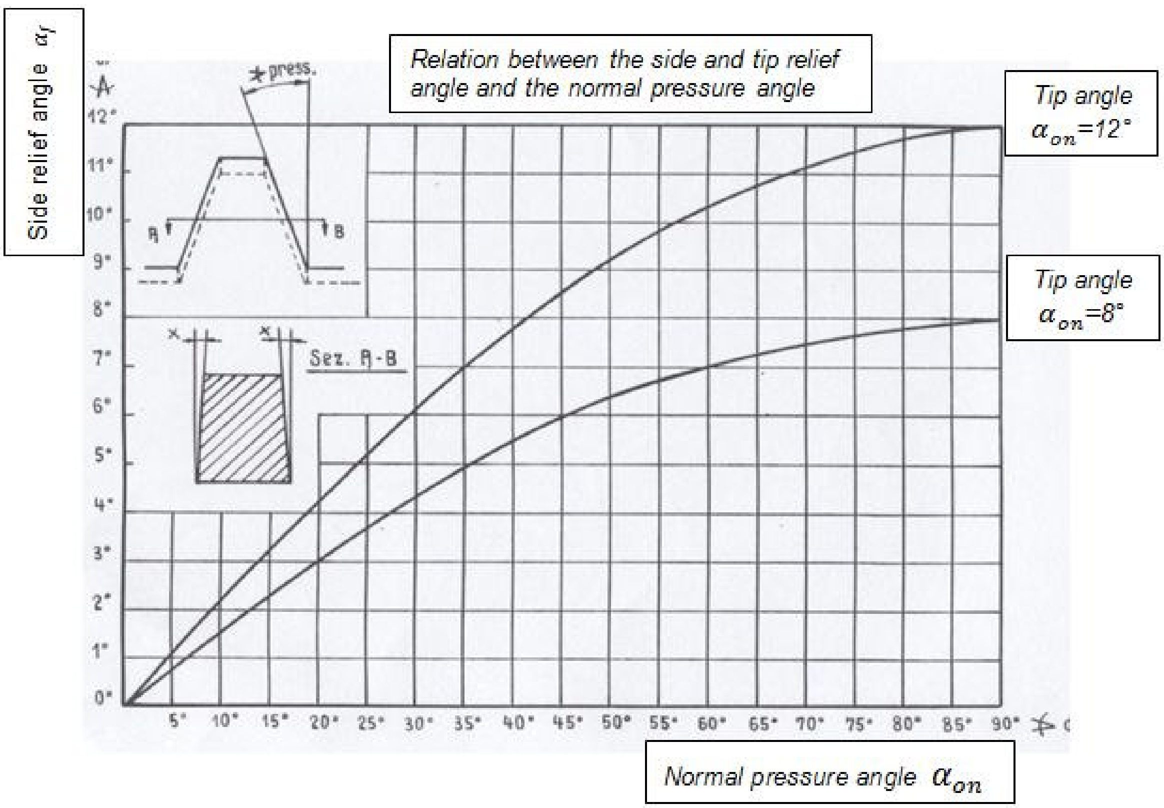

Figure No.8

If, for example, we consider a hob with a pressure angle of 20° and a tip relief angle of 10°, the side relief angle would be about 3,7°. This relief value would increase to about 4,4° if the tip relief were 12°.
As a general rule we can say that tip relief, and consequently side relief must be of a higher value if the material to be cut is soft while they must be as small as possible when cutting gears in hard steel or cast iron.
Towards the end part of the tooth in the area where the profile grinding wheel starts to move away from the hob, there is a reduction in side relief and, in some cases,

this may cause difficulty even before problems with profile variation arise.(see Fig. No.9).

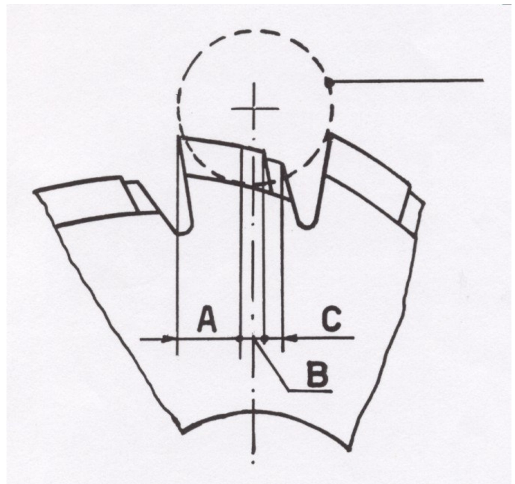

Figure No.9

The larger the tip relief of the hob, and therefore the larger the side relief of the tooth, the better the cutting action and the lower the cutting force exerted. The cutting edge, however, will be more fragile with the risk of premature chipping or lower overall hob performance.
To conclude on tip relief and on hob tooth relief in general, it is necessary to note that this relief is performed during the tooth roughing phase by so-called relieving lathes. The most recent versions of these machines are completely numerically controlled.
After heat treatment the tooth is finished by a special type of grinding know as relief grinding which gives the teeth their definitive form.
The wheel that grinds the teeth has a small diameter i.e. between 50 and 100 mm in relation to the height of the tooth and therefore the module of the hob.
It is necessary to make sure that this grinding wheel moves away from the tooth before it touches the next tooth. Clearly the smaller the size of the relieved back support area of the tooth, the better the hob as its useful life will be greater.
It is also clear that the smaller the tooth relief angle and the smaller the grinding wheel diameter, the smaller that this zone will be.
Modern relieving machines are all numerically controlled and they use electro-spindles which, in special cases, may command grinding wheels with very small diameters such as 25 – 30 mm.

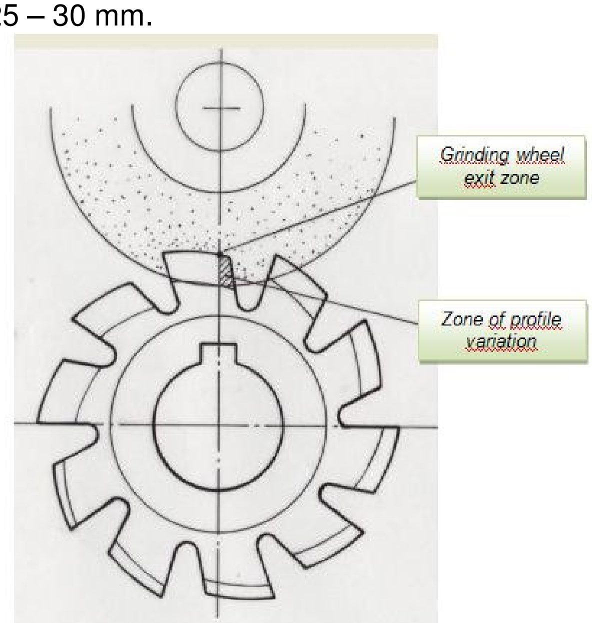

Figure No 10

Outside diameter

In theory the outside diameter of the hob can be of any size; in practice, apart from the minimum and maximum size limitations of the hobbing machine, it is necessary to base the choice of diameter on criteria of mass economy.

This, however, is not easy to determine.

First of all, it is necessary to consider that at constant cutting speeds, a hob with a smaller diameter revolves more times per minute.

As the number of revolutions per minute of the gear is directly proportional to the number of revolutions of the hob, it is logical to conclude that if the hob has a smaller diameter, the gear will revolve more quickly. Once a certain feed per piece revolution has been set, the feed per minute will be greater and therefore cutting times lower.

The following formulae therefore apply. They will be dealt with again at a later stage.

$$V_t = \frac{\Pi \cdot D \cdot N}{1000} \quad ; \quad N_g = \frac{N \cdot f}{Z} \quad ; \quad A' = A_g \cdot N_g \quad ; \quad t = \frac{L}{A'}$$

In these terms things would seem very simple: we should produce hobs with the smallest diameters possible!

We must, however, consider that it is not possible to cut many gashes on a small diameter hob and that in any case the length of the tooth becomes smaller. This means that the cost of the hob per piece produced increases.

This aspect of design will be better analysed when we examine cutting conditions. We can, however, affirm that the general tendency is to design hobs with a small diameter given the increasing importance of reducing hobbing time although this means that the usable length of the tooth decreases and therefore the number of possible resharpenings is lower. Figure No.13 clearly illustrates this.

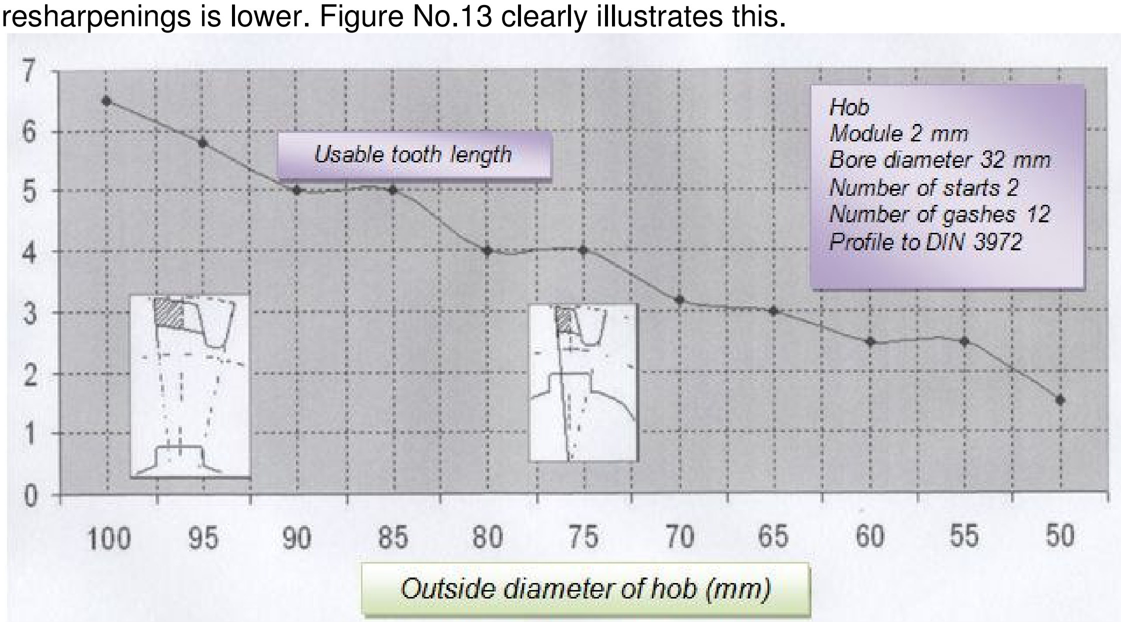

Figure No.11

Total length of hob

This characteristic of the hob has changed over the course of the last few years basically because of the fundamental consideration that the cost of the hob does not increase proportionally to its length while the number of pieces that it can machine increases more than its length in percentage.

For example, if we increase the length by 50%, the price increases by 40% while its performance may increase by up to 80%.

This concept is expressed graphically in figure No.12:

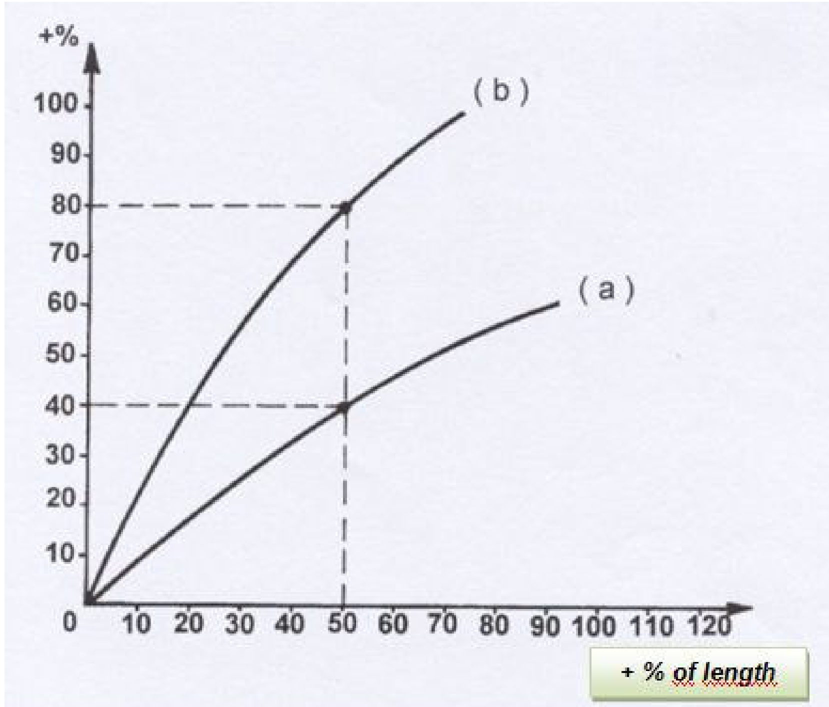

Figure No.12

a) % increase in hob cost

b) % increase in hob productivity

Nowadays it is not rare to come across hobs with a length of 250 mm but it is perfectly normal in the Automotive sector to see hobs from 180 – 200 mm in length.
Modern hobbing machines are built to use very long hobs and hobs with very small diameters but there are limitations in construction which mean that it is not possible to mount a hob of any length and reduce its diameter.
Normally the relation between length and diameter cannot be higher than 4.

Centring bore

This element of the hob is of extreme importance in that it has an impact on the quality of the gear produced.
The bore has a diameter with a very low tolerance. The DIN normative states a tolerance of H5 for high levels of quality and H6 for lower quality levels.
The tolerance on the ovality is 50% of that on the diameter.
A bore with too big a diameter may generate run out during hob set up and use, causing profile errors on the workpiece.
In any case the bore must be concentric with the primitive diameter of the hob and with the outside diameter. Any errors of concentricity will cause errors on the hobbed gear.
Today, hydraulic spindles are used on some types of hobbing machines. These eliminate any backlash between the spindle and the hob bore, centring the tool perfectly. However in normal hobbing where the gears are to be finished with a subsequent operation, this is not necessary.
With carbide hobs, on the other hand, it is necessary to make sure that the mating between the spindle and the hob is not too tight. In fact, because of the low thermal dilation that carbide has compared to the steel of the spindle (about half), the heat generated during machining may cause the spindle to expand and break the hob.
To facilitate bore grinding, the central part is usually widened. To centre the hob, it is sufficient to have two sections at its extremities which are co-axial between themselves and with the workpiece / hob pitch diameter. In this manner it is possible

to obtain a more precise bore diameter and mounting the hob on the machine will be easier. Figure No.13.

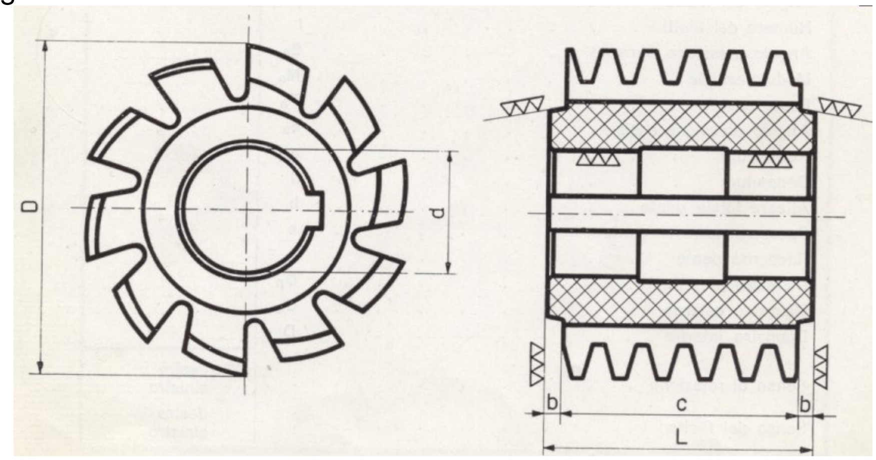

Figure No.13

The bore diameter has standard dimensions which are currently expressed in millimetres but it is still quite common to find the size of the bore indicated in inches. The most frequently used diameters today are shown in Table No.1

The driving keyway is normally longitudinal but in some cases it may be a clutch keyway especially if the hob has a small diameter.
In fact if a hob has a small diameter compared to the module and a large bore, it may be that there is not enough space for a longitudinal keyway. If the resistant section S becomes too small, the hob could break into pieces.
In this case it is better to have a clutch keyway.(figure No.14).

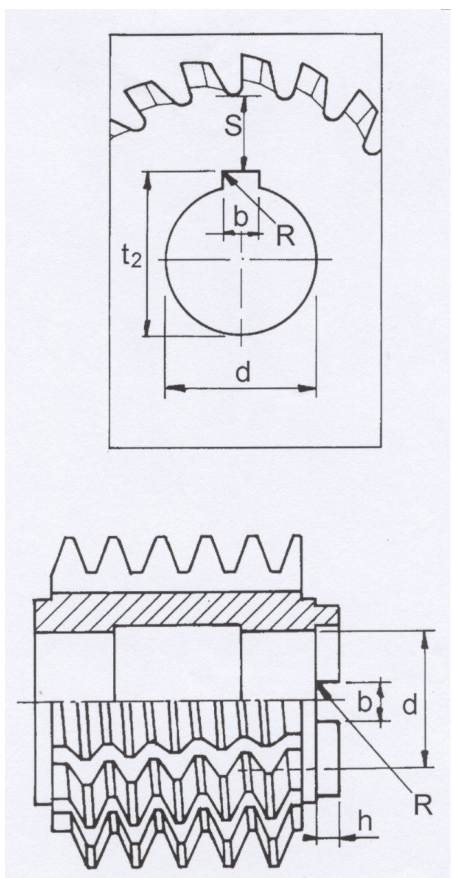

Figure No.14

Hob keyway dimensions are shown in Table No.1.

Table No.1: Keyway dimensions in hobs (mm)

Bore diameter	Longitudinal keyway			Clutch keyway		
	b	t_2	r	b	h	r
19,05	3,18	20,9	0,8	--	--	--
22	6,6	24,1	1,0	10,4	6,3	1,2
25,4	6,35	28,0	1,2	--	--	--
27	7,0	29,8	1,2	12,4	7,0	1,2
31,75	7,92	35,2	1,6	--	--	--
32	8,0	34,8	1,2	14,4	8,0	1,6
38,1	9,52	42,3	1,6	--	--	--
40	10,0	43,5	1,2	16,4	9,0	2,0
50	12,0	53,5	1,6	18,4	10,0	2,0
50,8	12,7	55,8	1,6	--	--	--

Note: the tolerances are all positive (+) apart from the value r of the clutch keyway which is negative (-).

Collars and side faces

Like all other parts of the hob, these two elements are also of great importance.
The centring collars must be concentric with the bore and the tolerances. For high precision hobs (Class AA) they are between 5 microns for modules up to 10mm and 6 microns for modules from 10 to 25.
The collars serve as a reference point and to check the run out of the hob during machine set up.
This run out should never be above 10 microns.
The side faces should be parallel to each other and perpendicular to the hob axis.
Perpendicular and planetary tolerances are always according to the DIN 3968 normative and they are from 3 microns for small-medium modules and up to 5 microns for larger modules.
Larger errors may generate defects such as blockage and accentuate run out errors of the hob on the spindle.

Tooth profile

The hob can produce any profile which repeats itself regularly on a circumference as long as this profile does not have undercuts.
There is therefore generally an unlimited number of hob tooth profiles.
If we consider, however, hobs that are used to cut cylindrical gears, the number of profiles decreases slightly.
When talking about the tooth profile, it is necessary to distinguish between the real tooth profile and that of the rack of reference.
The rack profile defines the gear that is to be cut whereas the real tooth profile is usually different from the reference one as it depends on the construction of the hob, for example it depends on the rake angles, the number of starts and diameter and therefore also on the helix angle of the thread etc.
When making reference to the hob profile, that of the rack of reference is intended unless otherwise specified.
The international normatives DIN, ISO, AGMA and so on quote the dimensions of the reference profile for so-called standard hobs and normally hobs that must finish a gear are distinguished from those that must cut a gear before it has undergone shaving or grinding.
Furthermore they distinguish between topping and non-topping hobs i.e. hobs that machine the outside diameter of the gear and those that do not.
Practically all hobs used in the Automotive Industry, in the commercial vehicle, tractor and earth moving machinery sectors, however, have special profiles as the gears nearly always have profile corrections. In particular nearly all of these hobs

are semi-topping types that is they are hobs which generate chamfers on the tips of the gear teeth.
With reference to figure No.15, the most common profile (B) has protuberance, which serves to generate an undercut at the base of the gear teeth to facilitate the finishing operation.
In (C) the classic profile of semi-topping hobs is shown where there are areas at the base of the teeth that are destined to generate chamfers on the tooth tips.
In (E) we have the full radius profile. The tooth tip is linked by a single radius which is to eliminate all of the sharp edges on the hob tooth tips since these may be particularly wear and damage prone. These profiles were designed to increase hob performance. The gear generated by these hobs usually has a root diameter that is smaller than normal.
In (F) the profile of a topping hob is shown with the tooth base that machines the external diameter of the gear. In some cases it is possible to avoid turning the workpiece before hobbing and in any case with this type of hob it is possible to obtain perfect concentricity between the pitch diameter and the outside diameter. Lastly in (G) we have an example of a special profile which generates a taper near the gear tooth tip.
Naturally these profiles may also be combined so it is possible to have semi-topping hobs with protuberance, full radius hobs with protuberance and semi-topping and so on.

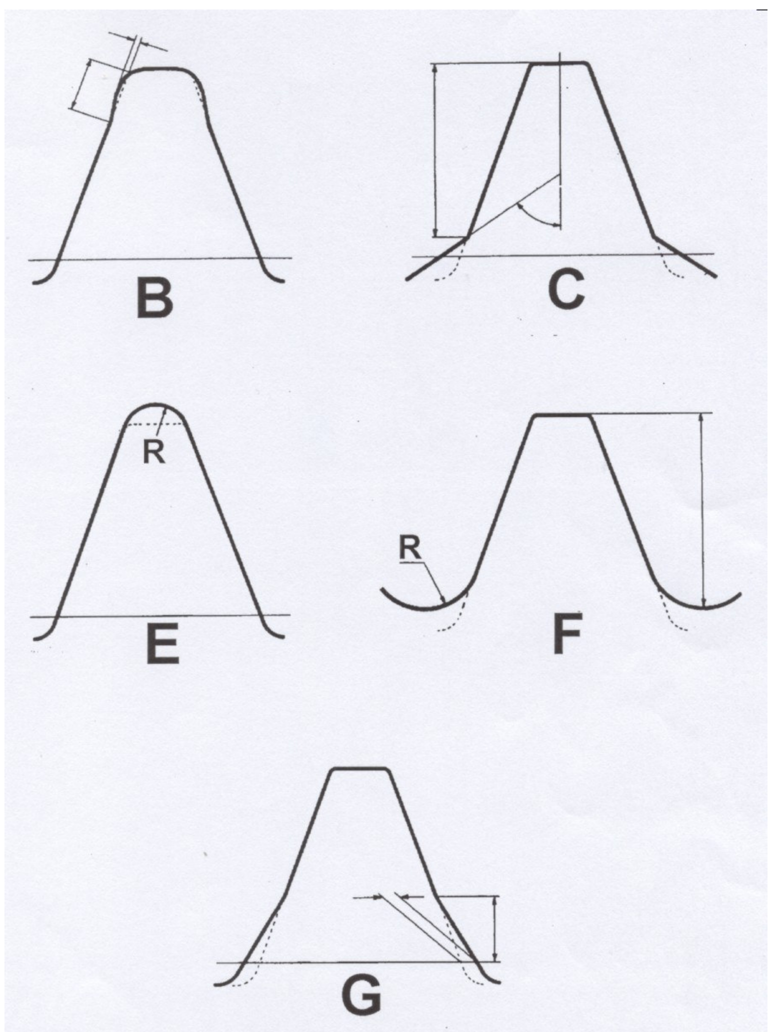

Figure No.15