Shaving methods

There are different shaving methods which substantially differs according to the direction of the movement given to the cutter. The choice of one method or another depends on the workpiece shape ,on the machine characteristics and on the type of production that has to be performed, i.e. small batches or big series.
For some methods the cutter has to be studied in a particular way both for what concerns serrations and the helix correction.
Before speaking of the different shaving methods, it is necessary to know an important parameter connected to this operation: the cross-of-axes angle.

Cross-of-axes angle γ

We have already stated that cutter and gear have different helix, i.e. their axes are not parallel. This is the essential condition for the shaving process.
The difference of the two helix angles, calculated along the operating pitch diameter, i.e. on the rolling diameter determines the *cross-of-axes angle γ*.
The cross-of-axes angle is an element that has to be chosen by the cutter designer, but the discretion margin is not very high.
Generally speaking, if you are working steel with resistance R = 600 ÷ 700 N/mm^2. its value can range between 10° and 15°. When you are working cast iron or light alloys it is possible to arrive up to 20°. As you will see, in some instances it is not possible to use such steep angles, because of obstacles (e.g. shoulders) which interferes with the cutter. In this case you will have to choose the highest possible angle, bearing in mind that it is practically impossible to work with angles lower than 3°.
The higher the cross-of-axes angle, the better the capacity and easiness of cutting, because of the high sliding speed.
But, meantime, you have a decrease of guiding action together with the progressive lost of control of tooth profile and helix direction.
High cross-of-axes angles imply a short cutter life.
On the other hand, if cross-of-axes angle decrease starting from 10° there is a gradual upsetting that reproduces the conditions of a parallel axes mating.
In case of gears that because of their shape do not allow a regular cross-of-axes, you can go as down as 3°, obtaining a glossy surface because of the intensified polishing action
You also have to note that cross-of-axes angle is not constant for a determined cutter. We said that the cutter and gear helixes are calculated on the operating pitch diameters. These varies every time that you resharpen a the cutter and therefore the cross-of-axes angle will change accordingly.
These are not variation that can influence the cutter operating because they remain the range of the tenth of degree, but it is obvious that you have to consider them when you assemble the cutter on the shaving machine.

Parallel shaving

The relative feed motion between cutter and gear takes place in the gear axes direction as shown in figure N°1.
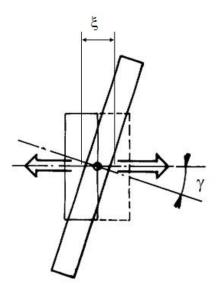
Fig.N°1- *Parallel shaving scheme (γ = cross of axes angle)*

You carry out various alternate strokes and when the stroke reverts, also the cutter rotation reverts.

The center distance between shaving cutter and workpiece reduces at each stroke turn until the prescribed chordal thickness in achieved.

In parallel shaving, as the same word says, the gear, or the cutter, are moved parallel to the workpiece axes, several times, backward and forward. The length of the backward and forward stroke could theoretically be equal to the gear tooth length, but it is usually a little bigger.

The cutter width has not relationship to the workpiece width. Theoretically it is possible to shave a limitless width gear by using a very narrow cutter.

This is the reason why the parallel shaving cannot be totally replaced by the diagonal shaving, which would be more economical, and even more by the plunge shaving, which can grant very big advantages.

The use of the shaving cutter with this system it is not the optimum one, because it cuts only with the central portion of the tooth. In fact the point of contact i.e. the intersection of the axes is in the middle of shaving cutter width This will be the only point where wear will be concentrated.

This inconvenient, which sensibly reduces the cutter life, can be relieved if you are able to shift the initial position of the point of contact from the center to one extreme.

When the cutter is worn out, you can simply turn it to be able to use another area of teeth.

This system requires a longer set-up and a particular care in its performance.

The main inconvenient of such method is that the shaving time is quit long, because cutter stroke is long.

The eventual crowning on the gear can be obtained by purposely tilting the workpiece holding table of the shaving machine, during the feed of the table itself.

Diagonal shaving
This method is also called "*conventional shaving*".
The relative motion between cutter and gear takes place with an angle included in the range 5°÷45° with reference to the gear axis; this angle is called diagonal angle ε .

You perform several alternate strokes and the feed in is gradual, same as in the parallel shaving.

In the diagonal shaving workpiece width, the cutter one and the *diagonal* angle are dependent one another; also the minimum stroke of the table depends on the previous parameter.

According to the notes of figure N°2 you have the following relationship:

$$tg\varepsilon = \frac{L_2 \cdot sen\,\gamma}{L_1 - L_2 \cos\gamma} = \frac{sen\,\gamma}{\dfrac{L_2}{L_1'} - \cos\gamma}$$

and also

$$l_1 = L_2 \cdot \frac{sen\gamma}{sen(\varepsilon + \gamma)}$$

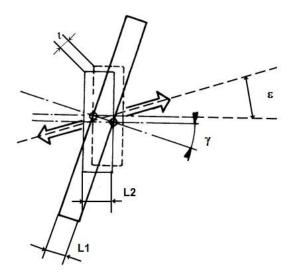where l_1 is the table stroke length.

Fig.N°2- *Diagonal shaving scheme*
γ = cross of axes angle
ε = diagonal angle
L_1 = shaving cutter tooth length
L_2 = gear tooth length

Of course such condition is valid as long as the useful length of cutter tooth is equal or smaller than gear tooth width, i.e.

$$L_1' \leq L_2 \quad \text{and then} \quad \frac{L_2}{L_1'} \geq 1$$

This means that the maximum diagonal angle depends upon the relationship between the length of the two teeth and the cross of axes angle γ .In the diagram of figure N°3 you can find the maximum diagonal angles for values $\dfrac{L_2}{L_1'}$ from 1 to 2
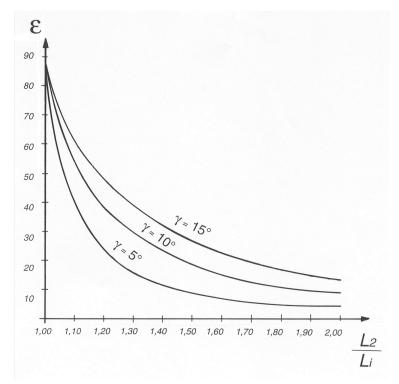
And for cross of axes angles of 5°, 10° and 15°.

Fig.N°3- *Correspondence between the maximum diagonal axes and the ratio $\dfrac{L_2}{L_1}$ for cross of axes angles of 5°, 10° and 15°*

For example, with a normal shaving cutter 20 mm wide you can shave with a diagonal angle $\varepsilon = 6°$ and cross of axes angle $\gamma = 10°$, gears up to a max face width of 45°.

The further advantage of diagonal shaving, in addition to the one of the better utilisation of he cutter against parallel shaving, is the shorter stroke necessary and this advantage is as bigger as steeper is the diagonal angle, as it clearly appears from the previous formula.

The better shaving time with the diagonal shaving can then be explained by the shorter length of the strokes and by the lesser number of strokes necessary.

For small gears, nearly always, one forward-backward stroke is enough, while for gears of larger module 2÷3 forward-backward strokes are necessary.

Of course the main parameter to be considered to determine the number of strokes is the stock removal.

It is important to notice that the number of forward strokes must always correspond to the no. of backward strokes, not only to return always in the initial once the cycle is over, but also because when the cutter feeds forward in one sense cuts better on one flank, while when it feeds backward it cuts better on the other flank.

The use of diagonal shaving is restricted to the fairly small gears, considering that the cost of the tools is in direct proportion with their width. The limit of gear width should be around 100 mm.

Sometimes it is not possible to use ideal cross of axes angles because of shoulders or other obstacles close to the workpiece. In this case you can consider also cutter with diagonal angle higher than 45° and in this case you name it *diagonal-transversal shaving.* In this case the cutter has to be carefully studied , especially for what concerns the crowning along the helix.

Cutter feed in movement towards the gear is perpendicular to gear axis (see fig. N°4).
Normally the cutter performs only forward-backward and the stroke is extremely short; therefore also cutting time will be very short.
In the underpass method, thanks to the crossed axis, if the meshing starts with the cutter in the low position, the contact will take place at the RH extreme of the gear face width and it will subsequently move along the whole face width up to the other extreme.
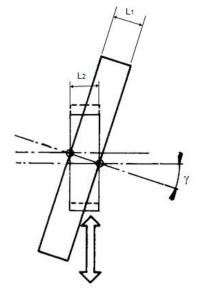

Fig.N°4- *Underpass shaving scheme (γ = cross of axes angle)*

The cutter then has a face width slightly larger than workpiece face width.
This method is the fastest and allows the smallest cutter wear because the cutter works progressively and partially along the whole face width.
This method is fit for gears having a face width of max 100 mm. Anyway the minimum working length of cutter tooth can be calculated with the following formula:

$$L_1^{'} = \frac{L_2}{\cos \gamma}$$

while stroke length can be calculated with :

$$l = L_1 \operatorname{sen} \gamma \qquad \text{where } \gamma \text{ is cross of axes angle}$$

The eventual crowning along gear helix can be obtained by appropriately grinding a hollow along cutter helix.
This method is normally used when the gear is close to a shoulder which is an obstacle for a normal cutter stroke, in the cutter longitudinal(or diagonal) sense
In these cases it is nearly always necessary to reduce cross of axes angle down to low values in order to avoid cutter/shoulder interference.
In these conditions sliding action is quite restricted and the cutter is cutting poorly.
The workpiece will have a glossy surface , due to the upsetting action.
The cutter working with underpass system have a special serrations, offset between one tooth and the other, so as to avoid that serrations traces remains on the shaved surface.
In fact, sliding is limited and it is not sufficient to cover the distance between one cutting edge and the other (serrations pitch).
The details of this characteristic will be covered when cutter serrations will be dealt with.

Plunge shaving
Cutter feed in movement towards the gear is radial to gear axis and there are no longitudinal movement of the cutter. The stroke of the cutter will be very short and the shaving time related to this method is the shortest. See figure N°5.
This system, anyway, requires a cutter studied in a very peculiar way.
First of all, serrations, as we will see better in details at a later stage, will have to be studied according to gear and cutter characteristics, especially for what concerns the offset between serrations teeth of one cutter tooth and the next one.
Secondly both cutter profile and helix will have to be designed to reproduce the required profile and helix onto the gear.
Cutter feed towards the gear will have to be performed according to a determined cycle, with speeds that, in absolute value, are small, with pauses, with inversion cycle, etc. This means that a simple conventional shaving machine cannot work with such method: CNC shaving machine are required, then, because they can ensure also a quite complex working cycle.
If you want to obtain a good surface finish, you have to pay a particular attention to the chipping removal direction.
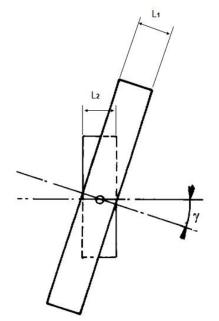

Fig.5- *Plunge shaving scheme (γ = cross of axes angle)*

The serrations related to such type of cutter must have an helical pattern and they have to be manufactured with a very high precision. CNC slotting machine are required for the best results.
Serrations are an important feature for all shaving cutters, but for plunge and underpass cutters the importance is vital.
The optimum performance of the cutter greatly depends on the serrations designing and manufacturing. A dedicated section will cover in details this subject.
The material removed by each cutting edge, i.e. practically, the radial feed-in speed must not be too small, because otherwise the cutting edges would slide on the surface without removing the chip, causing also a material strain-hardening, which is a great perspective problem for gear accuracy and cutter life.
On the other hand, speed must not be too high as well, because rippings might be generated and surface finish would come out poor.

Nowadays all middle and high mass production gears are plunge shaved because of the very short process times.

The time required to shave a car gearbox part with diagonal shaving is approximately 1 minute, while with plunge shaving only 10 seconds - or a little more - are required.

The use of plunge shaving in the high production lines has been made possible also by the launch on the market of the new generations of CNC shaving cutter resharpening machines that, especially in the latest models, have reached quality standards unthinkable only a few years ago.

Nowadays it is possible to perform special profiles and helix simply by digiting a few data on the keyboard, obtaining a good result in very short time.

Only a few years ago, many working hours and very clever operators were necessary to perform the same profiles and the same helix corrections.

**Shaving methods characteristics**
**Parallel shaving:**
❖ *You can shave gears with very large face width*   ❖ *There is no relationship between gear width and cutter width*   ❖ *Longer stroke means longer cycle time*   ❖ *The cutter works only with a limited contact area*   ❖ *Shorter cutter life*
**Diagonal shaving:**
❖ *You can grind gears with face width larger that the cutter face width (max 100 mm);*   ❖ *Stroke is shorter than in parallel shaving and depends on the cross of axes angle , from diagonal angle and from gear face width*   ❖ *There is a better use of the cutter that can exploit all its length*
**Underpass shaving:**
❖ *It can be used with shoulder gears with minimum cross of axes angle of 3*   ❖ *Cutter face width is larger than gear face width*   ❖ *Very short stroke*   ❖ *Offset serrations*
**Plunge Shaving:**
❖ *Shortest stroke and cycle time*   ❖ *Cutter face width is larger than gear face width*   ❖ *Offset serrations*   ❖ *Cutter helix have to be modified in function of the correction you require on the gear*   ❖ *To be used on CNC shaving machines*