Maag gear shaper cutter

This type of tool is still used in many factories, although it is not suitable for mass production.
Many years ago it was a valid alternative to circular shaper cutter, but today, as a result of the great progress of grinding machines for producing the circular shaper cutters, combined with high speed with which modern gear cutting machines can work, the linear cutters has lost much of its importance.
However, this type of shaper cutter is still used in many factories, especially for cutting or finishing large gears.

Figure N°1

The straight cutter type Maag is a portion of the rack, so it is able to meshing, with a gear with the same basic characteristics, without interference.
The Maag cutter works as a circular shaper cutter and then have the appropriate relief angles on the flanks, on the back of the tooth and on the cutting face.
The main cutting movement is held by the cutter , while the motions of rotation and translation in the direction of the pitch line of the cutter are given by the piece.
The circular table on which the workpiece is fixed makes a straight stroke at a constant speed "developing" the gear along the cutter.
For gears with a large number of teeth is not possible and convenient to use a cutter that performs in a single pass all the teeth of the piece, it would be necessary to have very long cutter, which, among other things, would be subject to large deformations giving rise to significant pitch errors.
It should also build machines of relevant dimensions.
All this is avoided by providing the rotary table of a return stroke so that the cutter can continue to cut another group of teeth.
This, of course, is a source of some error and an increase of cutting time: these two reasons, among others, that put this method of cutting in an situation of inferiority compared to the cut with circular shaper cutter.
The translation movement was given by linear racks and gears that would correspond exactly to the rack (cutter) and to the workpiece. Now this condition is overcome by use of CNC machines.
Following the action of cutting and friction of the cutter, the temperature of the cutter increases and then generates its elongation due to thermal expansion.
The racks of the kinematic chain do not heat up and then lost the correspondence between guide and cutter. In some models of machine had provided a heating system to avoid guide rack pitch errors.
The limits of machining gears with the Maag system are very large, ranging from gears with a diameter of 20 mm to a diameter of more than 5,000 mm.

In working with Maag cutter there is no a radial feed as the radial depth of cut is adjusted during set up, when the cutter is completely outside of the gear to be cut.
For cutting small gears in which you want to get a good machined surface, are used two cutters in set where one is roughing and one is finishing, and the set is built together with cutter which form a fixed pair.
In this case, the roughing cutter will have a higher wear, its thickness after successive resharpening decreases much faster than the finishing cutter and therefore will be necessary, in order to have the cutters on the same plane, removing a greater amount of material from finishing cutter.
But this solution is obviously not very rational because it involves an unnecessary waste of the finishing cutter.
However, is a more convenient solution if we provide to coupling more roughing cutters with a single finishing cutter.
There are several different types of Maag cutters in relation to the work they have to perform, and in particular it will have:
Roughing cutter: used for roughing the teeth and simultaneously create the definitive root diameter. The teeth of the rougher cutter have a chordal thickness smaller than the teeth of the finisher cutter , so they are more narrow and long.
Finishing cutter : used to finish the flanks of the teeth without touching the bottom, that is not changing the root diameter.
Pre-grinding cutter: is used to cut the teeth which need to be finished by grinding. The teeth are slightly narrower than the finisher cutter to allow a certain stock removal.
for grinding operation.
There are also combined roughing-finisher cutter (Fig. N°2) which are used to module 3.5 mm. But they also made Maag cutters for chains sprocket wheels or for other special profiles.
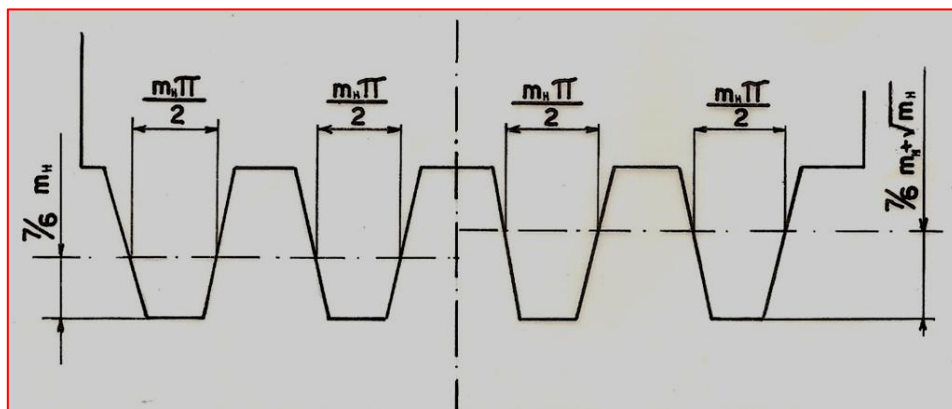
Figure N°2- *Scheme of rougher-finisher rectilinear cutter*

The rectilinear cutter type can cut any involute teeth, correct or not, or where the height of the teeth and the pressure angle is not normal.
The relation between the module of the gear and the working module (operating module and pressure angle operation) is given by the following formula:
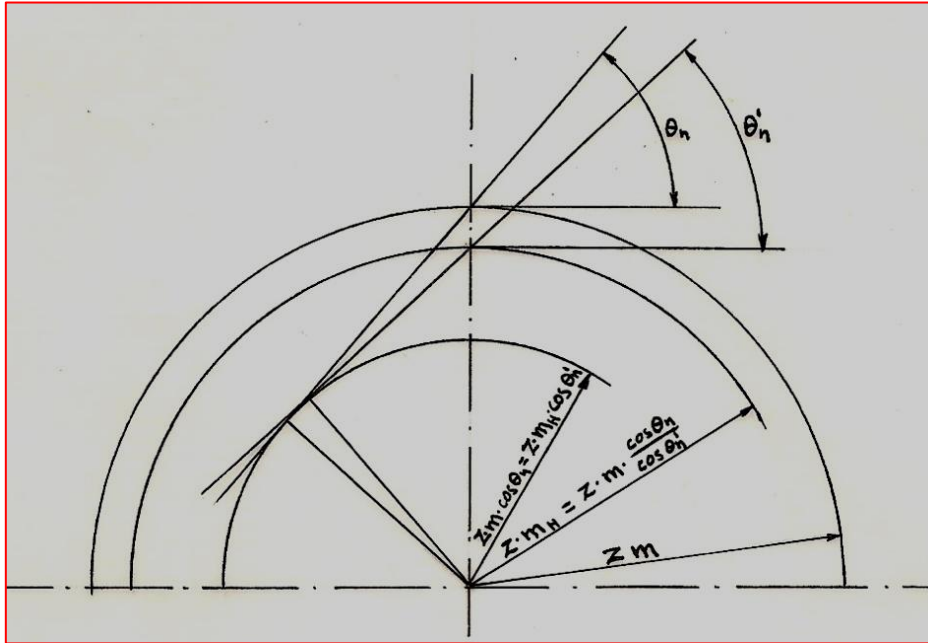
$$m_H = \frac{m \cdot \cos \theta_n}{\cos \theta_n'} \qquad \text{where:}$$

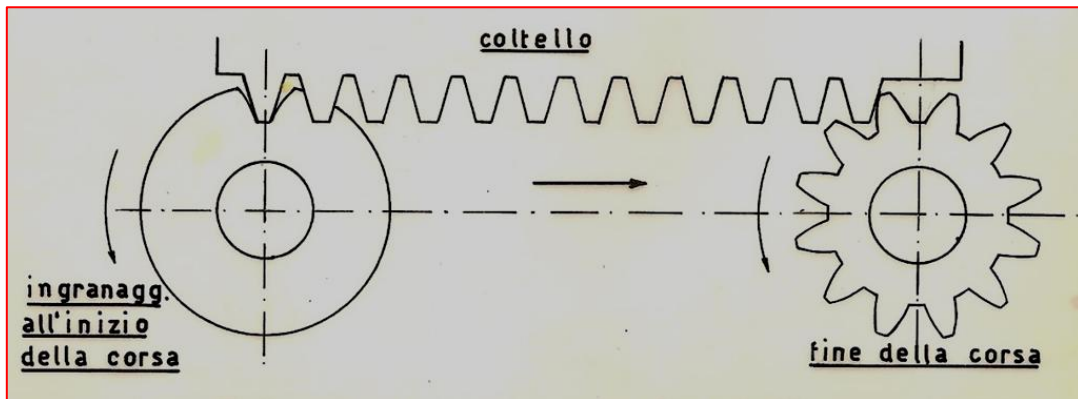θ_n = pressure angle of the gear to be cut
θ_n' = pressure angle of the cutter
m = module of the gear
m_H = module of the cutter

Figure N°3 - *Relation between the module and pressure angle*

Figure N°4- *How works a Maag shaper cutter*

Characteristic angles

The cutter can cut if it has all the characteristic angles of clearance that are typical of any other metal-cutting tool.

With reference to figure N°5 you can distinguish the following angles:

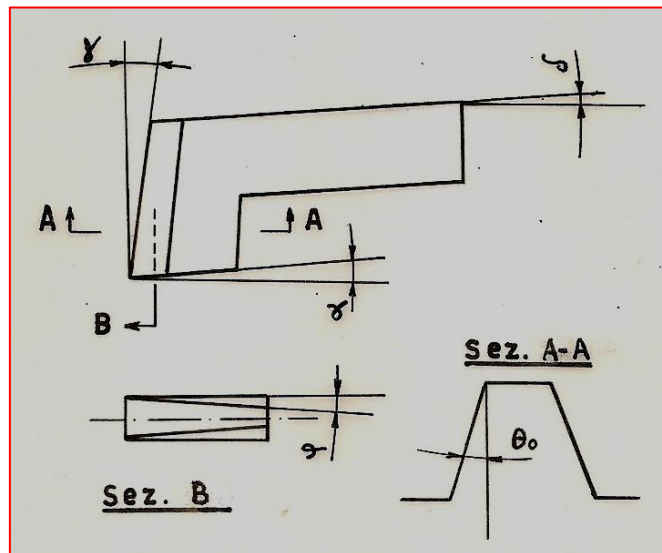φ = effective relief angle on the flanks

α = effective rack angle on working position

γ = tip relief angle on working position

θ_n = normal pressure angle

θ_0 = angle of inclination of the flank in a section normal of the stroke direction

δ = inclination of the cutter mounted in the machine (normally: $\delta = \alpha = 6°$)

Figure N°5- *Characteristic angles of a rectilinear shaper cutter*

Because in subsequent sharpening the profile should remain unchanged, it is necessary that the relief angles are linked. Their value must satisfy the following equation:

$$tan\,\varphi \cdot (1 - tan\,\alpha \cdot tan\,\gamma) = tan\,\theta_n \cdot tan\,\gamma$$

Has to keep in mind that the angle of inclination of the flank in a section normal to the direction of movement is different from theoretical inclination of the rack, and this value is given by:

$$tan\,\theta_0 = \frac{tan\,\theta_n}{1 - tan\,\alpha \cdot tan\,\gamma}$$

Maag shaper cutter for helical gear
A helical gear can be generated by a rack in which the teeth have, respect to the gear axis, the same primitive helix angle.
The cut of helical gears can be executed with the same cutter used for cutting spur gears when the base pitch of cutter is equal to the normal base pitch of the gear.
The cutter must describe with its cutting edge, a trajectory coinciding with the surface of the teeth of the generating rack and therefore must be equipped with a alternative movement in a direction inclined of the helix angle . (Figure N°6).
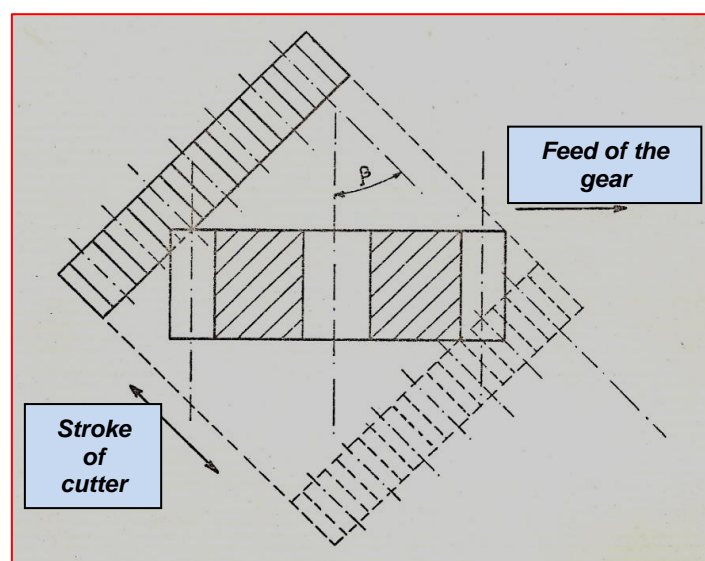
Figure N°6- *Cutting a helical gear with a spur cutter*

This system, of course, is only applicable for gear without shoulders, but we must remember that the cut with shaper cutters is particularly suitable for cutting gears intermediate or those close to shoulder, therefore the system shown schematically in figure N°6 is used especially for the processing of large gears.
For to work gears close to a shoulder we must use a cutter with the inclined teeth as shown in the figure N°7.
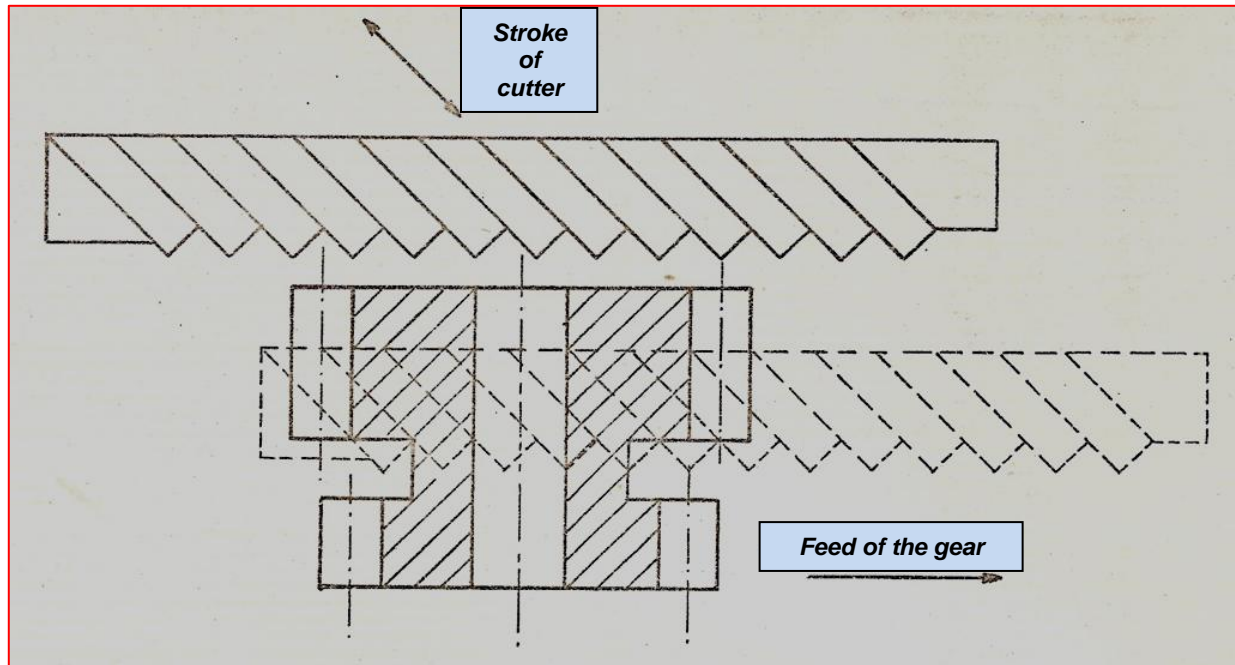
Figure N°7 – *Cutting a helical gear with a helical cutter*

Resharpening of rectilinear shaper cutter
The resharpening of spur cutters can be done in three ways: the first with a single groove on the tooth, the second with two grooves (one for each edge), the third simply flattening the cutting face.
This last solution, however, while being very fast, does not yield well-finished surface of the tooth.
However, there are many cases that do not need a very well finished surface, for example gears later shaved or ground, and then this method of resharpening is definitely to be recommended.
The cutting tool having a flat face are used for cutting soft and easily workable materials, such as aluminum, bronze, cast iron.
The sharpening with a single groove is suitable up to module 1 mm. For the larger module is preferable to perform two gorges.
The recommended resharpening cycle is illustrated in figures N°8 and N°9.
With the groove you must arrive gradually until at the cutting edge, in order to avoid to deform the cutting edge it's important not to cross the end of the cutting face.
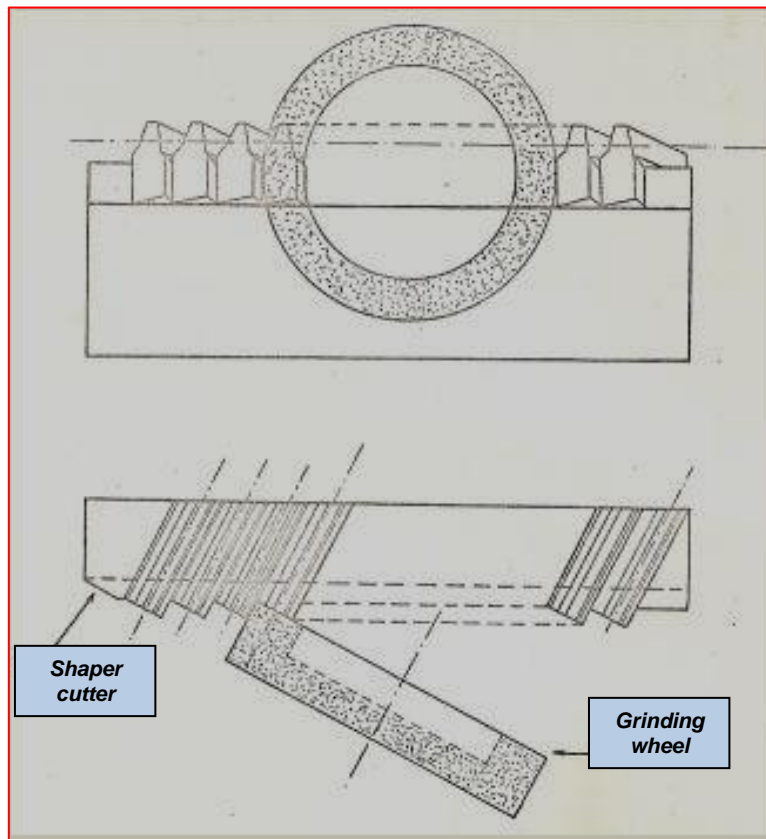In the helical cutters the resharpening plane is generally perpendicular to the helix angle (Fig. N°10) .
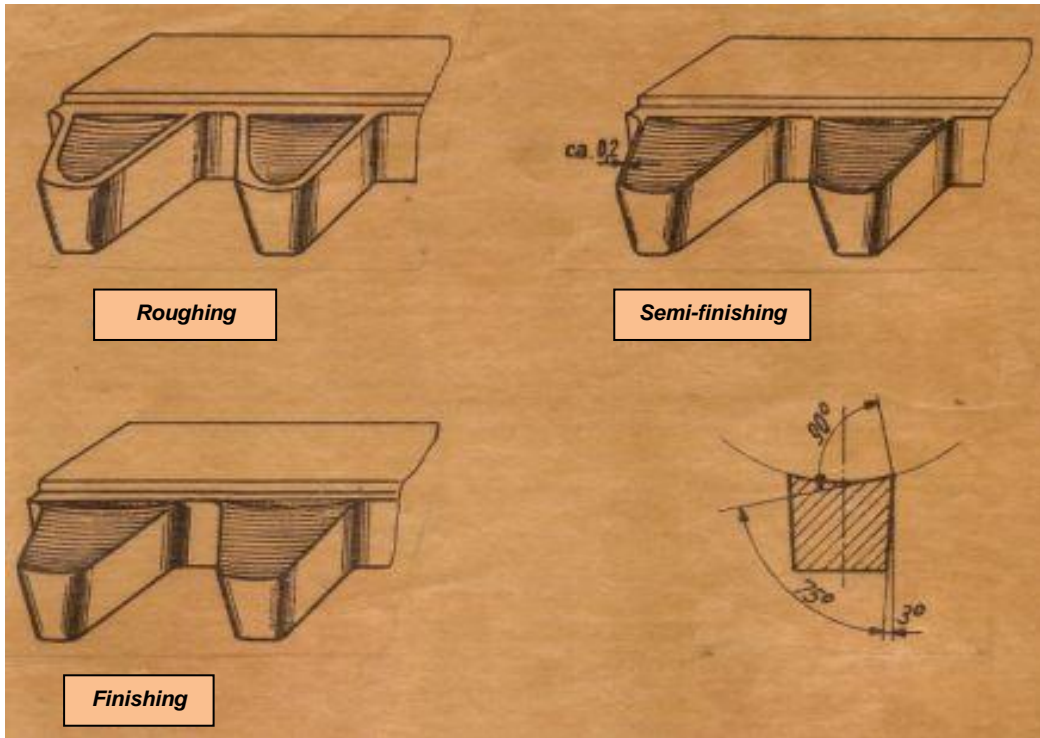
Figure N°8 – *Resharpening with one groove*
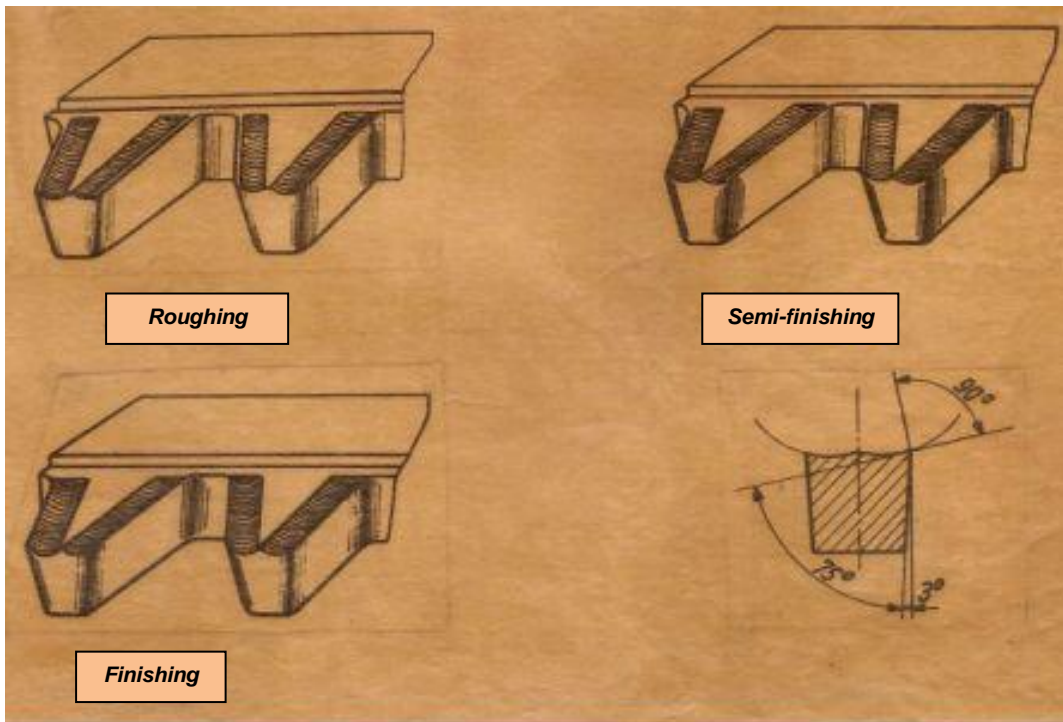
**Figure N°9** – *Resharpening with two groove*

Figure N°10- *Resharpening of a helical rectilinear shaper cutter*

Detachment of the cutter from the piece

In order to avoid scratches on the teeth surfaces and a very fast wear of the cutter, during the return stroke the cutter is detached from the piece.

The slide where the cutter is mounted, before to start the return stroke, is detached from the piece.

At the point where the table is detached from the body of the machine you can see a gap, in according to the value of this gap it's possible to calculate the real value of detachment of the cutter from the piece. The real detachment "b" depends also from the angle of the helix: the greater the helix angle, the greater must be the value of "b".
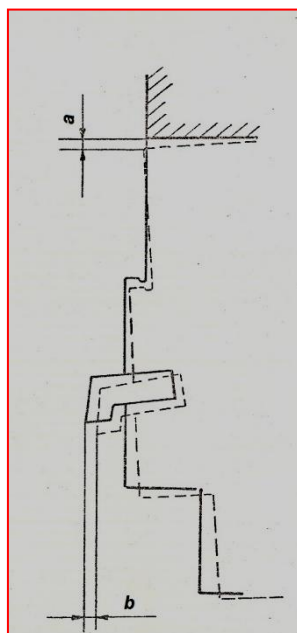
Figure N°11- *Detachment of the cutter during the return stroke*

Working with rectilinear cutter type Maag must establish the following working conditions:
1) *Length and position of the stroke*
2) *Cutting speed*
3) *Number of strokes per tooth (feed)*
4) *Cutting time*

1)- Length and position of the stroke
Corresponds to the width of the tooth of the gear to perform plus a supplement for the entry and exit.
Approximately can be considered, up to the tooth width of 50 mm, a length of entry and an length exit of about 5 mm.
The length of the stroke in the helical gears increases due to the helix angle. Since the helix angle β we have:

$$L_1 = \frac{L}{\cos \beta}$$

2)- Cutting speed
First you need to distinguish between average cutting speed and maximum cutting speed .
The slide change its speed from zero in the top point to a maximum in the middle of the stroke, before returning to zero at the lowest point where it will start the return stroke.
The law of variation is sinusoidal. The average speed in meters per minute will be:

$$V_{tm} = \frac{L_1.N}{1000}$$

In fact, the maximum cutting speed (periodic motion) is:

$$V_{tmax} = \frac{L_1 \cdot N \cdot \pi}{1000}$$

The ideal cutting speed, ie the one that reduces wear and gives the maximum performance cannot be determined *a priori*, because too many variables come into play, but must be found through a series of practical tests.
The wear limit, in principle should not exceed 0.5 to 0.7 mm for uncoated cutters; for the cutters coated with TiN the wear limit is 0.3 - 0.4 mm.
The recommended maximum cutting speed as a basis for further refinement are given in the table below. They are for uncoated cutters.
For tools coated with TiN (or other types of films), these values can be increased by 50%.

Max cutting speed for uncoated cutters (m/min)

Length of stroke	Material strength		
	$500 - 700$ N/mm^2	$700 - 900$ N/mm^2	$900 - 1000$ N/mm^2
$20 - 45$ mm	40 - 24	36 – 22	30 – 20
$35 - 60$ mm	35 - 20	32 - 18	26 - 16

3)- Number of strokes per tooth (feed)
This parameter is equivalent to the feed is determined by the diameter of the gear to be cut, to module and the desired accuracy.
The following table shows the values generally adopted.

Number of stroke per tooth

Module (mm)	One cutting pass		Two cutting pass			
	With finishing cutter		With roughing cutter		With finishing cutter	
	Z = 25 - 12	Z = 70 - 26	Z = 25 - 12	Z = 70 - 26	Z = 25 - 12	Z = 70 - 26
0,7 – 1,5	40 – 50	35 – 45	30 – 40	18 – 28	15 – 25	10 - 20
1,5 – 2,5	50 – 60	40 – 50	35 – 50	25 – 35	20 – 32	15 – 25
2,5 – 3,2	55 – 70	45 – 55	42 – 60	32 – 42	25 – 42	20 – 32
3,2 – 4,0	60 - 80	50 - 60	50 - 70	40 - 50	30 - 50	25 - 36

For cutting with two cutters coupled (roughing and finishing) are valid the roughing values.

4)- Cutting time

Depends on the number of strokes per minute, the number of strokes per division and the number of gear teeth. It is calculated by the following expression:

$$T = \frac{N_d \cdot Z \cdot 60}{N}$$

Where:
N_d = Number of strokes per division
N = Number of strokes per minute
Z = Number of teeth of the gear