

Serration characteristic of shaving cutters

The cutting edges of the shaving cutters are performed along the flank of every tooth through a slotting process which uses tools as per type of figure N°1.

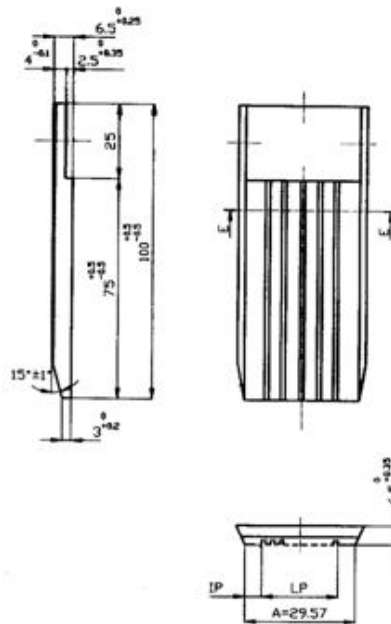


Fig.N°1- Example of a serration slotting tool used on serrating machine

The results is that each flank of the cutter tooth is grooved by serrations with rectilinear sides, whose intersection corners with tooth surface generate the cutting edge (fig. N°2).

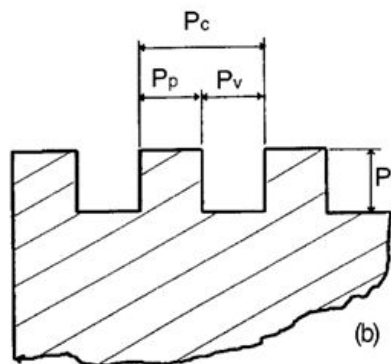
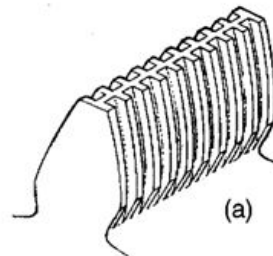


Fig.N° 2- Indication of the characteristic sizes of a shaving cutter serrations

Serrations are characterised by the following parameters:

- ◆ P_c = serrations pitch
- ◆ P_p = solid serration
- ◆ P_v = serration space
- ◆ P_r = serration depth

The serration pitch and the pattern splitting between solid and space, mainly depends on module and also on the stock removal.

Data normally used are indicated in table 1:

Tab. N°1 Serrations pitch in function of the module

Normal module m_n	Serrations pitch P_c	Notes
Up to 1,50	From 1,80 to 2,00	Provided module is the same, if stock removal increases, serrations pitch will be bigger. E.g. if you pass from a stock removal of 0.04 to one of 0.08 mm per flank, serrations pitch increases of ca. 10%
From 1,50 to 2,75	From 1,90 to 2,19	
From 2,75 onward	From 2,00 to 2,20	

The width of solid serration P_p and the space width P_v are normally the following:

Tab. N°2 Serrations sizing

Serrations pitch P_c	Width of solid Serration P_p	Serration space P_v
1,80	1,05	0,75
1,85	1,10	0,75
1,90	1,15	0,75
1,95	1,15	0,80
2,00	1,10 (or 1,20)	0,90 (or 0,80)
2,05	1,10	0,85
2,10	1,10	0,90
2,15	1,20	0,95
2,20	1,20	1,00

As far as the choice of P_p value (the width of solid serration), it is necessary to make an important consideration.

The sum of the serrations width of the teeth that are in contact with the gear determine the surface along which the force that pushes the cutter against the gear is distributed.

The wider the serrations, the wider the contact area and the more pressure (i.e. the ration between force and contact area will be smaller.

If we reduce the pressure (i.e. force per mm^2), then the cutting edges have difficulties in penetrating the steel and in forming chips.

Then, in those cases that create difficulties in steel removing, or in the cases where a gear made of high resistance material, it is important to reduce somehow the P_p value.

When you choose a slightly lower value of P_p you also have the advantage to have a wider space, to enable it to contain chippings and to improve the lubricant action.

Nevertheless, serrations must not be too small running the risk to make serrations teeth too week and subject to a premature breaking.

The serrations depth value P_r depends on module and on pressure angle.

Values most commonly used are those listed in Table 6

Normal Pressure Angle	Serrations Depth
Up to 17° 30'	Min = 0,20 + 0,22 m _n Max = 0,20 + 0,28 m _n
from 17° 30' to 22° 30'	Min = 0,20 + 0,28 m _n Max = 0,20 + 0,32 m _n
from 22° 30' onward	Min = 0,20 + 0,25 m _n Max = 0,20 + 0,28 m _n

It is important to specify that the serrations have not a constant depth all along the tooth height. This peculiarity does not come from a wrong manufacturing of the serration, but from the fact the every serrations root is rectilinear, i.e. it does not follow the tooth involute profile outer surface.

Practically all slotting machines that perform serrations give the tool a rectilinear movement, because if you wanted to follow the involute profile, the machine kinematism would be greatly complicated without granting the tool a real advantage in performance.

As you can see in figure no.23, serration depth is normally bigger in the central / lower area of the tooth. This is because once you resharpen, and reduce outside diameter accordingly, then you remove the portion of tooth where serration depth is narrower.

Thanks to such trick you increase the number of possible resharpenings and, meantime, you manufacture a more resistant tool close to outside diameter area.

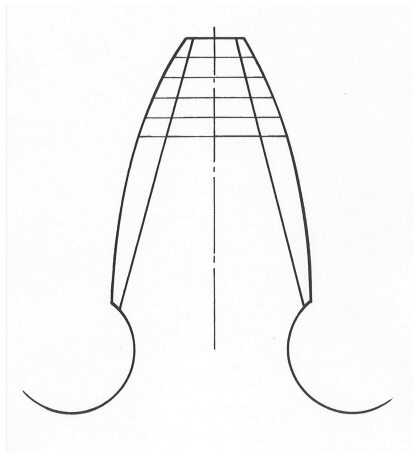


Fig.N°3- *The bottom of every serration is rectilinear, therefore serrations depth is not constant*

The position of serrations on the shaving cutter tooth also depends on the shaving method, i.e. on the way the cutter moves with reference to the workpiece.

During parallel and diagonal shaving the cutter moves axially with reference to the gear, and therefore the cutting edges (the serrations corners) move along the gear tooth flank in such a way to avoid that the same serration tooth never fall in the same position of the gear tooth flank.

During underpass and plunge shaving you do not have a longitudinal movement of the cutter with reference to the gear; in this case if you had the serrations teeth as per figure no.13a, then every serration tooth would fall in the same position during every part revolution, with the result that cutter tooth serration would leave markings on the gear tooth flank; in other words serrations teeth would remain "imprinted" along gear teeth flank.

It is then necessary to offset the serrations of one tooth with reference to the those of the next gear tooth, i.e. to perform an helical slotting as in figure N° 4(b)(c).

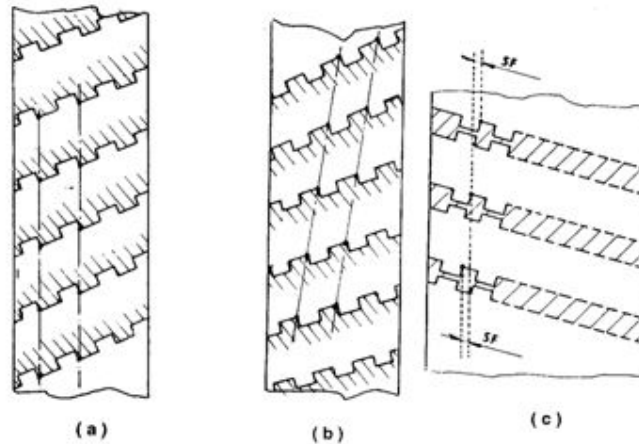


Fig.N°4- Serration offset in conventional shaving cutter (a) and in underpass + plunge cutters (b)

The serrations teeth offset of one tooth with reference to the next one is indicated with S_f in figure N°4(c).

There is an important relationship between serrations teeth offset S_f , Serrations pitch P_c and the gear number of teeth.

It is in fact necessary that on one tooth trace on a generic gear tooth (e.g. tooth Z_1) another tooth trace is overlapped, slightly offset, after on gear revolution (see figure N°5)

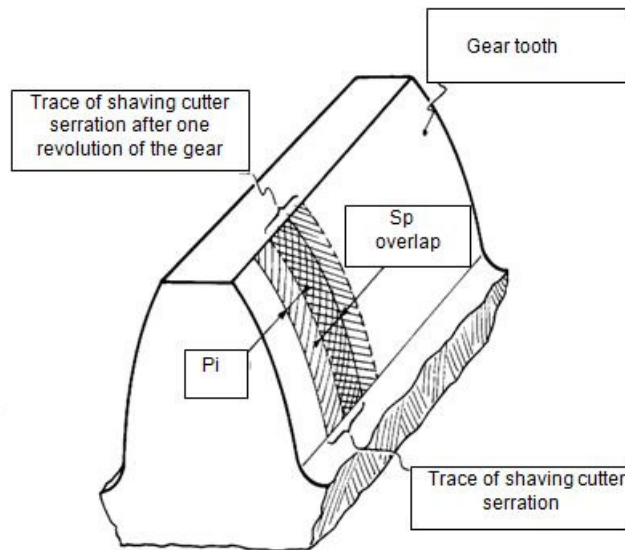


Fig.N°5- Serrations traces coming one after the other on a gear tooth must overlap

The trace of one serration on tooth Z_1 will be in a determined position, while the trace of the serration of the same row on the next tooth of the cutter on tooth Z_2 will be shifted of the value S_f , on teeth Z_3 will be shifted of $2 S_f$, and when the gear has completed the tour returning on tooth Z_1 the serration tooth trace will have been shifted of $Z S_f$.

In this interval, anyway, you can fit in many pitches P_c , e.g. n pitches, and so, in order to determine the value of P_i you can use the following relationship:

$$P_i = Z S_f - n P_c \quad \text{where:}$$

$$n P_c \leq Z S_f \leq (n + 1) P_c$$

The most commonly used value for P_i is $0.15 \div 0.25$ mm.
 In this way you guarantee an overimposing of traces of:
 $S_p = 0,8 - 1$ mm.

The value you have found for P_i is only temporary, because you still have to establish how many starts should the whole group of serrations be made of.
 If you consider the sequence of the serrations, if you follow the progression of the single shifts you will see that they follow an helix along the cylinder formed by the shaving cutter and the pitch of this helix will be $p = S_f \cdot Z_1$ as you can see in figure N°6.

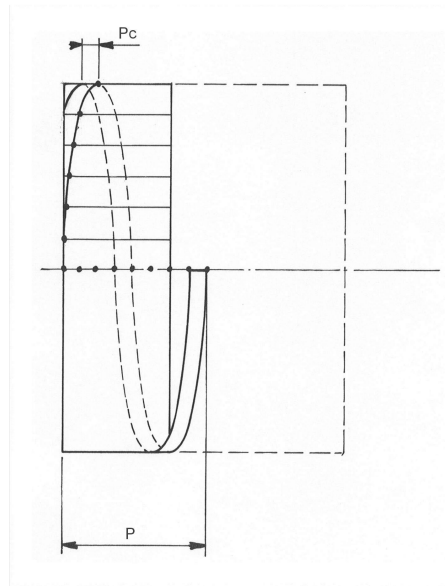


Fig.N°6- Offset serration are placed along an helix. The no. of starts must be an integer number

In this interval, you can find many serrations and everyone corresponds to an helix belonging to a different start.

The number of starts must be an integer number.

The following condition must be satisfied:

$$\frac{S_f \cdot Z_1}{P_c} = f \text{ (integer number)}$$

You will then choose as **f** the integer number closest to the ratio $\frac{S_f \cdot Z_1}{P_c}$ and the

recalculate the value $S_f = \frac{f \cdot P_c}{Z_1}$ verifying (just to be sure) that the P_i value is acceptable.

We now slightly touch the subject of serrations helix direction.

As you understand from the a.m. expression you need to choose son parameters in such a way that the number of start is an integer number and the overimposition of the traces of the single teeth of the gear has values included in that interval. Sometimes this can be obtained with a serration helix having the desired direction, but other times you have to assign a *negative value* to S_f ; of course the serration helix will have a direction opposite to the desired one.

In some instances this solution does not give good results and then it is necessary to reconsider the serration design, by varying the pitch P_c and the value of P_p and P_v .

The general consideration leading to a choice of serration helix direction are linked to the cutting direction of each cutting edge.

If you consider figure no.27a the cutting edges sliding direction is Right to Left if cross of axes angle is as per figure no.27a, conventionally indicated as positive (+ sign). If cross of axes angle has opposite direction, cutting direction will be the opposite.

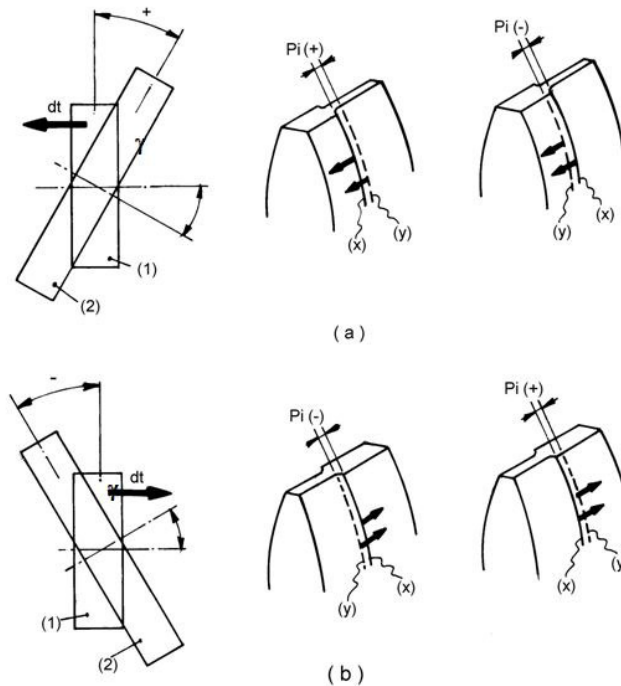


Fig.N°7- Offset direction must take into account the cutting direction
 (1) Gear
 (2) Shaving cutter
 (d_i) Cutting direction
 (x) Trace of a generic cutting edge
 (y) Trace of the following cutting edge

If you consider figure N°7a you see that, in case the shifting of the trace after on revolution of the gear is positive (positive P_i value), i.e. it falls into an area already worked by the previous cutting edge, during its path, finds a step which makes the entry of the corner onto the steel easier; cutting action will be easier and the surface finish will be good.

On the contrary, if with the same cross of axes angle the shifting of the trace after on revolution of the gear is negative (negative P_i value), i.e. it falls into an area not worked by the previous cutting edge, the corner would not correctly *bite* the steel and quality of the surface will be more irregular.

If the cross of axes of angles has a negative direction as in figure N°7b, the best cutter would be the one having the shifting arranged in such a way to have a negative P_i value, while the tooth quality surface will be very low in case of positive P_i value.

We have already outlined that it is advisable to avoid, wherever possible, that serrations cross at the tooth tip, creating a situation like the one on figure N°8a. Just at the top of the tooth the solid part of the serration is free, i.e. not supported by the internal *core* and therefore the serration itself will be more subject to breaking.

This inconvenient is particularly frequent on shaving cutters with small module.

This feature enables deeper serrations and, in practice, a higher number of resharpenings. This method normally used has proven so positive that, even if initially developed to solve the problem of the crossing of serration on tooth tip, it has been extended also go the cutter having a sufficient top land.

Figure N°8 shows the various instances that might happen and the related standard pattern of serrations from one flank to the other.

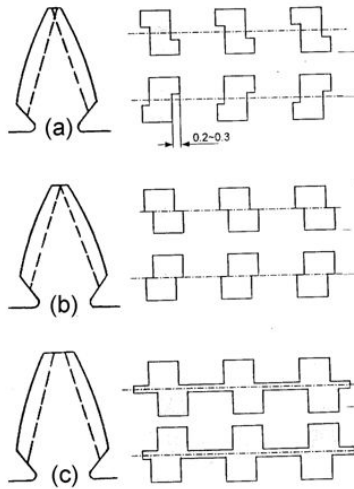


Fig.N°8- Indication of teeth offset along the two flanks of the same tooth in different cases to reinforce teeth tip.

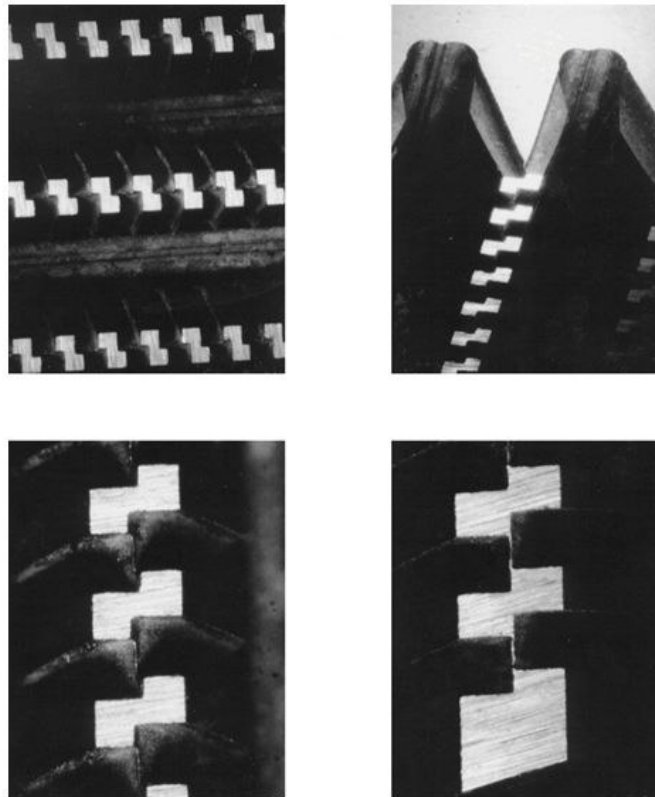


Fig.N°9- Some examples of serration

On cutter with module smaller than 1 mm, considering the extreme difficulty in slotting the serrations, sometimes the so called *cut serrations* are performed: the principle consists in carrying out circular cut, parallel to cutter faces as indicated in figure N°10.

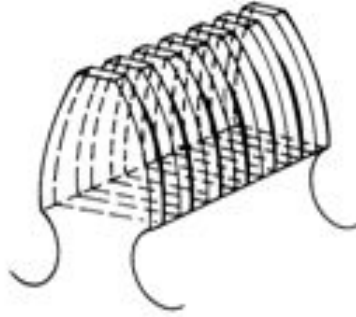


Fig.N°10- *Cut serration for modules smaller than 1 mm*

These cuts leave serrations without the internal solid supporting portion and, therefore, are quite delicate, but unfortunately there is no other way to create that type of serrations.

These circular cuts can be performed before heat treatment with thin turning tools or, better, with thin CBN wheels after heat treatment. With this latter system you could also obtain better cutting edges.

It is obvious that this type of serrations can be used only with diagonal and parallel methods.

The helical serration of underpass and plunge cutters have the teeth at the extremes with width varying from 0 to P_p size.

The tiny teeth are dangerous because they can easily brake and sometimes the bits can fall into both gear and cutter teeth during the rotation, running the risk to endanger profile and cutter itself.

Incomplete teeth are also dangerous from the safety point of view because they can cause injuries to the operators handling cutters.

From the a.m. reasons it is necessary to get rid of the incomplete teeth from both sides, as shown in figure N°11

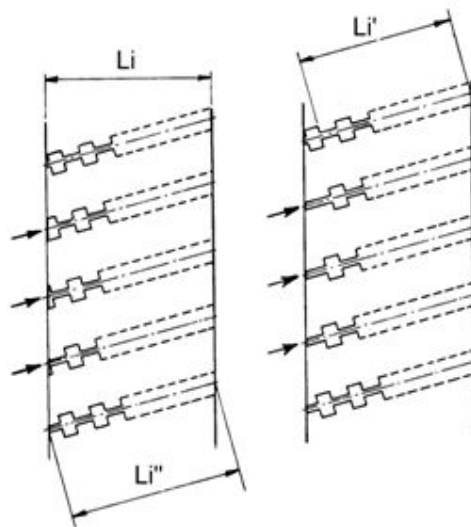


Fig.N°11- *Incomplete teeth are removed*