

## Theory of the “even contacts” in gear shaving: positive and negative features

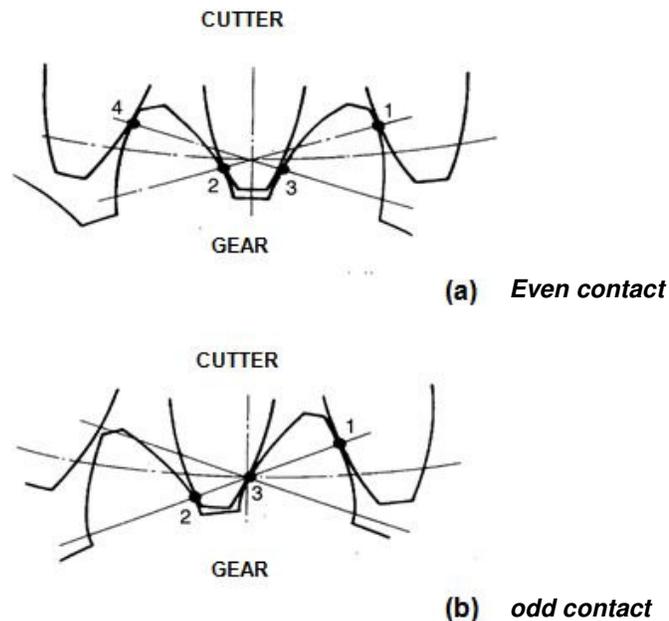
The gear shaving operation shows nowadays some features that are not enough studied. In particular some static and dynamics problems have not been deeply cleared.

For the technician working with the gear it is quite known that the project of the shaving cutter tool has to follow the so called method of the “even contacts”.

This method, therefore it is useful in most of the cases, offer its flank to the criticism looking to some bad data coming from day-by-day experience in the workshop when you work in some special condition.

As it is well known, the even contacts methods states that a shaving cutter, meshing with the gear during that shaving operation, must continuously keep an even number of contacts between its flanks and the ones of the gear to be cut.

The condition shown in figure N°1-a is difficult to be reached and it is also difficult to be kept during the shaving operation and throughout the shaving cutter life (i.e. after each resharpening of the tool). Often the number of the contacts points are odd, like the figure N° 1-b.



**Fig. N°1-** *Contacts points during shaving operation*

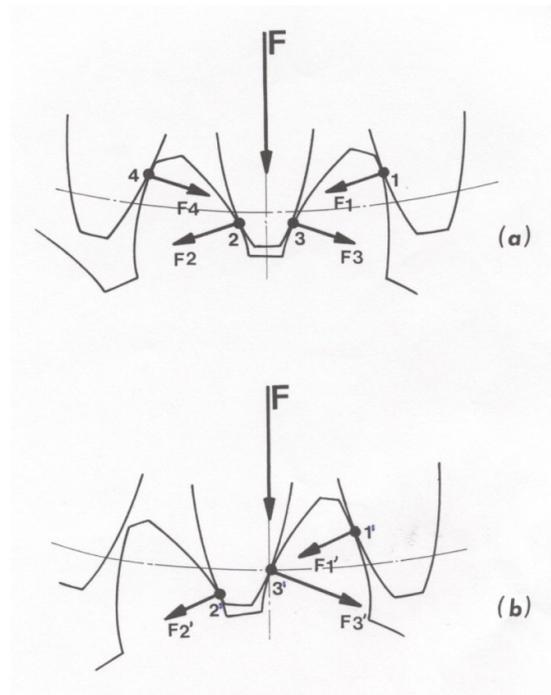
Sometimes the characteristic of the gear to be cut or of the shaving machine make very difficult or impossible to reach the even contacts condition: minimum and maximum center distance of the machine, ratio between the number of teeth of gear and shaving cutter, TIF value on the gear profile....

The importance of the need to keep the even contacts status during shaving it is easy to be seen from figure N°2: to equilibrate the forces involved in the process.

From the figure N°2-a, it is possible to understand how the force  $F$  applied on the shaving cutter can decompose in forces pushing on the left and right flanks of the tooth in a balanced way.

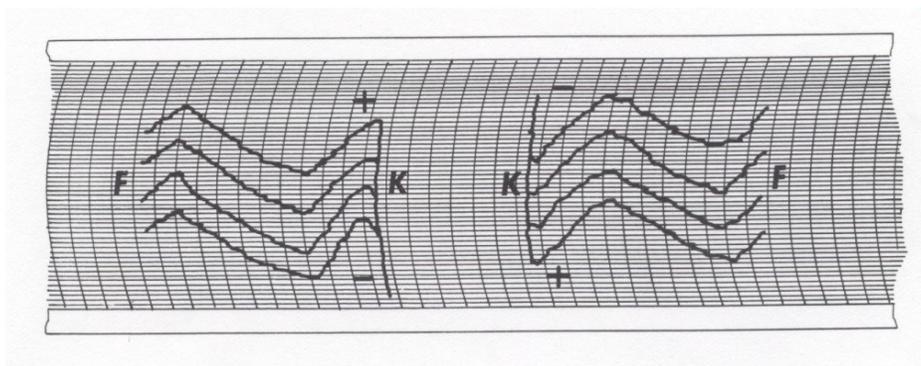
In this case also the shaving operation has a balanced action and the profile results normally in a good quality.

From figure N°2b can be seen the different situation that can be due by an unbalanced condition during the gear and tool meshing. The force  $F_3$  will balance the sum of the two forces  $F_1$  and  $F_2$ . In this case the cutting action of the shaving cutter in the point of application of the force  $F_3$  will be stronger than in the point of application of the forces  $F_1$  and  $F_2$  and this certainly will cause a bad result in the profile quality.



**Fig. N°2-** Forces applied on gear tooth

In figure N°3 it is possible to see the result of an unbalanced shaving action on the gear profile.



**Fig. N°3-**

In other words the odd contacts condition generates a force that tends to bend the tooth. Although the material flexion is very little we have to consider that nowadays the accuracy of the gear profile must remain within few microns and such an unbalanced process can make vain the whole operation.

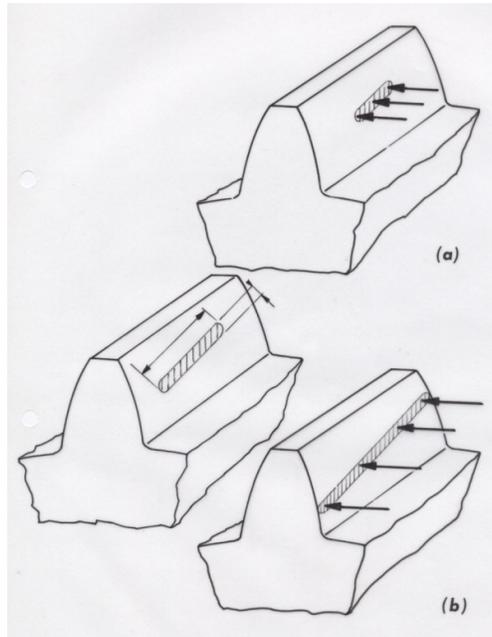
As it was said before, although the design of the shaving cutter normally follows the theory of even contacts, practically it happens that the gear profile does not result in a good quality.

The key for the interpretation of this experimental phenomenon must be found with a deeper analysis of the meshing condition between gear and tool.

In particular:

a)- because of the force pressing over the gear and tool flank the material of both has a certain plastic deformation that, together with the depth of the cutting edge, makes the contact in an "area" rather than a point (as the theory supposes).

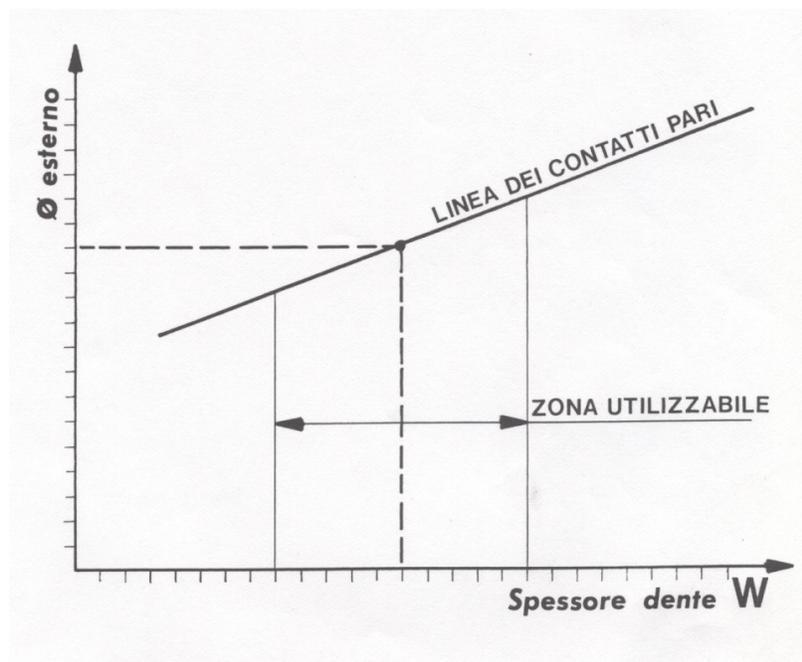
b)- in the previous sketch we have considered a radial section of the tooth, but practically the contact exists along an oblique tract (that depends from the characteristic of the mesh) and with a variable length (see figure N°4a). In case of plunge shaving cutter with a hollow on the helix the contact area cover all tooth width (see figure N°4b)



**Fig. N°4-** *The contact area is variable*

A further note is though keeping an even contact condition it is difficult to keep always the same number of contacts: whether the number of contacts is even, for example 4, it continuously changes during the shaving operation, for example 4 – 2 – 4 – 6 – 6 .... The even contacts condition must keep also after the resharpening operation of the tool. In this case have to reduce the outside diameter of vthe tool in relation with the reduction of the tooth thickness after resharpening.

It is usual the shaving cutter maker supplies the customer with a diagram or a table (resharpening table see figure n°5) for each tool where it is shown the relation between outside diameter and tooth thickness. In the same diagram it is also shown the operating area of the tool. If we follow the drawn line we are sure to keep the even contact condition.



**Fig. N°5**

At this point we start some criticism to this theory.

1)- If we consider a constant radial force  $F$ , when we pass from the condition of 4 contacts to the condition of 2 contacts, the force applied on the single point changes and in this case it becomes twice bigger. This means the material removal in those point is double than in the others points.

This means that though the force are balanced and do not bend the tooth in any case the intensity of the force on the teeth changes and this generates some negative effects.

The number of the contacts depends of the length of the path of contact. If the path of the contact is long and we have a sequence of  $4 - 6 - 4$ , on every flank we have  $2 - 3 - 2$  points of contact. In this case the force over each point has a variation of 30%. In case of a sequence of  $1 - 2 - 1$  point of contact, the force variation is 50%. In the first case the profile will be more regular than the second case.

The consideration fit the practice of the workshop that has shown it is easier to get better result when shaving gear with a high number of teeth. On the contrary it is very difficult to get good profile when gear has only 12 – 14 teeth. In conclusion it is easy to shave gear with a high number of teeth and small pressure angle (it is easy to keep even contacts condition with sequence  $4 - 6 - 4$ , whilst it is difficult to shave gears with a small number of teeth).

2)- Another reason that makes uncertain the even contact theory is the basic hypothesis that with the same “force” you should get the same cutting action. More correct is to say that with the same “pressure” on a specific area you can get the same cutting action.

Unfortunately with a constant force it is not sure we can get the same pressure.

We know that the contact between gear and tool is over an area and this area depends on the intensity of the applied force and from the curvature of the surface meshing.

As it is well known the curvature of a surface is the inverse of the curvature radius: the smaller the radius the bigger the curvature.

Normally a shaving cutter has a pitch diameter 200 mm, this roughly means a very small curvature of the tooth flank; gear is normally on the opposite (especially when it has a small number of teeth).

Moreover: near the base diameter the flank curvature is higher, near the outside diameter the curvature is small.

That to mean the area of the contact between tool and gear is extremely variable and consequently is the pressure in this area. In this way we can say the material removal near the outside diameter will be lower than near the base diameter.

Nevermore our speech is not completed because there are many other factors we have not yet kept in consideration. The first one is the sliding phenomenon of the surfaces in contact.

It is known that sliding is zero only on the pitch diameter but it is bigger the further we go from the pitch diameter. This phenomenon has to be taken in consideration when we define the area of the contact and the cutting action.

The second phenomenon is the sliding along the helix of the gear due by the cross angle between shaving cutter and gear. It is this movement that causes the cutting action of the shaver.

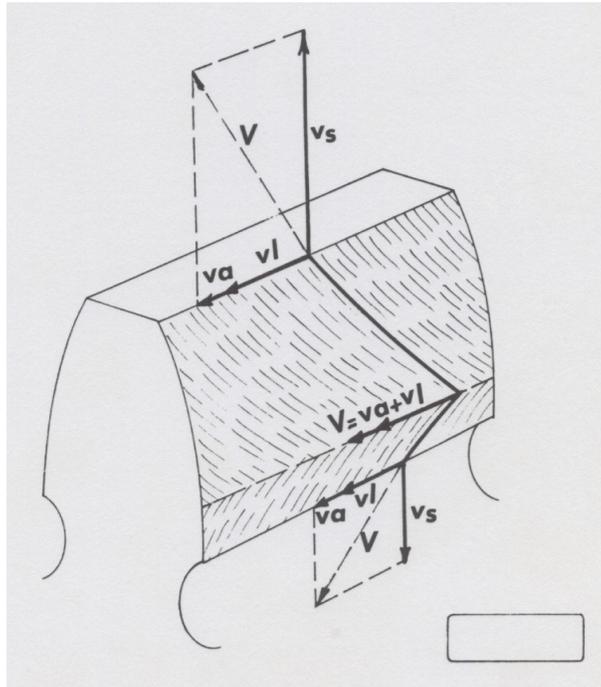
In this case too it is not studied enough the process of the generation of the chip, particularly the relation between the width and the position of the contact area and the direction of the cutting action that change continuously.

All of these features are not considered nowadays in the shaving cutter project. Moreover another important force is not considered enough in the general process : the force that generates the rotation of the system shaving cutter- gear. When you work with gear of big dimension this force cannot be neglected because it is really very big and therefore very critical.

From data supplied by Sicmat of Torino (Italy) (shaving machine maker) this radial force is around 4000 N for a shaver of module 2 mm and a gear of 20 mm face width. Whether we assume an even contact condition of 4 points it result:

$$F_1 = F_2 = F_3 = F_4 = \frac{F}{4 \cdot \sin \alpha} = \frac{4000}{4 \cdot \sin 20^\circ} = 2920 N$$

During the shaving it could be the number of contact sometimes becomes 2; this means a double value of the component on the contact area. If the contacts become 6, the force on the contact area is 1950 N.



**Fig. N°6-** The cutting speed vector is continuously variable

From these consideration it is easy to understand why sometimes the real process does not follow the theory.

The last parameter we want consider is the inertia of the shaver together with its spindle, and the inertia of the system shaver group-gear. How this parameter ply in the operation? (it should be a positive effect it is not well clear yet taking in consideration the quick variation of the speed this group has to follow.

From the above mentioned brief and simple notes it is easy to understand the shaving operation it is a very complex process where many parameters play and sometimes the theoretical forecast are not followed by good results.

In this situation the project engineer is in the dark and he can only rely on is long experience.

In this report we have only spoken about the design of the teeth of the shaving cutter but many other parameters affect the quality of the shaving : serration (pitch, tooth/space ratio, angles, differential pitch, depth), roughness (of the surface and of the internal serration), design of the space between tooth and tooth (milled/drilled7dept, width).

In conclusion we do not mean that who has a well working shaving cutter is a particular lucky person. The most of the shaving cutter works very well since the first use.

The problems arise when we have tough and/or critical condition, In these cases it is important the end user to be aware of the difficulties of the design and be more indulgent with the shaving cutter maker.