

Analysis of lead twist in modern high-performance grinding methods

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Abstract. According to quality requirements of road vehicles shafts, which bear dynamic seals, twisted-pattern micro-geometrical topography is not allowed. It is a question whether newer modern grinding methods – such as quick-point grinding and peel grinding – could provide twist-free topography. According to industrial experience, twist-free surfaces can be made, however with certain settings, same twist occurs. In this paper it is proved by detailed chip-geometrical analysis that the topography generated by the new procedures is theoretically twist-patterned because of the feeding motion of the CBN tool. The presented investigation was carried out by a single-grain wheel model and computer simulation.

1. Introduction

Vehicle shaft surface texture is critical for evaluating the wear of rotary dynamic seals [1]; given that an automobile has over eighty dynamic seals, possible failures cost the transportation and power industry millions of dollars per year [2]. Prescriptions for optimum performance of radial lip seals require a precise shaft surface texture and zero twist. It is worth noting that if the shaft surface texture is rough, the seal wears rapidly. On the other hand, if the texture is too smooth, the seal will not contact the shaft appropriately, leading again to problematic application. Ideally, the shaft surface should possess a texture that allows a fluid film of about 0.25 μm thick to form in the shaft-seal interface [3].

Of equal importance is the absence of a twist on the shaft surface [4]. This characteristic can initiate a fluid pumping effect, which, depending on the orientation of the twist may result to leakage or dry run [5]. The creation of a twist is inherent in all manufacturing processes, attributed to feed rate of the cutting tool in turning and the part orientation of either the workpiece or grinding disc. Twist pattern can be identified either as macro-geometrical, i.e. an axial periodic structure that is singularly or multiply circumferential, or micro-geometrical that describes high-frequency features on the shaft, either periodic or non-periodic, which are tilted with respect to the workpiece [6].

In traditional procedures, sealing surfaces can be made by plunge grinding and by very long spark-out time. In longitudinal feed grinding, attention should be paid on several conditions such as: wheel dressing, the parallelism of rotation axis of the wheel and the workpiece and the regulatory spiral created on the wheel by single point diamond regulation, see figure 1.



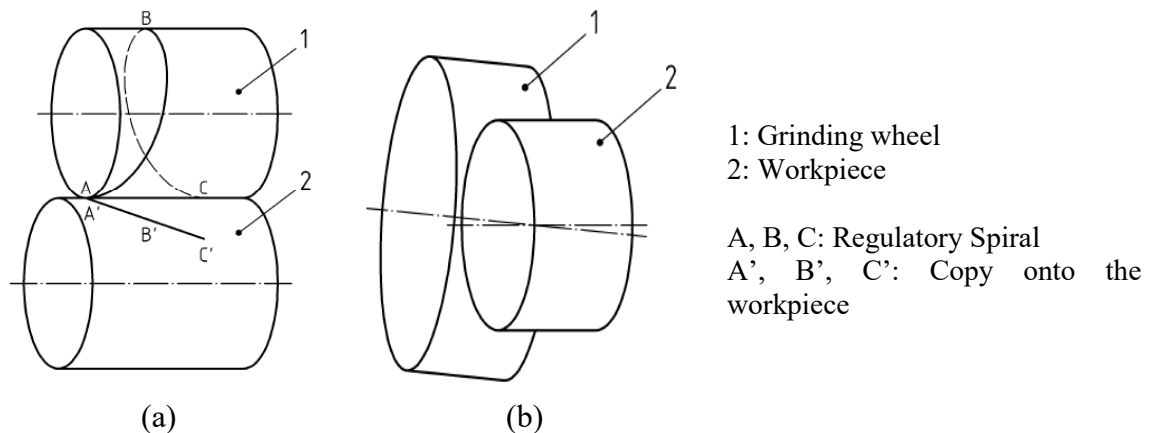


Figure 1 Basic cases of twist formation in grinding: a) Copy of the regulatory spiral b) Non-parallel axis between the grinding wheel and the workpiece

In case of the existence of a twist, the direction of oil flow is determined by the combination of three factors, namely rotation, twist and conveying direction [7-9], according to Table 1.

In advanced grinding procedures, i.e. in case of CBN wheels, the metal tool body made it possible to raise the wheel speed up to 100 to 200 m/s and the width of the wheel's contact surface to be decreased to some mm. However, with narrow wheels, the cylindrical surfaces can be ground only by applying longitudinal feed (v_{fL}).

Table 1. Conveying direction at twist

View Z	Rotation direction		Twist direction		Conveying direction	
	Right	Left	Right	Left	Right	Left
	+			+		+
	+		+		+	
		+	+			+
		+		+	+	

Advanced grinding processes must be examined from the point of twist generation, because their productivity is multiplied in comparison to the traditional plunge procedure, even when having moderate grinding conditions, see Table 2.

Table 2. Characteristic data of advanced grinding processes

Procedure	Plunge grinding	Peel grinding	Quick-point grinding
Parameter			
Wheel generatrix	 straight	 conical	 straight
Material removal rate Q (mm ³ /s)	Q	$5 \times Q$	$5 \times Q$
Main machine time T_m (min)	T_m	$1/5 \times T_m$	$1/5 \times T_m$

2. Parameters of twist topography

The significance of twist has intensified because of the tightening accuracy and surface quality prescriptions, as well the severe requirements of environmental protection. That is why automobile

factories ascertained and defined the twist parameters (figure 2) first in factory standards, then in ISO and DIN international standards, so that the degree of twist can be measured and thus controlled [10].

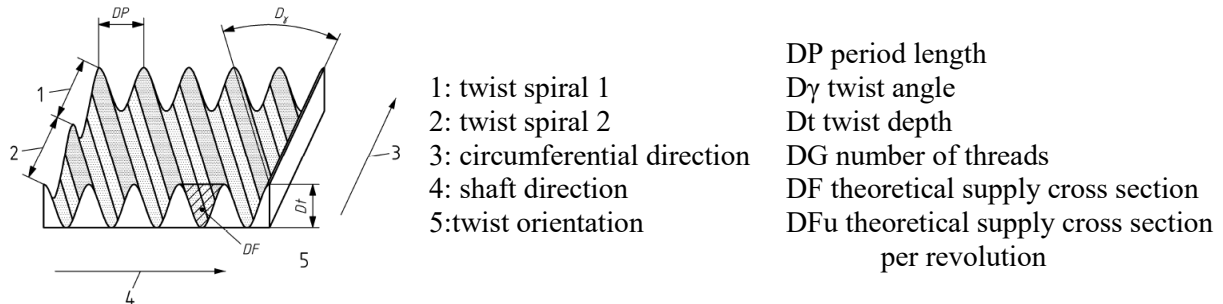


Figure 2 Twist parameters according to DIN EN ISO 25178-3:2012 [11]

Over the few past years, several twist measuring methods have been proposed. Some of them are the string method, stylus metrology and 3D surface topography based on interferometry or scatterometry. More on these methods can be found in the relevant literature [3, 12-14].

3. The examined grinding processes

Two procedures are wide-spread in advanced grinding processes: peel grinding and quick-point grinding [15].

Peel grinding can be performed by straight or an inclined wheel, as in figure 3. The point is that the CBN wheel is regulated in $v_{f,L}$ longitudinal feed direction in an 6° angle; therefore it can grind off the allowance, which is some tenths of mm, with a single feed rate. The back, cylindrical part of the wheel performs the smoothing grinding task without a separate spark-out phase. Because of the inclined position of the wheel, the lubricant can penetrate in the contact zone much more intensively, in that the wheel regulation is exact and easier. Furthermore, the wheel production is simpler. The angle of the wheel inclination is 15° and the inclination of the wheel shaft is considered in base plane (P_r).

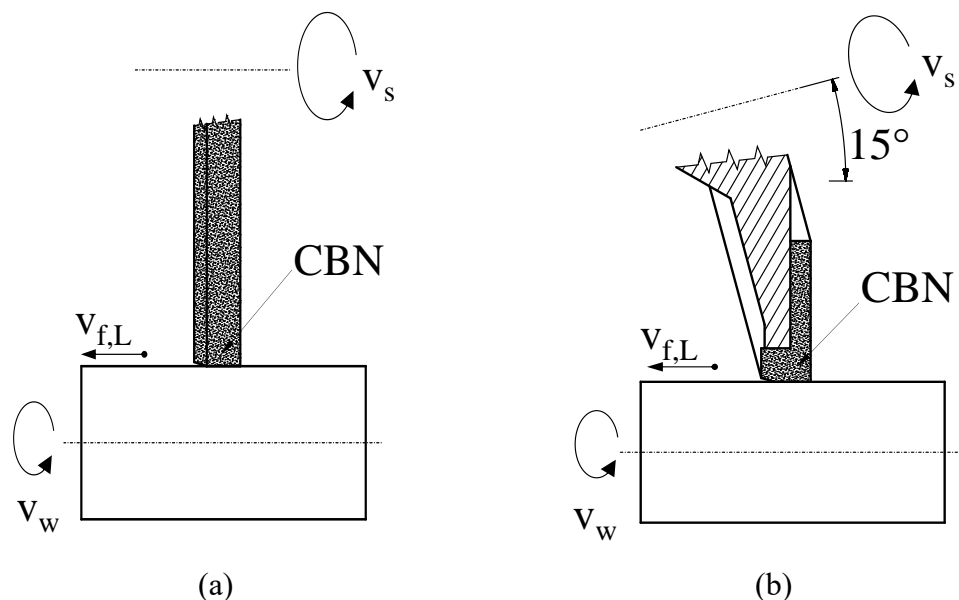


Figure 3 Peel grinding by a wheel in a) straight and b) inclined position

Quick-point grinding is seemingly similar, but the mechanism of material removal is different. The wheel is inclined, however not only in base plane, but also in perpendicular PS edge plane [16]. The

point of the procedure is given by the inclination characterized by angle β . In that way the wheel generatrix is not parallel to the workpiece generatrix, shrinking the contact to a point, as can be seen in figure 4, point D. The wheel generatrix is not conical but straight, parallel with the shaft.

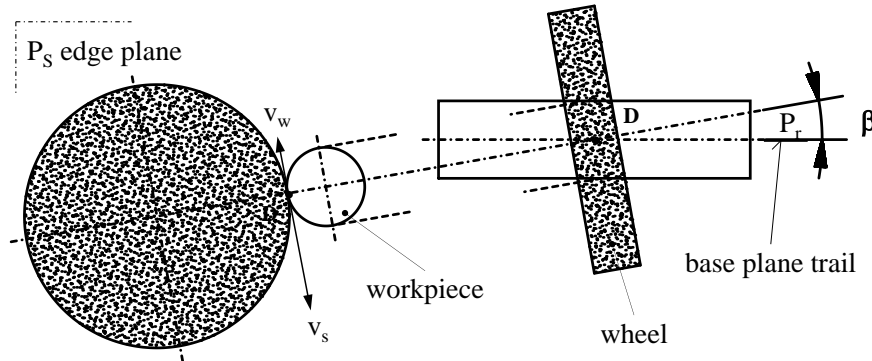


Figure 4 In quick-point grinding wheel is also inclined in the edge plane by angle β

The two procedures can be carried out on the same machine. If only cylindrical surfaces and shoulders must be processed, peel grinding, with its simpler geometry, is enough.

4. Cutting relations of peel grinding

The most important advantage of peel grinding is that the shoulders facing right and left can be ground in one clamp. There are two wheels in grinding-head-stock of the machine, which are positioned to programmable suitable positions as in figure 5. To rotate the shaft there is no need for a driving appliance, because the grinding forces are so small that the frictional torque from the peak is enough.

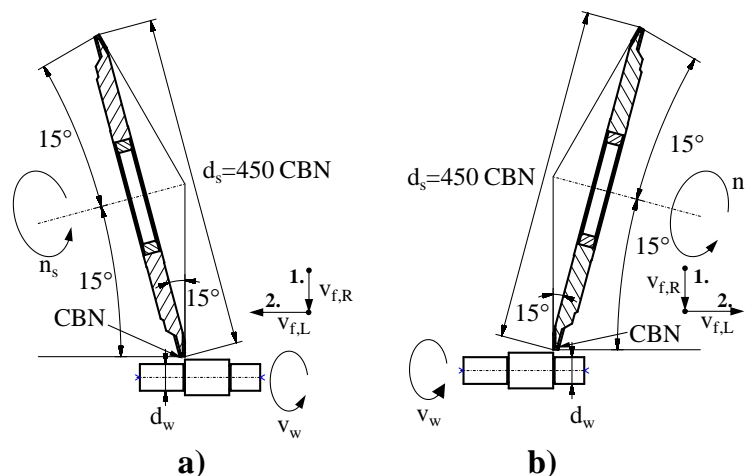


Figure 5 Wheel position in peel grinding

The material removal circumstances of peel grinding and the theoretically undeformed chip-cross-section can be seen in figure 6. Since the emerging grinding force is very small, it may be considered not significant. On the other hand, chip-cross section A_c is removed along a spiral, because of $v_{f,L}$ feed, the value of which is equal to f .

5. Analysis of the formation of twist at a single-grain wheel model

The chip formation and the evolution of the topography and thus the evolution of the twist in grinding is also analyzed by a single-grain wheel model, see figure 7. The grinding of such a cylindrical surface can be seen on the same figure, which starts at a left facing shoulder.

The three positions in figure 7b are distinguished from each other in the characteristics of the rotation of the workpiece compared to the grinding wheel (no rotation, inverse or identical rotational direction).

The two types of twists characterized by angles α and β are theoretically always present in case of peel grinding. However, their emergence is not always clear; in some cases it is not even noticeable. In case of inverse rotations – which is the regular case in grinding – the micro-twist is left-handed and the macro-twist is right-handed [17-19].

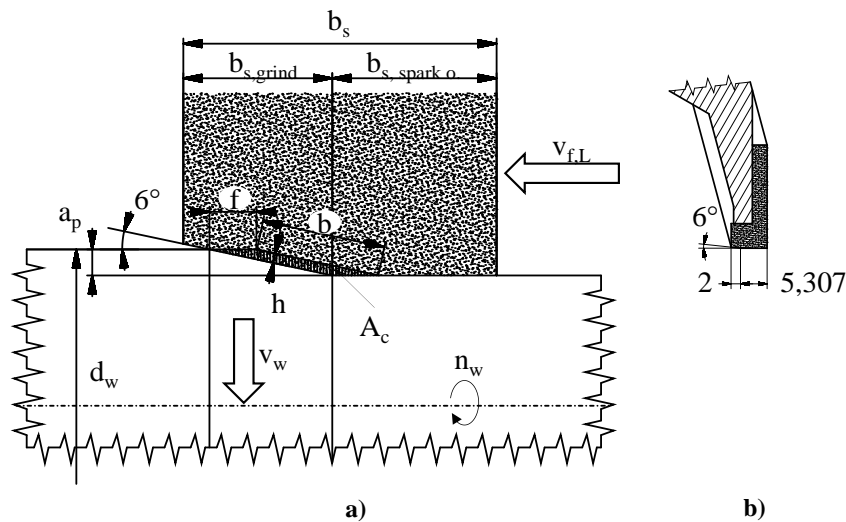


Figure 6 The working part of the wheel and the theoretically undeformed chip-cross-section in: a) contact zone; b) the profile of the wheel

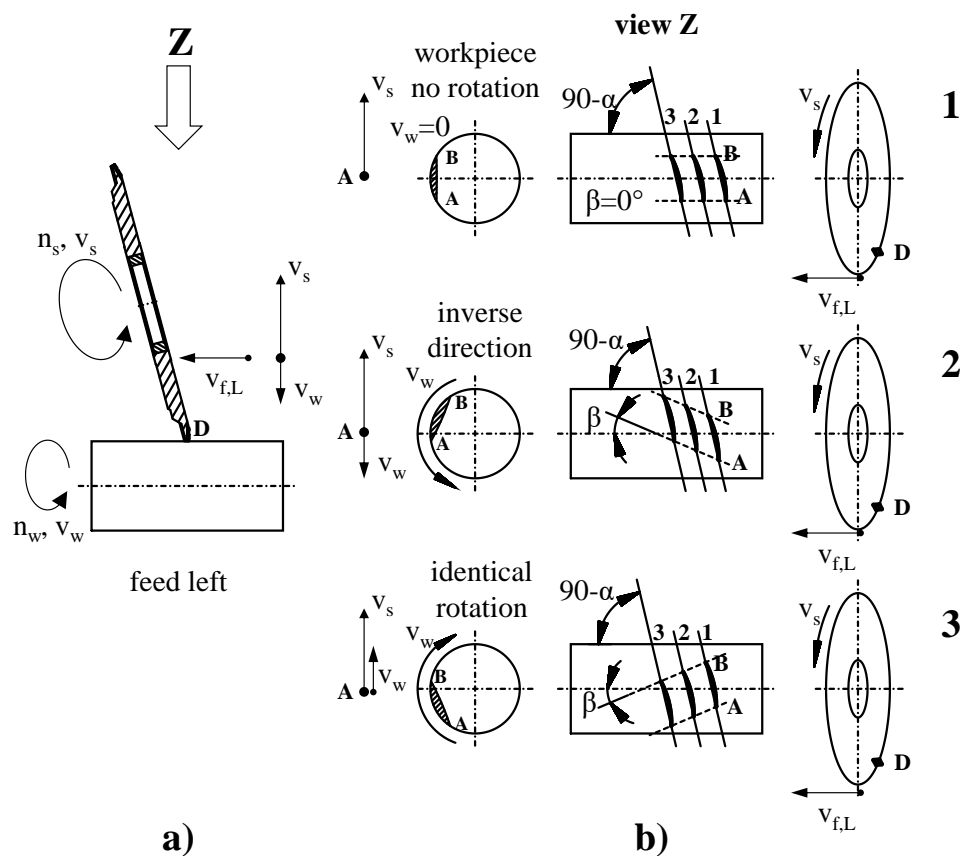


Figure 7 Twist generation work of the single grain wheel model a) general layout b) three typical cases of the twist generation

It is advisable to examine the shape and dimensions of the chip which was removed by a single grain (figure 8). The chip is crescent-shaped and curved in two mutually perpendicular shapes.

One plane is perpendicular to the rotation axis, and can be characterized with the trace AB. The other plane is the tangent plane which is perpendicular to the first one. In the drawing, the curvature of chip is shown in this plane. In order to make the investigation simpler, points A and B are projected into the tangent plane (figure 8b). Thus the maximum chip width b_{\max} can be defined as well as the chip length ℓ_g , which equals to the contact arc length.

In the second step, the chip is rectified in the tangent plane (figure 8c). The chip thickness is reported in the section of the chip which was transformed into the tangent plane (figure 8d).

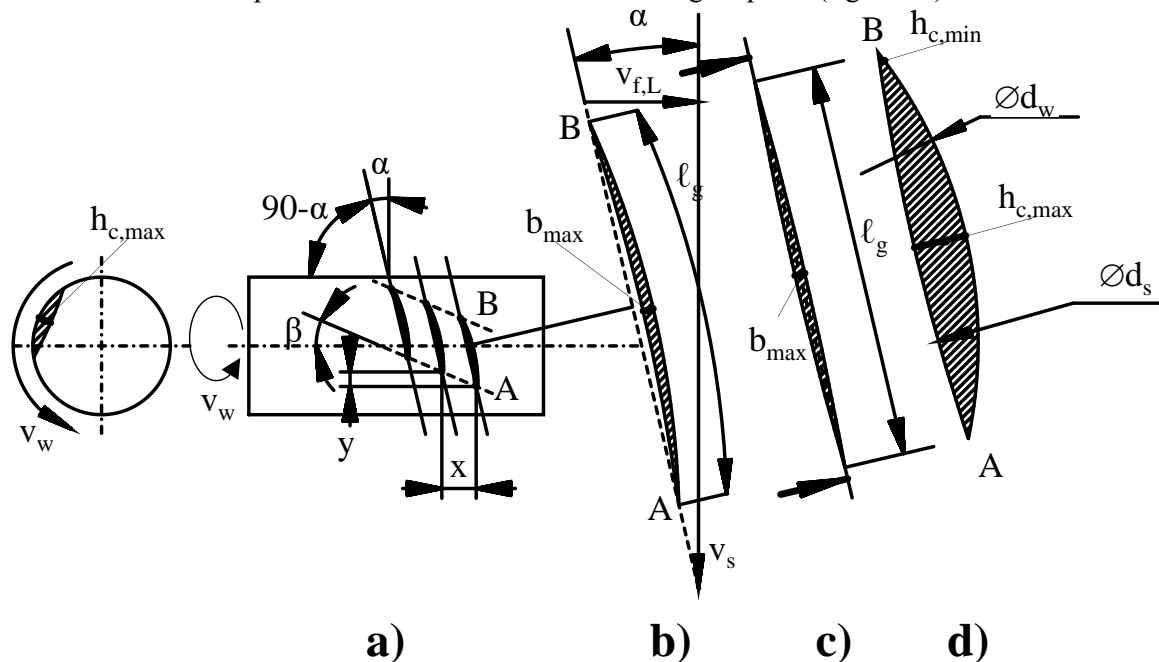


Figure 8 Theoretical undeformed chip shape of the single grain investigations: a) lay out of the scratches on the surface of the workpiece; b) the crescent-shaped chip magnified and transformed into the tangent plane; c) neglecting of the curvature, rectification; d) theoretical undeformed chip cross section

6. CAD based modelling of theoretical twist in peel grinding

The model of the external cylindrical surfaces of the workpiece form simple cylinders, and the base circle is modelled in the X-Y plane. More than one cylindrical surfaces can be on a workpiece, and their diameters and lengths can be defined in parametric form. The next step is the determination of the tangent line between the wheel and the part. Intersection points of the workpiece and the circles which indicate the periphery of the tool are determined for that. This gives the angular movement of the grinding wheel between the entry and exit points of the grain. The actual trajectory of the grinding grain can be calculated later with this knowledge. Although the shape of the grains is not known in grinding, in order to be able to model them, a simple shape was assumed, namely an equilateral triangle.

In view of the arc between the entry and exit points (point A and point B) and on the basis of the wheel diameter the calculation of the trajectory of the wheel can be performed. This is realized in two steps.

In the first step, it is assumed, that the workpiece does not rotate and there is no linear feed; in this case, the trajectory of the grain is a peripheral circular section of the grinding wheel. A point of the curve is recorded in this first step with the given accuracy (Original Trajectory).

In the second step it is taken into account that the trajectory of the grain changes, because of the peripheral speed of the workpiece (v_w) and the longitudinal feed velocity ($v_{f,L}$). A point of this modified

curve is calculated by numerical methods, and the modified trajectory is superposed into them. The next step is the creation of the theoretical undeformed chip shape. The grinding grain shape is guided along the modified trajectory and the excised material (chip) is removed; thus the imprint of the single grain is obtained on the cylindrical surface, which represents the workpiece (figure 9).

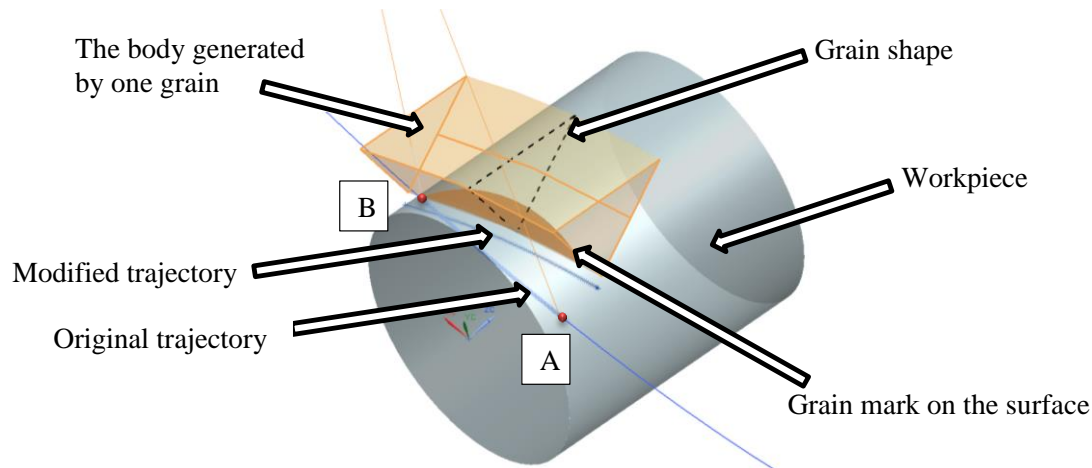


Figure 9 Mark of the single grain

The oblique position is clearly visible which is typical for micro-twist, and which is characterized by angle α at the previous geometrical analysis. The single grain removes a chip at every wheel rotation, and the location of chips positioned to each other translated along a helix shape. This positioning is denoted as macro-twist at the geometrical analysis. The positioning of the helix at the simulation is shown in figure 10. In reality, when there are many grains at the working part of the wheel, the marks are located more densely, partly overlapping each other both in longitudinal and lateral directions, but the orientation which was demonstrated by the simulation still persists.

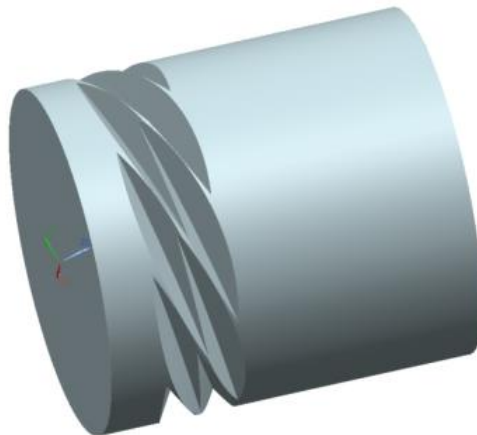


Figure 10 The successive oblique micro-twists (α) and the macro-twist formed by micro-twists (angles α and β in figure 8)

7. Conclusion

The studies made so far have shown that it is clear, that the peel grinding procedures performed by a conical wheel theoretically grind twisted surfaces. However, it is possible to implement such settings, by which such surfaces can be generated; it can be qualified as twist-free according to the actual factory standards and measurement methods, corresponding to the specifications. It could be a solution that in case of reverse-direction rotations the two types of twists can compensate or even theoretically cancel each other. For the conscious application of this, the additional knowledge of regularities and rules and

the deeper exploration of their relations with technological data are needed. Therefore the application of a polishing single-purpose machine is recommended for all cases, when the differences are greater than the allowed deviation.

Acknowledgement

This research was partially carried out in the framework of the Center of Excellence of Innovative Engineering Design and Technologies at the University of Miskolc. Furthermore the authors greatly appreciate the financial support of the National Research, Development and Innovation Office – NKFIH (No. of Agreement: OTKA K 116876).

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