

Cutting Tool Selection Criteria for Cylindrical Gear Manufacturing

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Introduction

This paper is divided into two parts. The first part is a general digression on the pressure angle on cylindrical gears. The pressure angle is a variable that plays an important role in defining the geometry of gears and hobs, yet it is not widely discussed. This introduction serves as a prerequisite for the second part of the paper.

The second part will show an application case of choosing the most suitable hob to cut a given gear. In this selection process, particular attention will be paid to the pressure angle of the hob for cutting with modified rolling, i.e., with a reduced pressure angle compared to that of the gear.

Part One: the pressure angle α

Definition

Typically, in gear geometry training courses, time is spent on profile shifting as an inexpensive means of adapting to the imposed center distance and to balance specific sliding. It is noted that the profile shift has effects especially on gears with few teeth.

In schooling, at least in Italy, the profile shift x is often introduced only as a means of avoiding undercutting for gears with fewer than 17 teeth. This somewhat myopic and biased view learned at school age, is difficult to remove with on-the-job training, which occurs later.

Much less time is devoted to the in-depth study of the pressure angle mainly because any modification, a value different from the standard ones (fixed at 20 by dogma), requires the purchase of specific tools despite the fact that the pressure angle affects bending strength, tooth thickness at the tip diameter and contact ratio (noise reduction)(Ref. 1).

Therefore, it tends to be taught that the profile shift and the pressure angle have similar effects on the tooth shape, but intervening on the former is cost-free, while modifying the latter is expensive (Ref. 1).

Often overlooked is the possibility of cutting gears with tools that have different pressure angles from the gear, resulting in benefits on several fronts. These type of tools are called “corrected lead” (Ref. 2), “short-pitched” (Ref. 3) or “modified rolling” hobs.

Before proceeding to analyze this possibility, it is worth noting that the involute geometry (and thus the shape of the tooth flank) is solely determined by the base circle from which the involute curve is “unrolled.” It is not the module or the pressure angle that defines the involute, but the base circle.

The standard Equation 1 is not the definition of the base circle, but rather that of the base pitch. In Equation 1, the only truly physical quantities are the number of teeth (which can be counted) and the diameter of the base circle, which, although not visible to the human eye, uniquely defines the shape of the involute curve. Infinite combinations of module m and pressure angle α can lead to the same base pitch and thus the same base circle diameter, if multiplied by the number of teeth.

$$d_b = zm \cos \alpha \quad (1)$$

where

d_b is the base diameter
 z is the number of teeth
 m is the module (without subscript, considering spur gear)
 α is the pressure angle

The module is therefore a conventional quantity used to define the size of the teeth (so much so that in AGMA documents, diametral pitch is found instead of the module). To simplify the approach, only spur gears are considered, so module and transverse module are the same.

A bit less conventional is the definition of the pressure angle, but there isn't just one: there is a distinction between the operating pressure angle and the reference profile pressure angle (Ref. 4).

The logical sequence for defining the shape of gear teeth starts with fixing the base diameter and the number of teeth (and then cutting it from root to tip circle). The base pitch p_b will then be uniquely determined.

$$p_b = \frac{\pi d_b}{z} \quad (2)$$

But this formula is also valid

$$p_b = \pi m \cos \alpha \quad (3)$$

At this point, there is only one degree of freedom: either the module or the pressure angle is fixed. Any combination of module and pressure angle that leads to the same base pitch will also result in the same shape of the tooth flank.

At an industrial level, however, it is convenient to follow the reverse path, having standardized the pressure angles and modules (Refs. 5,6).

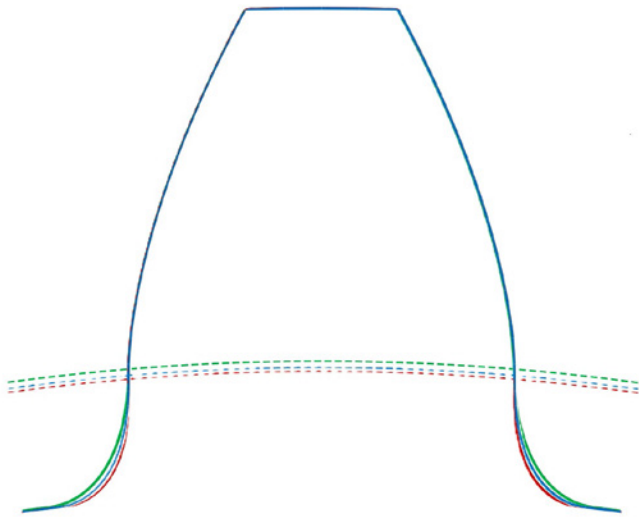


Figure 2—Different root form circles due to different pressure angles (red for 17.5 degrees, blue for 20 degrees, green for 22.5 degrees).

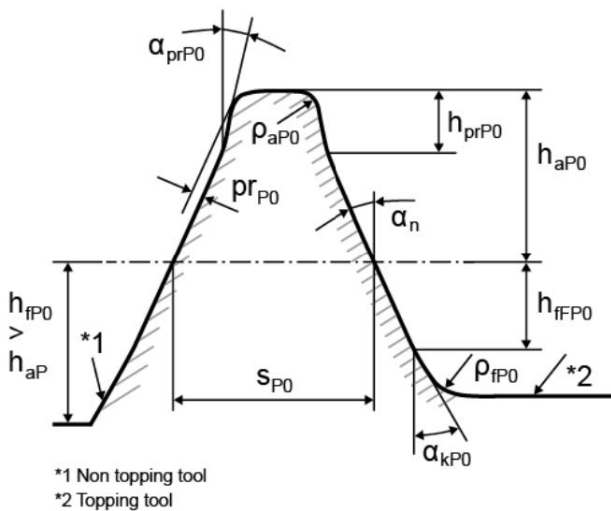


Figure 3—Reference profile symbols for hob in the db.

Gear Generation

With the newly defined tools, gears with different numbers of teeth were generated. It was required that, for the same number of teeth, the gears must have at least the same tooth thickness and the same tip diameter (the root diameter cannot be imposed, having defined the hob).

The obtained results, especially the root diameter and the root form diameter, are indicated in Table 2. The cutting pressure angle α_0 identifies the hob defined in the previous section.

In Figure 4 (using the same colors), the difference between the obtained form diameter and that of the gear cut with the 20 degrees hob is shown for each number of teeth, for various hob pressure angles.

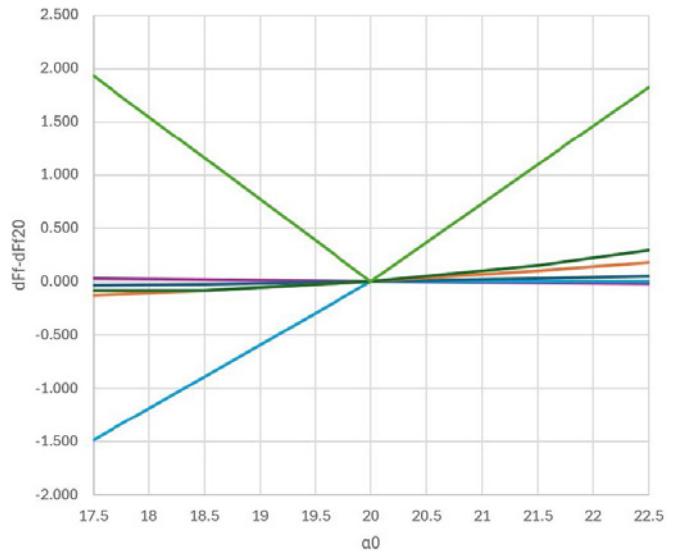
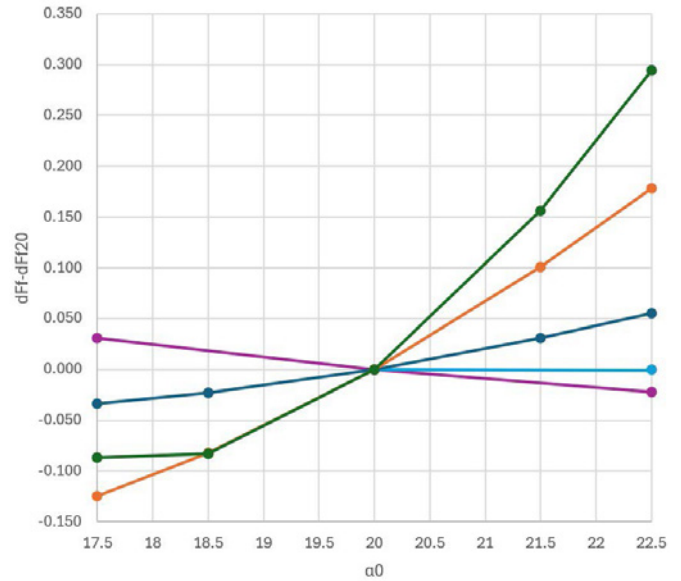


Figure 4—Variation of the root form diameter for different number of teeth z (see Table 2 for colors of z) versus hob pressure angles α_0 . In the upper plot the vertical scale is magnified between -0.15 and $+0.35$.

Analysis of Results

From the information presented in the previous clause, it can summarize that:

- Although the tooth height was requested to be the same on all gears, with different numbers of teeth, the obtained tooth height is not.
- The curvature of the involute flank is the same whatever the number of teeth.
- The tool's pressure angle affects the root form diameter of the cut gear, especially with a high number of teeth.
- The impact of the tool's pressure angle on the gear's root diameter is often negligible, being two orders of magnitude smaller than its effect on the root form diameter ($\approx 1/100$).
- If the tool's pressure angle is greater than that of the gear,

m	α	z	m_0	α_0	d_{Ff}	d_a	d_f	$d_{Ff}-d_{Ff20}$	d_f-d_{f20}	undercut
mm	°	-	mm	°	mm	mm	mm	mm	mm	-
1	20	11	0.985	17.5	10.430	13.0	8.488	0.031	-0.012	yes
1	20	11	1.000	20.0	10.400	13.0	8.500	0.000	0.000	yes
1	20	11	1.017	22.5	10.378	13.0	8.489	-0.022	-0.011	yes
1	20	17	0.985	17.5	14.494	19.0	14.494	-1.485	-0.006	yes
1	20	17	1.000	20.0	15.979	19.0	14.500	0.000	0.000	no
1	20	17	1.017	22.5	15.978	19.0	14.495	-0.001	-0.005	no
1	20	23	0.985	17.5	21.620	25.0	20.500	-0.034	0.000	no
1	20	23	0.991	18.5	21.631	25.0	20.500	-0.023	0.000	no
1	20	23	1.000	20.0	21.654	25.0	20.500	0.000	0.000	no
1	20	23	1.010	21.5	21.684	25.0	20.500	0.031	0.000	no
1	20	23	1.017	22.5	21.709	25.0	20.500	0.055	0.000	no
1	20	46	0.985	17.5	44.068	48.0	43.524	-0.124	0.024	no
1	20	46	0.991	18.5	44.111	48.0	43.508	-0.082	0.008	no
1	20	46	1.000	20.0	44.193	48.0	43.500	0.000	0.000	no
1	20	46	1.010	21.5	44.294	48.0	43.508	0.101	0.008	no
1	20	46	1.017	22.5	44.371	48.0	43.520	0.178	0.020	no
1	20	92	0.985	17.5	89.887	94.0	89.572	-0.086	0.072	no
1	20	92	0.991	18.5	89.891	94.0	89.525	-0.083	0.025	no
1	20	92	1.000	20.0	89.973	94.0	89.500	0.000	0.000	no
1	20	92	1.010	21.5	90.130	94.0	89.523	0.156	0.023	no
1	20	92	1.017	22.5	90.267	94.0	89.561	0.294	0.061	no
1	20	1000	0.985	17.5	999.712	1002	998.515	1.930	1.015	no
1	20	1000	1.000	20.0	997.782	1002	997.500	0.000	0.000	no
1	20	1000	1.017	22.5	999.611	1002	998.365	1.829	0.865	no

Table 2—Gear data for different number of teeth z and different hob pressure angles α_0 .

the root form diameter increases with the cutting angle, except in cases of undercutting.

- For hob with pressure angles less than gear, the relationship is typically the opposite, although verification is advisable.

Case 2: Gear HCR 20 Degrees Hobbing and Grinding

As a second case study, a 52-tooth HCR gear with a 20 degrees pressure angle for automotive use, cut with a hob and finished by grinding, was selected. High contact-ratio or HCR gears are gears defined with a contact ratio greater than 2.0 (Ref. 10), sometimes called also long-addendum gears. The drawing also indicated semi-topping and tolerances on diameters and tooth thickness. To simplify the study, calculations were done without

considering tolerances on tooth thickness and diameters. It was chosen to position on the maximum tip diameter and average tooth thickness.

Comparison was made only between the case with a 20-degree hob (as per drawing) and 17.5 degrees (actual), on this gear. Then, an analysis was carried out on what happens when using this same hob with a 78-tooth gear, with the same reference profile and tooth thickness as the Z52 gear.

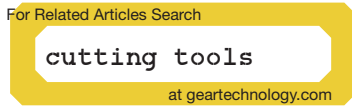
Z52 Geometry

The gear in Figure 5 was cut with the hob in Figure 6, specially designed for this gear with a pressure angle less than that of the gear to reduce wear on the tip. The geometry of the obtained gear exactly reflects the requested one.

A comparison was made between the geometry obtained with the indicated hob and a hob with the same pressure angle as the gear and the same values of protuberance and protuberance angle as the previous hob.

Figure 7 shows different geometries of the gear hobbled with a hob with pressure angle of 20 degrees in green and of 17.5 degrees in red. The involute profile is the same. In the same picture there are four elements: tooth form and hob profile for both cases. Involute profile is the same, root diameter is the same, but also after grinding, root form is different. In Figure 8 only hobs are shown.

It is evident that the use of a hob with modified rolling brings benefits to the root form diameter after grinding (Figure 9), which is lower. In fact, to avoid meshing interference, it is important that the start of contact occurs in the part of the tooth where the involute is. That is, it is important that the root form diameter is lower than active root diameter (SAP, Start of Active Profile): $d_{Ff} < d_{Nf}$.



DATI COSTRUTTIVI DENTATURA	GEAR DATA	I
Numero denti	NO. of teeth	52
Modulo normale	Module	1.948
Modulo circonferenziale	Transverse module	2.368
Angolo di pressione normale	Normal pressure angle	20°
Angolo di pressione circonferenziale	Transverse pressure angle	23°51'44"
Diametro primitivo	Pitch diameter	123.11
Diametro base	Base diameter	112.587
Diametro esterno	Outside diameter	126 ⁰ _{-0.20}
Diametro interno	Root diameter	113 ⁰ _{-0.30}
Inclinazione elica primitiva	Pitch elix angle	34°38'
Inclinazione elica base	Base elix angle	32°16'46"
Senso elica	Hand of elix	DESTRO
Lunghezza fascia teorica (b)	Theoretical face width	22
Spessore dente sul D.P. prima di rettifica	Tooth thickness on D.P. before ground	2.195 ⁰ _{-0.04}
Spessore dente sul D.P. dopo rettifica	Tooth thickness on D.P. after ground	1.995 ⁰ _{-0.04}
Misura fra due rulli, diametro rulli ø4 prima di rettifica	Measurement over two pin, pin diameter ø4 before ground	128.005 ⁰ _{-0.11}
Misura fra due rulli, diametro rulli ø4 dopo rettifica	Measurement over two pin, pin diameter ø4 after ground	127.47 ⁰ _{-0.11}
Diametro inizio evolvente (TIF)	Tru Involute Form Diameter	116
Inizio profilo attivo (SAP)	Start of Active Profile	116.4
Fine profilo attivo (EAP)	End of Active Profile	125.7

Figure 5—Table with data for gear Z52 from the gear drawing.

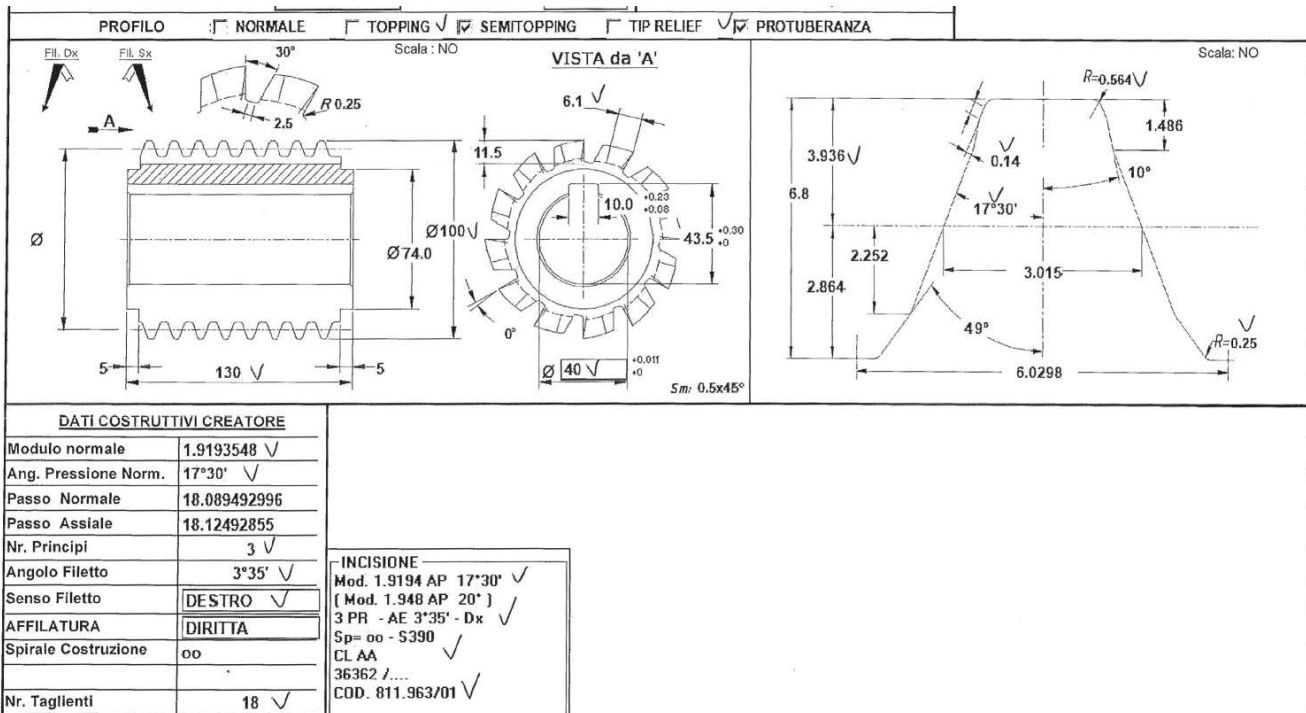


Figure 6—The hob used to cut the gear Z52.

Description	Symbol	Unit	Design	Cut	Difference
Pressure angle of the tool	α_0	°	20.000	17.500	2.5
Tip diameter	d_a	mm	126.000	126.000	0
Root diameter	d_f	mm	112.722	112.722	0
Root form diameter, hobbled	$d_{Ff temp}$	mm	118.267	117.074	0.625
Measurement over 2 pins, hobbled	$M_{dk temp 4}$	mm	128.005	128.005	0
Root form diameter, grinded	d_{Ff}	mm	117.476	116.112	0.604
Measurement over 2 pins, grinded	$M_{dk 4}$	mm	127.470	127.470	0

Table 3—Comparison for gear manufacturing of the gear Z52.

Z78 Geometry

The same hob with a 17.5-degree pressure angle and protuberance was used to cut a gear with 78 teeth that had the same reference profile and thickness as the one with 52 just examined.

Complication arose due to the presence of the grinding step following the hobbing. Thus, two cases were examined: one with the same stock allowance also left on the z52 gear, the other with the same root diameter as the design one. The results are shown in Table 4.

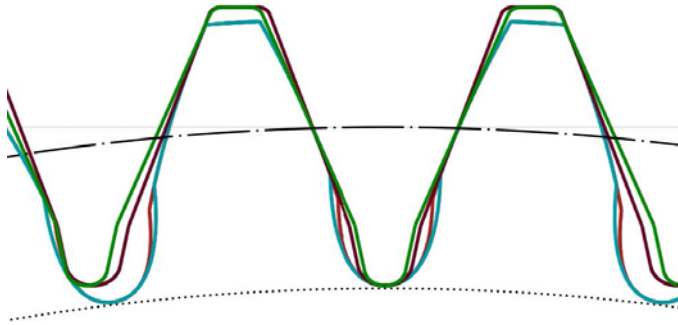


Figure 7—Gear Z52 hobbing by hob with $\alpha = 20$ degrees (green shades) and $\alpha = 17.5$ degrees (red shades). The base circle is dotted. The dash-dotted circle is tangent to the reference line of the hob (the same in both cases).

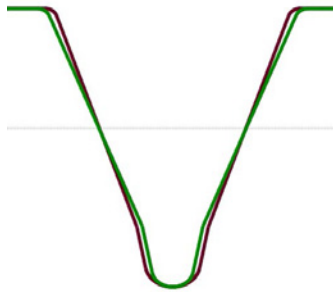


Figure 8—Hob with $\alpha = 20$ degrees (green) versus $\alpha = 17.5$ degrees (red).

Z52 Strength

Although the scope of this paper focuses on production, it was deemed appropriate to investigate the consequences of modified rolling on tooth strength.

In both examined cases per gear Z52, the tooth flank shape is identical. Therefore, the contact pressure during operation is not affected by the production process with modified pressure angle, nor will it affect the resistance to macropitting.

The situation is different concerning the tooth root bending strength because the radius of curvature of root fillet is indeed different in the two cases.

The FEM solver of the same software used for all previous calculations was used. A pair of identical Z52 gears with face width $b = 10\text{mm}$ in a 1:1 ratio was assembled, and an arbitrary load of $T = 450\text{ Nm}$ @ 10 rpm was applied. The absolute value of the calculated stress is not important; rather, the comparison between the stresses at the tooth root between the two geometries is crucial.

The results shown in Table 5 and indicate another advantage in using a hob with modified rolling for this gear: there is not an effective reduction of stress at the tooth root.

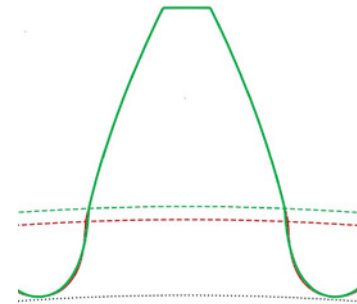


Figure 9—Root form circle (dashed) after grinding for the gear Z52 hobbled by hob with $\alpha = 20$ degrees (green shades) and $\alpha = 17.5$ degrees (red shades).

Description	Symbol	Unit	Design	Same q	Same d_r
Pressure angle	α_{hobber}	°	20.000	17.500	17.500
Tip diameter	d_a	mm	187.555	187.555	187.555
Root diameter	d_f	mm	174.277	174.371	174.277
Root form diameter, hobbled	d_{FLP}	mm	178.464	177.751	177.681
Measurement over 2 pins, hobbled	M_{dkp4}	mm	189.566	189.565	189.485
Profile shift coefficient, hobbled	x_{Ep}		-0.6102	0.4030	0.3785
Root form diameter, grinded	d_{FI}	mm	177.463	176.745	176.845
Measurement over 2 pins, grinded	M_{dk4}	mm	189.026	189.026	189.026
Profile shift coefficient, grinded	x_E		-0.751	-0.751	-0.751
Stock allowance	q	mm	0.188	0.188	1.505

Table 4—Comparison for gear manufacturing of the gear Z78.

Description	Symbol	Unit	Design	Cut	Difference
Maximum equivalent stress	σ_{emax}	N/mm ²	168.77	172.44	-2%
Diameter	d_{\sigmaemax}	mm	127.19	127.30	

Table 5—Stress on the gear Z52 hobbled with hob pressure angle 20 and 17.5 degrees.

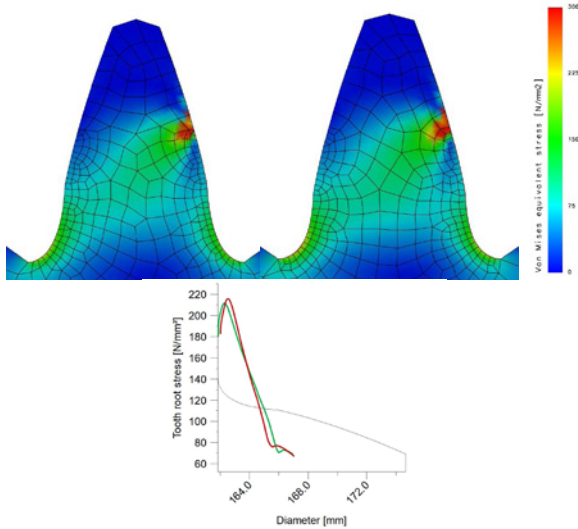


Figure 10—Von Mises equivalent stress on the designed gear (hobbed with hob pressure angle 20 degrees, green) and cut gear (hobbed with hob pressure angle 17.5 degrees, red). KISSsoft images with kind permission by KISSsoft AG.

Machining step		
Pre- and final machining	Final machining stock: Profil III DIN 3972:1952	↕
Final machining stock	q	0.08000000 mm ++ +
Pre-machining		
Tool type	Cutter/Tool: Hobbing cutter	↕
Input	Factors	
Data source	Own Input	⊞
Designation	Enter...	
Addendum coefficient	h_{a0}^*	1.55330000 ++
Tip radius coefficient	r_{f0}^*	0.30000000 ++
Dedendum coefficient	h_{f0}^*	1.00000000 ++
Root radius coefficient	r_{r0}^*	0.26000000 ++
Protuberance height coefficient	h_{p0}^*	0.00000000 ++
Protuberance angle	α_{p0}	0.00000000 ° ++
Protuberance coefficient	pr_{f0}^*	0.00000000 ++
Root form height coefficient	h_{r0}^*	0.78000000 ++
Profile angle of the chamfer flank	α_{040}	54.99999492 ° ++
Tooth thickness factor reference line	s_{f0}^*	1.57079633
<input type="checkbox"/> Topping tool		
Addendum coefficient Reference profile Gear	h_{a0}^*	0.97101200 ++
Tip alteration of gear	k_{m0}	-0.02100000 mm ++

Figure 11—Windows with the definition of the profile designed for the gear Z30. KISSsoft image with kind permission by KISSsoft AG.

Figure 12—Window of the hob searching for the gear Z30. KISSsoft image with kind permission by KISSsoft AG.

m_n	0.75	mm
α_n	20	°
β	20	°
z	30	
x	0.36098	
d_a	25.9	mm
Hob	Profile III DIN 3972	
q	0.08	mm

Table 6—Gear data.

With only one case examined, it is not possible to establish a universal rule regarding the relationship between modified rolling and changes in bending strength. As seen in section 1.2.3, it is also not possible to establish rules for geometry. However, it is interesting to note that the tooth strength changes depending on the production process, particularly based on the pressure angle of the hob.

Part Two: Hob Selection

Some drawings of cylindrical gears was examined, and efforts were made to determine as quickly as possible which hob could be used to cut them. The search did not always focus solely on hobs with the same pressure angle as the workpiece but also extended to a broader range, paying particular attention to the results obtained. The production process also includes a grinding phase after heat treatment.

Part of the searching process was already described in Ref. 11 to which reference is made for the flow diagram. Compared to what was reported in that paper, the software used has undergone significant updates: it is now possible to easily save a new hob in the database and view its dimensioned geometry to compare it with the drawing provided by the toolmaker. The search for the modified rolling hob also extends smoothly to slightly different base pitches (which will result in a non-constant allowance as the grinding process takes place).

Manual and individual operations that the operator previously performed on the screen have been automated with the help of a Windows macro recorder. This allows for a quick and automatic generation of a list of usable hobs, with the geometric characteristics of the gear cut with each hob listed alongside.

Case 1: Industrial Gearbox Z30

A helical cylindrical gear of a small-sized parallel industrial gearbox is examined. The gear shown in Table 6 was designed with a profile II, achievable with a profile III hob + grinding. The drawing specifies “profile III + grinding,” and the strength calculations were performed with this geometry.

The gear data, including the required profile, were entered into the workshop’s calculation software (Figure 11). A search for suitable hobs was then conducted in the available database (Figure 11). It can be noted that the search can be extended by setting ranges for lengths and angles. The search results are in Table 7. Searching through a database of 850 records took only a few tenths of a second.

For this gear, the workshop did not deem it necessary to adopt modified rolling hobbing.

In Figure 13 and Table 8, the difference between the design profile (black) and the obtained profile (color coded) can be observed.

Name	m_n mm	α_n °	h_{aP0} mm	ρ_{aP0} mm	h_{fP0} mm	h_{prP0} mm	α_{Pr0} °	pr mm	h_{FIPO} mm	α_{KPO} °	Topping	ρ_{fPO} mm
Searching for	0.750	20.000	1.165	0.225	0.750	0.000	0.000	0.000	0.585	55.000	No	0.195
Existing tools												
Hob 1567	0.750	20.000	0.938	0.150	0.766	0.000	0.000	0.000	0.422	38.000	No	0.200
Deviation			-0.227	-0.075	0.016				-0.163	-17.0		0.005
Hob 1568	0.750	20.000	0.938	0.150	0.766	0.000	0.000	0.000	0.422	38.000	No	0.200
Deviation			-0.227	-0.075	0.016				-0.163	-17.0		0.005
Hob 1572	0.750	20.000	1.179	0.152	0.769	0.000	0.000	0.000	0.426	40.000	No	0.200
Deviation			0.014	-0.073	0.019				-0.159	-15.0		0.005
Hob 1573	0.750	20.000	1.179	0.152	0.769	0.000	0.000	0.000	0.426	40.000	No	0.200
Deviation			0.014	-0.073	0.019				-0.159	-15.0		0.005
Hob 1574	0.750	20.000	1.179	0.152	0.769	0.000	0.000	0.000	0.426	40.000	No	0.200
Deviation			0.014	-0.073	0.019				-0.159	-15.0		0.005
Hob 1575	0.750	20.000	1.179	0.152	0.769	0.000	0.000	0.000	0.426	40.000	No	0.200
Deviation			0.014	-0.073	0.019				-0.159	-15.0		0.005
Hob 1626	0.750	20.000	0.938	0.150	0.766	0.000	0.000	0.000	0.422	38.000	No	0.200
Deviation			-0.227	-0.075	0.016				-0.163	-17.0		0.005
Hob 1627	0.750	20.000	0.938	0.150	0.766	0.000	0.000	0.000	0.422	38.000	No	0.200
Deviation			-0.227	-0.075	0.016				-0.163	-17.0		0.005
Hob 1628	0.750	20.000	0.938	0.150	0.766	0.000	0.000	0.000	0.422	38.000	No	0.200
Deviation			-0.227	-0.075	0.016				-0.163	-17.0		0.005
Hob 1629	0.750	20.000	0.938	0.150	0.766	0.000	0.000	0.000	0.422	38.000	No	0.200
Deviation			-0.227	-0.075	0.016				-0.163	-17.0		0.005
Hob 1630	0.750	20.000	0.938	0.150	0.766	0.000	0.000	0.000	0.422	38.000	No	0.200
Deviation			-0.227	-0.075	0.016				-0.163	-17.0		0.005
Hob 1631	0.750	20.000	0.938	0.150	0.766	0.000	0.000	0.000	0.422	38.000	No	0.200
Deviation			-0.227	-0.075	0.016				-0.163	-17.0		0.005
Hob 1632	0.750	20.000	0.938	0.150	0.766	0.000	0.000	0.000	0.422	38.000	No	0.200
Deviation			-0.227	-0.075	0.016				-0.163	-17.0		0.005

Table 7—Result of the hob searching for the gear Z30 m_n 0.75.

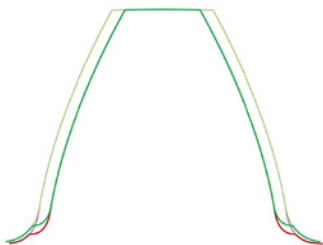


Figure 13—Geometry of the gear Z30 designed (green) and cut by “Hob 1572” (red), with and without stock allowance.

Description	Symbol	Unit	Design	Cut
Root diameter	d_r	mm	22.5356	22.5076
Root form diameter, grinded	d_{Fr}	mm	23.0117	22.9306

Table 8—Comparison for gear manufacturing of the gear Z30.

m_n	13.5	mm
α_n	25	°
β	0	°
z	11	
x	0.20053	
d_a	179.5	mm
d_f	120.8	mm

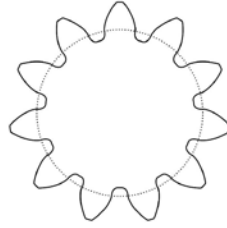


Table 9—Gear data of Z11.

Figure 14—Gear geometry of Z11, with the base circle.

Machining step	
Pre- and final machining	Final machining stock: Own Input
Final machining stock	q 0.18500000 mm
Pre-machining	
Tool type	Cutter/Tool: Hobbing cutter
Input	Lengths
Data source	Own Input
Designation	Enter...
Addendum	h_{add} 16.77000000 mm
Tip radius	r_{tip} 1.50000000 mm
Dedendum	h_{ded} 16.20000000 mm
Root radius	r_{root} 0.01350000 mm
Protuberance height	h_{prot} 1.80000000 mm
Protuberance angle	α_{prot} 4.50000000 °
Protuberance	p_{prot} 0.24172168 mm
Root form height	h_{root} 0.00000000 mm
Profile angle of the chamfer flank	α_{cham} 0.00000000 °
Tooth thickness reference line	s_{ref} 21.20575041 mm

Figure 15—Window with the definition of the profile designed for the gear Z11. KISSsoft image with kind permission by KISSsoft AG.

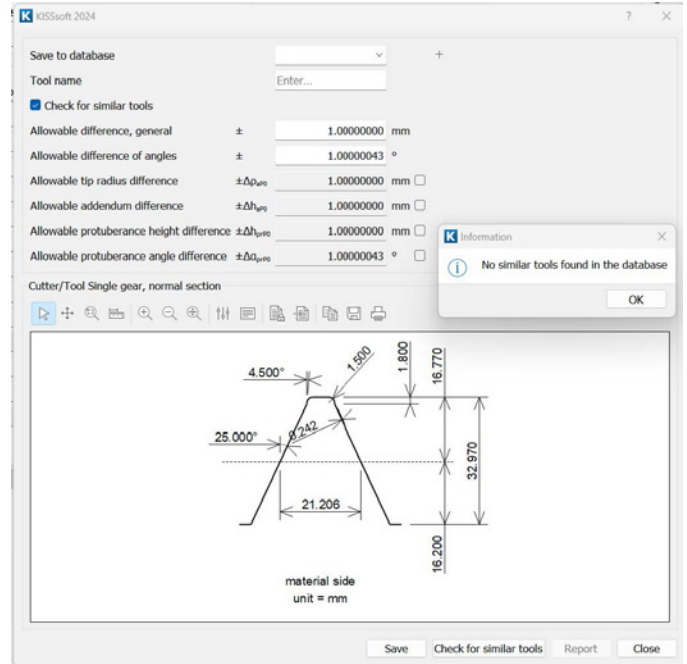


Figure 16—Window of the hob searching for the gear Z11. KISSsoft image with kind permission by KISSsoft AG.

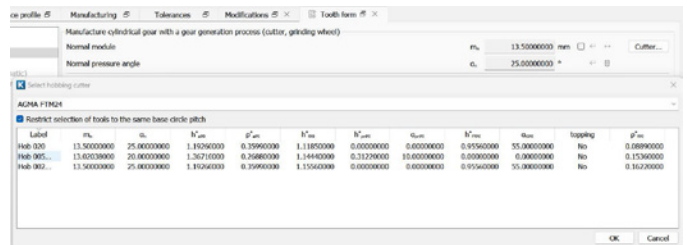


Figure 17—Window of the hob searching for the gear Z11. KISSsoft image with kind permission by KISSsoft AG.

Description	Symbol	Unit	Design	Hob 002	Hob 005	Hob 020
Hob pressure angle	α_0	°	25	25	20	25
Hob module	m_0	mm	13.5	13.5	13.02	13.5
Tip diameter	d_a	mm	179.5	179.5	179.5	179.5
Root diameter, hobbed	d_{ftmp}	mm	120.8256	122.1654	120.8021	122.1654
Root form diameter, hobbed	$d_{Ff tmp}$	mm	137.4522	135.283	137.2446	135.283
Root diameter, grinded	d_f	mm	120.8256	120.7787	120.7787	120.7787
Root form diameter, grinded	d_{Ff}	mm	135.7743	137.4447	137.4447	137.4447

Table 10—Comparison for gear manufacturing of the gear Z11.

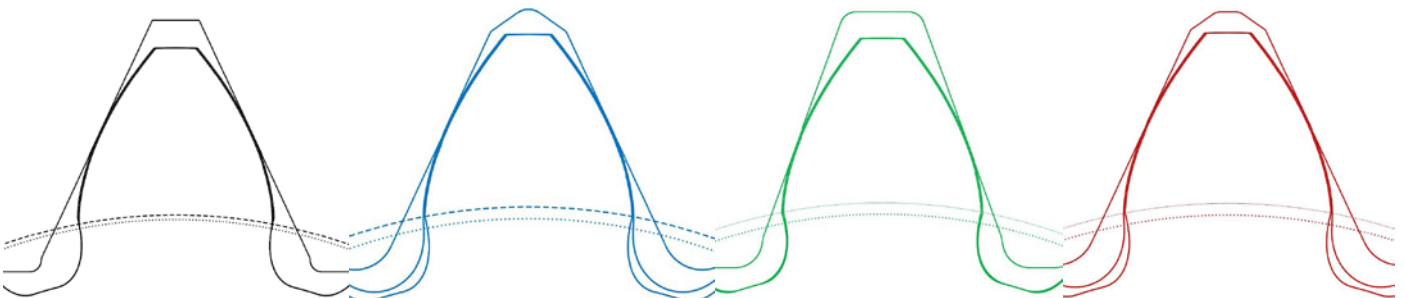


Figure 18—Comparison for gear manufacturing of the gear Z11: tooth form with and without stock allowance, base circle (dotted), root form circle (dashed) and hob.

Case 2: Tractor Gear Z11

A spur cylindrical gear for agricultural applications is being examined. The geometry is in Table 9 and Figure 14.

As in the previous case, after entering the gear geometry, a search was conducted in the current tool database to see if there was a suitable hob to cut the gear. The search did not yield any results (Figure 15 and Figure 16).

At this point, the decision was made to use modified rolling. In this case, there is no tool search feature like in the previous case, but there is the option to view all hobs that have the same base pitch as the gear with a tolerance of ± 2 percent (Figure 17). The number of solutions found is fortunately small, so it is possible to calculate the three options individually. The results are in Table 10 and Figure 18.

Hob 002 and Hob 020 are very similar, only the root radius value ρ_{FP0} are different, but these hobs are not for topping, so the tooth form they generate are identical.

Hob 005 has protuberance and a lower pressure angle than the gear.

The gear is manufactured by the Hob 005.

The list of hobs to be examined could have been very long (as in the previous example). Therefore, it was decided to automate the generation of Table 10 with a VBA macro in Excel. This macro, in turn, calls a *Windows* macro recorded on *Jitbit macro recorder* (Figure 19) that simulates the operations (mouse

clicks) that the operator would manually perform for each row indicated in Figure 17.

- The first line (in red) activates the *KISSsoft* window, where the file with the gear and the hob geometry are already defined.
- The second line (in green) activates the “tooth form” window with the tool’s data.
- The third line (in blue) performs the calculation using the F5 shortcut.
- The remaining lines close any message or error windows that may appear when using an unsuitable tool by an ENTER key press.

In Figure 20 there is the portion of VBA code that calls this macro from *Excel* after inserting the tool definition into the *KISSsoft* file of the gear. In the Excel macro, there are “Wait” commands for the execution of operations on *KISSsoft*.

Open Issues

Taking into account what has just been described and what has already been reported in the two previous publications (Refs. 11,12), it is appropriate to address some open issues.

The procedure for automatically selecting the modified hob, however, computerized, can still be further optimized for speed. While for hobs with the same pressure angle as the workpiece, it is possible to use internal programming functions within the

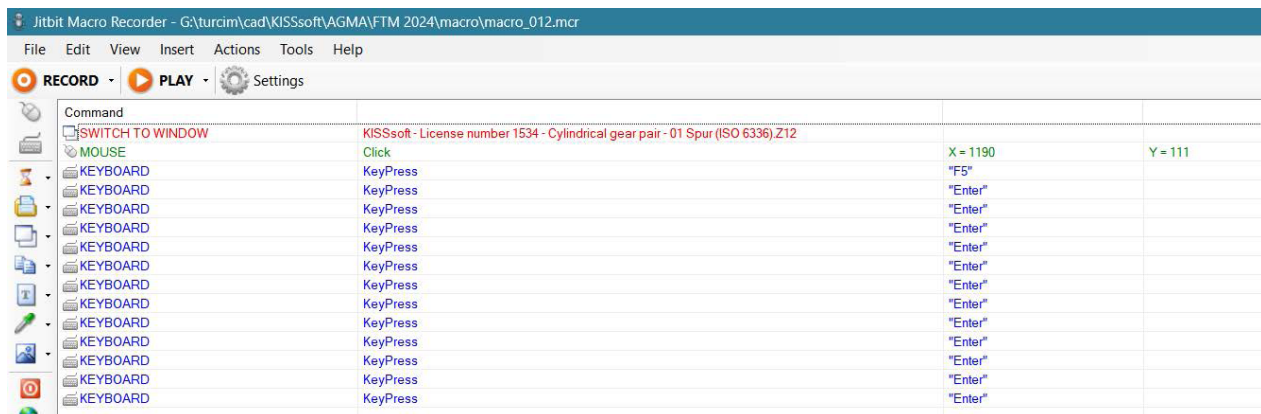


Figure 19—Jitbit macro to run the tooth form calculation in KISSsoft.

```

Set a = New CKISSsoft
Call a.GetModule("Z011", True)
Call a.LoadFile(nomeFile)

Call a.ShowInterface(False) ' sara falso + pausa di qualche sec per far apparire l'interfaccia

Wait 1

response = ShellExecute(0, "open", NomeMacro, vbNullString, vbNullString, SW_SHOWNORMAL)

' pausa per dar tempo di eseguire la macro

Wait 3

' si potrebbe pensare di salvare il file z11 via com invece del wait

FileCopy DirTmpKiss & "\KISS_0\z05result1.tmp", percorso + "\logdir\log" & i & ".txt"
    
```

Figure 20—Part of the VBA macro code.

software used, this is not the case for selecting and calculating with modified hobs. The method described in this paper indeed uses a Windows macro recorder. This type of macro requires predefined latency times, calibrated for the worst-case scenario (slower), as the processing time for each tool is not known in advance. It is advisable to investigate how to switch from asynchronous to synchronous execution, which is significantly faster. Thankfully, in the new version of KISSsoft, released after the first draft of this paper, there is a function to calculate the tooth form, avoiding the external macro recorder.

It would also be advisable to investigate the strength of gears cut by modified rolling hobs. Sometimes, there may even be two meshing cylindrical gears that have been cut each by a hob with a different pressure angle. This results in a nominal pressure angle α for the gear pair, a working pressure angle for the pair α_w , and two cutting pressure angles α_{01} and α_{02} , which are responsible for the form factor (geometry factor) in the strength calculations according to ISO 6336 and AGMA 2001 standards. At present, the standards do not explicitly address the use of two different hob pressure angles. The same applies to calculation software based on these standards.

Smart Editing of the Gear Data

Before the conclusions, it could be interesting and funny note that the use of a different couple of “pressure angle & module” helped a designer to get a gear drawing accepted despite the reference diameter d was greater than the tip diameter d_a , i.e., outside than the gear. Everyone was aware of the strange shape of the gear in Figure 21A, but neither the workshop nor quality control were able to process a gear with $d > d_a$, mainly due to the tooth thickness being defined on the reference diameter. But since $d = d_b/\cos(\alpha)$, it was enough for the designer to decrease α to decrease d below d_a .

Also the root radius was modified to get the same root tooth form diameter. The data of the “two” gears are in Table 11 and the position of the reference diameters are shown in Figure 21B.

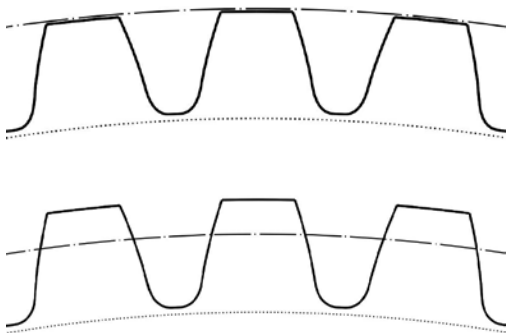


Figure 21—The original gear (A) and the edited one (B): same geometry of the involute but different data definitions (reference circle in dash-dotted, base circle in dotted).

Description	Symbol	Units	Original	Edited
number of teeth	z		62	62
module	m	mm	1.56	1.527974
pressure angle	α	°	20.5	17
base diameter	d_b	mm	90.5949	90.5949
reference diameter	d	mm	96.72	94.73438

Table 11—Edited gear data.

Conclusions

Cutting with a hob having a pressure angle lower than that of the gear can be driven by two distinct needs:

- “Dig” deeper into the workpiece and thus obtain a longer involute flank, effectively reducing the root form diameter.
- Enhance the hob’s strength, particularly by increasing its thickness at the tip.

This technique is industry-specific: it is more common in transmission systems (automotive, agriculture), where the pressure angle is considered a variable, rather than a universal constant (either in design or production), as is the case of industrial gearboxes.

Opting to cut with a pressure angle different from that of the workpiece inevitably brings to complications in terms of calculation and management, especially when using a hob to cut a gear with a different number of teeth than the one for which it was designed.

This paper has presented the adoption of the selection of hobs with modified rolling, supported by extensive calculations on the company’s hob database. The procedure adopted aids the operator in choosing the most suitable tool based on the geometry of the gear that would be produced with each analyzed tool.

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