

DESIGN OF A COMPUTER-AIDED GEAR MANUFACTURING TOOL – RACK-SHAPED CUTTER

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In this work, the calculation of Maag gear shaper cutter parameters is performed for spur gears with helical teeth in three variants – straight-tooth tool with machine offset, helical-tooth tool without machine offset and helical-tooth tool with machine offset. It is therefore a prerequisite that the manufactured involute gearing has helical teeth for each variant. The created CAD program is universal and can be used for construction in other combinations as well. The tool clamping angles on the tool holder, the cutting geometry of the cutter and the characteristic of the gearing are introduced into the calculation. The output of the work will be then calculated individual parameters of the Maag shaping cutter in the tooling system, necessary for its construction. The calculation are performed in program T-Flex CAD and the summary output is graphical 2D/3D representation of the rack-shaped cutter in its base, normal and side planes, always in a different design based on the change of the tool input data and gearing characteristic. The analysis of the tool's involute profile was solved by vector calculus and matrices and by rotating the tool in the chosen coordinate systems. The specific calculation of the tool parameters will be solved using goniometric functions.

KEYWORDS

Spur gears, straight and helical teeth, cutting geometry, clamping angles, rack-shaped cutter, T-Flex CAD program

1 INTRODUCTION

Spur gears with straight and helical teeth are produced by shaping, using the hobbing method [Manufacturing 2020], [Marek 2015], [Micietova 2009]. The tool here is the rack-shaped cutter. The profile on its cutting edge for each tooth is determined from the basic profile of the rack using the pair wheel-rack [Zahnraeder 2020]. Tool tooth profile angles, tooth pitch and height depend on the gear characteristics. However, the cutting efficiency and accuracy of gear production depend much more on clamping the tool into the sliding ram holder and on re-sharpening the tool on its top face [Mrkvica 2009].

Rack cutters belong to the tools that can be used for the production of all kinds of spur gears, normal and herringbone, corrected and uncorrected, with straight or inclined teeth, for a given module with any number of teeth, but only for external gearing [Dimensionieren 2019]. If we compare the rack-type tools to other tools used for gearing, they are the simplest as to their production and their sharpening [Gear 2020]. They are one of the most accurate tooth cutting tools as to the wheel profile accuracy and the quality of the machined surface of the tooth flank [Kosir 2012], [Safar 2011], [Cep 2014]. The disadvantage of this method is the lower productivity of the machine [Mrkvica 2011].

The analysis of the rack-shaped cutter profiles, related to the calculation of the basic parameters of the tool, is solved in the available literature using goniometric functions that describe the relationships among the planes and the cutting edges of the relevant planes [Schmidt 1974]. To solve the given task, a more suitable approach is to use vector calculus and matrices [Benes 2016], [Litecka 2016]. This will make it easier to convert the calculation into a computer form.

The calculation is made for a tool for spur gear with helical teeth. Into the calculation, we will include chosen angle for the tool clamping on a forming machine, cutting geometry of the tool, and gear characteristics. The entire calculation is done for involute gearing and these equation sets can be also used for other types of racks [Mrkvica 1986], [Mrkvica 1992].

2 PRACTICAL EXAMPLES OF THE DESIGN OF A RACK CUTTER

2.1 Input parameters for the calculation of the rack-shaped cutter

Input parameters of the machined wheel:

m [mm] – module (from standard CSN 22 254), for the given example we chose $m=5$,

α_n [°] – angle of mesh in the normal plane, 20° is most often chosen, (if $\beta_0 = 0^\circ$, then $\alpha_n = \alpha_\xi$, where α_ξ is mesh angle in the gear face plane), for this example we have chosen $\alpha_n = 20^\circ$,

β_0 [°] – angle of gear tooth inclination, for gearing with straight teeth $\beta_0 = 0^\circ$ (for helical gearing the value of β_0 is selected), for the given example (variant A, variant B and variant C) we have chosen the helical gearing of the wheel, i.e. $\beta_0 = 11^\circ 11'$.

Input parameters of the cutting tool (according to technological conditions of machining):

α_{12} [°] – tool clearance angle in the back plane on the tooth head of the rack-shaped cutter (12° is most often chosen), for this example we chose $\alpha_{12} = 12^\circ$,

z [-] – number of teeth (according to the module from standard CSN 22 254), for $m=5$ the number of teeth is $z=9$ [CSN 222540 1973],

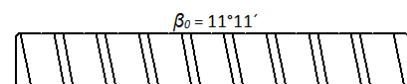
α_{07} [°] – the angle of the rack cutter in the ram of the shaping machine, for this example we chose for variant A $\alpha_{07} = 11^\circ 11'$, for variant B $\alpha_{07} = 0^\circ$ and for variant C $\alpha_{07} = 3^\circ 11'$,

α_{17} [°] – working back angle of the face on the tooth head of the rack cutter (for Maag machines a value of 6°30' is chosen), for this example we have chosen $\alpha_{17} = 6^\circ 30'$,

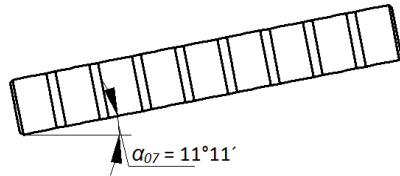
α_{15} [°] – tooth face angle tooth, for this example we have chosen $\alpha_{15} = 0^\circ$.

Variant A:

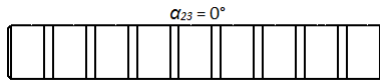
- workpiece:



- clamping the tool in the shaping machine:



- cutting tool (after the calculation):



Variant B:

$$\beta_0 = 11^\circ 11', \alpha_{07} = 0^\circ, \alpha_{23} = 11^\circ 7' 59''$$

Variant C:

$$\beta_0 = 11^\circ 11', \alpha_{07} = 3^\circ 11', \alpha_{23} = 7^\circ 57' 49''$$

2.2 Calculated parameters for the design of the rack-shaped cutter

Mesh angle in the gear face plane α_ξ

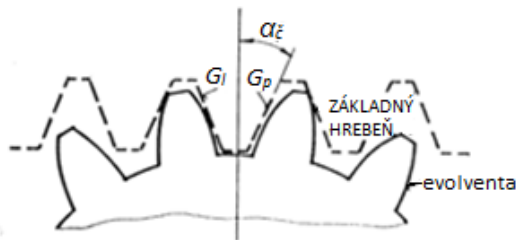


Figure 1. The face plane of the involute gear with the profile of the basic rack [Mrkvica 1986]

$$\tan \alpha_\xi = \frac{\tan \alpha_{23}}{\cos \beta_0} = \frac{\tan 20^\circ}{\cos 11^\circ 11'} \Rightarrow \alpha_\xi = 20^\circ 21' 20'' \quad (1)$$

The angle α_ξ is the same for all three variants.

Working back clearance angle on the tooth cutter head α_{27}

$$\alpha_{27} = \alpha_{12} - \alpha_{17} = 12^\circ - 6^\circ 30' = 5^\circ 30' \quad (2)$$

The angle α_{27} is the same for all three variants.

Angle of inclination of the tooth back to the setting of the grinding cradle (clearance angle in the back plane) α_{23}

Variant A:

$$\begin{aligned} \tan \alpha_{23a} &= \cos(\alpha_{12} - \alpha_{17}) \cdot \tan(\beta_0 - \alpha_{07a}) = \\ &= \cos 5^\circ 30' \cdot \tan(11^\circ 11' - 11^\circ 11') = 0 \Rightarrow \alpha_{23a} = 0^\circ \end{aligned} \quad (3)$$

Variant B: $\alpha_{23b} = 11^\circ 7' 59''$,

Variant C: $\alpha_{23c} = 7^\circ 57' 49''$.

Angle of rotation of the face from the ground plane α_{56}

Variant A:

$$\tan \alpha_{56a} = \frac{\tan \alpha_{23a}}{\cos \alpha_{12}} = \frac{\tan 0^\circ}{\cos 12^\circ} = 0 \Rightarrow \alpha_{56a} = 0^\circ \quad (4)$$

Variant B: $\alpha_{56b} = 11^\circ 22' 31''$,

Variant C: $\alpha_{56c} = 8^\circ 8' 21''$.

Substitution relationships

Variant A:

$$\begin{aligned} a_\alpha &= \sin \alpha_{07a} \cdot \sin \alpha_{56a} \cdot \cos \alpha_{27} \\ -\cos \alpha_{07a} \cdot \cos \alpha_{56a} \cdot \cos(\alpha_{12} + \alpha_{15}) &= -0,959574156 \end{aligned} \quad (5)$$

Variant B: $a_b = -0,958933323$,

Variant C: $a_c = -0,958974927$.

Substitution parameter b:

Variant A:

$$\begin{aligned} b_\alpha &= \sin \alpha_{07a} \cdot \sin \alpha_{23a} \cdot \sin \alpha_{56a} \cdot \sin \alpha_{27} \\ &- \sin \alpha_{07a} \cdot \cos \alpha_{23a} \cdot \cos \alpha_{56a} \cdot \sin(\alpha_{17} + \alpha_{15}) - \\ &\cos \alpha_{56a} \cdot \cos \alpha_{07a} \cdot \sin \alpha_{23a} \cdot \sin(\alpha_{12} + \alpha_{15}) \\ &= -0,021955649 \end{aligned} \quad (6)$$

Variant B: $b_b = -0,039356668$,

Variant C: $b_c = -0,034529362$

Substitution parameter c:

Variant A:

$$c_\alpha = \sin \alpha_{56a} \cdot \sin \alpha_{27} = \sin 0^\circ \cdot \sin 5^\circ 30' = 0 \quad (7)$$

Variant B: $c_b = 0,018904074$,

Variant C: $c_c = 0,013569646$

Substitution parameter d:

Variant A:

$$\begin{aligned} d_\alpha &= \cos \alpha_{23a} \cdot \cos \alpha_{56a} \cdot \cos(\alpha_{17} + \alpha_{15}) \\ &+ \sin \alpha_{23a} \cdot \sin \alpha_{56a} \cdot \cos \alpha_{27} \\ &= 0,993571855 \end{aligned} \quad (8)$$

Variant B: $d_b = 0,993632454$,

Variant C: $d_c = 0,993602975$

Substitution parameter e:

Variant A:

$$\begin{aligned} e_\alpha &= \sin \alpha_{07a} \cdot \cos \alpha_{56a} \cdot \cos(\alpha_{12} + \alpha_{15}) \\ &+ \cos \alpha_{23a} \cdot \sin \alpha_{56a} \cdot \cos \alpha_{27} \\ &= 0,189710743 \end{aligned} \quad (9)$$

Variant B: $e_b = 0,192631741$,

Variant C: $e_c = 0,19333756$

Substitution parameter f:

Variant A:

$$\begin{aligned} f_\alpha &= \sin \alpha_{07a} \cdot \cos \alpha_{56a} \cdot \sin \alpha_{23a} \cdot \sin(\alpha_{12} + \alpha_{15}) \\ &+ \cos \alpha_{07a} \cdot \sin \alpha_{56a} \cdot \sin \alpha_{23a} \cdot \sin \alpha_{27} \\ &- \cos \alpha_{07a} \cdot \cos \alpha_{23a} \cdot \cos \alpha_{56a} \cdot \sin(\alpha_{17} + \alpha_{15}) \end{aligned} \quad (10)$$

$$= -0,111053667$$

Variant B: $f_b = -0,105240864$,

Variant C: $f_c = -0,107350422$

Angle of the tooth edge in the normal plane of the rack tool (P_n) – position of the right side α_{34P}

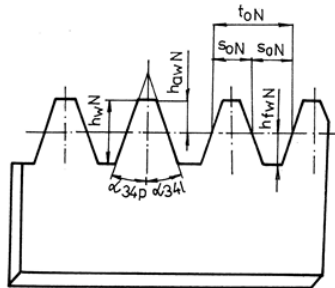


Figure 2. View of the normal (production) plane of the rack-shaped cutter [Mrkvica 1986]

Variant A:

$$\tan \alpha_{34PA} = \frac{b_{\alpha} \cos \beta_0 + d_{\alpha} \tan \alpha_n - f_{\alpha} \sin \beta_0}{c_{\alpha} \tan \alpha_n - a_{\alpha} \cos \beta_0 + e_{\alpha} \sin \beta_0} \quad (11)$$

$$\Rightarrow \alpha_{34PA} = 20^{\circ}17'23''$$

Variant B: $\alpha_{34PB} = 19^{\circ}13'25''$,

Variant C: $\alpha_{34PC} = 19^{\circ}31'18''$

Angle of the tooth edge in the normal plane of the rack tool (P_n)

– position of the left side α_{34L}

Variant A:

$$\tan \alpha_{34LA} = \frac{b_{\alpha} \cos \beta_0 - d_{\alpha} \tan \alpha_n - f_{\alpha} \sin \beta_0}{c_{\alpha} \tan \alpha_n + a_{\alpha} \cos \beta_0 - e_{\alpha} \sin \beta_0} \quad (12)$$

$$\Rightarrow \alpha_{34LA} = 20^{\circ}17'23''$$

Variant B: $\alpha_{34LB} = 21^{\circ}21'40''$,

Variant C: $\alpha_{34LC} = 21^{\circ}3'18''$

Angle of the tooth edge in the base plane of the rack tool (P_r)

– position of the right side β_P

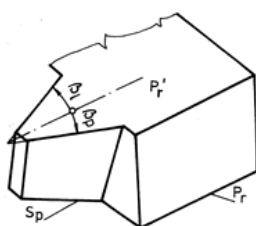


Figure 3. Angles of edges in the ground plane P_r [Mrkvica 1986]

Variant A:

$$\tan \beta_{PA} = \sin \alpha_{12} \tan \alpha_{23\alpha} + \frac{\cos \alpha_{12}}{\cos \alpha_{23\alpha}} \cdot \tan \alpha_{34PA} \quad (13)$$

$$\Rightarrow \beta_{PA} = 19^{\circ}52'53''$$

Variant B: $\beta_{PB} = 21^{\circ}13'59''$,

Variant C: $\beta_{PC} = 20^{\circ}46'11''$

Angle of the tooth edge in the base plane of the rack tool (P_r)

– position of the left side β_L

Variant A:

$$\tan \beta_{LA} = \sin \alpha_{12} \tan \alpha_{23\alpha} - \frac{\cos \alpha_{12}}{\cos \alpha_{23\alpha}} \cdot \tan \alpha_{34LA} \quad (14)$$

$$\Rightarrow \beta_{LA} = -19^{\circ}52'53''$$

Variant B: $\beta_{LB} = -19^{\circ}14'18''$,

Variant C: $\beta_{LC} = -19^{\circ}20'53''$

Height of the addendum in the face plane of the wheel h_{aw}

$$h_{aw} = \frac{m}{\cos \beta_0} + 0,25 \cdot m = 6,34678 \text{ mm} \quad (15)$$

Height of the addendum in the face plane of the wheel h_{aw} is the same for all three variants.

Tooth height in the face plane of the wheel h_w

$$h_w = 2 \cdot \frac{m}{\cos \beta_0} + 0,25 \cdot m + c_f = 12,54356 \text{ mm} \quad (16)$$

Tooth height h_w in the face plane is the same for all three variants, where c_f – radial clearance at the heel determine it according to design considerations, for example according [19].

Addendum height in the tool reference plane of the rack-shaped cutter h_{awU}

$$h_{awU} = \frac{h_{aw}}{\cos \alpha_{17}} = \frac{6,34678}{\cos 6^{\circ}30'} = 6,38784 \text{ mm} \quad (17)$$

Addendum height in the tool reference plane of the rack-shaped cutter h_{awU} is the same for all three variants.

Tooth height in the tool reference plane of the rack-shaped cutter h_{wU}

$$h_{wU} = \frac{h_w}{\cos \alpha_{17}} = \frac{12,54356}{\cos 6^{\circ}30'} = 12,62471 \text{ mm} \quad (18)$$

Tooth height in the tool reference plane of the rack-shaped cutter h_{wU} is the same for all three variants.

Addendum height in the normal plane of the rack-shaped cutter h_{awN}

$$h_{awN} = \frac{h_{aw}}{\cos \alpha_{12}} = 6,24825 \text{ mm} \quad (19)$$

Addendum height in the normal plane of the rack-shaped cutter h_{awN} is the same for all three variants.

Tooth height in the normal plane of the rack-shaped cutter h_{wN}

$$h_{wN} = \frac{h_w}{\cos \alpha_{12}} = 12,34883 \text{ mm} \quad (20)$$

Tooth height in the normal plane of the rack-shaped cutter h_{wN} is the same for all three variants.

Rack tool pitch in its tool reference plane t_{oN}

$$t_{oNA} = 2 \cdot \frac{\pi \cdot m}{4 \cdot \tan \alpha_n} \cdot \frac{\cos \alpha_{12}}{\cos \alpha_{17}} \cdot (\tan \alpha_{34PA} + \tan \alpha_{34LA}) = 15,707865 \text{ mm} \quad (21)$$

Variant B: $t_{oNB} = 15,716305 \text{ mm}$,

Variant C: $f_{oNc} = 15,709892\text{mm}$

Rack tool pitch in its normal plane t_{oN}

$$t_{oNa} = 2 \cdot \frac{\pi \cdot m}{4 \cdot \tan \alpha_n} \cdot \frac{\cos \alpha_{12}}{\cos \alpha_{17}} \cdot (\tan \alpha_{24Pa} + \tan \alpha_{24La}) \quad (22)$$

$$= 15,707865\text{mm}$$

Variant B: $f_{oNb} = 15,716305\text{mm}$,

Variant C: $f_{oNc} = 15,709892\text{mm}$

3 THE RACK-SHAPED CUTTER CALCULATION IN PROGRAM T-FLEX CAD

3.1 Creation of a program database

Input parameters have been entered into the database to calculate output parameters – gearing module (m) ranging from 1 to 20mm, number of teeth of the tool (z), radial clearance at the heel of the rack-shaped cutter (c_f) and input dimensional parameters for the 2D/3D drawing of the tool itself, which have been taken from the standard ČSN 22 2540 – tool length l_w [mm], tool width b [mm] and tool thickness h_{uw} [mm]. The supporting input parameter from which the other input parameters were derived was the gearing module [CSN 222540 1973].

3.2 Creating of variable editor

The editor is divided into 4 group fields – scale offset, tool, gearing, calculations. Both the values of the tool and gearing input parameters from the program database and other input parameters that were not defined in the program database were transferred into the tool and gearing group box. For the tool group these were the parameters α_{12} [°], α_{07} [°], α_{17} [°] and α_{15} [°]. For the gearing group these were the parameters α_n [°], and β_0 [°] [Mrkvica 1986].

Obráběné kolo			
Modul [m]	5		
Úhel sklonu zubu [beta_0]	11.18333	11	11
Záběrový úhel v normálové rovině [alfa_n]	20	20	0
Nástroj - vstupní údaje			
Počet zubů [z]	9	Zadat počet zubů ručně	0
Délka nože [lw] (mm)	140	Zadat délku nože ručně	0
Šířka nože [b1] (mm)	60	Zadat šířku nože ručně	0
Výška nože [Huw] (mm)	20	Zadat výšku nože ručně	0
Úhel vyklonění nože [alfa_07]	11.18333	11	11
Úhel hřbetu nože [alfa_12]	12	12	0
Úhel čela zubu nástroje [alfa_15]	0	0	0
Pracovní úhel čela nástroje [alfa_17]	6.5	6	30

Figure 4. Input parameters of the group field of the machined wheel and the group field of the tool for the production of a straight-toothed tool with an offset in the slide of the shaping machine ($\alpha_{07}=11^{\circ}11'0''$), with a tool clearance angle in the back plane on the tooth head of the rack-shaped cutter $\alpha_{12} = 12^{\circ}$ [Jurga 2020]

The editor has been set up so that input parameters can be pulled automatically from the program database or entered manually. Input parameters that were not from program database were entered manually in the variable editor or in a more user-friendly environment called **nastavit_externe_premenne_modelu**. As these are in all cases angular measurements, the input parameter values are entered in the form **stupne_minuty_sekundy** – see Fig. 4. The decision to automatically convert input parameter values or to enter them manually was conditional on entering an individual condition for the parameters from the programme's database.

For example, the expression $z_rucne==0?z_database:z_rucne$ from the group array gearing means, that if the value z_rucne equals 0, then value z is pulled from the program database. The determining programmed into the group field **calculations** and additional equations have been added for the graphical design of the tool. For example $\text{int}(z/2)*2$, which means that we divide the number of teeth of the tool by 2 and then multiply by 2 to get the correct number of teeth.

3.3 Creation of the tool model

Consists of several steps:

- **ejection** (the area dimension of the tool has been changed to a volume dimension with a thickness of 20mm, depending on the gearing module or manual input f the tool thickness value) – see Fig. 5 and Fig. 6.
- **transformation of the tool back plane** – based on the chosen tool clearance angle in the back plane on the tooth head of the rack-shaped cutter $\alpha_{12} = 12^{\circ}$, the plane of the back of the cutter is deflected at this angle from the ejection model – see Fig. 7.

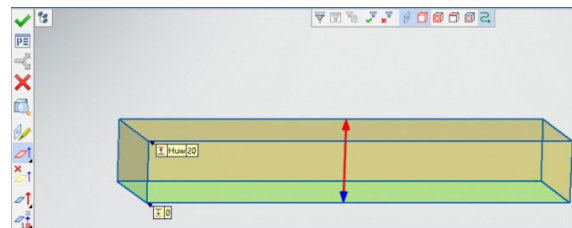


Figure 5. Creation of the so-called 20mm thickness ejection according to ČSN 22 2540 for a given module $m=5\text{mm}$, same strategy for a tool with straight or helical teeth

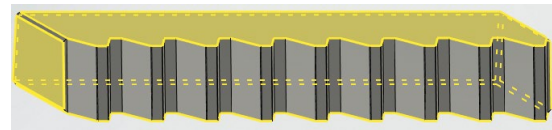


Figure 6. Display of the ejection strategy already on the finished tool with straight teeth for gear module $m=5\text{mm}$ with number of teeth $z=9$. Ejection is also shown in this view the area of the tooth teeth, which are not counted in the area of the tool dimension during ejection

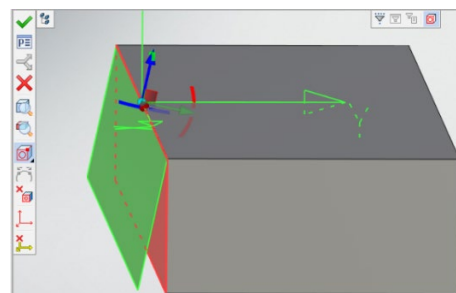


Figure 7. Deflection of the plane of the back at an angle $\alpha_{12} = 12^{\circ}$ from so-called extension model

- **boolean 1** – this strategy involves forming the sides of the teeth on the right side of the tool by pulling along the curve (for a tool with straight teeth in the top-down direction and for a tool with inclined teeth, pulling the curve of the side of the tooth twice from the centre upwards and from the centre downwards) and a distribution of the total number of teeth of the tool for the selected module $m=5$ according to a line array with the conditions of the number of

$ParnaNeparna = z/2 : z/2 + 0,5 = 5$ (the number of teeth for the right side of the tool is $9/2 + 0,5 = 5$) and pitch in the ground plane t_{ow} – see Fig. 8 and Fig. 9.

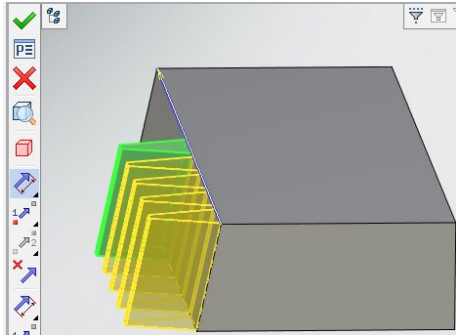


Figure 8. Creating the sides of the teeth on the right side of the tool by pulling along the curve for module $m=5\text{mm}$ (total number of teeth of the tool $z=9$), where the tooth marked in green is the tooth common to the right and left

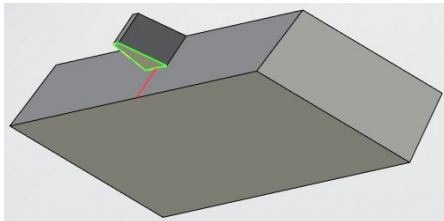


Figure 9. The strategy of forming the sides of a rack tool tooth with inclined teeth by pulling the curve of the sides of the rack tooth from the centre downwards with the rack tooth already formed in the direction from the centre upwards

- **boolean 2** – this strategy involves forming the sides of the teeth on the left side of the tool by pulling along the curve and dividing the total number of teeth of the tool for the module $m=5$ according to a linear array with the conditions of the number of $ParnaNeparna = z/2 : z/2 + 0,5 = 5$ (the number of teeth for the left side of the tool is therefore $9/2 + 0,5 = 5$) and pitch in the ground plane t_{ow} .

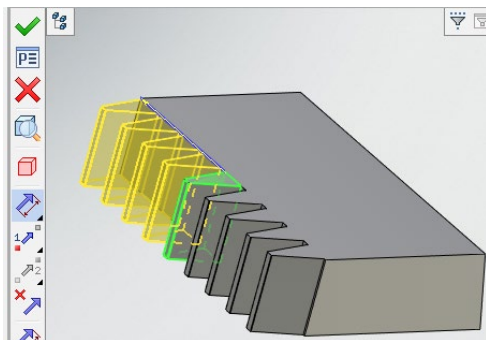


Figure 10. Creating the sides of the teeth on the left side of the tool by pulling along the curve for the module $m=5\text{mm}$ (total number of teeth of the tool $z=9$), where the tooth marked in green is the tooth common to the right and left side

The reason for introducing the boolean 1 and boolean 2 strategy was to find a methodology to appropriately distribute an odd number of tool teeth, in addition to forming the sides of the tool teeth, so that when creating a drawing it does not happen that, for example, for the selected module $m=5$, which has an odd number of teeth $z=9$ a tool with an even number of teeth is displayed on the drawing.

- **knocking down the edges of the tool body 1**

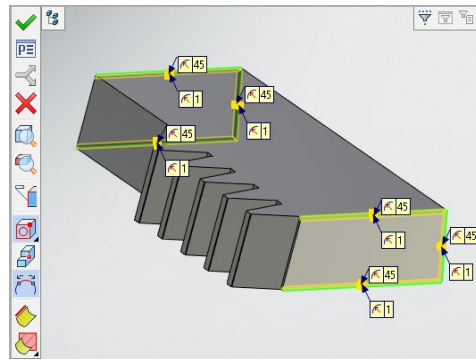


Figure 11. Knocking down of edges of 1 tool body with straight teeth

- **knocking down the edges of the tool body 2**

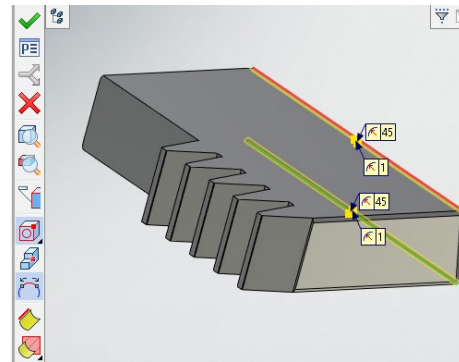


Figure 12. Knocking down of edges 2 tool body with straight teeth

3.4 The output of the rack-shaped cutter program

Obráběné kolo											
Modul [m]	5										
Úhel sklonu zubu [beta_0]	11.18333	11	11	0	0						
Zábřevový úhel v normálové rovině [alfa_n]	20	20	0	0							
Nástroj - vstupní údaje											
Počet zubů [z]	9	Zadat počet zubů ručně	0								
Délka nože [l] (mm)	140	Zadat délku nože ručně	0								
Šířka nože [b] (mm)	60	Zadat šířku nože ručně	0								
Výška nože [h_w] (mm)	20	Zadat výšku nože ručně	0								
Úhel vyklonění nože [alfa_07]	11.18333	11	11	0	0						
Úhel hřbetu nože [alfa_12]	12	12	0	0	0						
Úhel čela zubu nástroje [alfa_15]	0	0	0	0	0						
Pracovní úhel čela nástroje [alfa_17]	6.5	6	30	0							
Výsledné hodnoty											
a =	-0.959574	b =	-0.021956	c =	0	d =	0.993572	e =	0.189711	f =	-0.111054
beta P	19	52	54	beta L	-19	52	54				
alfa 34P	20	17	23	alfa 34L	20	17	23				
alfa 23	0	0	0	alfa 27	5	30	0	alfa 56	0	0	0
Výška hlavy zubu nože v čelní rovině [h_w] (mm)	6.34678										
Výška hlavy zubu nože v čelní rovině [h_w] (mm)	12.54355										
Výška hlavy zubu nože v základní rovině [h_wU] (mm)	6.387842										
Výška zubu nože v základní rovině [h_wU] (mm)	12.62471										
Výška hlavy zubu v normálové rovině [h_wN] (mm)	6.248252										
Výška zubu nože v normálové rovině [h_wN] (mm)	12.34883										
Rozeztup zubu nože v základní rovině [t_w] (mm)	15.70796										
Rozeztup zubu nože v normálové rovině [t_wN] (mm)	15.70796										

Figure 13. Program check summary table for a straight-tooth ($\alpha_{23} = 0^\circ$) rack-shaped cutter tilted in the cutter slide at an angle of $\alpha_{07} = 11^\circ 11'$ for the selected module $m=5\text{mm}$ [Jurga2020]

The numerical output of the program is a clear summary table (the way to the table **Parametre – Nastavit' externé premenné modelu**), where we can find a summary of the input parameters for the tool (α_{12} , α_{07} , α_{17} , α_{15}), dimensional

characteristics of the rack tool (l_w, b, h_{uw}) and input parameters for gearing (m, z, β_0, α_n). At the same time we can find the calculated parameters of the tool (α_{27} —working clearance angle on the addendum, α_{23} —angle of inclination of the back of the tooth to the setting of the grinding cradle, α_{56} —angle of rotation of the face from the ground plane, α_{34} —angle of the tooth edge in the normal plane of the rack cutter, for right side and left side position, β —angle of the tooth edge in the base plane of the tool, for right side and left side position, h_{aw} —height of the addendum in the face plane of the wheel, h_w —tooth height in the face plane, h_{awU} —height of the cutter tooth head in the ground plane, h_{wU} —tooth height in the tool reference plane, h_{awN} —height of the tool tooth head in the normal plane, h_{wN} —tooth height in the normal plane, t_{ow} —rack tooth pitch in its tool reference, t_{oN} —rack tool pitch in its normal plane and calculated gearing parameters (α_e —mesh angle in the gear face plane).

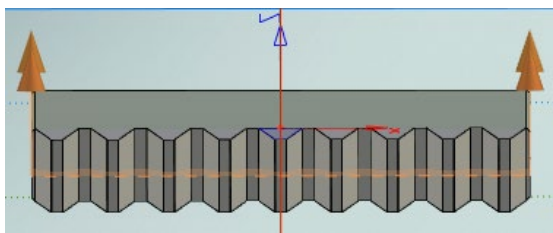


Figure 14. Graphical 3D representation of a straight-toothed rack shaped cutter ($\alpha_{23} = 0^\circ$) inclined in the cutter slide at angle $\alpha_{07} = 11^\circ 11'$ for a selected module $m=5\text{mm}$ for the production of helical gearing with an inclination of the wheel teeth $\beta_0 = 11^\circ 11'$

4 CONCLUSIONS

Calculation procedure of a rack-shaped cutter for spur gearing with helical teeth, the analysis of the tool's involute profile using vector calculations and matrices based on the tool's rotation in the chosen coordinate systems has not been solved separately in this thesis due to its large scope [Mrkvica 1992]. The selected tool clamping angles on the tool holder were introduced into the calculation, tool cutting geometry and gearing characteristics too. The rack-shaped cutter was structurally designed so, that when clamped in the trimmer slide and moved in the direction of trimming, the blade of the cutter tooth formed an enveloping involute of the side of the wheel tooth. In chapter 2, a procedure for calculating the individual tool parameters required for the tool construction using goniometric functions was applied in three variations. The tool had to be able to procedure geometrically identical helical tooth gearing within the three variants, with a wheel tooth inclination angle of $\beta_0 = 11^\circ 11'$.

The first variant featured a straight-toothed tool that was clamped in the slide of the shaping machine at an angle $\alpha_{07} = 11^\circ 11'$. The second variant was a tool with helical teeth, which was clamped in the slide of the shaping machine at an angle $\alpha_{07} = 0^\circ$. The third variant was a combination of the previous 2 variants, i.e. a tool with helical teeth, which was clamped in the slide of the shaping machine at an angle $\alpha_{07} = 3^\circ 11'$.

As part of the work, the size of the rack cutter back (α_{Bnt}), which has a significant influence on the work of the tool itself, was also checked [Svec 1965]. Since the partial task was to decide which tool is the most favourable due to its blade, for use in machining, for the costs of production, control of wear and grinding under the condition of production of gearing with

helical teeth as the best option seems to be the first option, i.e. a straight-toothed tool with a tilt in the slide of the shaping machine. Based on the parameters that entered into the calculation under all three options ($\alpha_n=20^\circ, \alpha_{27}=5^\circ 30', \alpha_{17}=6^\circ 30', \alpha_{12}=12^\circ$) it can be seen that the angle (α_{Bnt}) is not large enough, therefore it would be desirable to adjust the sizes of the input parameters so that the size of the angle (α_{Bnt}) is greater than 2° , which has a major impact on the machining of particularly difficult to machine materials, steels with a tendency to galling [Svec 1970].

The main part of the practical output of the thesis is a computer program programmed in the 3D CAD modeller T-Flex, where, on the basis of a change in the input data of the machined wheel (m [mm], α_n [°], β_0 [°]) and for the tool group these were the parameters α_{12} [°], α_{07} [°], α_{17} [°], α_{15} [°] and subsequently calculated tool parameters, it is possible to generate online a graphical drawing of the tool in 2D/3D view in its basic and normal planes. For each different variant, the program automatically generates a new tool with its new characteristics (dimensions, number of teeth, etc.). The same for both straight and helical tooth tools. The procedure for creating this computer program is described in chapter 3. This program in the T-Flex CAD modeler can be used directly by designers and technologists (interfacing with CAM) in practise, or it can be used for further practical training in the design of machine tools [Jurga 2020].

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