Manufacturing of spur gears having normal teeth on different pressure angles by module disc milling cutter

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ABSTRACT

The aim of this study is the manufacturing analysis of five spur gear pairs where the initial geometric parameters are the same only the pressure angle is different. Firstly, the gears must be designed and modelled. After that, I analyse the modification of this geometric parameter for the manufacturing parameters of the pinion and the gear in the case of gear cutting by module disc milling cutter. Using this technology the one tooth cutting can repeat from tooth to tooth in the function of the number of teeth. I would like to find correlations between the pressure angle and the manufacturing parameters. For this purpose, I define the initial technological parameters and calculate necessary technological parameters for the manufacturing process in a general way. I also define the manufacturing parameters for the given gear geometries. This analysis is practical and theoretical at the same time since the results and the process can help the manufacturing engineers to develop the gear manufacturing processes and applying my results for similar manufacturing problems.

KEYWORDS

spur gear, pressure angle, manufacturing, analysis, gear, pinion

1. INTRODUCTION

The involute profile is selected based on experience of geometric, tooth connection and load transmission. It can be generated by constructive and mathematical way. The involute curve is always generated from the base circle of the gear [10, 11, 19, 21].

The parametric equation of the involute curve is (Fig. 1) [10, 21]

\[
\begin{align*}
    x &= r_b \cdot \sin \phi - r_b \cdot \varphi \cdot \cos \phi \\
    y &= r_b \cdot \cos \phi + r_b \cdot \varphi \cdot \sin \phi
\end{align*}
\]

The polar angle is the \( \alpha \). The \( \varphi \) angle is

\[
\varphi = \text{inv} \alpha + \alpha
\]

The following two equations can also be derived on Fig. 1. [10, 21]:

\[
\rho = r_b \cdot \varphi
\]

Based on (3) and (4)

\[
\varphi = \tan \alpha
\]

Substituting (5) into (2) and expressing \( \text{inv} \alpha \)

\[
\text{inv} \alpha = \tan \alpha \approx \alpha
\]

The common normal line, which is the common tangent line of the base circles, has to go
The connection always takes place on this line. This line is called line of action. This line and the common tangent line of the rolling circles \( (r_{w1}, r_{w2}) \) always include an angle \([19] \). This angle is called pressure angle. If the centre distance is modified from \( a \) to \( a_0 \), the pressure angle will be also modified to \( a_0 \).

The pressure angle that belongs to the pitch circle radius \( (r_p) \) is called base profile angle \( (\alpha_p) \).

Starting from the pitch and the rolling circle radiuses, the radius of the base circle from which the arc can be generated is \([10, 11, 19, 21] \)

\[
r_b = r_p \cdot \cos \alpha_p = r_w \cdot \cos \alpha_w \\
r_w = r_p \cdot \frac{\cos \alpha_p}{\cos \alpha_w}
\]  

The centre distance is

\[
a = r_{w1} + r_{w2} = r_{p1} \cdot \frac{\cos \alpha_p}{\cos \alpha_w} + r_{p2} \cdot \frac{\cos \alpha_p}{\cos \alpha_w} = a_0 \cdot \frac{\cos \alpha_p}{\cos \alpha_w}
\]

The elementary centre distance is \([10, 11, 19, 21] \)

\[
a = r_{p1} + r_{p2} = \frac{d_{p1} + d_{p2}}{2}
\]

1.1. The properties of spur gear having normal teeth

The basic rack gear tooth profile contains the base parameters of the normal section (circular pitch, whole depth, basic rack gear tooth profile angle and clearance). This profile has infinite number of teeth along a line. The basic rack gear tooth profile of an involute gear is standardized (Fig. 3) \([10, 11, 19, 21] \).

During the manufacturing process, the pitch circle of the gear is rolled down on the tool centre line without slip \([4, 5, 7, 8, 12, 15, 16] \). The tool centre line and the tool reference line can be different because the pitch circle of the gear can be rolled down any parallel lines of the tool centre line \([1, 2, 5, 11, 12, 21] \). The phenomenon when the tool centre line and the tool reference line are not same is called gear having addendum modification \([10, 11, 21] \). This process is also called addendum modification. This parameter can be calculated by the following formula \([10, 11, 21] \)

\[
x_1 \cdot m_{lex}
\]

The \( x \) is positive when the basic profile is moved from the gear axis (Fig. 4b). The \( x \) is negative when the basic profile is moved to the gear axis (Fig. 4a). If \( x = 0 \), the tool centre line and the tool reference line are the same. This type of gear pair is called x-zero gear drive \([10, 11, 21] \).

1.2. Determination of the tooth thickness in general way

Based on Fig. 5a the tooth thickness is \([10, 11, 21] \)
Based on Fig. 5b the tooth thickness is \[ s_p = \frac{p_p}{2} - 2 \cdot x \cdot m_{ax} \cdot \tan \alpha_p = m_{ax} \cdot \left( \frac{\pi}{2} - 2 \cdot x \cdot \tan \alpha_p \right) \] (12)

The \( \sigma \) angle is (Fig. 6) \[ \sigma = \text{inv} \alpha_p + \frac{s_p}{2 \cdot r_p} = \text{inv} \alpha + \frac{s}{2 \cdot r} \] (14)

The \( s \) tooth thickness is on an arbitrary circle is
\[ s = 2 \cdot r \cdot \left( \frac{s_p}{2 \cdot r_p} + \text{inv} \alpha_p - \text{inv} \alpha \right) \] (15)

### 1.3. Manufacturing of spur gear by module disc milling cutter

Spur and helical gears could be manufactured by plain milling technology on a horizontal knee type milling machine (Figs 8 and 9) or a CNC milling machine (Fig. 9) \([1, 3-5, 8, 9, 12, 15, 16]\). The profile of the module disc milling cutter is the same as that of the tooth space \([1, 2, 4, 7-9, 11, 12]\). The tool is doing rotation \((\vec{v}_r)\) and linear \((\vec{v}_l)\) motions at the same time. This linear motion could also be provided by the workpiece (Fig. 7). After one tooth is ready the division form tooth to tooth could be made possible by a dividing head (Fig. 8) in a classical way. The milling process can restart again \([1-4, 9, 11, 12, 15, 16]\).

The geometric shape of the module disc milling cutter can be seen in Fig. 10. The geometry of the tool depends on the number of teeth and the module of the gear \([1, 2, 9, 12, 15, 16]\).
2. GEOMETRIC DESIGN AND MODELLING OF SPUR GEARS HAVING NORMAL TEETH

Knowing the references’ recommendations [10, 11, 13, 19, 20, 21] and the initial gear parameters all of the other geometric parameters can be calculated by MATLAB software, which was created by me. The formulas for the gear design were programmed into this software. The output parameters of this program are the calculated geometric parameters, the profile curves of the elements and a txt file that contains the point coordinates of the profile points. The involute profile curves on the pinion and the gear in the case of $\alpha_w = 23^\circ$ as an example can be seen in Fig. 11.

Geometrically, the shape of the involute curves is similar to both gear pairs since the base circle diameters are the same for each gear pair. The differences are the arc length between the root and the outside circles. The tooth connections take place on different $d_w$ rolling circle diameters [10, 11, 21]. The calculated geometric parameters of the designed gear pairs can be seen in Table 1.

Knowing the geometric parameters of the gear pairs the CAD models and the assembly can be done by SolidWorks software. These models are important for the manufacturing simulations (CAM) [3, 17, 18] and the tooth contact analysis (TCA) [10]. The CAD models of a gear pair ($\alpha_w = 23^\circ$) can be seen in Fig. 12.

The effect of the pressure angle on the geometric parameters can be seen in the diagrams of Fig. 13.
3. ANALYSIS OF THE MANUFACTURING PARAMETERS

3.1. Determination of the technological parameters by general way

The gear cutting process by module disc milling cutter is applicable in a conventional way (gear cutting on horizontal knee type milling machine) or in a modern way (application of CNC machine) too [1, 3–5, 8, 9, 12, 15, 16]. Since the basis of the modern way is the conventional way, I analyse this gear cutting technology in the conventional way. The gear parameters are changing (tooth thickness, diameters, pressure angle, etc.), consequently the tool geometry must be also changed [1, 2, 7–9, 11, 12, 15, 16]. Gears having different geometries need different cutting tools in geometric aspects.

The cutting process for one tooth can be seen in Fig. 14. This process must be repeated in the function of the number of teeth. The gear is fixed into a clamping device. After the cutting of one tooth the gear has to be divided according to the circular pitch. The tool has two motions: rotation \( (v_r) \) and linear \( (v_f) \) motions at the same time [1, 2, 4–9, 11, 12,

![Involute profile of the pinion \( \alpha_w=23^\circ \)](image)

![Involute profile of the gear \( \alpha_w=23^\circ \)](image)

Fig. 11. The profiles of the gear pairs \( (\alpha_w = 23^\circ) \)
| Geometric parameters | Gear drive I | Gear drive II | Gear drive III | Gear drive IV | Gear drive V |
|----------------------|-------------|--------------|----------------|----------------|----------------|
| \( m_{a1} \) [mm]    | 6           |              |                |                |                |
| \( z_1 \)            | 20          |              |                |                |                |
| \( z_2 \)            | 30          |              |                |                |                |
| \( \omega_p \) [°]   | 20          |              |                |                |                |
| \( \epsilon_0 \)     | 0.2         |              |                |                |                |
| \( l_m \) [mm]       |              | 1.5          |                |                |                |
| \( l_m \) [mm]       |              | 50           |                |                |                |
| \( \alpha_m \) [°]   | 20 21 22 23 24 |              |                |                |                |
| \( \delta_{d1} \) [mm] | 120          |              |                |                |                |
| \( \delta_{d2} \) [mm] | 180          |              |                |                |                |
| \( \delta_{d3} \) [mm] | 112.763      |              |                |                |                |
| \( \delta_{d4} \) [mm] | 169.144      |              |                |                |                |
| \( \delta_{d5} \) [mm] | 120 120.785 121.618 122.501 123.434 |              |                |                |                |
| \( \delta_{d6} \) [mm] | 180 181.178 182.428 183.752 185.151 |              |                |                |                |
| \( \delta_{d7} \) [mm] | 192 193.154 194.329 195.522 196.728 |              |                |                |                |
| \( \delta_{d8} \) [mm] | 105.6 106.409 107.317 108.331 109.458 |              |                |                |                |
| \( \delta_{d9} \) [mm] | 150 150.982 152.023 153.125 154.295 |              |                |                |                |
| \( \delta_{d10} \) [mm] | 150          |              |                |                |                |
| \( \gamma \) [mm]    | 0 0.163 0.337 0.521 0.715 |              |                |                |                |
| \( h \) [mm]        | 12 11.976 11.901 11.770 11.568 |              |                |                |                |
| \( h_a \) [mm]      | 6 5.988 5.950 5.885 5.788 |              |                |                |                |
| \( c \) [mm]        | 1.2         |              |                |                |                |
| \( p_a \) [mm]      | 18.849      |              |                |                |                |
| \( p_a \) [mm]      | 18.849 18.973 19.103 19.242 19.389 |              |                |                |                |
| \( p_a \) [mm]      | 7.2 7.188 7.150 7.085 6.988 |              |                |                |                |
| \( p_a \) [mm]      | 13.2 13.176 13.101 12.970 12.776 |              |                |                |                |
| \( p_a \) [mm]      | 132 132.761 133.520 134.271 135.011 |              |                |                |                |
| \( p_a \) [mm]      | 192 193.154 194.329 195.522 196.728 |              |                |                |                |
| \( p_a \) [mm]      | 105.6 106.409 107.317 108.331 109.458 |              |                |                |                |
| \( p_a \) [mm]      | 165.6 166.802 168.126 169.582 171.175 |              |                |                |                |
| \( j_i \) [mm]      | 0.942 0.948 0.955 0.962 0.969 |              |                |                |                |
| \( x_1 \)           | 0 0.065 0.134 0.208 0.286 |              |                |                |                |
| \( x_2 \)           | 0 0.102 0.218 0.351 0.499 |              |                |                |                |
| \( s_1 \) [mm]      | 9.424 9.710 10.014 10.335 10.674 |              |                |                |                |
| \( s_2 \) [mm]      | 9.424 9.871 10.380 10.957 11.608 |              |                |                |                |
| \( s_3 \) [mm]      | 8.953 9.005 9.045 9.071 9.082 |              |                |                |                |
| \( s_4 \) [mm]      | 8.953 9.019 9.103 9.208 9.336 |              |                |                |                |

The separated chip volume can be seen in Fig. 15. The widest distance is the \( w_a \) tooth space on the outside circle of the gear.

The chip thickness is continuously changing along the \( i \) arc of contact, that is why this parameter will be considered by average value, which is called \( h_m \) medium chip thickness \([1, 2, 3, 6, 7, 12, 14]\). The \( V_h \) volume, which has a complex shape, can be approximated by the \( V_{T1} \) and \( V_{Pr} \) prism volumes (Fig. 15) because of the simplification of the calculation and design process:

\[
V_h = V_{T1} = V_{Pr}
\]

It means

\[
h \cdot w_a \cdot f_z = i \cdot w_a \cdot h_m
\]

\[
h_m = \frac{h \cdot f_z}{i}
\]

Substituting (18) into (21) the \( h_m \) medium chip thickness is

\[
h_m = h \cdot f_z \cdot \frac{360°}{\varphi \cdot D - \pi}
\]

Considering Fig. 6 and formulae (12)–(15) \( w_a \) tooth space on the outside circle can be determined. A side view for the manufacturing process can be seen in Fig. 16. The blue milling cutter is milling one tooth. The \( \alpha_u \) angle can be calculated from the OFG triangle:

\[
\cos \alpha_u = \frac{d_b}{d_a} \Rightarrow \alpha_u = \ldots
\]

Based on (6)

\[
\cos \alpha_u = \tan \alpha_a - \alpha_a
\]

\[
\sin \alpha_u = \tan \alpha_a - \alpha_a
\]

Based on (15) and considering the \( j_i \) backlash that we have to provide between the teeth \([10, 11, 12, 19, 20, 21]\) the \( x_a \) tooth thickness on the \( d_a \) outside circle is (Fig. 16)

![Fig. 12. The CAD model of a gear pair \((z_1=20, z_2=30, \text{max}=6 \text{ mm}, a_\omega=23°, \text{Gear drive IV})\)](image-url)
The perimeter of the given circle has to be equal with the multiplication of the number of teeth and the given pitch, which is interpreted on the given circle of the gear [10, 11, 21]:

\[
d_p \cdot \pi = z \cdot t_p \Rightarrow d_p = \frac{z}{t_p} \quad (27)
\]

\[
d_a \cdot \pi = z \cdot t_a \Rightarrow d_a = \frac{z}{t_a} \quad (28)
\]

Based on (27) and (28) the circular pitch on the outside circle is

\[
t_a = \frac{d_a \cdot t_p}{d_p} \quad (29)
\]

Based on (26) and (29) the \( w_a \) tooth thickness on the outside diameter is (Fig. 16)

\[
w_a = t_a - s_a \quad (30)
\]

Knowing the specific cutting force \( k_c \) from the material property, the \( h_m \) and the \( w_a \) the cutting force for one edge of the tool can be determined:

\[
F_{c1} = k_c \cdot h_m \cdot w_a \quad (31)
\]

The \( t \) tooth pitch means the peripheral distance between two neighbouring teeth on the tool [1–9, 12, 14–16]:

\[
t = \frac{D \cdot \pi}{z_i} \quad (32)
\]

The \( \psi \) switch number means the number of the working teeth along the \( i \) arc of contact (Fig. 14) [1–9, 12, 14–16]:

\[
\psi = \frac{s_a}{d_a} \left( \frac{2 \pi}{d_p} + \ln \alpha_p - \ln \alpha_a \right) \cdot d_a - \frac{i}{2} \quad (26)
\]
Fig. 14. The cutting process for one tooth

Fig. 15. The approximation by volume constancy
Considering the \( i \) switch number the total cutting force along the \( i \) arc of contact is

\[
F_c = j \cdot F_{c1} \tag{34}
\]

Substituting (22), (31) and (33) into (34)

\[
F_c = k_c \cdot w_a \cdot h \cdot f_z \cdot z_t \frac{\pi}{D} \tag{35}
\]

The rotational cutting speed is [1–9, 12, 14–16]

\[
v_c = D \cdot \pi \cdot n \tag{36}
\]

The feed speed is [1–9, 12, 14–16]

\[
v_f = f_z \cdot z \cdot n \tag{37}
\]

Knowing of the cutting force (35) and the cutting speed (36) the cutting power is

\[
P_c = F_c \cdot v_c = k_c \cdot w_a \cdot h \cdot f_z \cdot z_t \cdot n \tag{38}
\]

Based on Fig. 14, the overall machining time that is needed for the manufacturing of all of the teeth is

\[
T = \frac{L}{v_f} \cdot z = \frac{m + x_{1o} + l_m + x_{2o} + m \cdot z}{v_f} \tag{39}
\]

### 3.2. Manufacturing design and analysis for the designed gear pairs

Knowing the geometric parameters of the gear pairs, the geometric and manufacturing formulas I tried to find correlations between the geometric formulas and the manufacturing parameters for the concrete cases and analyse the results. The geometric parameters are found in Table 1. The initial manufacturing parameters are found in Table 2. According to the subchapter 3.1., I made an Excel table to determine the manufacturing parameters for each gear pair. The results can be seen in Tables 3 and 4 for the pinions and the gears.

The correlation between the pressure angle (\( \alpha_{wa} \)) and the angle of contact (\( \phi_c \)) can be seen in Fig. 17. The diagram is the same for the cohesive connecting pinions and gears. The shape of the diagram is parabola. The angle of contact is exponentially decreasing while the pressure angle is increasing.

The correlation between the pressure angle (\( \alpha_{wa} \)) and the arc of contact (\( i \)) can be seen in Fig. 18. The diagram is the same for the cohesive connecting pinions and gears.

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**Table 2. The initial manufacturing parameters**

| Manufacturing parameters | Value |
|--------------------------|-------|
| D [mm]                   | 120   |
| \( z_t \) [mm]           | 18    |
| \( f_a \) [mm]           | 0.06  |
| \( l_m \) [mm]           | 50    |
| \( k_c \) [N mm\(^{-2}\)] | 5,000 |
| \( x_{1o}, x_{2o} \) [mm] | 3     |

\[
\psi = \frac{i}{t} = \frac{q^*}{360} \cdot z_t \tag{33}
\]

Considering the \( \psi \) switch number the total cutting force along the \( i \) arc of contact is

\[
F_c = \psi \cdot F_{c1}
\]

### Table 3. Manufacturing parameters for the pinions

| Manufacturing parameters | 20    | 21    | 22    | 23    | 24    |
|--------------------------|-------|-------|-------|-------|-------|
| \( v_c \) [m min\(^{-1}\)] | 45.216| 37.546| 37.516| 37.423| 37.258| 37.012|
| \( m \) [mm]             | 37.569| 37.722| 38.608| 38.407| 38.107|
| \( q_t \) [\(^\circ\)]   | 38.759| 38.722| 38.608| 38.407| 38.107|
| \( i \) [mm]             | 40.568| 40.529| 40.409| 40.199| 39.885|
| \( h_m \) [mm]           | 0.019522| 0.019505| 0.019452| 0.019358| 0.019219|
| \( w_a \) [mm]           | 17.037| 17.288| 17.527| 17.750| 17.951|
| \( F_{c1} \) [N]         | 1663.068| 1686.138| 1704.787| 1718.105| 1725.060|
| \( \psi \)               | 0.028| 0.026| 0.020| 0.010| 0.004|
| \( F_s \) [N]            | 3373.353| 3416.913| 3444.468| 3453.295| 3440.237|
| \( P_c \) [W]            | 2542.159| 2574.985| 2595.751| 2602.403| 2592.562|
| \( v_f \) [mm min\(^{-1}\)] | 129.6| 120.221| 20.192| 20.141| 20.065|
| \( T \) [min]            | 20.230| 20.221| 20.192| 20.141| 20.065|
The shape of the diagram is parabola. The arc of contact is exponentially decreasing while the pressure angle is increasing. The highest result is in the case of $\alpha_w = 20^\circ$. The lowest result is in the case of $\alpha_w = 24^\circ$.

The correlation between the pressure angle ($\alpha_w$) and the cutting force for one edge ($F_{c1}$) can be seen in Fig. 19. I got higher results for the pinion than for the gear. The results are increasing in the function of the pressure angle in the case of the pinion. The highest result is received in the case of $\alpha_w = 23^\circ$. The shape of the diagram is parabola. The higher the pressure angle, the higher the cutting force for one edge on the tool tooth.

The highest result is received in the case of $\alpha_w = 23^\circ$ on the gear. The results are continuously increasing in the

### Table 4. Manufacturing parameters for the gears

| Manufacturing parameters | $20$ | $21$ | $22$ | $23$ | $24$ |
|--------------------------|------|------|------|------|------|
| $v_c$ [m min$^{-1}$]     | 45.216 |      |      |      |      |
| $m$ [mm]                 | 37.546 | 37.516 | 37.423 | 37.258 | 37.012 |
| $\phi_\alpha$ [$^\circ$] | 38.759 | 38.722 | 38.608 | 38.407 | 38.107 |
| $t$ [mm]                 | 40.568 | 40.529 | 40.409 | 40.199 | 39.885 |
| $h_m$ [mm]               | 0.019522 | 0.019505 | 0.019452 | 0.019358 | 0.019219 |
| $w_s$ [mm]               | 16.144 | 16.392 | 16.601 | 16.762 | 16.864 |
| $F_{c1}$ [N]             | 1575.952 | 1598.717 | 1614.679 | 1622.500 | 1620.632 |
| $\psi$                   | 2.028 | 2.026 | 2.020 | 2.010 | 1.994 |
| $F_c$ [N]                | 3196.647 | 3239.757 | 3262.407 | 3261.133 | 3231.980 |
| $P_c$ [W]                | 2408.993 | 2441.481 | 2458.550 | 2457.590 | 2435.620 |
| $v_t$ [mm min$^{-1}$]    | 129.6 |      |      |      |      |
| $T$ [min]                | 30.346 | 30.332 | 30.288 | 30.212 | 30.098 |
function of the increasing pressure angle until $\alpha_w = 23^\circ$. The shape of the diagram is a parabola until this main point. The lowest result is in the case of $\alpha_w = 20^\circ$.

The correlation between the pressure angle ($\alpha_w$) and the total cutting force ($F_c$) can be seen in Fig. 20. I got higher results for the pinion than for the gear. The results are continuously increasing in the function of the increasing pressure angle until $\alpha_w = 23^\circ$ in both cases. The shapes of the diagrams are a parabola until these main points. The highest results are in the case of $\alpha_w = 23^\circ$ in both cases. The lowest results are in the case of $\alpha_w = 20^\circ$ in both cases.

The correlation between the pressure angle ($\alpha_w$) and the switch number ($\psi$) can be seen in Fig. 21. I got the same
results for the cohesive, connecting pinion and gear. The shape of the diagram is a parabola. The higher the pressure angle, the lower the switch number. The highest result is received in the case of $\alpha_w = 20^\circ$. The lowest result is received in the case of $\alpha_w = 24^\circ$.

The correlation between the pressure angle ($\alpha_w$) and the cutting power ($P_c$) can be seen in Fig. 22. I got higher results for the pinion than for the gear. The shapes of the diagrams are a parabola until $\alpha_w = 23^\circ$ in both cases. The results are continuously increasing in the function of the increasing pressure angle until this main point. The highest results are in the case of $\alpha_w = 23^\circ$ in both cases. The lowest results are in the case of $\alpha_w = 20^\circ$ in both cases.

The correlation between the pressure angle ($\alpha_w$) and the machining time ($T$) can be seen in Fig. 23. The shapes of the diagrams are a parabola in both cases. I got higher results for the gear than for the pinion. The main reason is the higher number of teeth around the perimeter of the gear (Table 1). The higher the pressure angle, the less the machining time in both cases. I got the highest results in the case of $\alpha_w = 20^\circ$ for the cohesive, connecting pairs. I got the lowest results in the case of $\alpha_w = 24^\circ$ for the cohesive, connecting pairs.

Fig. 22. The correlation between the pressure angle and the cutting power

Fig. 23. The correlation between the pressure angle and the machining time
4. CONCLUSION

The aim of this study is to find correlations between the modified geometric parameter, that is the pressure angle and the manufacturing parameters in the case of gear cutting by module disc milling cutter for the pinion and the gear. This technology can be executed in a conventional way (using a horizontal knee type milling cutter) or a computer numerical controlled way (using of a CNC milling machine). In this work, I determined the necessary technological parameters for both cases in a general way.

Firstly, I designed five types of connecting gear pairs where the difference between the initial parameters was the pressure angle beside the constancy of the other initial geometric parameters. I made a computer program in MATLAB language to enhance the design time and process for the output geometric parameters and the involute profile points. The received geometric results can be imported into the SolidWorks designer software where the CAD models can be generated for the tooth contact analysis (TCA) and the computer aided manufacturing (CAM) analysis. The CAM analysis is important for making CNC programs for CNC machines among other things if we choose CNC manufacturing for the gears.

I selected the conventional manufacturing process for the gears since this is the oldest way for which the newest methods are built up. I determined all of the necessary technological parameters for the manufacturing design in a general way. After that, I chose initial parameters with concrete values for the manufacturing design. I made an Excel table to determine the manufacturing parameters for the pinion and the gear. Considering the results, I made diagrams for the possible correlations of the analysed technological parameters and the pressure angle. I determined the consequences.

This study is theoretical and practical at the same time. In a theoretical way, there are a lot of ways to continue this research. In a practical way, this study can help the manufacturing engineers to design such manufacturing technologies for spur gears since my developed process is general. The received formulas are useable for the manufacturing of different types of spur gears by module disc milling cutter in a conventional or CNC way.

Obviously, changing the tooth space geometrically a different type of module disc type milling cutter is needed. It is another field how it is possible to design the tool for these manufacturing problems.

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## NOMINATIONS

| Symbol | Unit | Parameter |
|--------|------|-----------|
| \( \varphi \) | [°] | The sum of the involute angle and the angle between the arbitrary radius and the base circle radius |
| \( \alpha \) | [°] | Angle between the arbitrary radius and the base circle radius |
| \( \rho \) | [mm] | Curvature radius of the involute curve |
| \( \sigma \) | [°] | Angle between the basic circle radius and the tooth centre line |
| \( \psi \) | | Switch number |
| \( \alpha_t \) | [°] | Angle between the outside circle radius and the base circle radius |
| \( \varphi_k \) | [°] | Angle of contact |
| \( \nu_c \) | [m min\(^{-1}\)] | Real cutting speed |
| \( \nu_f \) | [mm min\(^{-1}\)] | Feed speed |
| \( \epsilon_0 \) | | Clearance factor (\( \epsilon_0 = 0.25 \)) |
| \( a \) | [mm] | Normal centre distance |
| \( a_0 \) | [mm] | Elementary centre distance |
| \( c \) | [mm] | Clearance |
| \( C \) | | Main point |
| \( D \) | [mm] | Diameter of the module disc milling cutter |
| \( d_{a0} \) | [mm] | Outside circle diameter of the pinion |
| \( d_{a1} \) | [mm] | Outside circle diameter of the gear |
| \( d_{b0} \) | [mm] | Base circle diameter of the pinion |
| \( d_{b1} \) | [mm] | Base circle diameter of the gear |
| \( d_{r0} \) | [mm] | Root circle diameter of the pinion |
| \( d_{r1} \) | [mm] | Root circle diameter of the gear |
| \( d_{p1} \) | [mm] | Pitch circle diameter of the pinion |
| \( d_{p2} \) | [mm] | Pitch circle diameter of the gear |
| \( d_{w1} \) | [mm] | Rolling circle diameter of the pinion |
| \( d_{w2} \) | [mm] | Rolling circle diameter of the gear |
| \( F_c \) | [N] | Total cutting force |
| \( F_{c1} \) | [N] | Cutting force for one edge |
| \( f \) | [mm] | Feed for one edge |
| \( h \) | [mm] | Whole depth |
| \( h' \) | [mm] | Working depth |
| \( h_s \) | [mm] | Addendum |
| \( h_r \) | [mm] | Dedendum |
| \( h_m \) | [mm] | Medium chip thickness |
| \( i \) | [mm] | Arc of contact |
| \( \text{inv} \ \alpha \) | [°] | Arbitrary involute angle (polar angle) |
| \( \text{inv} \ \alpha_t \) | [°] | Involute angle of the outside circle |
| \( \text{inv} \ \alpha_p \) | [°] | Involute angle of the pitch circle |
| \( \text{inv} \ \alpha_w \) | [°] | Involute angle of the rolling circle |
| \( j_s \) | [mm] | Backlash |

(continued)