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MANUFACTURING ANALYSIS OF FACE MILLING TECHNOLOGY BY TOOL SETTING USING THE SAME INITIAL PARAMETERS

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Abstract: The axis of rotation of the tool is perpendicular for the machined surface in case of face milling technology. This technology is applicable for manufacturing of planar surfaces. It can be feasible by conventional or computer numerical controlled (CNC) machines. The aim of this study is the manufacturing analysis of different tool settings that can cause different arc of contacts. The applied manufacturing parameters are the same except the tool position is changed in comparison with the workpiece. The tool is doing rotation motion while we are moving the table under to tool. The edge geometry of the tool can significantly influence the chip separation conditions, the tool wear and the received surface roughness.

KEYWORDS: face milling, tool setting, arc of contact, workpiece

1 Introduction

The schematic functional figure of a vertical knee type face milling machine can be seen on Figure 1.

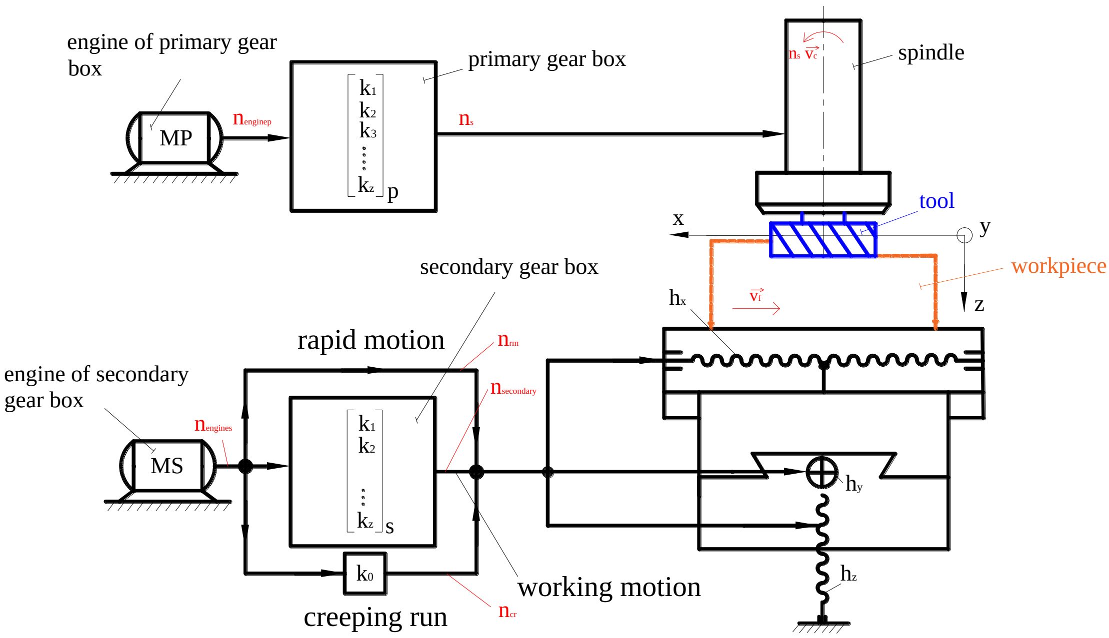

Fig. 1. The function of a vertical knee - type milling machine

Based on the primary gear box the discreet number of revolutions can be adjusted for the tool. The k_1, k_2, k_3,… parameters are the gear ratios for each tooth gear pairs that are necessary for the creation of the different output number of revoltions (n_s). The *MP* engine can provide a

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permanent number of revolution ($n_{enginep}$). The adjustable number of revolutions on the spindle can be calculated by the following formula [1]:

$$\begin{bmatrix} n_{s1} \\ n_{s2} \\ . \\ . \\ . \\ n_{sz} \end{bmatrix}_p = n_{enginep} \cdot \begin{bmatrix} k_1 \\ k_2 \\ . \\ . \\ . \\ k_z \end{bmatrix}_p \tag{1}$$

The workpiece can be movable into *x*, *y* and *z* perpendicular directions mechanically by the table [3, 4, 5]. Rapid motion, working motion and creeping run can be switchable into these directions [3, 4, 5, 8, 9, 11-13]. The table speeds are into the different *x*, *y*, *z* directions in general if we use the secondary gear box [1]:

$$\begin{bmatrix} v_{f1} \\ v_{f2} \\ . \\ . \\ . \\ v_{fz} \end{bmatrix}_{x,y,z} = n_{engines} \cdot C_{x,y,z} \cdot h_{x,y,z} \cdot \begin{bmatrix} k_1 \\ k_2 \\ . \\ . \\ . \\ k_z \end{bmatrix}_s \tag{2}$$

The speeds of the rapid motions are [1]

$$v_{rx,y,z} = n_{engines} \cdot C_{x,y,z} \cdot h_{x,y,z} \tag{3}$$

The speeds of the creeping run that can provide a slow motion are [1]

$$v_{crx,y,z} = n_{engines} \cdot k_0 \cdot C_{x,y,z} \cdot h_{x,y,z} \tag{4}$$

The face milling technology (Figure 2) is usable on manual or CNC machines. Nowdays, there are a lot of types of inserts that can improve the effectiveness and influence the cutting force, the cutting power and the surface roughness [6, 7].

Synchronization of two motions (linear and rotational) are necessary for the execution of the technology [3, 5, 8, 9, 11-13]. In case of manual or CNC machine the tool can do rotational motion and the workpiece can do the linear motion under the workpiece. The tool also can do the two motions simultaneously beside the standing workpiece in case of CNC machine [5, 8, 9].

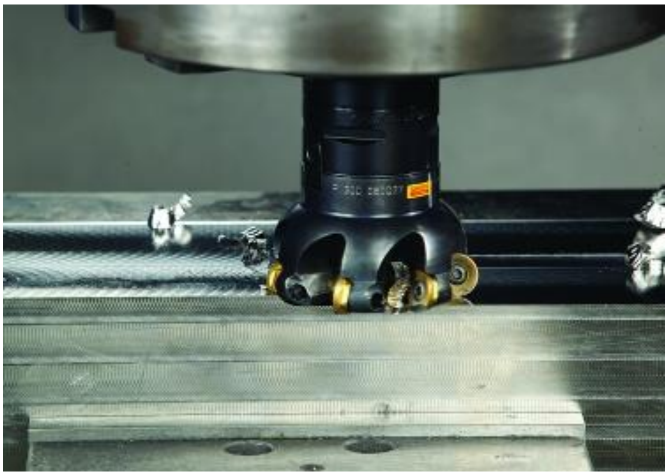


Fig. 2. Face milling technology on a CNC machine with inserted tool [10]

2 Material and Methods

The overall calculations and analysis were done by analytical calculations and computational solution. According to the tool position in comparison with the workpiece three versions can be [1, 3, 5, 8, 9]:

- the tool diameter (*D*) is wider than the workpiece width (b_w) but the symmetric lines of the tool and the workpiece are not same (Figure 3),
- the tool diameter (*D*) is wider than the workpiece width (b_w) and the symmetric lines of the tool and the workpiece are the same (Figure 4),
- the tool diameter (*D*) and the slot width (b_w) are the same (Figure 5),
- the slot width (b_w) is lower than the tool diameter (*D*) but the φ_1 angle of contact is 90° (Figure 6).

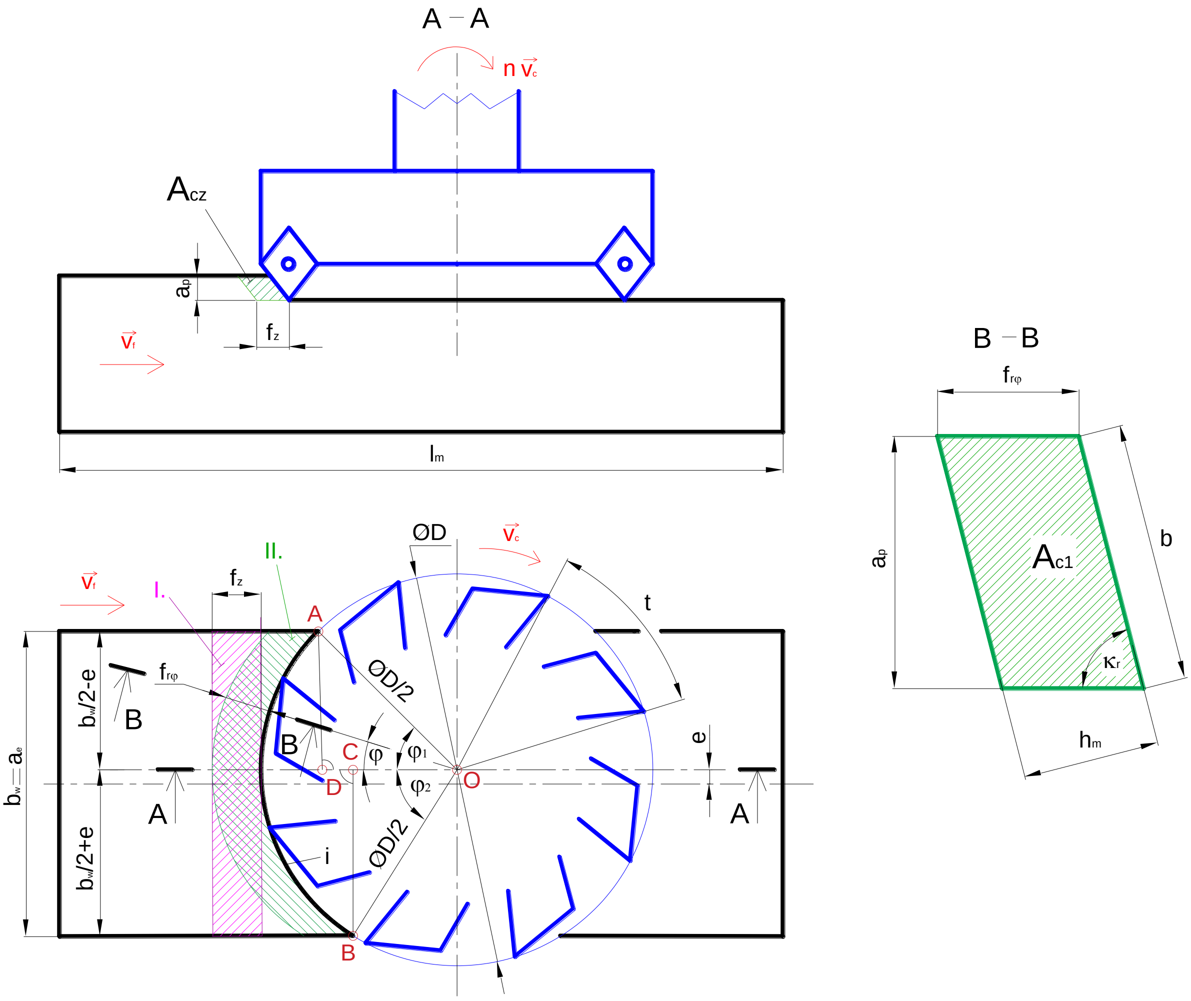


Fig. 3. The *D* is wider than the b_w and *e>0*

Based on Figure 3 the φ_1 and φ_2 are

$$\varphi_1 = \frac{\frac{b_w}{2} - e}{\frac{D}{2}} \tag{5}$$

$$\varphi_1 = \frac{\frac{b_w}{2} + e}{\frac{D}{2}} \tag{6}$$

The *i* arc of contact is [1, 2, 5]

$$i = D \cdot \pi \cdot \frac{\varphi_1 + \varphi_2}{360} \tag{7}$$

The switch number (*Ψ*) means the number of the working teeth along the *i* arc of contact that can highly influence the received surface roughness [1, 2, 5]

$$\Psi = \frac{i}{t} = z \cdot \frac{\varphi_1 + \varphi_2}{360} \tag{8}$$

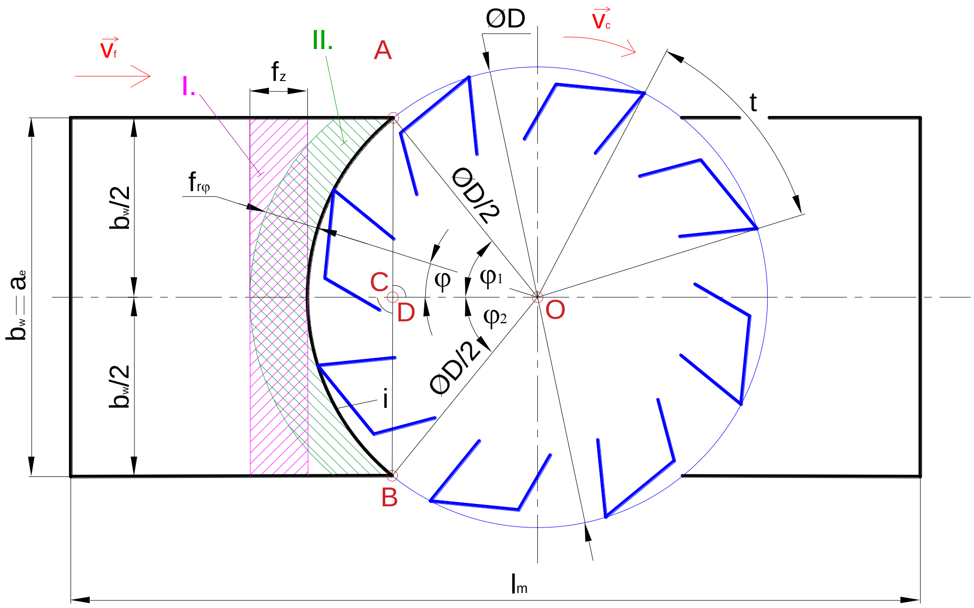


Fig. 4. *D* is wider than the b_w and *e=0*

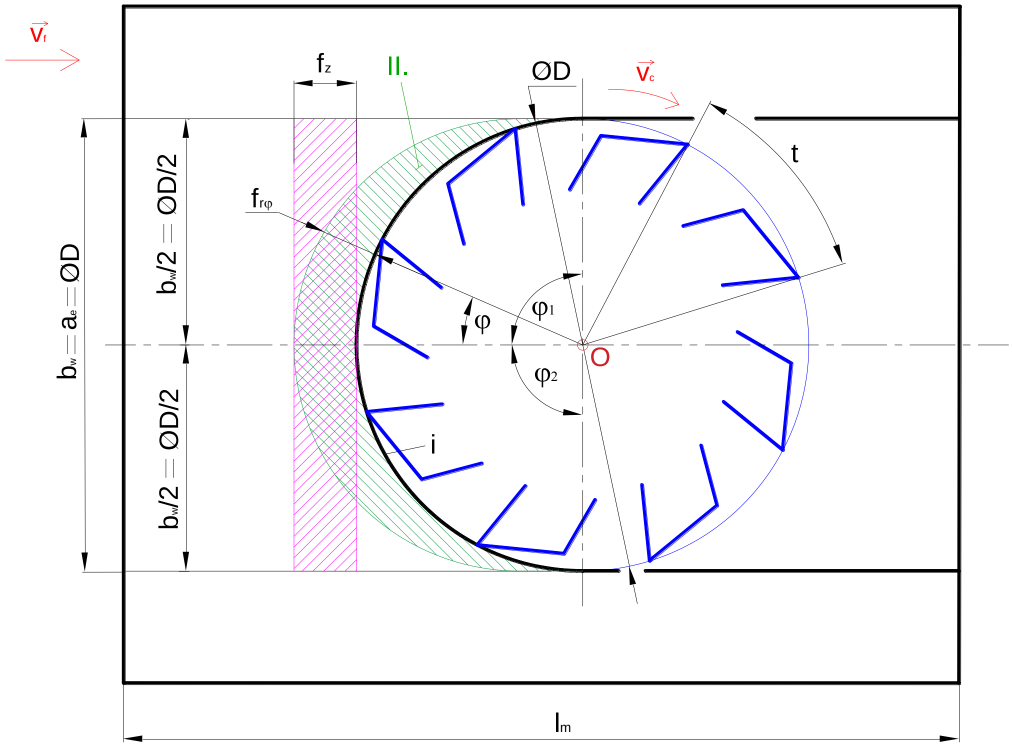


Fig. 5. *D* and b_w are the same

Based on Figure 4

$$\varphi_1 = \varphi_2 \neq 90° \tag{9}$$

Based on Figure 5

$$\varphi_1 = \varphi_2 = 90° \tag{10}$$

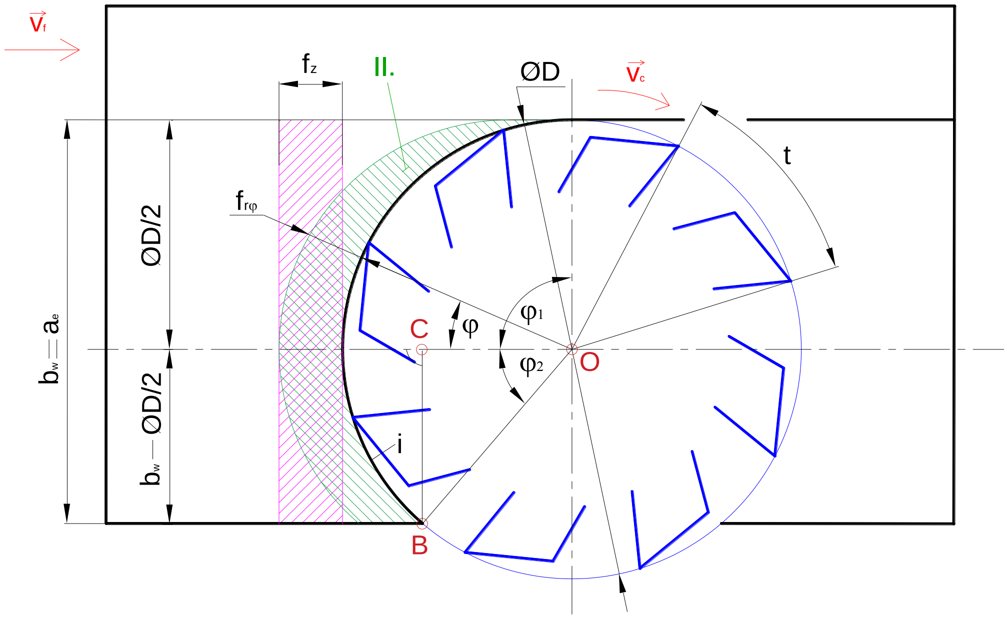


Fig. 6. b_w<D but the φ_1=90°

The interpretation of the manufacturing length can be seen on Figure 7. We are moving the workpiece under the rotating tool [5, 8, 9].

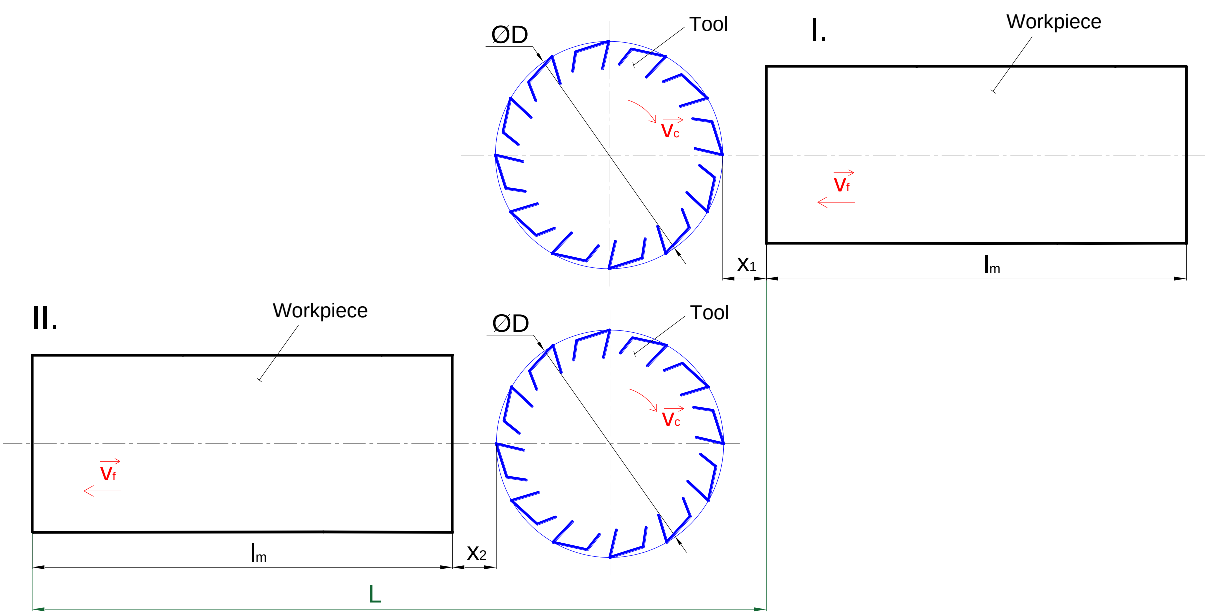


Fig. 7. The interpretation of the manufacturing length

The manufacturing length is (Figure 7)

$$L = l_m + x_1 + x_2 + D \tag{11}$$

The type of the workpiece material is selected for *Fe490 (C45)*, where the specific cutting force is $k_{c1.1} = 2110 \frac{N}{mm^2}$ and the specific force component is z_k=*0.17*. [4]
The initial geometrical and manufacturing parameters can be seen on Table 1.

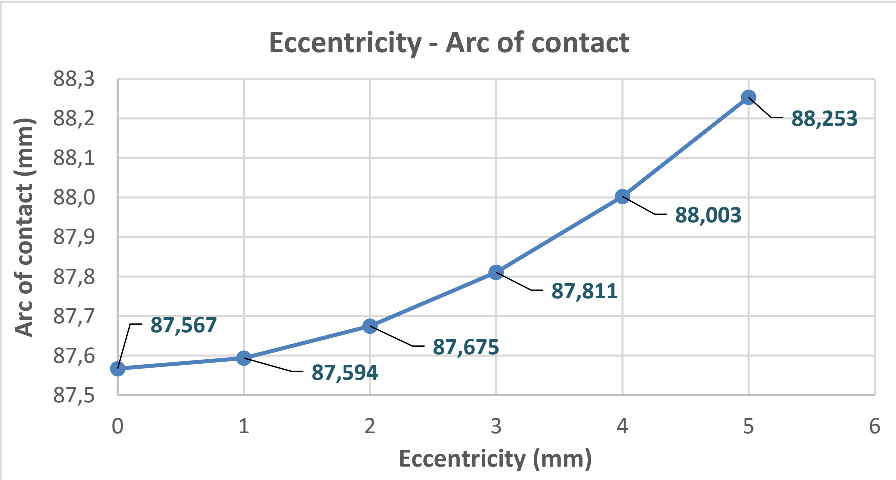
Table 1. The initial geometric and manufacturing parameters

Number of teeth on the tool	z= 20
Tool diameter	D= 120 mm
Workpiece / slot width	b_w= 80 mm
Feed for one edge	f_z= 0.2 mm
Axial depth of cut	a_p= 2 mm
Number of revolution of the tool	n_s= 125 1/min
Major tool cutting edge angle	κ_r= 45°

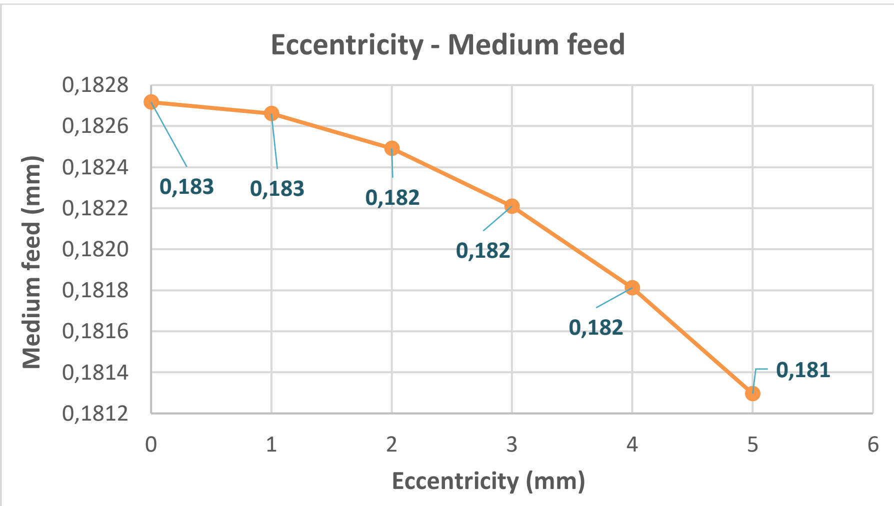
3 Results

Knowing of the initial parameters (Table 1) manufacturing analyses were done to compare the calculated manufacturing parameters. The calculations were done by [1, 2] references.

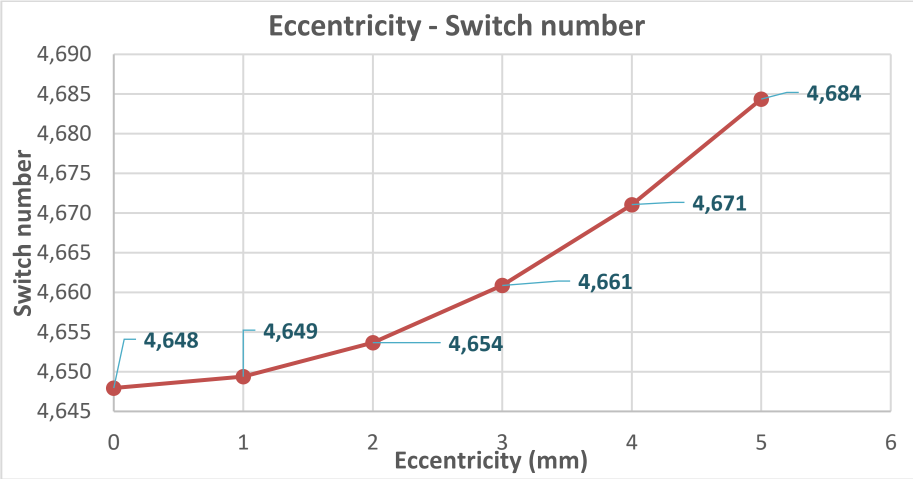
3.1 Manufacturing analysis based on the modification of the *e* eccentricity



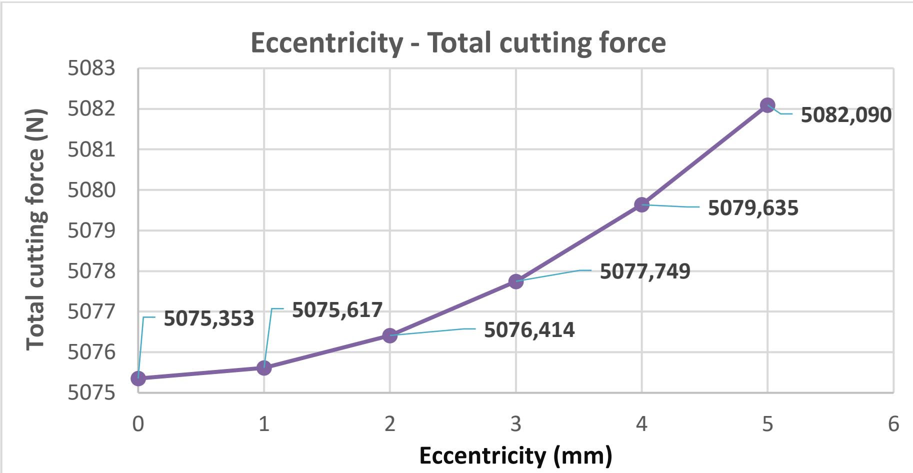
a) Eccentricity – Arc of contact



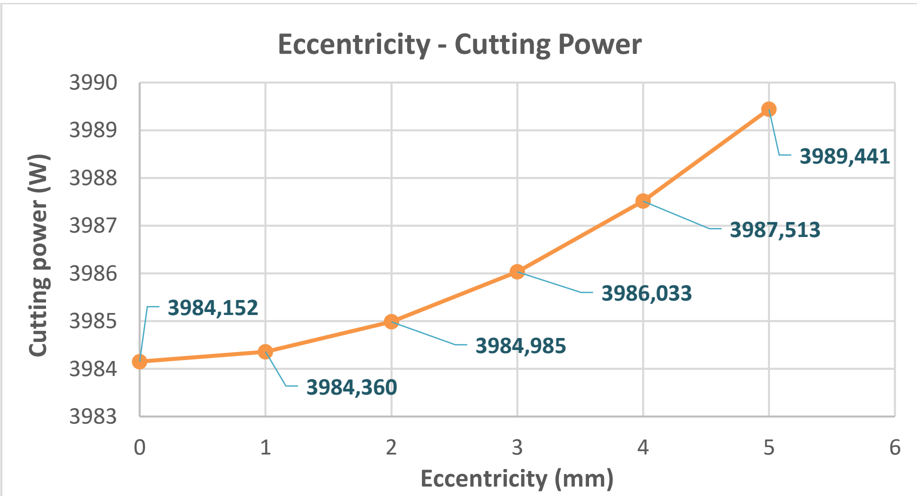
b) Eccentricity – Medium feed



c) Eccentricity – Switch number



d) Eccentricity – Total cutting force



e) Eccentricity – Cutting Power

Fig. 8. The received manufacturing parameters when $D>b_w$

According to adjustment of Figure 3 the eccentricity was modified from 0 mm to 5 mm, where the step was 1. The results can be seen on Figure 8 on discreet values. The shape of the charts are a parabola in each cases that is the shape of the exponential function. The arc of contact, switch number, total cutting force and cutting power are exponentially increasing in the function of the increasing eccentricity (Figure 8. a, c-e). In spite of the them, the medium feed is exponentially decreasing in the function of the increasing eccentricity (Figure 8.b.).

When $e=0$ and $\varphi_1=\varphi_2$, the symmetric lines of the tool and the workpiece are the same in this case (Figure 4). If the $e>1$ and $\varphi_1<\varphi_2$, the symmetric lines of the tool and the workpiece are not same (Figure 3).

3.2 Manufacturing analysis when $D=b_w$

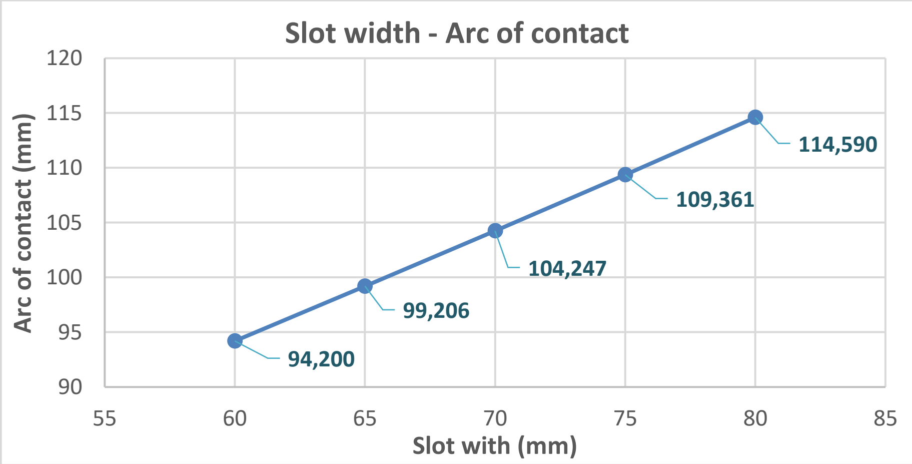
We held the D tool diameter constant, consequently $D=b_w=120\ mm$ was selected. It is special case (Figure 5) when $\varphi_1=\varphi_2=90°$. The calculated results can be seen on Table 2.

Table 2. The received manufacturing parameters when $D=b_w$

i	$f_{r\varphi}$	$\bar{h}$	F_{c1}	Ψ	F_c	P_c
188.4 mm	0.127 mm	0.09 mm	809.445 N	10	8094.455 N	6354.147 W

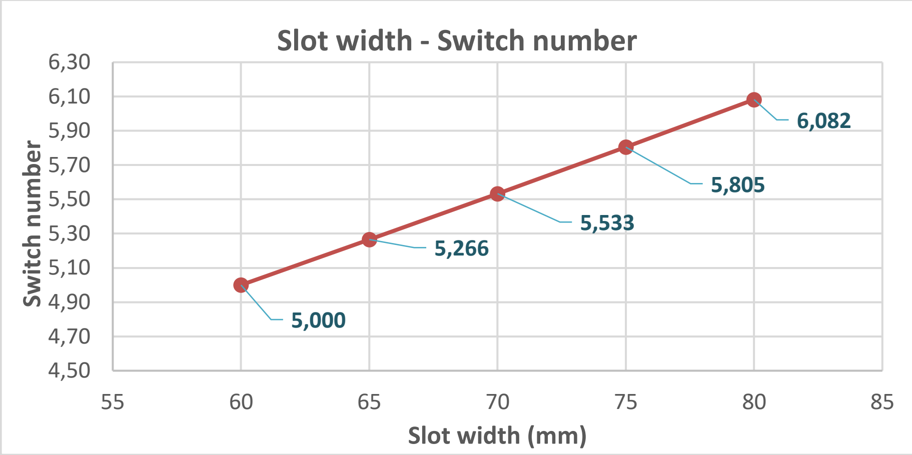
3.3 Manufacturing analysis when $D>b_w$ and $\varphi_1=90°>\varphi_2$

According to adjustment of Figure 6 the slot width was modified from 60 mm to 80 mm, where the step was 5. The results can be seen on Figure 9 on discreet values.

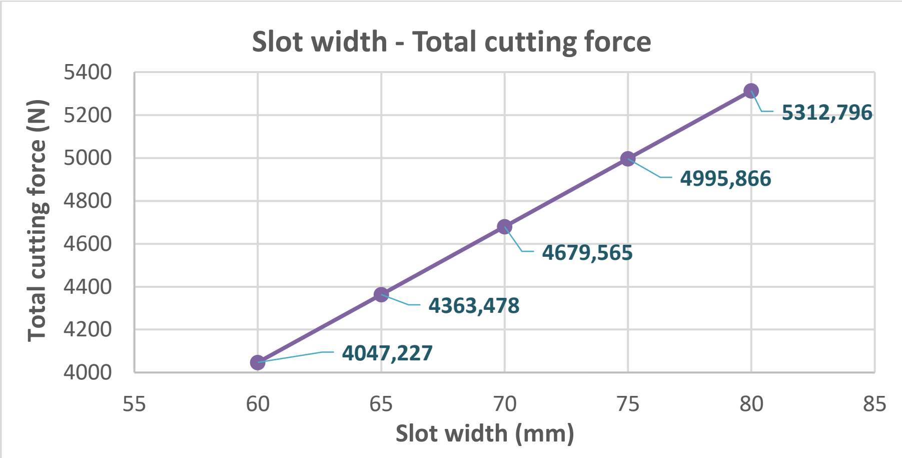


a) Slot width – Arc of contact

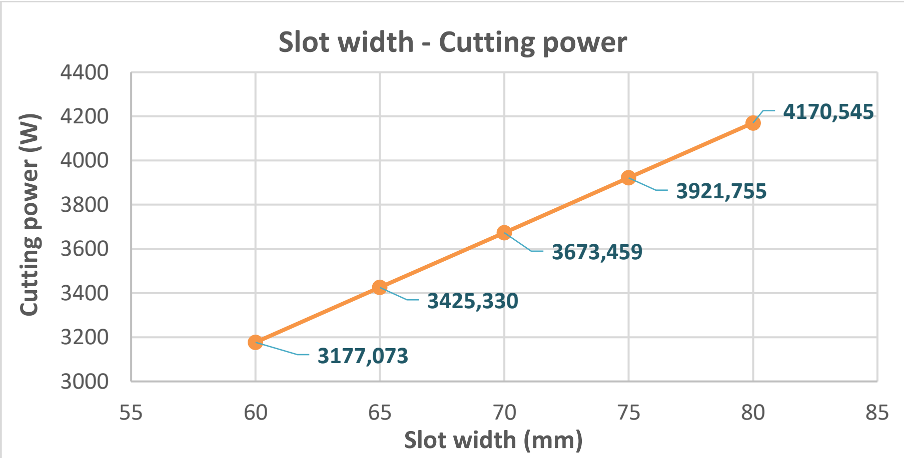
b) Slot width – Medium feed



c) Slot width – Switch number



d) Slot width – Total cutting force



e) Slot width – Cutting power

Fig. 9. The received manufacturing parameters when $D>b_w$ and $\varphi_1=90°>\varphi_2$

Linear proportion can be seen in the function of the increasing slot width between the arc of contact, switch number, total cutting force and cutting power (Figure 9.a and c-e). The more the slot width, the more the received manufacturing parameters.

Parabolic function can be seen on Figure 9.b between increasing of the sloth width and increasing of the medium feed. The correlation between those parameters are exponential function.

3.4 Evaluation and discussion

Comparing the received results of the 3.1., 3.2. and 3.3. subchapters the following statements can be determined:

- Arc of contact (*i*): the highest value was received on the arrangement of Figure 5 due to the usage of the half perimeter of the milling cutter for the chip separation process. The calculated arc of contacts are higher on Figure 6 than on Figure 3.
- Medium feed ($f_{r\varphi}$): along the points of the arc of contact the radial feed is changing in the function of the φ angle that is also changing. This is the reason why we have to calculate a medium feed. This parameter is the lowest on the arrangement of Figure 6. If we use the arrangement of Figure 3 we can get higher values. This parameter is exponentially decreasing in the function of the increasing of the eccentricity (Figure 8.b). It is exponentially increasing in the function of the increasing slot width (Figure 9.b).
- Switch number (Ψ): we can gain the highest value if the arrangement of Figure 5 is used. The lowest results are in case of the arrangement of Figure 3. If the arrangement of Figure 6 is used we can get higher results than the usage of the arrangement of Figure 3. It is know the more the switch number, more teeth can work on the arc of contact consequently better surface roughness can be gained.
- Total cutting force (F_c): since the switch number is the highest in case of the arrangement of Figure 5 that is why the total cutting force is also the highest in this adjustment. The results are mainly lower in case of the arrangement of Figure 6 than in case of the arrangement of Figure 3.
- Cutting power (P_c): since the total cutting force is the highest in case of the arrangement of Figure 5 consequently the cutting power is also the highest in this case. This parameter is mainly lower in case of the arrangement of Figure 6 than in case of the arrangement of Figure 3.

CONCLUSION

Considering the constancy of the initial manufacturing parameters, the type and the geometric establishment of the face milling cutter and the workpiece material we analysed the manufacturing parameters that we could gain during the manufacturing calculations. We modified the position of the tool in comparison with the workpiece. We analysed the effect of this modification for different arrangements, created charts and analysed the received results.

This publication is practical and theoretical at the same time. It can be a base for further manufacturing researches to improve and deeply analyse this technology. It is well-known that the milling technology in general is the most complex cutting technology that is feasible on manual cutting machines or CNC machines. After the determination of the manufacturing parameters the manufacturing simulation and the CNC program writing can be. The type of the tool can significantly influence the surface roughness of the machined workpiece.

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NOMENCLATURE

Parameter	**Unit**	**Name**
$\vec{v_f}(t), v_f = \lvert\vec{v_f}\rvert$	m/min	feed speed
D	mm	outside diameter of the tool
$n_{enginep}$	1/min	number of revolution on the engine of the primary gear box
$n_{s1}, n_{s2}, \ldots, n_{sz}$	1/min	number of revolutions on the spindle

$\mathbf{n_{engines}}$	1/min	number of revolution on the engine of the secondary gear box
$\mathbf{n_{cr}}$	1/min	number of revolution on the creeping run
$\mathbf{n_{secondary}}$	1/min	number of revolution on the secondary gear box
$\mathbf{n_m}$	1/min	number of revolution of the rapid motion
$\mathbf{x, y, z}$		coordinate directions
$\mathbf{k_1, k_2, \ldots, k_z}$		gear ratios of the primary and secondary gear boxes
$\mathbf{h_x, h_y, h_z}$	mm	lead of threads of the feed screw
$\mathbf{C_x, C_y, C_z}$		machine constants
$\mathbf{v_{f1}, v_{f2}, \ldots, v_{fz}}$	m/min	adjustable table speeds
$\mathbf{v_{rx}, v_{ry}, v_{rz}}$	mm/min	speeds of the rapid motion
$\mathbf{v_{crx}, v_{cry}, v_{crz}}$	mm/min	speeds of the creeping run
$\mathbf{k_0}$		transmission ratio of the creeping run k_0~1/200
$\mathbf{b_w}$	mm	workpiece width/slot
$\mathbf{a_p}$	mm	axial depth of cut
$\mathbf{a_e}$	mm	radial depth of cut
$\mathbf{f_z}$	mm/rev	feed for one major cutting edge
$\vec{\mathbf{v_c}}, v_c = \lvert\vec{v_c}\rvert$	m/min	cutting speed
$\mathbf{l_m}$	mm	workpiece length
$\mathbf{x_1, x_2}$	mm	overrunings
φ_1, φ_2	°	angle of contacts
φ	°	concrete angle position of the medium feed
$\mathbf{i}$	mm	arc of contact
$\mathbf{f_{r\varphi}}$	mm/rev	medium feed along the i arc of contact
$\mathbf{f}$	mm/rev	total feed
$\mathbf{e}$	mm	eccentricity
$\mathbf{A_{c1}}$	mm^2	theoretical chip section
$\mathbf{h_m}$	mm	medium chip thickness
$\mathbf{t}$	mm	tooth pitch
$\mathbf{k_c}$	N/mm^2	specific cutting force
$\vec{\mathbf{F_{c1}}}, F_{c1} = \lvert\vec{F_{c1}}\rvert$	N	cutting force for one edge
$\vec{\mathbf{F_c}}, F_c = \lvert\vec{F_c}\rvert$	N	total cutting force
Ψ		switch number
$\mathbf{P_c}$	W	cutting power
$\mathbf{T_c}$	min	machining time
κ_r	°	major tool cutting edge angle
$\mathbf{z}$		number of cutting edges on the tool
$\mathbf{L}$	mm	Manufacturing length
$\mathbf{k_{c1.1}}$	N/mm^2	specific cutting force
$\mathbf{z_k}$		specific force component