Report CAM Project

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Group Nr. 65

1. Notation and Formula

1.1 Face Milling Formula

$$h_d = f_z \cdot \cos\frac{\varphi_0}{2} \cdot \sin k_r$$

$$\varphi_0 = \frac{2\pi}{Z}$$

$$\varphi = \sin\left(\frac{D/_2 - a_e}{D/_2}\right)^{-1}$$

$$n = \frac{v_c \cdot 1000}{\pi \cdot D}$$

$$v_f = n \cdot Z \cdot f_z$$

$$z = \frac{\varphi}{\varphi_0}$$

$$k_c = k_{c1} \cdot h_m^{-m_c} \cdot \left(1 - \frac{\gamma_0}{100}\right)$$

$$h_d = f_z \cdot \cos\frac{\varphi_0}{2} \cdot \sin k_r$$

$$Ad = f_z \cdot \cos\frac{\varphi_0}{2} \cdot a_p$$

$$F_c = A_d \cdot k_c$$

$$T_c = \frac{2 \cdot f_c \cdot D/_2}{1000}$$

$$P_c = T_c \cdot \frac{2\pi n}{60}$$

$$R_a = \frac{f_Z^2 \cdot 10^3}{32 \cdot R}$$

1.2 Slab milling formula

$$h_d = f_z \cdot \sin\varphi$$

$$\varphi_0 = \frac{2\pi}{Z}$$

$$\varphi = \cos\left(1 - \frac{a_e}{D/_2}\right)^{-1}$$

$$n = \frac{v_c \cdot 1000}{\pi \cdot D}$$

$$v_f = n \cdot Z \cdot f_z$$

$$z = \frac{\varphi}{\varphi_0}$$

$$k_c = k_{c1} \cdot {h_m}^{-m_c} \cdot \left(1 - \frac{\gamma_0}{100}\right)$$

$$h_d = f_z \cdot \sin\varphi$$

$$A_d = h_d \cdot a_p$$

$$F_c = A_d \cdot k_c$$

$$T_c = F_c \cdot \frac{D}{2} \cdot 10^{-3}$$

$$P_c = T_c \cdot \frac{2\pi n}{60}$$

$$R_a = \frac{f_Z^2 \cdot 10^3}{4 \cdot 8 \cdot R}$$ if $2 \cdot \pi \cdot R \gg 60 \cdot Z \cdot f_z$

1.2 Drilling Formula

$$h_d = f_z \cdot \sin\frac{\theta}{2}$$

$$f_z = \frac{f}{2}$$

$$n = \frac{v_c \cdot 1000}{\pi \cdot D}$$

$$k_c = k_{c1} \cdot h_m^{-m_c} \cdot (1 - \frac{\gamma_0}{100})$$

$$A_d = f \cdot \frac{D}{2}$$

$$F_c = A_d \cdot k_c$$

$$T_c = F_c \cdot \frac{D}{2} \cdot 10^{-3}$$

$$\omega = \frac{v_c \cdot 1000}{60 \cdot {}^{D}/_{2}}$$

$$P_c = T_c \cdot \omega$$

2. Introduction of Project Product

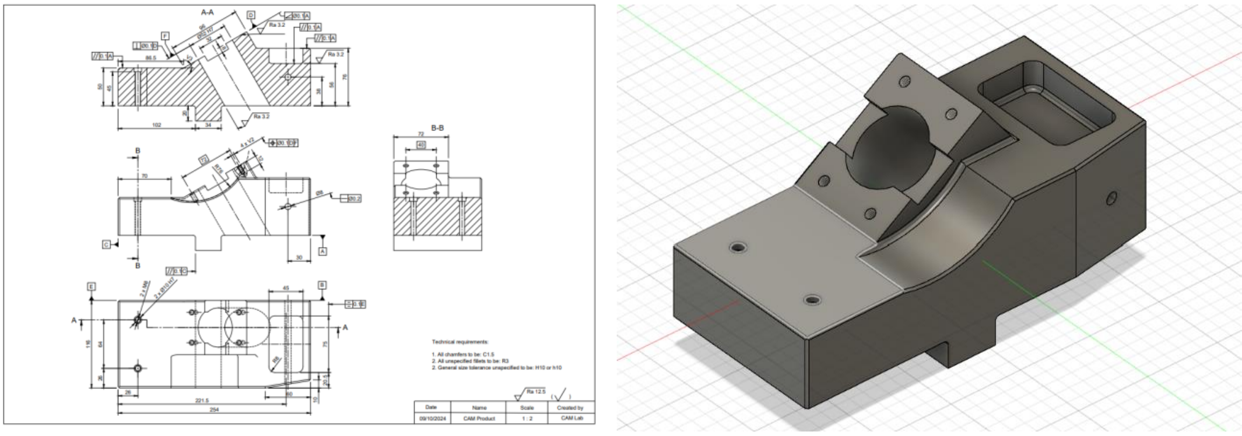

Fig.1: 2D and 3D representation of the requested product.

2.1 Inputs and variables:

Machining features for the development of the product:

- **Material**: P.4.Z.AN
- **Threaded holes:** M8x1.25
- **Stock size:** 264 x 126 x 132 mm

Machine tool limits details:

- **Rapid speed:** 42 m/min
- **Maximum Spindle Rotational Speed:** 14000 rpm
- **Spindle power:** 16 kW
- **Working area:** 1160 x 1000 x 900 mm
- **Tool changing time:** 15 s
- **Spindle repositioning time:** 5 s
- **Loading and unloading time:** 60 s
-

2.2 Features and Operations

2.2.1 Features

Each face of the final product has its own features to be addressed during the manufacturing process, here we provide the list of the features divided by faces.

Top face:

- curved surface (x1)
- pocket (x1)
- chamfers (x12)
- counterbore threaded holes (x2)
- tilted surface:
    - through hole (x1)
    - threaded holes (x4)
    - slots (x2)

Lateral face:

- tilted surface (x1)
- chamfer (x1)

Second lateral face:

- through hole (x1)

2.2.2 Operations

The main operations used to produce the requested product are milling and drilling, in particular the following ones:

Milling:

- Face rough milling
- Face finish milling
- Chamfers
- Slab milling

Drilling:

- Reaming
- Counterboring
- Tapping

Here we can see the operations performed in each Setup:

Requirements: the general requirement is a roughness of 12.5 μm and stays the same for all setups, except if differently stated, same for chamfers that need to be 1.5, fillets must be R3, and general size tolerance is requested to be H10.

Setup 1: For this setup there are no additional requirements.

Operation Number	**Operation name**	**Feature**
1	Roughing	Bottom face
2	Roughing	Back face
3	Roughing	Front face

4	Roughing	First half bottom face
5	Roughing	Second half bottom face
6	Finishing	First half bottom face
7	Finishing	Second half bottom face

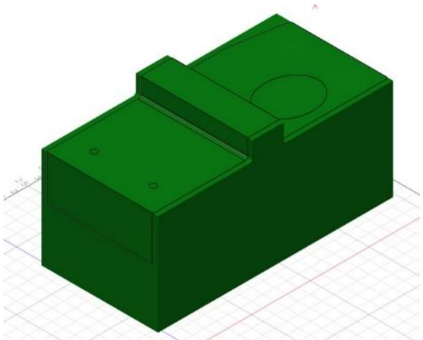

Fig.2: Results after first setup

Setup 2: In this setup the additional requirement is 0.2 mm tolerance for the through hole.

Operation Number	**Operation name**	**Feature**
1	Roughing	Right face
2	Drilling	Through hole
3	Roughing	Tilted face
4	Chamfer	Right face

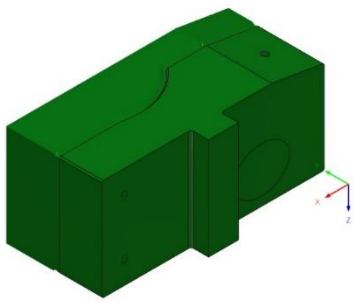

Fig.3: Results after second setup

Setup 3: In this setup there aren’t any additional requirements

Operation Number	**Operation Name**	**Feature**
1	Roughing	Left face
2	Chamfer	Left face

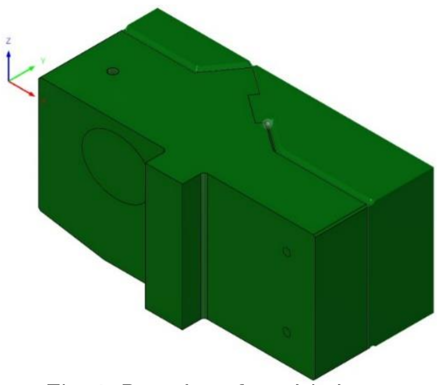

Fig.4: Results after third setup

Setup 4: The additional requirements for this setup are: Roughness of the pocket, the big hole and for the tilted face needs to be 3.2, furthermore the frontal through holes are M8 and the counterbored holes have a tolerance of H7.

Operation Number	Operation Name	Feature
1	Roughing	Top front face
2	Roughing	Top rear face
3	Roughing	Lateral face
4	Chamfer	Front chamfer
5	Chamfer	Rear chamfer
6	Finishing	Rear face
7	Finishing	Lateral face
8	Roughing	Rear pocket
9	Finishing	Rear pocket
10	Roughing	Tilted rear surface
11	Roughing	Tilted front surface
12	Finishing	Lateral fillet
13	Finishing	Rear fillet
14	Finishing	Tilted surface
15	Contouring	Curved surface
16	Finishing	Tilted face
17	Finishing	Tilted face
18	Drilling	Front holes
19	Counterboring	Front holes
20	Reaming	Front holes
21	Drilling	Tilted face holes
22	Drilling	Big hole tilted face
23	Boring	Big hole tilted face
24	Tapping	Tilted surface holes
25	Tapping	Front holes

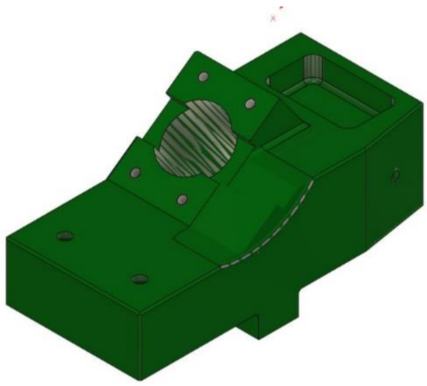

Fig.5: Results after fourth setup

Setup 5: no additional requirements.

Operation number	Operation name	Feature
1	Roughing	Curved surface
2	Finishing	Curved surface

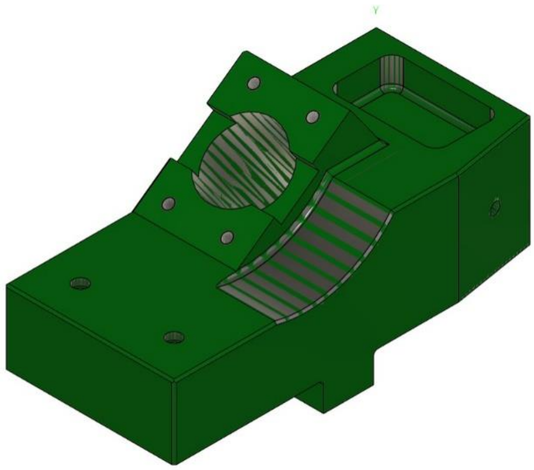

Fig.6: Results after fifth setup

2.3 Precedence graph

To realize the precedence graph, we followed 2 basic rules:

Rule 1: roughing operations before finishing operations

Rule 2: surfaces before holes

Setup 1:

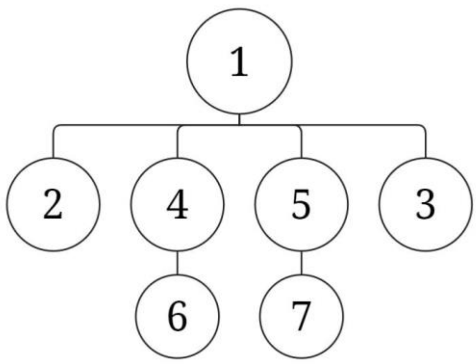

Fig.7: precedence graph setup 1

Setup 2: In this setup we decided to break the second rule, because by doing the drilling before the roughing operation we allow the tool to cut the material perpendicularly to the surface, given that the hole lies on a tilted surface.

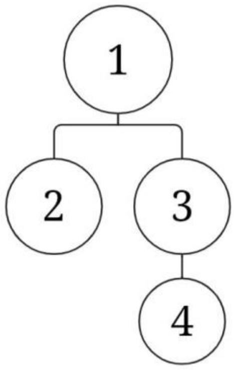

Fig.8: precedence graph setup 2

Setup 3:

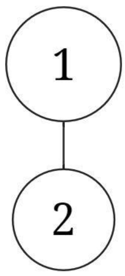

Fig.9: precedence graph setup 3

Setup 4:

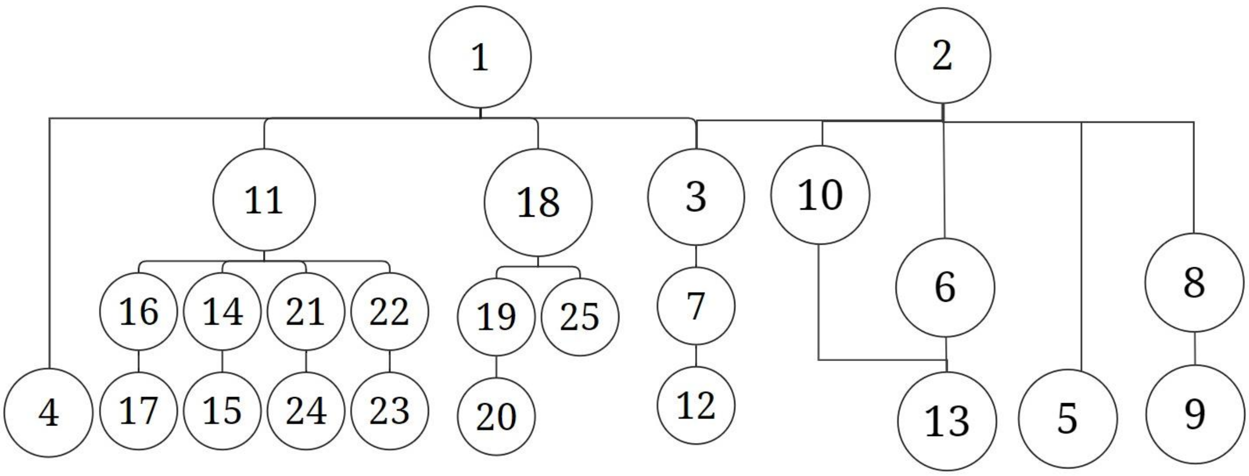

Fig.10: precedence graph setup 4

Setup 5:

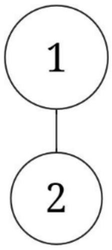

Fig.11: precedence graph setup 5

3. Detailed Final Solution to Realize the Product

3.1 Throughput of the product

To evaluate the throughput of the product we must consider the data regarding the time needed to perform certain operations, for example the tool changing time (15s), loading and unloading time (60s), positioning time and spindle repositioning time.
Once we compute the time [minutes/part] needed to fully manufacture the product we can simply divide 60 [minutes/hour] by that quantity to obtain the final throughput [parts/hour].

	Total feed time	Total rapid time	Total changing time	Machining time
Setup 1	0:14:29	0:00:01	0:00:15	0:14:45
Setup 2	0:04:49	0:00:01	0:01:00	0:05:39
Setup 3	0:03:57	0:00:01	0:00:15	0:04:12
Setup 4	0:20:00	0:00:15	0:04:15	0:24:30
Setup 5	0:00:31	0:00:03	0:00:00	0:00:34

Total machining time resulting in: 0:49:36

Total setup changing time: 0:05:00

Cycle time is 0:54:40

Throughput is 1.098 parts/hour

3.2 Setup Information

To complete the manufacturing of the product 5 different setups were chosen.

The first setup is used to realize the bottom, the front and the rear faces of the product.

The second one allowed us to machine the right face with the inclined face and the through hole.

The third setup is used to perform the operations needed for the left face

The fourth and by far the longest one is the one that includes the more advanced features found on the top face of the product.

The final one was used to realize the curved surface

Thanks to this configuration all the parallelism and perpendicularity constraints are guaranteed.

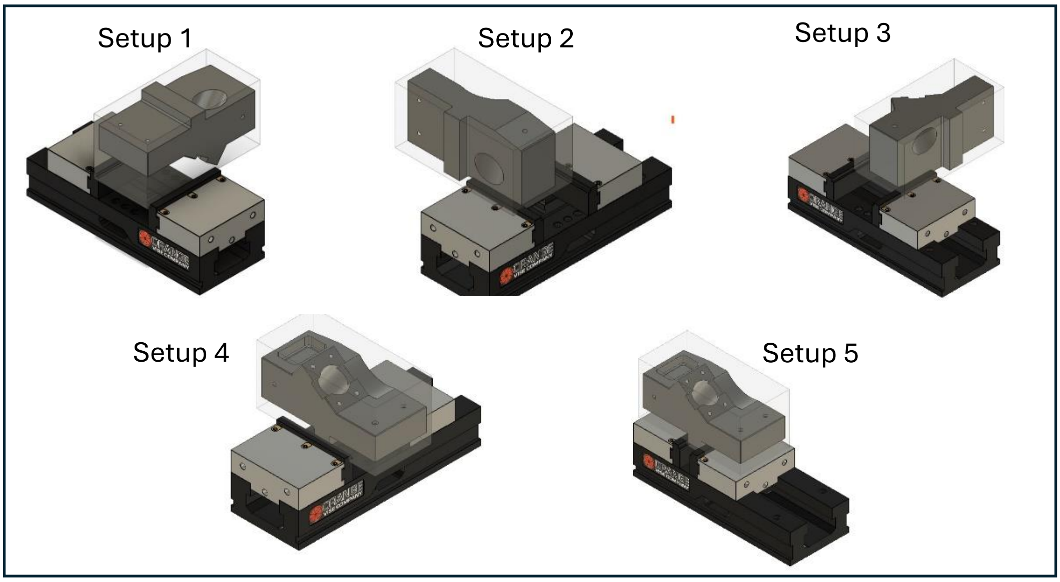

Fig.12: representation of all setups

3.3 Manufacturing Resources:

All the tools we have used were selected from the Sandvik Corovant catalogue.

The cutting parameters of the tools have been selected respecting both the limitations of the machine and the guidelines provided by Sandvik.

3.3.1 Setup 1

#	Operation	Tools	Dc	ae	ap	fz	n
1	Face Milling	1K334-2000-300-XD 1730	20	10	2	0,14	2390
2	Face Milling	1K334-2000-300-XD 1730	20	10	5	0,14	2390
3	Face Milling	1K334-2000-300-XD 1730	20	10	5	0,14	2390
4	Face Milling	1K334-2000-300-XD 1730	20	10	20	0,14	2390
5	Face Milling	1K334-2000-300-XD 1730	20	10	20	0,14	2390
6	Face Milling	1K334-1000-300-XD 1730	10	5	20	0,07	7960
7	Face Milling	1K334-1000-300-XD 1730	10	5	20	0,07	7960

3.3.2 Setup 2

#	Operation	Tools	Dc	ae	ap	fz	n
1	Face Milling	1K334-2000-300-XD 1730	20	10	5	0,14	2390
2	Drilling	861.1-0800-160A1-GM GC34	8	\	121	0,2	3980
3	Face Milling	1K334-2000-300-XD 1730	20	10	10	0,14	2390
4	Face Milling	490-025A20-08L	10	1,5	5	0,2	3570

3.3.3 Setup 3

#	Operation	Tools	Dc	ae	ap	fz	n
1	Face Milling	1K334-2000-300-XD 1730	20	10	5	0,14	2390
2	Chamfer	1C050-0150-045-XA 1620	10	1,5	1,5	0,1	5000

3.3.4 Setup 4

#	Operation	Tools	Dc	ae	ap	fz	n
1	Face Milling	1K334-2000-300-XD 1730	20	10	20	0,14	2390
2	Face Milling	1K334-2000-300-XD 1730	20	10	20	0,14	2390
3	Face Milling	1K334-2000-300-XD 1730	20	10	20	0,14	2390
4	Chamfer	1C050-0150-045-XA 1620	10	1,5	1,5	0,1	5000
5	Chamfer	1C050-0150-045-XA 1620	10	1,5	1,5	0,1	5000
6	Face Milling	1K334-1000-300-XD 1730	10	5	10	0,07	7960
7	Face Milling	1K334-1000-300-XD 1730	10	5	10	0,07	7960
8	Pocket	1K334-2000-300-XD 1730	20	20	20	0,08	1990
9	Pocket Coun	1K334-1000-300-XD 1730	10	10	20	0,07	7980
10	Face Milling	1K334-2000-300-XD 1730	20	10	15	0,14	2390
11	Face Milling	1K334-2000-300-XD 1730	20	10	15	0,14	2390
12	Face Milling	1K334-1000-300-XD 1730	10	5	15	0,07	7980
13	Face Milling	1K334-1000-300-XD 1730	10	5	15	0,07	7980
14	Face Milling	1K334-1000-300-XD 1730	10	5	8	0,07	7980
15	Face Milling	1K334-2000-300-XD 1730	20	10	8	0,14	2390
16	Face Milling	490-025A20-08L	25	12,5	15	0,2	3570
17	Face Milling	490-025A20-08L	25	12,5	15	0,2	3570
18	Drilling	460.1-0680-051A1-XM GC34	6,8	\	55	0,14	4240
19	Drilling	460.1-0980-029A0-XM GC34	9,8	\	10	0,25	2270
20	Reaming	830B-E06D1000H7S12	10	\	10	1,2	33200
21	Drilling	460.1-0680-051A1-XM GC34	6,8	\	12	0,25	2270
22	Drilling	DS20-D4000DM40-04	40	\	110	0,08	1840
23	Boring	1K334-2000-300-XD 1730	20	10	10	0,14	2390
24	Tapping	T300-XM170DA-M8 B110	8	\	12	1,25	712
25	Tapping	T200-XM101DA-M8 C150	8	\	50	1,25	287

3.3.5 Setup 5

1	Slab Milling	1K334-2000-300-XD 1730	20	10	20	0,14	2390
2	Slab Milling	1K334-2000-300-XD 1730	20	10	20	0,14	2390

4 Verification of operations

To assess the feasibility of the operation we selected the worst-case scenario for the depth of cut (a_p).

4.1 Milling tools

“Sandvik Coromill® Dura Solid carbide end Mill” (1K334-2000-300-XD 1730)

Operation number:

- Setup 1: 1,2,3, 4,5
- Setup 2: 1,3
- Setup 3: 1
- Setup 4: 1,2,3,8,10,11,15
- Setup 5: 1,2

D	ae	ap	Z	phi	phi_0	z	kr	kr(rad)	fz	n
20	10	20	4	1,570796	1,570796	1	90	1,570796	0,14	2390

hd	Ad	mc	kcs	kc	Fc	Tc	Pc	r	Ra
0,14	2,8	0,25	1180	1929,079	5401,421	54,01421	13518,69	3	0,204167

“Sandvik Coromill® Dura Solid carbide end Mill” (1K334-1000-300-XD 1730)

Operation number:

- Setup 1: 6,7
- Setup 4: 6,7,9,12,13,14

D	ae	ap	Z	phi	phi_0	z	kr	kr(rad)	fz	n
10	5	20	4	1,570796	1,570796	1	90	1,570796	0,07	7960

hd	Ad	mc	kcs	kc	Fc	Tc	Pc	r	Ra
0,07	1,4	0,25	1180	2294,074	3211,704	16,05852	13385,89	3	0,051042

Sandvik CoroMill® 490 square shoulder milling cutter (490-025A20-08L)

Operation number:

- Setup 4: 16,17
- Setup 2: 4

D	ae	ap	Z	phi	phi_0	z	kr	kr(rad)	fz	n
25	12,5	5	4	1,570796	1,570796	1	90	1,570796	0,2	3570

hd	Ad	mc	kcs	kc	Fc	Tc	Pc	r	Ra
0,2	1	0,25	1180	1764,512	1764,512	22,05639	8245,773	3	0,416667

4.2 Chamfer tool

Sandvik CoroMill® Dura solid carbide end mill for chamfer milling (1C050-0150-045-XA 1620)

Operation number:

- Setup 3: 2
- Setup 4: 4,5

D	ae	ap	Z	phi	phi_0	z	kr	kr(rad)	fz	n
10	1,5	1,5	5	0,795399	1,256637	0,632958	90	1,570796	0,1	5000

hd	Ad	mc	kcs	kc	Fc	Tc	Pc	r	Ra
0,1	0,15	0,25	1180	2098,37	314,7555	1,573777	824,0279	3	0,104167

4.3 Drilling Tools

Sandvik CoroDrill® 861 solid carbide drill (861.1-0800-160A1-GM GC34)

Operation number:

- Setup 2: 2

D	ap	Z	fz	n	teta	teta(rad)	hd
8	121	2	0,2	3980	70	1,22173	0,114715

Ad	mc	kcs	kc	Fc	Tc	Pc
0,8	0,25	1180	2027,574	1622,059	6,488236	2704,197

Sandvik CoroDrill® 460 solid carbide drill (460.1-0680-051A1-XM GC34)

Operation number:

- Setup 4: 18,21

D	ap	Z	fz	n	teta	teta(rad)	hd	Ad	mc
6,8	55	2	0,14	4240	70	1,22173	0,080301	0,476	0,25

kcs	kc	Fc	Tc	Pc
1180	2216,676	1055,138	3,587468	1592,878

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Sandvik CoroDrill® 460 solid carbide drill (460.1-0980-029A0-XM GC34)

Operation number:

- Setup 4: 19

D	ap	Z	fz	n	teta	teta(rad)	hd	Ad	mc
9,8	10	2	0,25	2270	70	1,22173	0,143394	1,225	0,25

kcs	kc	Fc	Tc	Pc
1180	1917,561	2349,012	11,51016	2736,124

Sandvik CoroDrill® DS20 indexable insert drill (DS20-D4000DM40-04)

Operation number:

- *Setup 4: 22*

D	ap	Z	fz	n	teta	teta(rad)	hd	Ad	mc
40	110	2	0,08	1840	81	1,413717	0,051956	1,6	0,25

kcs	kc	Fc	Tc	Pc
1180	2471,573	3954,516	79,09033	15239,47

4.4 Reaming tool

Sandvik CoroReamer™ 830 solid carbide head for reaming (830B-E06D1000H7S12)

Operation number:

- Setup 4: 20

Dint	Dext	ap	Z	fz	n	teta	teta(rad)	hd	Ad
9,8	10	10	6	1,2	33200	90	1,570796	0,848528	0,12

mc	kcs	kc	Fc	Tc	Pc
0,25	1180	1229,463	147,5356	4,381806	15234,21

4.5 Tapping tool

Sandvik CoroTap™ 300 cutting tap with spiral flutes (T300-XM170DA-M8 B110)

Operation number:

- Setup 4: 24

Dint	Dext	ap	Z	fz	n	teta	teta(rad)	hd	Ad
6,8	8	12	3	1,25	712	45	0,785398	0,478354	0,75

mc	kcs	kc	Fc	Tc	Pc
0,25	1180	1418,876	1064,157	11,81215	880,7192

Sandvik CoroTap™ 200 cutting tap with spiral point5 (T200-XM101DA-M8 C150)

Operation number:

- Setup 4: 25

Dint	Dext	ap	Z	fz	n	teta	teta(rad)	hd	Ad
6,8	8	50	3	1,25	287	90	1,570796	0,883883	0,75

mc	kcs	kc	Fc	Tc	Pc
0,25	1180	1216,979	912,7346	10,13135	304,4935

Discussion on technical requirements:

To conclude, to perform the operations needed to manufacture the product we used the functions of Autodesk Fusion360 to optimize the process and to simulate the output to check the feasibility of our solution.

The solution was intended to be optimal, utilizing at best the capabilities of our machine and the tools we selected.

Additionally, we based our choice of tools on Sandvik's online catalogue that provided us with all kinds of information regarding each tool, allowing us to calculate whether every choice complied with the requirements and respected the constraints given by the machine we were working with.

In particular, we were able to use the material type (P1.4.Z.AN) and the HB of 220 to select the appropriate tools and their cutting parameters.

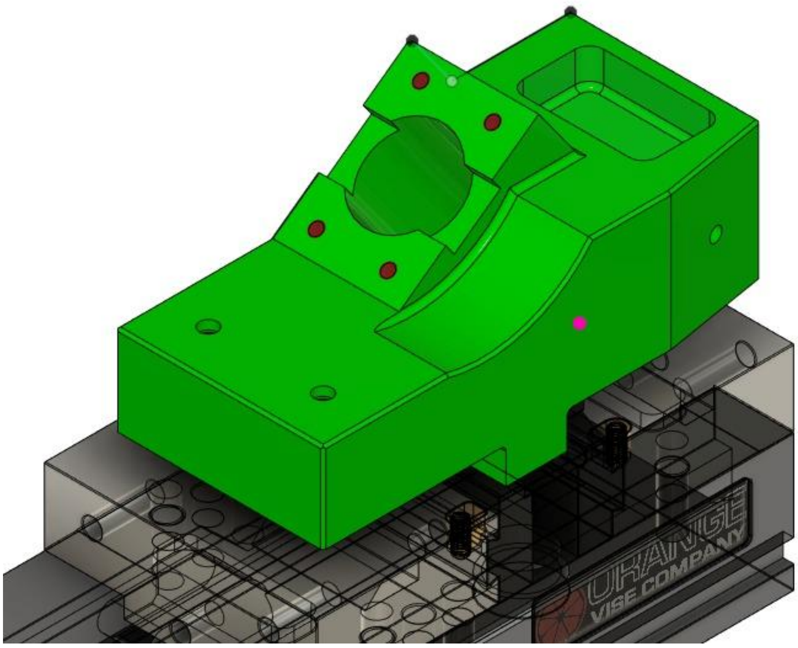

Fig.13 Final product