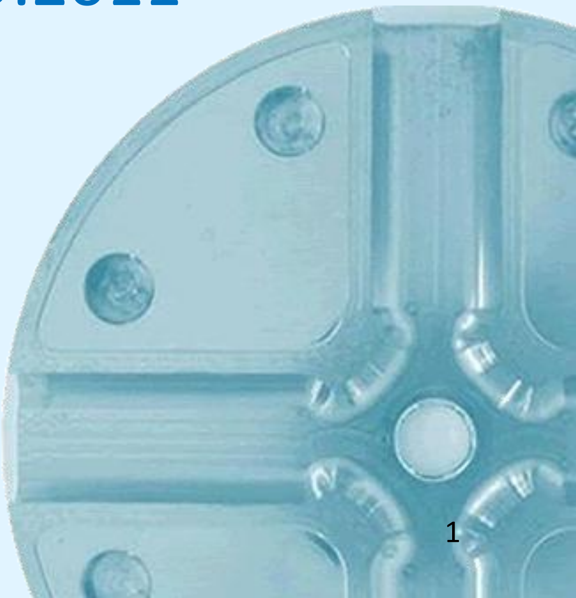
TUT

Modeling of disk machining for the CLIC RF accelerating structures

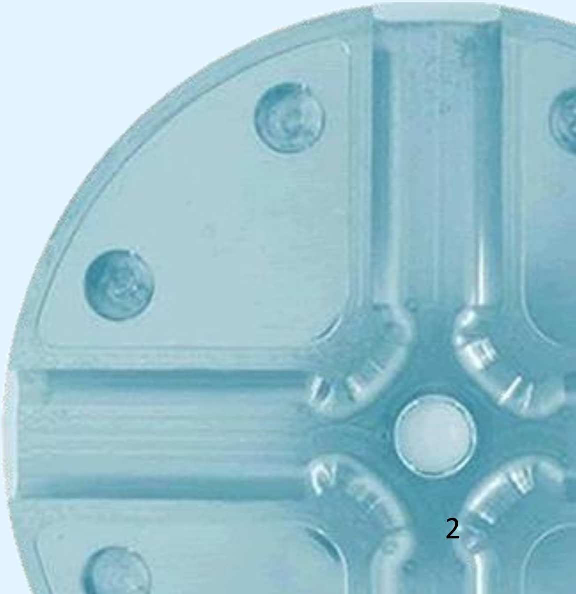
MeChanICs project meeting - 6.9.2011

Joni Turunen



Agenda

- Introduction
- Methodology
- Manufacturing a disk
- Theoretical model
- Summary

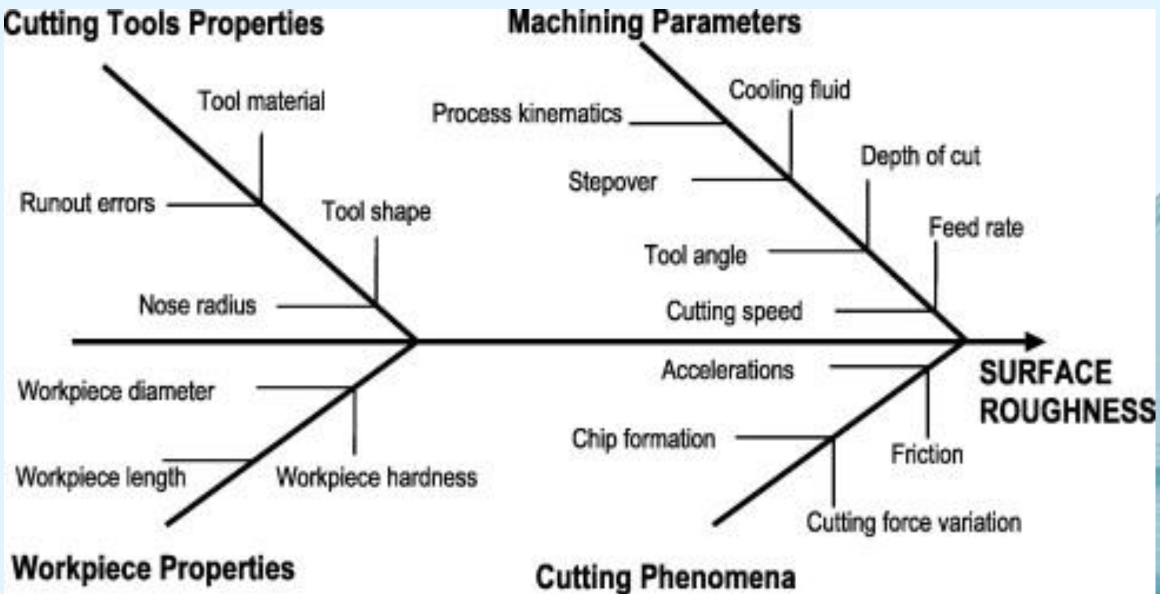


Introduction

- The price of a single disk is a major cost driver in CLIC
  - In total around 4.1 million disks will be needed
- The price of a disk consists mostly of machining
  - The reason is the tight dimensional tolerances of the disk
  - Surface roughness Ra 25 nm and shape accuracy 5 µm
- A model for machining was created as part of the theory of my master of science thesis to estimate the time needed for machining
  - The cost of a disk is dependent on the machining time
  - The most time taking part of the is the ultra precision milling and turning down to few micrometers

Methodology

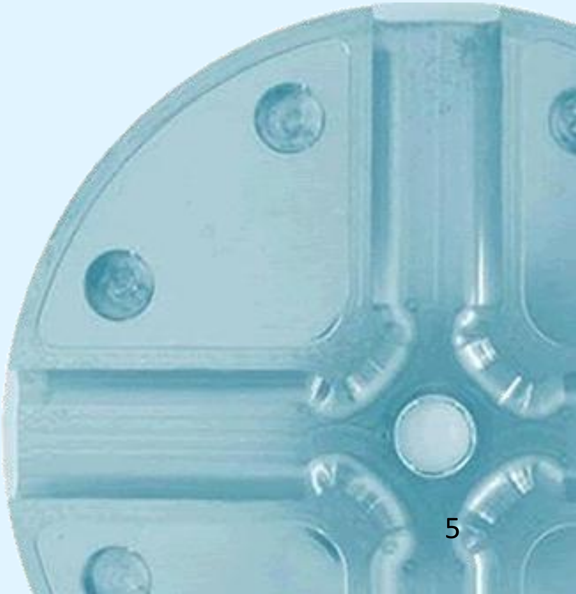
- One approach to the model would be to take into account all the possible variations and changes during the cutting operation (which some people have done)
  - This will require a really complicated model



Benardos, P. G. & Vosniakos, G.-C. 2003. Predicting Surface Roughness in Machining: A Review. International Journal of Machine Tools and Manufacture. Vol. 43(8), pp. 833-844.

Methodology

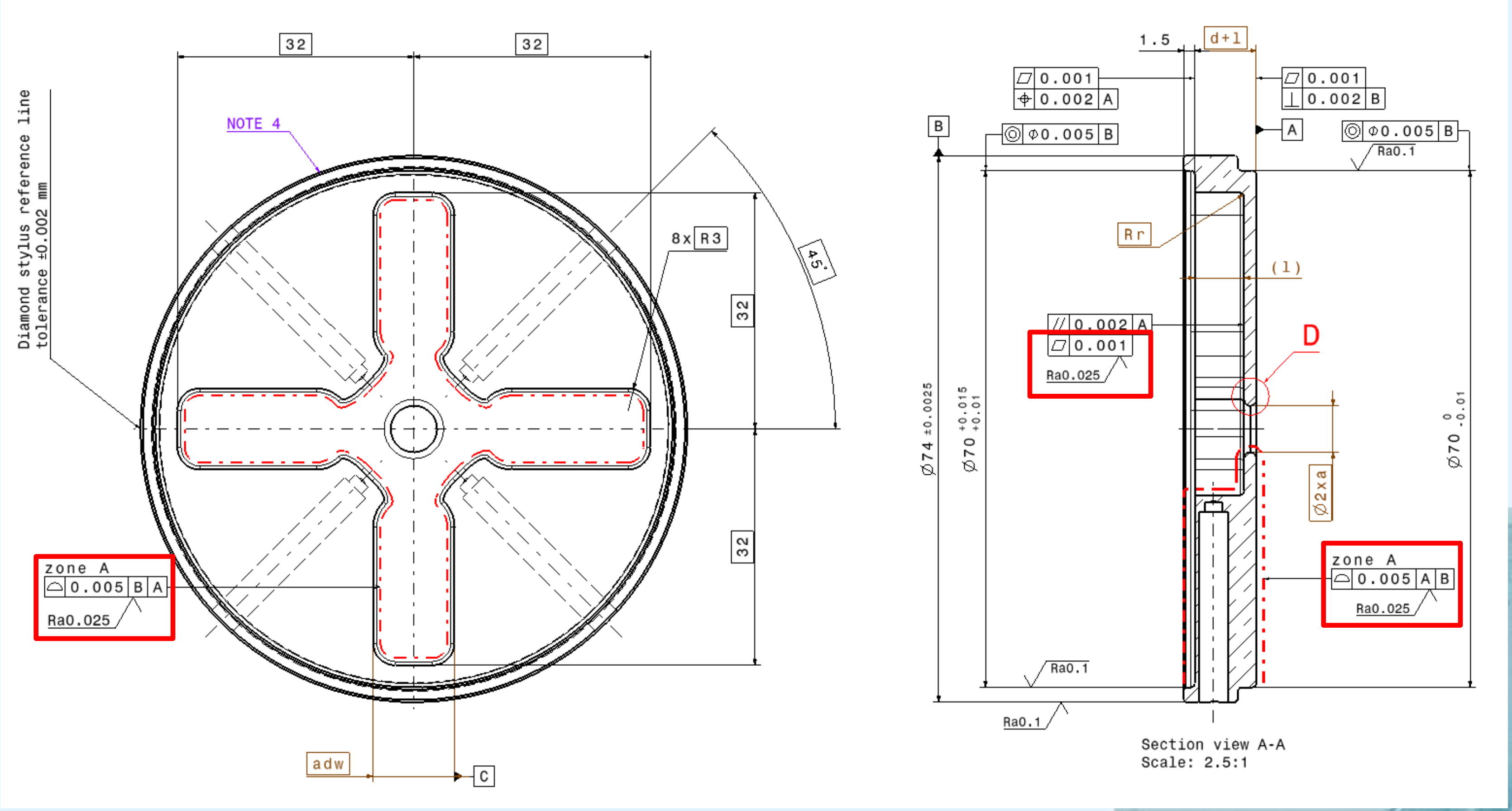
- Another approach is to construct an ideal theoretical model
  - Easier to create
  - This gives ideal surface roughness



Manufacturing an RF disk

1. Inspection of material
2. Cutting raw material to disks
3. Rough machining (down to 1 mm)
4. Stress relief
5. Pre-machining (Down to 100 µm)
6. Stress relief (optional)
7. Finishing machining (down to 10 µm)
8. Stress relief
9. Ultra precision machining (down to <10 µm)
10. Degreasing
11. Quality control
12. Packaging & shipping

Sample disk – TD24 R0.5



- Cell shape accuracy 5 μm
- Flatness accuracy 1 μm
- Cell shape roughness Ra 0.025 μm

Theoretical model

- The model is based on tool geometry and tool feed
  - Ideal surface roughness is a function of only tool feed and geometry and it represents the best possible surface finish which can be obtained with given tool shape and feed[1]
  - Controlled waviness diamond tools are close to an ideal geometry
  - The machining setup still remains as an error source which has not been integrated into model
- The tight tolerances require a feed rate of only few tens of mm/min and tool feed (i.e. radial depth of cut) of few micrometers

[1] Krizbergs, J. & Kromanis, A. 2006. Methods for prediction of the surface roughness 3D parameters according to technological parameters. 5th International DAAAM Baltic Conference.

Theoretical model

Input:

- Tool geometry
- Surface roughness

→ **Function 1: Ideal surface roughness** →

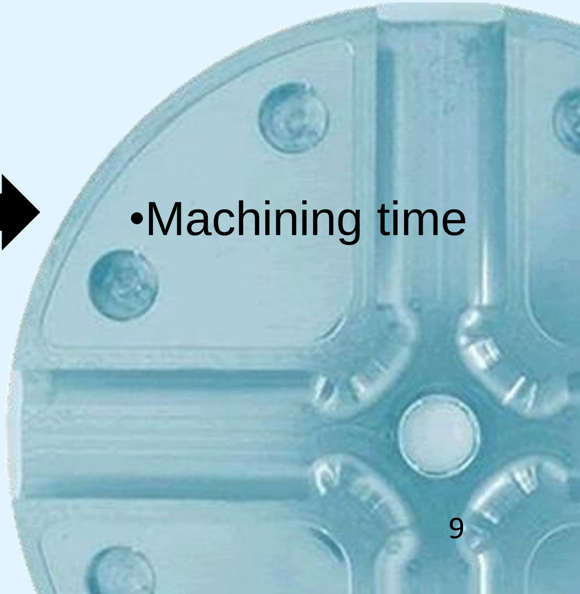
Output:

- Tool feed

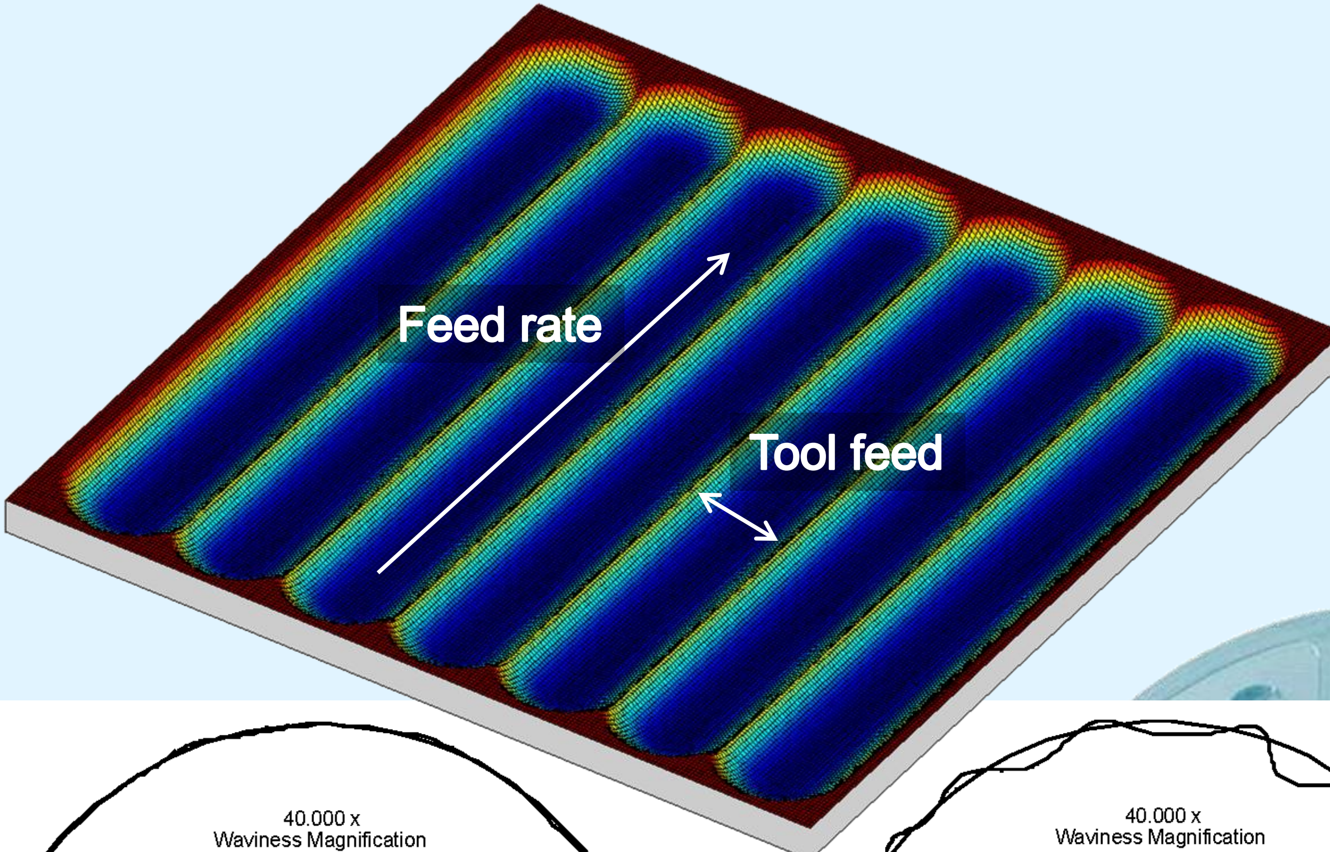
- Surface area
- Tool feed
- Feed rate

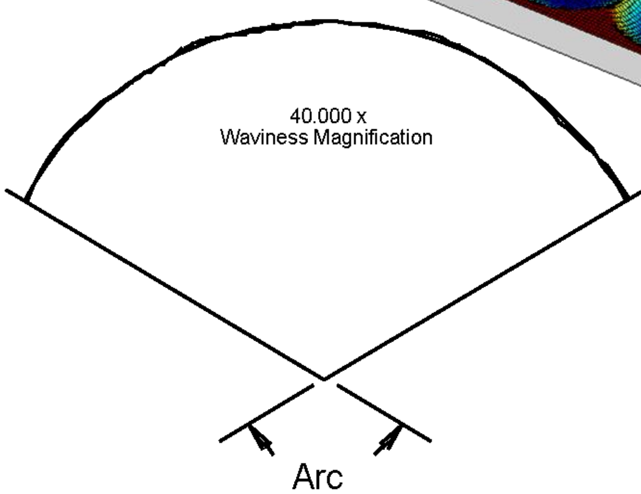
→ **Function 2: Machining time** →

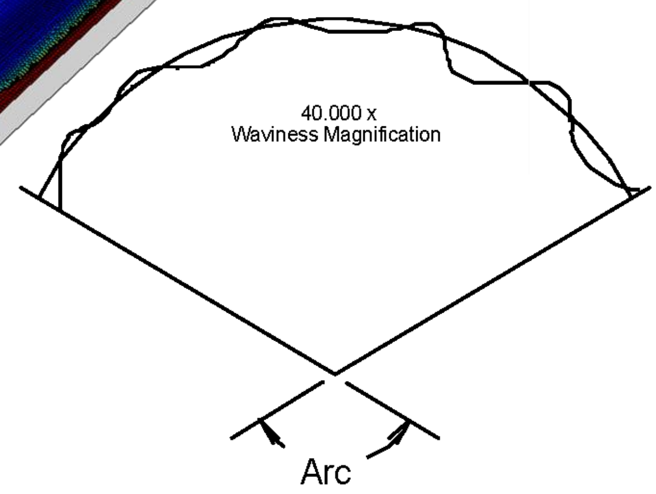
- Machining time



Surface generated by ideal ball end mill



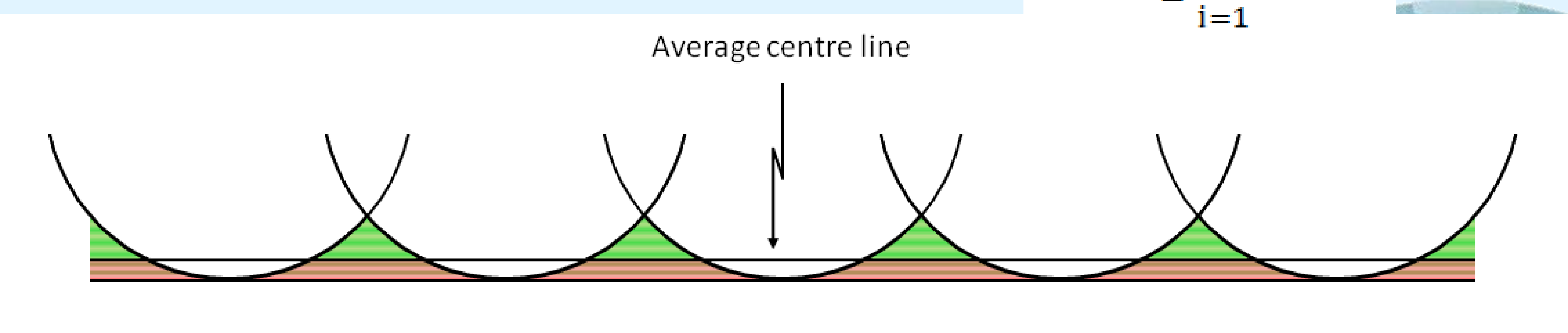




1. Calculating the ideal surface roughness Ra

- Based on the tool geometry the position of the average centre line can be calculated
- The formula defined by ISO-4287 is used to calculate surface roughness Ra for the given tool shape and feed

$$\mathrm{Ra} = \frac{1}{\mathrm{L}} \sum_{i=1}^{L} |z_i(x)|$$



$$t = \frac{A_{tot}}{Ae \cdot Vf}$$

2. Calculating the machining time

- Based on the surface roughness requirement an appropriate feed rate is selected (a tool with single cutting tooth is used)
- The time to machine a certain area can be then calculated as a function of feed rate and tool feed

$$time = \frac{Area}{tool\ feed \cdot feed\ rate}$$

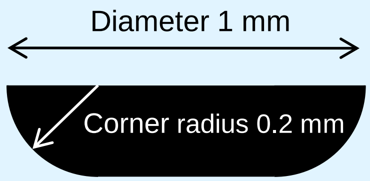
- If necessary, any of these parameters can be set to a constant value as well

Theoretical model

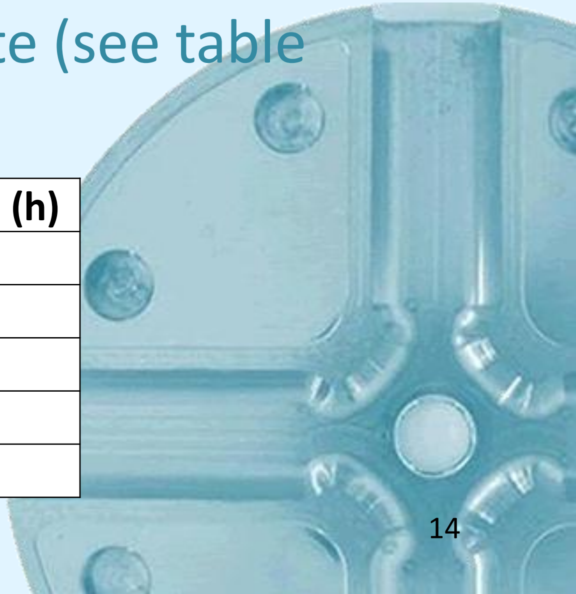
- The model was extended to cover toroidal shaped tools (tools with flat bottom and round corners)
- Same model can also be applied to turning
  - Triangle and ball shaped inserts
- The shape accuracy of the workpiece is not directly taken into account in the machining time calculations
  - A controlled waviness diamond tool and a good machining setup will improve shape accuracy
  - Most of the time the low surface roughness is the reason for long machining time

Example

- Finishing milling with toroidal tool
  - TD24 R0.5
  - Input for F1:
    - Corner radius = 0.2 mm, diameter = 1.0 mm and desired surface roughness (see table below)
  - Input for F2:
    - Area to be milled 2620 mm^2, feed rate (see table below)

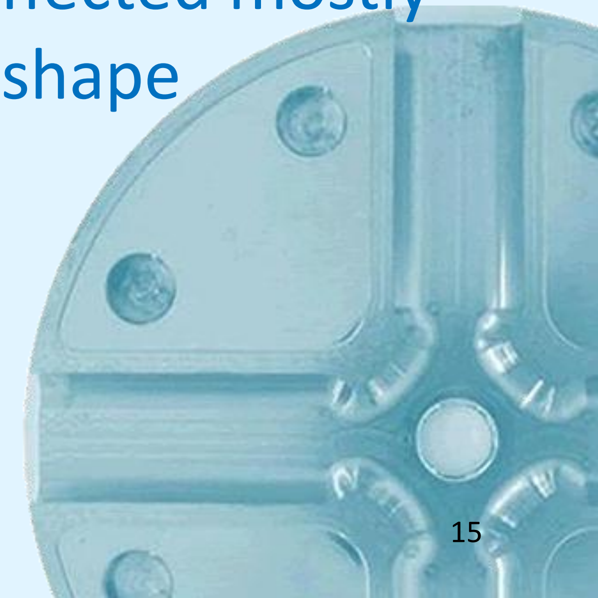


Ra (nm)	Feed rate (m/min)	**Milling time (h)**
25	13E-3	**5,2**
50	19E-3	**3,6**
75	23E-3	**2,9**
100	27E-3	**2,5**
125	31E-3	**2,1**



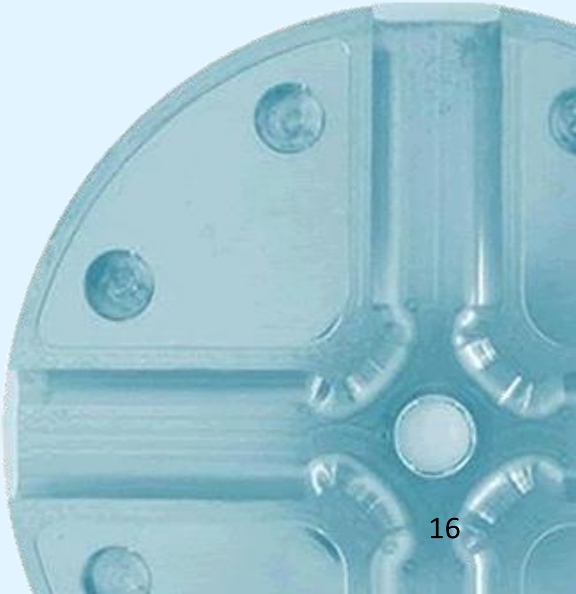
Summary

- The machining modeled by tool geometry gives the machining time for the desired surface roughness Ra and feed rate
- The very low surface roughness Ra requirement (25 nm) is the main reason for the long machining time
- Shape accuracy of the workpiece is affected mostly by the machining setup and the tool shape accuracy



Thank you for your attention

Questions?



Extras

The effects of tolerances

"RF/Breakdowns" →

"Beam Physics" ↓

Shape accuracy (µm)	Surface roughness (nm): 25	50	75	100
5	Reference			Technically unfeasible
10				
15			More conventional machining can be used	
20	Technically unfeasible			

Tools

<table>
<tr><td colspan="2"></td><td colspan="4">Surface roughness (nm)</td></tr>
<tr><td rowspan="5">Shape accuracy (µm)</td><td></td><td>25</td><td>50</td><td>75</td><td>100</td></tr>
<tr><td>5</td><td colspan="2" rowspan="2">Monocrystalline diamond</td><td colspan="2" rowspan="2">Monocrystalline diamond</td></tr>
<tr><td>10</td></tr>
<tr><td>15</td><td rowspan="2"></td><td rowspan="2">Non-controlled diamond</td><td colspan="2" rowspan="2">Polycrystalline diamond/carbide</td></tr>
<tr><td>20</td></tr>
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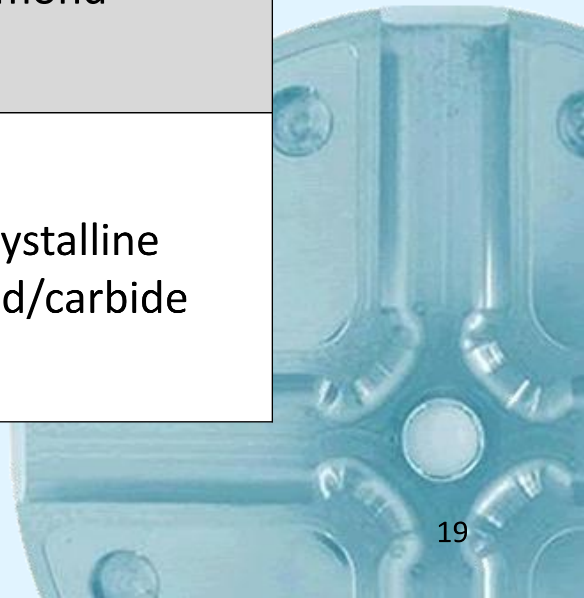

Machines

		Surface roughness (nm)			
Shape accuracy (µm)		25	50	75	100
	5	Ultra precision machine	Ultra precision machine	Ultra precision machine	Ultra precision machine
	10	Ultra precision machine	Ultra precision machine	Ultra precision machine	Ultra precision machine
	15	Ultra precision machine	Ultra precision machine	High precision machine	High precision machine
	20	High precision machine	High precision machine	High precision machine	High precision machine

Machined surface