Fast-tool-servo diamond turning of free-form intraocular lenses from hydrophobic acrylic polymer

euspen SIG - Micro/Nano Manufacturing

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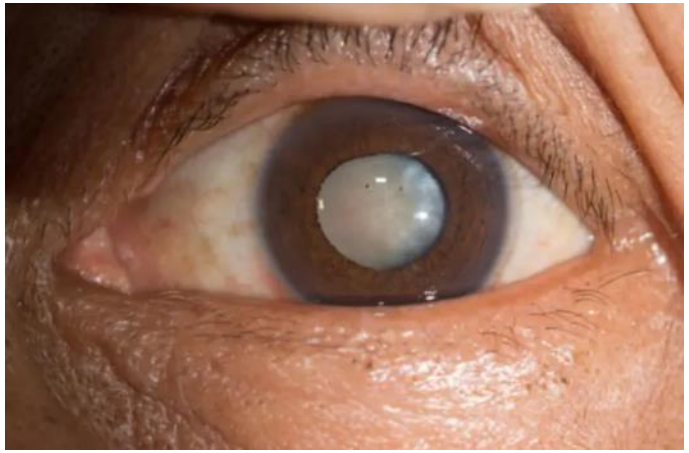
What is intraocular lens (IOL)?

from mass production to made-to-order

Normal eyesight
Source: Dr. Cyres K. Mehta´s International Eye Center



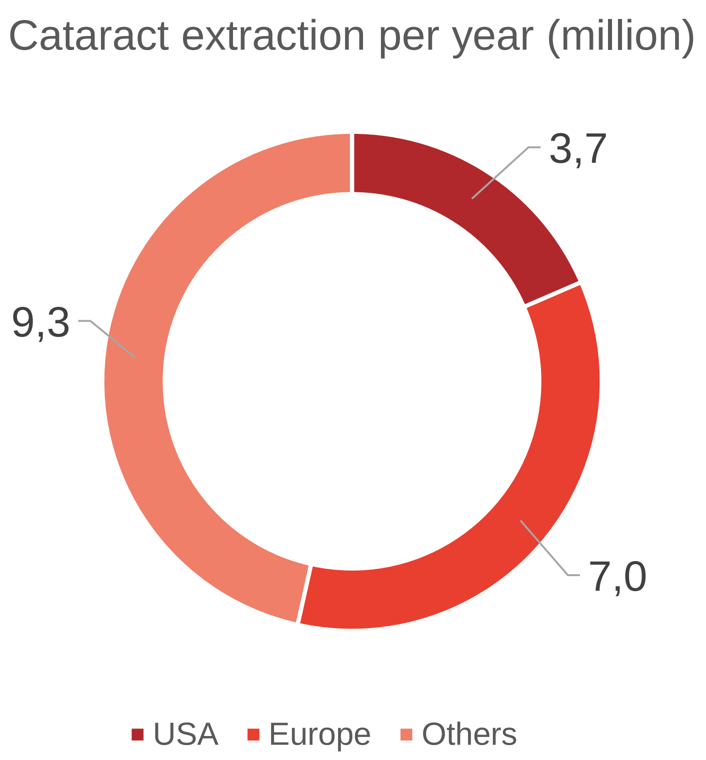
Eyes with cataract
Source: American Academy of ophthalmology

Cataracts eyesight
Source: Dr. Cyres K. Mehta´s International Eye Center

Diamond-turned intraocular lens with 4-loop haptics made of hydrophilic acrylic polymer

Motivation

Low productivity of individualized IOLs



Data source: National Institutes of Health – Cataract surgery practice patterns worldwide (2021)

Nanotech 350 FG

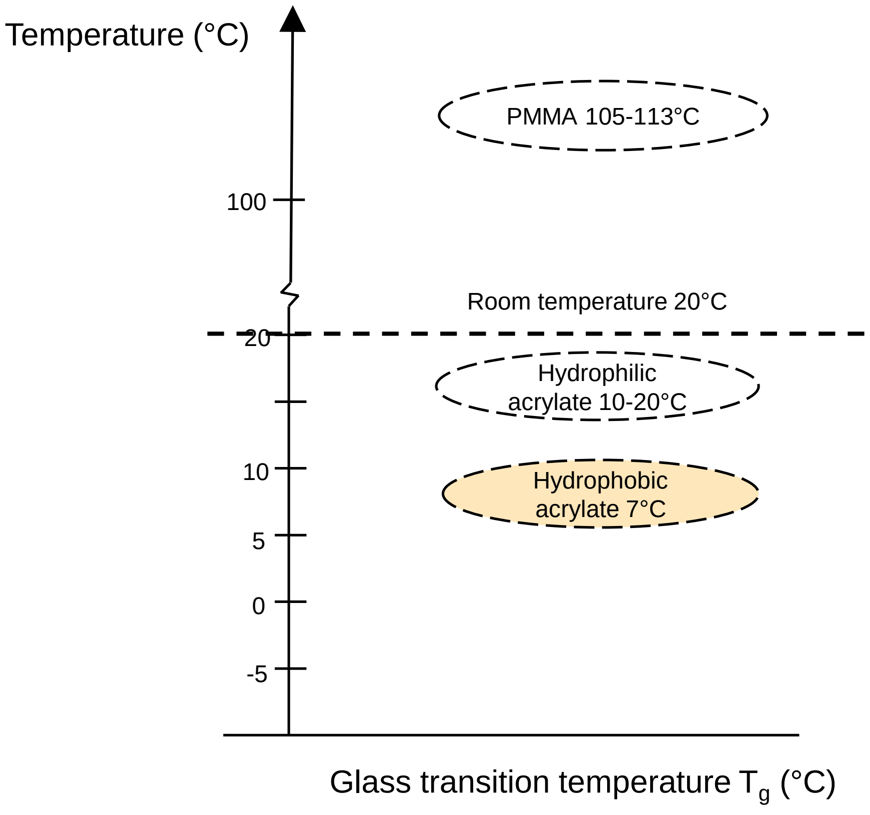
- About 800,000 cataract operations performed in Germany every year
- Production capacity is around 4,000 units per year even at unrealistic full capacity utilization

→ Only 0,5% demand could be satisfied in idealized case

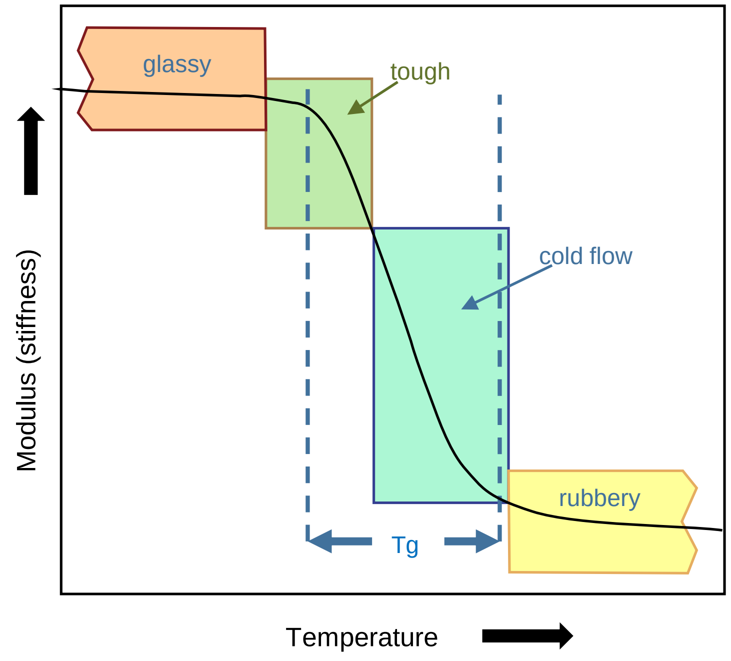
➔ Parallelized production to **increase productivity** and reduce manufacturing cost

Motivation

Uneconomical manufacturing of hydrophobic IOLs



Comparison of glass transition temperature for IOL material



Typical stiffness curve for polymers with machinability ranges

- Due to its lower glass transfer temperature, Hydrophobic acrylate must be cooled during processing

- Cooling is not needed for other materials

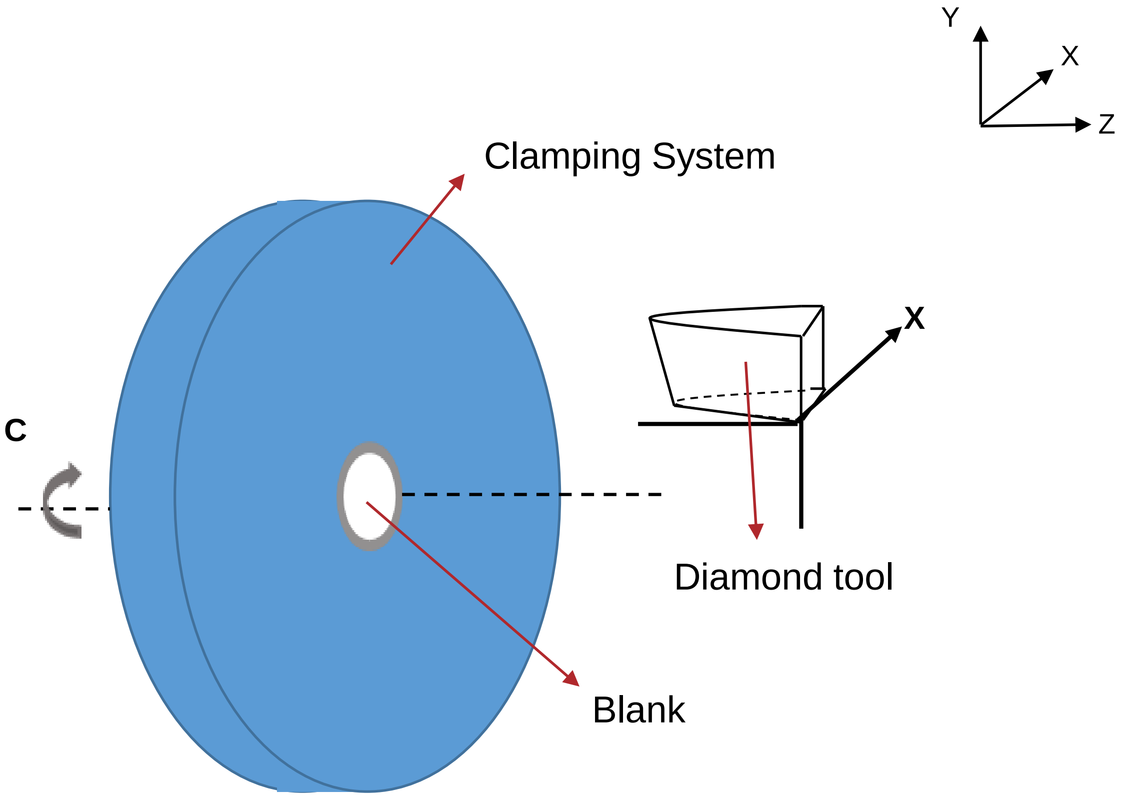
→ Hydrophilic acrylate: soft only after absorbing water after cut process

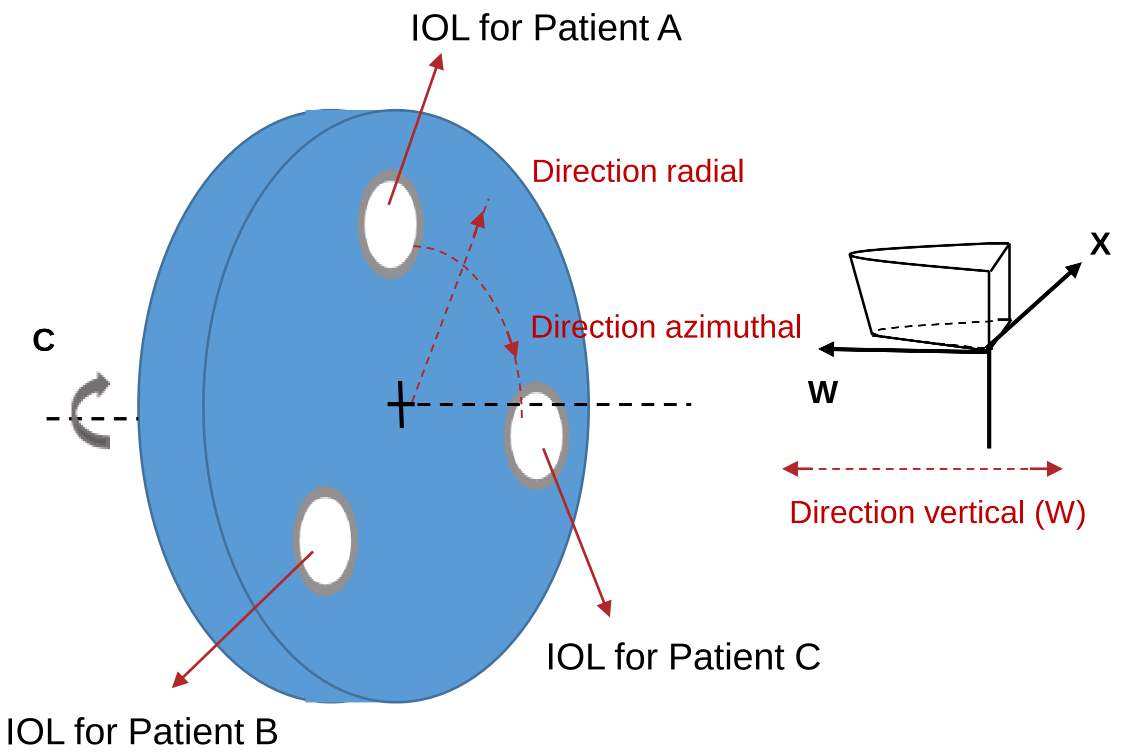
→ PMMA: much higher T_g

➔ Novel processing to **enable the economical manufacturing** of hydrophobic IOLs

Parallelized manufacturing

On-axis <-> Off-axis



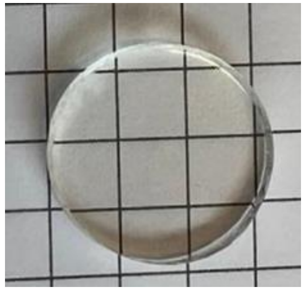


- 2-axis turning
- On-axis

- 2-axis turning + Fast Tool Servo
- Off-axis

Projekt structure

How to realize parallelized manufacturing?



Blanks of hydrophobic
acrylic polymer (D =16mm)

Simultaneous manufacturing of 3 IOLs from hydrophobic acrylic polymer

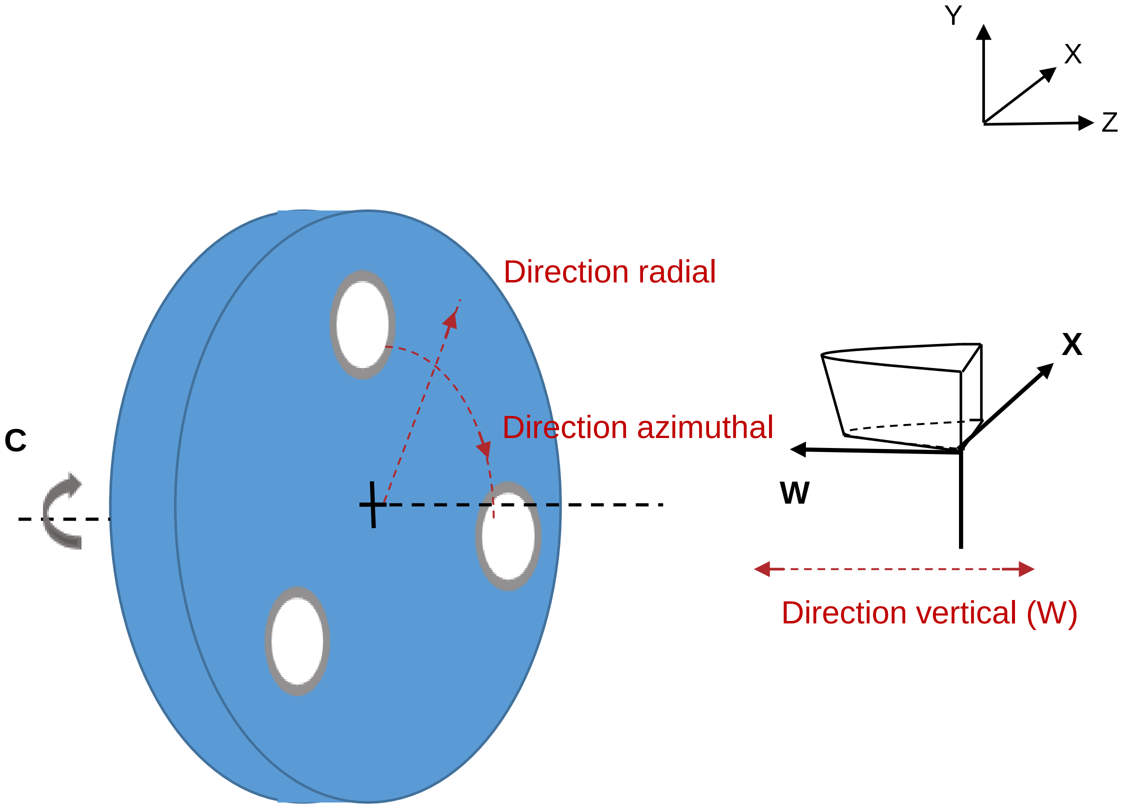
Machining of hydrophobic arcylic polymer with FTS

Clamping system for simultaneous manufacturing

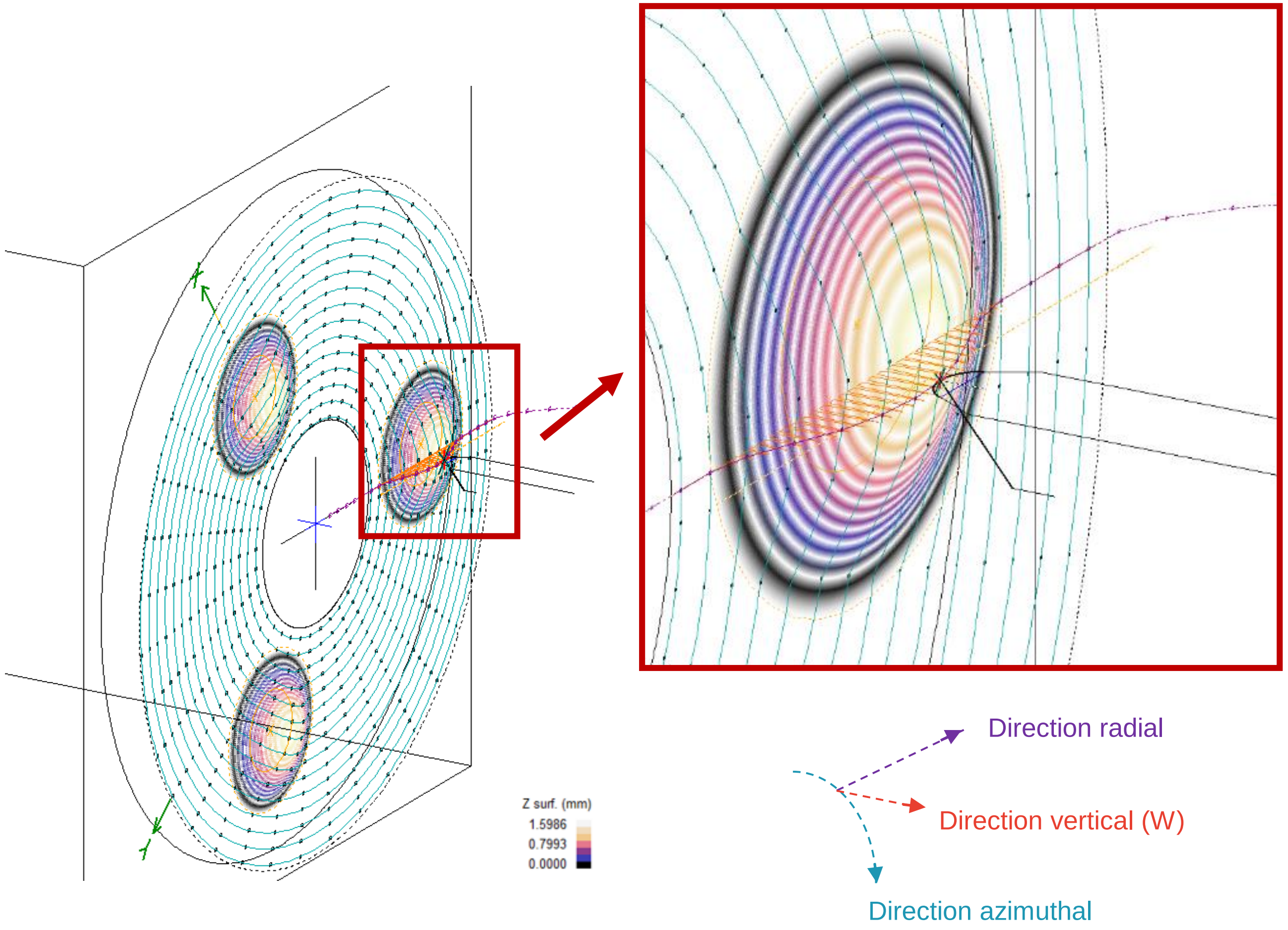
In-Process cooling

Aim IOL, with
4-loop haptics

Computer-aided manufacturing (CAM)



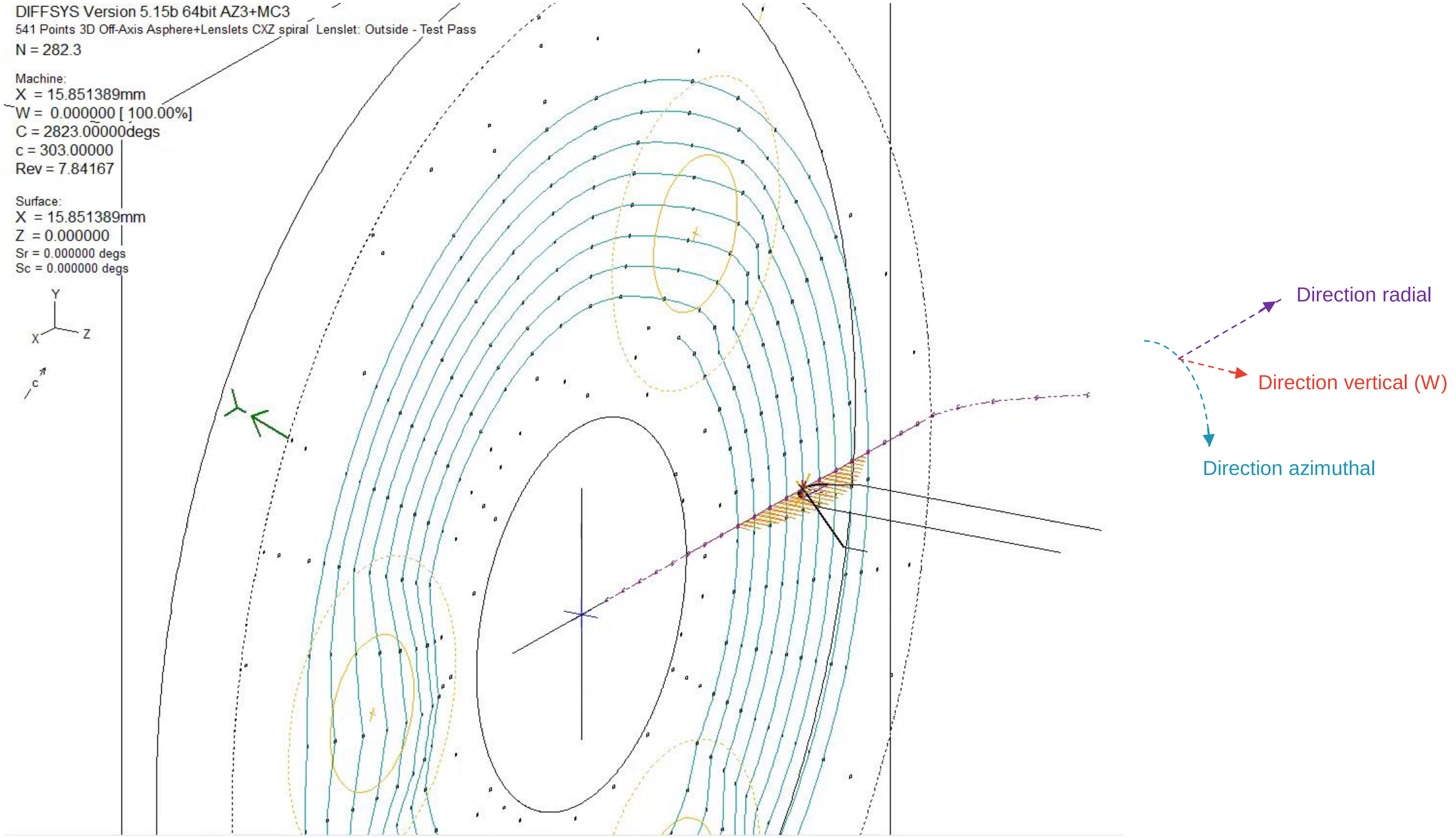
$$W = f(x, C)$$



CAM simulated tool path in azimuthal, radial and W directions; Demo IOLs with cutting path area (D = 50 mm, blue) and lens geometry (d = 6 mm, colored)

Machinability, Clamping system and In-Process cooling

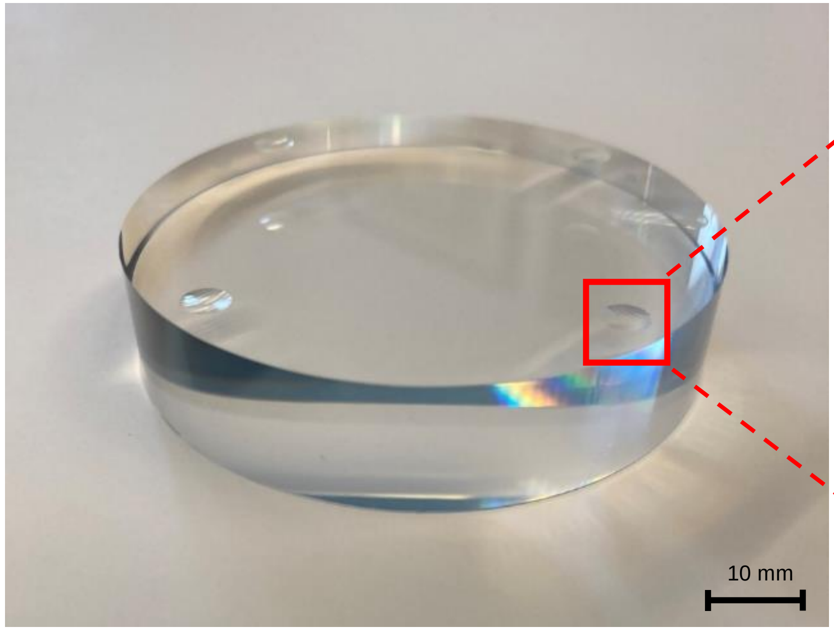
Simulation of manufacturing process in Diffsys



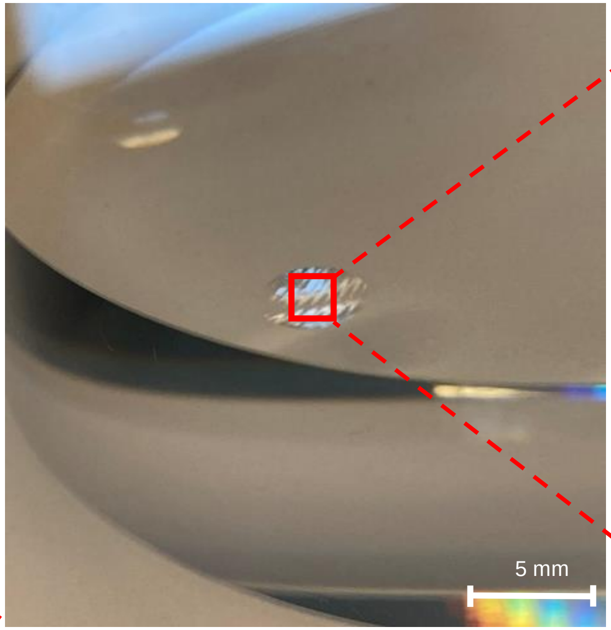
Simulation of diamond tool trajectory in Diffsys

Machinability, Clamping system and In-Process cooling

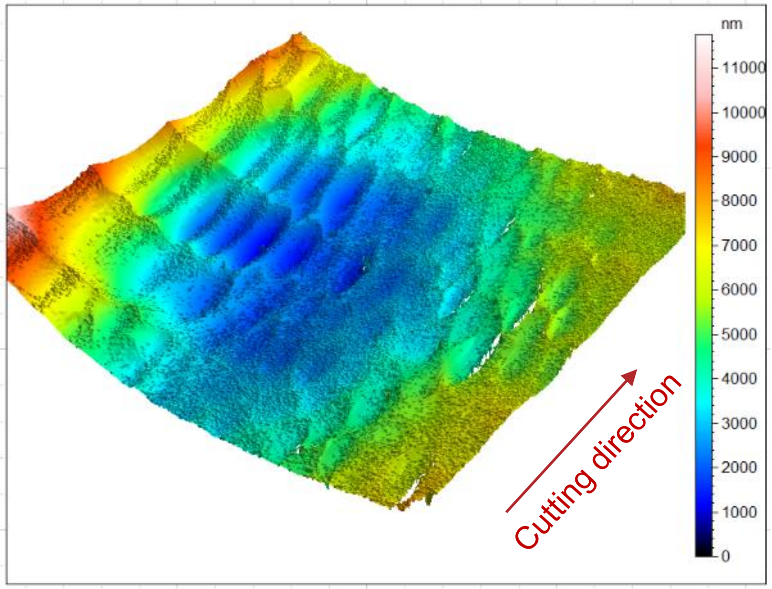
Preparatory work with PMMA



Demo lens made of PMMA, the diameter of the blank is about 60mm and the diameter of each lens is about 4.5mm



Faceting of the demo lenses

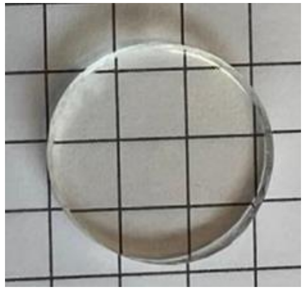


White Light Interferometry (WLI) test, 50x magnification

Machining parameters	Demonstration	Typical example
Cutting depth a_p	*50 µm*	*5 - 10 µm*
Corner radius r_ε	*0,5 mm*	*0,5 mm*
Kinematic roughness $R_{kin} = \frac{f^2}{8 \cdot r_\varepsilon}$	*100 nm*	*10 nm*
Feed *f*	*20 µm/Revolution* *(V_f = 2 mm/min und n =100 1/min)*	*6,3 µm/Revolution*

Project structure

How to realize parallelized manufacturing?



Blanks of hydrophobic acrylic polymer (diameter about 16mm)

Simultaneous manufacturing of 3 IOLs from hydrophobic acrylic polymer

Machining of hydrophobic arcylic polymer with FTS

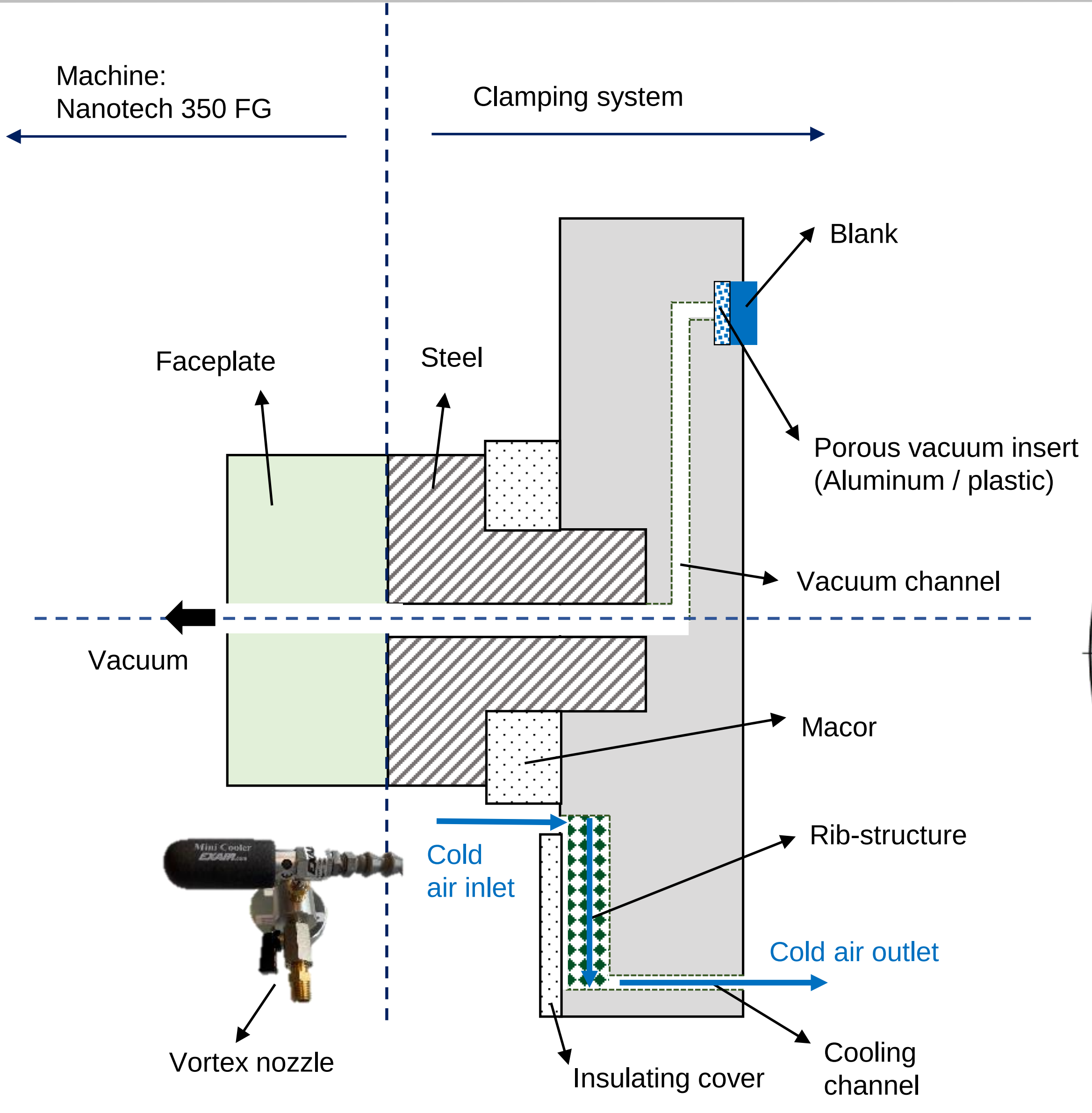
Clamping system for simultaneous manufacturing

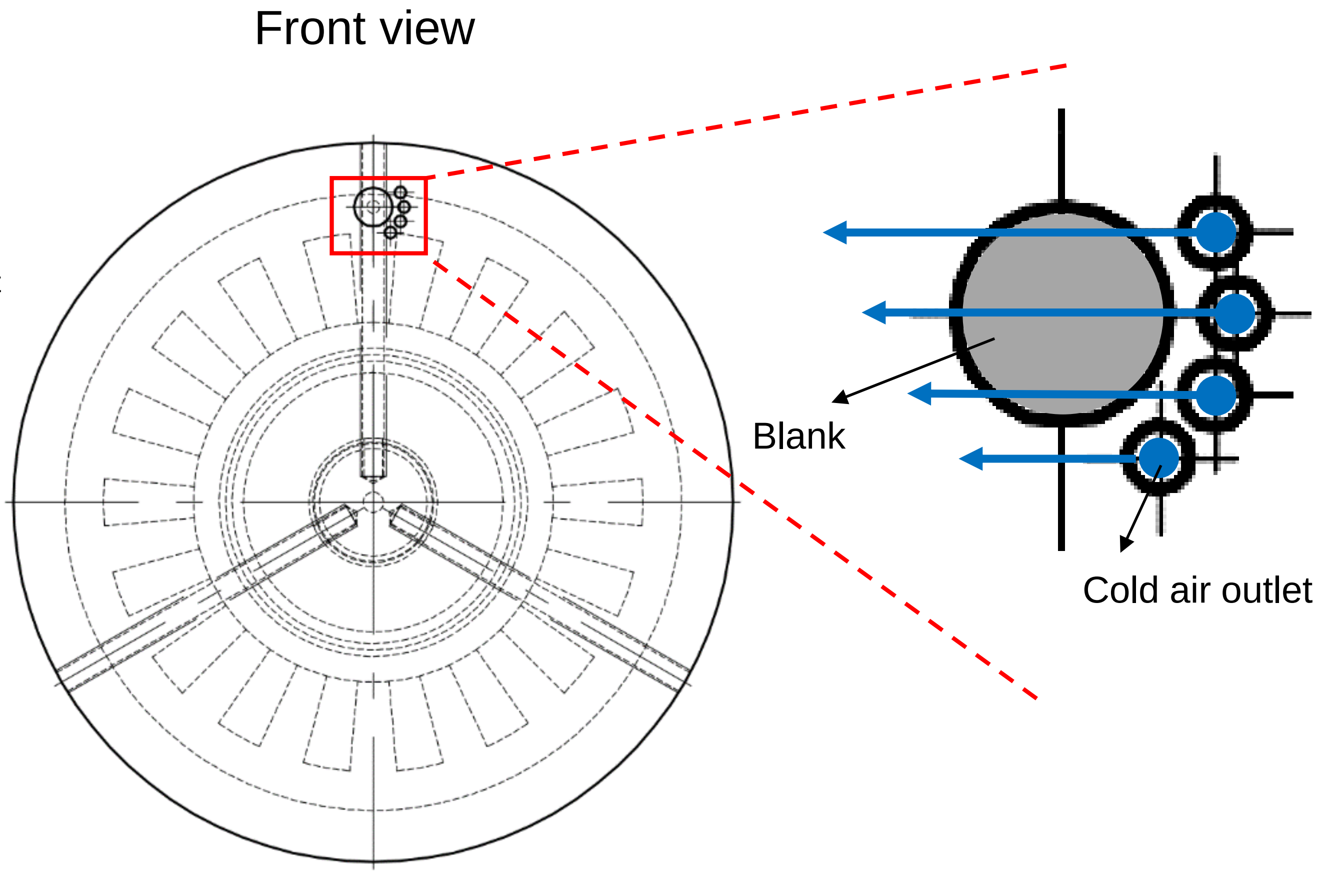
In-Process cooling

Aim IOL, with 4-loop haptics

Machinability, Clamping system and In-Process cooling

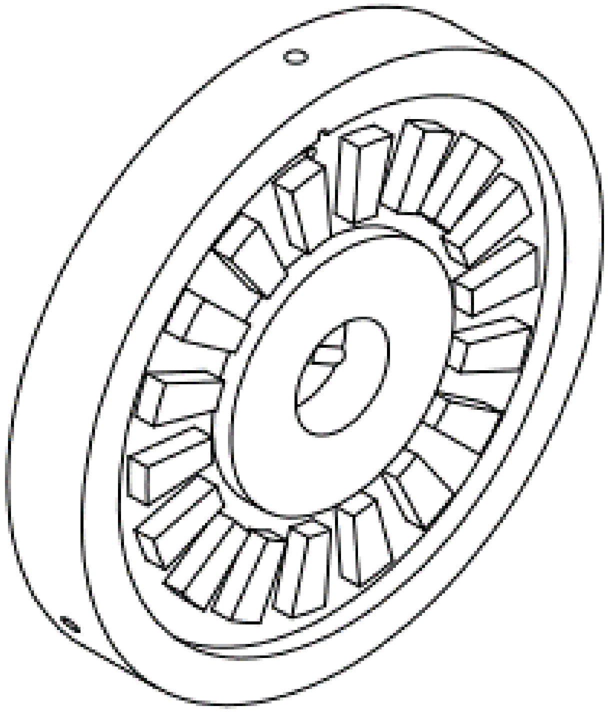
Clamping system with embedded cooling



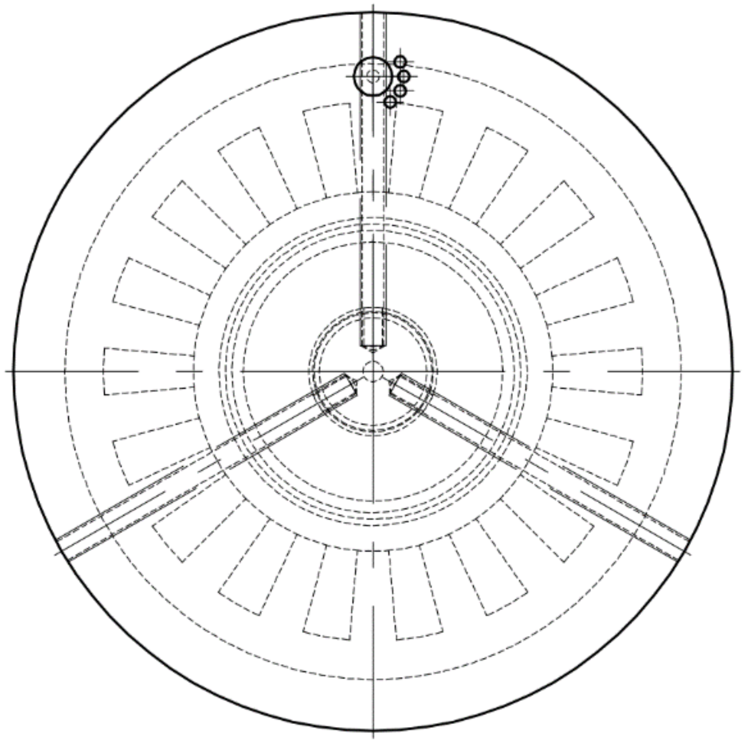


Drawings

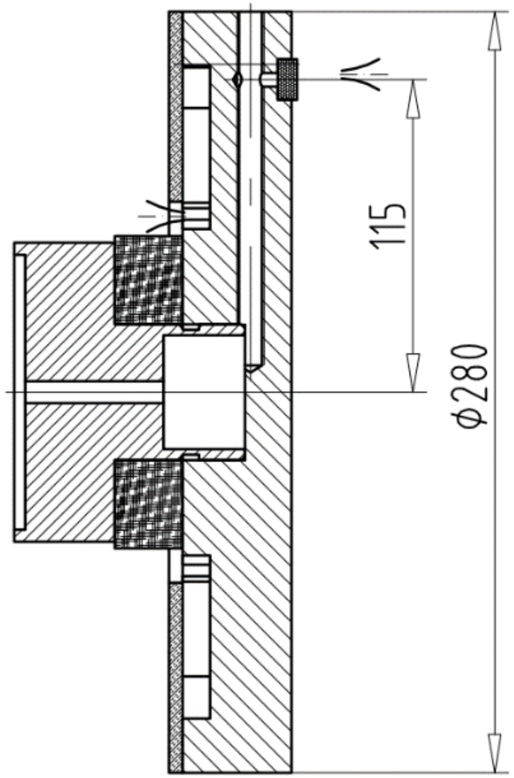
Backside



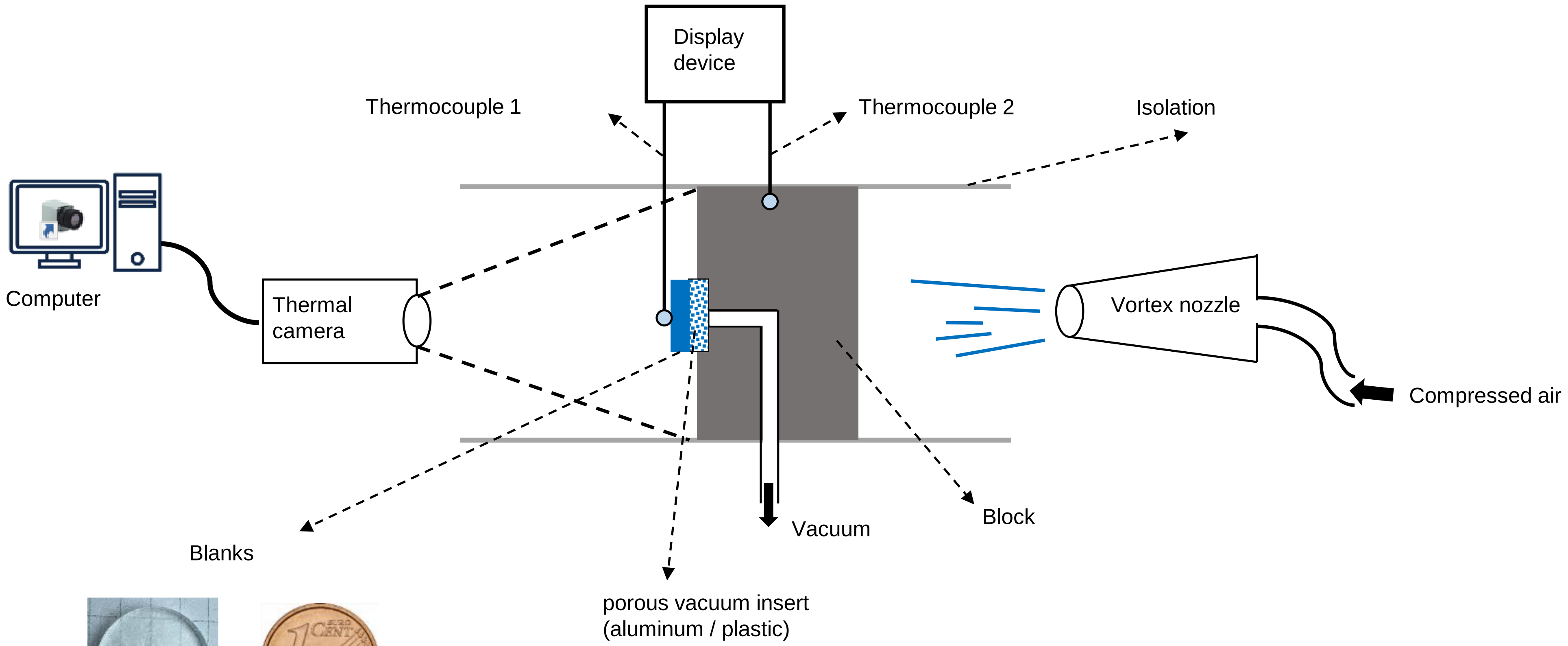
Front view



Side view

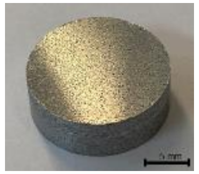


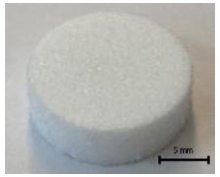
Concept for measuring cooling performance and thermal conductivity




PMMA


1 cent coin

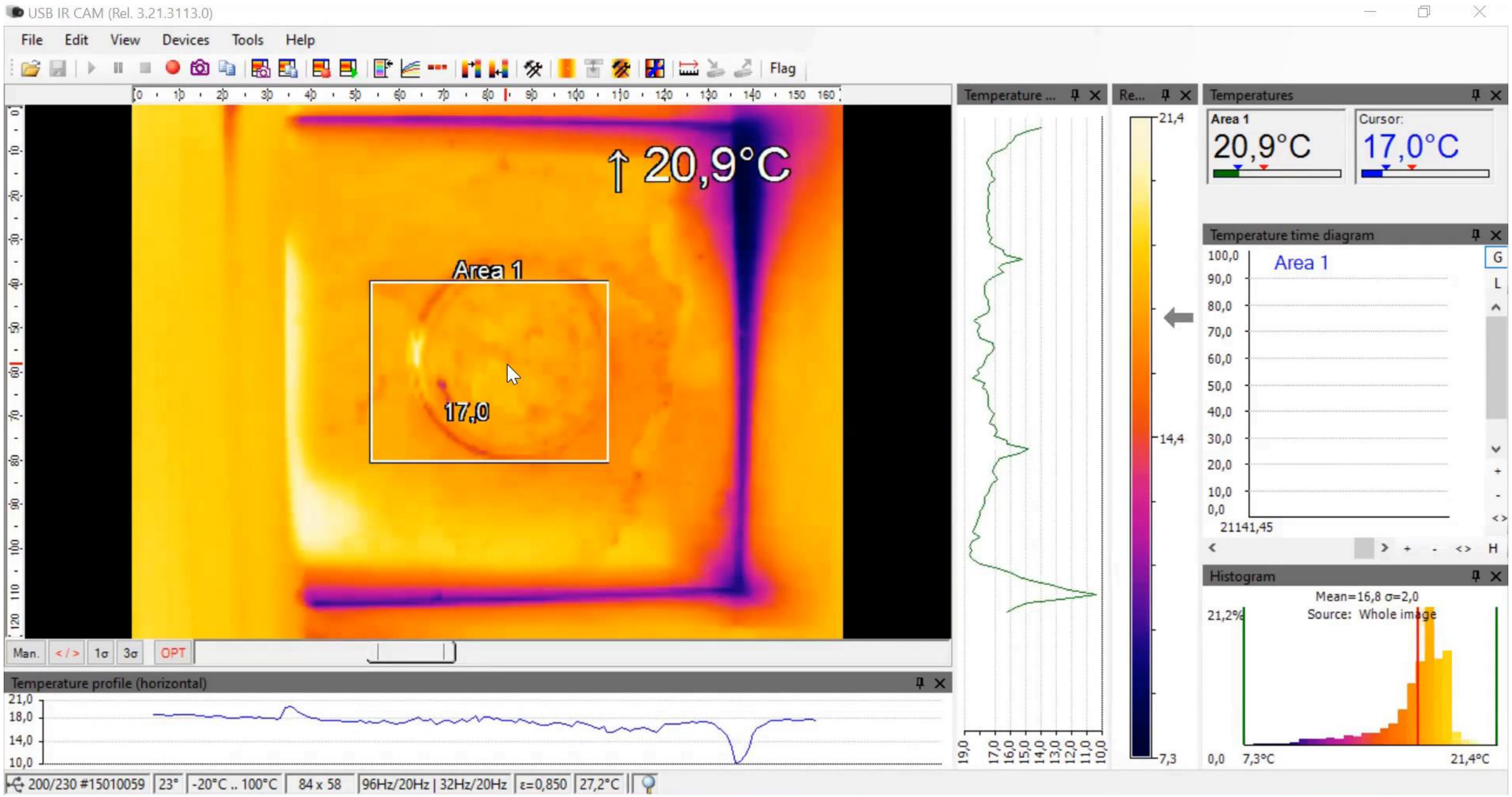

Porous aluminum insert


Porous plastic insert

Machinability, Clamping system and In-Process cooling

Recorded cooling process with thermal camera

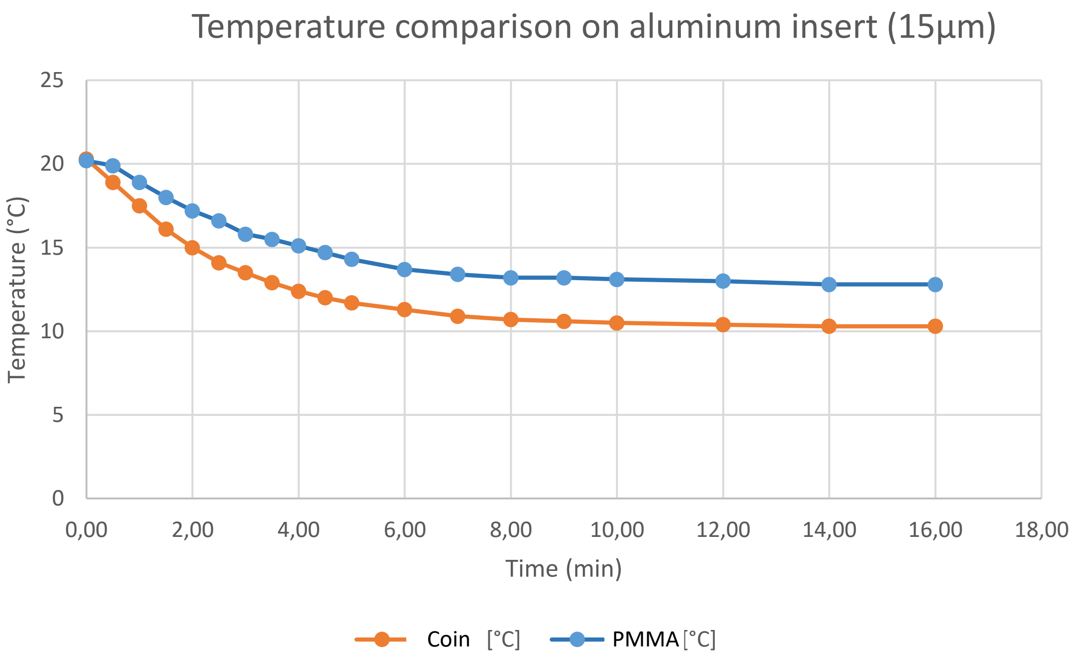
IWT
Leibniz-Institut für Werkstofforientierte Technologien



Cooling performance test recorded with thermal imaging camera PI200, accelerated 16x

Machinability, Clamping system and In-Process cooling

Evaluation of the cooling test results



- The temperature at the outlet of the nozzle is approx. 5 °C
- The lowest temperature on the processing surface that can be achieved with the vortex nozzle is approx. 10 °C

➔ More powerful cooling device is needed

Conclusion

Simultaneous manufacturing of 3 IOLs from hydrophobic acrylic polymer

Machining of hydrophobic arcylic polymer with FTS

- Machinability of PMMA with FTS has been proven
→ hydrophobic polymer
- Research on manufacturing parameters
→ optical surface

Clamping system for simultaneous manufacturing

- Design → Construction
- Dynamic performance

In-Process cooling

- More powerful cooling device
- Dynamic cooling performance

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