PAUL SCHERRER INSTITUT PSI

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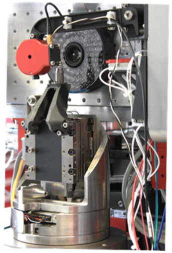
Application of Additive Manufacturing in the Development of a Sample Holder for a Fixed Target Vector Scanning Diffractometer at SwissFEL

With contribution of Jan Hora, Patrick Hirschi, Haimo Jöhri, Claude Pradervand and Bill Pedrini

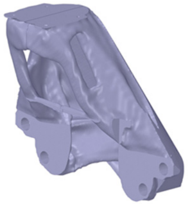
Medsi 2018, Paris, 25-29 June 2018

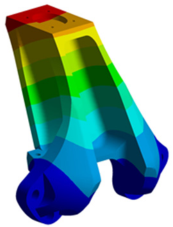
Outline

- Introduction MX at SwissFEL
  - Design requirement

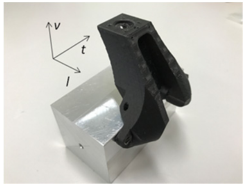


- Design for additive Manufacturing
  - Form finding with topology optimisation
  - From simulation to design



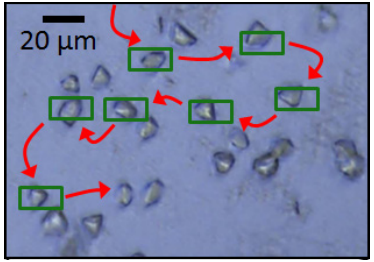


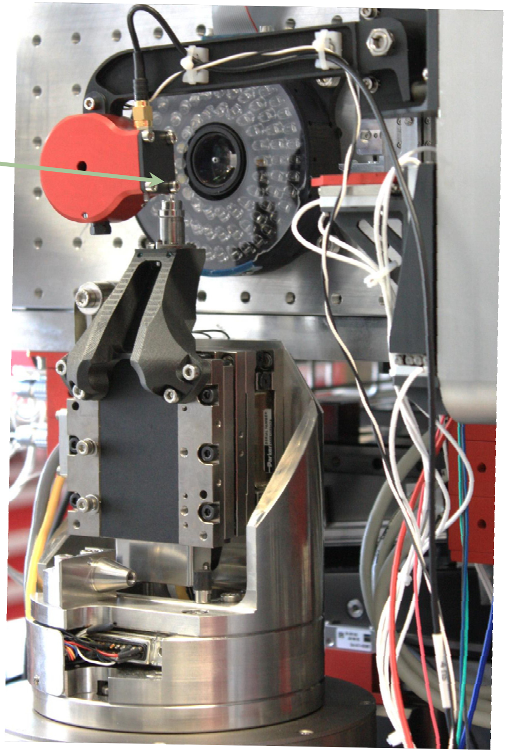
- Qualification test



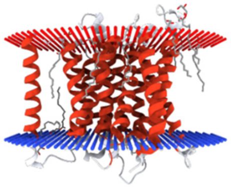
Serial protein crystallography

Sample chip

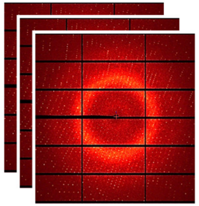




protein structure

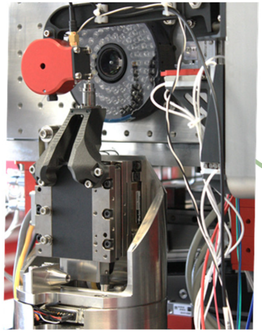


Serial dataset

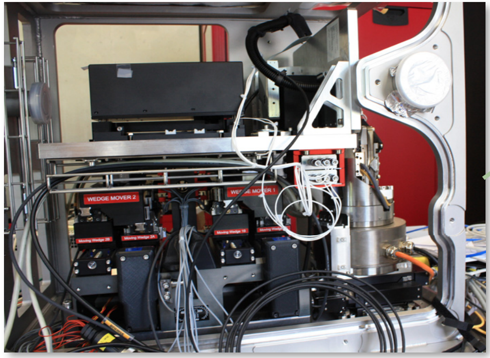


Courtesy of Isabelle Martiel

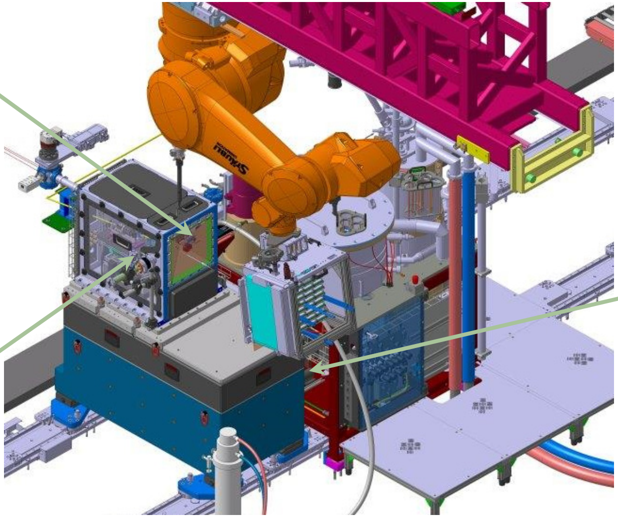
Macromolecular Crystallography (MX) at SwissFEL



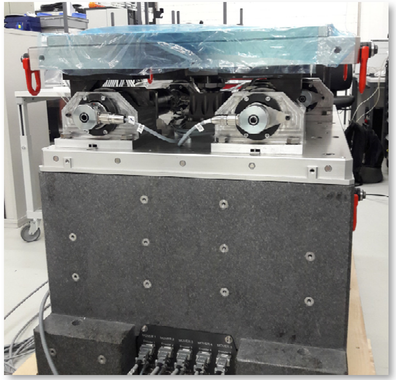
Sample diffractometer



Experiment chamber



MX at SwissFEL endstation Bernina



Chamber is supported by movers with eccentric cam-shaft drivers and on a granite block

Sample diffractometer

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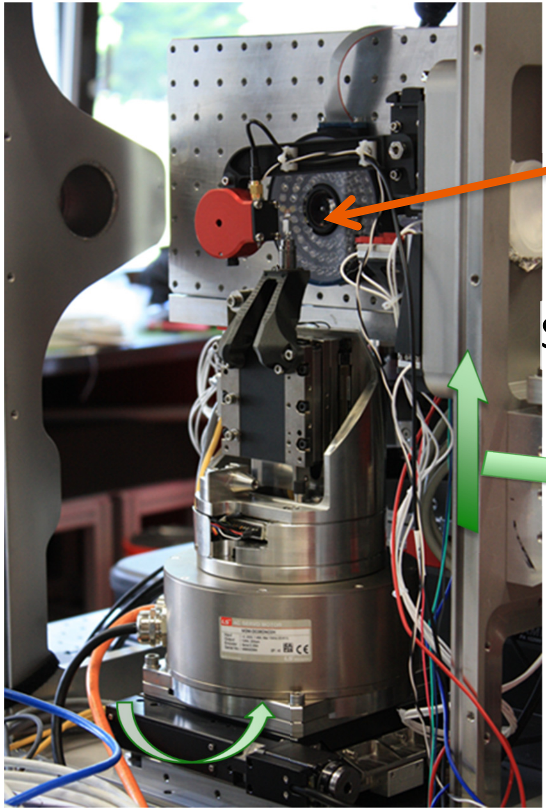
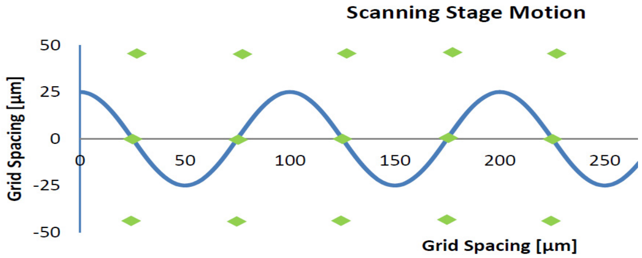


X-rays

Scanning Stage Y

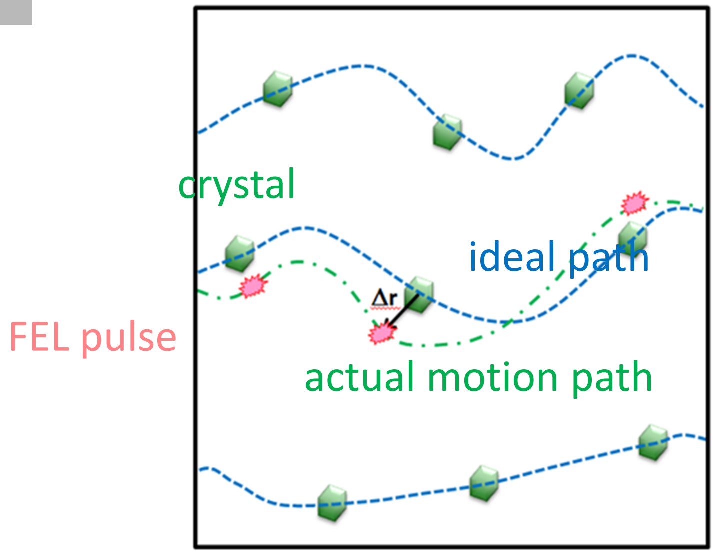
Scanning Stage X

Y rotation(Omega)



Specification

Total error budget $\Delta r < 1.2\ \mu m$



Parameter	Required
Range in X and Y	10 mm
Max speed	10 mm/sec
Max acceleration	2.5 m/s^2
Frequency	50 Hz
Eigenfrequency	400 Hz
Sample holder deformation	200 nm
Weight of sample holder + sample pin	100 g
Ambient vibrations	100 nm

Design goals

Design goal of sample holder

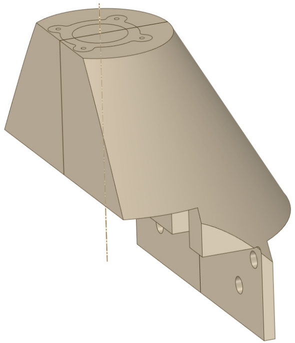
- Weight < 70 g → light
- Deformation < 200 nm with maximal 2.5 m/s^2 at 50 Hz → stiff

Material

- Aluminum by traditional CNC manufacturing
- Carbon fiber composites by advanced manufacturing

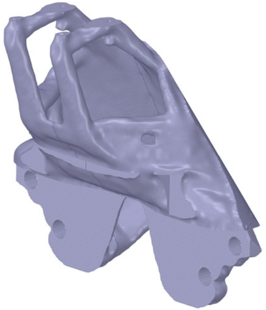
	Aluminium	Carbon composite UD	Micro-carbon reinforced Polyamide
Density/ g/cm^3	2.7	1.4	1.2
Tensile modul/GPa	70	54	1.4
Bending modul/GPa	70	51	2.9

Topology optimisation

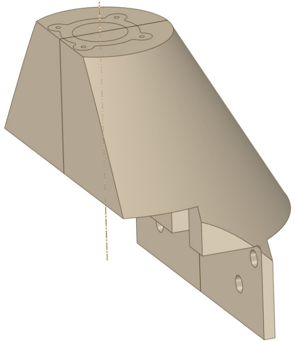


design space and constraints defined in CAD

Topology optimisation



Maximize the 1st eigenfrequency



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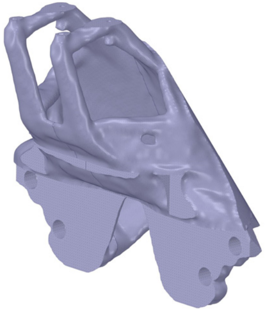
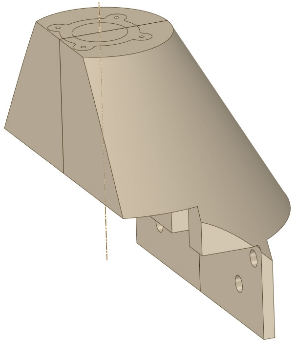
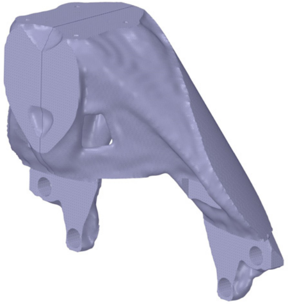
Topology optimisation



Maximize the 1st eigenfrequency

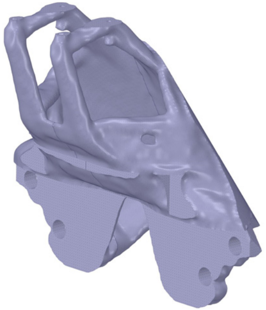




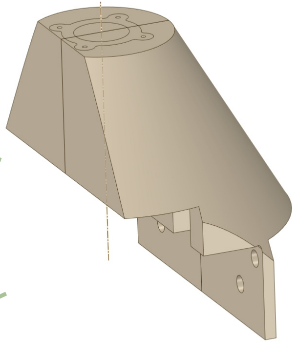
Maximize the 1st and 2nd eigenfrequencies,
Corresponding to the two scanning directions

design space and constraints
defined in CAD

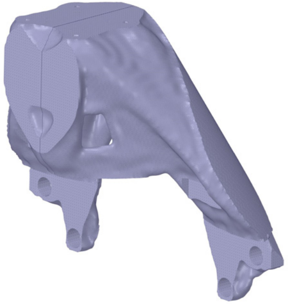
Topology optimisation



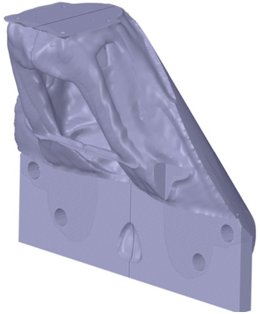
Maximize the 1st eigenfrequency



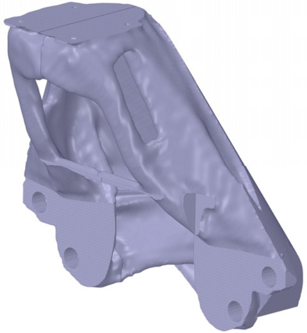
design space and constraints defined in CAD



Maximize the 1st and 2nd eigenfrequencies, Corresponding to the two scanning directions



Maximize the stiffness for two static load cases, retaining 50% volume

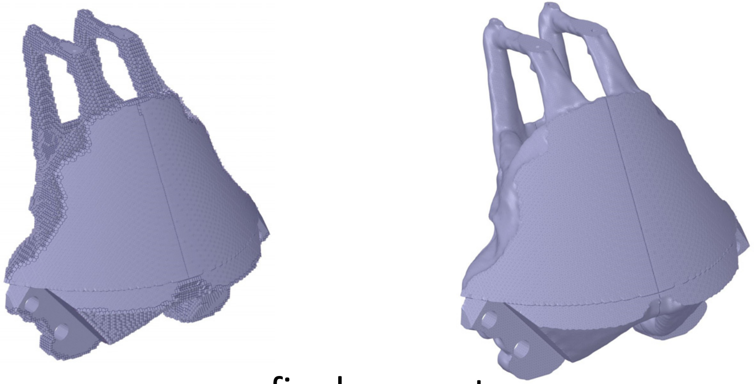


Maximize the stiffness, retaining 25% volume

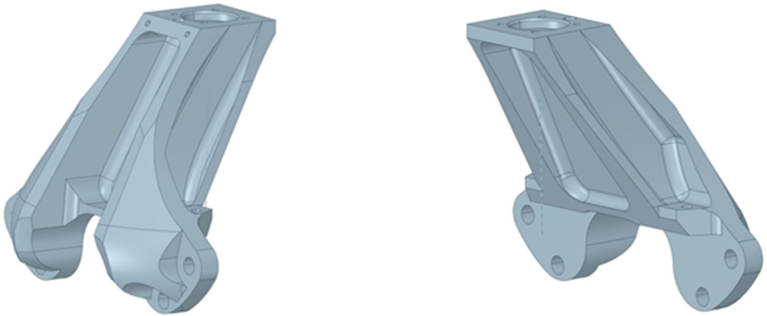
Simulation to design

Maximize the 1st eigenfrequency

Retained elements smoothed geometry



final geometry



Simulation leads not to sole optimum, but to many optima of solution in most engineering design

Solution is only as good as defined objectives (goals, responses)

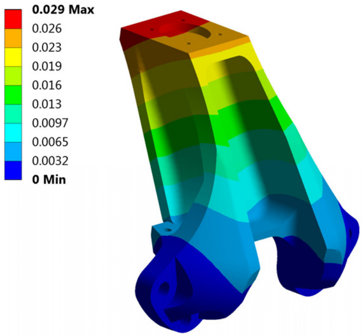
Fine tunning of geometry necessary

Final design is compromised to be CNC machiniable and 3D printable

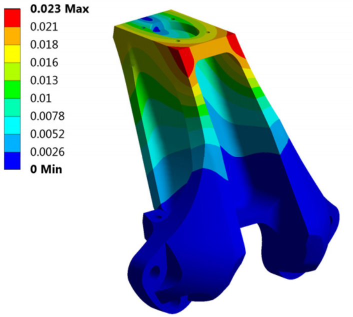
Design validation

Aluminium

a_y

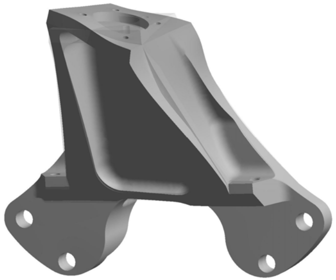


a_x



1. Mode

2. Mode



	Alu	Carbon fibre UD
m/ g	64	33
	Deformation [nm]	
a_y	29	32
a_x	23	30
	Eigenfrequency [Hz]	
f_1	790	713
f_2	1‘350	1‘206

Fibre orientation is not UD, but with 0°/45°/90°, to have a quasi isotropic stiffness.

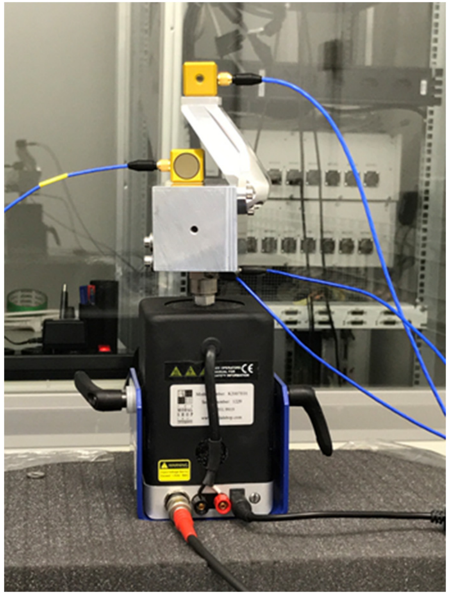
Measurement setup

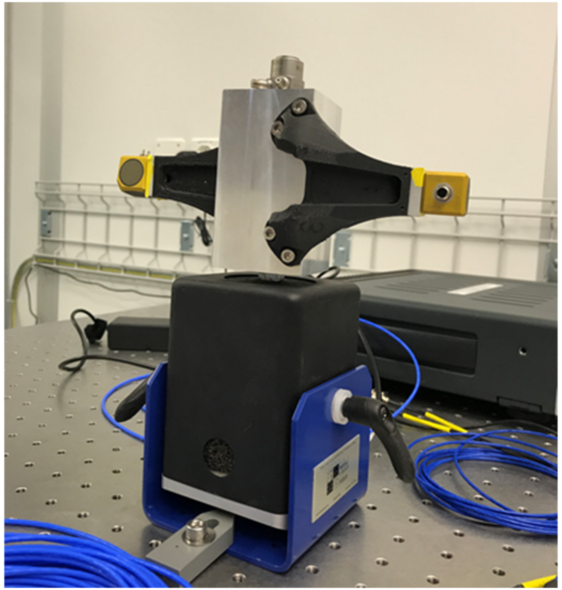
Mini SmartShaker TMS K2007/E01

Impedance sensor PCB 288D01 with one force cell and one accelerometer and two triaxial accelerometers PCB 356B18

Input acceleration signal on adaptor

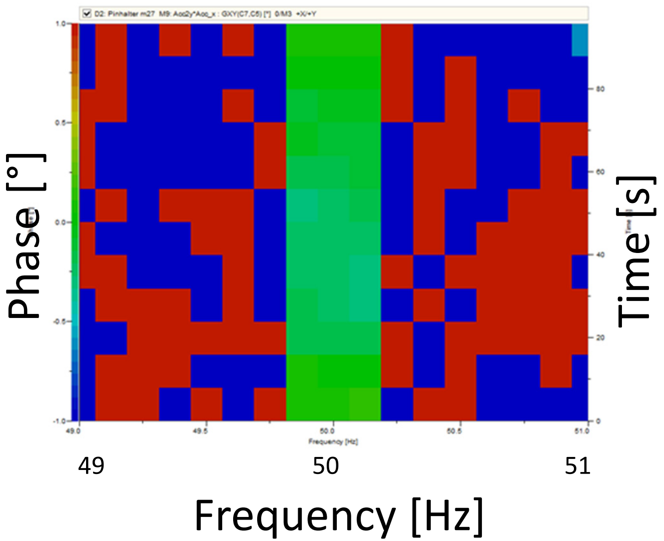
Output acceleration on the top of sample holder

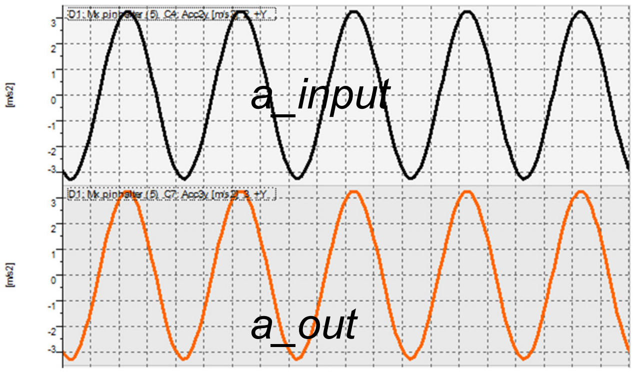




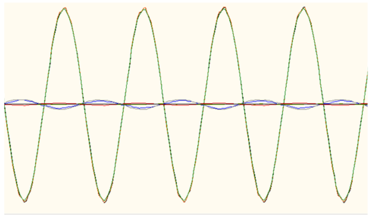
Mechanical measurement

Harmonical movement at 50 Hz with 3.3 m/s^2
Phase shift of the output and input is calculated at excitaion frequency.





The error source ist off-axis movement



Mesaurement results

4 samples have been tested:

M1: 3D printed micro-fibre reinforced polyamide

M2, M3: 3D printed carbon fibre with quasi isotropic orientation

M2 was printed from curved side

M3 was printed from flat side

M4: Aluminium

	Aluminium M4	Composites M2/M3
m/ g	63	40
Vertical		
Phase [°]	0.16	0.36
Transversal		
Phase [°]	-	0.31

Summary and Outlook

- Topoloy optimisation plays a key feature in advanced manufacturing. Sample holder geometry is compromised to be both CNC machinable and 3D printable
- Both aluminum, and endless carbon fibre reinforced composite are qualified. Mirco-fibre reinforced polyamide has a phase shift more than 4 time of the part with endless carbon fibre, and is too soft
- Aluminium part is though more stiff, but is 50% heavier. The 3D printed composite is prefered for the application at SwissFEL MX
- Additive manufacturing with carbon fibre reinforced composites enables a light and stiff part with complex and optimized geometry. Further knowledge on material properties , printing process still need to be gained

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Acknowelges

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- Peter Hottinger for assistance in the measurement

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