
CERN

Prototype microwire braiding machine

Master's Thesis Presentation

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Background

CERN's Wire Scanners:

- Measure the transverse beam particle density **profile**
- 12 **carbon yarns** of 7 μm diameter used
- Stronger wires necessary for higher power beams

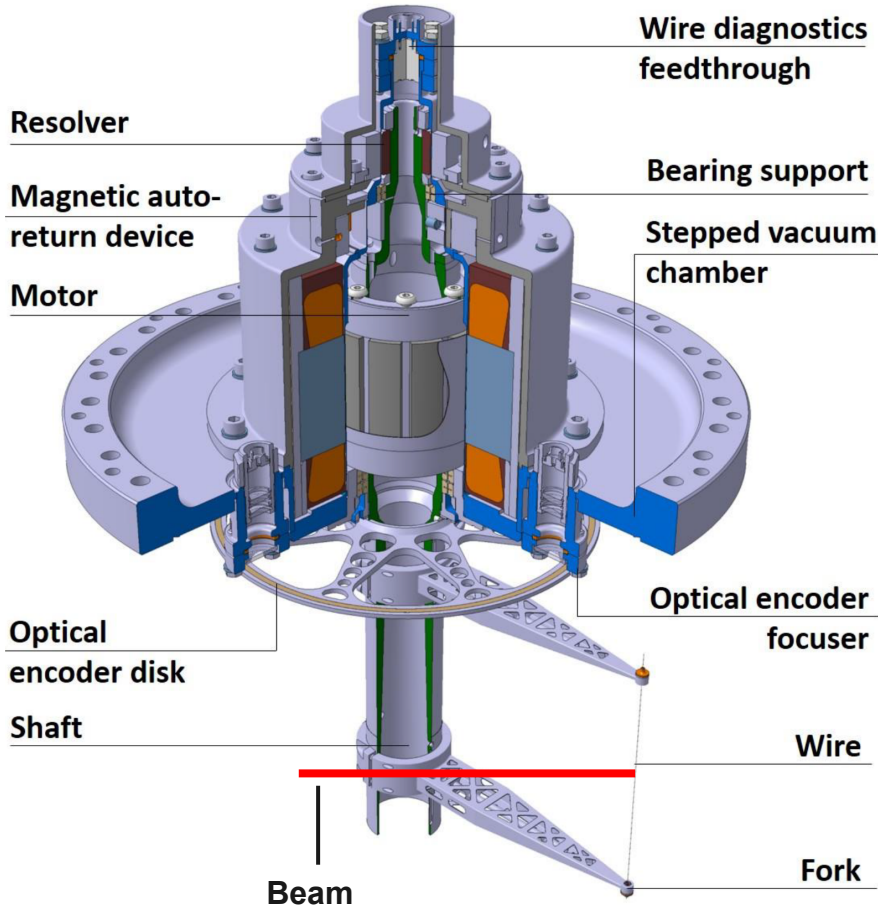


Fig. : Part-section through PSB kinematic unit. Veness, R., Andersson, P., Andreazza, W., Chritin, N., Dehning, B., Emery, J., … Blasco, J. L. S. (n.d.). INSTALLATION AND TEST OF PRE-SERIES WIRE SCANNERS FOR THE LHC INJECTOR UPGRADE PROJECT AT CERN, 412–414.

Problem Statement

- Currently wires are **twisted** manually
- Extremely **thin wires**
- Small **quantity** needed
- **Customization** for different instruments

Research Objective

Produce high quality braided micro wires

- Braiding **regularity**
- **Packing** factor

Project approach

- State of the art
- Challenges
- Wire assessment
- Design process
- Machine testing
- Wire evaluation

State of the art

Wire braiding

- Braiding methodologies **largely unchanged** during the last century

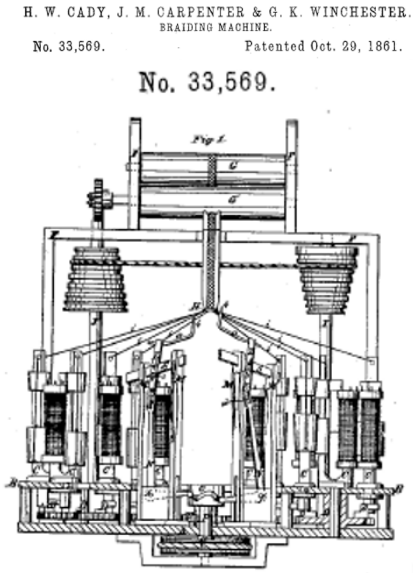

H. W. CADY, J. M. CARPENTER & G. K. WINCHESTER.
BRAIDING MACHINE.
No. 33,569. Patented Oct. 29, 1861.
No. 33,569.

Fig.: US Patent No. 33,596.

Microwire braiding

- Limited literature
- Focused in different material and topologies

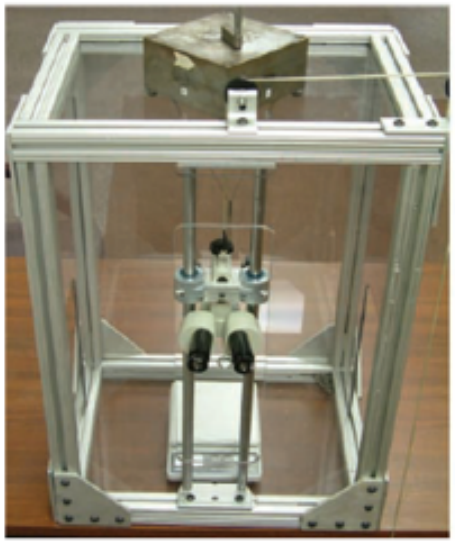


Fig.: 3TEX microwire braiding machine

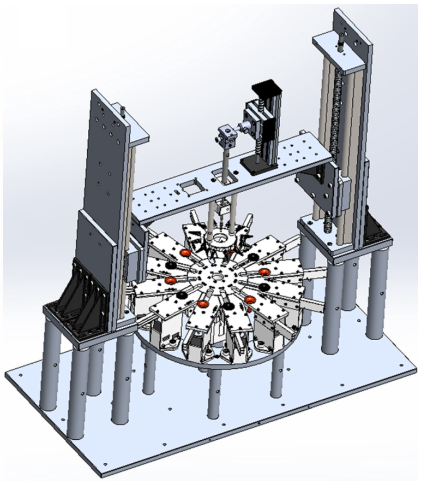


Fig.: "Highly Flexible Precisely Braided Multielectrode Probes and Combinatorics for Future Neuroprostheses", Taegyo et al

Challenges

Braiding **topology:**

- Tight packing for maximum sampling

Yarns **availability:**

- Material
- Diameters
- Length
- Format
- Quantity

Yarns **dimensions:**

- Unable to use commercial braiding machines
- Cannot just miniaturize the commercially available machines

Wire Assessment

Braided length:

- Machine parameter
- **Uniform** braided wire of 200 mm

Braided wavelength:

- **Regular** braiding
- **Optimum** investigation necessary

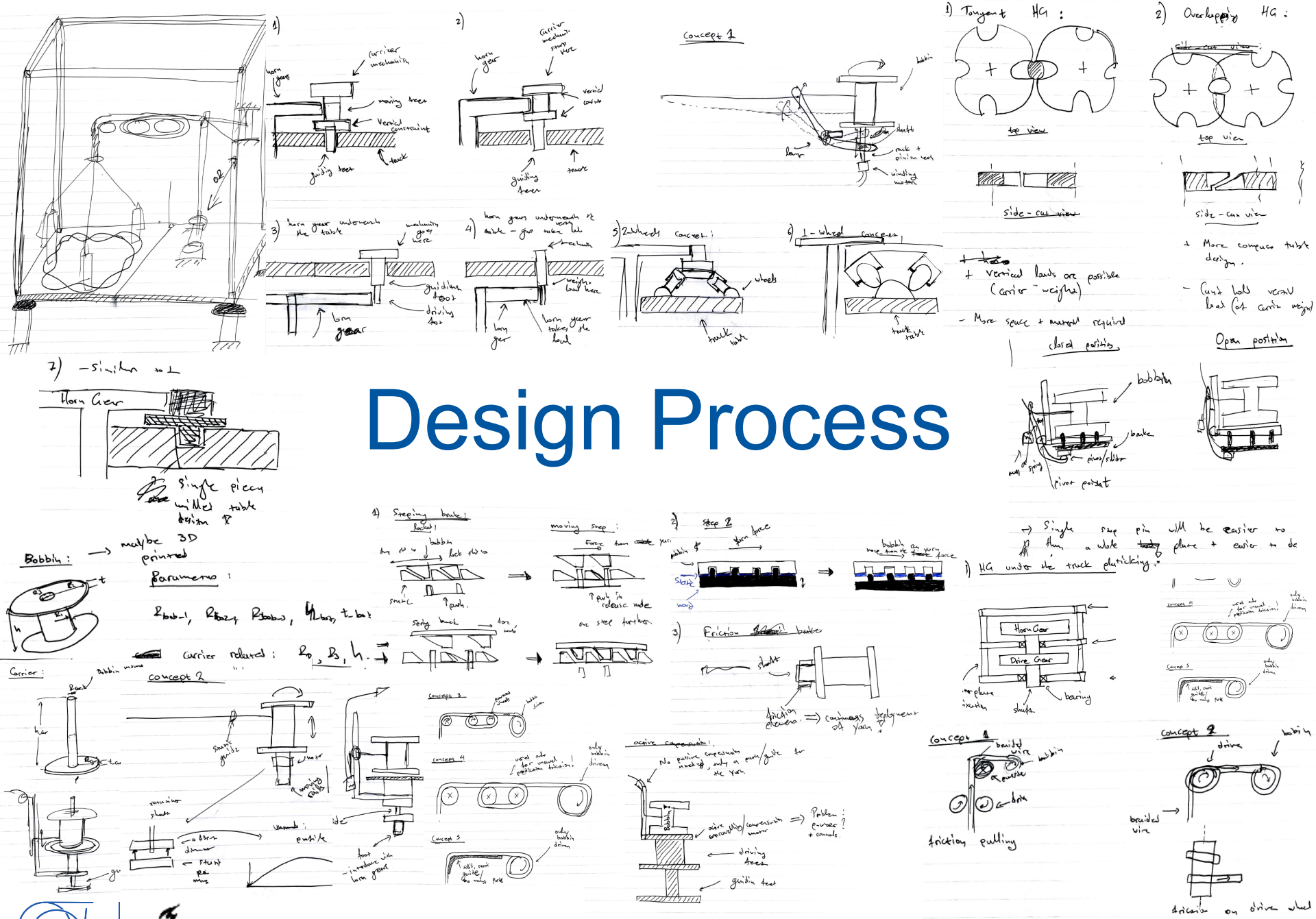
Wire packing:

- As **tight** as possible

Mechanical properties:

- **Tensile** strength tests

Design Process



Design Tools

Design **process:**

1. Conceptual
2. Preliminary
3. Detailed

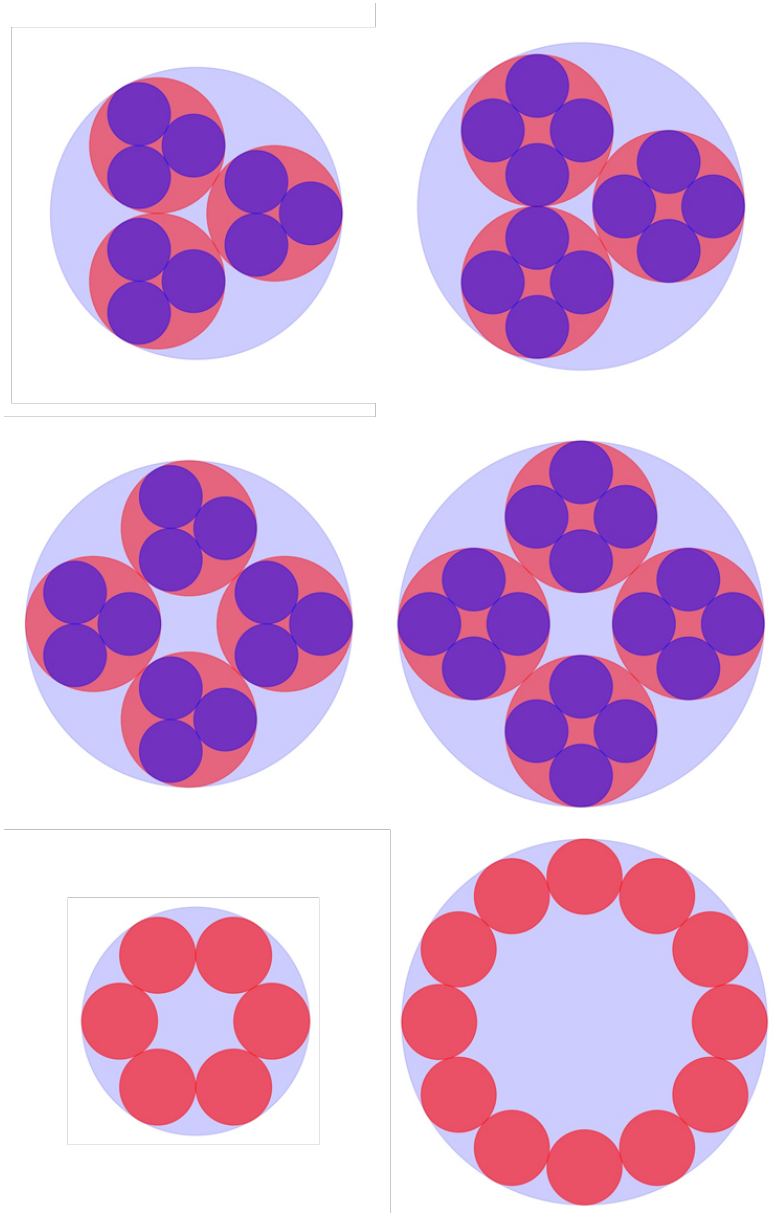
Design **evaluation:**

- **Trade off** criteria
- Rapid **prototyping**
- Kinematic **simulations** in CATIA®
- Design **iterations**

Conceptual design

Braiding topology:

- Dense **packing**
- **Round** wires



Conceptual design

Braiding topology:

- Dense **packing**
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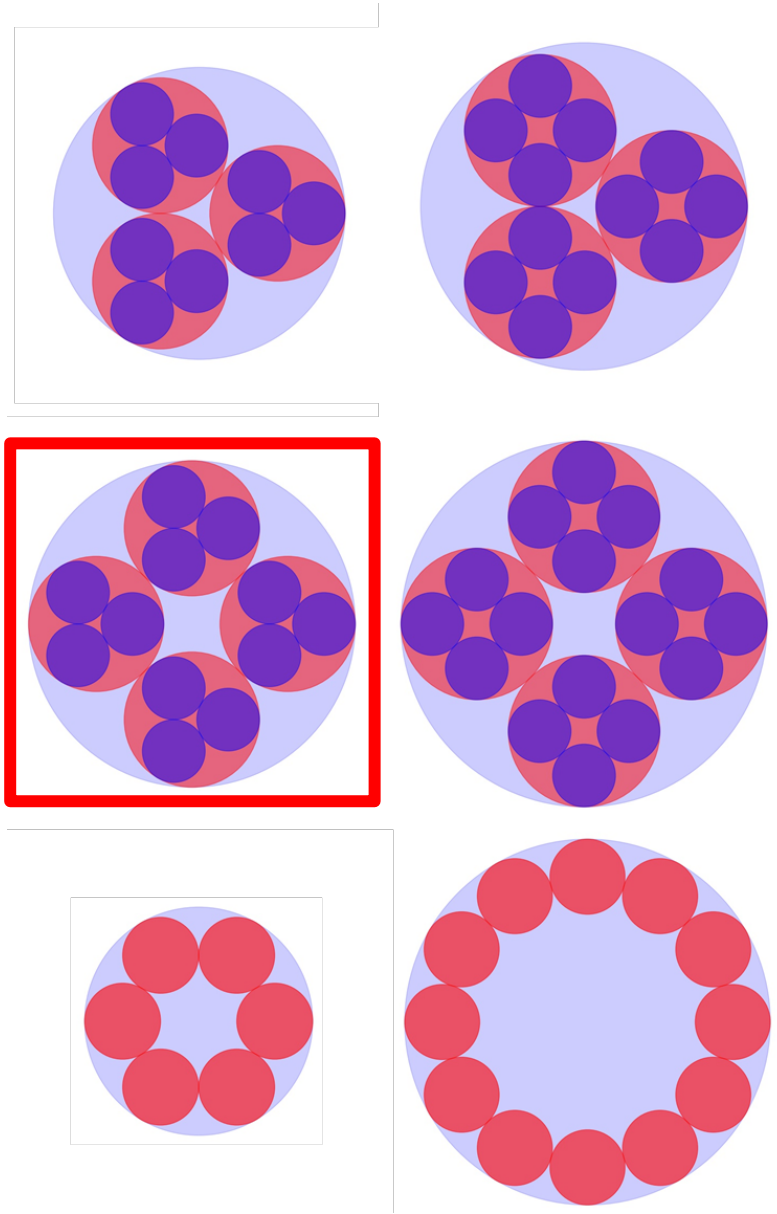

Conceptual design

Braiding topology:

- Dense **packing**
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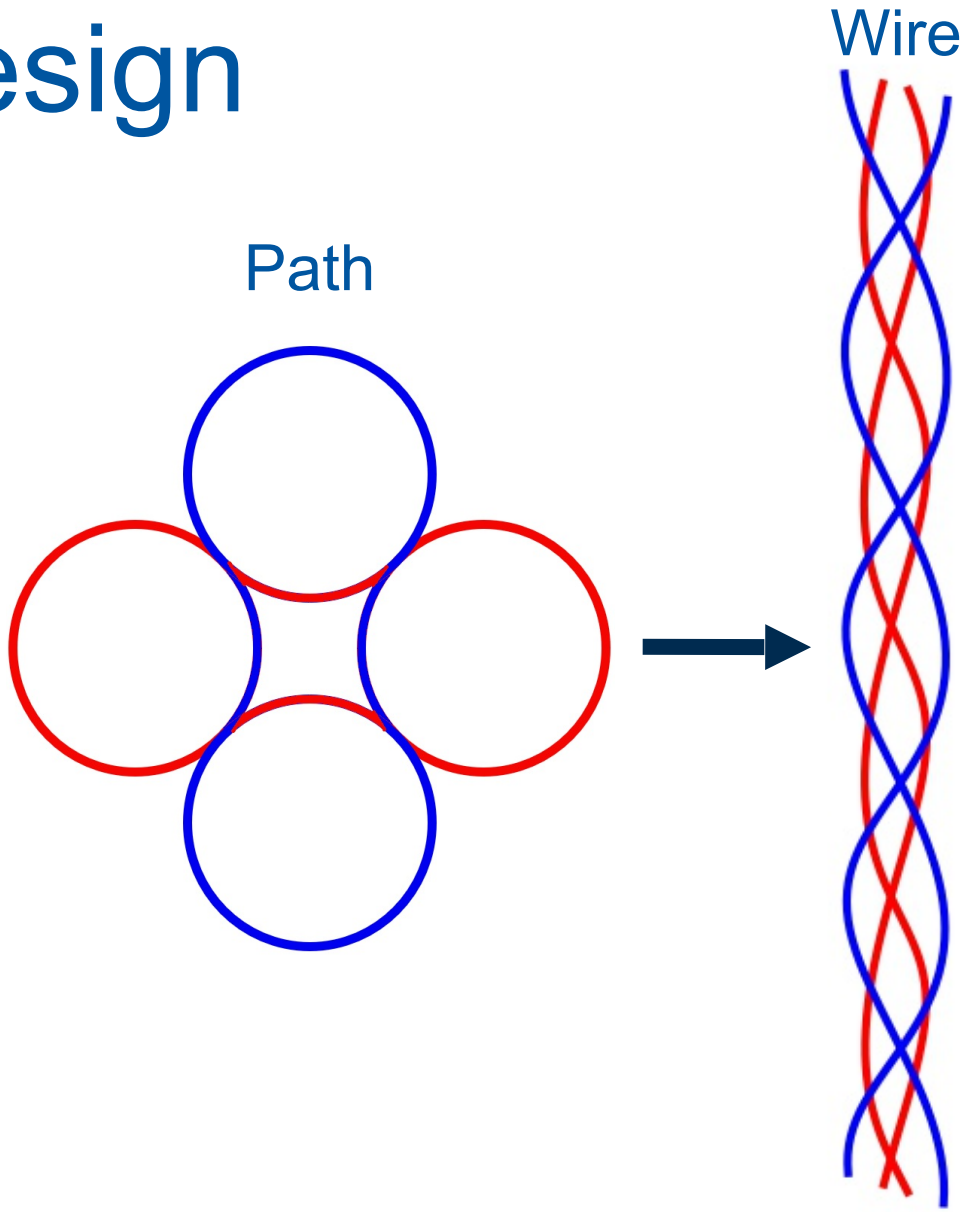
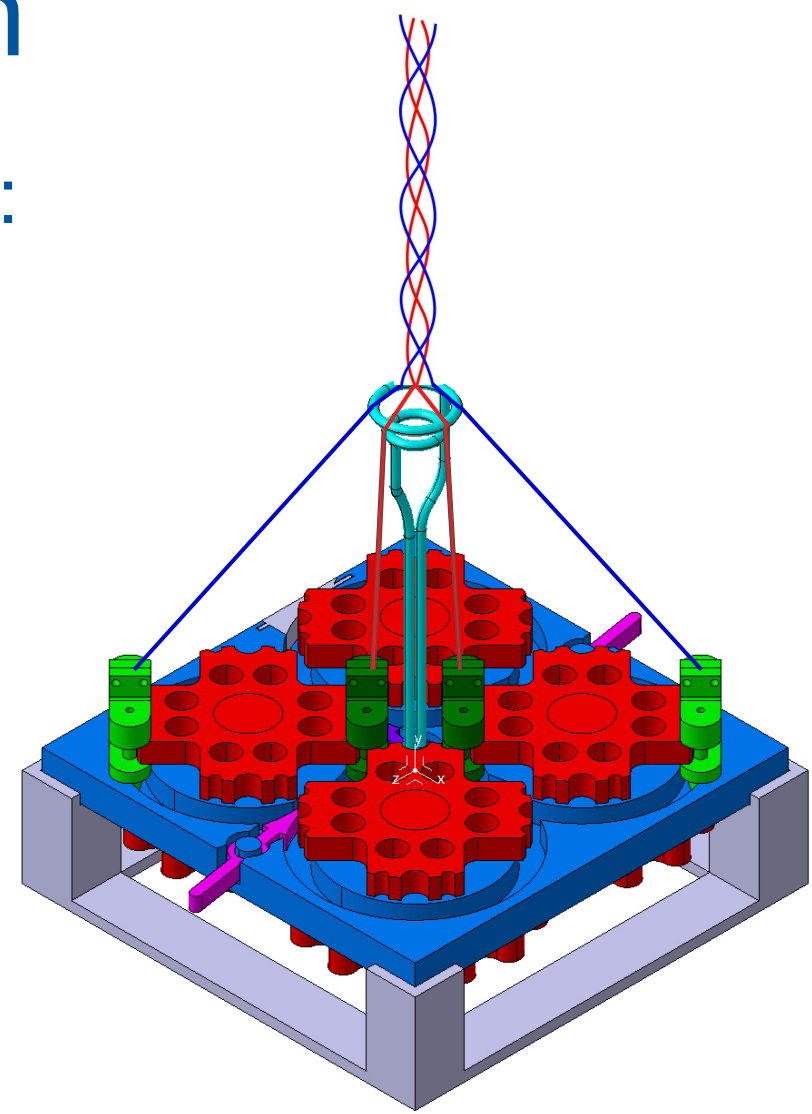


Preliminary Design

3D printed proof of concept:

- General **concept** evaluation
- **Mechanisms** evaluation
- **Weak points** identified

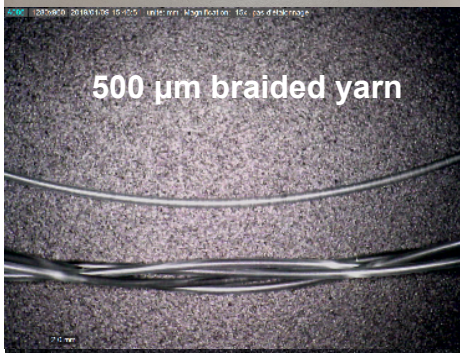


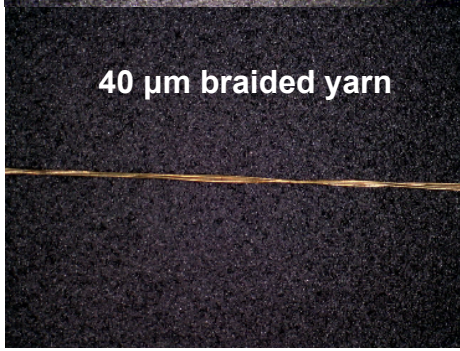
Design Evaluation

Braided:

- **2.5 mm** cord
- **0.5 mm** wire
- **40 µm** wire

Evaluated selected concept, braiding process and braiding results

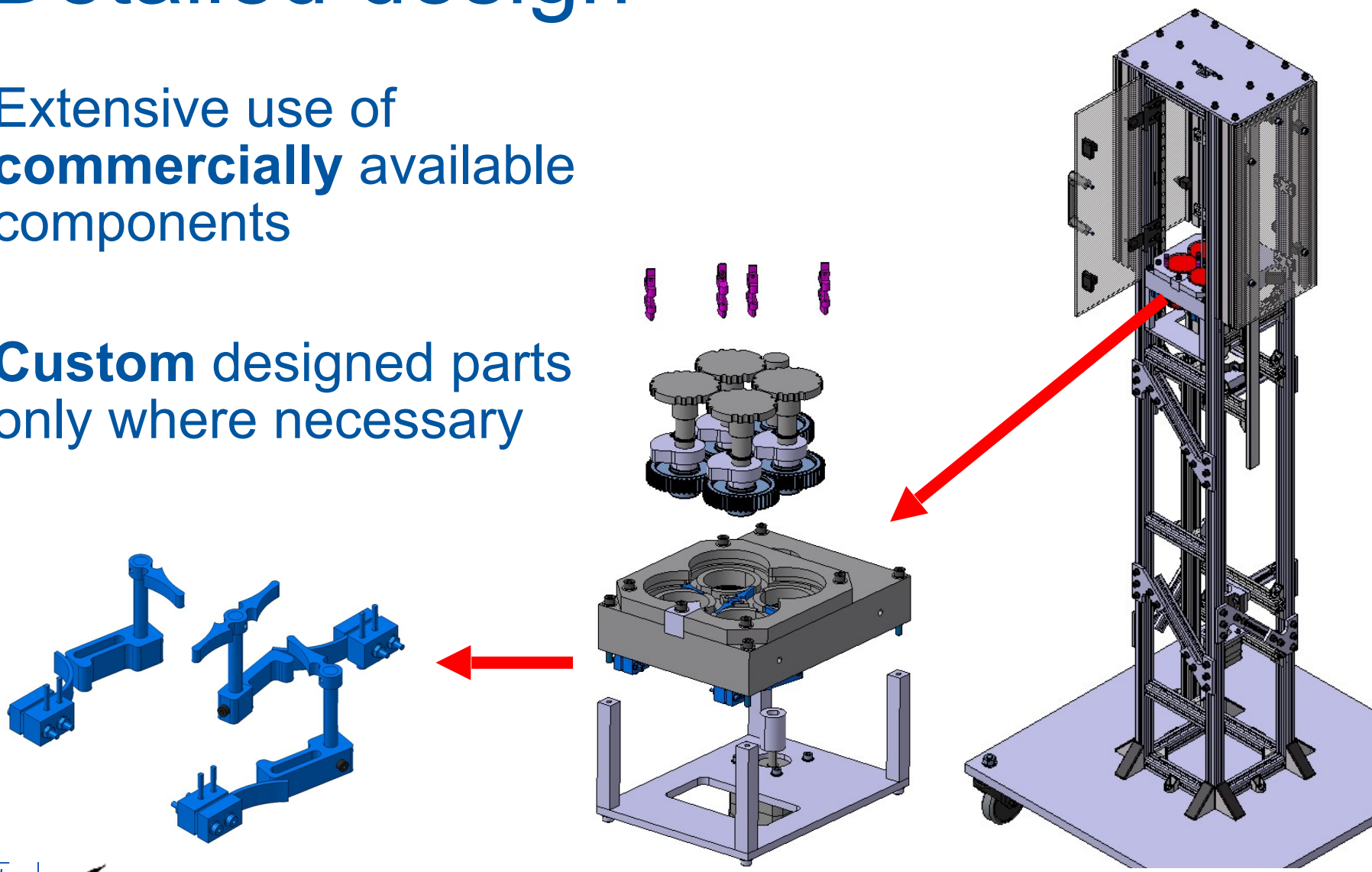




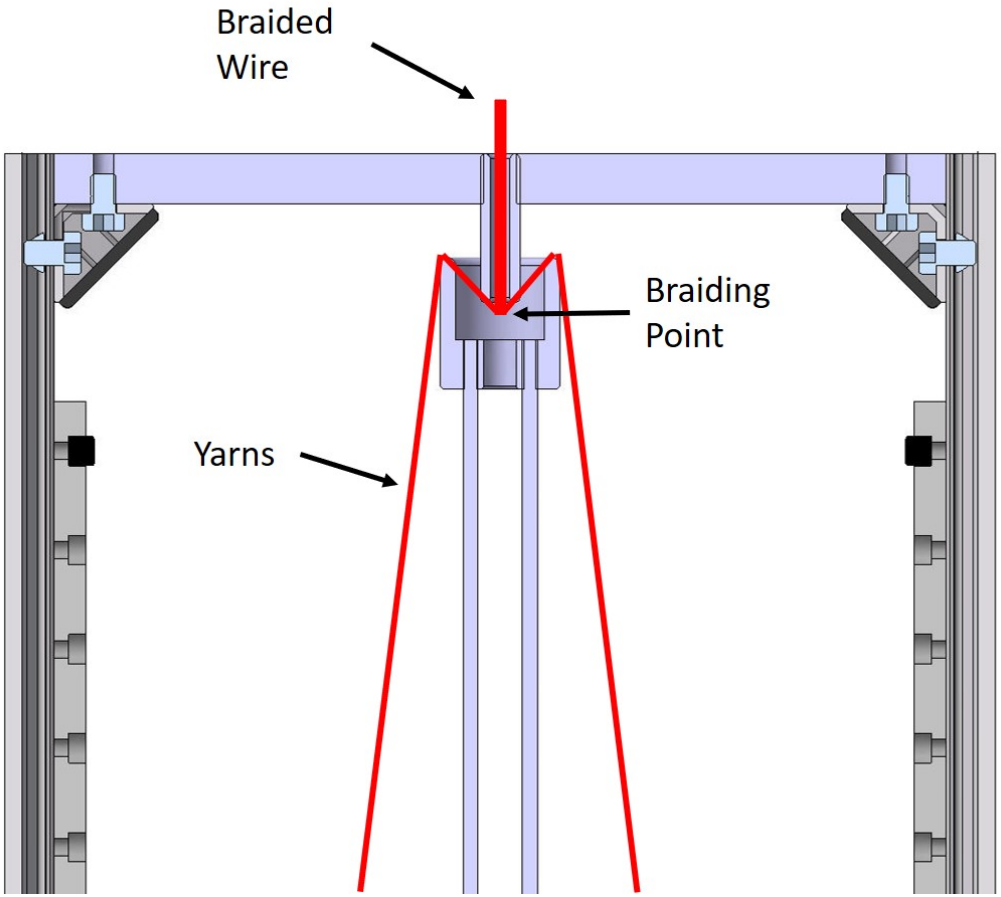
Detailed design

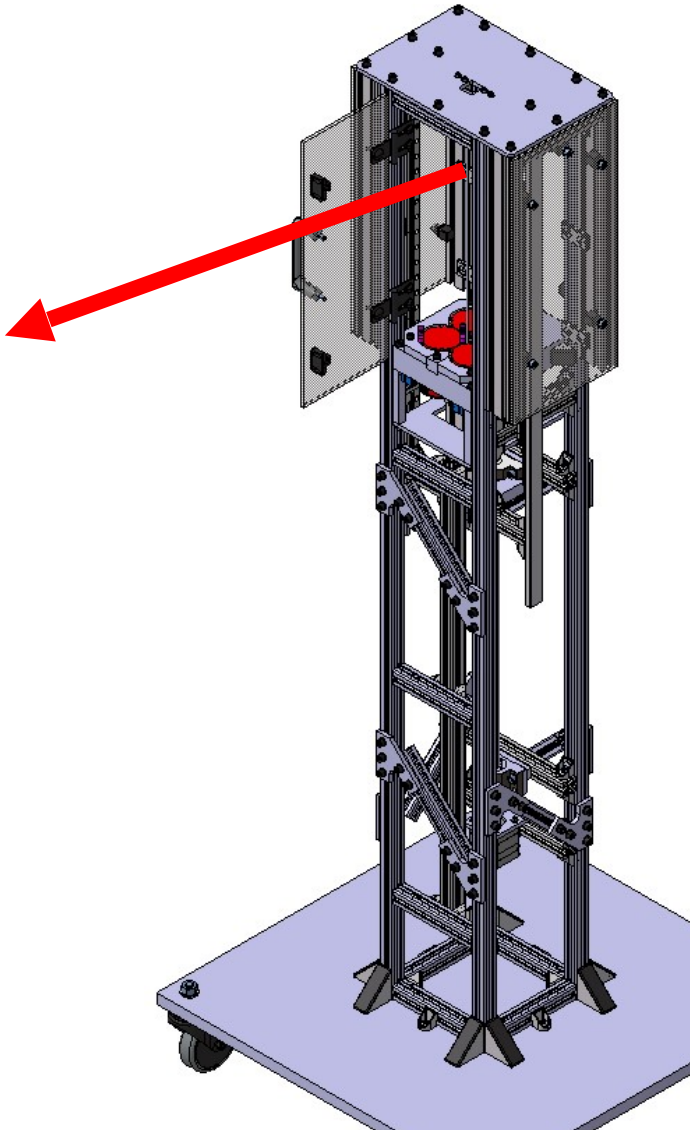
Extensive use of **commercially** available components

Custom designed parts only where necessary



Detailed design





Machine Testing

Testing

Static Tests:

- Assembly
- Fit check

Dynamic Tests:

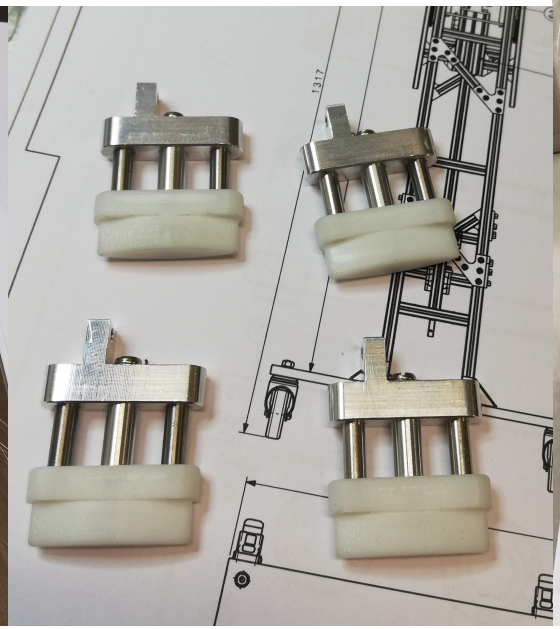
- Manual operation
- Sub-system by sub-system basis

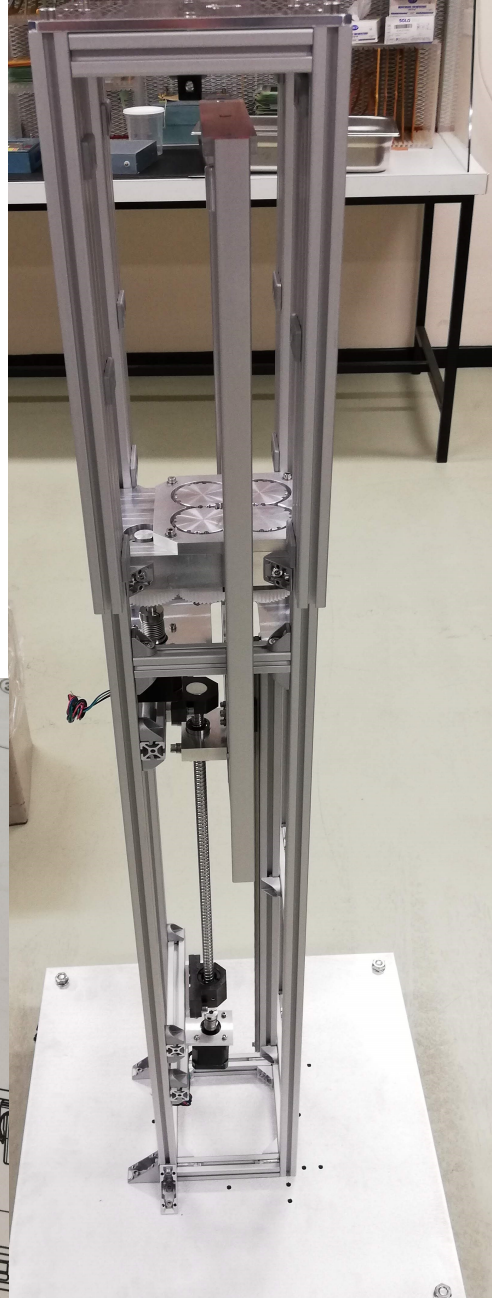
Functional Tests:

- Complete machine **operation**
- Functional issues detected and corrected
- Wire **braiding**

Static test

- Machine **assembly**
- Components **fit** evaluated
- Initial **design** evaluation





Dynamic tests

Gam gears issues

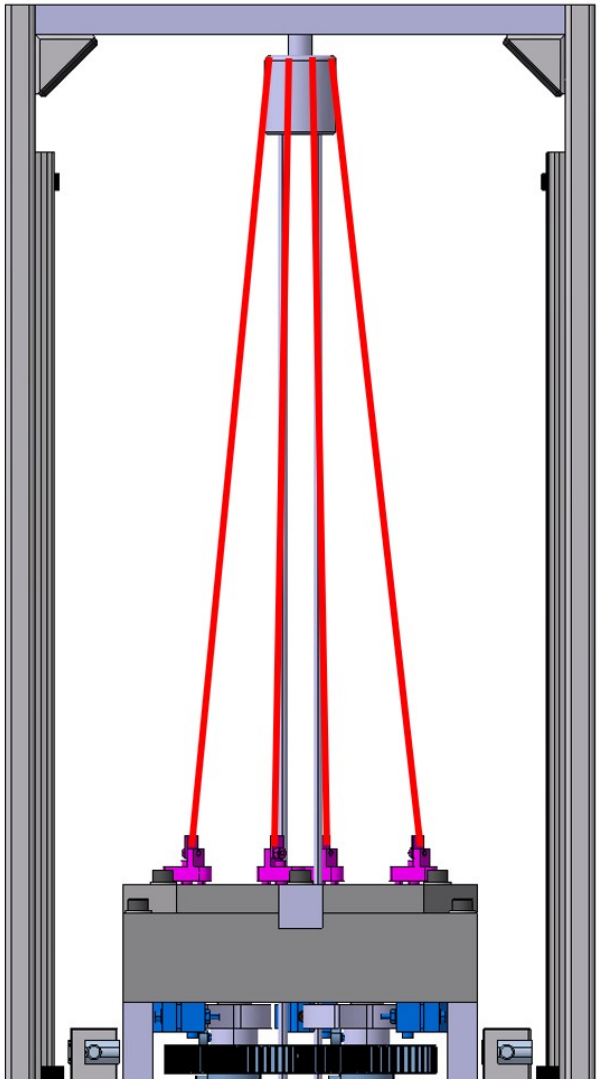
- Steep transition area → sticking
- **Solved:** redesigned cam gears with softer transition

Leaf springs too stiff

- System sticks
- **Solved:** reduced spring stiffness and modified the mounting

Functional tests: Guiding issue

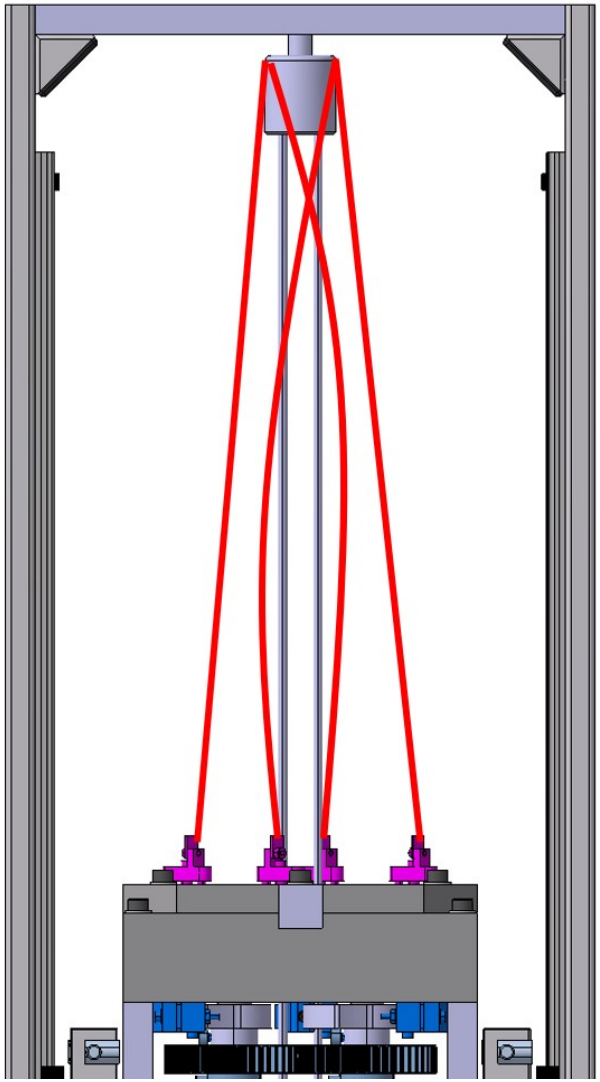
- Wires **entangle** in the guiding system
- Wires **break**
- Machine **stops**
- Constant **interventions** necessary
- **Irregular** braiding



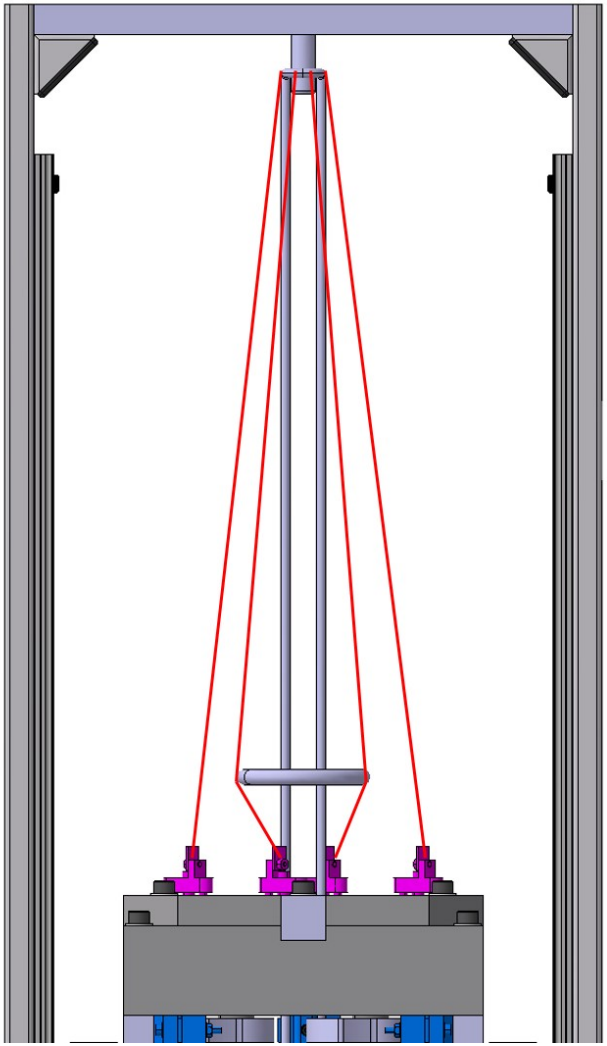
Guiding issue

Root cause analysis:

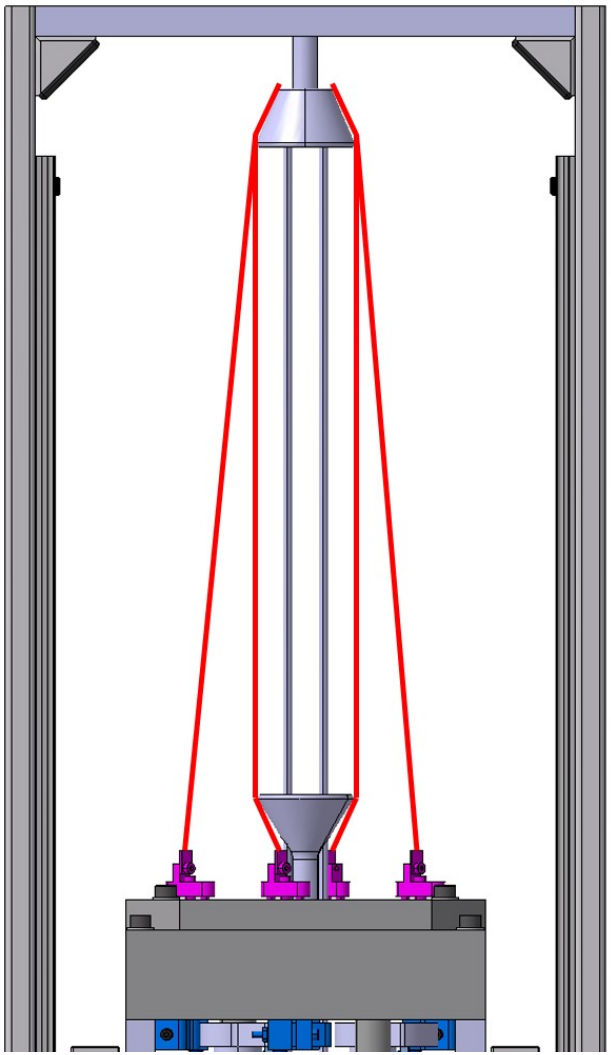
- Wire **material**
- Guiding system **material**
- Guiding system **geometry**
- Lack of wire **tension**



Guiding issue: troubleshooting



Guiding issue: troubleshooting



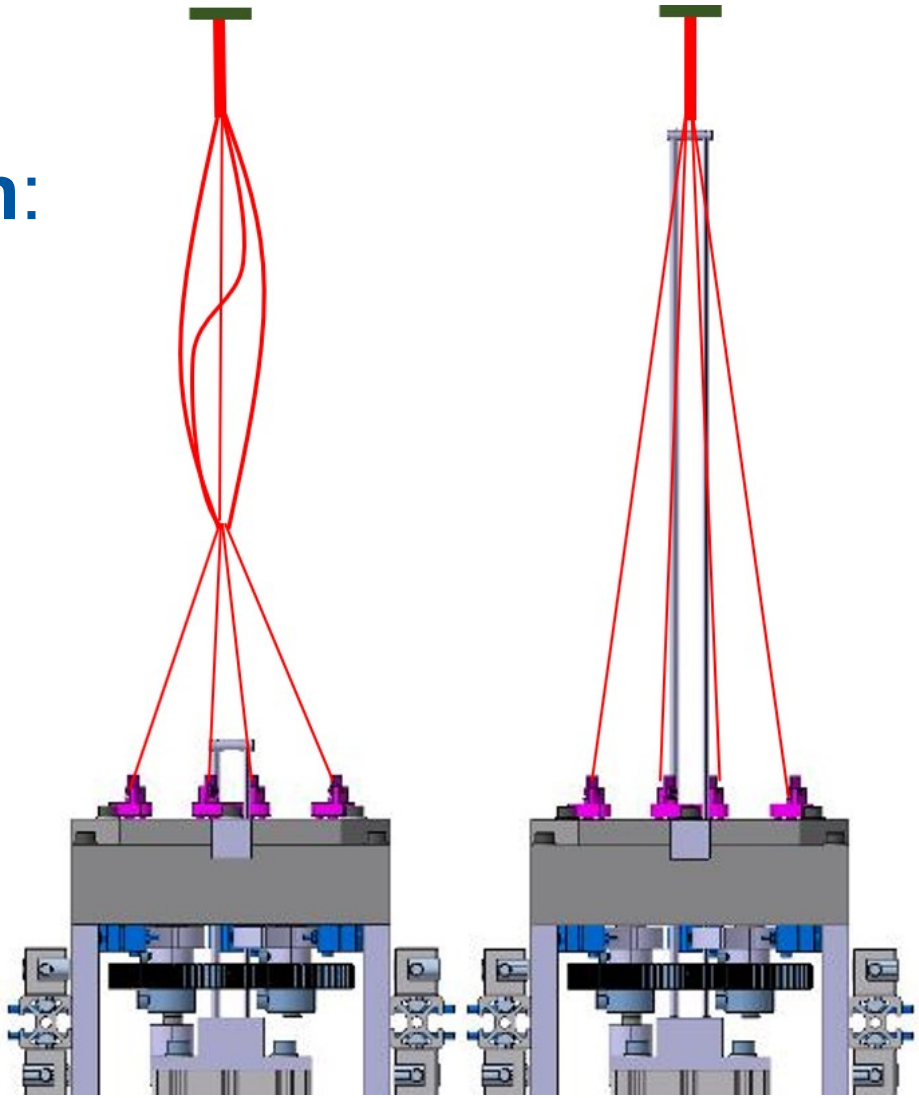
Guiding issue: solved

Guiding system **redesign**:

- Coupling removed
- Simpler design

Spring added for **wire tensioning**

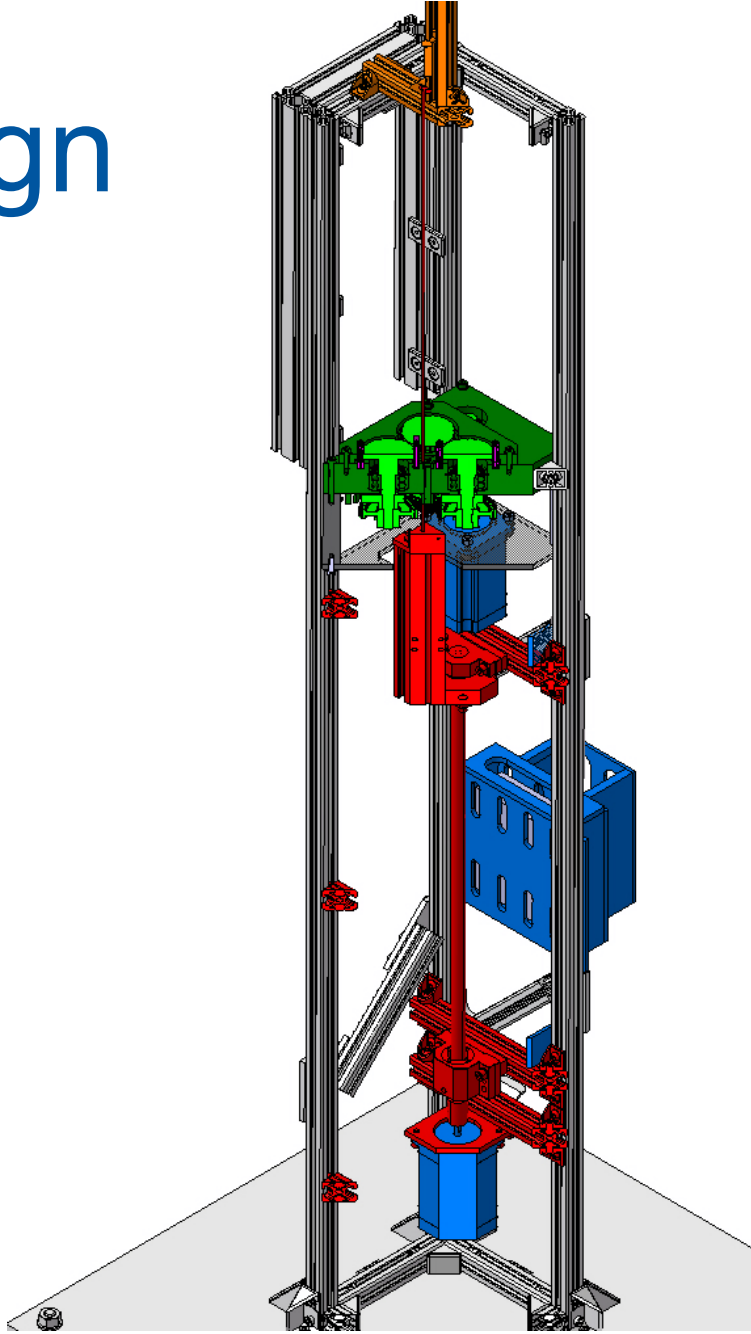
Tight braiding



Final Machine Design

Redesigned initial **guiding mechanism**

Redesigned **cam gears**



Wire Braiding Evaluation

Wire braiding evaluation

Stainless steel:

- 250 µm
- 50 µm

Nylon:

- 100 µm

Carbon:

- 100 µm

Dimensions measurement:

- Microscopy along wire length

Braiding regularity:

- Average and st. dev of dimensions along length

Wire packing:

- Wire occupied area compared to envelope

Mechanical testing of wires:

- Tensile tests

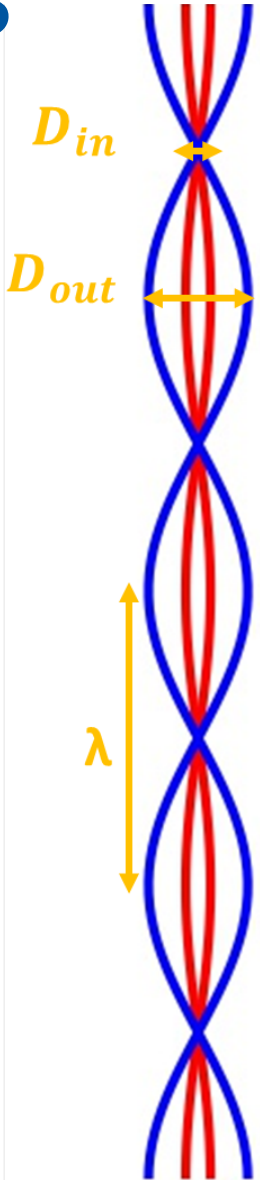
Microscopy measurements

Measure 3 braiding quantities of the wire:

- Inner diameter **D_{in} [µm]**
- Outer diameter **D_{out} [µm]**
- Braiding wavelength **λ [µm]**

Measurements conducted along the braided length:

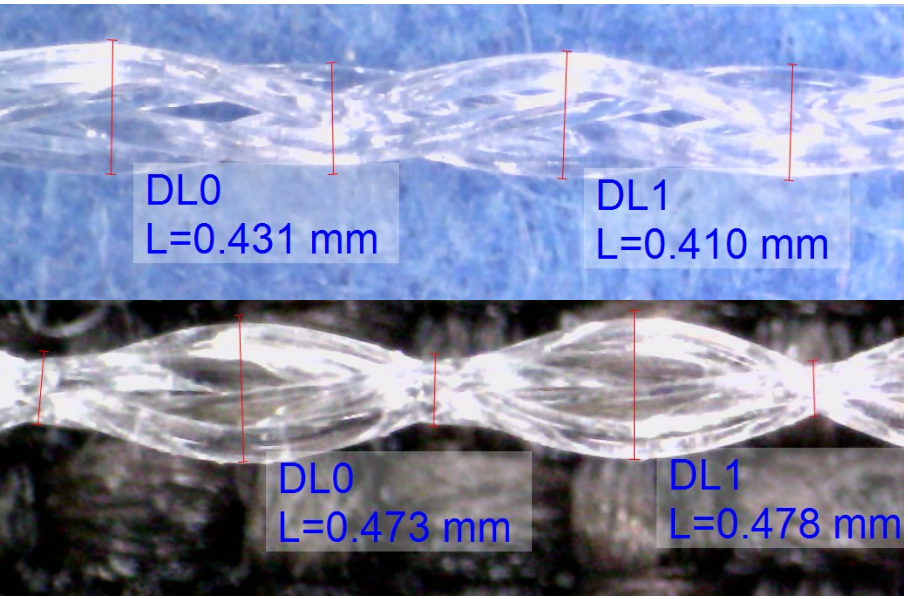
- Determine braiding regularity

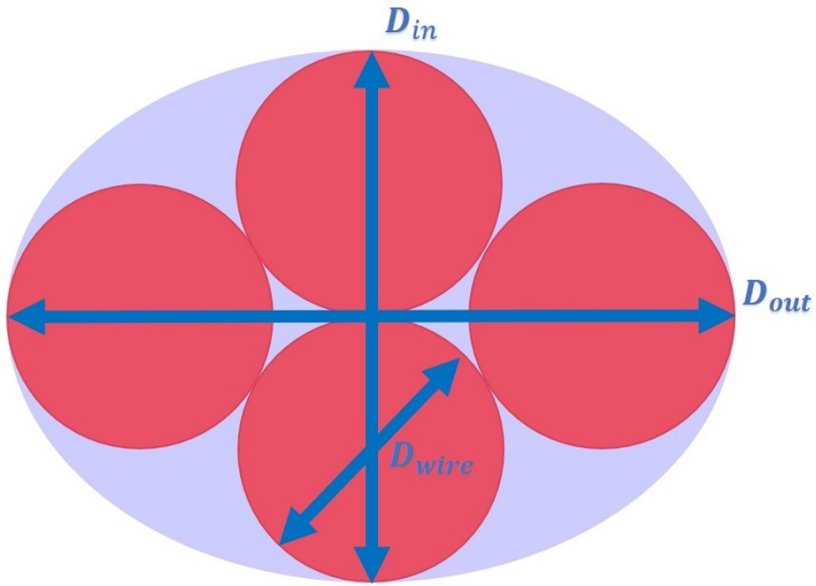


Packing factor

Function of the Packing Factor (F_p):

$$F_p = \frac{A_{wires}}{A_{envelope}} = \frac{n_{wires} \times D_{wires}^2}{D_{out} \times D_{in}}$$

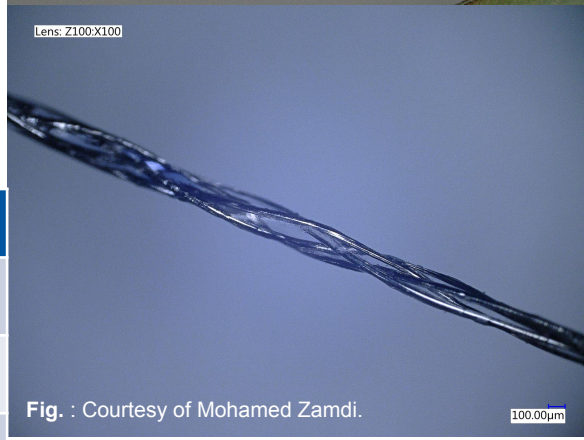




Stainless steel wires

Problematic braiding

- Rigid
- Cause random braids when deformed
- Highly irregular braiding



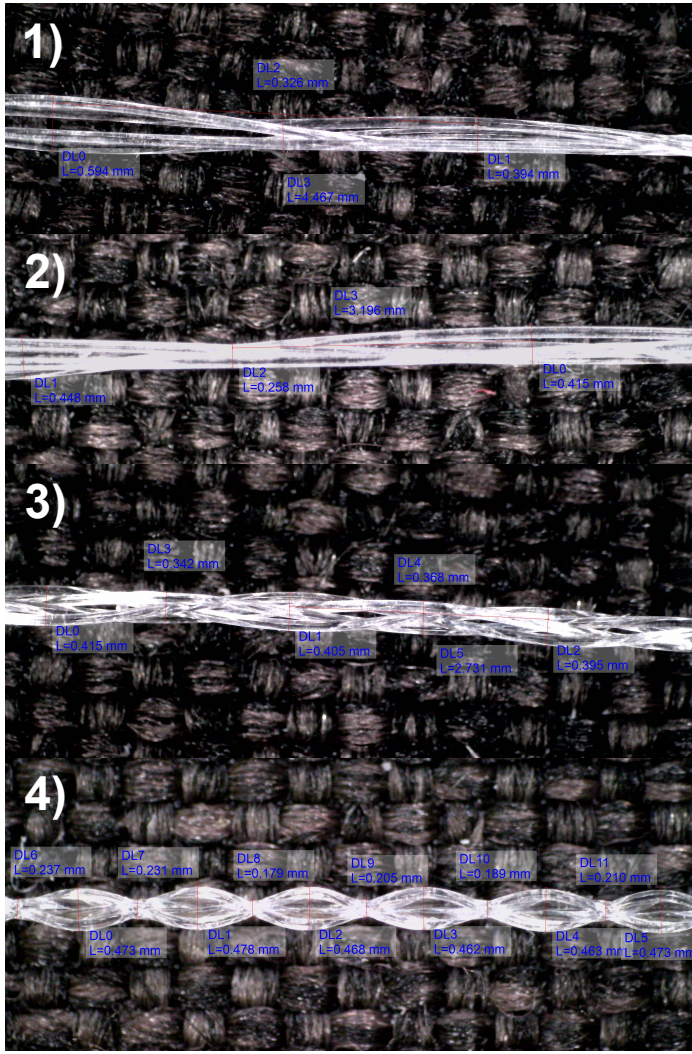
Diameter	250 µm			50 µm		
Data [unit]	D_{in}	D_{out}	λ	D_{in}	D_{out}	λ
Average [µm]	476	930	5026	142	241	1142
Normalized σ [%]	11.3	8.9	N/A	22.9	19.8	33.1
F_p [%]	56			29		

Nylon wires - Machine development

More flexible and slide better than Stainless Steel

Different version implemented to investigate and improve optimum machine performance

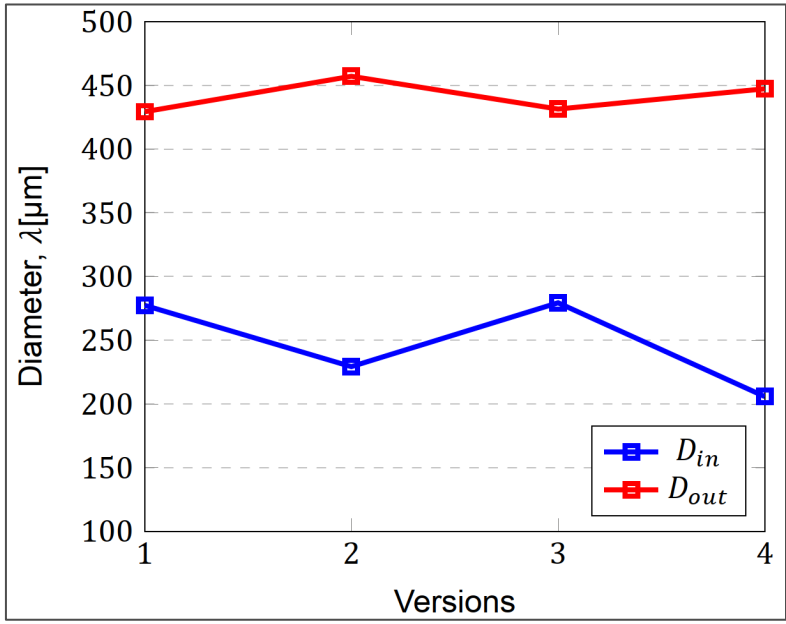
Version	Description
1	No guiding with spring
2	Guiding with no spring
3	Guiding with spring
4	Tight guiding with spring

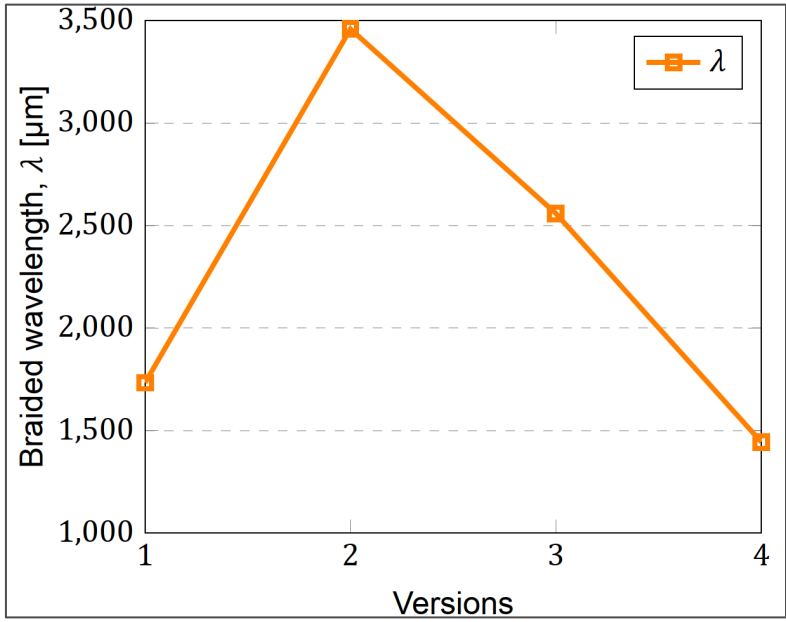


Average values

Wire **diameters** seem constant no matter the machine version → signs of only **material dependency**

Braided **wavelength** shows large variation → signs of **machine dependency**



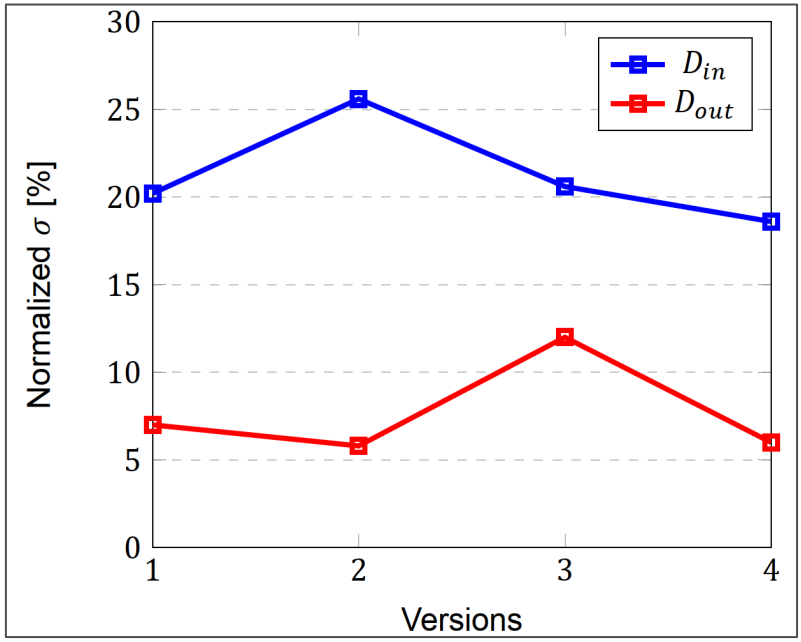


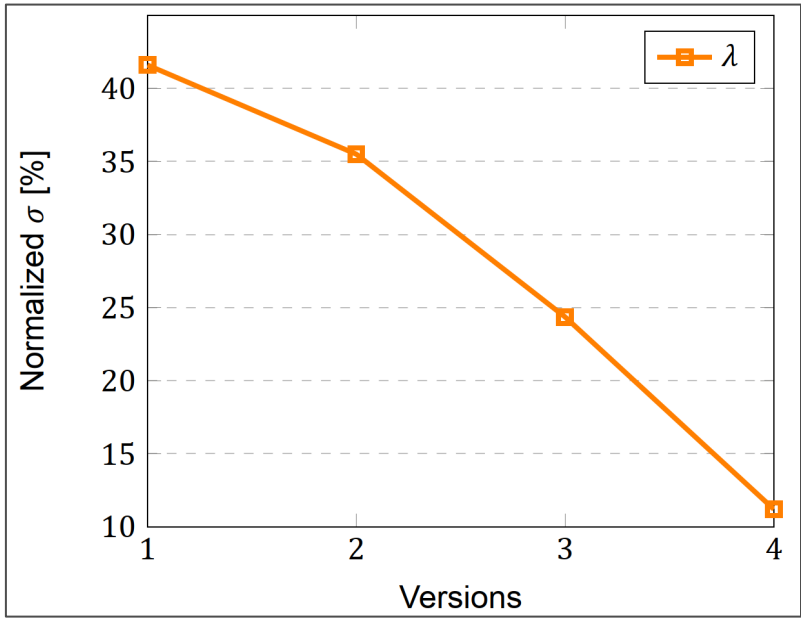
Normalized values

Outer diameter constant → **yarn material dependent**

Inner diameter shows large variations → **yarn material dependent**

Braiding wavelength optimized → **machine settings dependent**



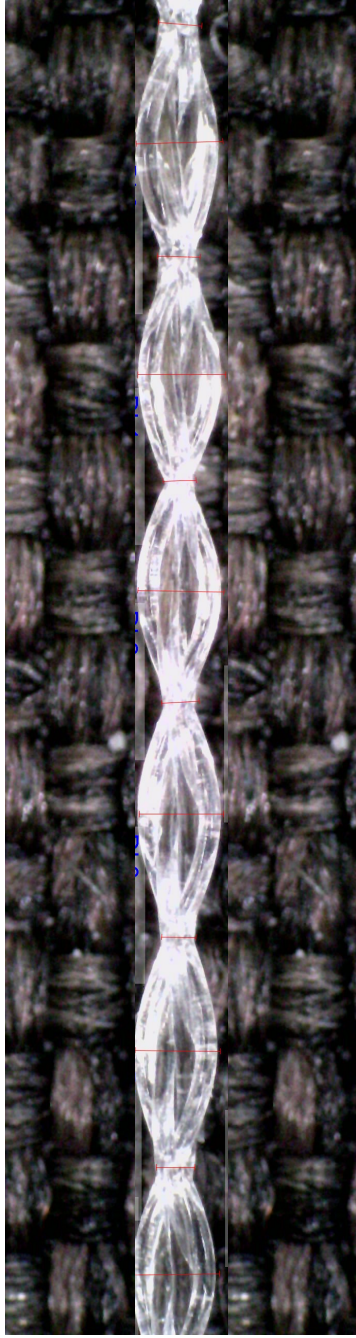


Nylon wires conclusion

Packing factor very low

Highly **regular braiding**

Data [unit]	D_{in}	D_{out}	λ
Average [μm]	191	472	1370
Normalized σ [%]	11.09	1.2	**11.3**
F_p [%]	**44**		



Carbon wires

Packing factor very high!

- More flexible than nylon

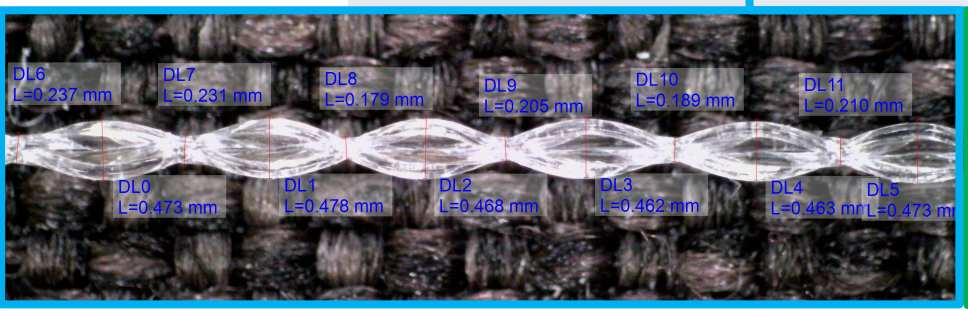
Highly **regular braiding**

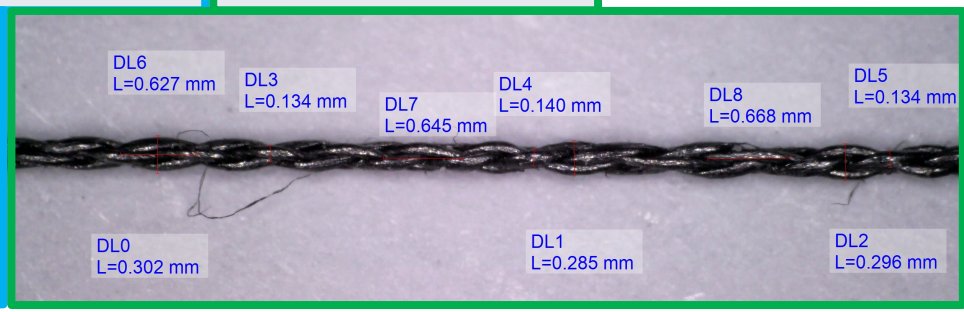
Data [unit]	D_{in}	D_{out}	λ
Average [μm]	146	285	627
Normalized σ [%]	8.2	6.1	**10.2**
F_p [%]		**96**	

Results comparison

- Similar **regularity** for both wires
- Superior **packing factor** for carbon wires

	Nylon			Carbon		
Data [unit]	**D_{in}**	**D_{out}**	**λ**	**D_{in}**	**D_{out}**	**λ**
Average [μm]	191	472	1370	146	285	627
Normalized σ [%]	11.09	1.2	11.3	8.2	6.1	10.2
F_p [%]	44			96		



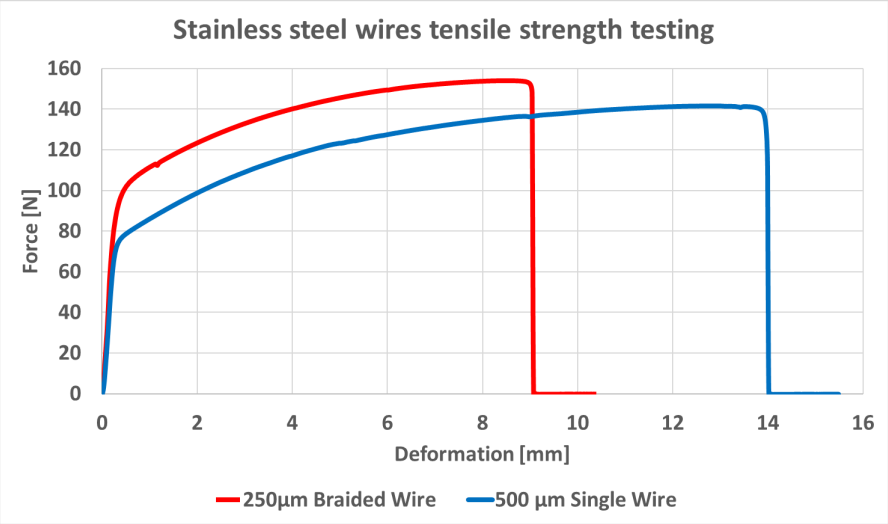


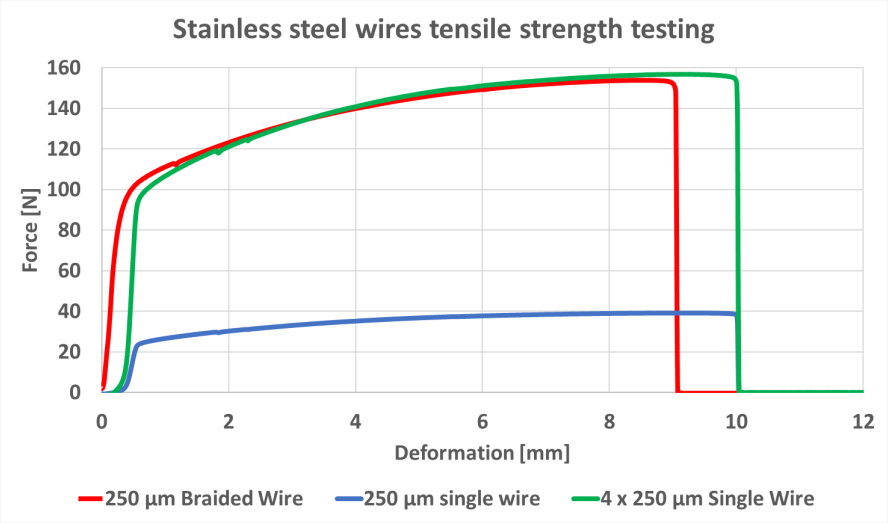
Tensile testing of stainless steel

Tested at BATH University

Promising results

Not enough data → further investigation necessary





Conclusion

- Standardized Microwire braiding **procedure investigated** and **proven possible**
- **Prototype** MBM **designed**, **built** and **tested**
- **Tested** different wires material and dimensions
- **Optimum wire braiding technique** identified
- Braiding **characteristics dependence** to wire or machine identified
- General wire **braiding experience** obtained

Future work

- Braiding **7 µm wires**
- **Tensile testing** of braided wires
- **Testing the wires** in CERN's accelerators in the future

Thank you!

Q&A

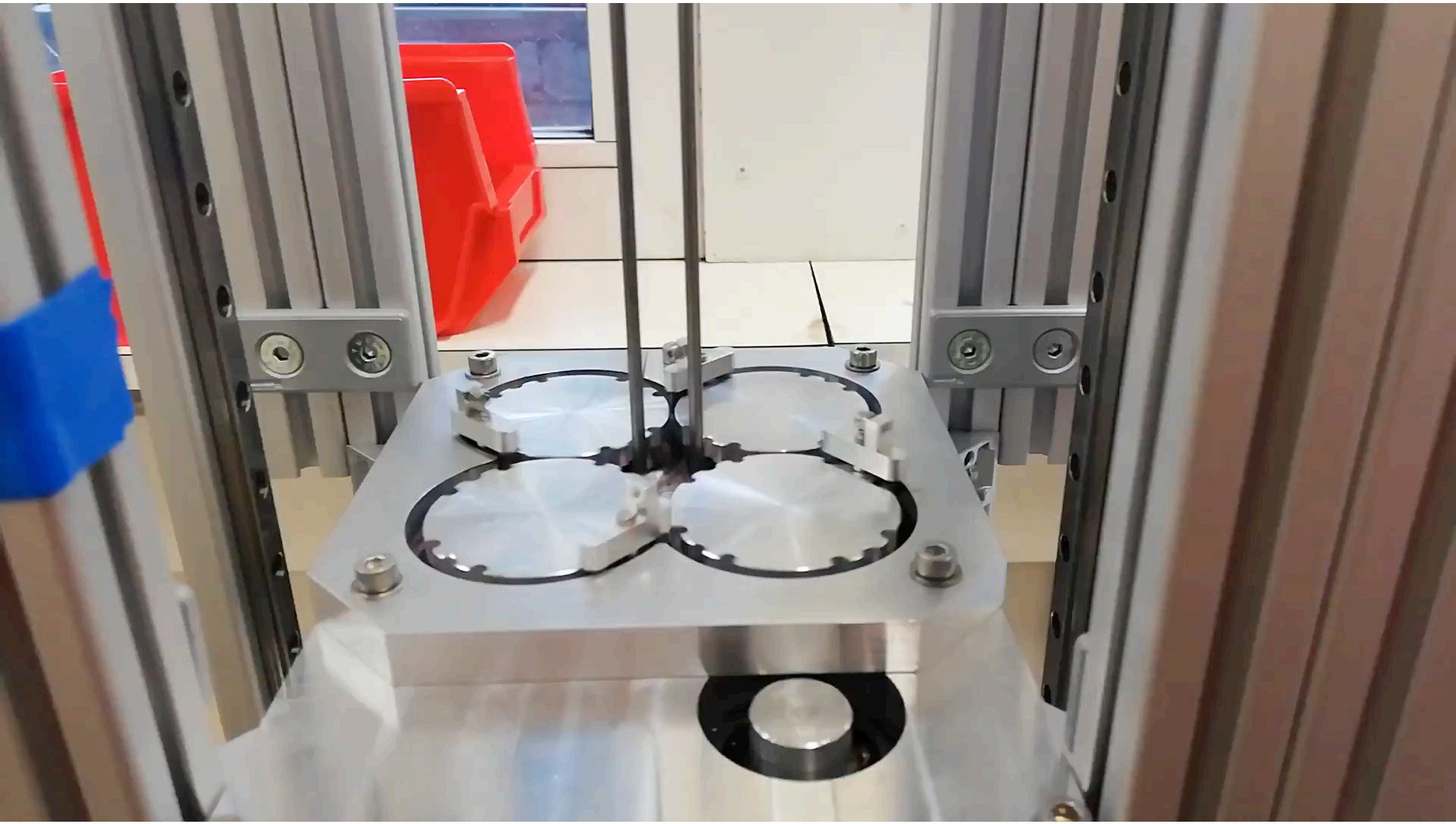

CERN

Discussion

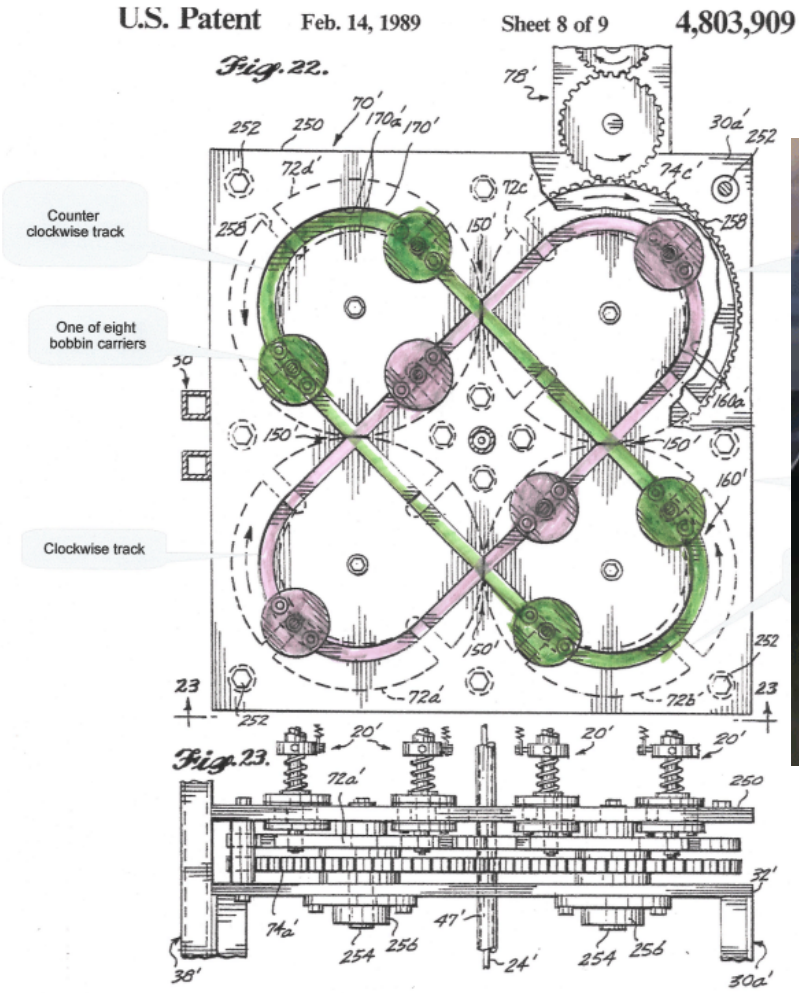
- Optimum braiding **wavelength**
- Wire **packing** and material influence
- Tensile tests
- **Optimality** braiding conditions could be redefined!

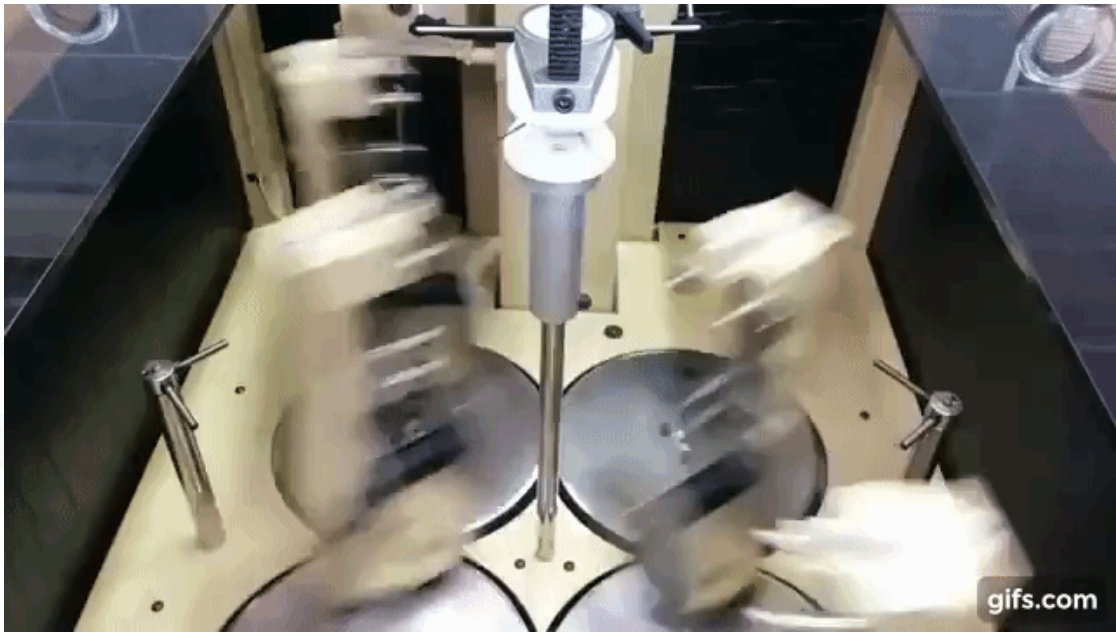
Backup slides.

Braiding Method



Braiding Pattern





Braiding Pattern

Number of Bundles [-]	Yarns in bundle [-]	Total Yarns [-]	Packing Factor [%]
2	2	4	25
2	3	6	32.3
2	4	8	34.3
2	5	10	34.3
2	6	12	33.4
3	2	6	32.3
3	3	9	41.8
3	4	12	44.8
3	5	15	44.3
3	6	18	43.1
4	2	8	34.3
4	3	12	44.3
4	4	16	47.1
4	5	20	47
4	6	24	45.8
5	2	10	34.3
5	3	15	44.3
5	4	20	47
5	5	25	47
5	5	25	45.7
6	2	12	33.3
6	3	18	43.1
6	4	24	45.8
6	5	30	45.7
6	6	36	44.4

Braiding Pattern

Prototype yarns created for better shape visualization. 1) 3x1, 2) 4x1, 3) 6x1, 4) 3x4 and 5) 4x3

State of the Art

Wire Braiding Machines

Braiding methodologies **largely unchanged** during the last century

Similar techniques used until today for braiding in wires, textiles and even carbon fibers

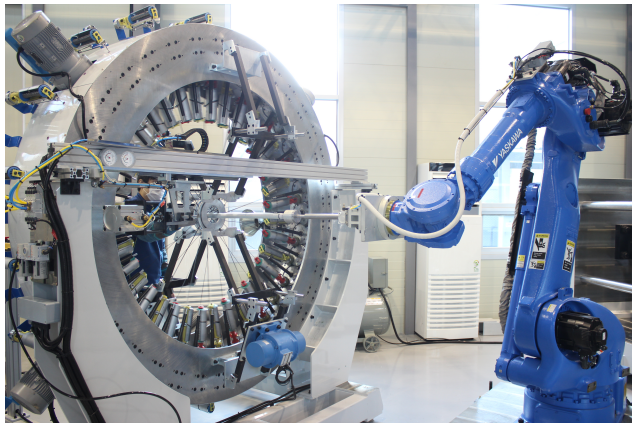
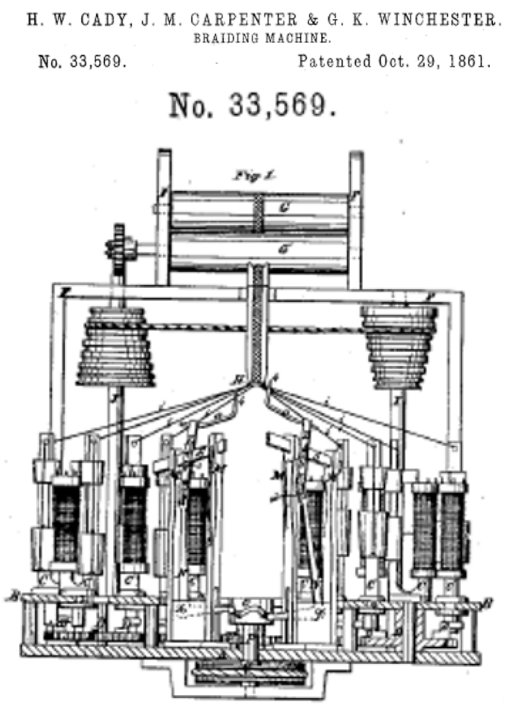


Fig.: t4l company (http://www.t4l.co.kr/en/)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No. 33,569. Patented Oct. 29, 1861.
No. 33,569.

Fig.: US Patent No. 33,596.

Microwire Braiding

Mei Zhang et al:

- Only **twisting** technique used

3TEX :

- **Manual**
- 16 bundles of 25 yarns

Taegyo et al:

- **Tubular** braiding

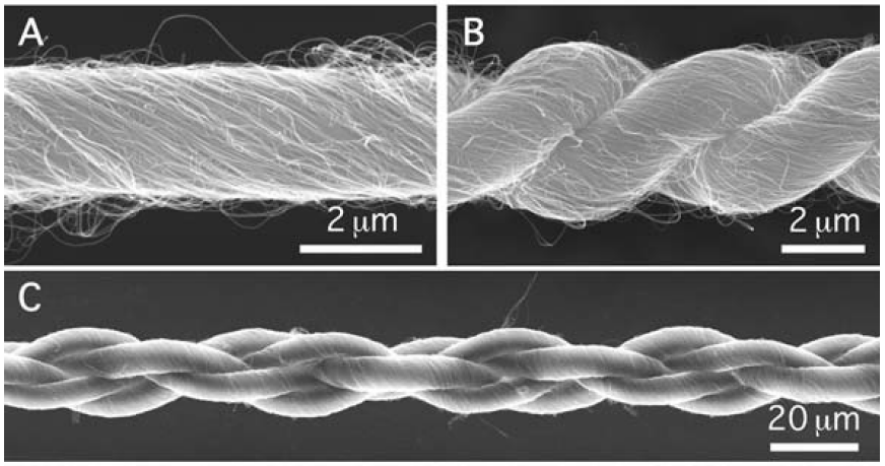


Fig.: "Multifunctional Carbon Nanotube Yarns by Downsizing an Ancient Technology", Mei

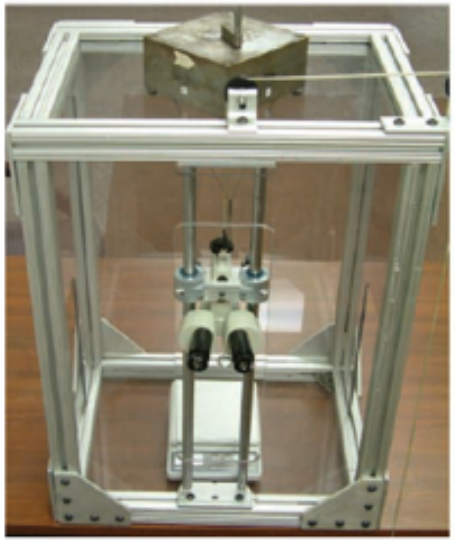


Fig.: 3TEX microwire braiding machine

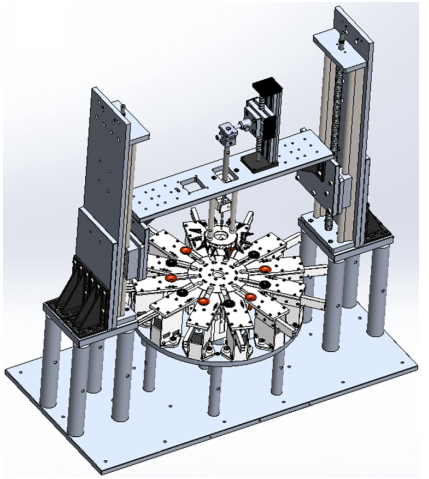
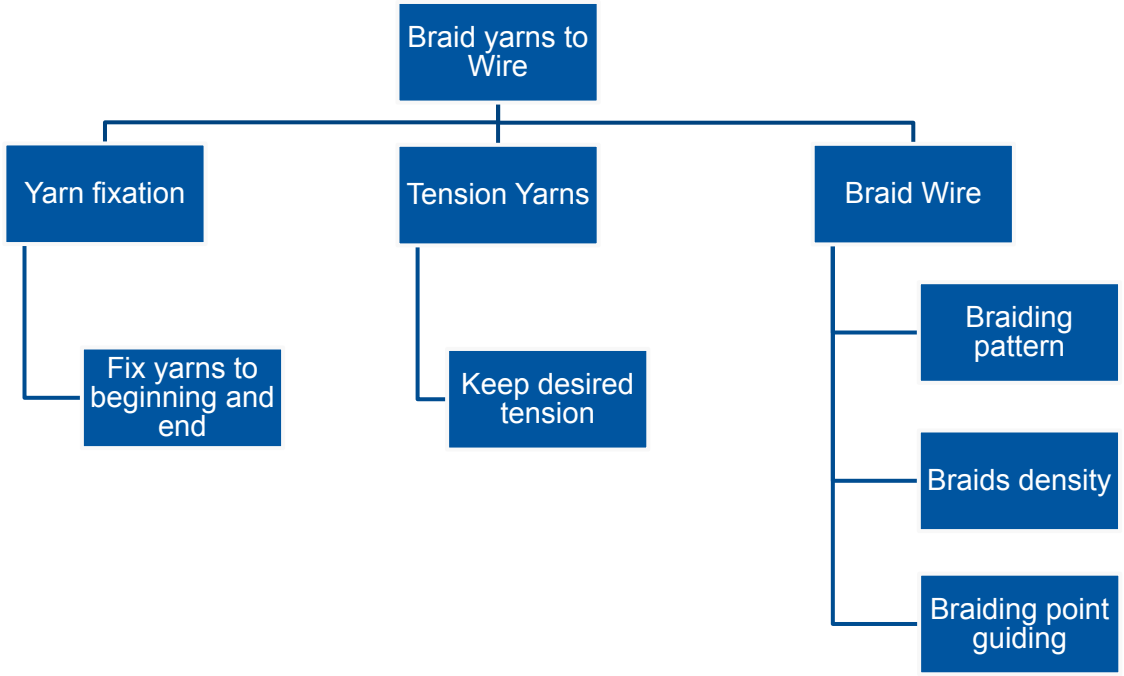


Fig.: "Highly Flexible Precisely Braided Multielectrode Probes and Combinatorics for Future Neuroprostheses", Taegyo et al

Design Method

Functional Decomposition

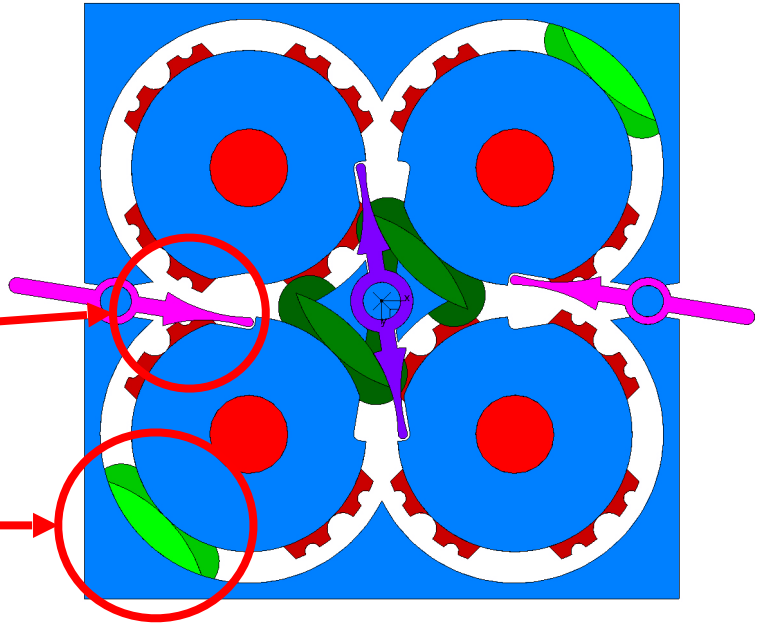


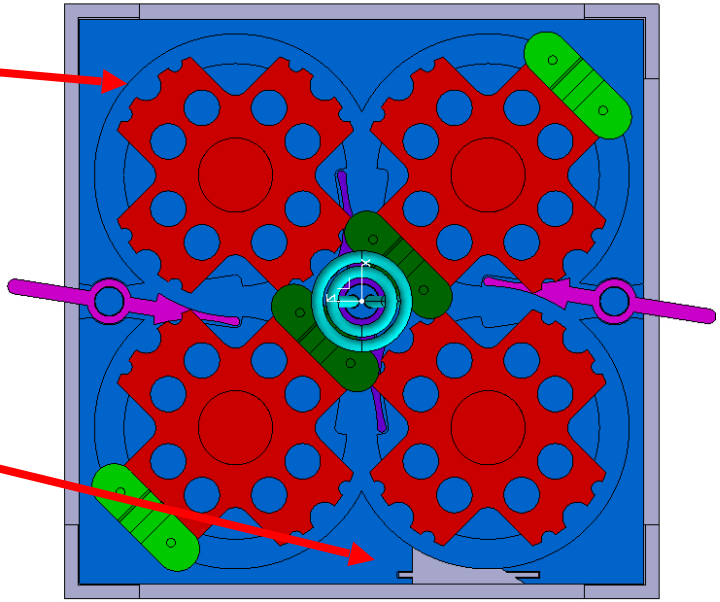
Trade off tables

Concept\Criteria	Wire Quality	Complexity/ Ease of assembly/ Maintenance	Design/ manufacturing difficulty	Total
Weight Factor [%]	**50**	**20**	**30**	**100**
Circular (traditional) path	5	4	4	**450**
Simple Rectangular path	2	2	3	**230**
Circular Pattern 2	5	3	3	**400**

Issues detected

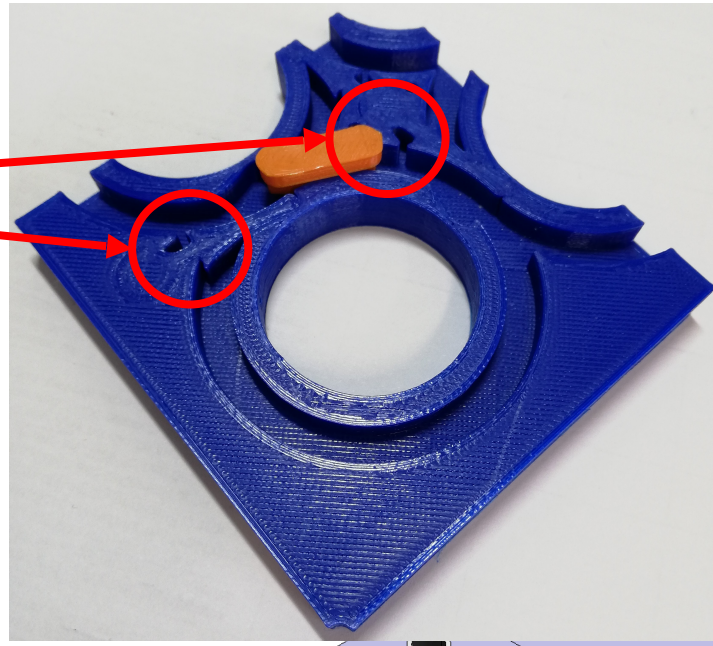
- Sharp points along the path
- Carrier – Path tolerances
- Horn gears dimensions and interference
- Lack of +z constraint for the carriers
- Gate for carrier input unusable

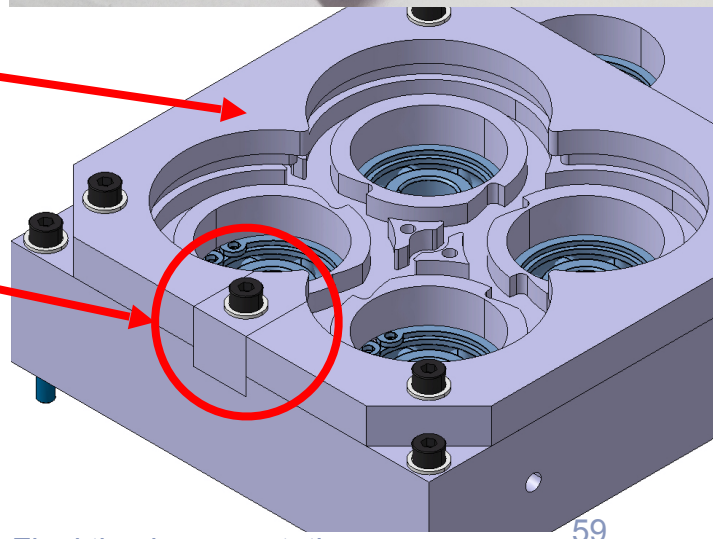




Issues resolved

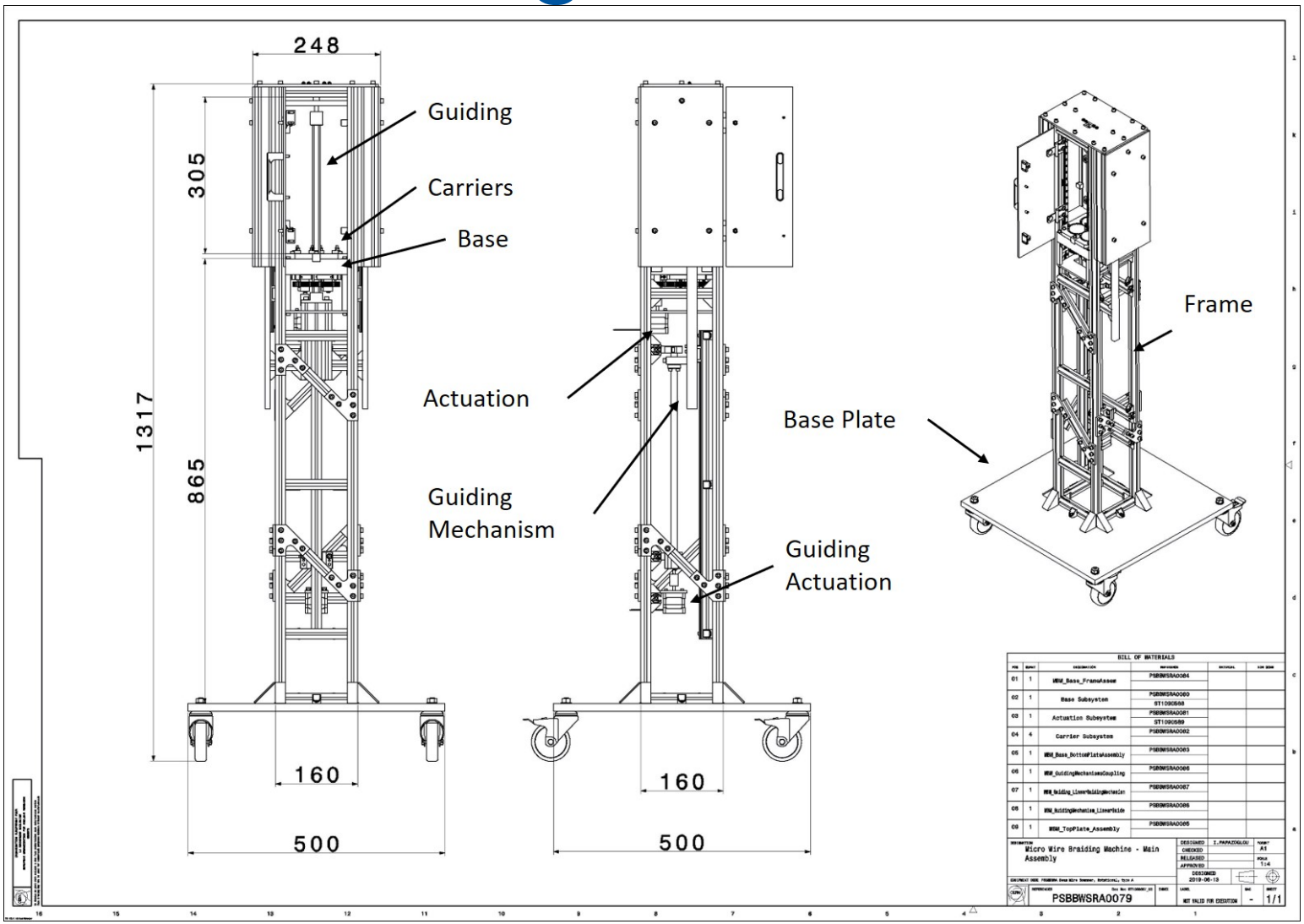
- Sharp points along the path
- Carrier – Path tolerances
- Horn gears dimensions and interference
- Lack of +z constraint for the carriers.
- Gate for carrier input unusable



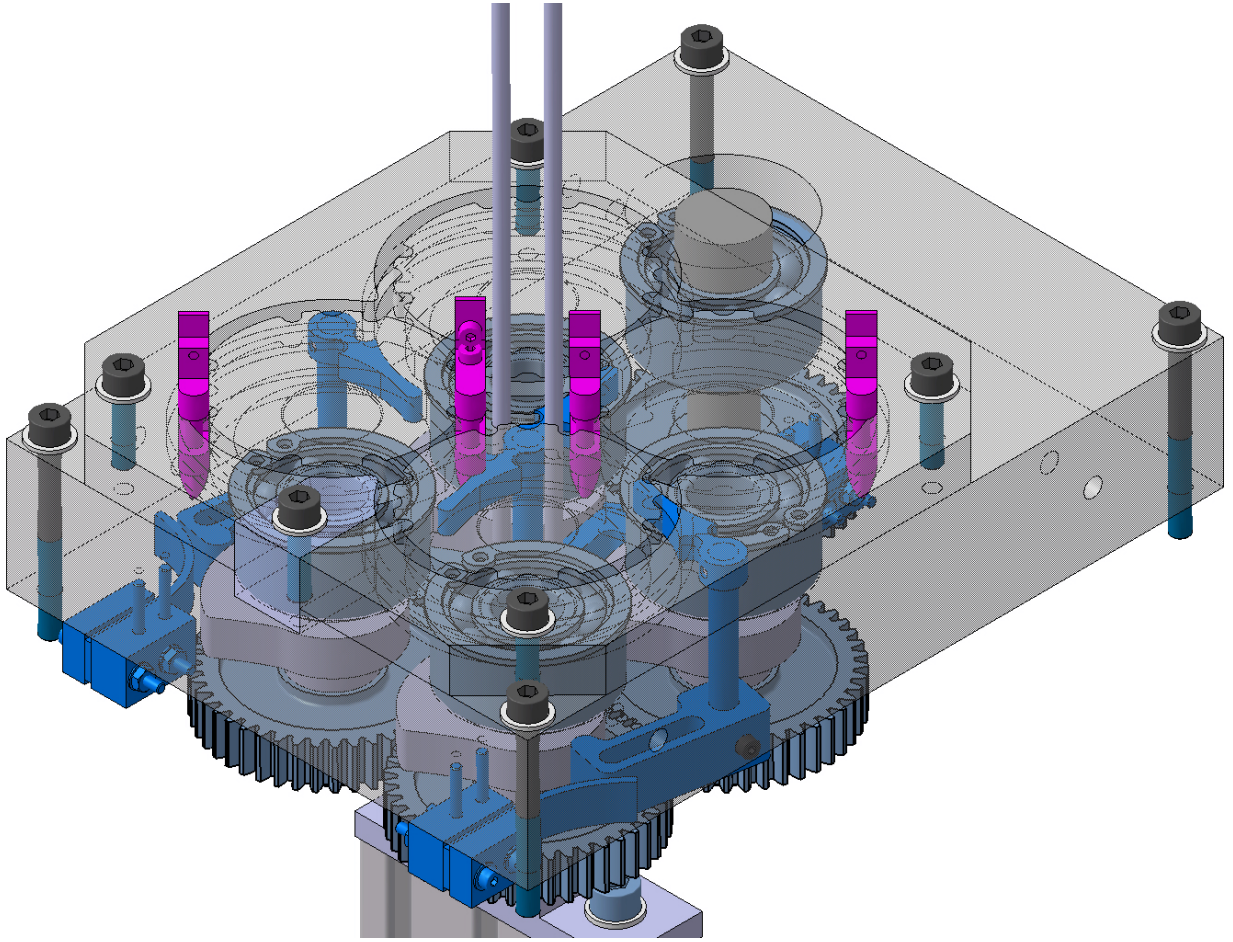


Machine Design

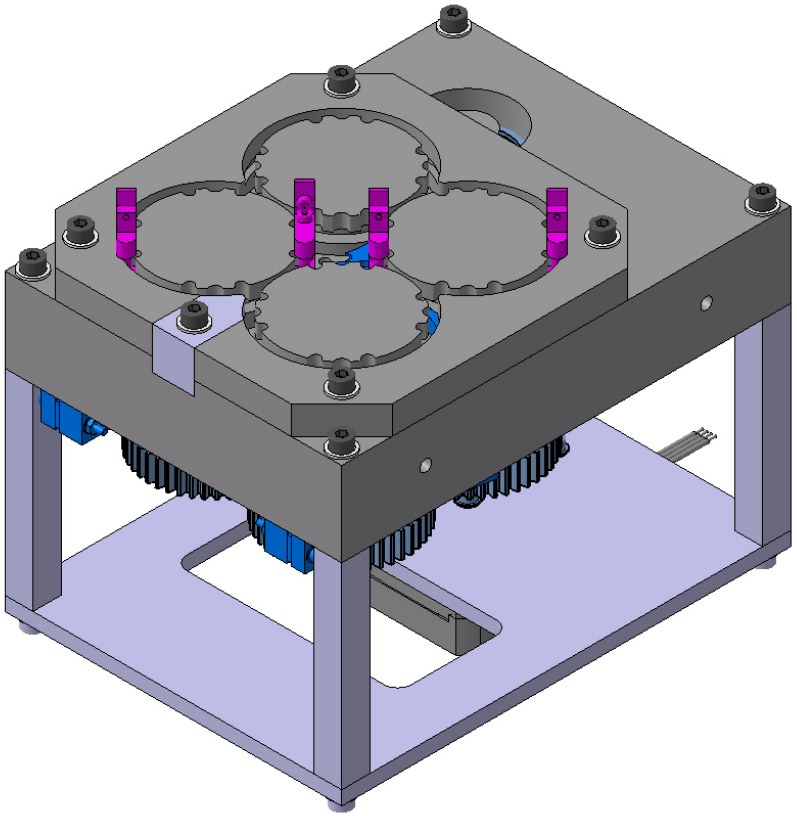
Detailed design

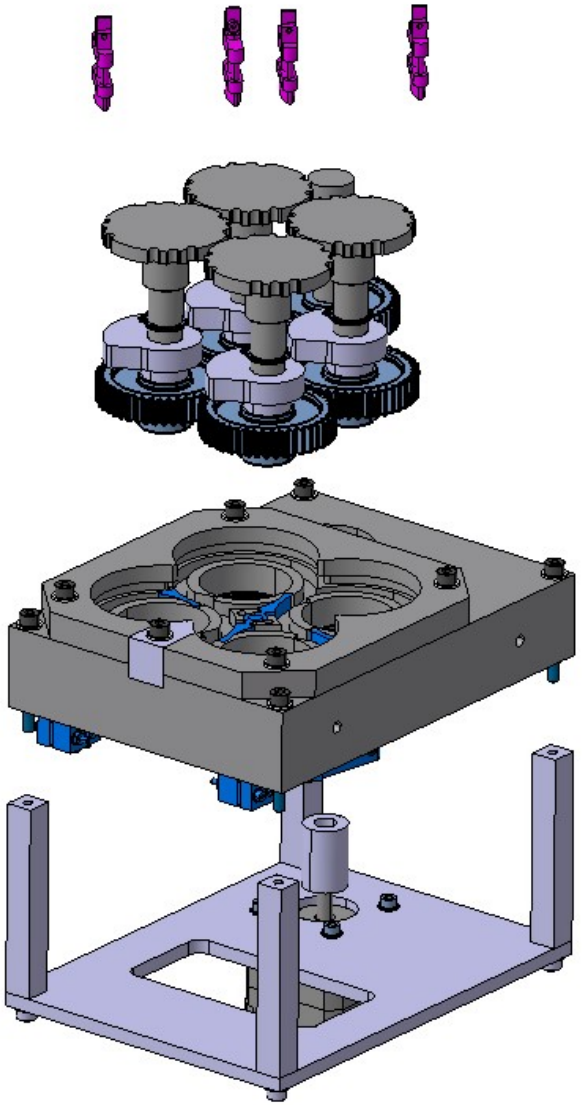


Main body assembled

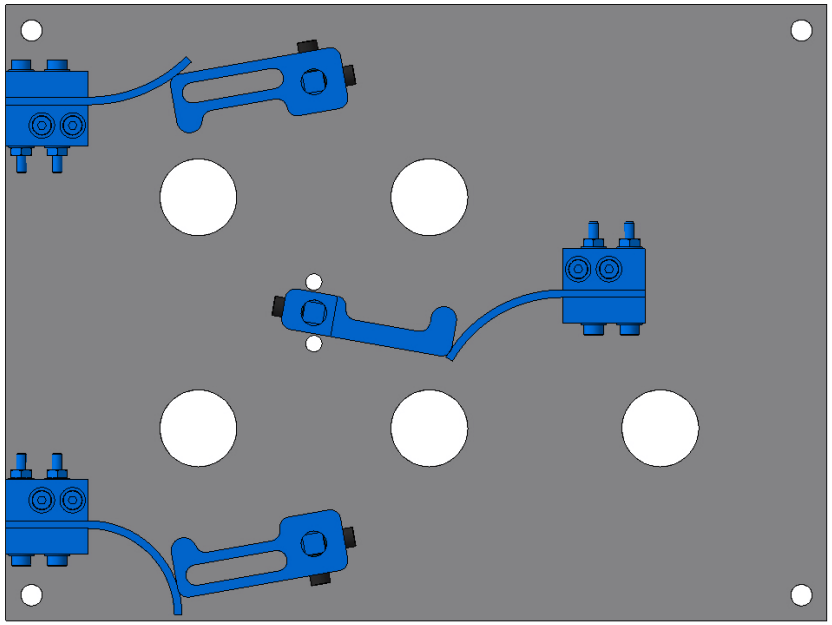


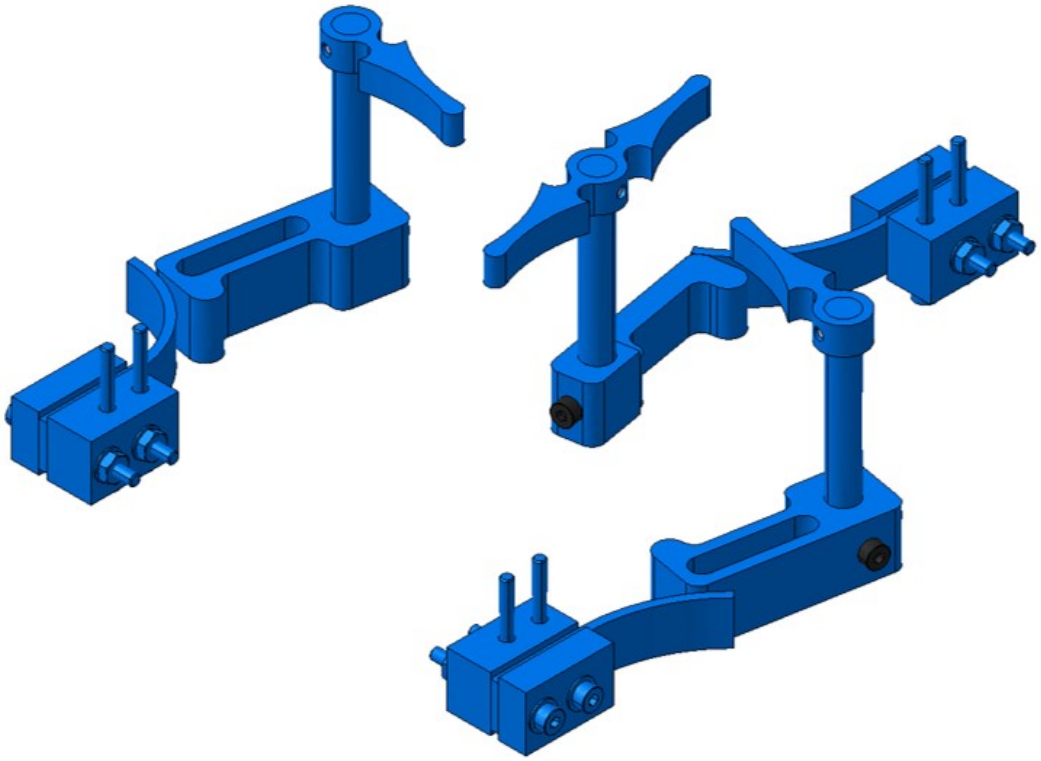
Main body exploded



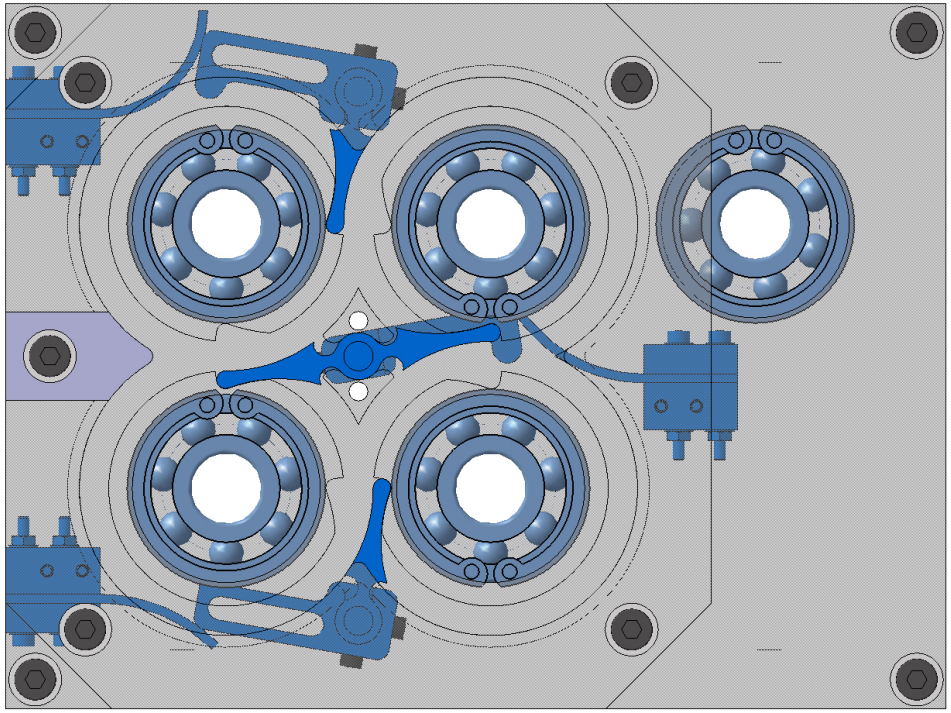


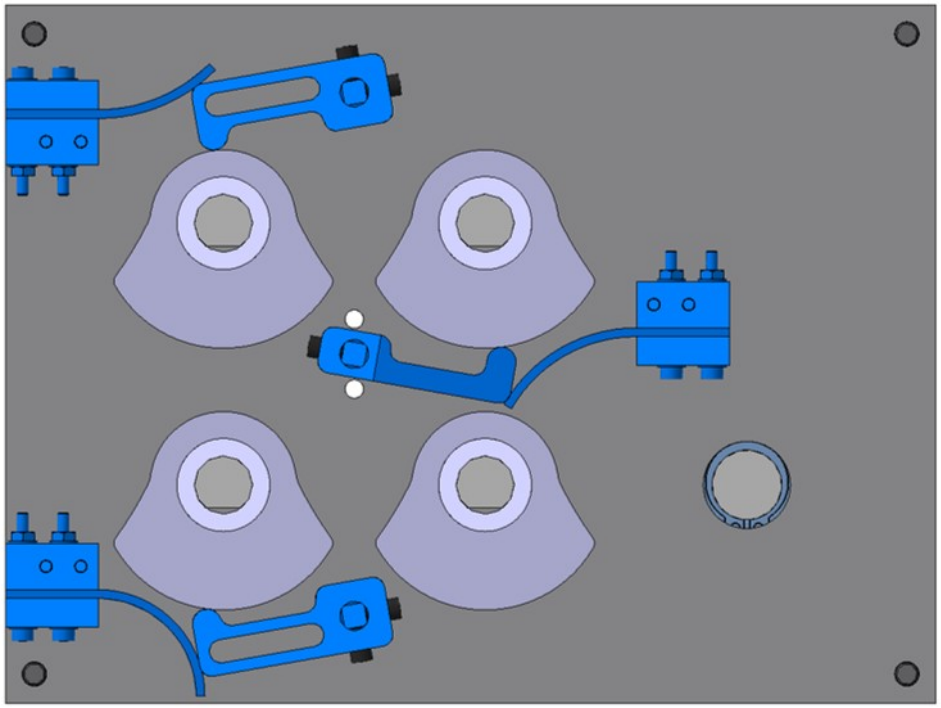
Path Change Mechanisms



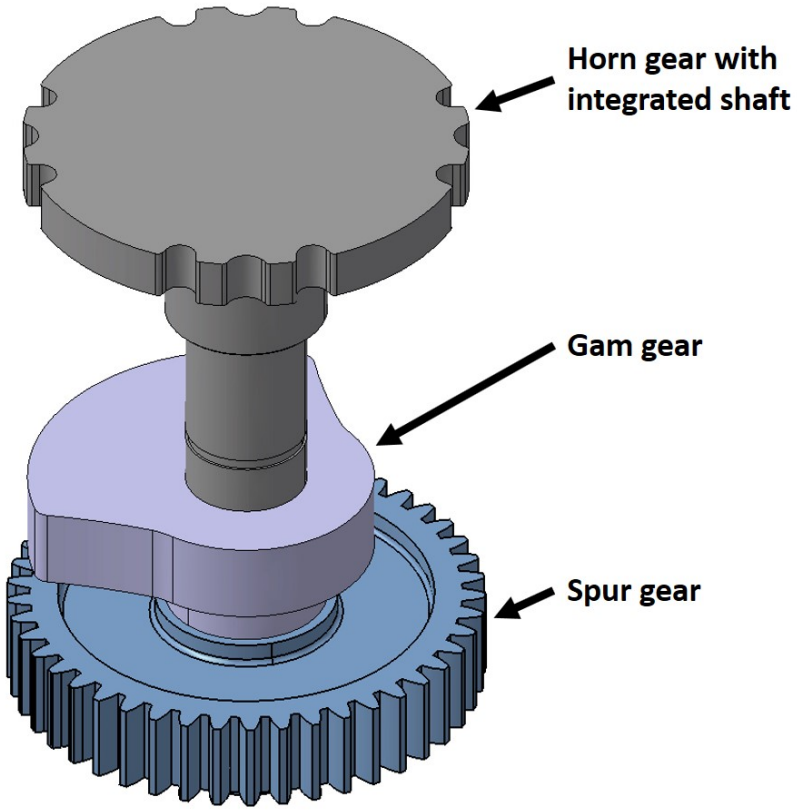


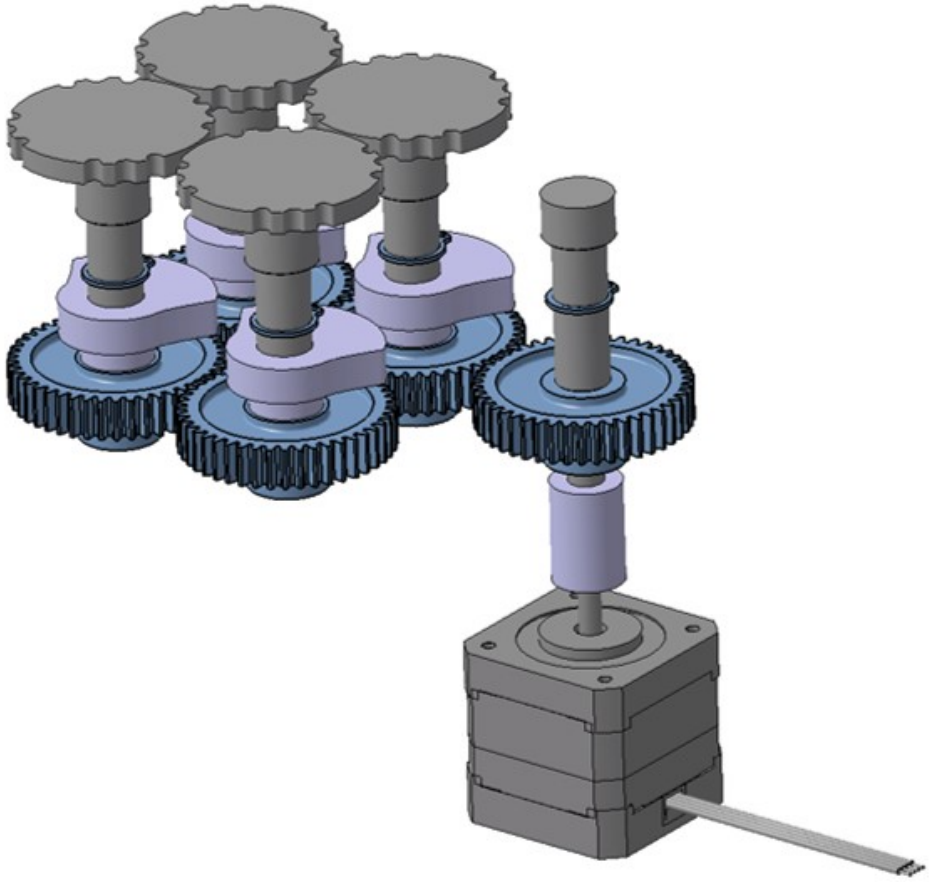
Path Change Mechanisms



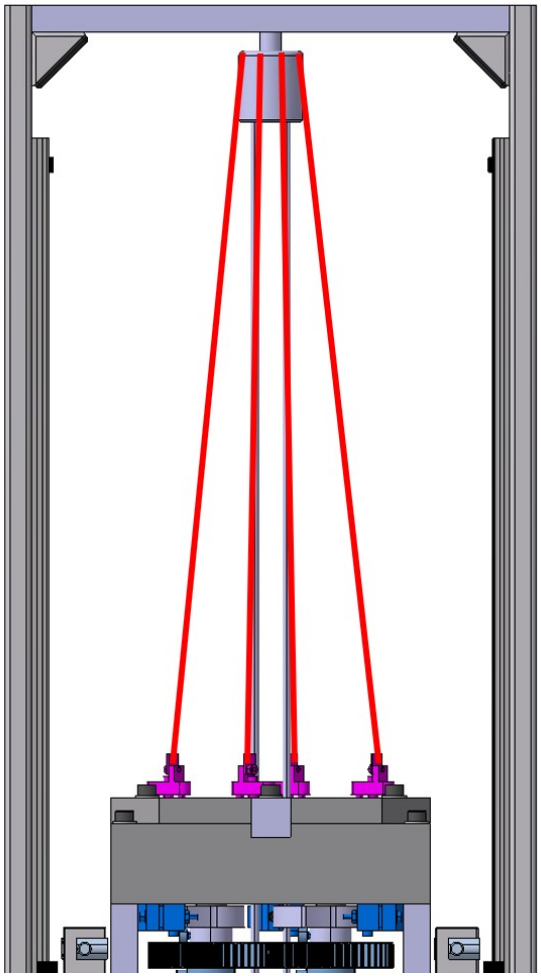


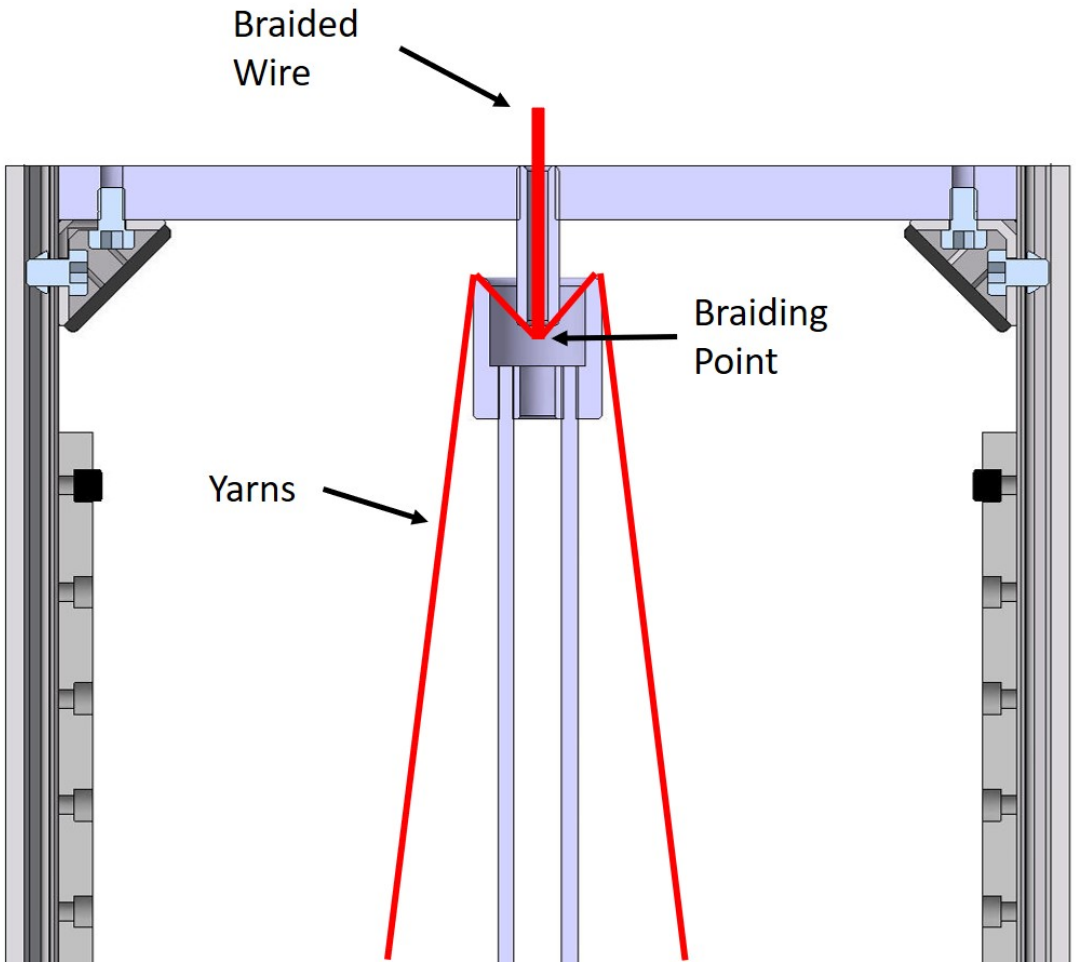
Gears Assembly



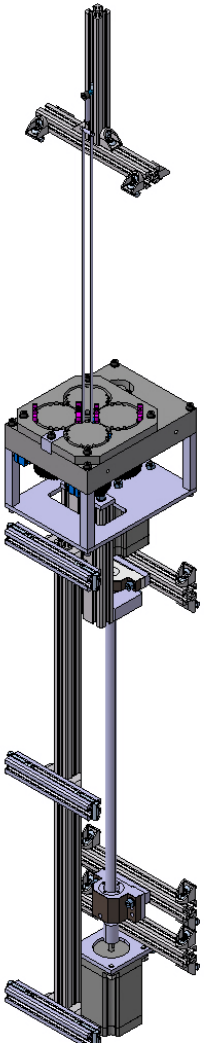


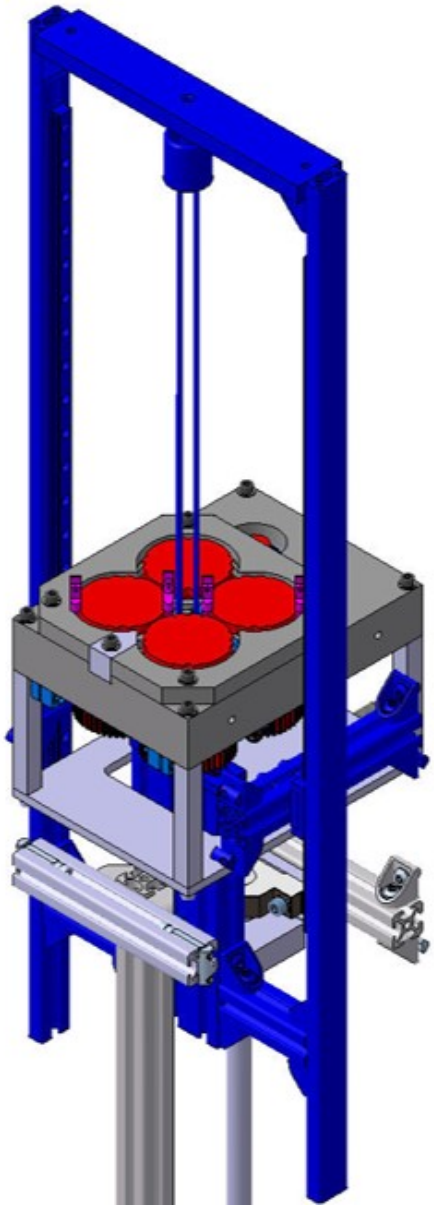
Guiding System



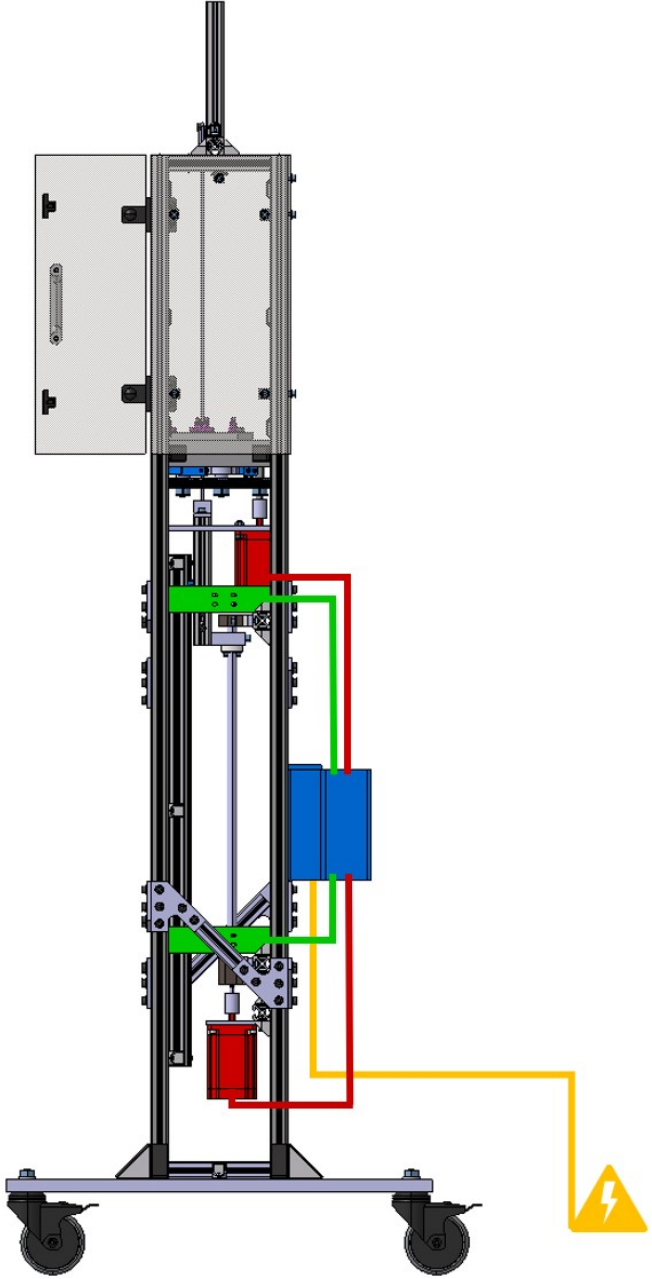


Guiding System



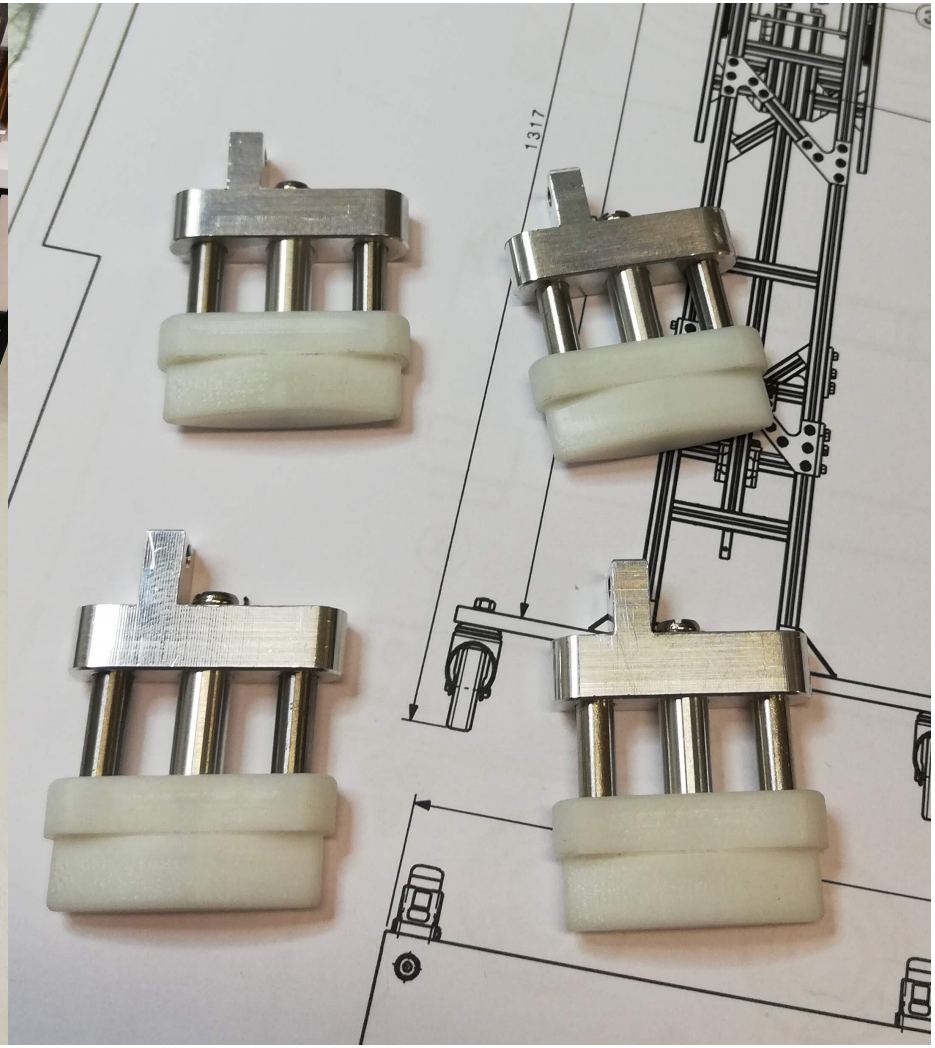


Electronics



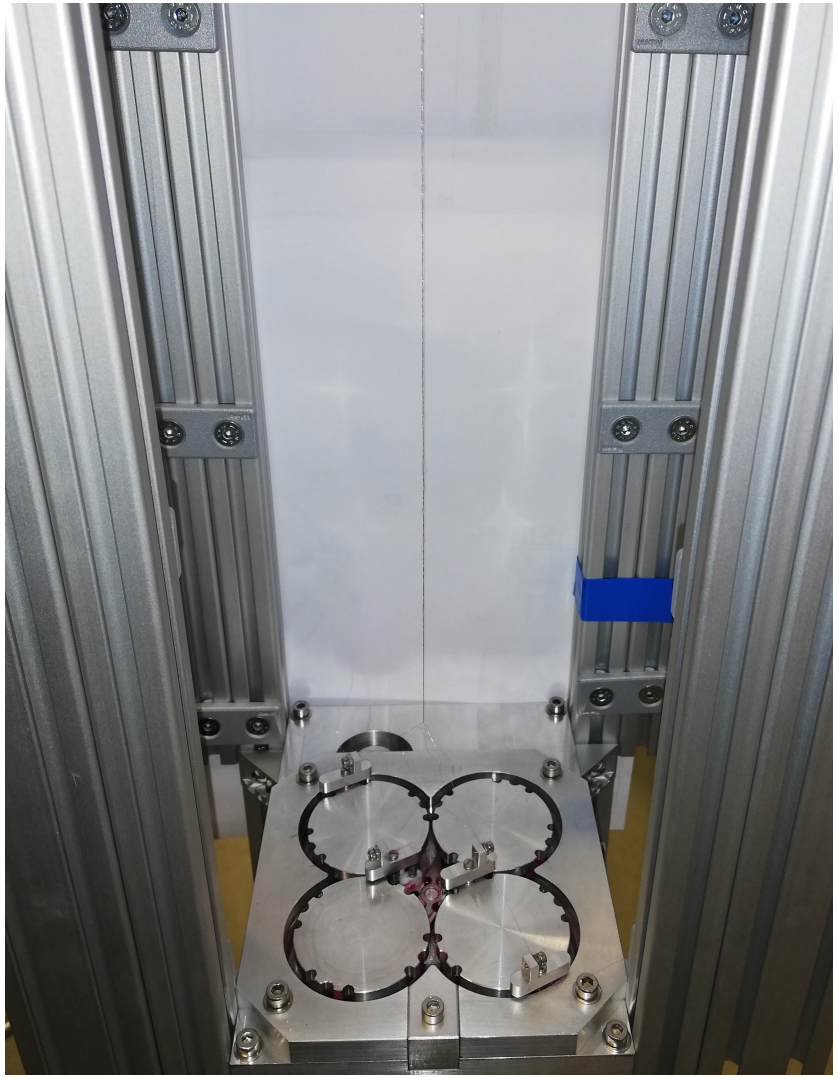
Machine Pictures

Components 1



Components 2

Wire Braiding



Testing

Packing factor methods

Theoretical packing factor for 4 wires = 73.3 %

- F_p 1: Based on encapsulating envelope
- F_p 2: Based on ellipse
- F_p 3: Based on average between D_in and D_out

Wire	D_out	D_in	D_avg	F_p 1[%]	F_p 2[%]	F_p 3[%]
SS 250 um	930	476	703	29	56	51
SS 50 um	241	142	191	17	29	27
Nylon 100 um	472	191	332	18	44	36
Carbon 100 um	285	146	215	49	96	86

Stainless steel

Diameter	250 µm			50 µm		
Data [unit]	**D_{in}**	**D_{out}**	**λ**	**D_{in}**	**D_{out}**	**λ**
Average [µm]	476	930	5026	142	241	1142
Sigma [µm]	54	105	N/A	33	48	358
Normalized σ [%]	11.3	8.9	N/A	22.9	19.8	33.1
F_p [%]	56			29		

Nylon

Data [unit]	D_{in}	D_{out}	λ
Average [µm]	191	472	1370
Sigma [µm]	23	5	155
Normalized σ [%]	11.09	1.2	11.3
F_p [%]	44		

Carbon

Data [unit]	D_{in}	D_{out}	λ
Average [µm]	146	285	627
Sigma [µm]	12	17	64
Normalized σ [%]	8.2	6.1	10.2
F_p [%]	96		