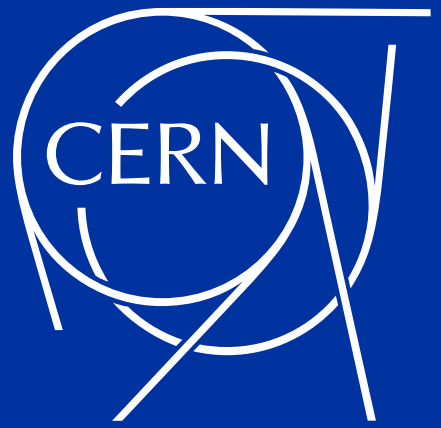


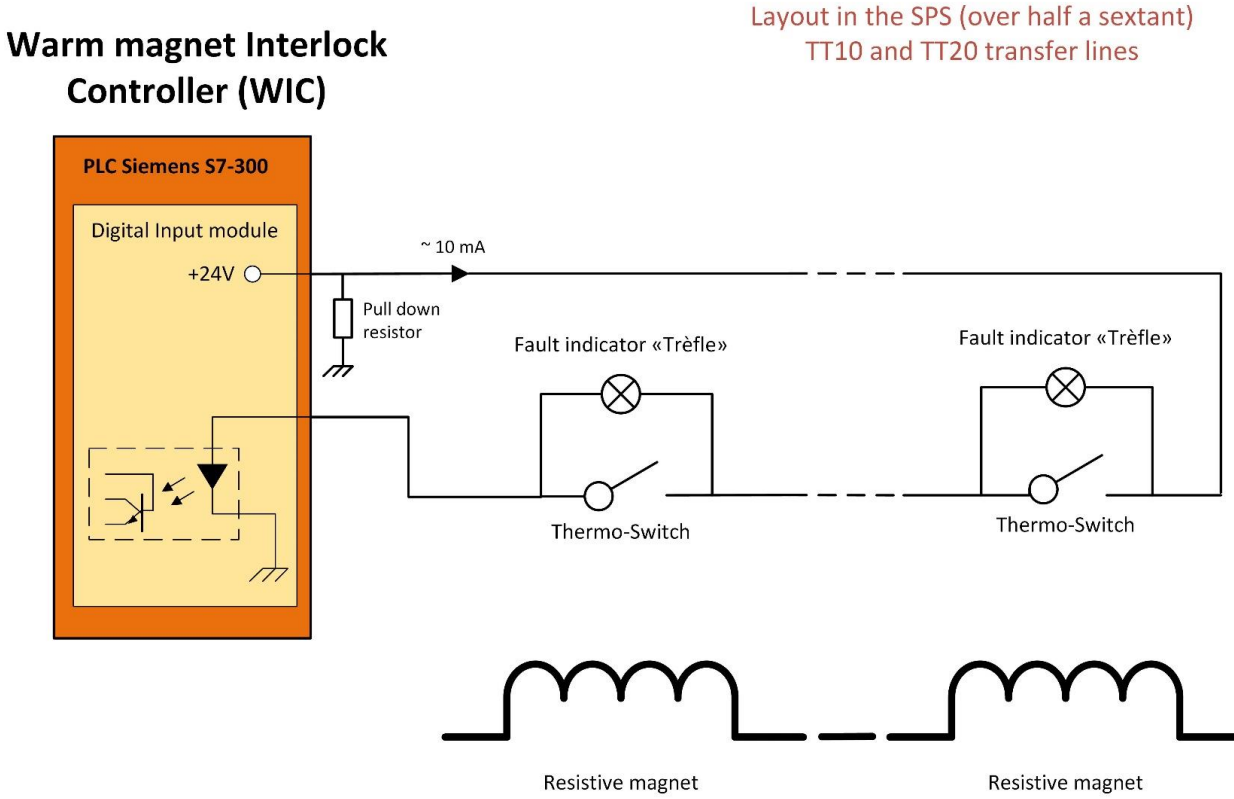
TREFLE Project Status: Concept and Design

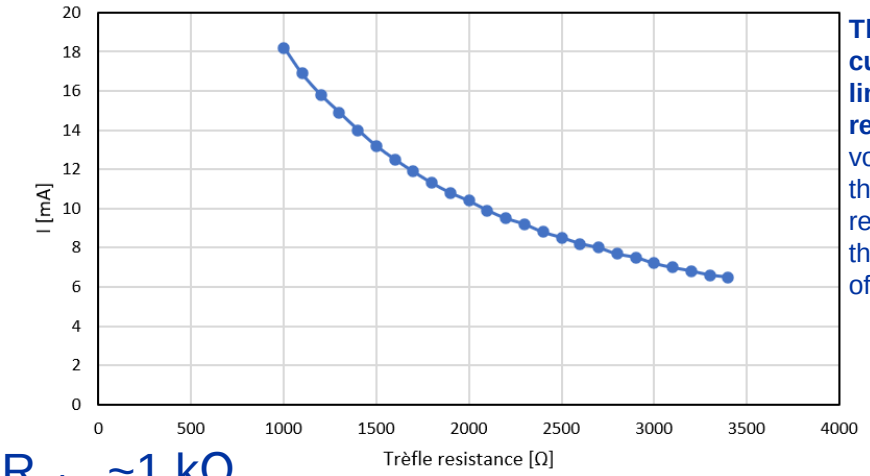
M. Timmins on behalf of the EN/MME team

06/06/2025

Electrical Circuit

- **When thermo-switch activates (opens), the current goes to the trèfle in parallel to it. The trèfle latches and even if the temperature increase disappears, the trèfle keeps the position until is manually reset.**



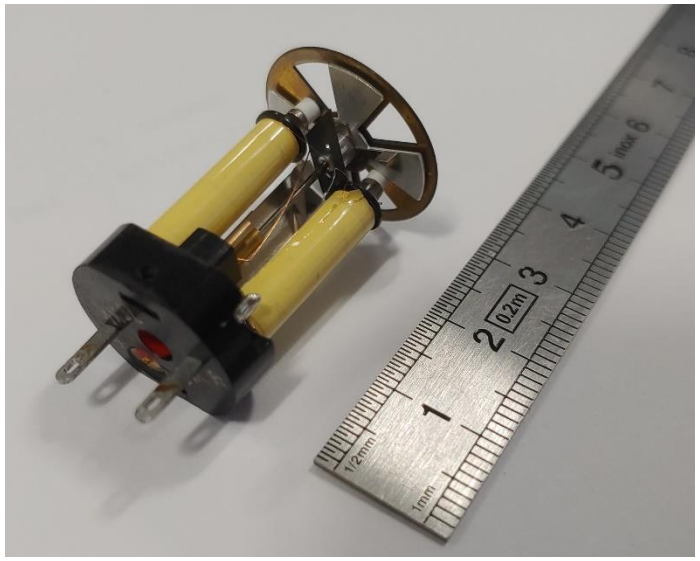


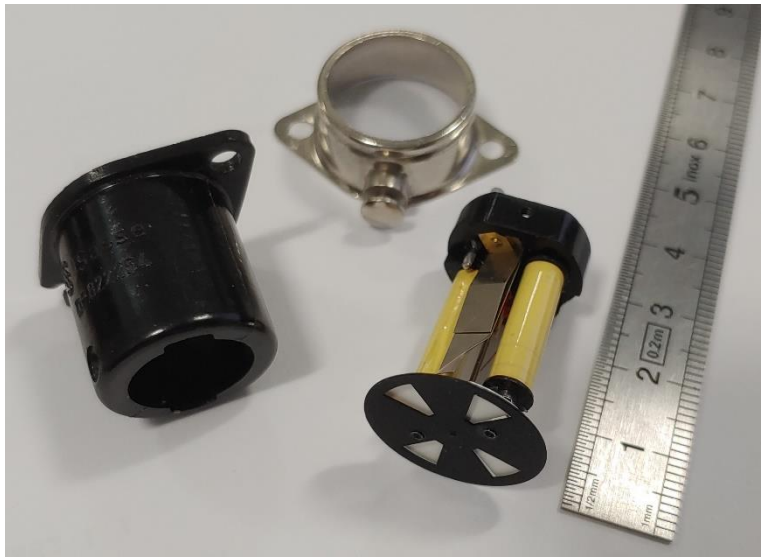
The available current is non-linear with trèfle resistance due to a voltage divider with the pull-down resistor in parallel to the input impedance of the PLC module.

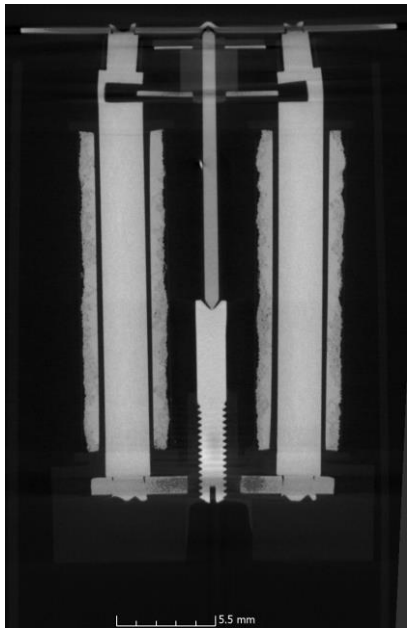
$R_{trèfle}$~1 kΩ

Thermo-switch normally closed

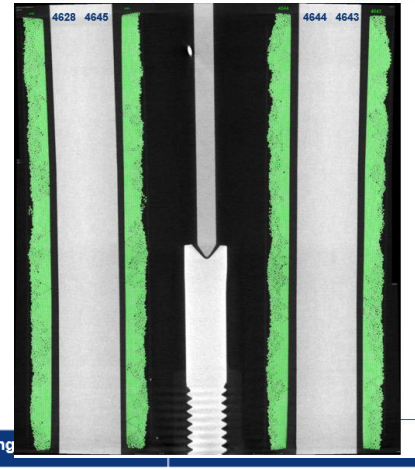
Original TREFLE – reverse engineering



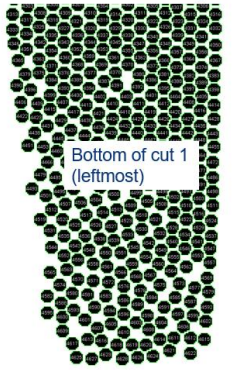




Microcomputed x-Ray tomography (NDT)



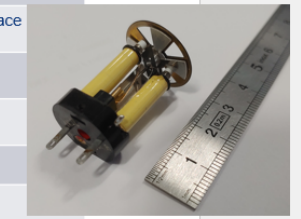
Analysis done with ImageJ



Average: 4640 turns/coil

Part	Materials	Manufacturing	
Coils (holder + wire)	Enamelled copper wire. Plastic holder	Coil winding. Injection moulding	Slided in place. Tin soldering (wire)
Magnetic core (2 shafts + 1 bridge plate)	Iron/steel/nickel (high permeability)	Grinding/turning. Forming/milling	Riveted & placed in injection mould
Magnetic plate	Iron/steel/nickel (high permeability)	Forming (stamped) / milling	Press-fit / glued
Needle seat	Brass	Turning	Screwed in place
Needle shaft	Steel? Stainless steel?	Grinding/turning	Press-fit & adjusted in place
Spring wire	Spring steel? CuBe?	Forming (bending)	Glued & adjusted in place
Latching sheet	Spring steel? Steel? SS? Ni?	Forming (stamping/bending)	Clamped
Clamp for latching sheet	Brass	Turning/milling	Screwed
Indicator disc	Aluminium?	Forming (stamping) + Painting	Press-fit / glued
Indicator frame	Aluminium?	Forming (stamping) + Painting	Riveted
Contacts	Ni-coated copper?	Commercial?	Placed in injection mould
Back housing	Plastic	Injection moulding	Screwed
Front housing	Ni/Cr plated steel + polycarbonate?	Forming (stamping) + Injection moulding?	Screwed
Reset button + spring	Metal	Turning/milling	Press-fit

Jorge Guardia | 04-May-2021 6



TREFLE design

- Triggering by the rotation of a rotor induced by a current through a solenoid

- Millinewtons force to rotate.

- Friction based design to hold rotor in open position

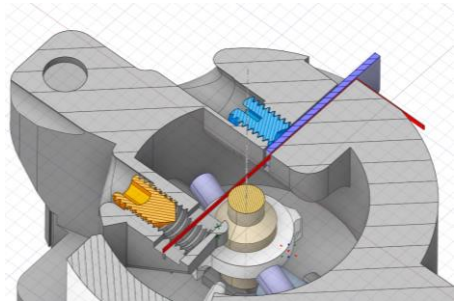
  - Friction high to keep position open
  - Friction low to make sure it triggers

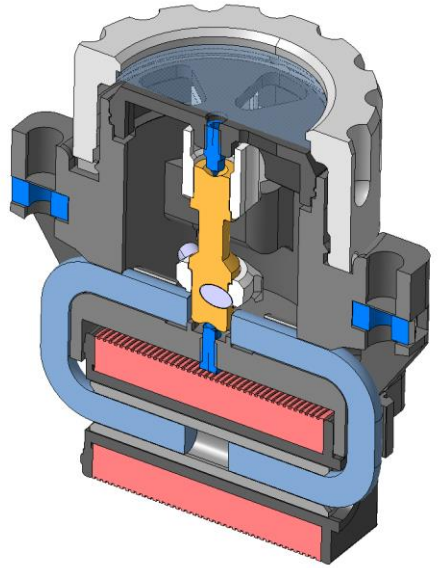
  Friction can be adjusted based on current (calibration process)

  - Max friction: **12.5 mA** (used for magnetization)
  - Nominal friction: **9 mA**
  - Min Friction: **6 mA**

- Good mechanical position required for rotor in radial and height for optimum performance (assembly process)

- No play allowed (assembly process)





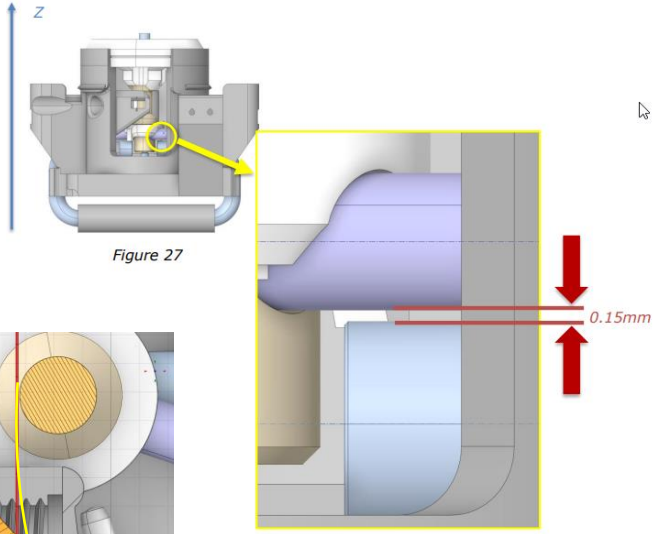
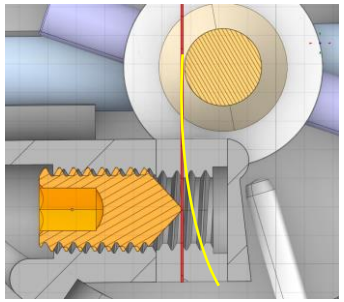


Figure 27



Current seen by the trefle

Current calculations

Design made for 9 mA nominal (safety margin)

Turns	10500				Red bullets=problem for the PLC system (exceeds limits / undefined state)													
R_In [Ω]	2400				The flags are to check the disipated power in the R_pull-down (red >5 W, yellow >1 W)													
V_In [V]	24																	
					Trefle On (TS open), logic state 0								Trefle Off (TS closed), logic state 1					
	R_PD [Ω]	R Trefle [Ω]	R_cable [Ω]	R_In // R_PD [Ω]	I Trefle [mA]	V Trefle [V]	[A.turns]	P Trefle [W]	V In [V]	I In [mA]	I PD [mA]	P PD [W]	I cable [mA]	V In [V]	I In [mA]	I PD [mA]	P PD [W]	P cable [W]
Operation lowest R (14 °C, -2σ)	390	1480	40	335.5	12.9	19.1	135.8	0.2	4.3	1.8	11.1	0.0	63.9	21.4	8.9	55.0	1.2	0.2
	390	1480	340	335.5	11.1	16.5	116.9	0.2	3.7	1.6	9.6	0.0	35.5	11.9	5.0	30.6	0.4	0.4
Operation mean R (15 °C, μ)	390	1504	40	335.5	12.8	19.2	134.1	0.2	4.3	1.8	11.0	0.0	63.9	21.4	8.9	55.0	1.2	0.2
	390	1504	340	335.5	11.0	16.6	115.6	0.2	3.7	1.5	9.5	0.0	35.5	11.9	5.0	30.6	0.4	0.4
Operation highest R (25 °C, +2σ)	390	1580	40	335.5	12.3	19.4	128.9	0.2	4.1	1.7	10.6	0.0	63.9	21.4	8.9	55.0	1.2	0.2
	390	1580	340	335.5	10.6	16.8	111.7	0.2	3.6	1.5	9.2	0.0	35.5	11.9	5.0	30.6	0.4	0.4

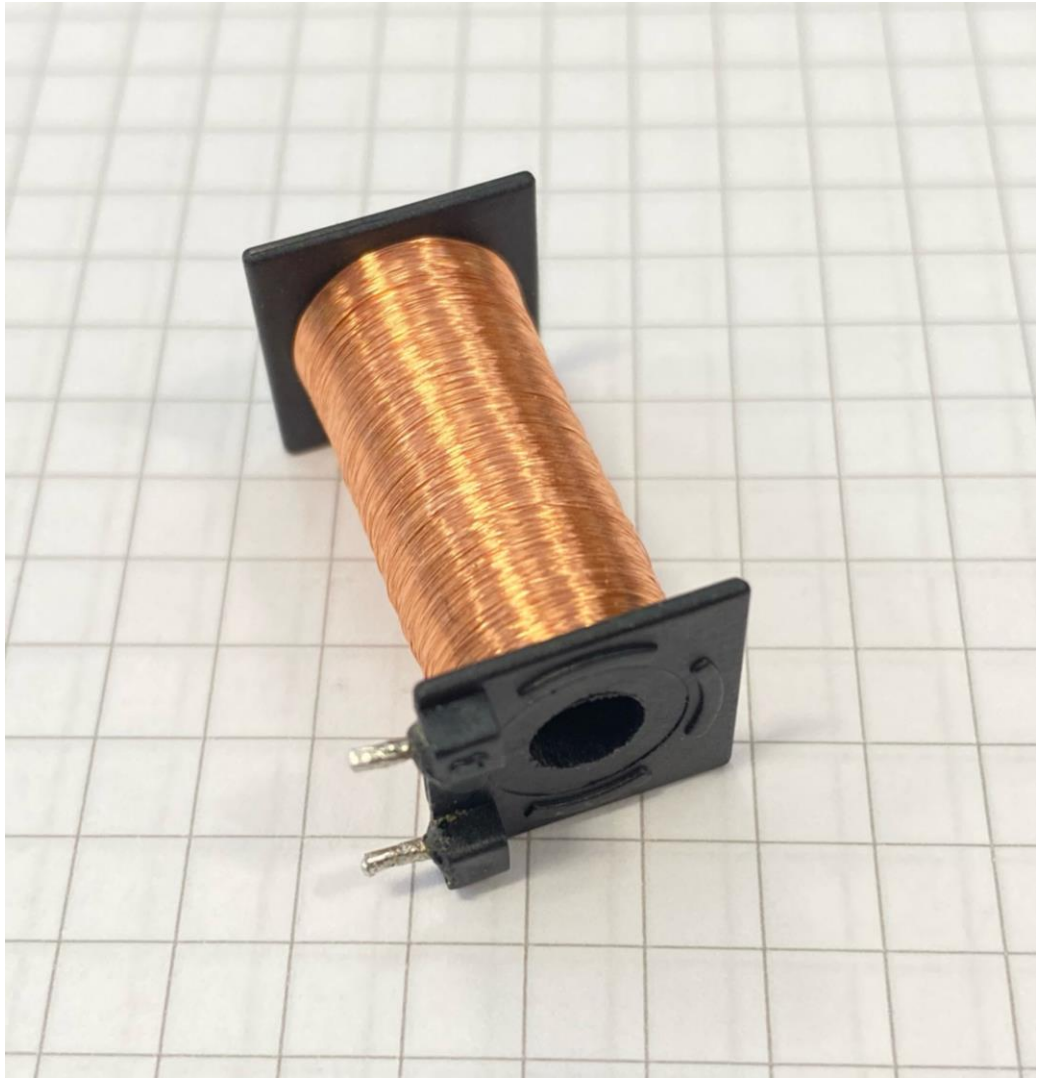
SPS PLC circuit parameters OK

Trefle current (tunnel at 15 °C): Between 11.0 and 12.8 mA
Trefle current (tunnel 14-25 °C): Between 10.6 and 12.9 mA

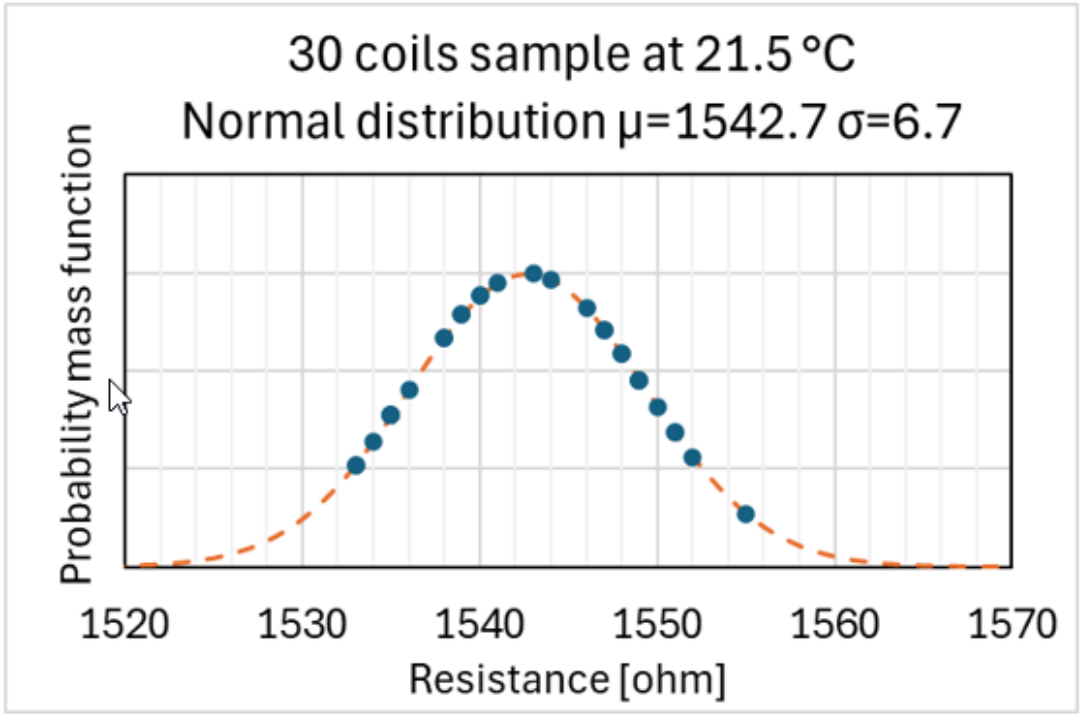
Ampere.turns are proportional to the solenoid magnetic force

Coil Specifications

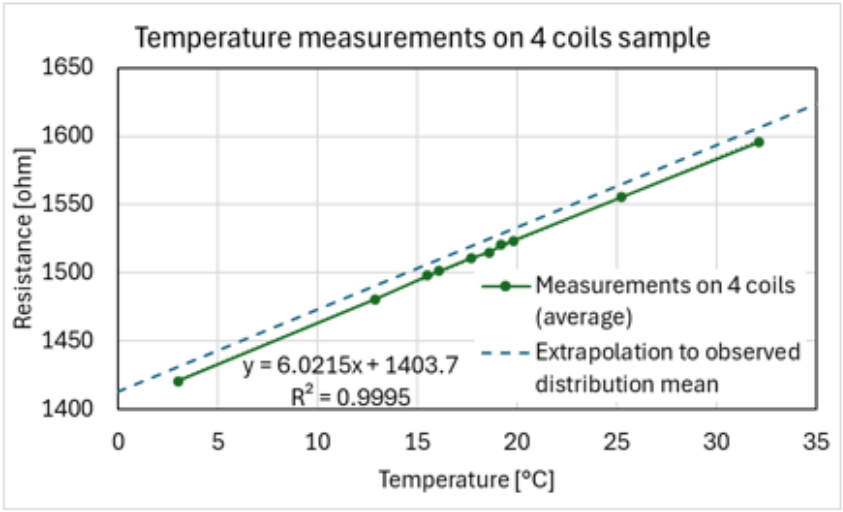
- **Coil Support**: Injection-moulded PA6.6GF30Dimensions: 14×14×23.5 mm with Ø5 mm hole
- **Winding Wire**: Copper enamelled wire, Ø0.0710 mm Polyurethane P180, Class 180 (IEC 60317-51), Grade 1
- **Specs**:10,500 turns~135 ampere-turns at 19.5 V
- **Resistance**: 1500–1580 Ω (Avg. 1515 Ω @ 20°C, based on PC1002464)
- **Cabling**: 14.5 cm of insulated flat double cable (0.1 mm²)
- **Insulation & Protection**: Thermal tape Class B to protect winding (23 mm); Extra tape to secure external cable



Coils Measurements



Sample of 30 coils from batch of 202. Order PC1222393.
Measurements 27/09/2024 (J.Guardia)



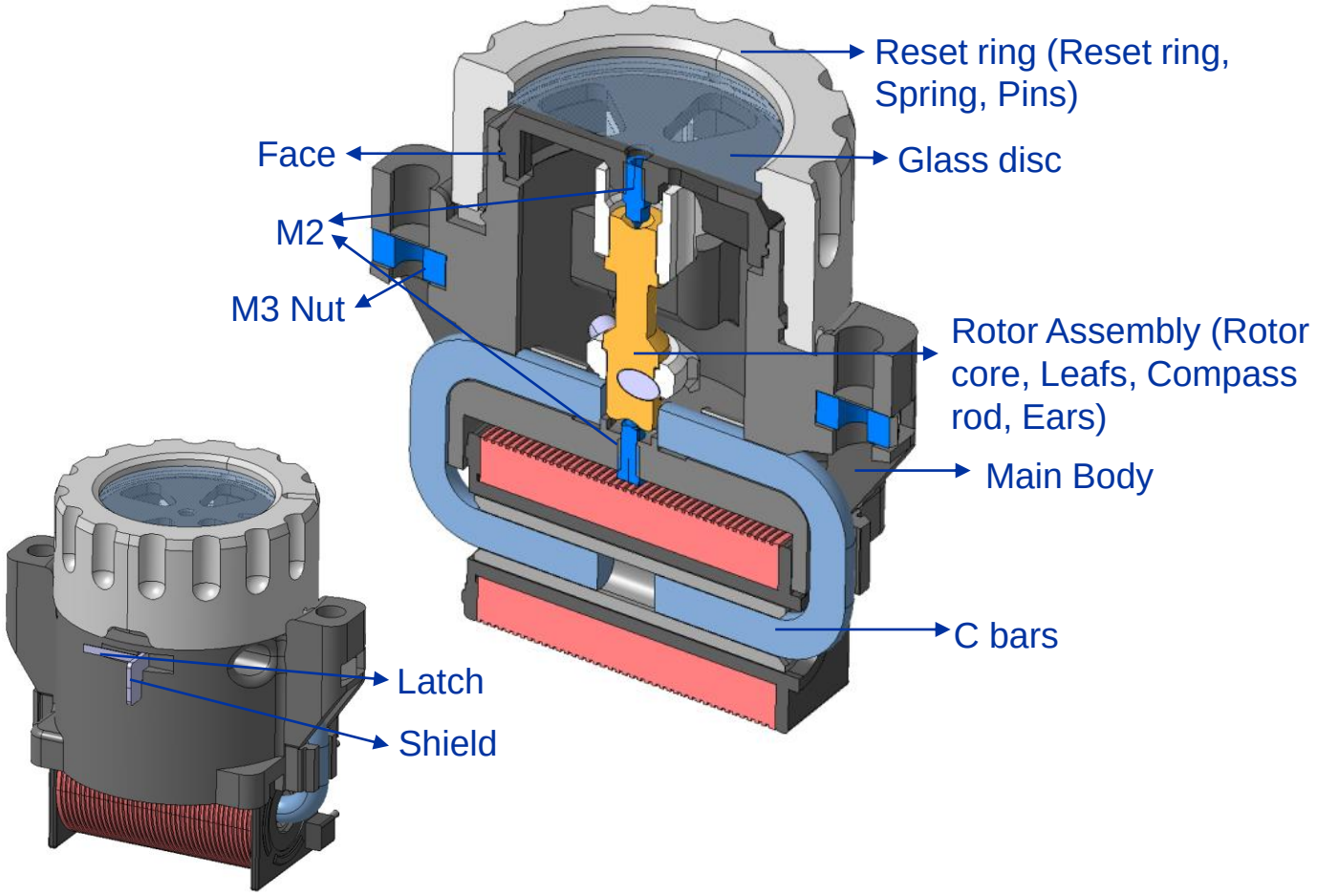
4 coil sample used to obtain temperature sensitivity (slope)

Extrapolation to observed distribution mean					
slope	intercept				
6.0215	1413.204				
Temp. [C]	R [ohm]	% wrt 20°C		"-2σ"	"+2σ"
5	1443.31	94.1		1429.9	1456.7
10	1473.42	96.1		1460	1486.8
15	1503.53	98.0		1490.1	1516.9
20	1533.63	100.0		1520.3	1547
21.5	1542.67	100.6		1529.3	1556
25	1563.74	102.0		1550.4	1577.1
30	1593.85	103.9		1580.5	1607.2
35	1623.96	105.9		1610.6	1637.3

R at 15°C=1504 ohm
R at 20°C=1533 ohm

Materials

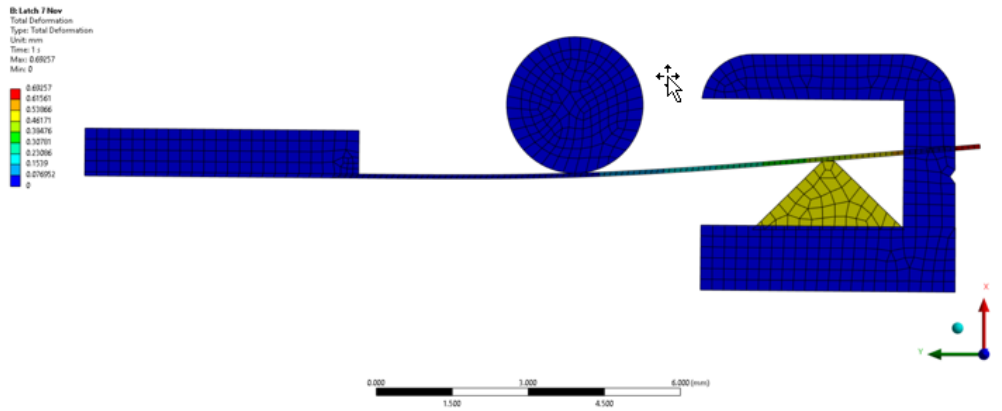
- **Main Body, Reset ring, Leafs, Lears, Face** – ABS Plastic
- **Rotor Core** – Brass CW713R - CuZn37Mn3A12PbSi
- **C bars** – Steel with coating
- **Compass rod**– Steel with coating
- **Shield** – Stainless Steel 301
- **Latch** - Kanthal
- **M2 screws** – Stainless Steel 316
- **Glass disc** – Makrolon polycarbonate

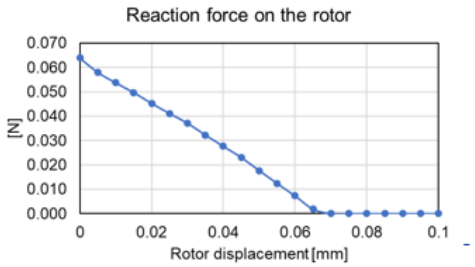


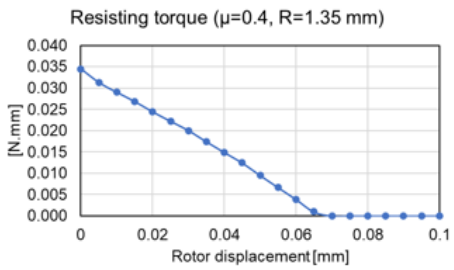
Coating – Zinc electroplating (blue), Thickness 15um

Rotor position

2. Sensitivity analysis of the position of the rotor performed by Jorge







60μm displacement in the rotor results in loosing all resistance torq given by friction.

- Sensitive to position
- Needs to be stable and accurately positioned

Adjustable Set screws

Metal rotor

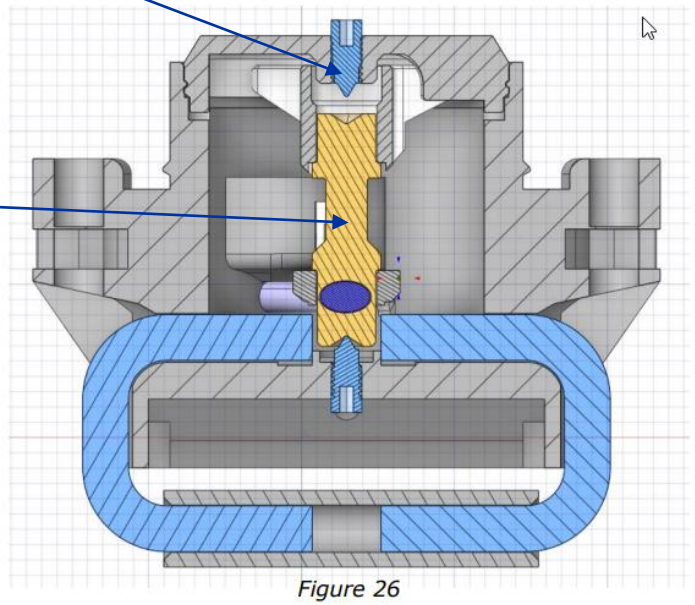
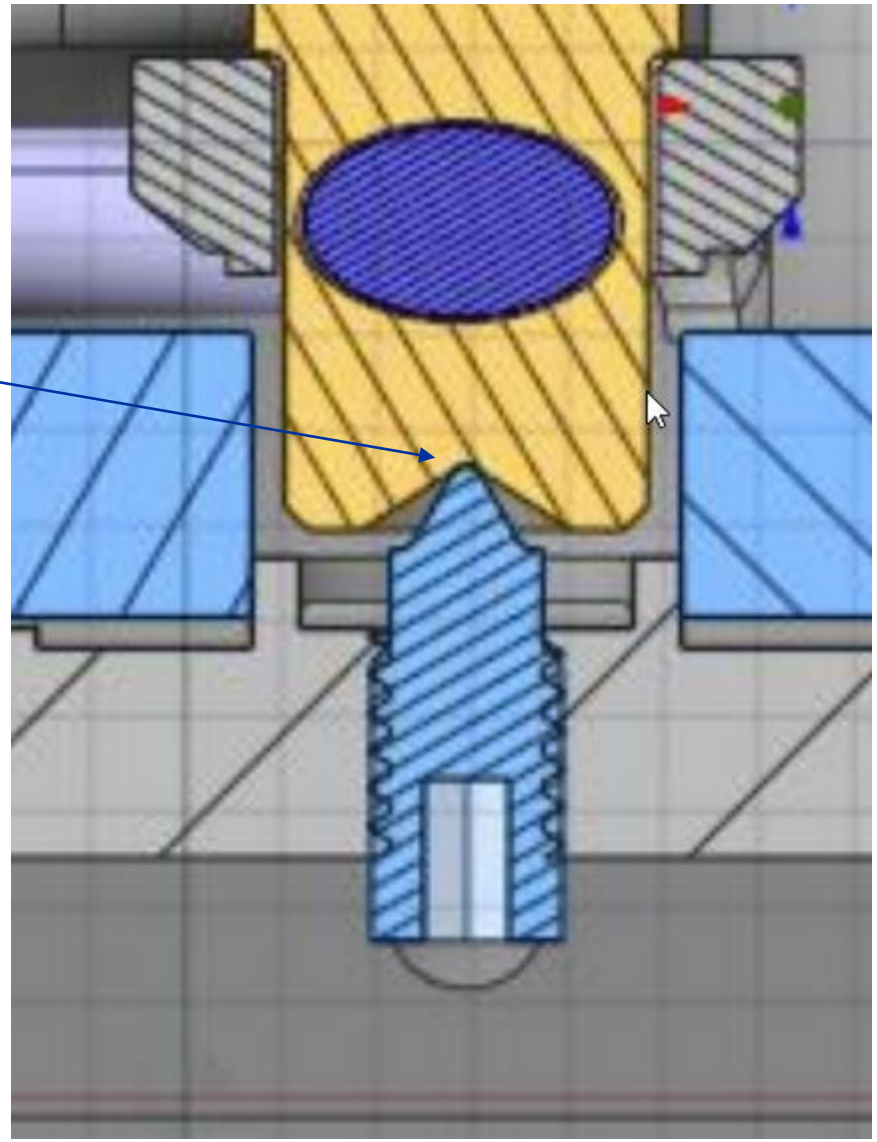


Figure 26

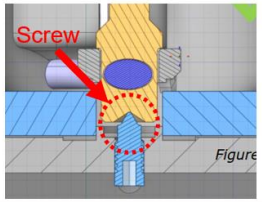
Reduced friction on rotor

Custom made pointed screws in St steel to reduction friction to brass rotor.

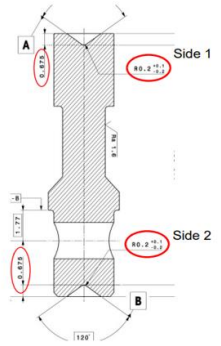


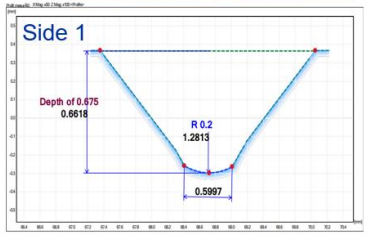
Rotor Production Issue

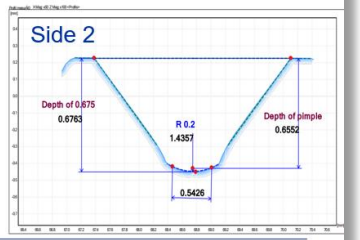
- The production of the rotors encountered an issue.
- EDMS 3235690: Measurement of the two radius R0.2 according to the drawing LHCCIWAB0010.
- It has a significant impact on functionality, as the screws in contact can move.



Measurement of the two radius R 0.2 and their depth of 0.675



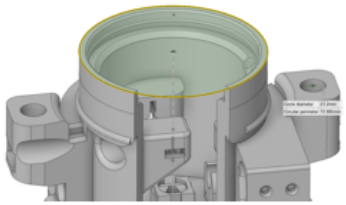




Plastic components

Trefle meeting 24/11/2023

1. **Issues with the 3D printing accuracy. Dimensions out of tolerance. Dispersion in dimensions from one batch to another.**



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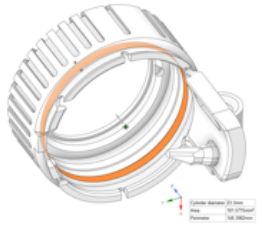


Reset ring

Preliminary dimension measurements (caliper)					
	Nominal (ø)	Claimed tolerance (±)	Measured pre-series (ø)	Measured latest prototype (ø)	Measured after calibration (ø)
Body diameter	23.2	0.1	23.34	23.37	23.3
Reset ring diameter	23.3	0.1	23.38	23.3	23.28
Gap (radius)	0.05	0.1	0.02	-0.035	-0.01
Assembly sliding fit			ok	nok	Almost ok

OK by luck

Resulting actions taken

- Tomography ongoing to validate manual measurements.
- Ongoing machine calibration investigations.
- Increased gap by 0.025mm (to be confirmed from final metrology measurements)

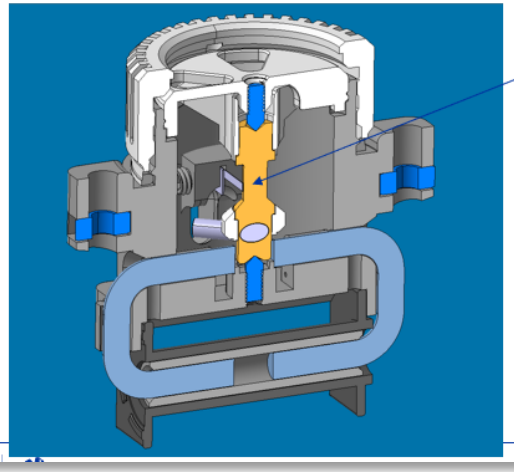
- Tolerances were an issue on Polymer parts
- Tapped holes improved
- New machines procured by TE/MSC
- Quality gate
- Good results so far

Material choices

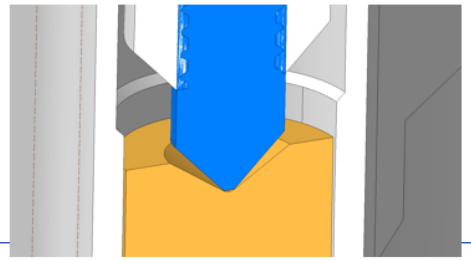
3. Improvement in the design

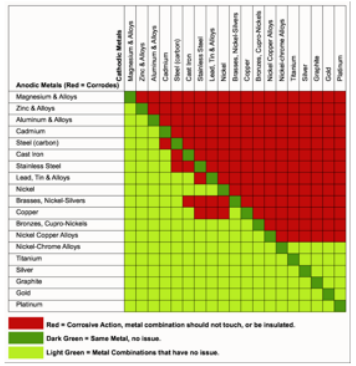
New rotor design using Bronze for important function surfaces:

- Better control of the concentricity and cylindricity of the rotor
- Better control of the friction coefficient between latch and rotor.
- No major increase in cost. brass inserts ~ Bronze rotor
- Galvanic coupling Bronze/St. Steel being checked with S. Sgobba
- No need to carry out pre-series (only a few prototypes)



New rotor material (bronze)

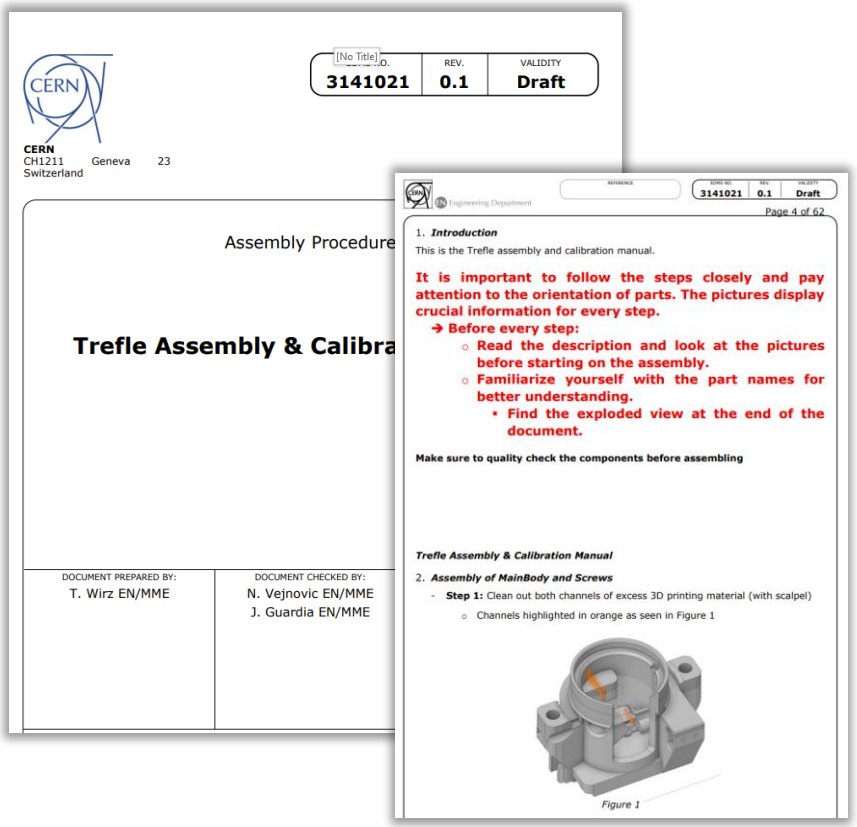




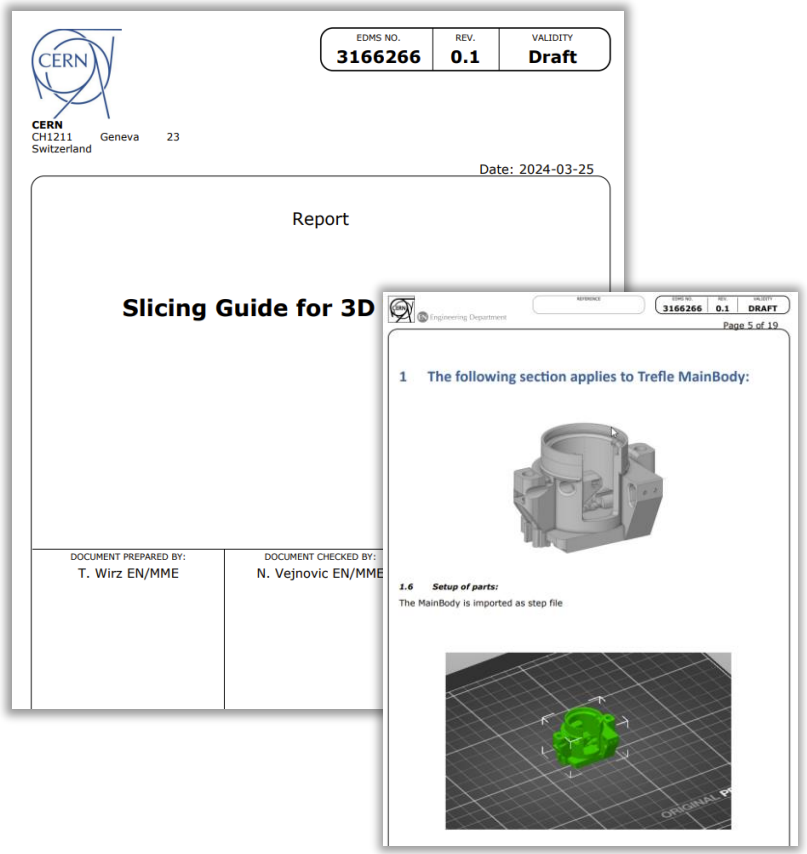
Galvanic coupling

- Risk of corrosion
- Galvanic coupling
- Metalography on current operation trefle
- Identification of materials and application of equivalent grades to new Trefle
- Brass / St steel

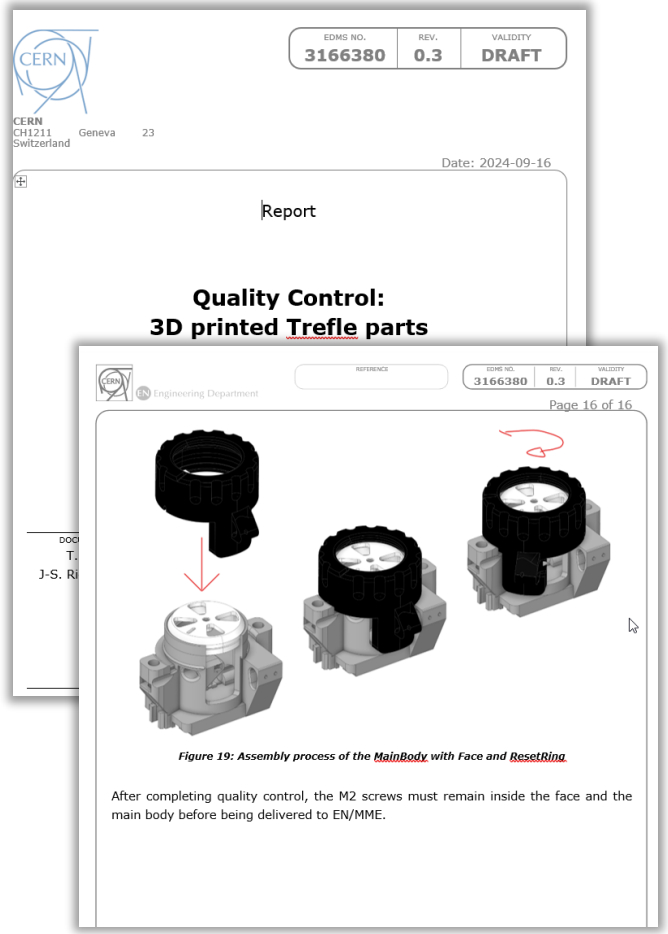
Documentation



[Assembly and calibration manual Edms: 3141021]



[3D printing guide Edms: 3166266]



[3D printing quality checks Edms: 3166380]

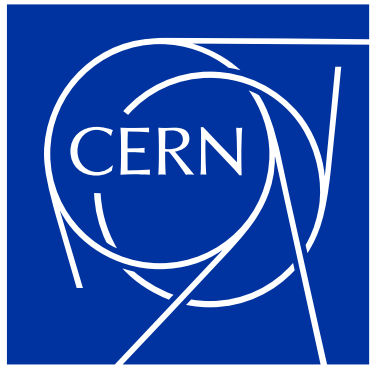
Conclusion

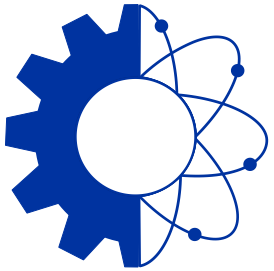
Trefle is robust if all the steps are fulfilled correctly:

- Production within tolerances (geometry, coatings, material specs)
- Inspection steps and quality gate respected (metrology, NDT, quality gate manual)
- Assembly and calibration procedure strictly followed (documentation provided)

Results don’t take into account the following:

- Performance after ageing and radiation tests
- Performance after Reverse polarization effect





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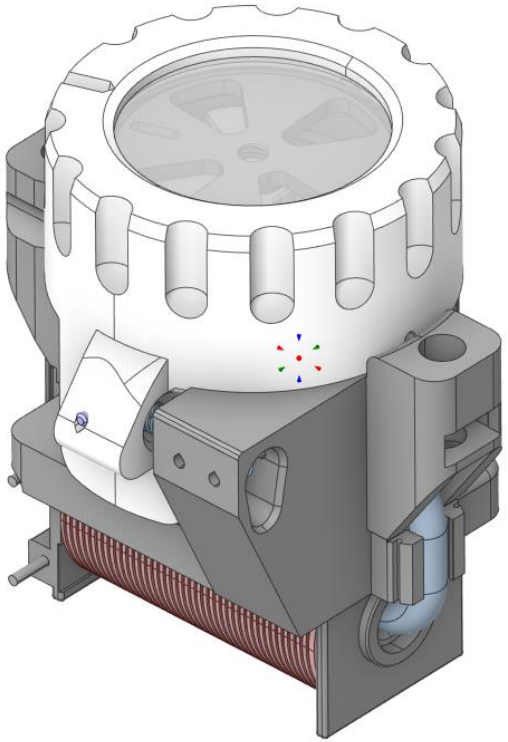
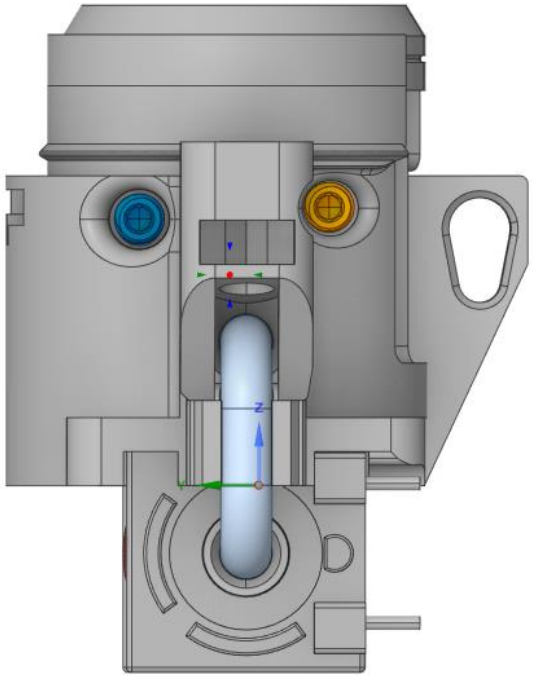
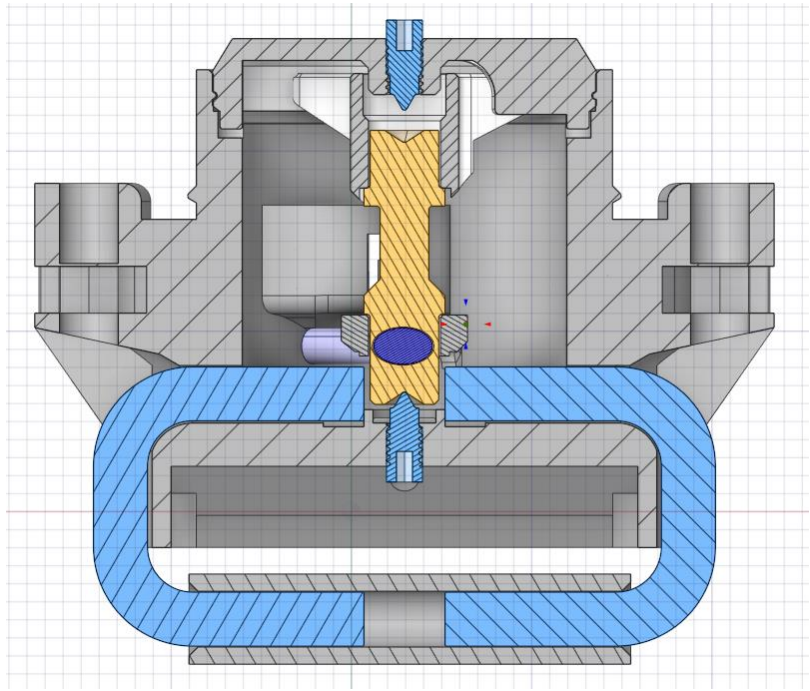
Trefle device

- **Electro-mechanical visual indicator for SPS magnets and the design is based on friction. Each one is activated by a thermo-switch. One cable line contains ~50 couples of thermo-switch+trèfle in series. If one is activated, the control room receives a signal, but the exact location needs to be checked on site by identifying the activated trèfle.**







Trefle Coil

- **Coil 10,000 turns, wire diameter 0.06 mm, DC resistance 1.84 kΩ**
- **Voltage 12V (current 6.5 mA) / (further tested successfully with 9V and 7.5V, worked but unreliably with 5V)**