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Design of an automated system for a removable decay pipe window for LBNF

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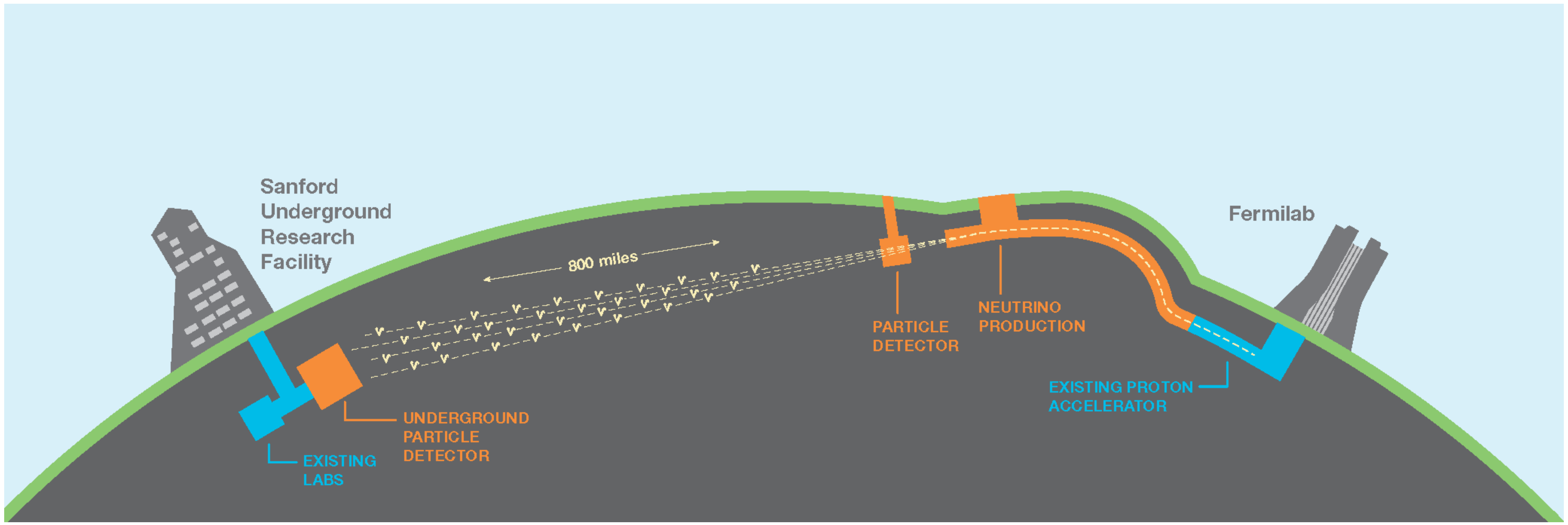
Final Presentation

23rd September 2016

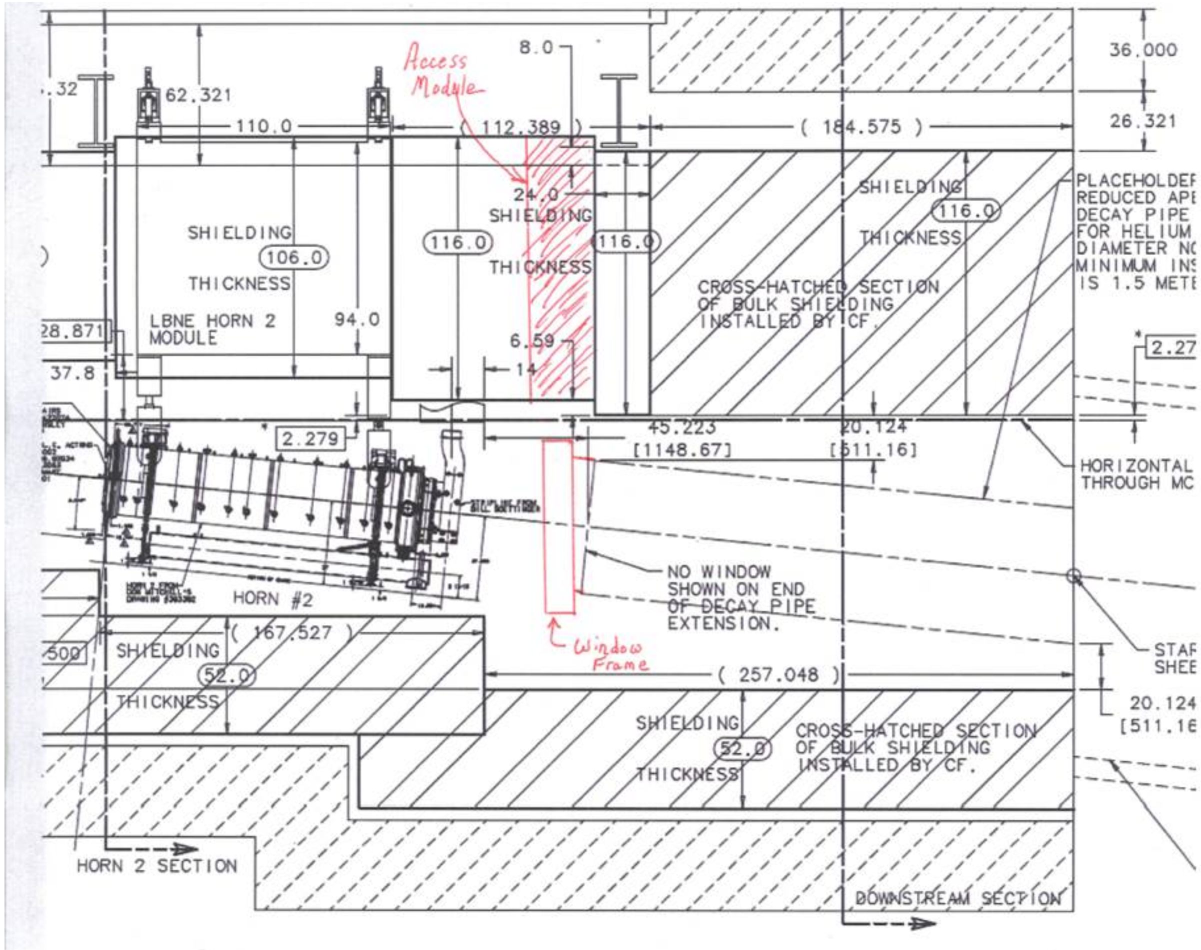
LBNF

Long-Baseline Neutrino Facility

Sending neutrinos on a 800 mi (1,300 km) journey

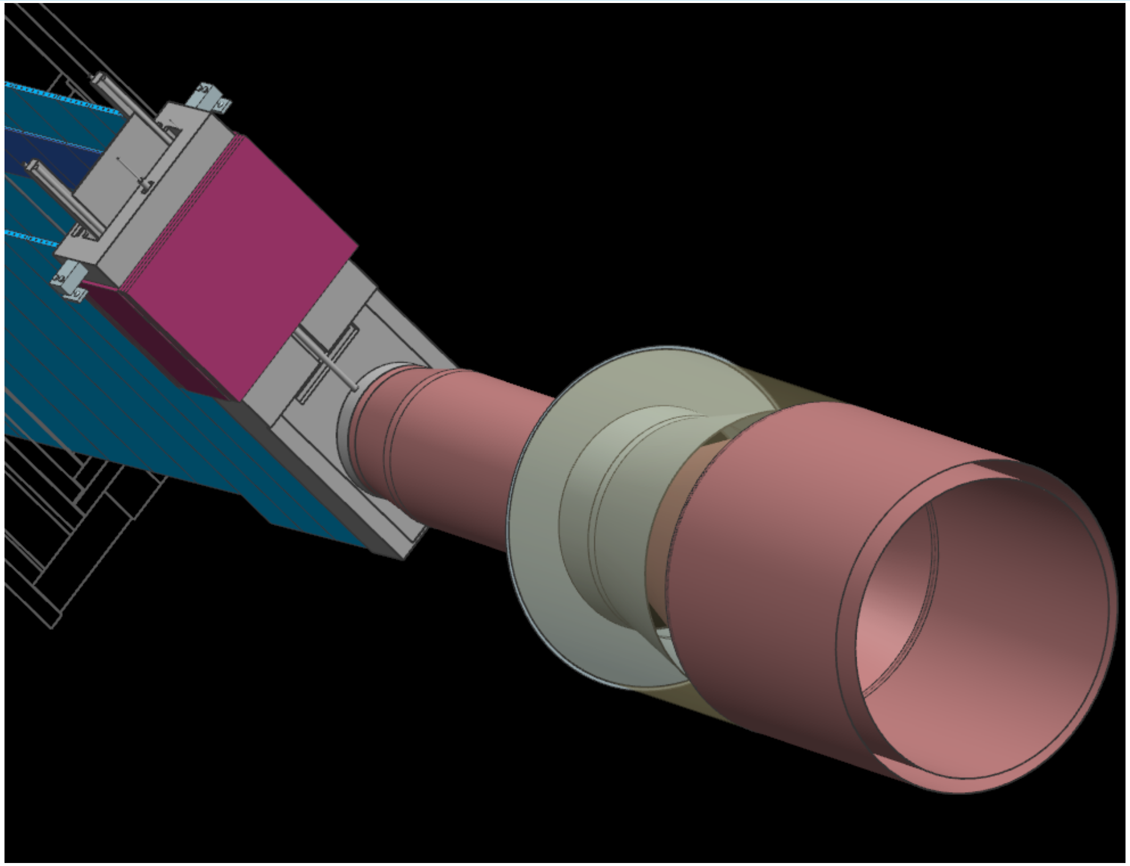


Project Specification



- Decay Pipe at a Positive Helium pressure 5 psig (0.34 bar)
- Operation 2.3 MW
- Window diameter of 1.5 meter
- Window should be curved and include a center section of beryllium
- Remotely Removable

- Highly radioactive environment: human access is not possible;
- Beam-on dose rates preclude use of an elastomeric seal;
- Remote positioning and tightening;
- Permissible Seal Leak rate less 0.01 Std.cc/sec



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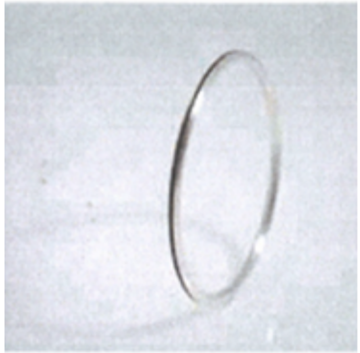
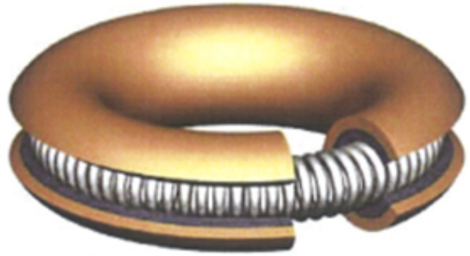
Seal system

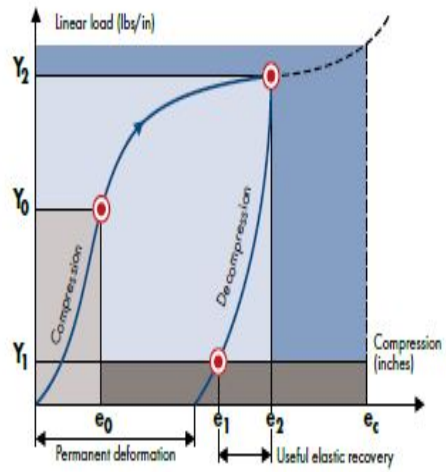
Helicoflex® Seal





DEFINITION OF TERMS

- Y_0 = load on the compression curve above which leak rate is at required level
- Y_2 = load required to reach optimum compression e2
- Y_1 = load on the decompression curve below which leak rate exceeds required level
- e_2 = optimum compression
- e_c = compression limit beyond which there is risk of damaging the spring



Jacket Material	HELIUM SEALING Cross Section	e_2	e_c	Y_2 lbs/inch	Y_1 lbs/inch	Pu68°F PSI	Pu-Θ392°F PSI	BUBBLE SEALING Y_2 lbs/inch	Y_1 lbs/inch	Pu68°F PSI	Pu-Θ392°F PSI	Max Temp °F
Aluminum	0.063	0.024	0.028	857	114	7250	N/A	514	114	5075	N/A	302
	0.075	0.028	0.033	914	114	7540	N/A	571	114	5800	N/A	302
	0.087	0.028	0.035	942	114	7685	N/A	600	114	5800	N/A	356
	0.098	0.028	0.035	999	114	7975	725	657	114	6090	725	428
	0.118	0.031	0.039	1056	143	7975	1450	742	114	6525	1450	482
	0.138	0.031	0.039	1085	143	7975	2030	799	114	6815	2030	482
	0.157	0.035	0.043	1142	143	8700	2465	857	114	7250	2465	536
	0.177	0.035	0.047	1199	143	8700	2900	914	114	7540	2900	536
	0.197	0.035	0.055	1256	171	9135	3190	971	143	7975	3190	572
	0.217	0.035	0.063	1313	171	9425	3480	1028	143	8265	3480	608
	0.236	0.039	0.071	1399	200	9715	3625	1113	171	8700	3625	644
	0.276	0.039	0.087	1542	228	10150	4060	1171	200	9425	4060	644
	0.315	0.039	0.102	1656	286	10440	4640	1285	228	9860	4495	680

Dimensions in inches

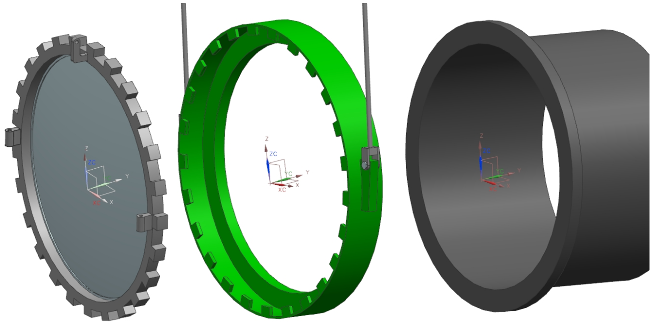
Seal System Performance and loading

- Metal Seals achieve leak rates on the order of 10-6 Std cc Helium / second.
  - This is better than the 0.01 cc/sec requirement.

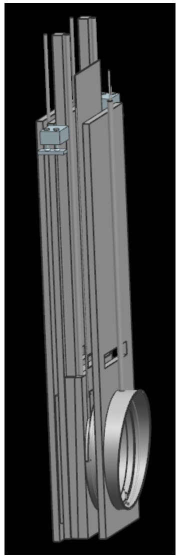
- Requires high load applied to seal:
  - 1542 pounds per linear inch
  - Total compression on seal is about 286,000 pounds (1.27 MN)
- For comparison, the loading due to the 5 psig internal pressure is about 13,000 pounds

Previous Solutions

Autoclave with rotating ring



Pressured slabs



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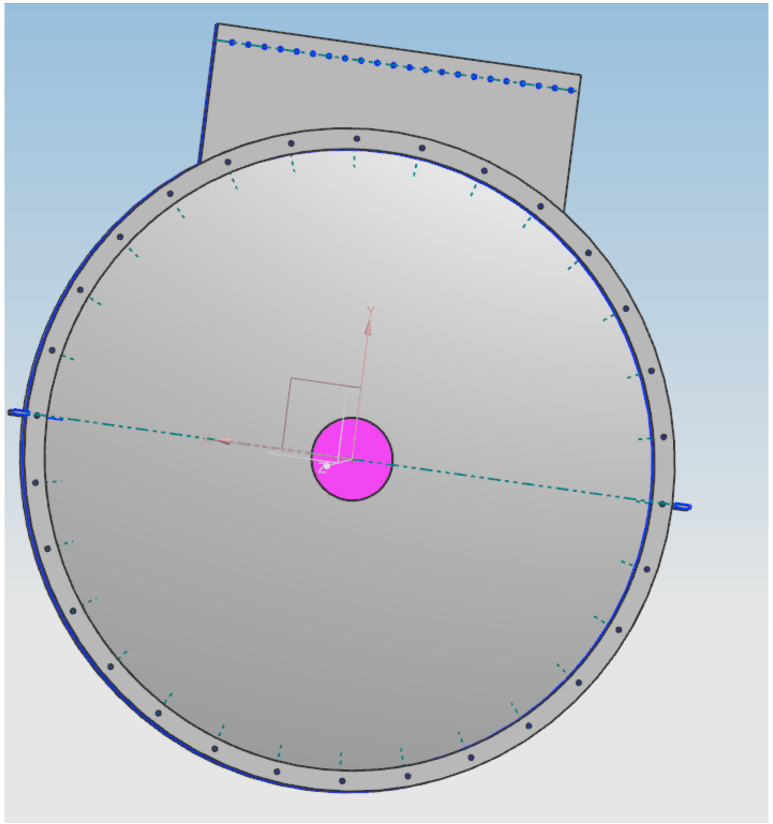
New Solution

There wasn't enough pressure on the seal

Use of a flange



Flange Choice

Corrosion problems: use of steel is not possible

Two solutions: Titanium, Stainless Steel

We choose Titanium HEX HEAD M12

Safety Factor: 4.5

Flange Calculation

$$Fi = k \times Sp \times At$$

$$k = 0.9$$

$$T = 0.2 \times Fi \times d = 176\,Nm$$

$$T = 129\ lbs\ ft$$

$$Fr = Y2 \times D \times \pi = 1{,}27 \times 106\ \mathrm{N}$$

$$\eta = 4.5$$

$$n = Fr/Fi * \eta = 80$$

Bolt parameters

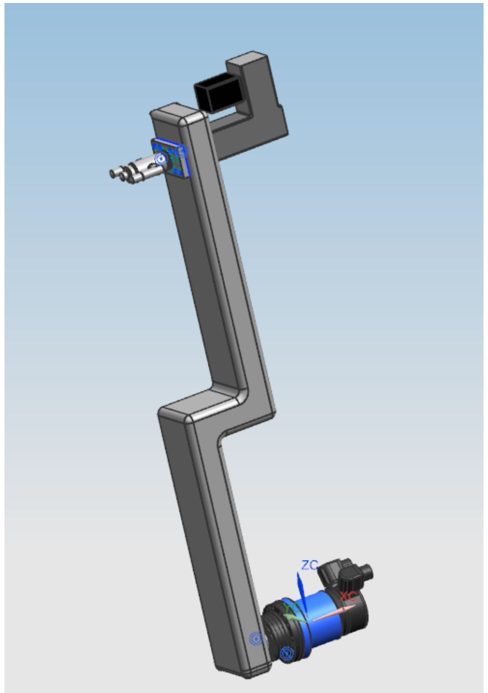
Density	4420kg/m^3 (276lb/ft^3)
Young's Modulus	110GPa (16 x 10^6 psi)
Yield Strength	828MPa (120 x 10^3 psi)
Ultimate Tensile Strength	1030MPa (149 x 10^3 psi)
Compressive Strength	960MPa (139 x 10^3 psi)
Shear Modulus	43GPa (6.24 x 10^6 psi)
Ductility	10% elongation at break
Poisson's Ratio	0.34
Hardness	36 Rockwell C
Strength-to-Weight Ratio	187 kNm/kg
Stiffness-to-Weight Ratio	24.9 Mnm/kg
Bolt type	M12
PL Strength	792MPa
Stress Area	92,1 mm^2

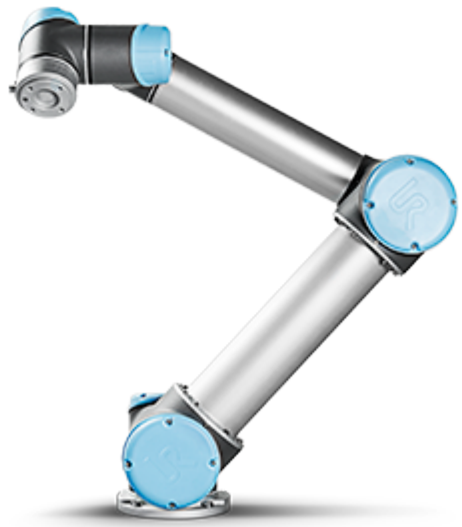
Two possible solutions

Tailored Design

Commercial Robot

We chose to have a conceptual design of both the solutions in order to understand which can be better for our purposes.





Tailored Design

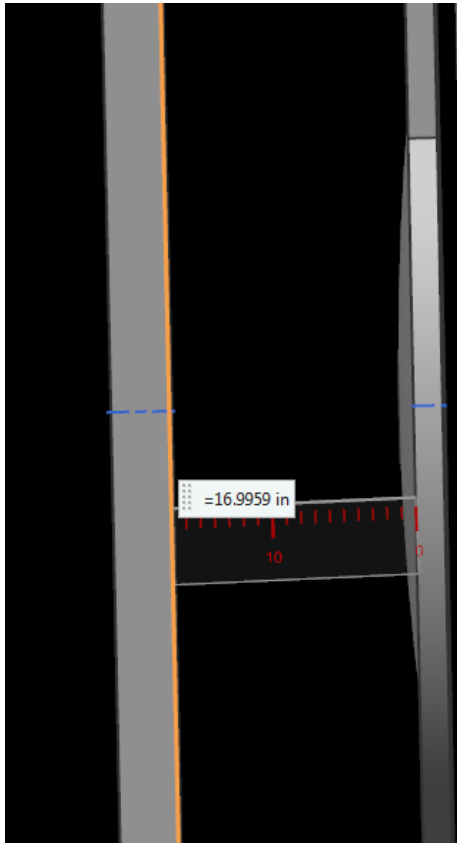
Replacement system requirements

Major problem: space

Cartesian robot not possible

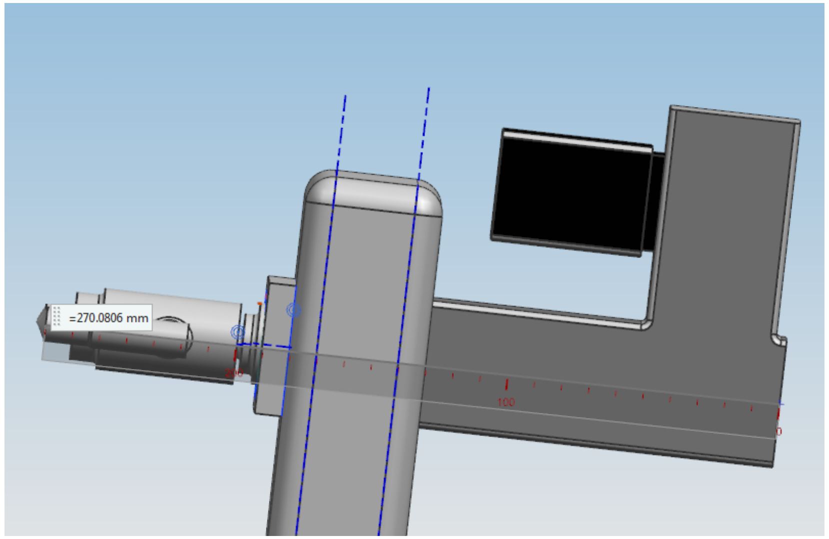
2 Degrees of Freedom needed

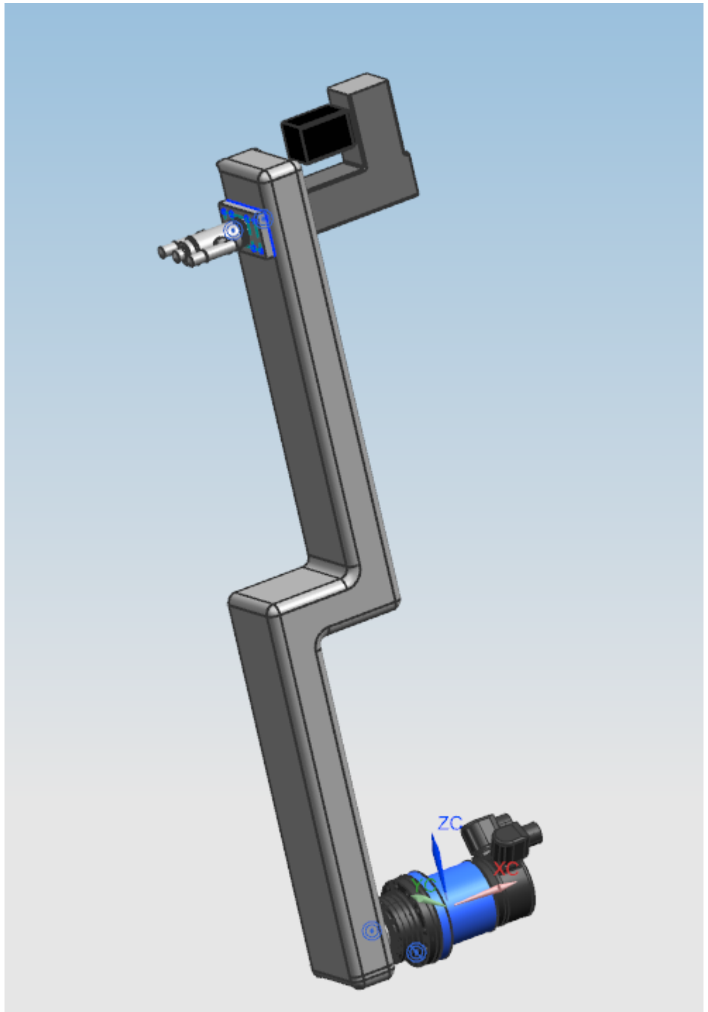
We can use steel and aluminum



Replacement system design

- Rotational + Prismatic Joint
- Curve Profile
- Hydraulic Bolt Tightener
- Socket Head Bolts





Saving space

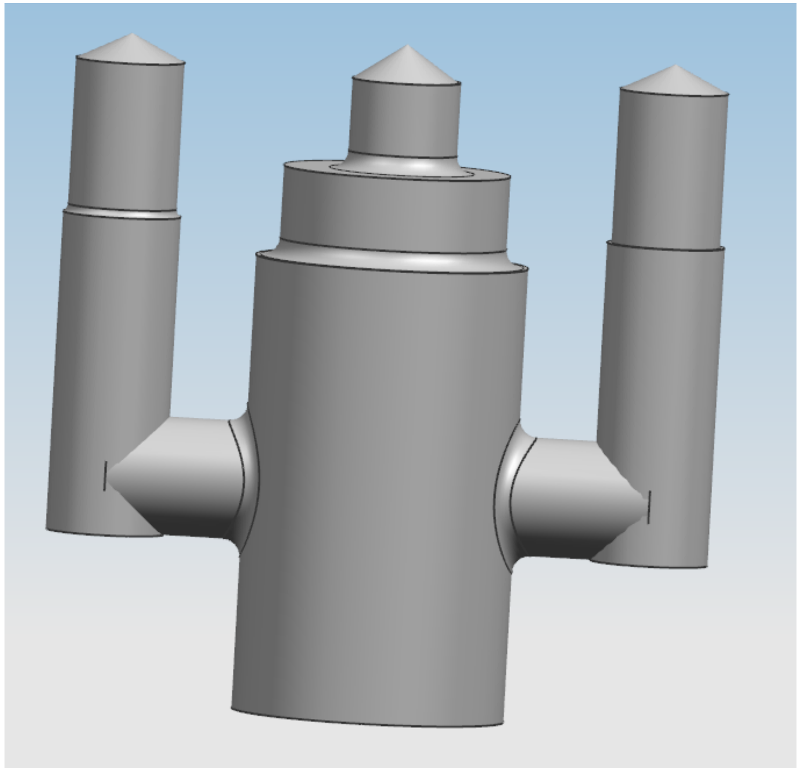
LynxDrive 20C with Harmonic Drive Technology

Linear Actuator with Parallel Motor

Reducing Torque

Aluminum hollow body

2 supporting pins on bolt tightener

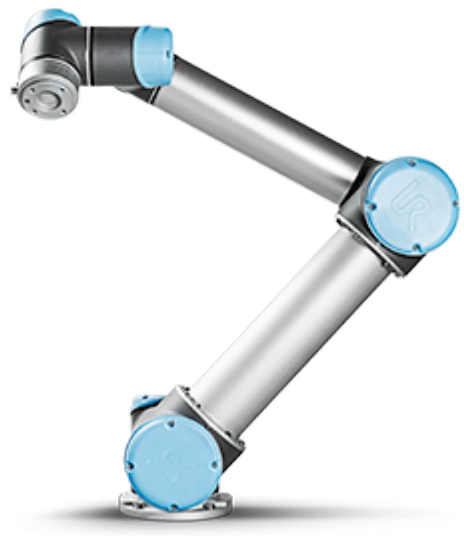


Commercial Robot

What do we need

Buying a Commercial Robot, we want it to be:

- Light
- Versatile
- With high payload-weight ratio



Our Choice

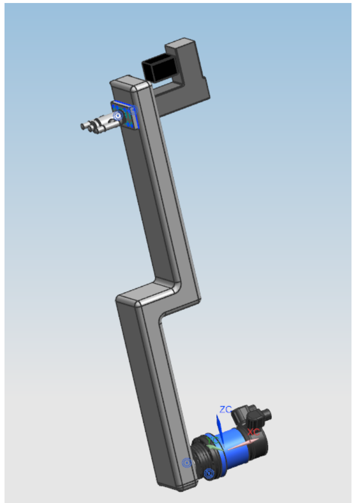
Technical specifications UR5 Item no. 110105

We accept no liability for any printing errors or technical changes.

6-axis robot arm with a working radius of 850 mm / 33.5 in

Weight:	18.4 kg / 40.6 lbs
Payload:	5 kg / 11 lbs
Reach:	850 mm / 33.5 in
Joint ranges:	+/- 360°
Speed:	All joints: 180°/s. Tool: Typical 1 m/s. / 39.4 in/s.
Repeatability:	+/- 0.1 mm / +/- 0.0039 in (4 mils)
Footprint:	Ø149 mm / 5.9 in
Degrees of freedom:	6 rotating joints
Control box size (WxHxD):	475 mm x 423 mm x 268 mm / 18.7 x 16.7 x 10.6 in
I/O ports:	Controlbox / Tool conn. Digital in: 16 / 2 Digital out: 16 / 2 Analog in: 2 / 2 Analog out: 2 / -
I/O power supply:	24 V 2A in control box and 12 V/24 V 600 mA in tool
Communication:	TCP/IP 100 Mbit: IEEE 802.3u, 100BASE-TX Ethernet socket & Modbus TCP

Pros and Cons: Commercial vs Tailored Designed

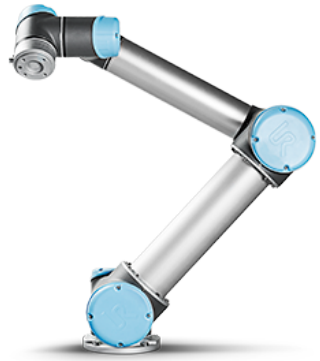


- \+ No need for adaptability
- \+ Developed in Lab
- \+ Optimized for this task

- \- Need for testing
- \- Costs
- \- More human resources required
- \- Cannot be reused for other applications

- \+ Versatile (can be reused)
- \+ Already tested
- \+ Cheaper
- \+ Fewer human resources needed

- \- Not Optimized
- \- Need to adapt to the task



Our Choice

Commercial Robot

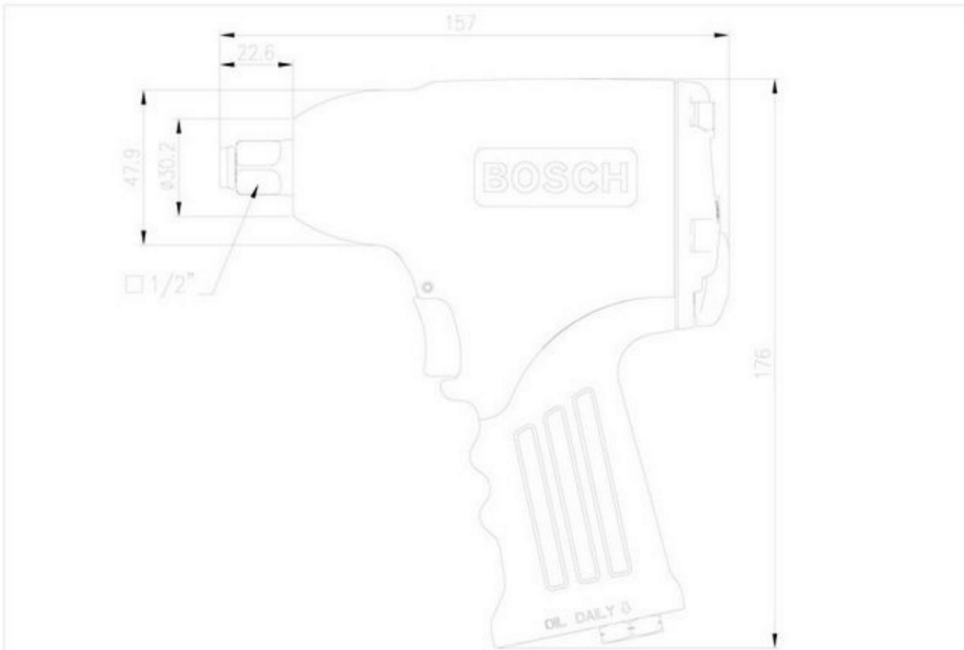
Impact Wrench - Requirements

Weight < 5kg

Small (less than 30 cm)

Max Torque > 176 Nm

Remotely Controllable Torque



Impact Wrench – Our Choice

Pneumatic 1/2

The most important data

Max. tightening torque	310 Nm
No-load speed	7000 1/min

Part number: 0 607 450 629

Technical data

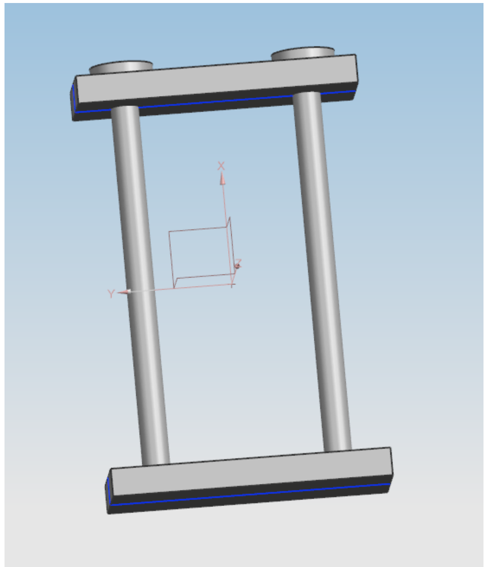
Max. tightening torque	310 Nm
No-load speed	7000 1/min
Direction of rotation (R = right; L = left)	R/L
Air consumption under load	8,5 l/s/cfm
Weight as per EPTA	2,3 kg
Bit holder	1/2" external square
Connecting thread	1/4"-NPT
Hose inner diameter	10 mm

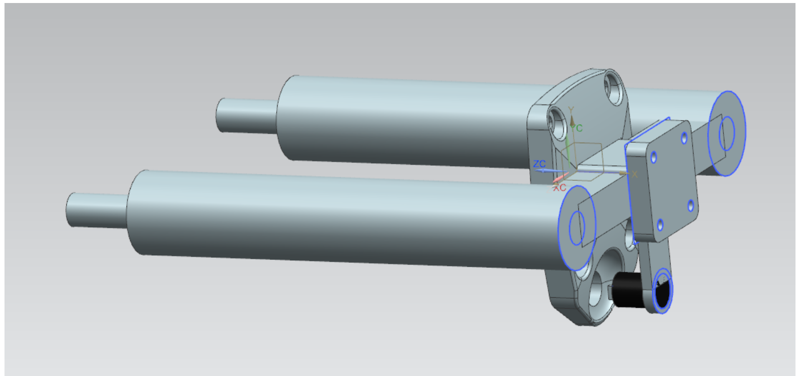
Impact Wrench - Automation

The impact wrench is meant to be manual

We have to find a way to automatize it:

- Button holder
- Stepper motor switch
- Pressure regulation



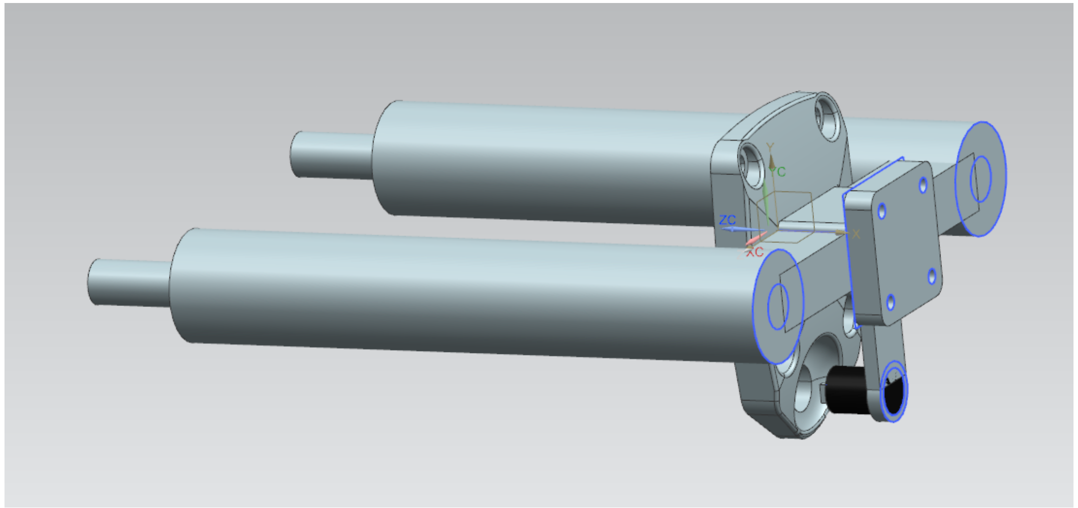


Impact Wrench and Robot Link

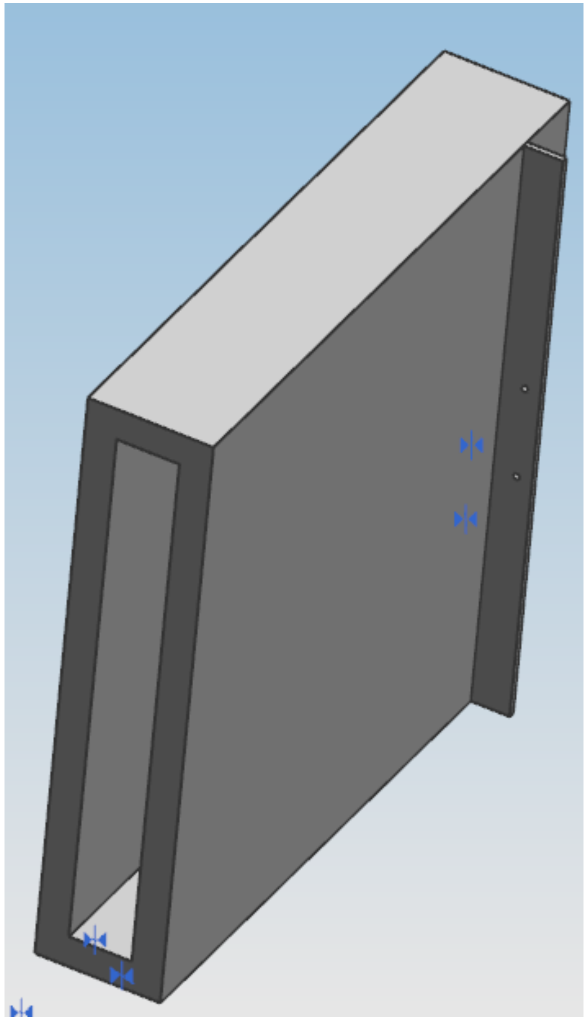
Discharge the torque: two supporting pins

Modeled starting from the impact wrench rear cover

Switch flanged



Window Replacement System



Window still activated when removed

Need for a radiation shield

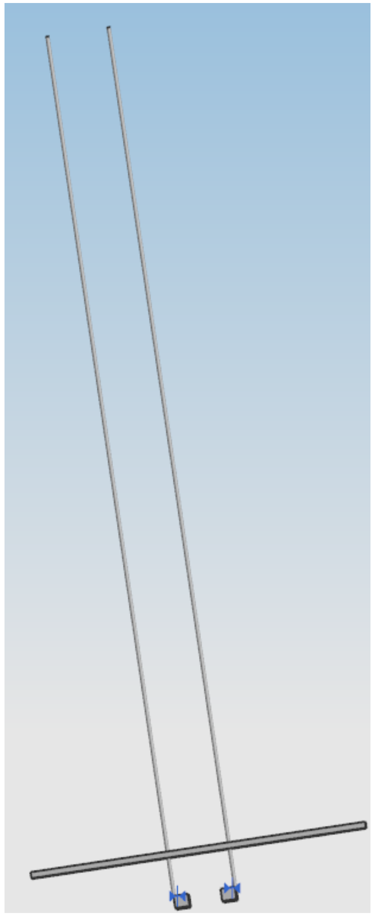
Steel shield 5 cm thick

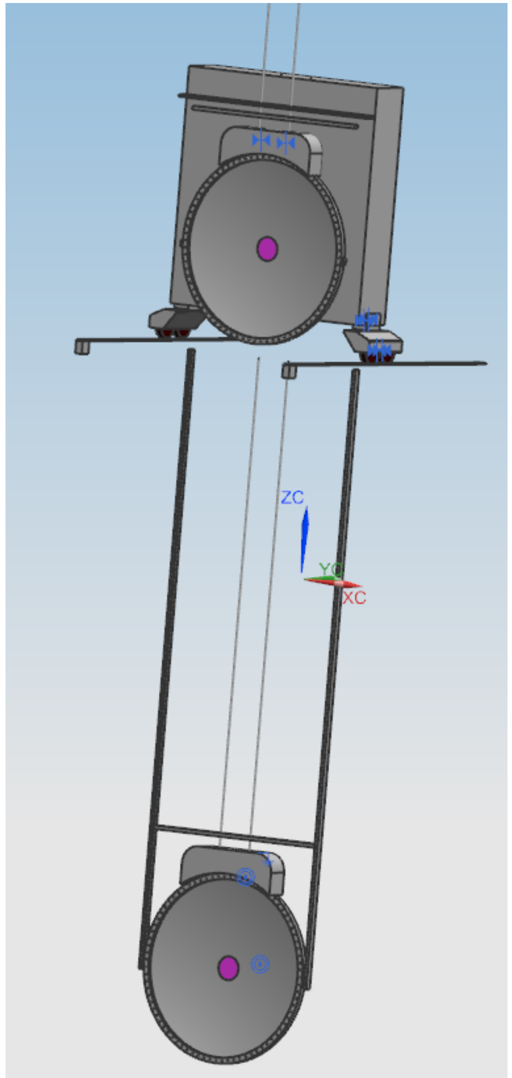
Window Replacement System

Wheel-mounted system

Two blocks come inside the window and clock in order to carry it

Everything is moved with threaded rods





AirLock

We want not to lose all the Helium

Installation of an AirLock

Opened just at beginning and ending of the operation

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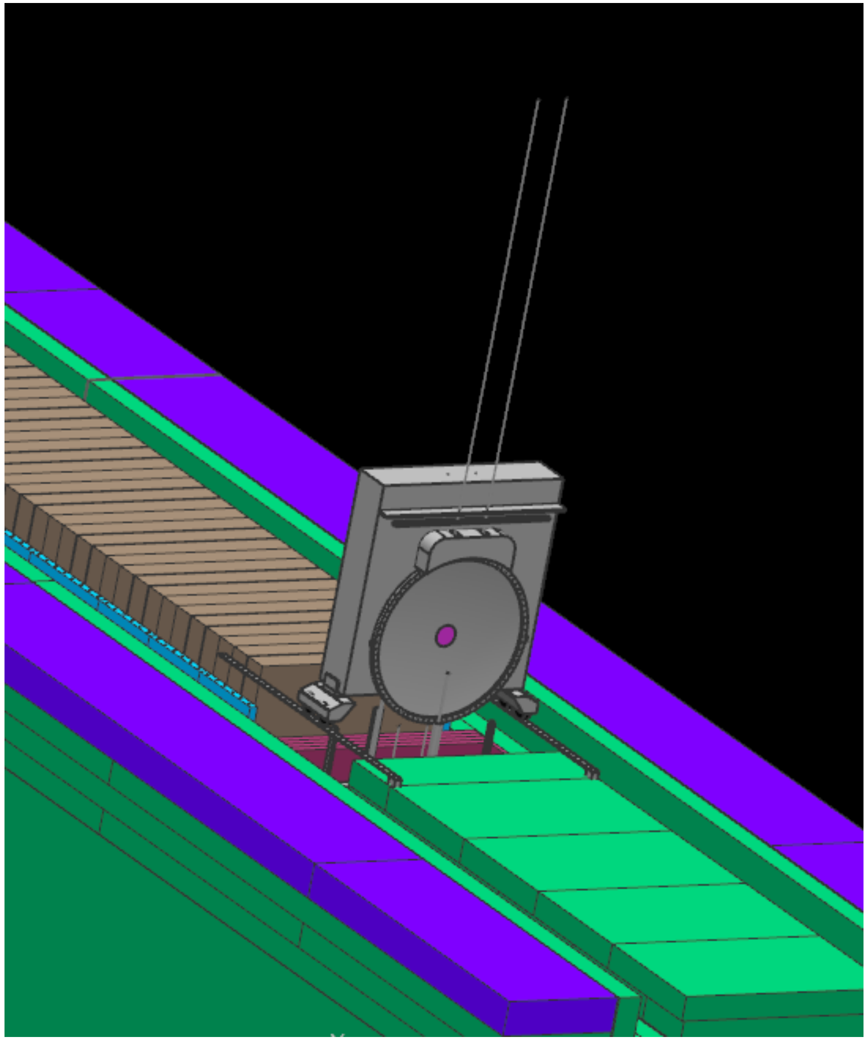
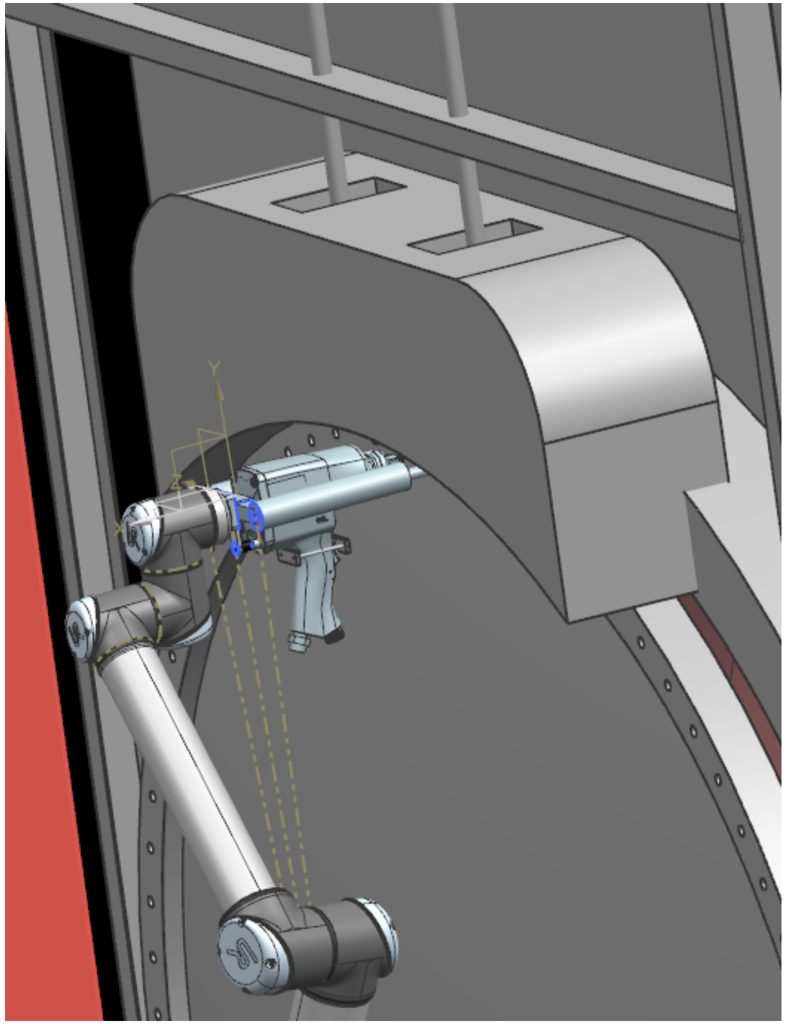
Full Design





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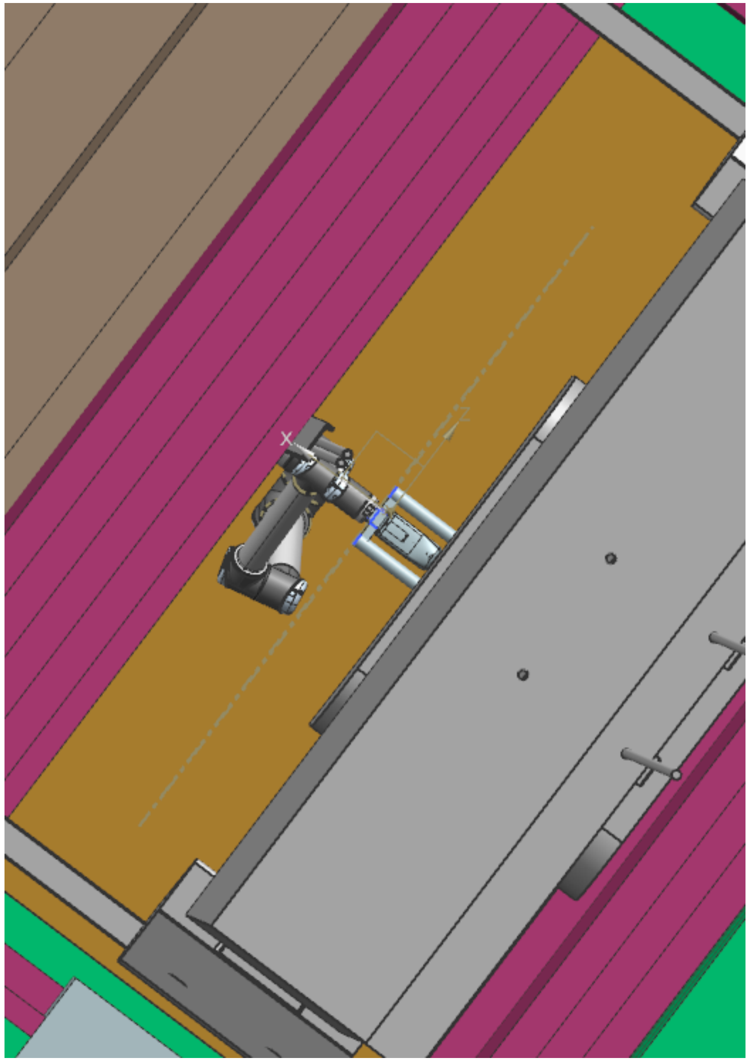
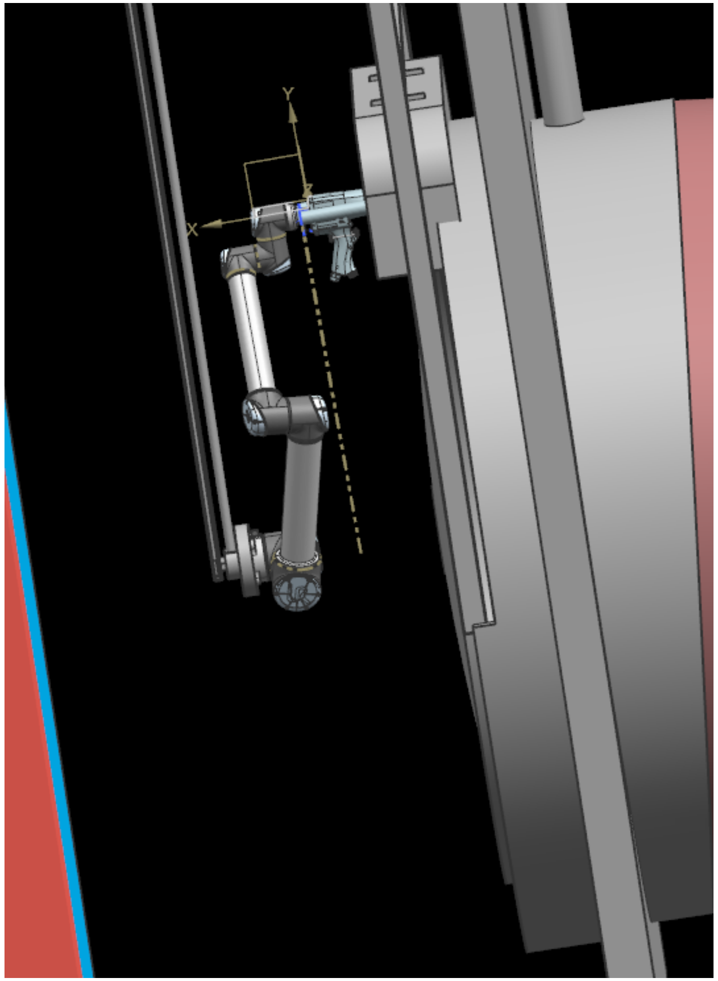
Full Design





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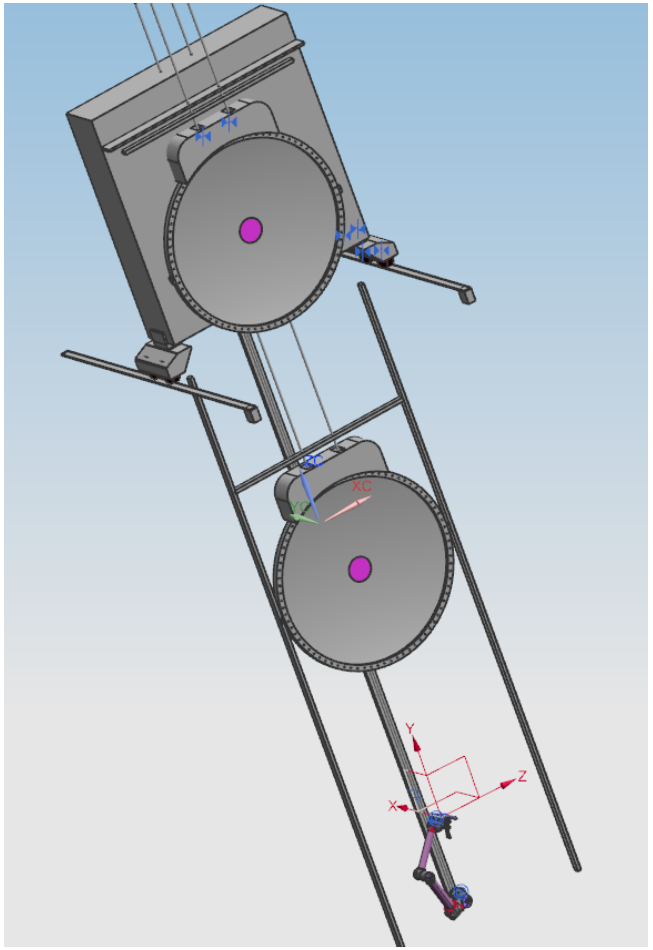
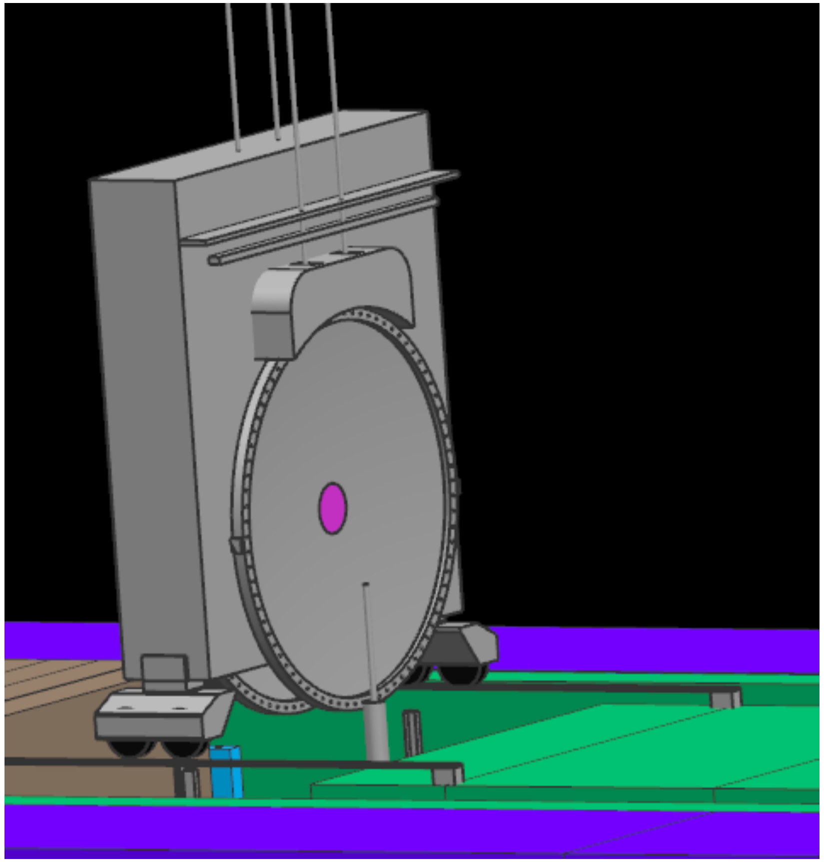
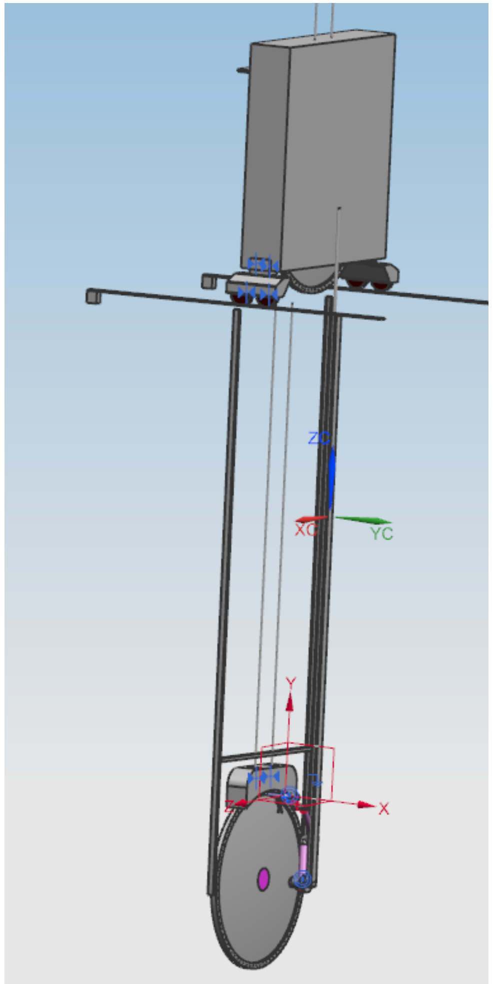
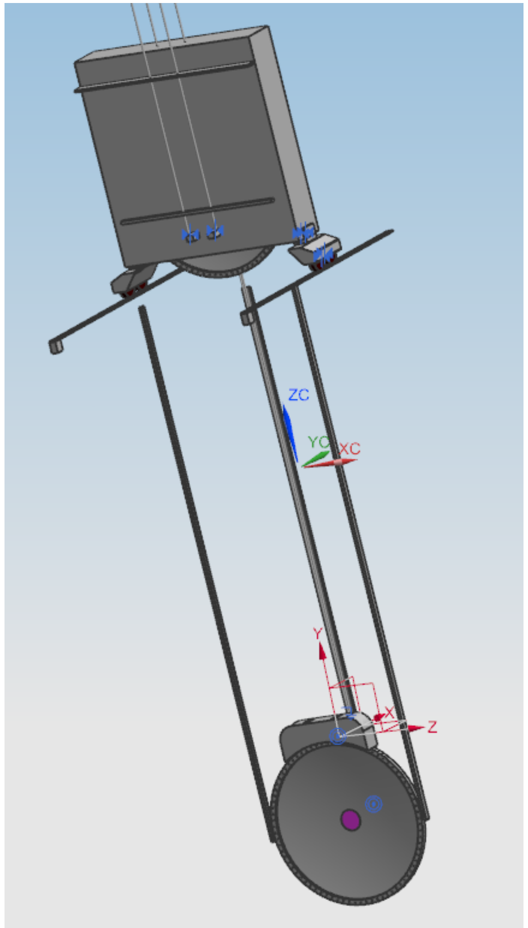
Full Design





Full Design





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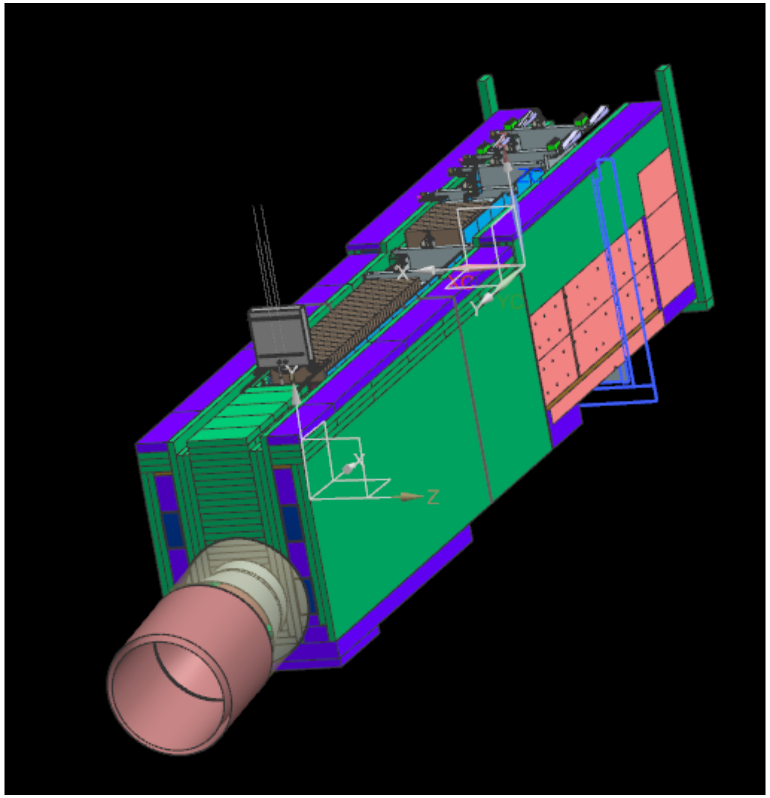
Further Steps

Simulations and sizing;

Development of a control system based on vision;

Purchase of Robot and Impact Wrench;

Testing.



Thanks for your attention