Mechanical Design and System Validation of the FARHA-ONE facility

DIPARTIMENTO DI INGEGNERIA INDUSTRIALE

HEROBOTS

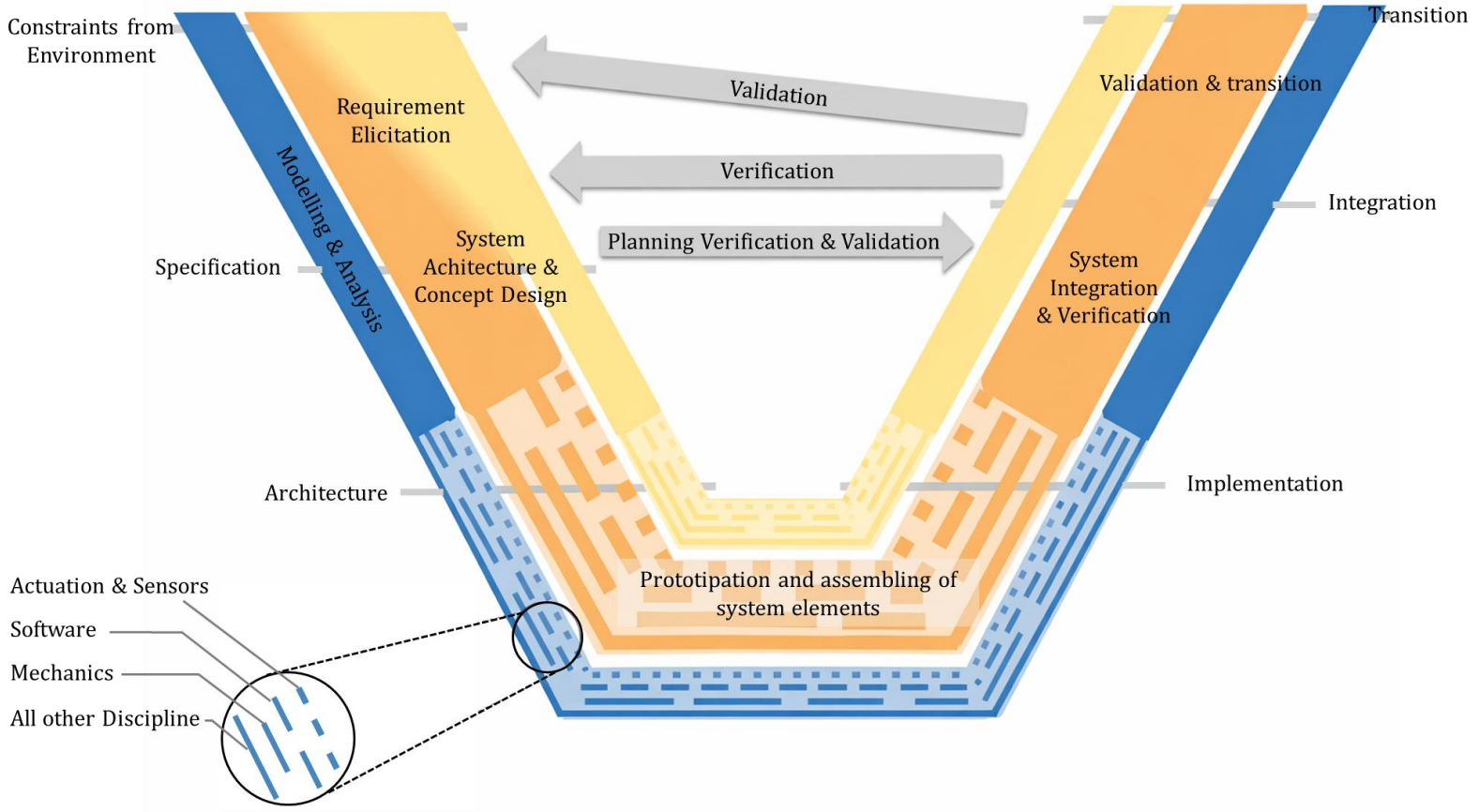
CONSORZIO RFX
Ricerca Formazione Innovazione

ideas

Consiglio Nazionale delle Ricerche

Research Objectives

1. Define a structured, requirement-driven design procedure
2. Design a robotic manipulator tailored to the target environment
3. Validate the approach through numerical and experimental analyses

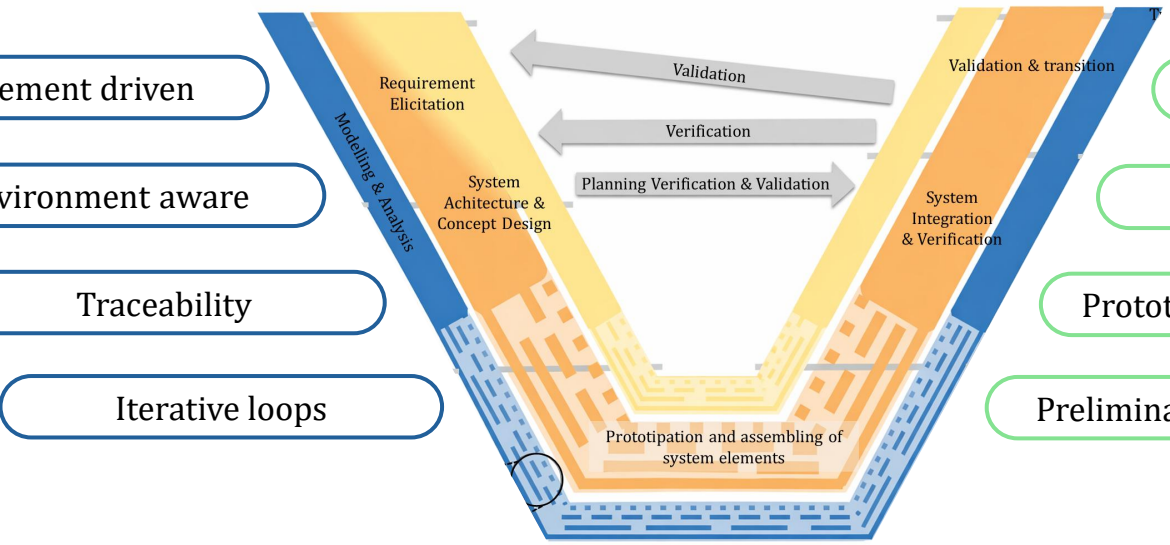


A General Design Procedure for Robotic Systems

Workflow of the procedure and use cases

Design Methods

- Requirement driven
- Environment aware
- Traceability
- Iterative loops

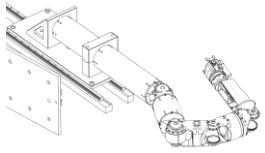


Validation Methods

- Experimental Validation
- System Integration
- Prototypation as test-rig
- Preliminary Simulation

Use Cases

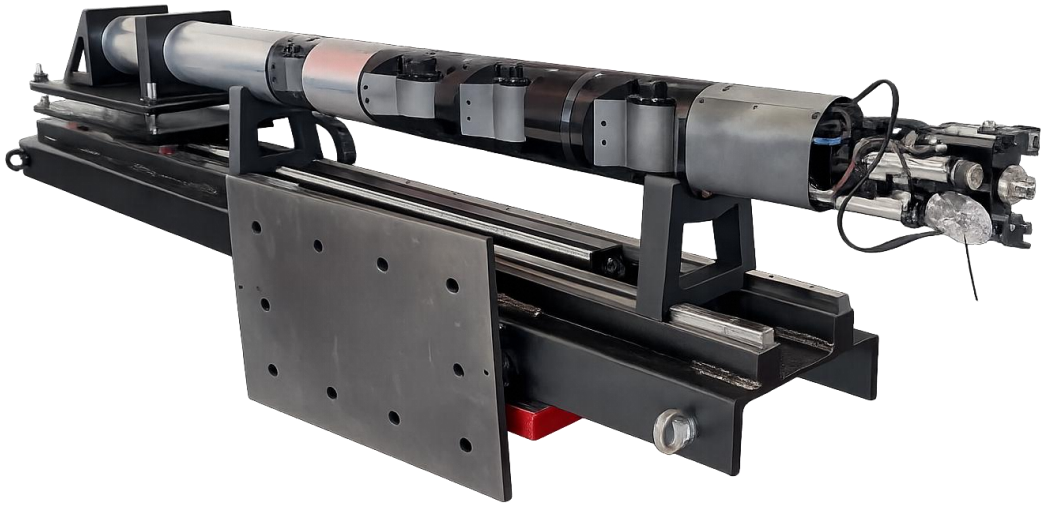
- ROMAN #1



Nuclear Fusion as an Extreme Use Case: Nefertari Project

Project goal: Realization of a Remote Handling Facility made up by two sub-module:

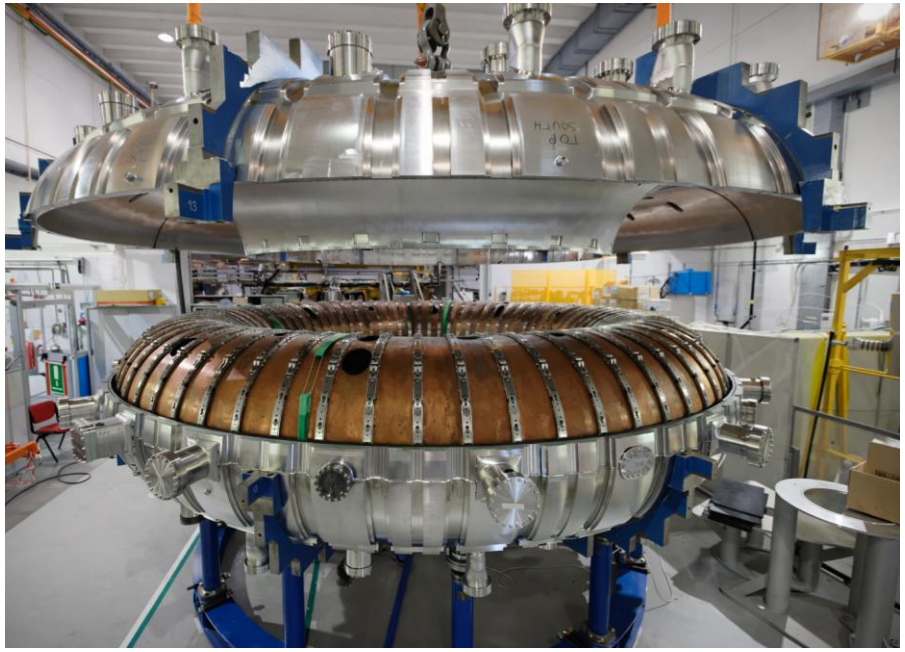
Robotic **Man**ipulator for remote maintenance in the RFX-mod2

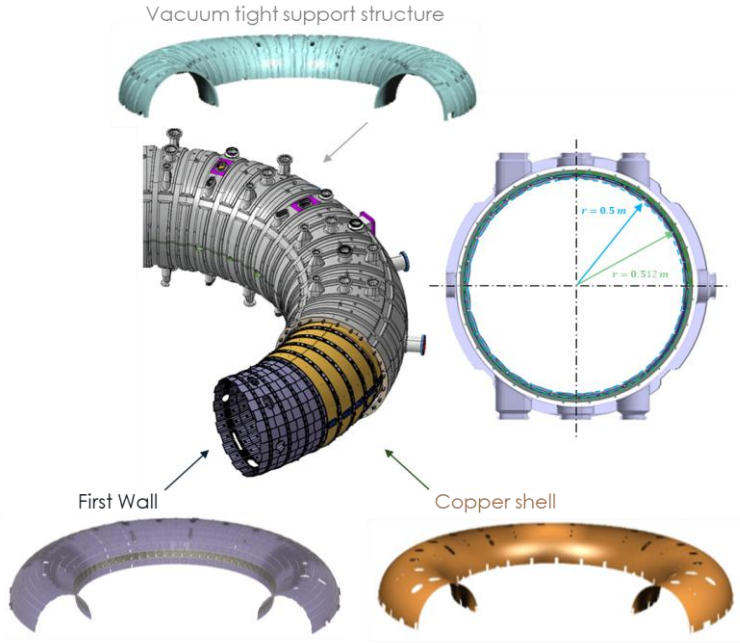


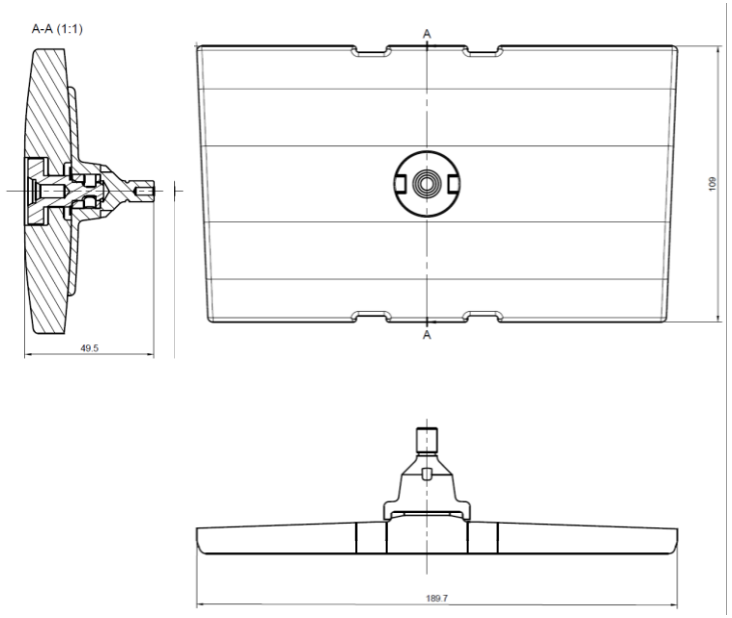
A 1:1 mock-up of a sector of the RFX-mod2

RFX-mod 2 system

Analysis of the environment structure for the Needs Extraction







RFX-mod 2 system

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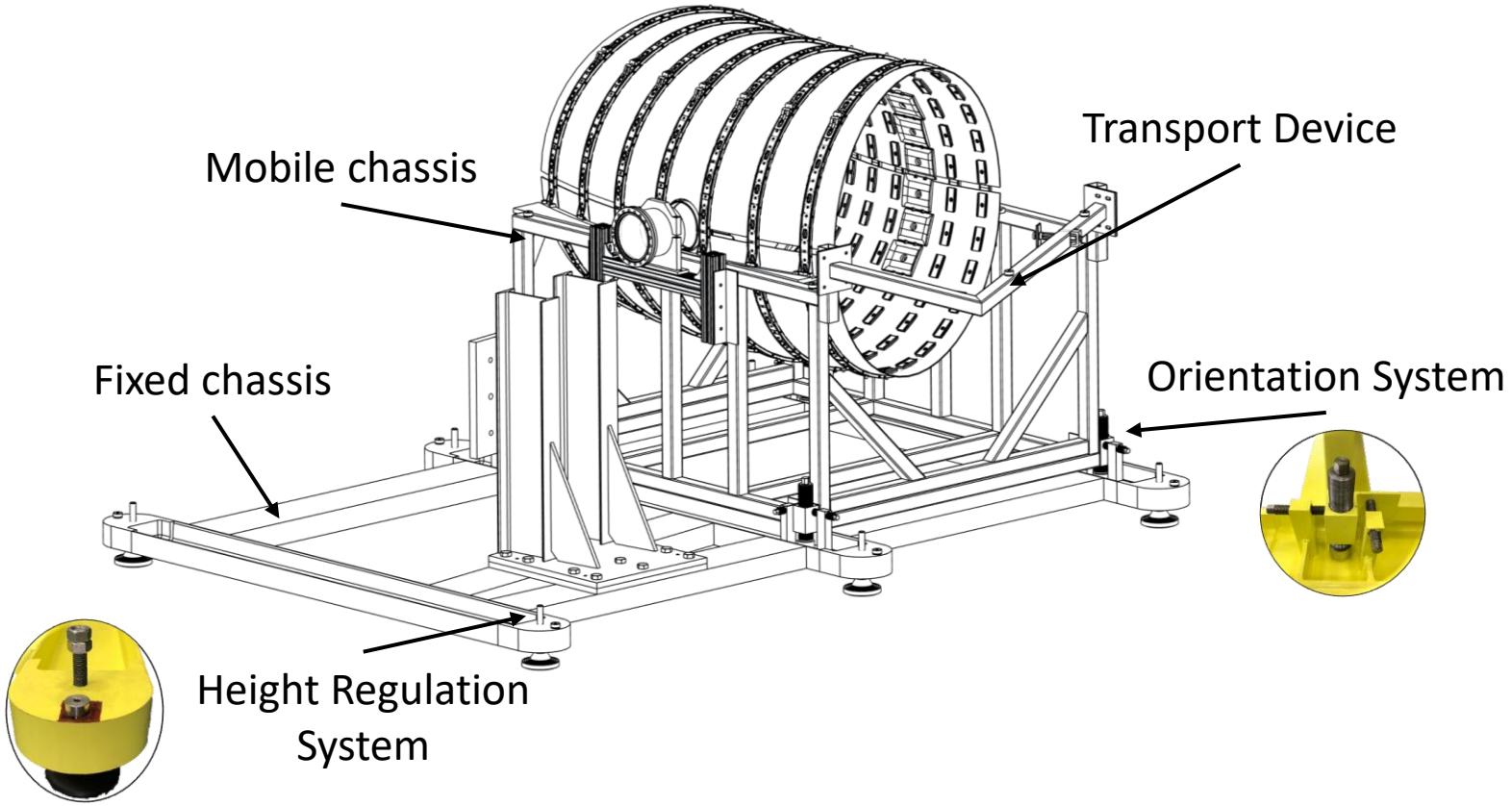
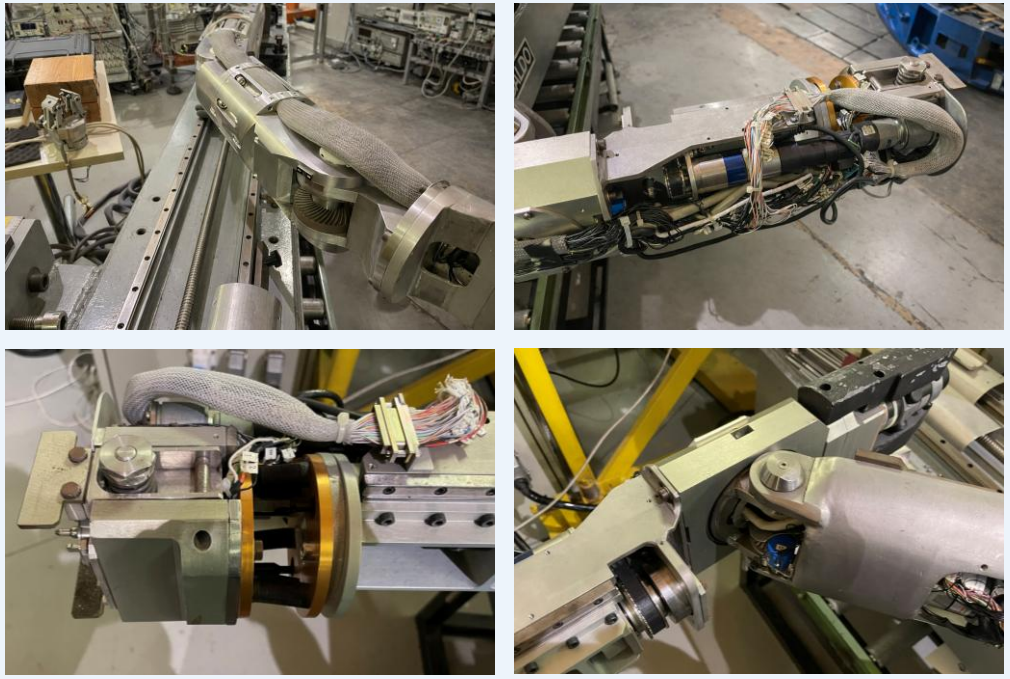
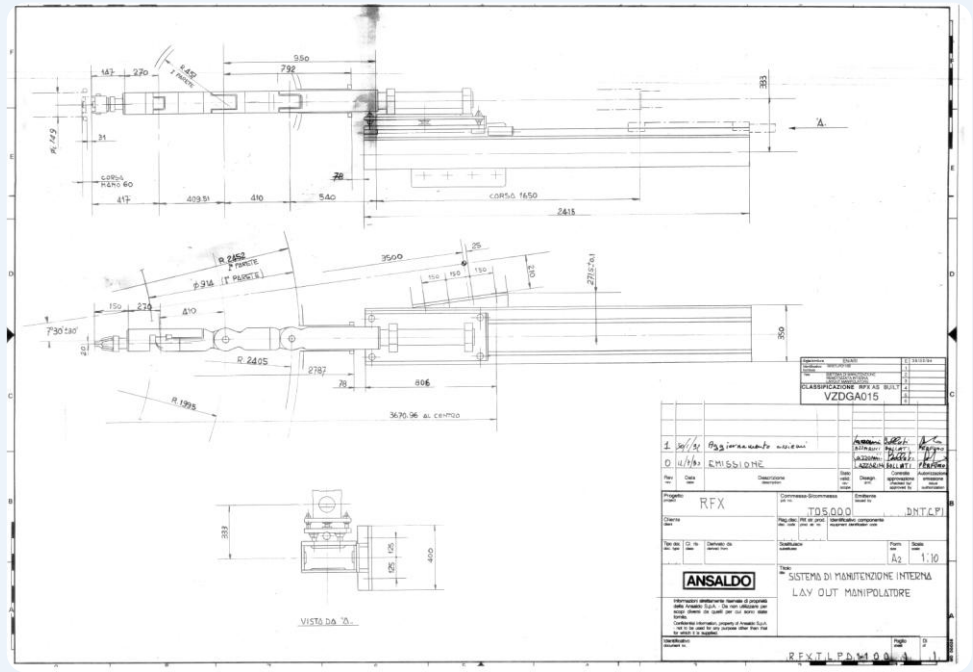


Definition of the Kinematic Architecture

Analysis of the needs and limits of the old robotic system to develop the new kinematic chain





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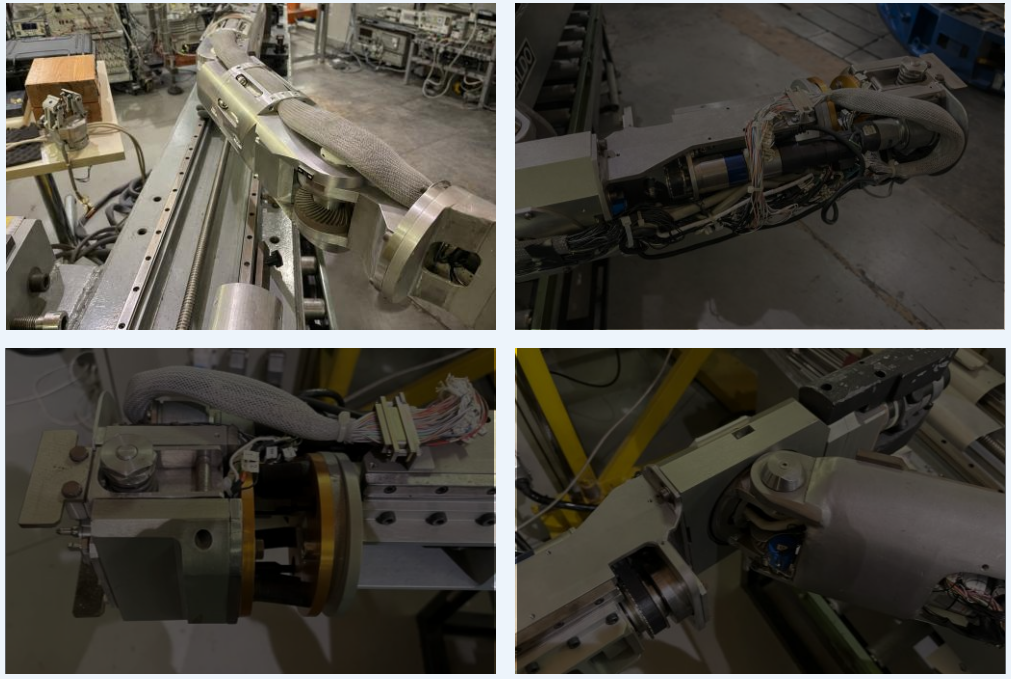

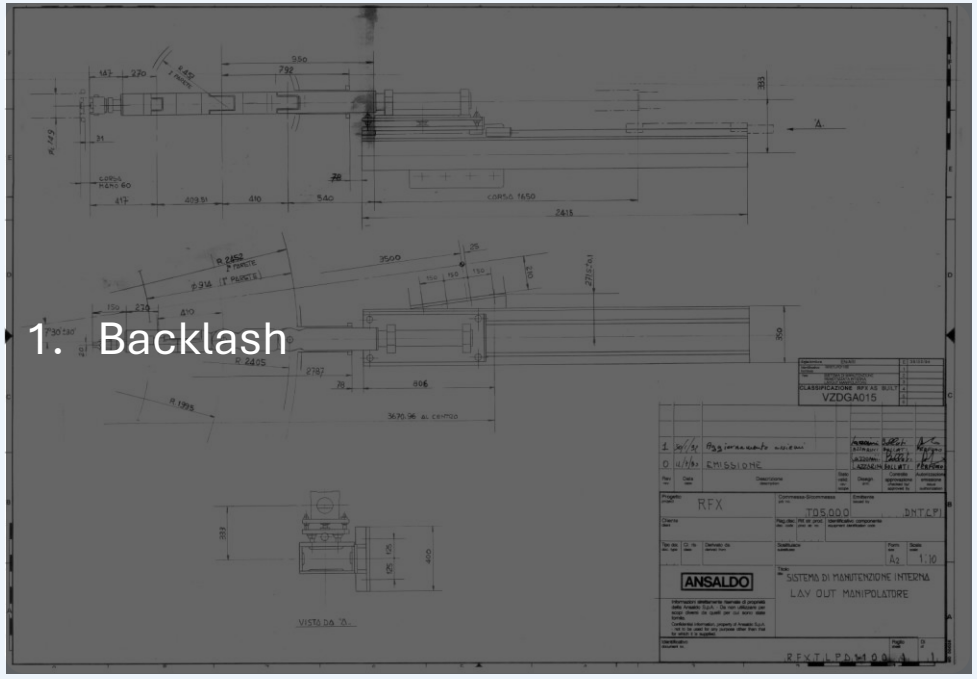

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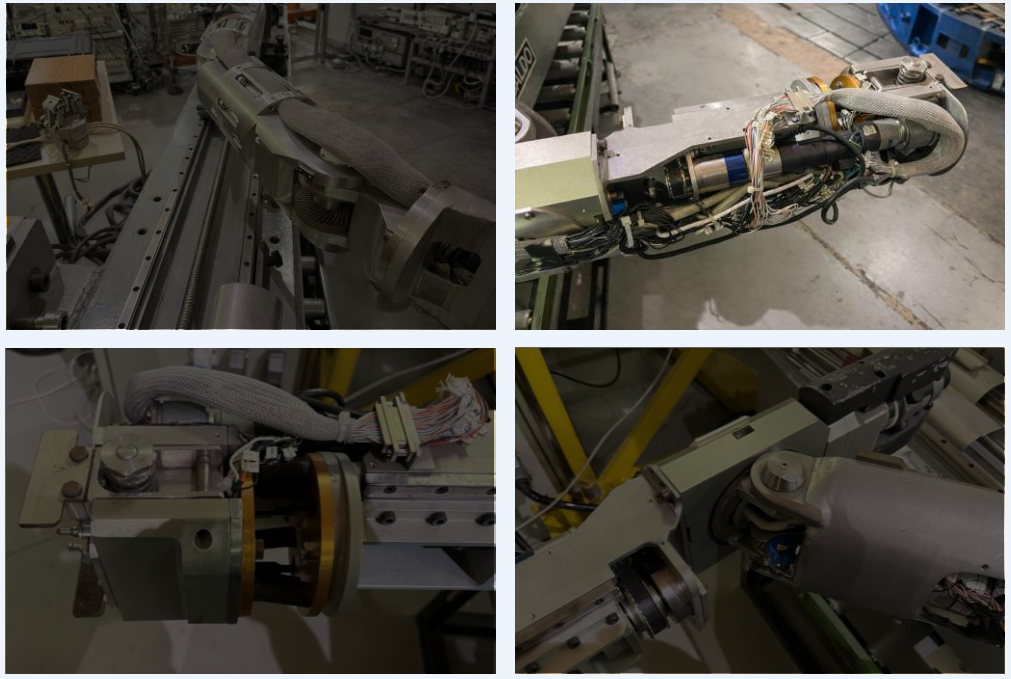

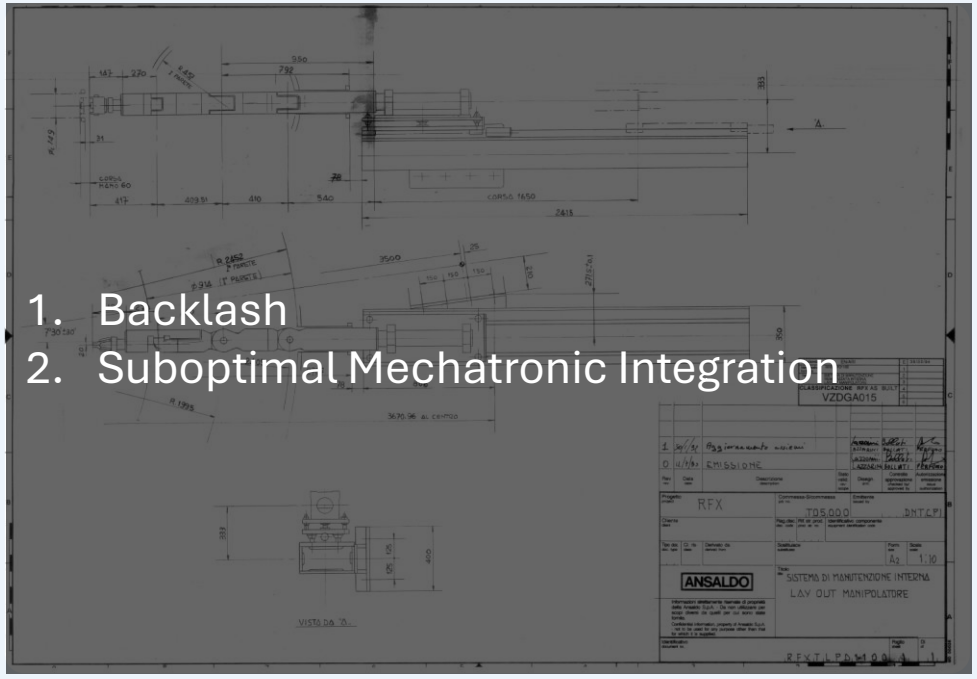

1. Backlash
2. Suboptimal Mechatronic Integration

Definition of the Kinematic Architecture

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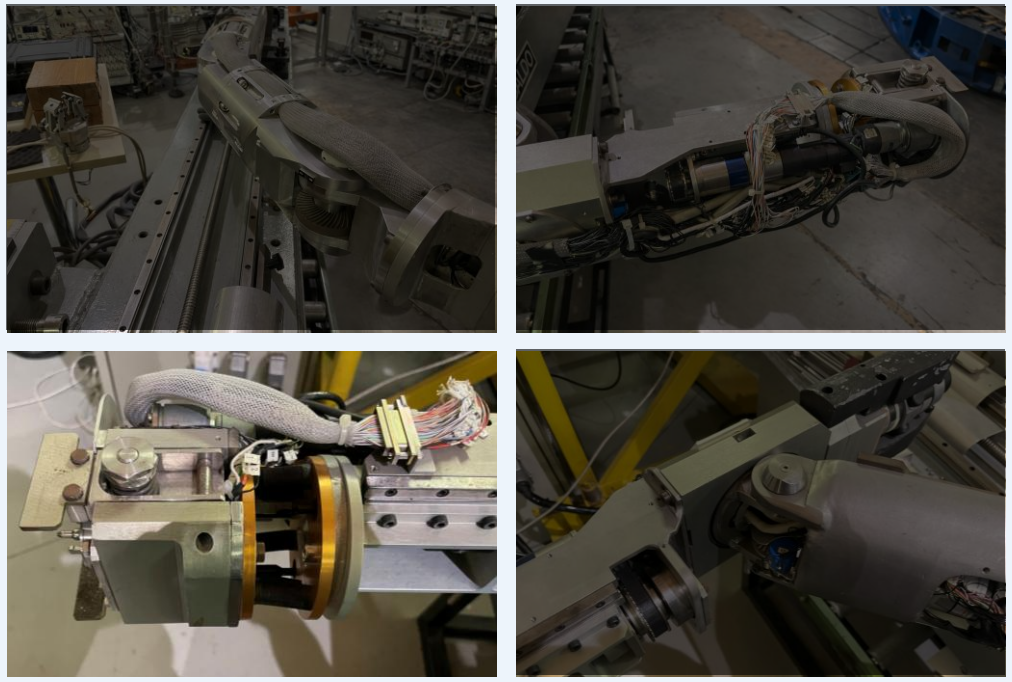
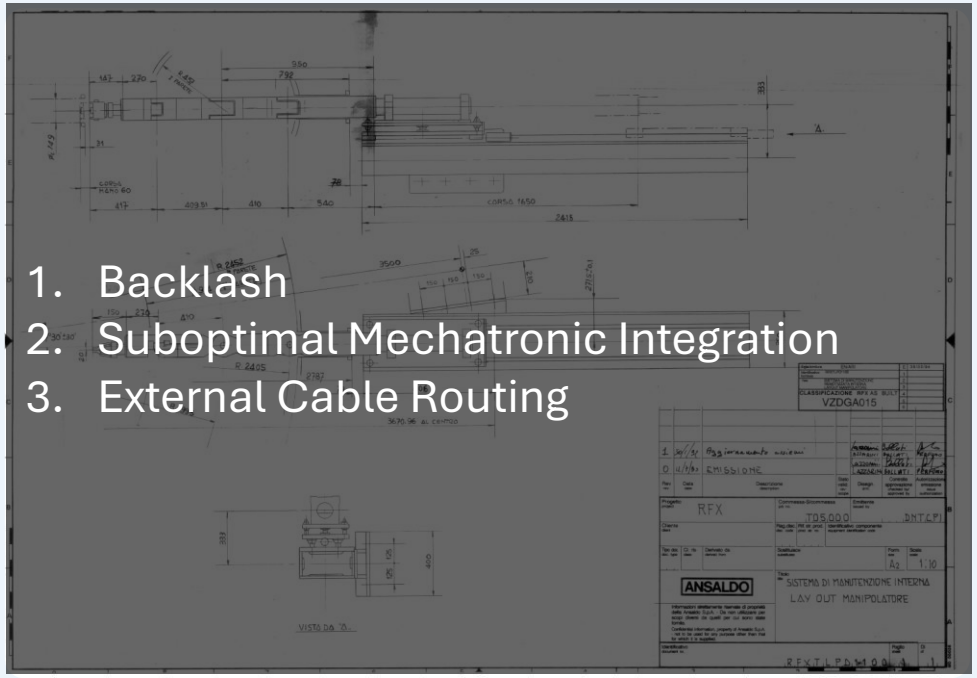
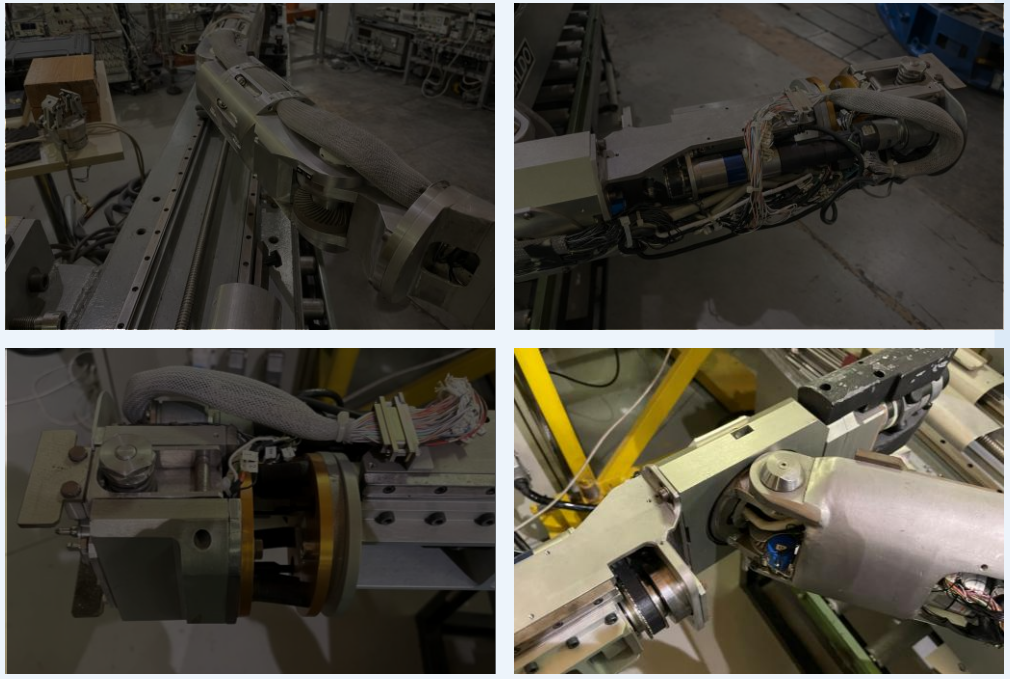




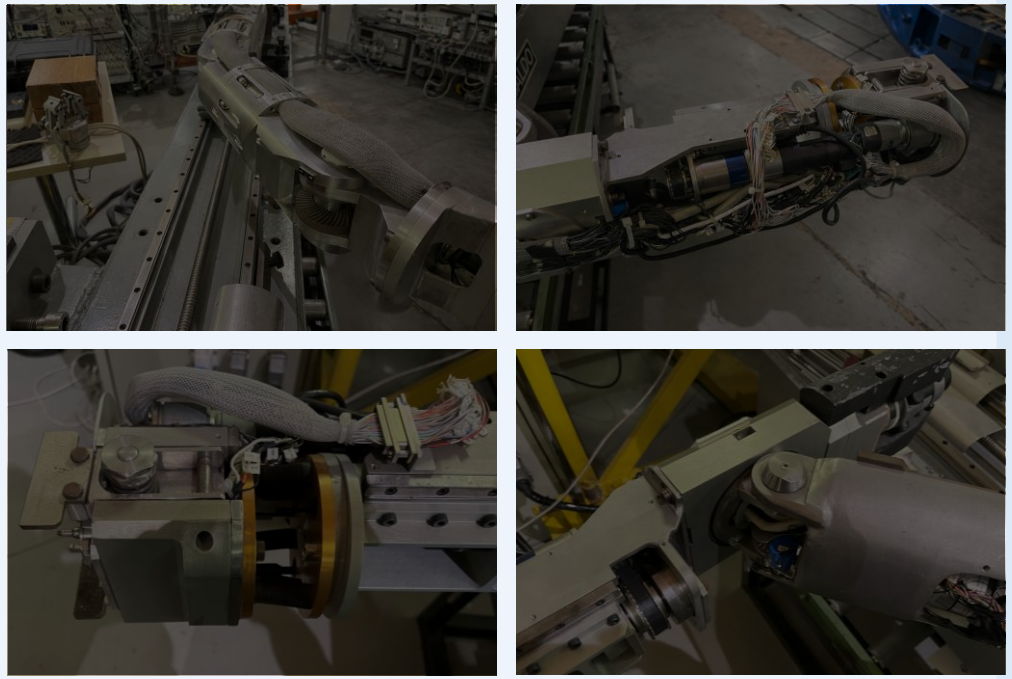
Definition of the Kinematic Architecture

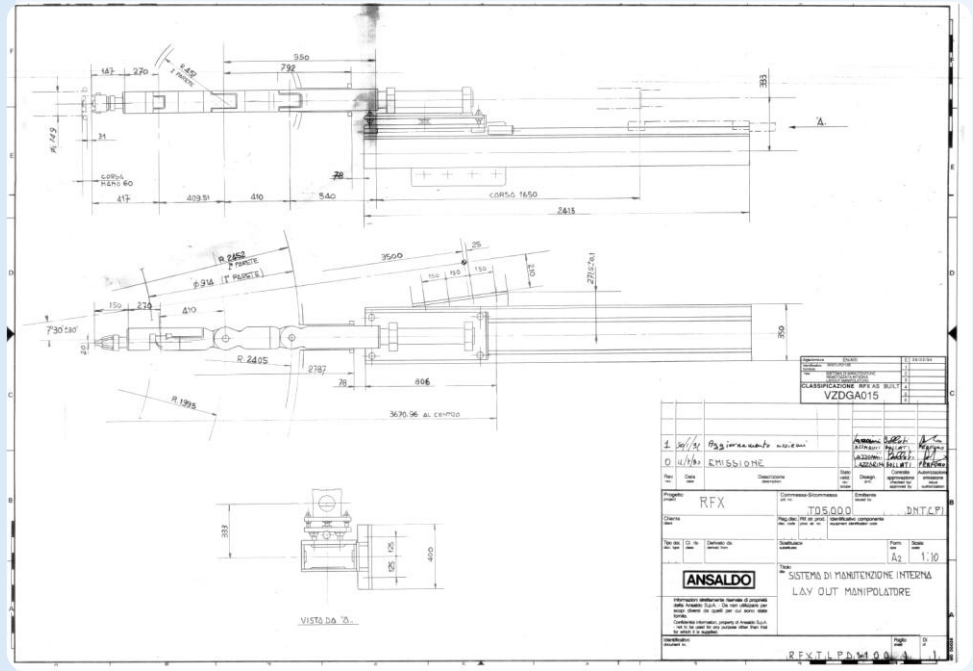
Analysis of the needs and limits of the old robotic system to develop the new kinematic chain



1. Backlash
2. Suboptimal Mechatronic Integration
3. External Cable Routing
4. Incident Joint Axes Compliance

Definition of the Kinematic Architecture





Requirements Elicitation

Definition of the Kinematic Architecture

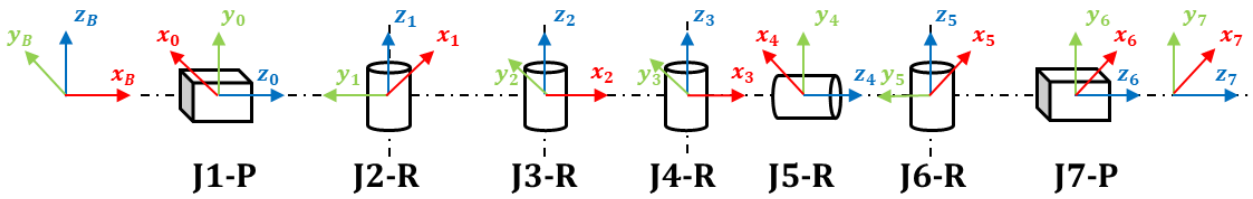
Analysis of the needs and limits of the old robotic system to develop the new kinematic chain

FR – 01 – Arm joints must be manually **backdriveable**

FR – 02 – Reach of **four** poloidal sectors on both sides of the port

FR – 03 – Reach of **all tiles** on all poloidal rings

FR – 04 – **No contact** is allowed in the machine



ISO/IEC/IEEE International Standard - Systems and software engineering -- Life cycle processes -- Requirements engineering, ISO/IEC/IEEE 29148:2018(E), pp.1-104, Nov. 2018.

Requested torque analysis – actuation sizing

Analysis oriented to define the mechanical properties of the arm and its actuators

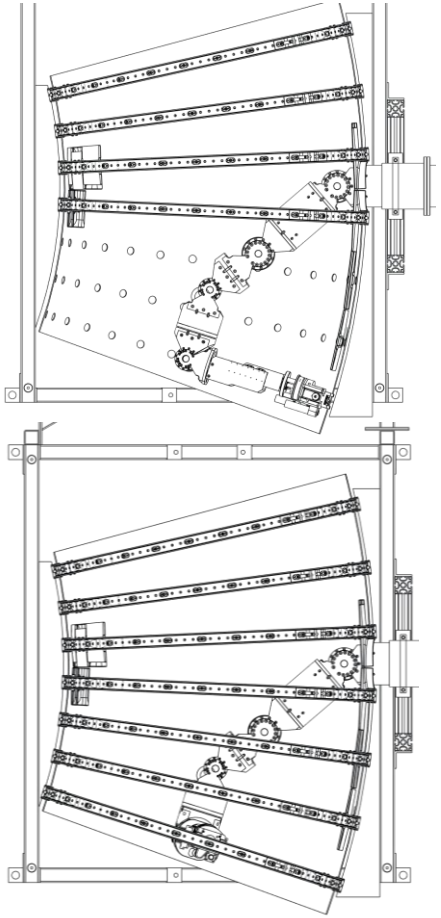
FR – 05 – System should perform a **pushing action** to disengage the tiles

FR – 06 – System should be able to push on **each** tile **position**

MR – 01 – Inertial deflection must not exceed **2.5 mm** in any direction

MR – 02 – Maximum axial deflection must be maximum **2.5 mm** under a nominal thrust of 150 N

MR – 03 – Mechanical stress must remain **below** the material **yield strength** during maximum joint acceleration.



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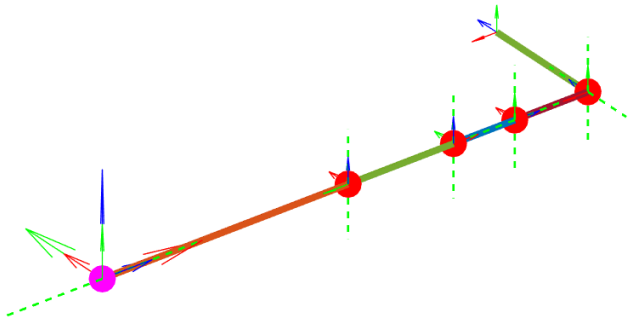
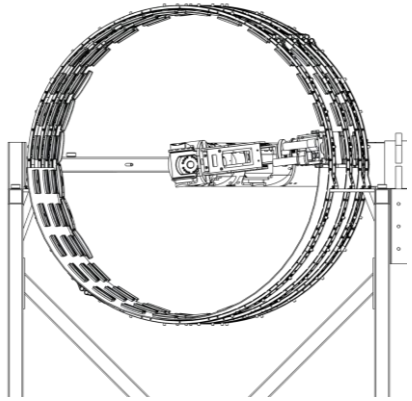
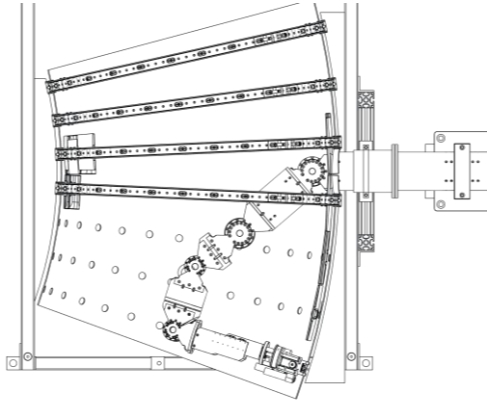


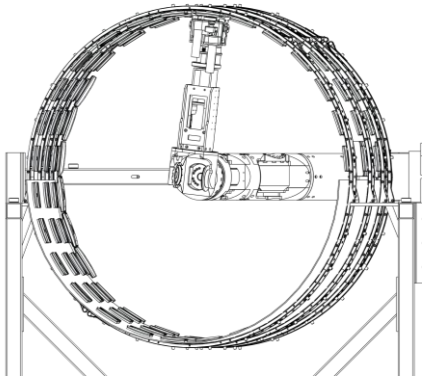
A **topological model** of the arm has been developed considering kinematic chain, hypothetical joint-masses and hypothetical joint-accelerations

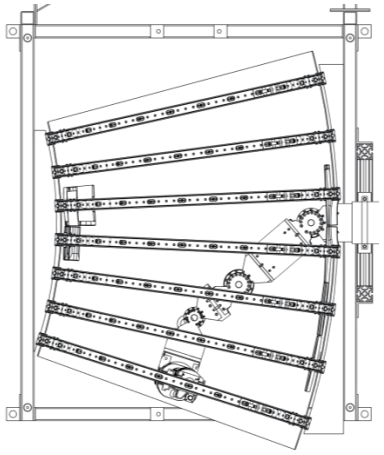
Critic configuration for gearboxes



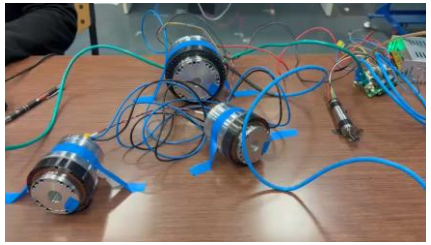


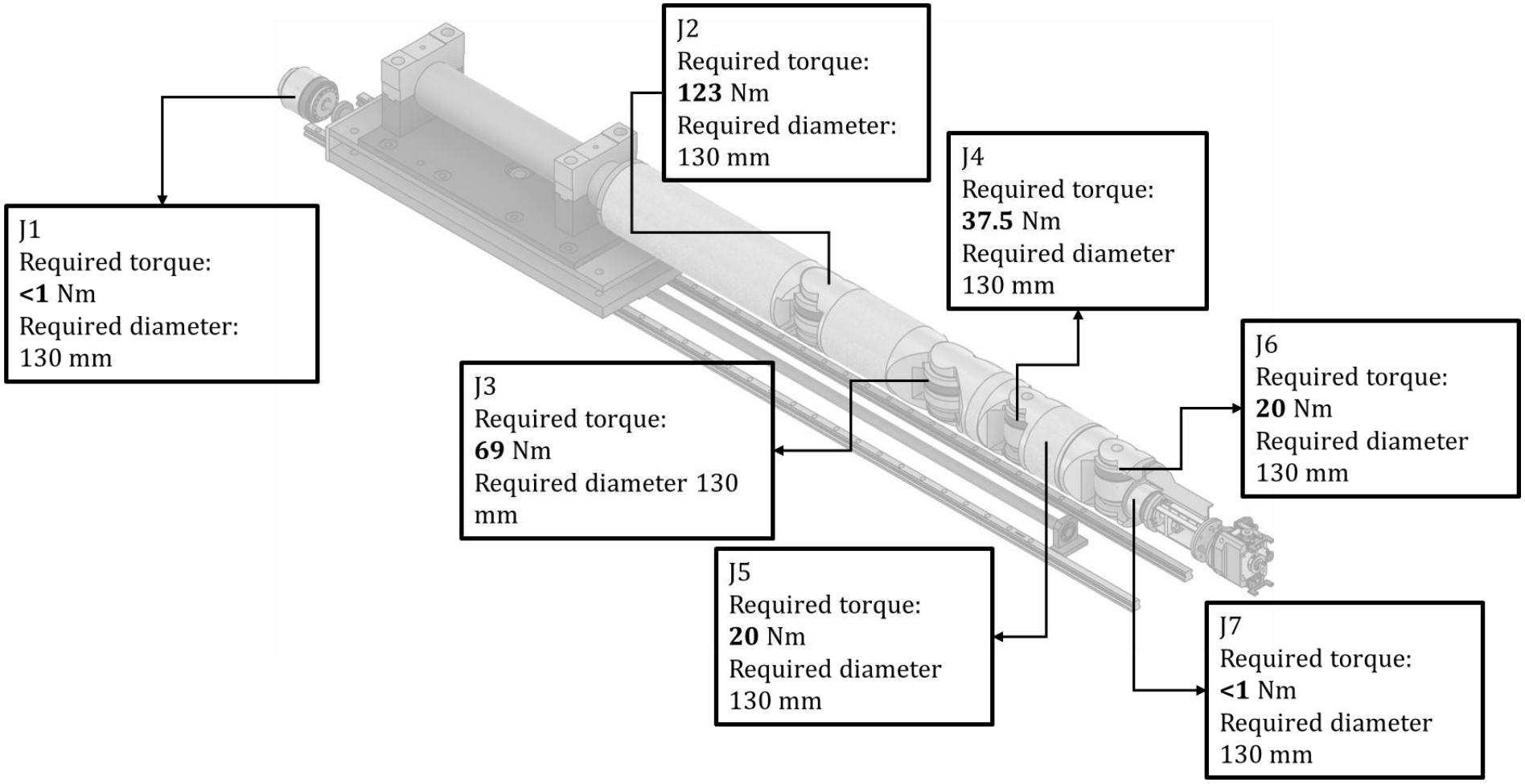
Critic configuration for ball-bearings





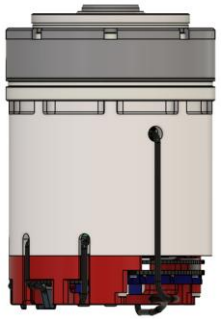
Overview of the techincal specifics of the arm



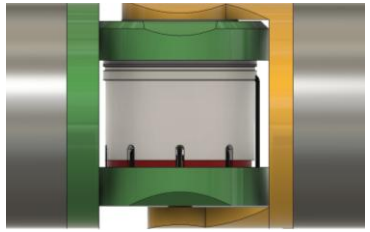


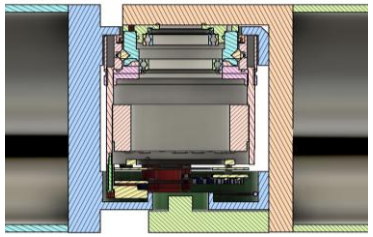
Concept Generation: Joint-link interface design

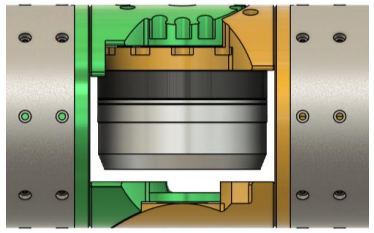
Parallelized concept design generation to individuate the best mechanical interface between joint and link

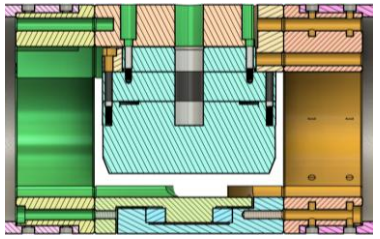


Tuaka – ECY-107





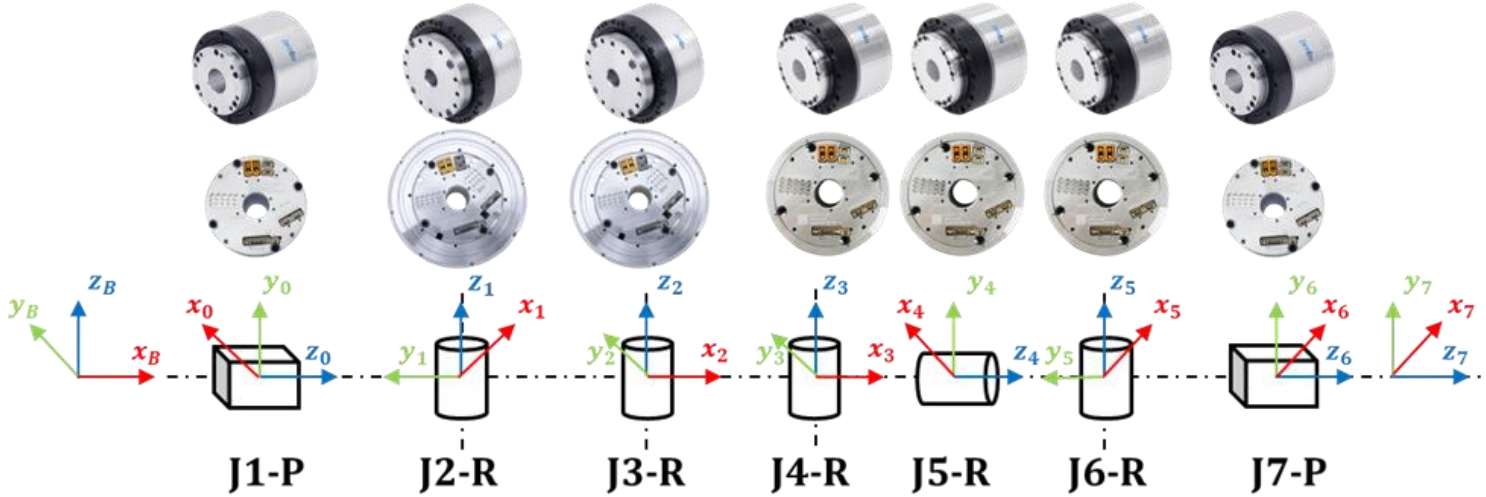




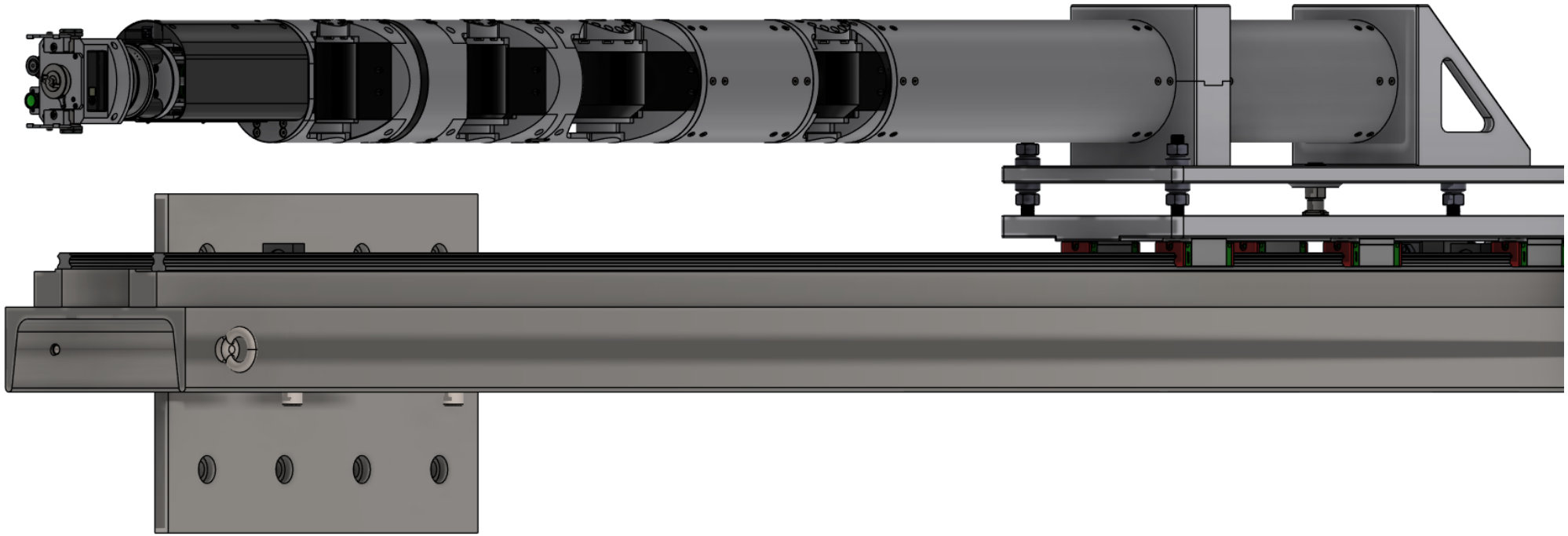
ZeroErr – 110- Iv6

Technical Specification of the actuation unit

Roman's Actuators										
	Brand	**Model**	**Power Input Voltage [V]**	**Power [W]**	**Gear Ratio**	**Brake**	**Sensors**	**Hollow bore diameter [mm]**	**Communication**	**Torque sensor**
J1	ZeroErr	eRob70H50I-FHM-18ET	48	75	50	NO	HPMTE*	18	EtherCAT	Virtual
J2	ZeroErr	eRob110H100I-FHM-18ET[V6]	48	723	100	NO	HPMTE*	18	EtherCAT	Virtual
J3	ZeroErr	eRob110H100I-FHM-18ET[V6]	48	723	100	NO	HPMTE*	18	EtherCAT	Virtual
J4	ZeroErr	eRob80H100I-FHM-18ET	48	146	100	NO	HPMTE*	18	EtherCAT	Virtual
J5	ZeroErr	eRob80H100I-BHM-18ET	48	146	100	YES	HPMTE*	18	EtherCAT	Virtual
J6	ZeroErr	eRob80H100I-FHM-18ET	48	146	100	NO	HPMTE*	18	EtherCAT	Virtual
J7	ZeroErr	eRob70H50I-FHM-18ET	48	75	50	NO	HPMTE*	18	EtherCAT	Virtual

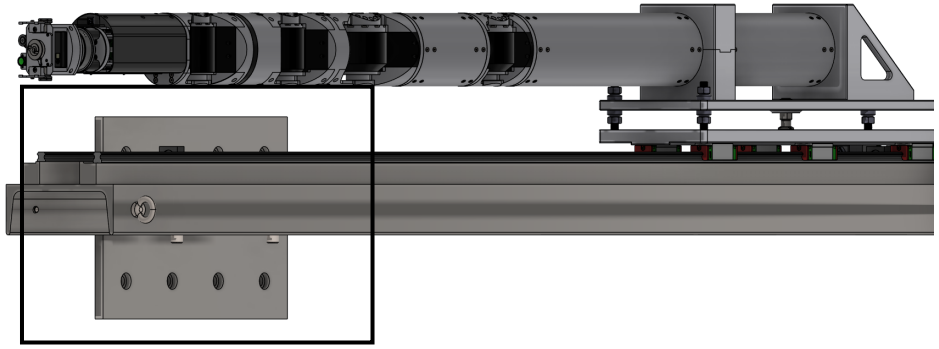


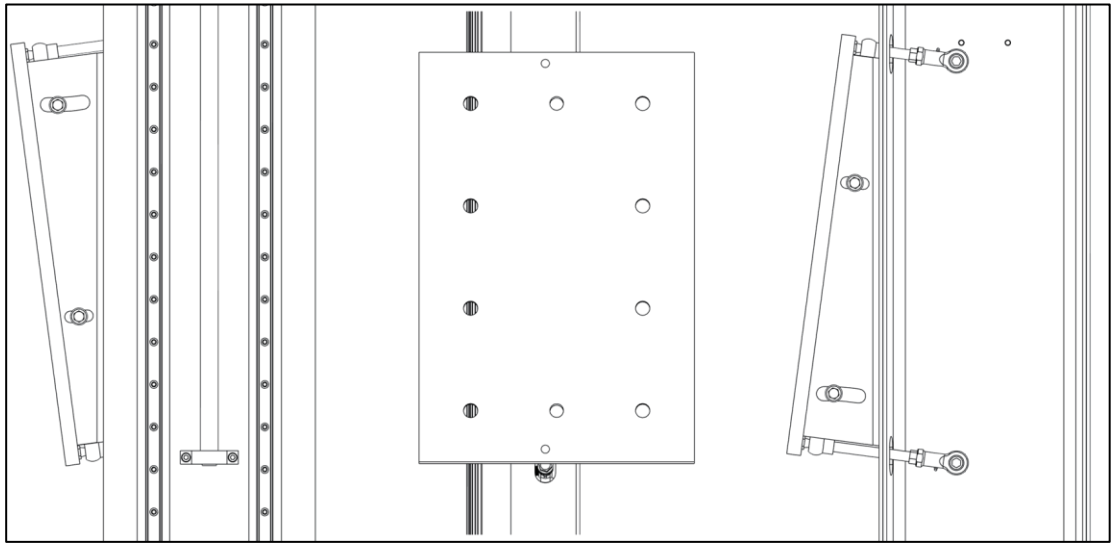
Concept Generation: Design of the whole structure



Concept Generation: Calibration mechanism

Regulation and interface devices for integration and calibration procedure





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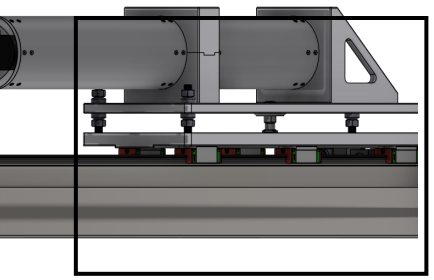
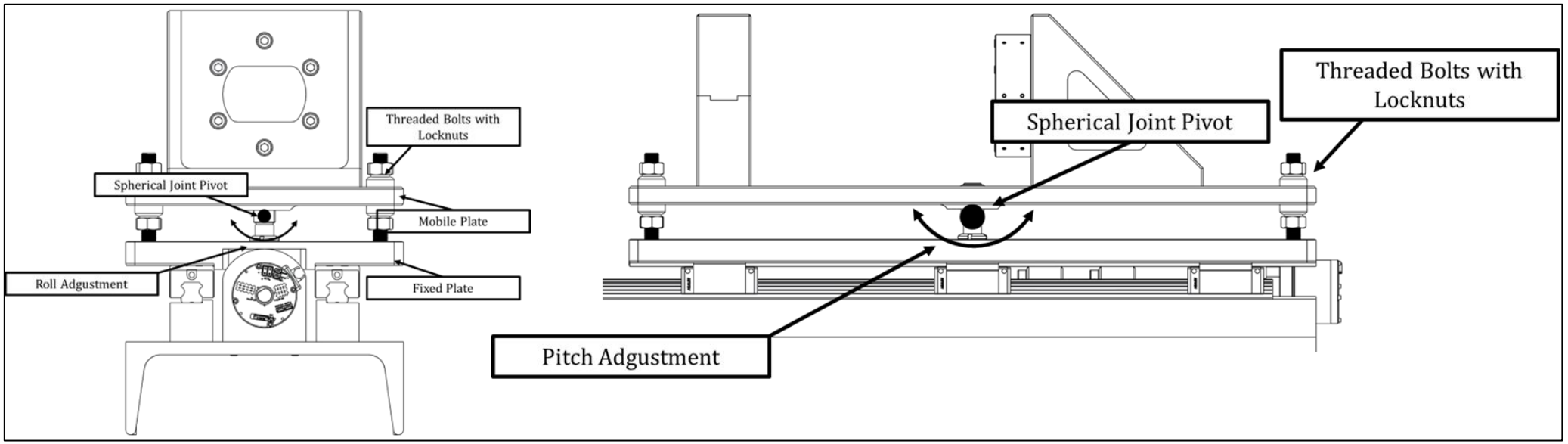


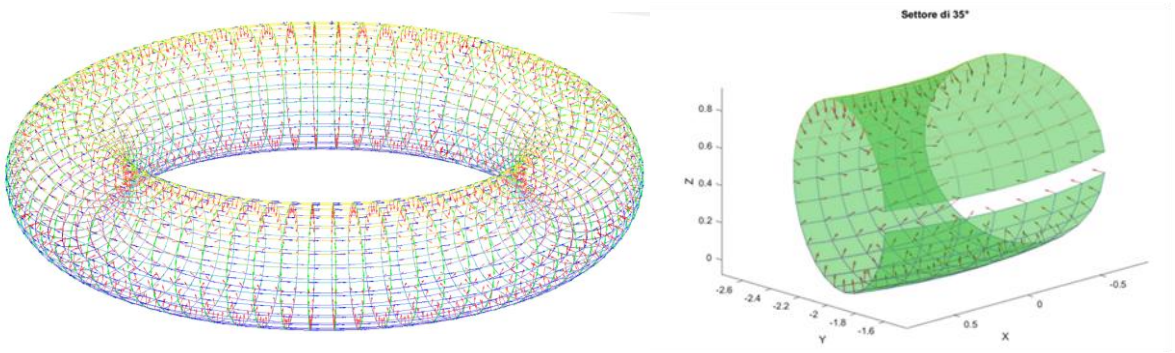


Verification in simulation: kinematic analysis

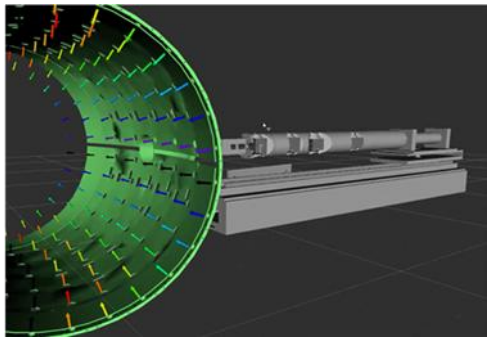
Reachability analysis and collision avoidance analyzed in ros2-environment

FR-02 – Reach of four poloidal sectors on both sides of the port

FR-03 – Reach of all tiles on all poloidal rings



Point cloud generation of the tiles frame poses



Redundancy level analysis of the arm inside the machine

ISO/IEC/IEEE International Standard - Systems and software engineering -- Life cycle processes -- Requirements engineering, ISO/IEC/IEEE 29148:2018(E), pp.1-104, Nov. 2018.

Verification in simulation: kinematic analysis

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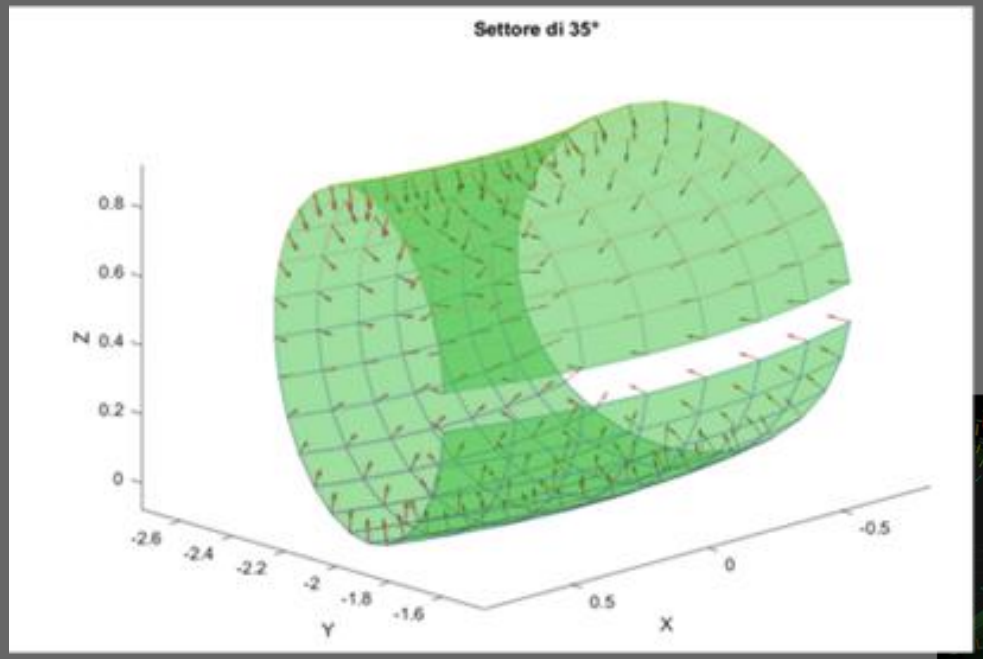
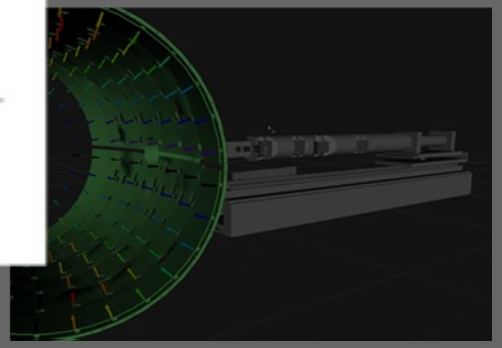
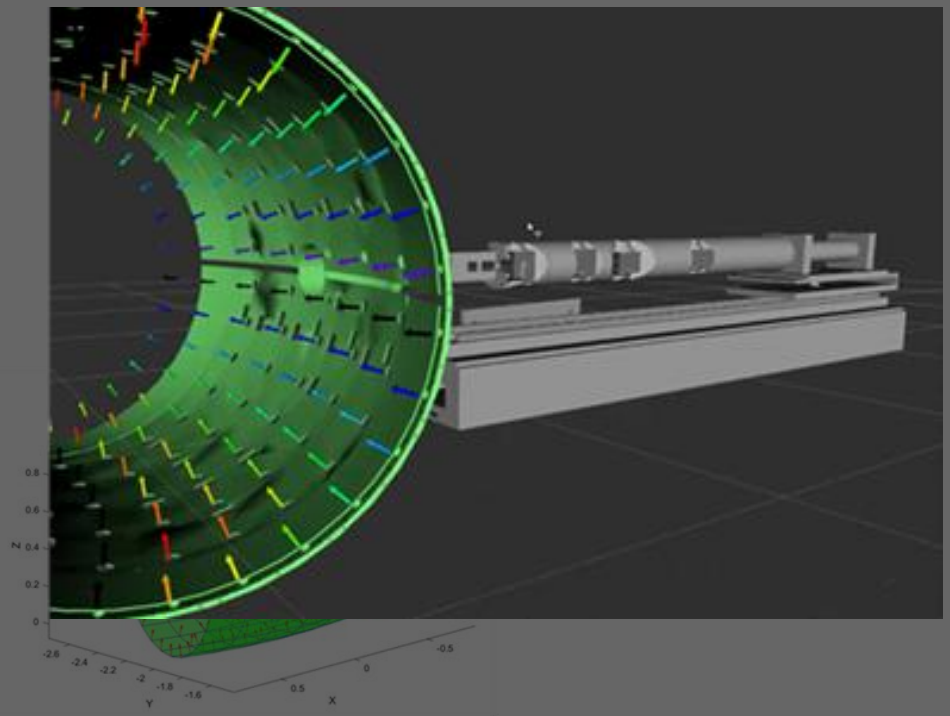




Reachability analysis with an evaluation of the redundancy level of the arm inside the machine

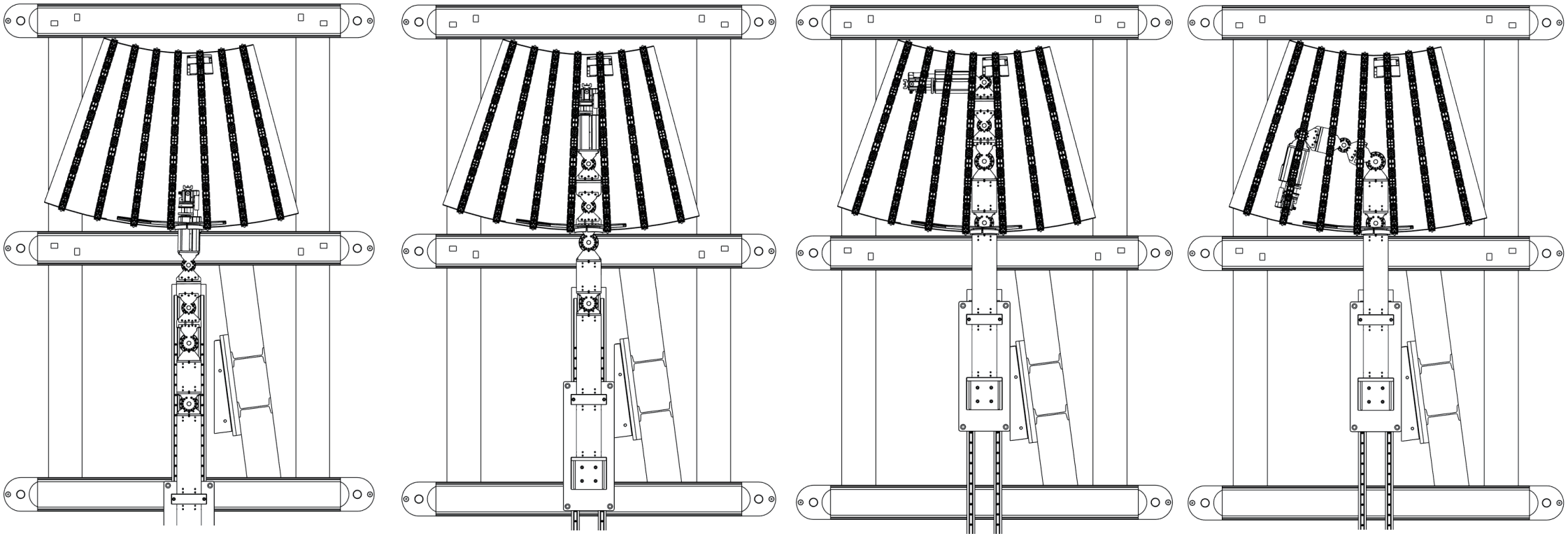
Verification in simulation: kinematic analysis

Reachability analysis and collision avoidance analyzed in ros2-environment



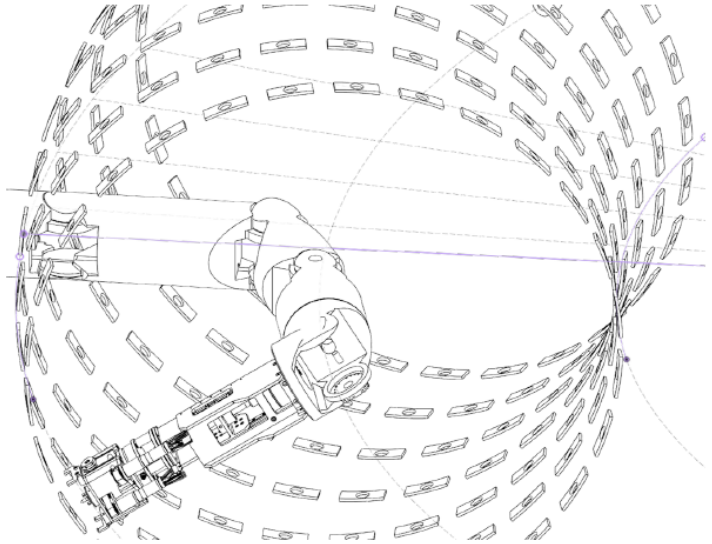
Verification in simulation: kinematic analysis

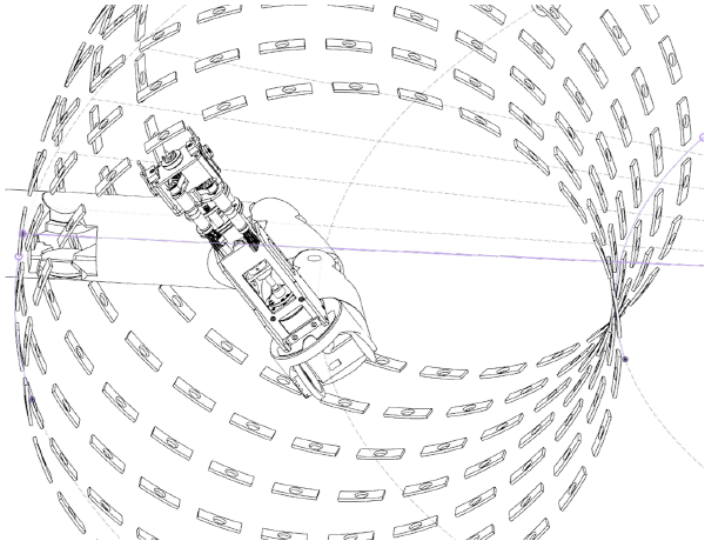
Reachability analysis and collision avoidance analysis in cad-3d environment

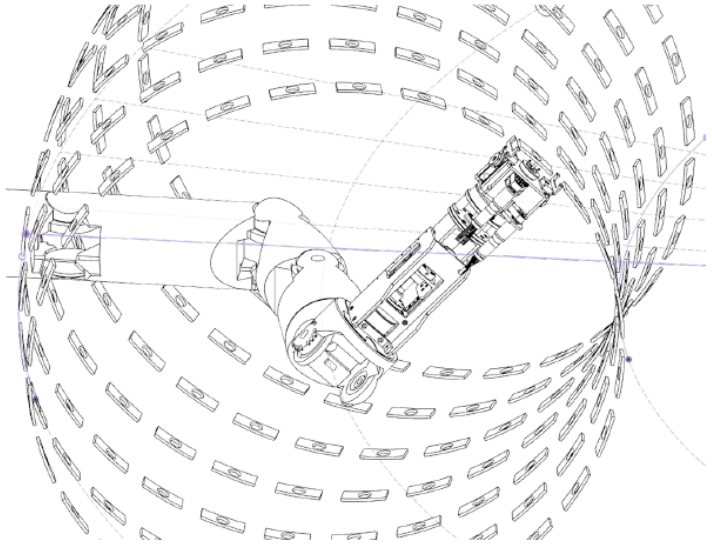


Verification in simulation: kinematic analysis

Reachability analysis and collision avoidance analysis in cad-3d environment







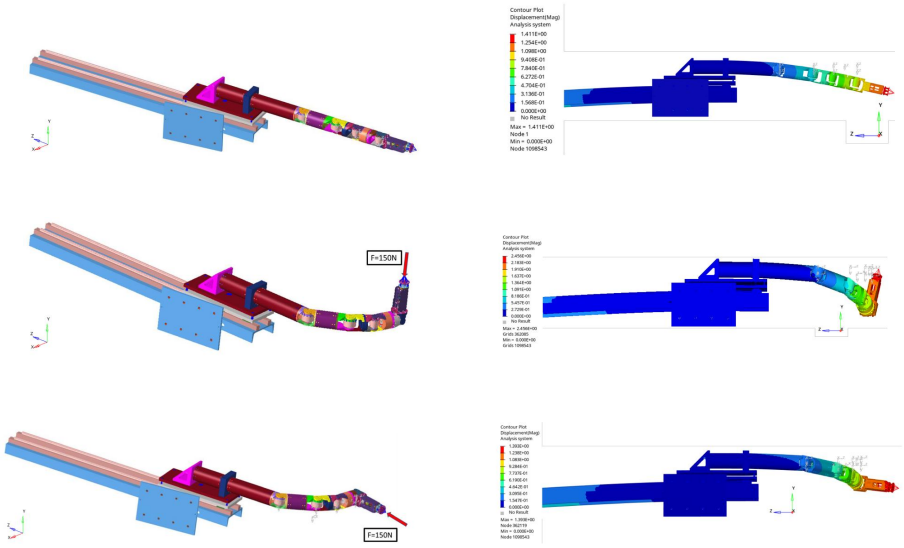
Verification in simulation: structural analysis

Design criteria at the base of the structural analysis

MR – 01 – Inertial deflection must not exceed **2.5 mm** in any direction

MR – 02 – Maximum axial deflection must be maximum **2.5 mm** under a nominal thrust of 150 N

MR – 03 – Mechanical stress must remain **below** the material **yield strength** during maximum joint acceleration.



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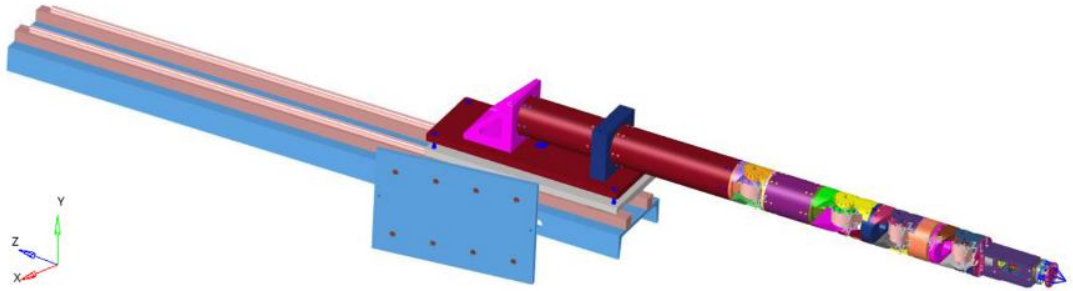
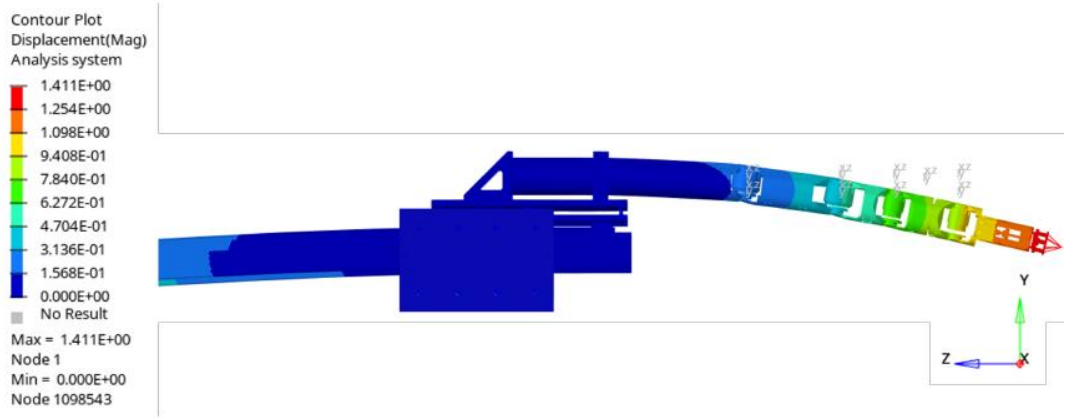
Verification in simulation: structural analysis

Vertical deflection evaluation – straight configuration

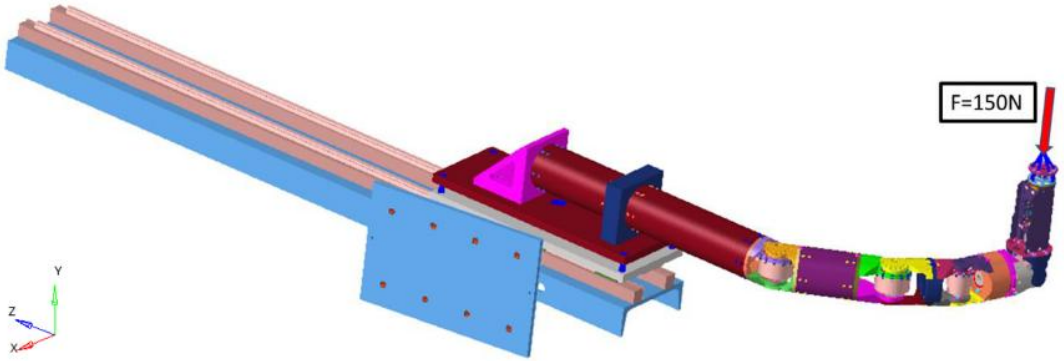


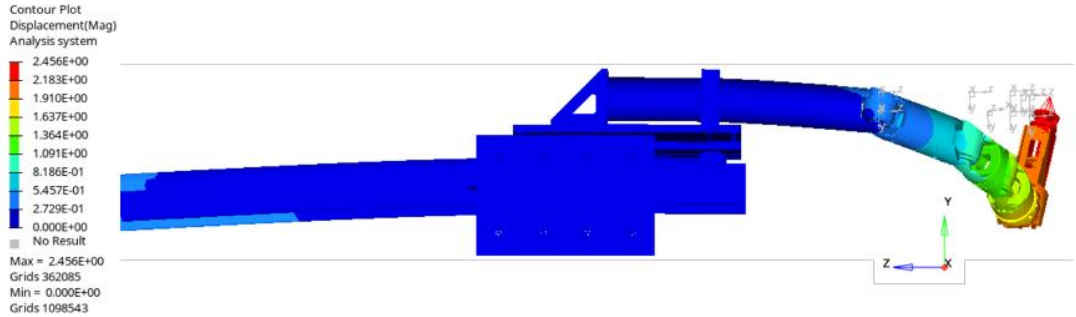


Joint Configurations								
Configuration	**J1 [°]**	**J2 [°]**	**J3 [°]**	**J4 [°]**	**J5 [°]**	**J6 [°]**	**J7 [mm]**	**Notes**
A	0	0	0	0	0	0	0	Straight configuration
B	1440	- 33	- 16	- 23	90	90	50	Critic Operative
C	1440	- 33	- 16	- 23	0	90	50	Critic Operative

Verification in simulation: structural analysis

Vertical deflection evaluation under max load and critic operative configuration





Joint Configurations								
Configuration	**J1 [°]**	**J2 [°]**	**J3 [°]**	**J4 [°]**	**J5 [°]**	**J6 [°]**	**J7 [mm]**	**Notes**
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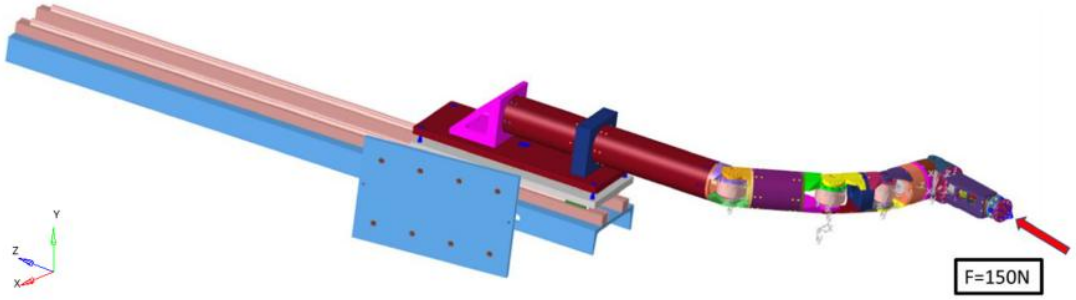
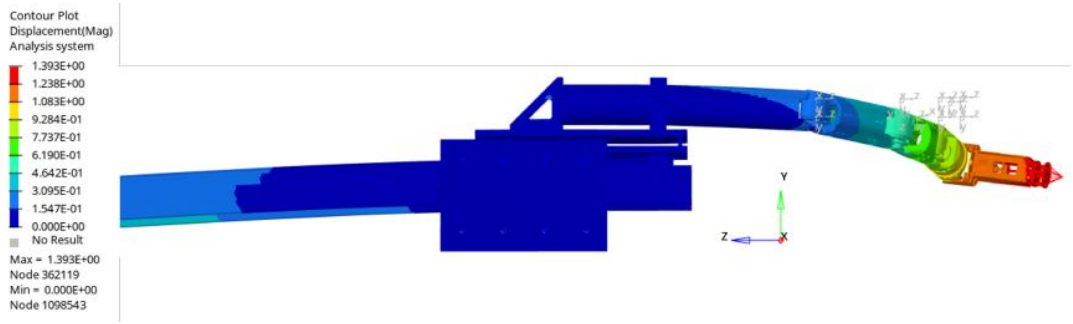
Verification in simulation: structural analysis

Vertical deflection evaluation under max load and critic operative configuration





Joint Configurations								
Configuration	**J1 [°]**	**J2 [°]**	**J3 [°]**	**J4 [°]**	**J5 [°]**	**J6 [°]**	**J7 [mm]**	**Notes**
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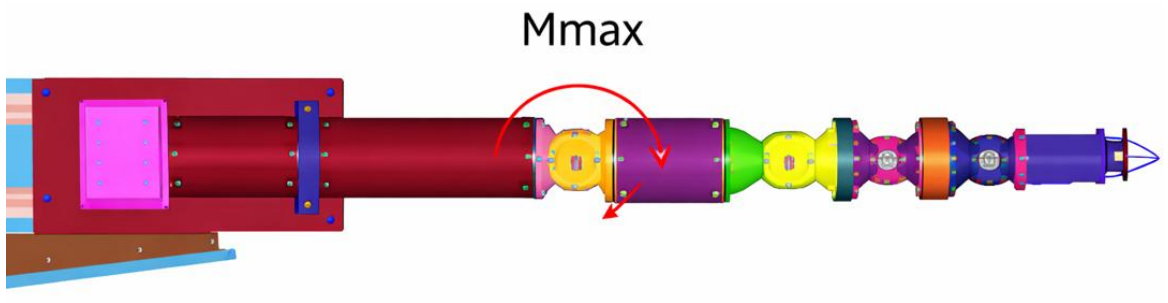
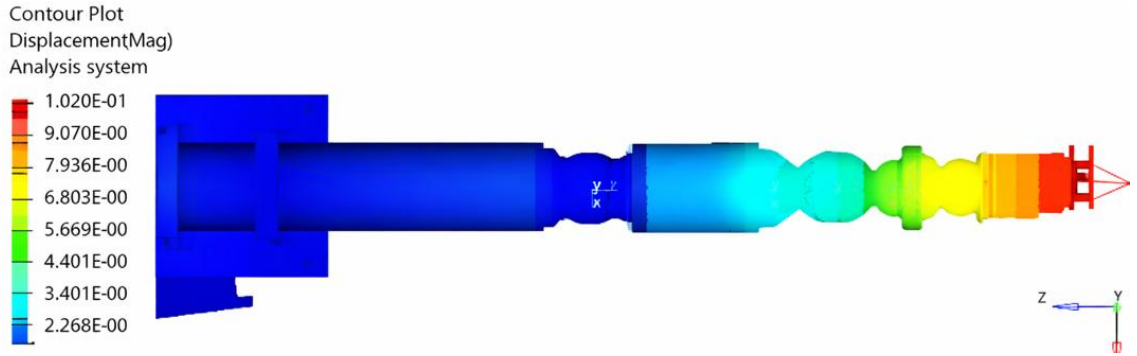
Verification in simulation: structural analysis

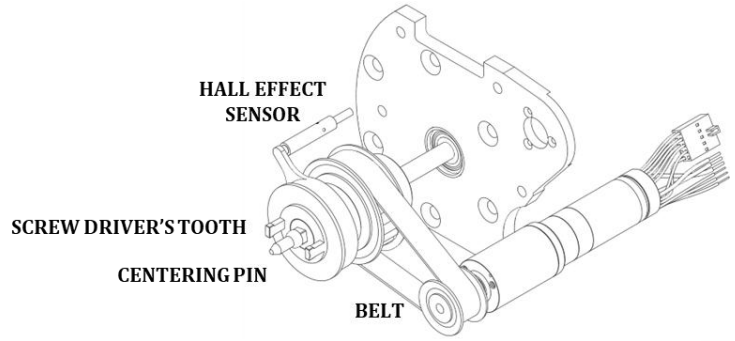
Max amplitude evalution with max torque at the joint



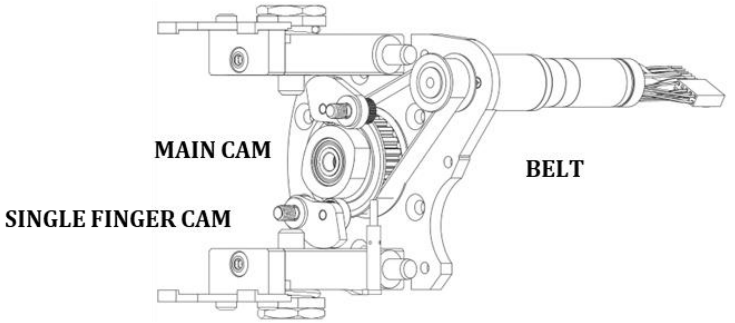


ROMAN maintenance routine operations end-effector

A task-oriented customization of a robust and reliable gripper



SCREWDRIVER MECHANISM



GRIPPER MECHANISM

Validation of ROMAN system

Facility Acceptance Test of the robotic arm subsystem

Structural Dimensioning

Joint ROM

EE Reliability

Full-Load Deflection

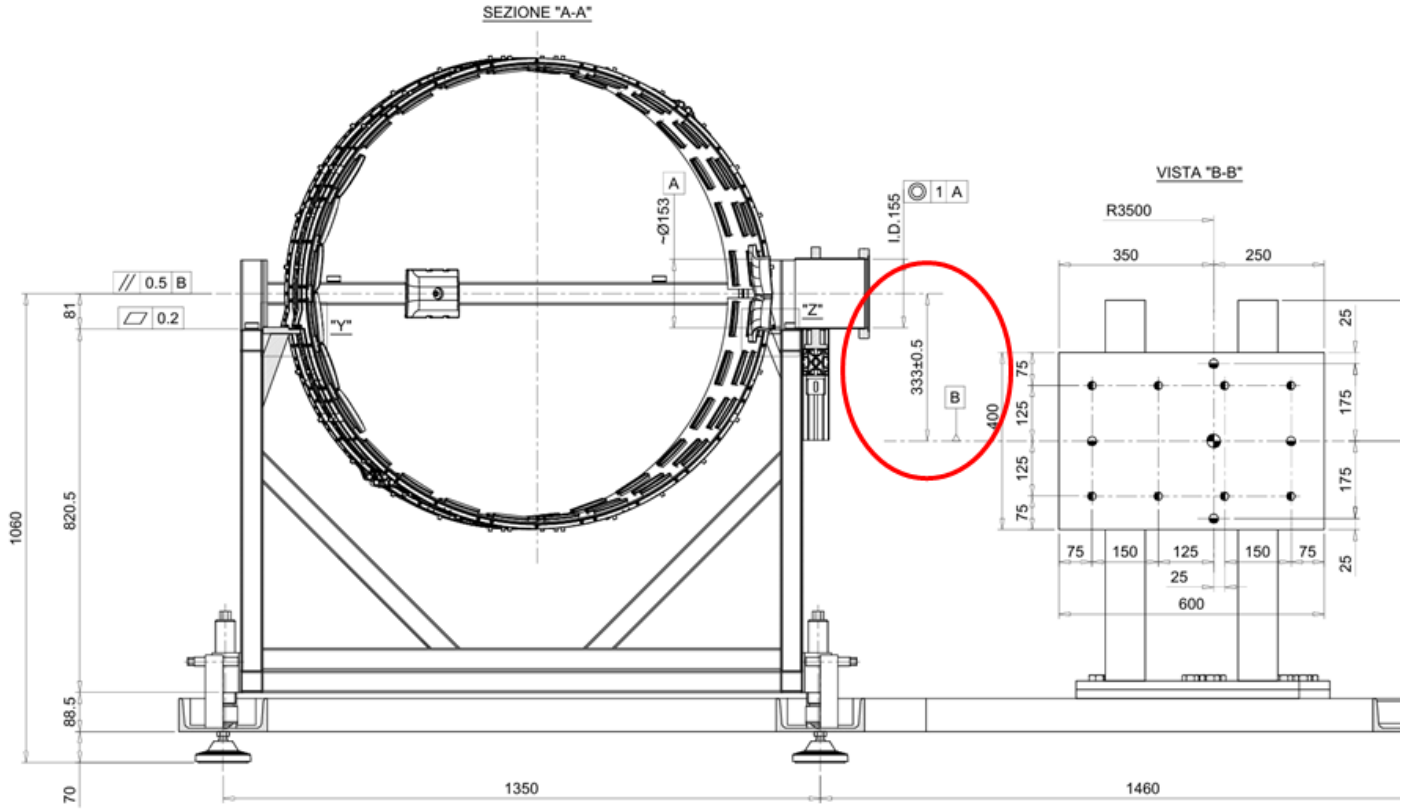
Repeatability

Validation of a robotic solution for confined space

Integration within the facility and metrology activity

FR – 02 – Reach of **four** poloidal sectors on both sides of the port

FR – 03 – Reach of **all tiles** on all poloidal rings



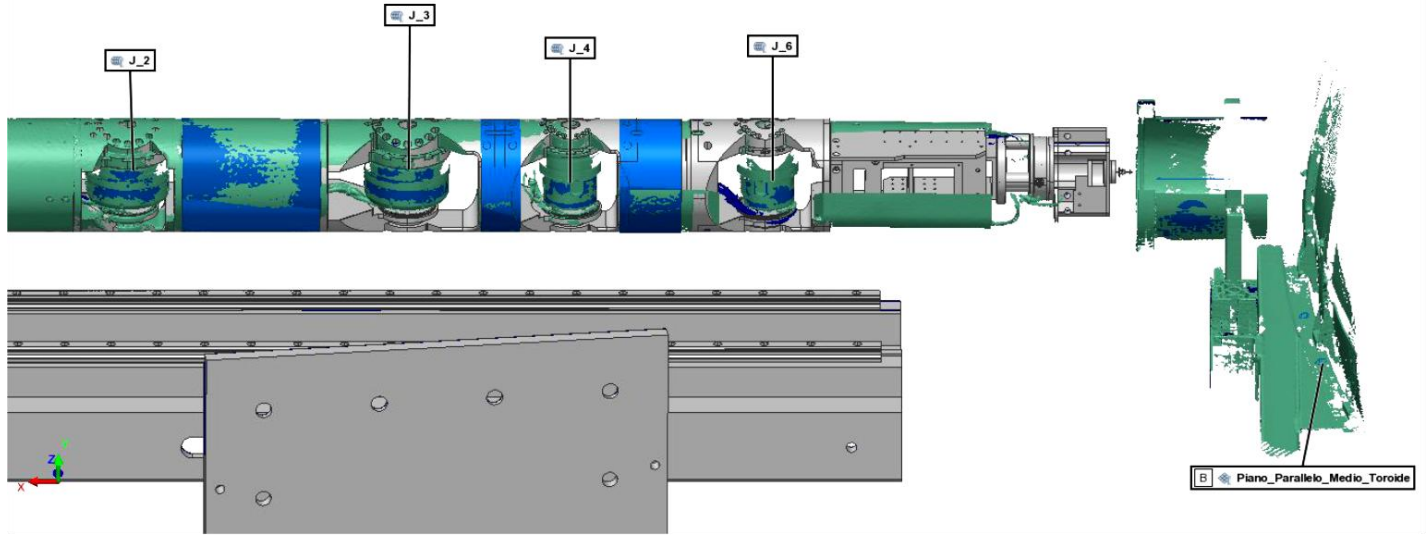
ISO/IEC/IEEE International Standard - Systems and software engineering -- Life cycle processes -- Requirements engineering, ISO/IEC/IEEE 29148:2018(E), pp.1-104, Nov. 2018.

Validation of a robotic solution for confined space

Integration within the facility and metrology activity

FR – 08 – System must ensure **coaxiality** of the **arm longitudinal** axis with access port axis

FR – 09 – System must ensure **orthogonality** of the **vertical joint** axis with the mid toroidal plane



ISO/IEC/IEEE International Standard - Systems and software engineering -- Life cycle processes -- Requirements engineering, ISO/IEC/IEEE 29148:2018(E), pp.1-104, Nov. 2018.

Thank You!

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