UNIVERSITÀ DEGLI STUDI DI PADOVA

The Deployment Mechanism of the E.T.PACK Deorbit System

functional and qualification tests

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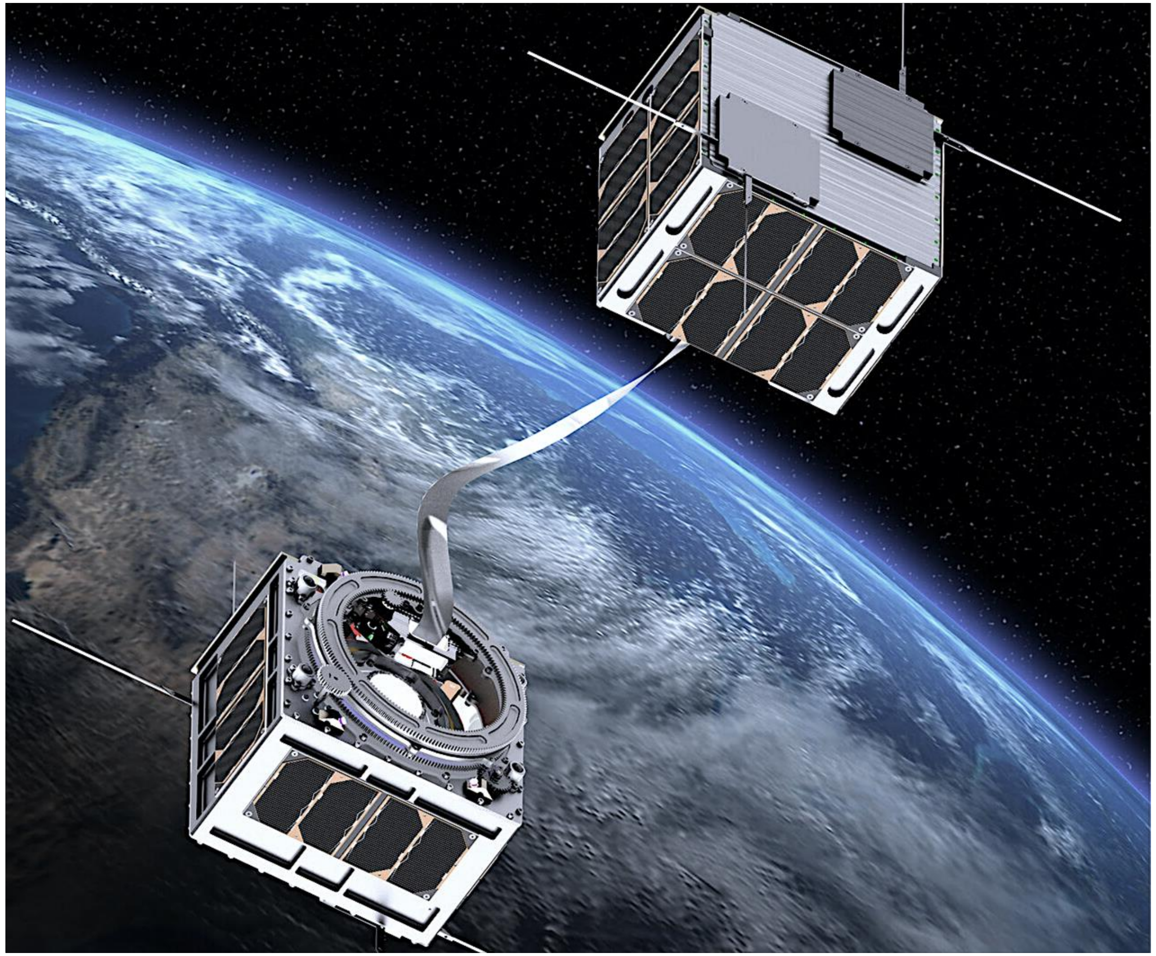


1. Introduction

- Contemporary research efforts are experiencing a significant paradigm shift for moving in space, primarily motivated by:
  - ✓ Space Environmental Pollution
  - ✓ Space Debris Problem

⇩

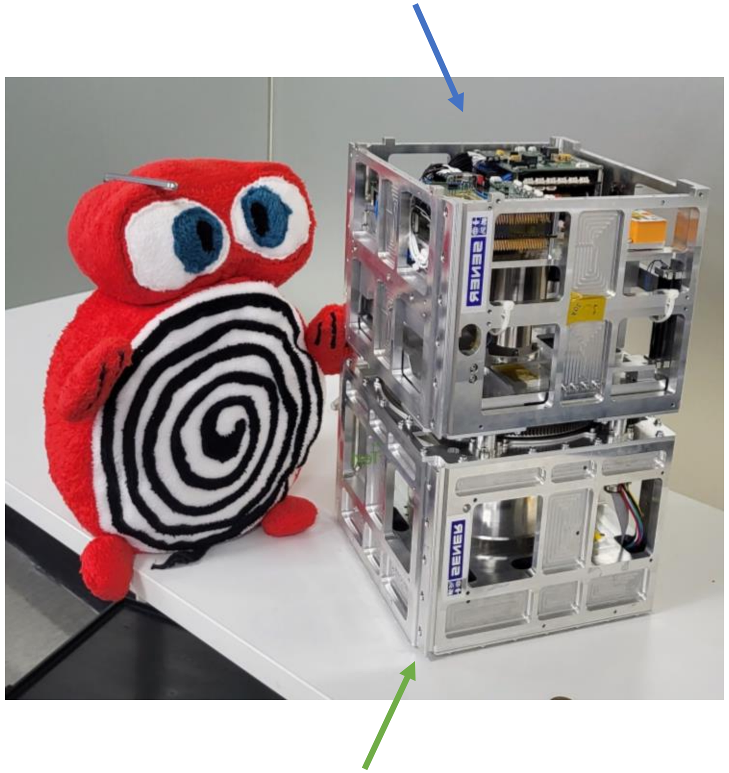
- Propellant-less propulsion

⇩

- Electrodynamic Tethers can provide adequate propulsion for space debris removal without the complications of combustions and with a minimal impact on the space environment.

1.1 The E.T.PACK Project

- **E.T.PACK Project aim**
  - ✓ Design, manufacturing, and test an autonomous Deorbit Kit Prototype for end-of-life satellite deorbiting [1,2]
  - ✓ Funded by the *European Innovation Council*
- **The Deorbit Kit Prototype**
  - ✓ is a 12U CubeSat with a total mass of 24 kg



[1] *Sánchez-Arriaga, G., Naghdi, S., Wätzig, K., Schilm, J., Lorenzini, E. C., Tajmar, M., Post, A. (2020). The E.T.PACK project: towards a fully passive and consumable-less deorbit kit based on low-work-function tether technology. Acta Astronautica, 177, 821-827.*

[2] *L. Tarabini Castellani, S. García González, A. Ortega, S. Madrid, E.C. Lorenzini, L. Olivieri, G. Sarego, A. Brunello, A. Valmorbida, M. Tajmar, C. Drobny, J-P. Wulfkuehler, R. Nerger, K. Wätzig, S. Shahsvani, G. Sánchez-Arriaga, Deorbit kit demonstration mission, Journal of Space Safety Engineering, Volume 9, Issue 2, 2022, Pages 165-173, ISSN 2468-8967, https://doi.org/10.1016/j.jsse.2022.01.004.*

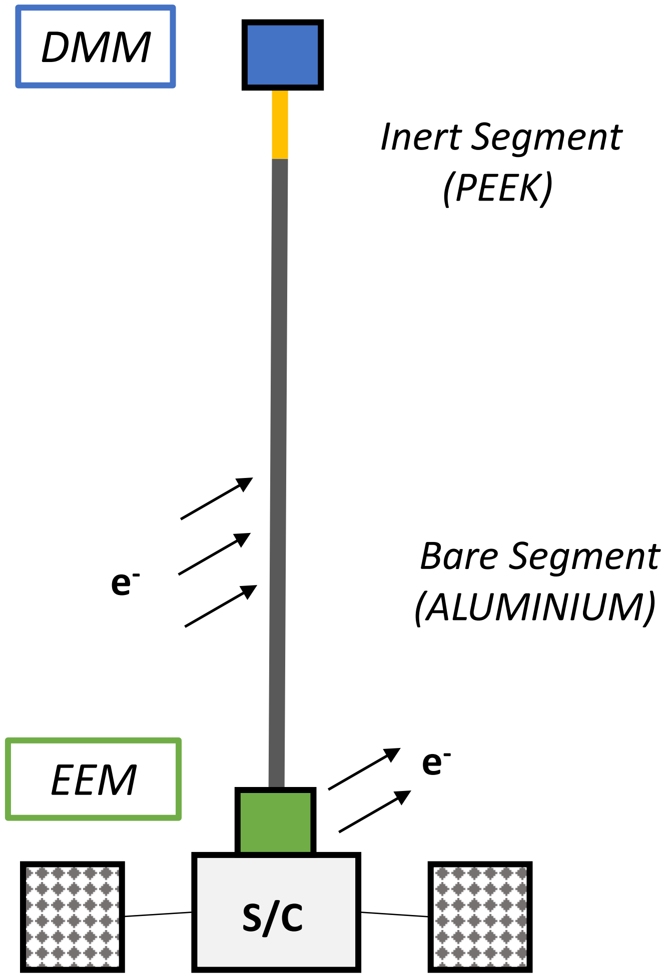
1.1 The E.T.PACK Project

- **The Bare Electrodynamic Tether** [3]

  ✓ The total tape length is ~500 m.

  ✓ The bare portion of the E.T.PACK bare electrodynamic tether consists in a conductive aluminum tape of 2.5 cm of width and 40 µm of thickness.

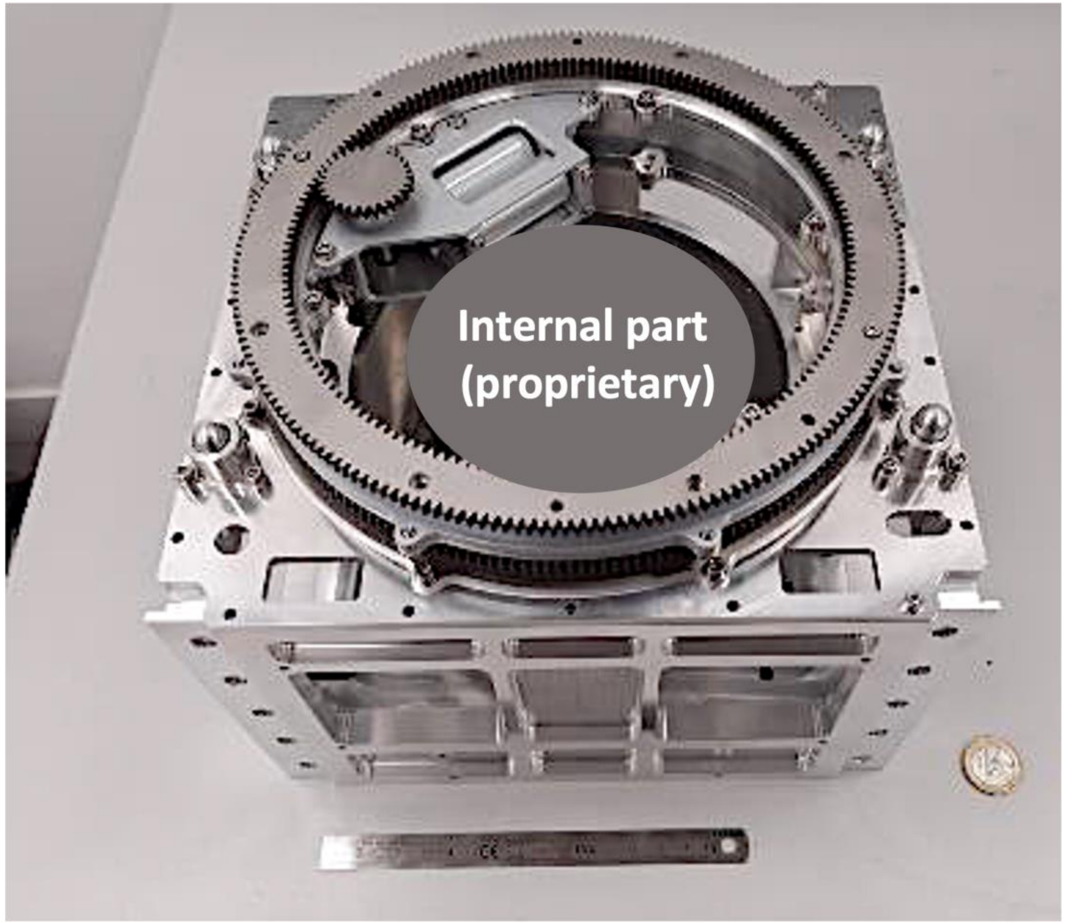
  ✓ For the much shorter inert portion of the tether, the material chosen is PEEK with 50 µm of thickness.



[3] *Sanmartin, Juan & Martinez-Sanchez, Manuel & Ahedo, Eduardo. (1993). Bare wire anodes for electrodynamic tethers. Journal of Propulsion and Power - J PROPUL POWER. 9. 353-360. 10.2514/3.23629.*

2. The Deployment Mechanism Module

- **The Deployment Mechanism Module (DMM)**
  - ✓ is compact, with a total volume of 5.2lt and a mass of 12.5 Kg
  - ✓ the external surface is equipped with solar panels serving the dual purpose of recharging the batteries and providing power to the avionics system [4]
  - ✓ includes:
    1. *The Deployment Mechanism (DM)*
    2. *The Tape Spool*
    3. *The Docking Mechanism*
    4. *A Cold Gas System*
    5. *Electrical and Electronics*



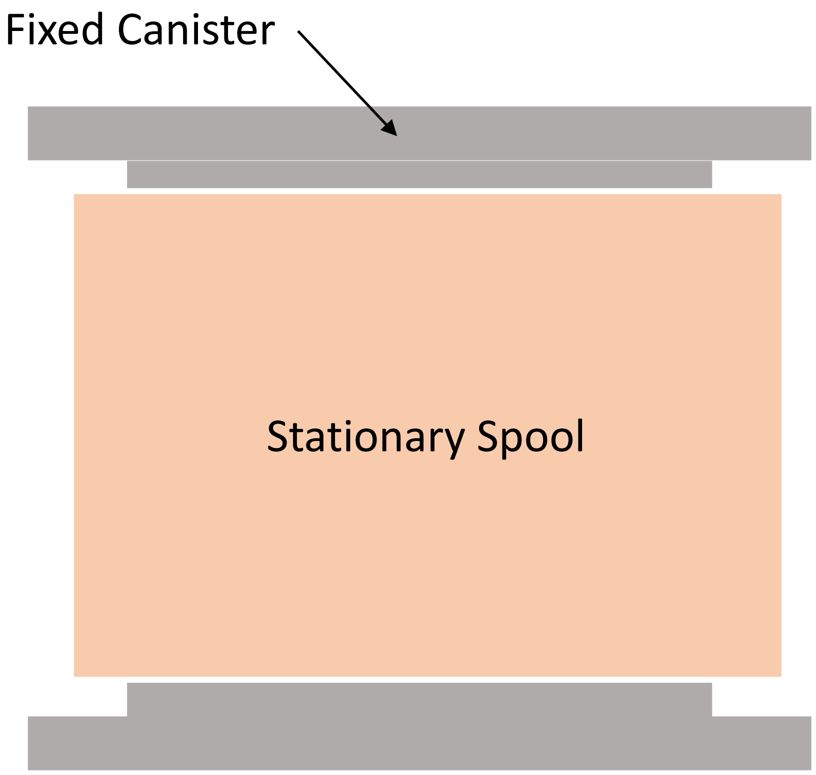
[4] L. Tarabini Castellani, S. García González, A. Ortega, S. Madrid, E.C. Lorenzini, L. Olivieri, G. Sarego, A. Brunello, A. Valmorbida, M. Tajmar, C. Drobny, J-P. Wulfkuehler, R. Nerger, K. Wätzig, S. Shahsvani, G. Sánchez-Arriaga, Deorbit kit demonstration mission, Journal of Space Safety Engineering, Volume 9, Issue 2, 2022, Pages 165-173, ISSN 2468-8967, https://doi.org/10.1016/j.jsse.2022.01.004.

2.1 The tape Spool

- **The Spool design**

  ✓ Investigation of spool type and dimensions according to the volume available in the DMM

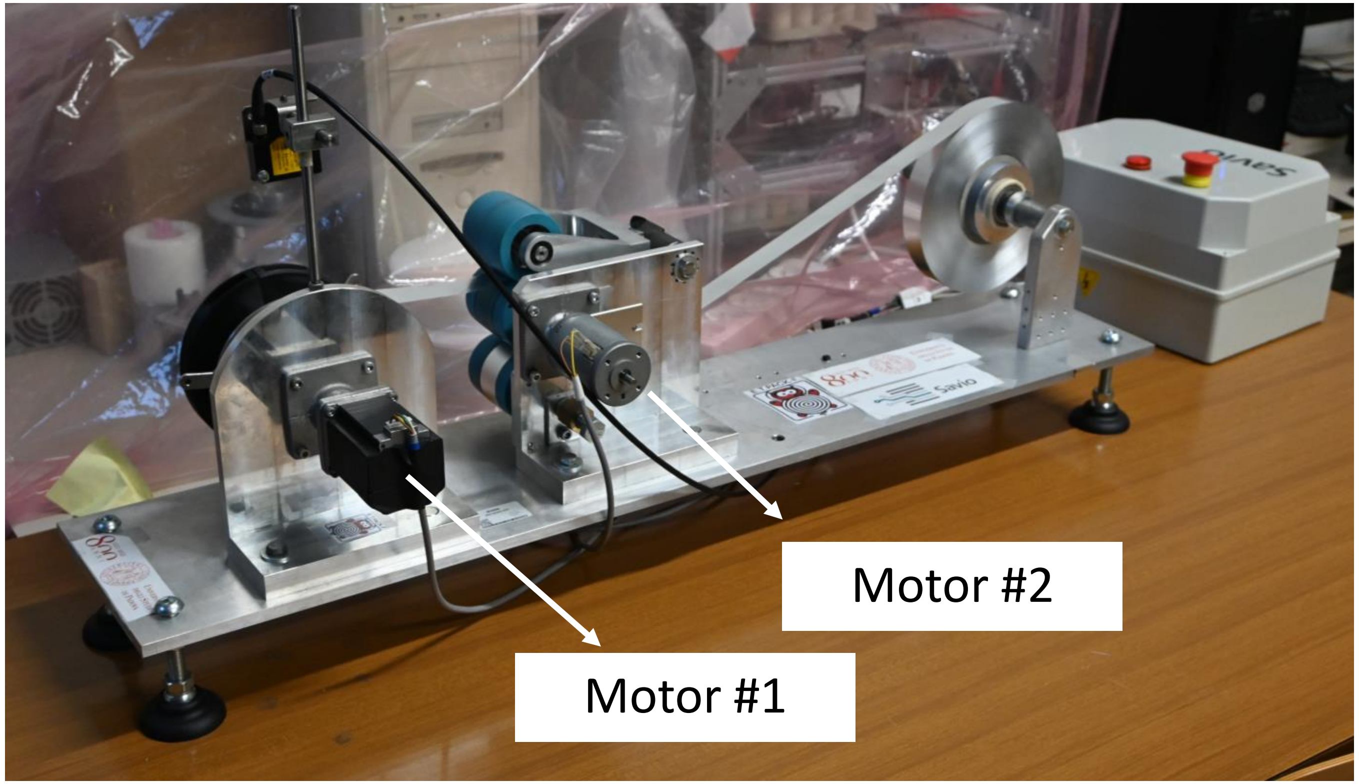
  ✓ A trade off analysis led to the selection of a stationary spool and parallel spooling [5]



[5] *Sarego, G., Olivieri, L., Valmorbida, A. et al. Deployment requirements for deorbiting electrodynamic tether technology. CEAS Space J 13, 567–581 (2021). https://doi.org/10.1007/s12567-021-00349-5*

2.1 The tape Spool

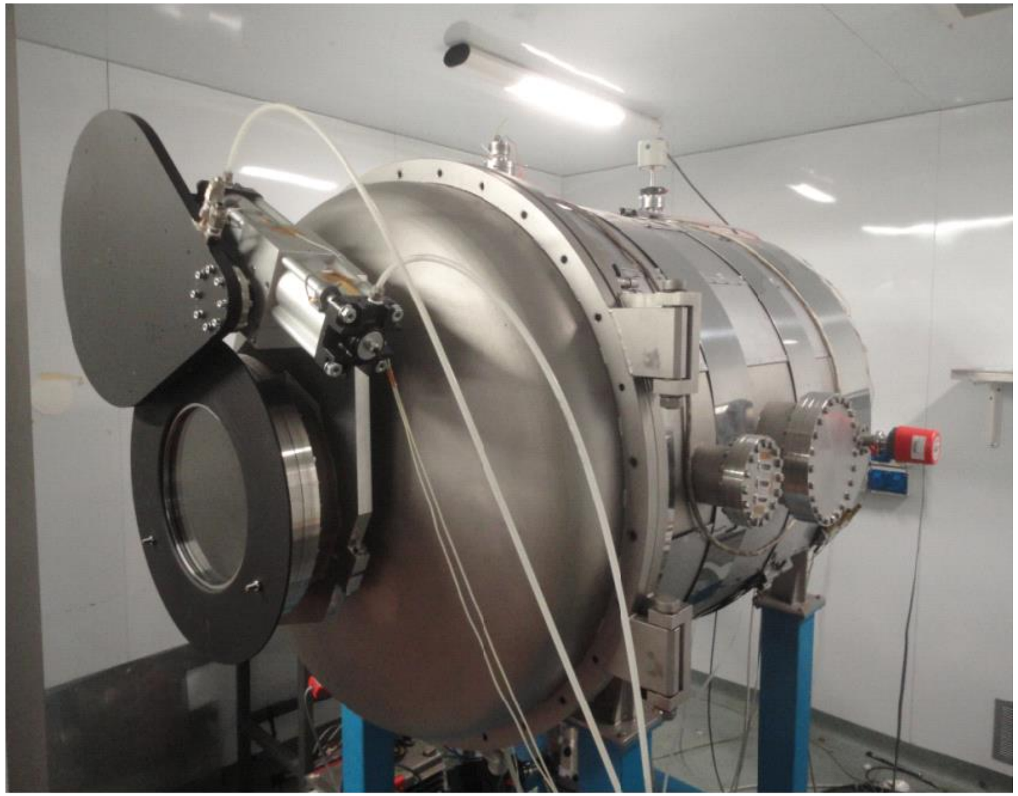
- **The Spooling Machine**
  - ✓ create the spool
  - ✓ is accurate in maintaining the tape tension and in keeping the coils aligned
  - ✓ computes accurately (within 1%) the spooled tape length using the encoder of the stepper motor and the coil diameter measured by the laser sensor



2.1.1 Cold Welding test

- **Aim of Test Campaign**
  - ✓ verification of cold welding formation throught tension measurements

- **Testing procedures**
  1. Tape tether tension measurement
  2. Thermal Vacuum (TV) / Thermal Balance (TB) test
  3. Tape tether tension measurement after TV/TB

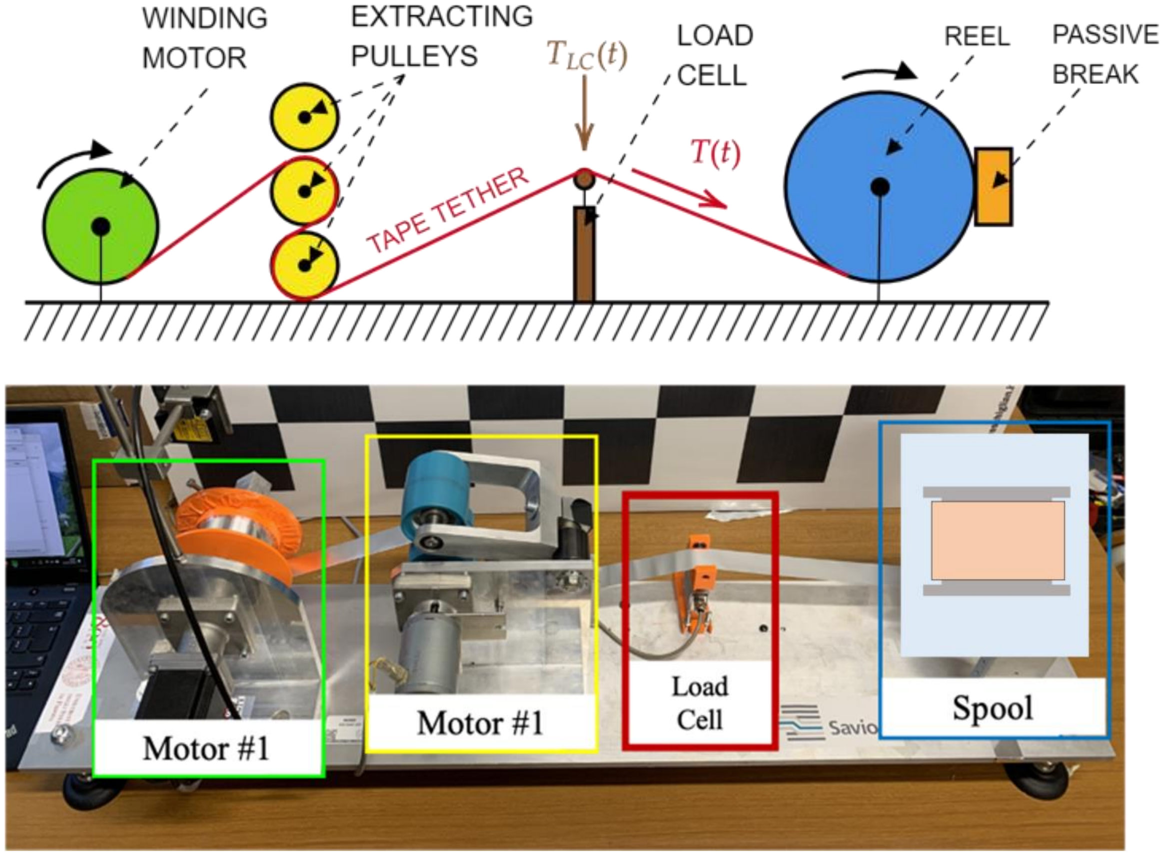


Thermal Vacuum Chamber at UniPD

2.1.1 Cold Welding test

1. Tape tether tension measurements

- ✓ The tape spool was monuted on a free-rotating reel
- ✓ A passive brake system was introduced for maintaining a minimum tension
- ✓ Tape tension was monitored with a Burster load cell

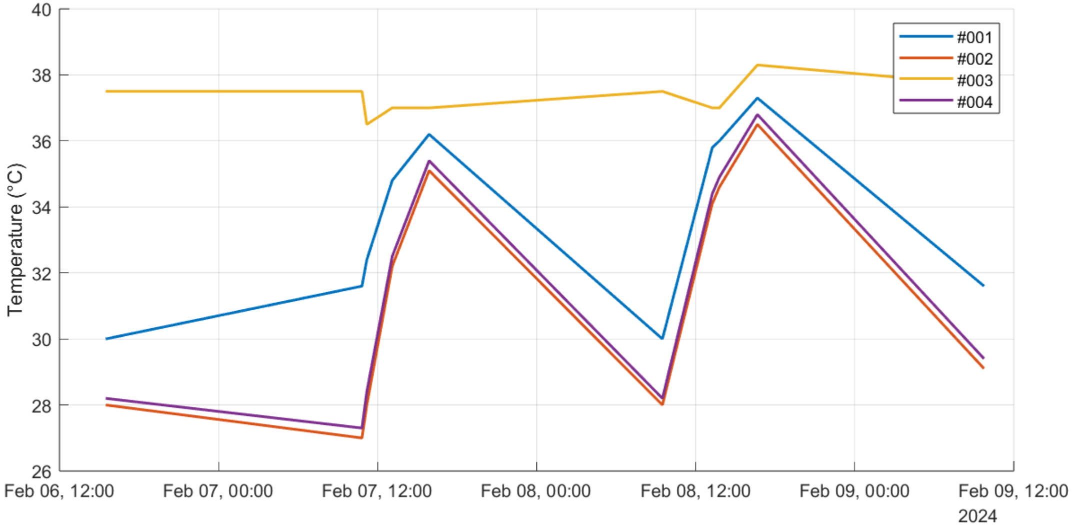


Scheme of the tape tension measurement test

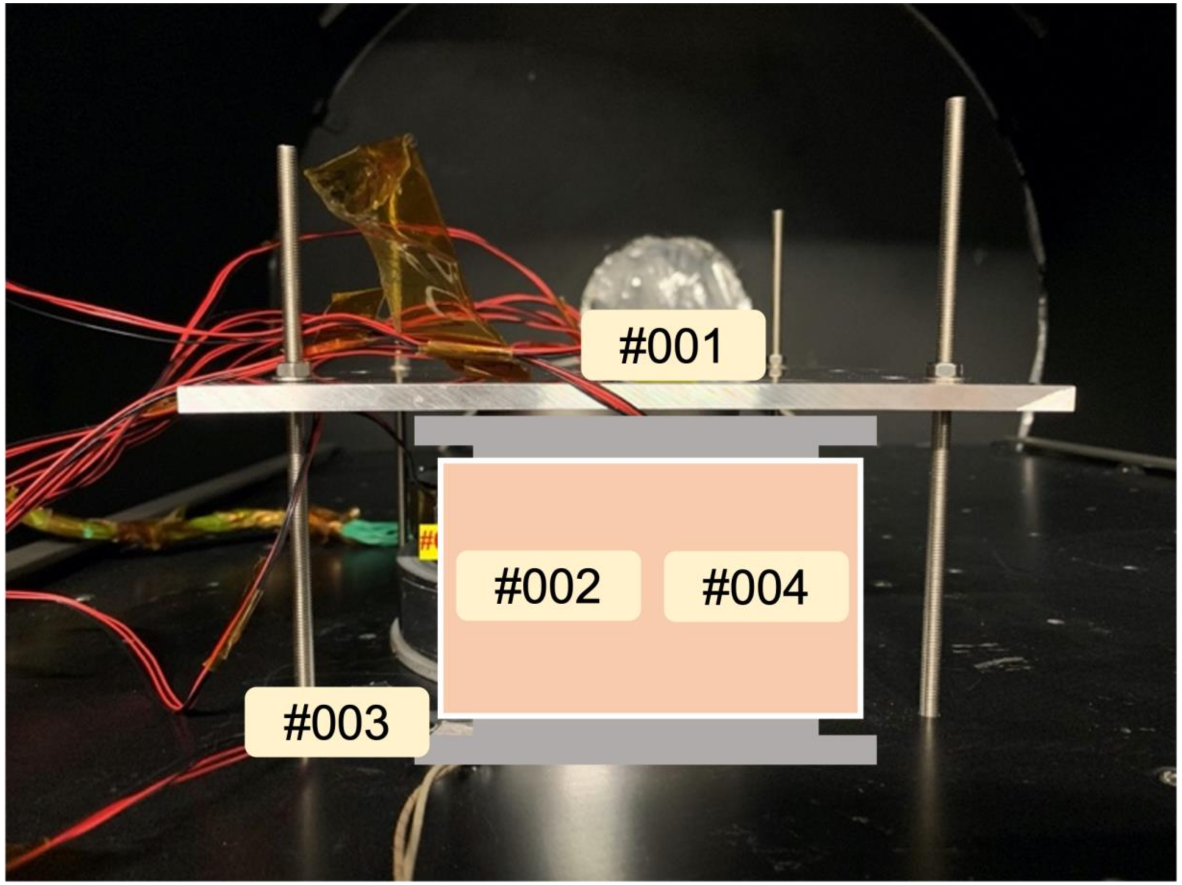
2.1.1 Cold Welding test

2. Thermal Vacuum (TV) / Thermal Balance (TB) Test

- Installation of the spool into the UniPD TV chamber
- Thermal cycling of spool:



- Real-time temperature monitoring with 4-wire PT100 sensors
- Employing single control loop for temperature regulation

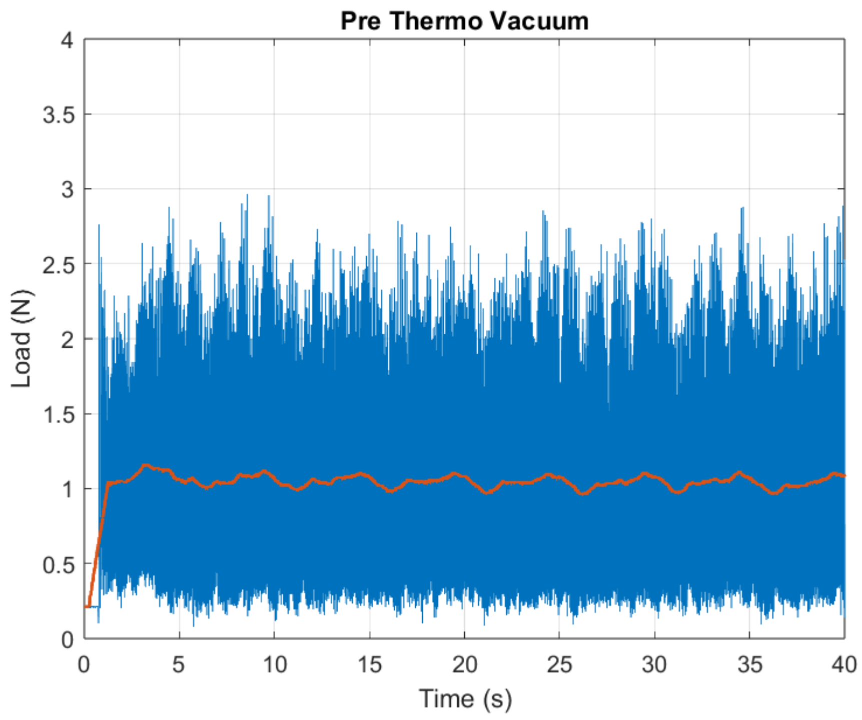


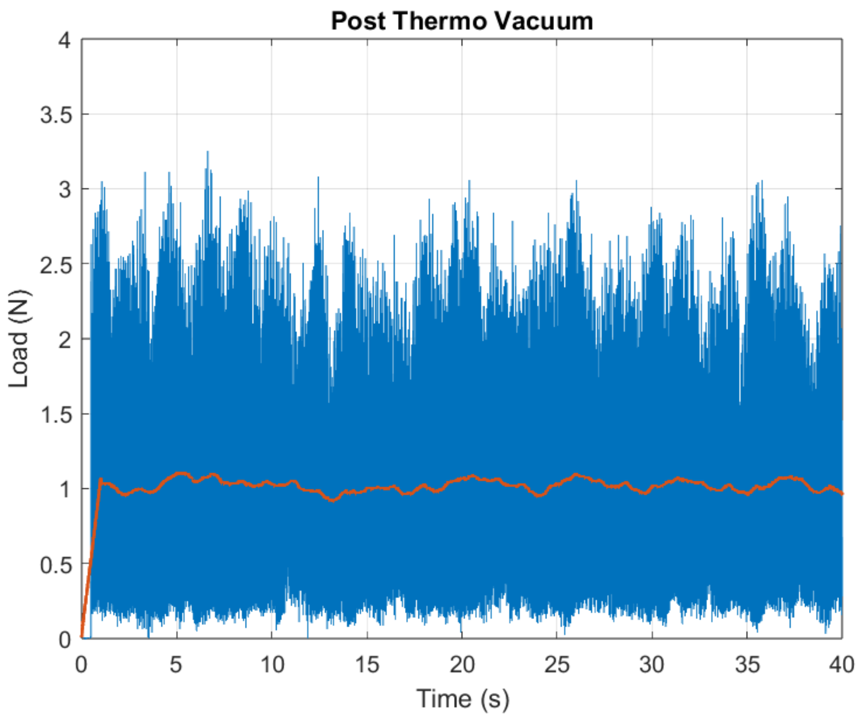
TV/TB test into the TV Chamber

2.1.1 Cold Welding test

3. Comparison of Tape Tether Tension / Status between pre and post TV/TB tests

- Observation of stable average tension
- Absence of cold-welding





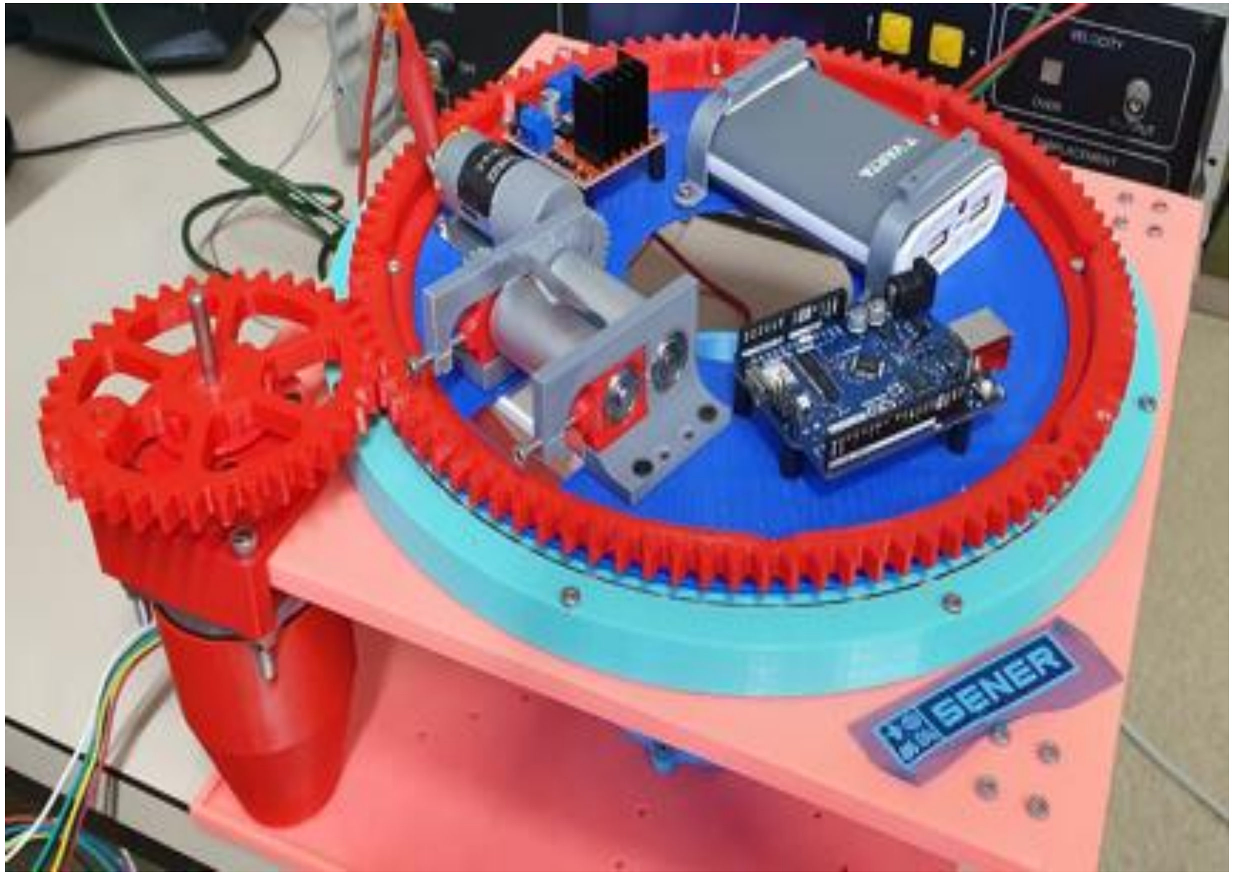
2.1.2 Shaker Tests

- **Aim of test campaign**
  - ✓ perform pre and post vibration searches to detect anomalies of fundamental modes of the spool
  - ✓ Validate the resistance of the spool to launch loads
- **Testing procedures**
  1. Sine Sweep (Search)
  2. Sine High Levels (amplitude 0.1g)
  3. Random Vibrations (PSD of Canisterized Payloads)
  4. Sine Sweep (Search)
- **Results**
  - ✓ no marked changes in resonant frequencies
  - ✓ no significant changes observed in the tether spool or canister after vibration tests

Shaker at UniPD

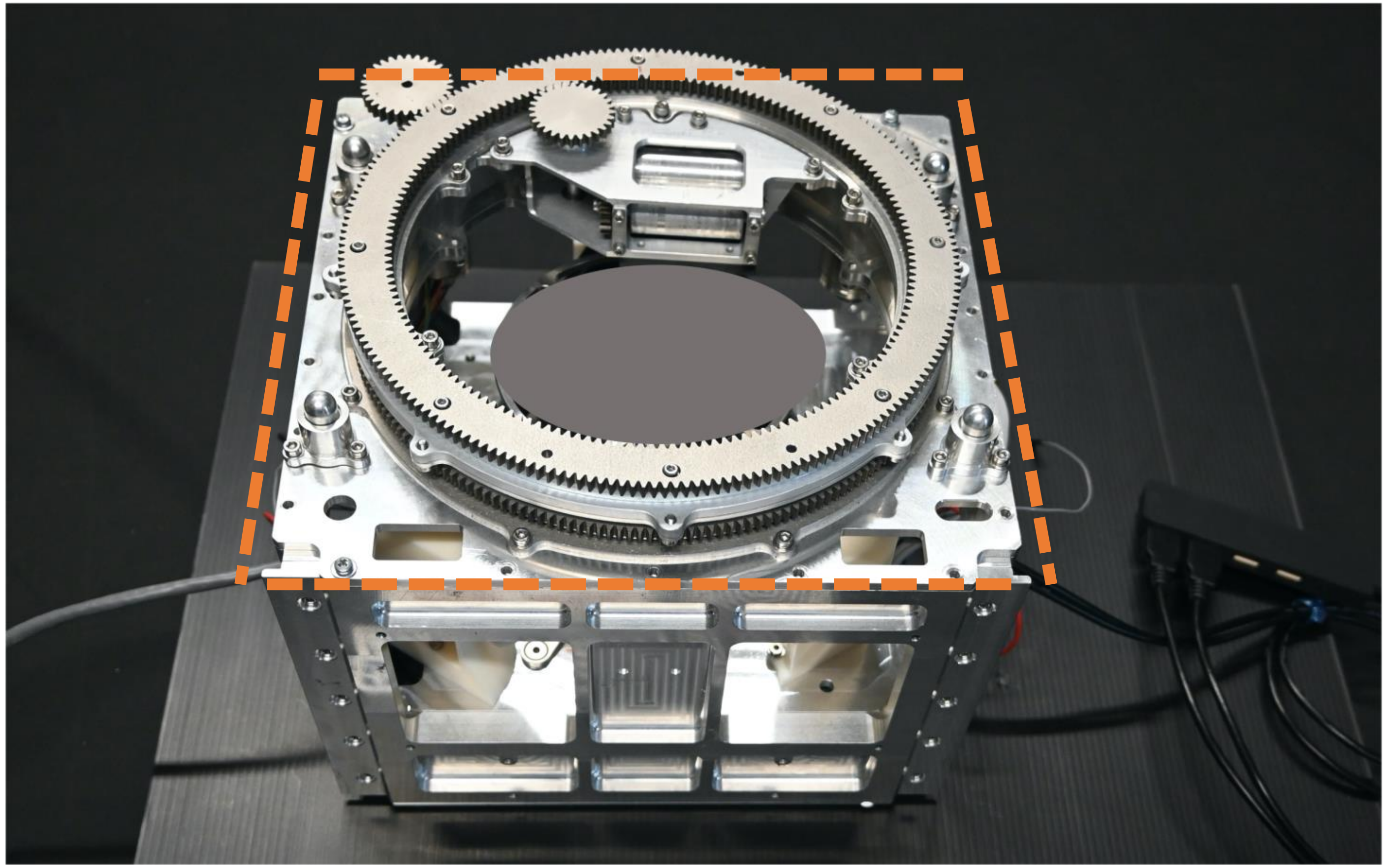
2.2 The Deployment Mechanism

- **Plastic Breadborad Prototype**
  - ✓ representative model in terms of dimensions and volume of the DM
  - ✓ the plastic breadboard prototype was useful in conducting preliminary tests related to tape extraction
  - ✓ definition of DM components and extraction methodology



2.2 The Deployment Mechanism

Deployment Mechanism

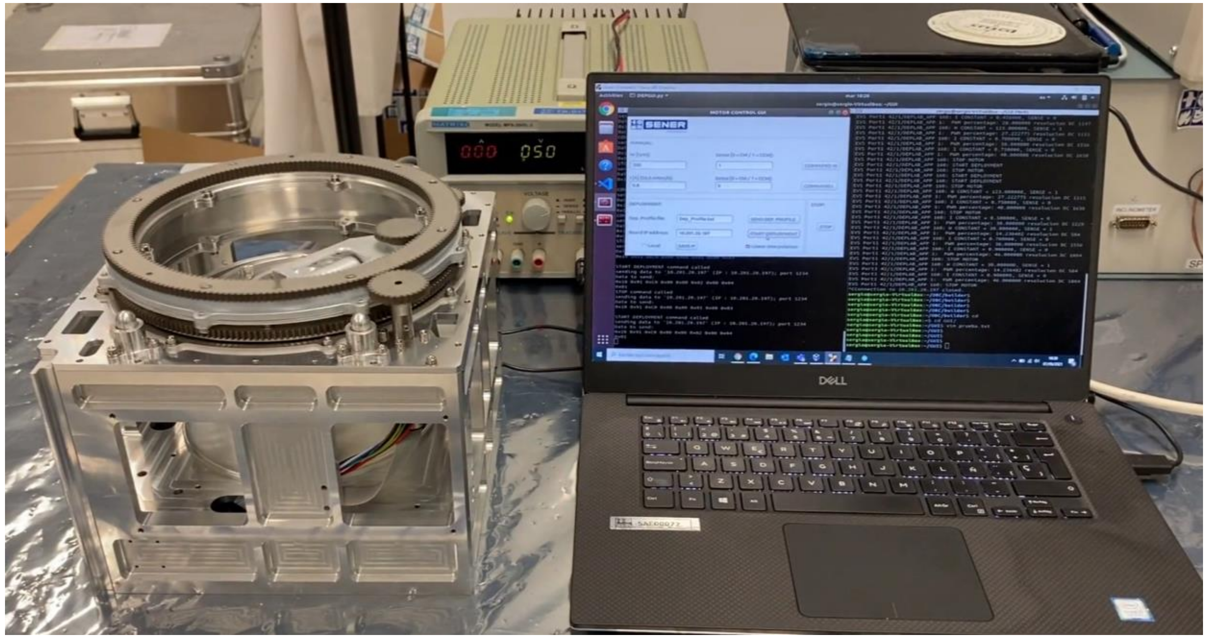


- **The DM engineering Model**
  - ✓ Fixed to the top part of the DMM

3. Deployment tests

- **Aim of test campaign**
  - ✓ Check the DM capability to deploy smoothly different sections of tape made of different materials
  - ✓ Evaluate the status of the tape after extraction

- **Test Procedure**
  1. Constant Deployment Velocities
  2. Specific Deployment Profile

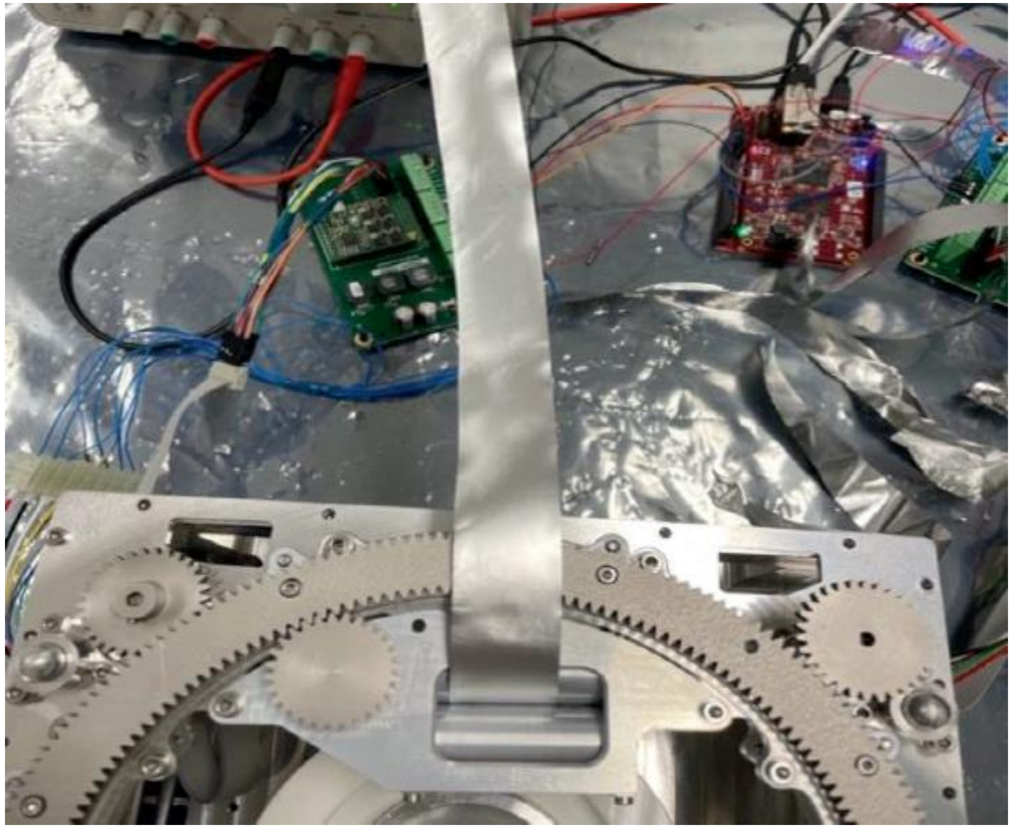


Deployment test setup

3.1 Constant Velocity Tests

- **Methodology**
  - ✓ Tapes were tested at speeds corresponding to:
    1. Maximum (550 RPM),
    2. Prevalent (80 RPM),
    3. Minimum (30 RPM)

- **Results**
  - ✓ Aluminum and PEEK tape inspection after several meters of extraction revealed no damage
  - ✓ the design of DM was validated



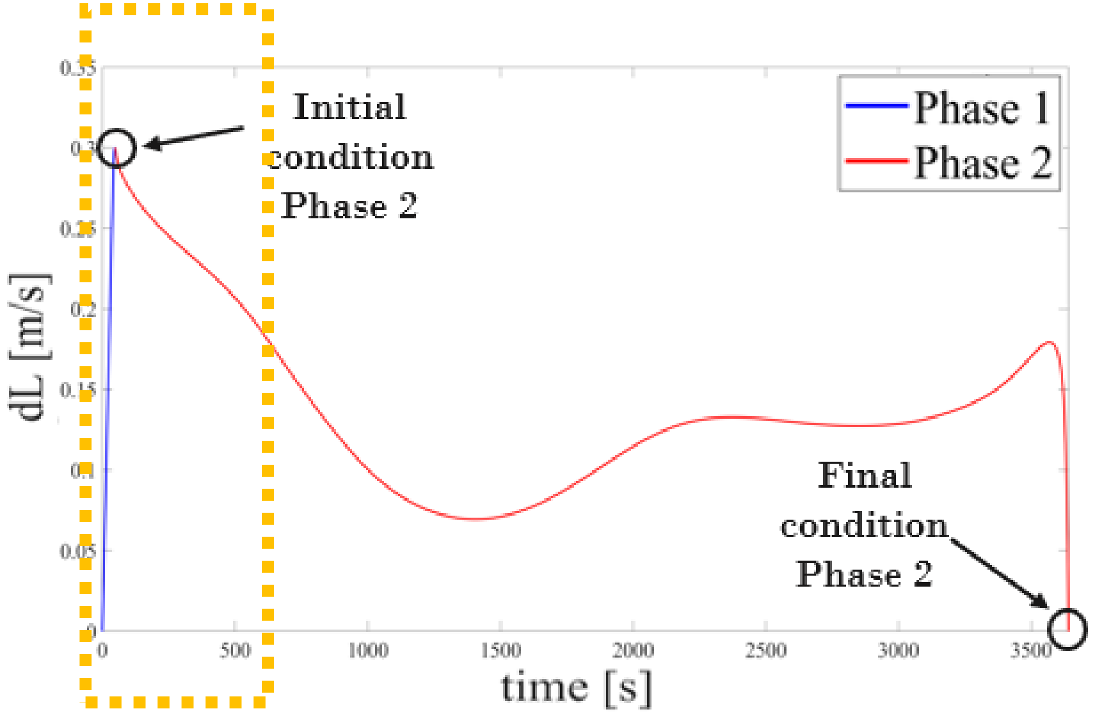
Status of the Aluminium tape

3.1 Constant Velocity Tests

- **Transition between tapes**
  - ✓ Different thicknesses and different mechanical properties
  - ✓ Test conducted at a constant velocity

3.2. Partial Deployment Profile tests

- **The Deployment Profile**
  - **Phase 1**
    - ✓ separation phase between the two modules
    - ✓ *boundary conditions*: the maximum tether velocity and a span time of 50 s
  - **Phase 2**
    - ✓ Optimization using BOCOP software
    - ✓ *boundary conditions*: initial and final state, total deployment time
    - ✓ Conversion of length rate profile (dl/dt) to angular velocity with the Archimedean spiral model

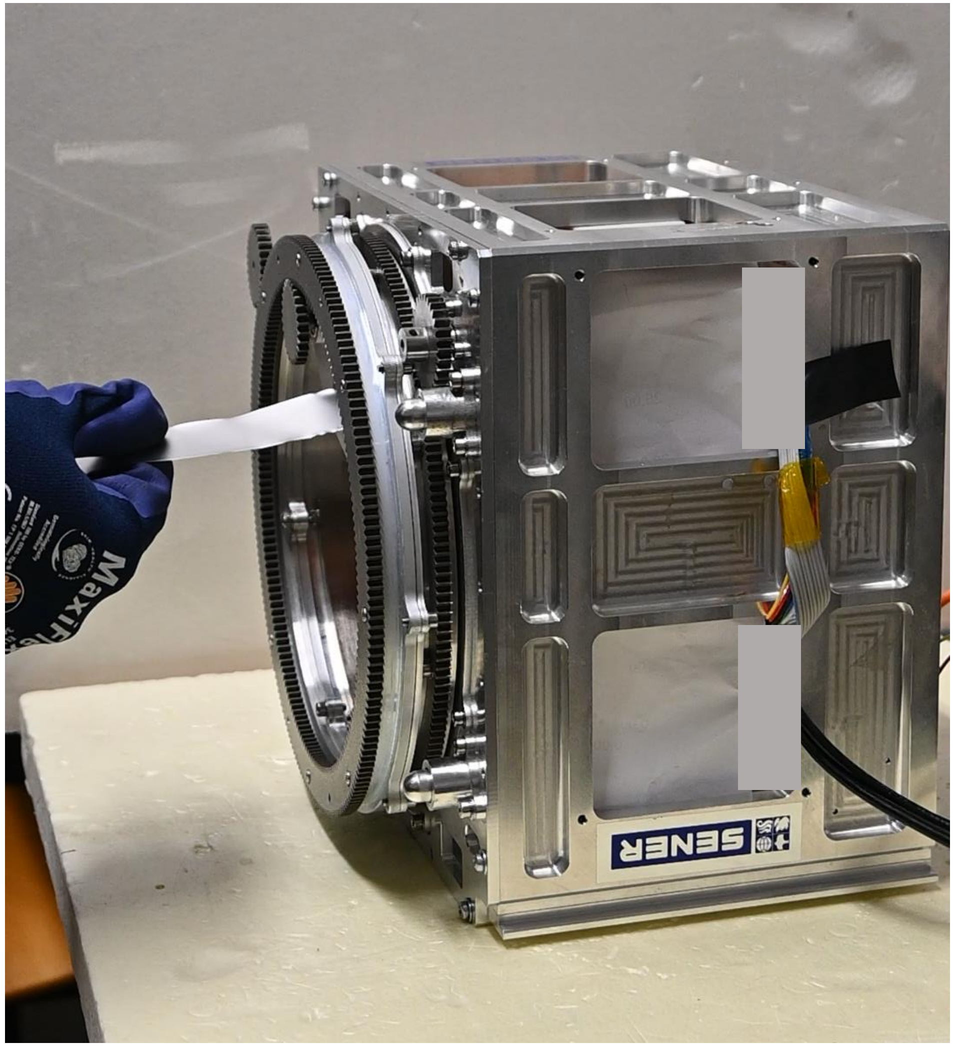


Partial Deployment Test

3.2. Partial Deployment Profile tests

- **Partial deployment test**

✓ Initial and critical acceleration phase
✓ Needs manual intervention



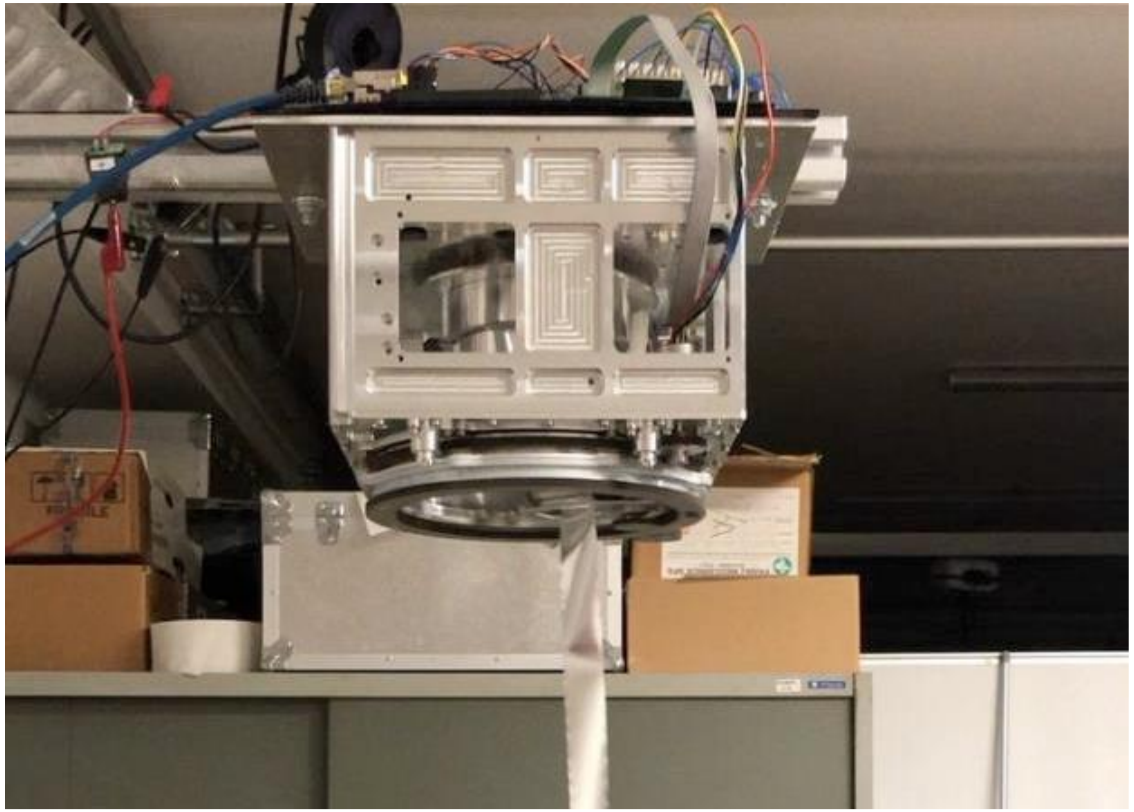
4. Future Developments

- **End-to-End Deployment tests**

  ✓ End-to-end deployment requires to deploy approximately 500 m of tape

  ✓ Up-side-down configuration for preventing manual intervention

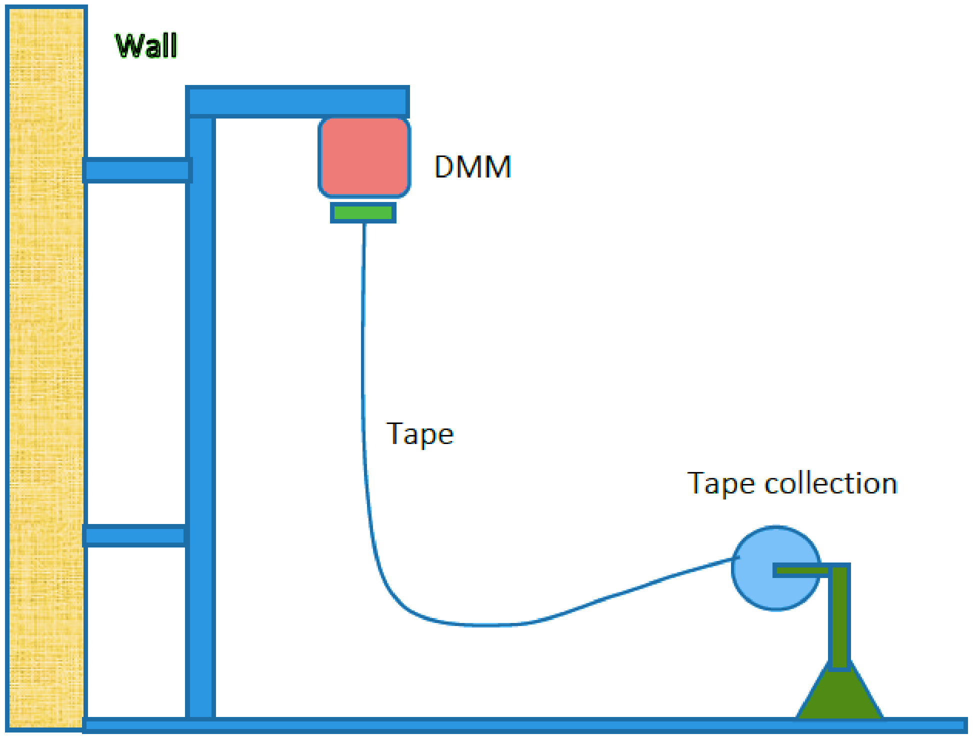
  ✓ A recollecting machine was designed and manufactured to roll up the tape post-deployment, facilitating its gathering after extraction from the DM.



The DMM in the up-side-down configuration

4. Future Developments

- **Re - Collecting Machine**
  - ✓ retrieves and rewinds the tape
  - ✓ manages tape exit speed variability and rotation to correct twists and rewind
  - ✓ control software utilizes a camera to detect deployed tape amount and twists



The Re-Collecting Machine

5. Final Remarks

- **The Deployer Mechanism (DMM)**
  - ✓ The tape spool design was validated through:
    - *Shaker Tests*
    - *Cold Welding Tests*
  - ✓ The Deployer Mechanism design was validated through:
    - *Constant velocity deployment tests*
    - *Specific Deployment profile test*
- **Future Developments**
  - ✓ Re-Collecting Machine for End-to-End Deployment tests

Thank you!