ESAIL D3.3.3
Auxiliary tether reel test plan

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1	0	27 April 2012	All	Initial issue	Rosta

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List of Acronym and Abbreviation

DLR	German Aerospace Center (Deutsches Zentrum für Luft und Raumfahrt)
ESAIL	Electric solar wind sail
ZARM	Center of Applied Space Technology and Microgravity (Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation)
TLR	Technical readiness level
AU	Astronomical Unit
PSD	Power Spectral Density
TBD	To be define
COTS	commercial off-the-shelf

Reference Documents

[RD01]	ESAIL Proposal - Part B: Description of Work
[RD02]	Design description of the Remote Unit, D4.2, Version 4.1
[RD03]	Design description auxiliary tether reel, D3.3.2, Version 1.0

Applicable Documents

[AD01]	ECSS System engineering general requirements, ECSS-E-ST-10C, 06. March 2009
[AD02]	ECSS Standard Testing, ECSS-E-10-03A, 15. February 2002

1. Scope of this Document

This report presents the test plan for the auxiliary tether reel tests in the framework of the Esail Project [RD01]. The test configuration and the required equipment are described, the test facility in which the tests were performed, too.
The tests will be performed to validate as well as to show the functionality and reliability of the auxiliary reel design.
The following tests will be performed:

- Vibration
- Shock
- Thermal vacuum

The thermal vacuums as well as the shock and vibration tests are carried out to support the development beside the design of the auxiliary tether reel mechanism to reach TRL 4 – 5.
To reach these levels the mechanism should be validated in laboratory conditions respectively in relevant environment [AD01].

Note that the test plan written in this document does not present qualification tests but is done in the course of development toward TLR 4-5.
This is important due to the fact that the launcher as well as the design of the main spacecraft at this stage of work are unknown. Hence the tests will be performed according to general standards in [AD02].

2. Test Item Description

2.1. *Auxiliary Tether Reel*

For the tests the auxiliary tether reel mechanism is used. The design is show in Figure 1 the short description of the mechanism can be find in [RD02]. The detailed concept as well as the detailed design is described in [RD03].

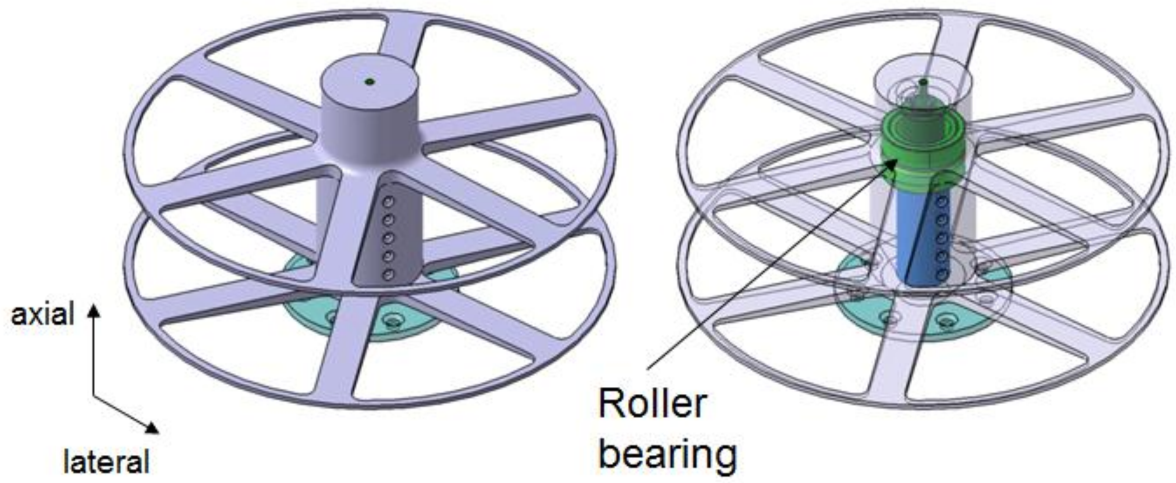

Figure 1: Auxiliary tether reel mechanism origin design with a roller bearing

The operating experience of testing and validation of space system figured out, that mostly in rotating systems roller bearings are a critical point under low temperature and vacuum environments. The original design of the deployment mechanism used roller bearings to carry the loads. To improve the design as well as to reduce the weight, of the mechanism the roller bearing is replaced by sliding bearings. Every other part of the origin design remains the same. This small change considered the above mentioned critical point, it also reduces the weight by 6 g. The auxiliary tether reel design with sliding bearings is show in Figure 2.

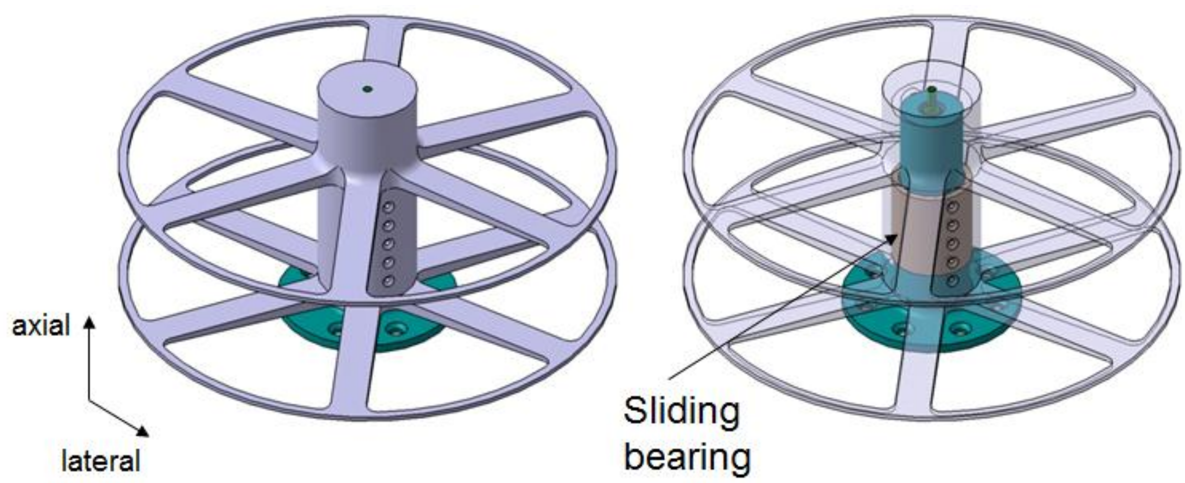

Figure 2: Auxiliary tether reel mechanism design with sliding bearing

3. Test Setup

3.1. *Test Facilities*

3.1.1. Shaker: Tiravib

The shaker in Figure 3 operated by DLR Bremen shall be used to perform the vibration testing of the auxiliary tether reel.

Figure 3: DLR Bremen Shaker

Performance:

- Max. force in sinusoidal mode: 11 000 N
- Max. force in random mode: 11 000 N
- Max. displacement: 51 mm (peak-to-peak)
- Max. velocity: 1.8 m/sec
- Max. acceleration: 950 m/sec² (without mass)
- Frequency range: 2 … 5000 Hz

- Technical Characteristics:
- Guidance of moving equipment by rolling elements (PP) and damping elements
- Mass of moving equipment: 11.5 kg
- Maximum mass load: 150 kg
- Stiffness of suspension: axial 80 kN/m; out of axis 3 kN/m; rotating stiffness 50 kN/m

The shaker can be operated in two different configurations, depending on the axes along which the test object shall be accelerated. The two configurations are shown in Figure 4, the left for horizontal excitements (slip table), the right for vertical excitements (head expander)

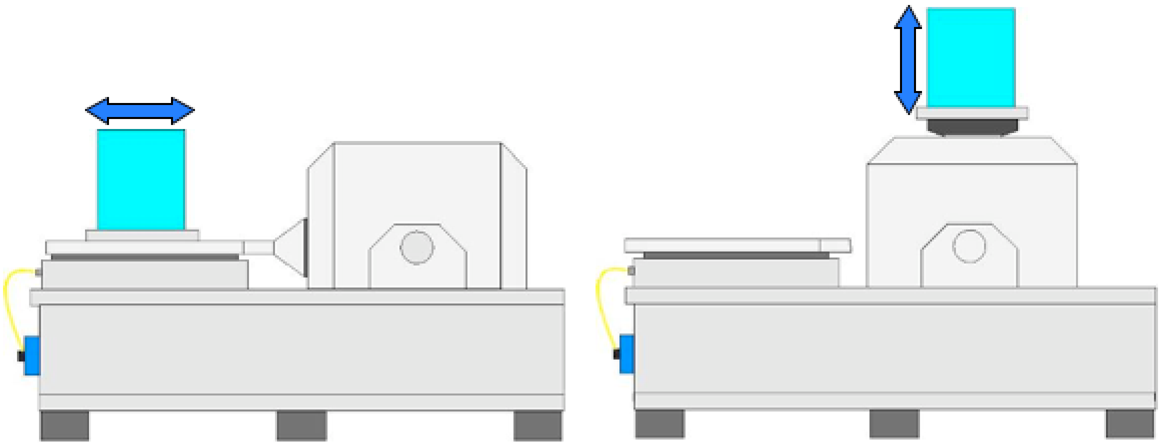

Figure 4: Shaker TIRA Vib. Left: In horizontal configuration with test object on a slip table. Right: in vertical configuration with test object on head expander.

3.1.2. Thermal Vacuum Chamber

The Sun simulation facility shown in Figure 5 is also operated by DLR Bremen and shall be used to perform the thermal vacuum tests.

Figure 5: DLR Bremen Sun simulation facility

Preformance.

- Volume: 0,45 m^3
- Vacuum: 1.33*10-3 Pa with Q Gas = 13 Pa*l*s
- Temperature of the cold wall: 80 K to 373 K
- Cooling medium: liquid nitrogen
- Sun simulation: 0…1,4 KW/m2 at 100mm diameter, spectrum 200 – 2500nm
- Size of the test item

  max. Diameter 800mm
  max. Length 850mm
  max. Weight 50 kg

4. Test Overview

4.1. *Test Program Sequence*

The performed test can be split in four different test sequences. They are listed in Figure 6.

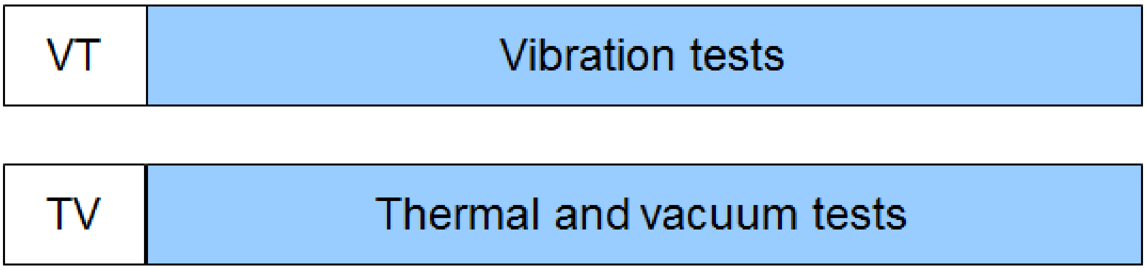

Figure 6: Test program sequence

4.2. *General Considerations*

These development tests shall assess the feasibility of the design and also validate the new design concept. In addition it shall confirm the manufacturability as well as the reliability of the developed design [AD02].

The tests will be performed in order to investigate following key issues:

- Functionality of the mechanism under relevant environment
- Reliability of the mechanism
- Structural behaviour

The Esail deployment phase, i.e. the phase where the auxiliary tether reel mechanism shall be work, is at a distance of 1 AU. Thus the relevant environmental conditions for the thermal and vacuum tests are the conditions at 1 AU, TBD°C and 10^{-5} mbar.

Note that in case of shock and vibration tests the relevant values are specified by the selected launcher. Furthermore the test range depends on the transfer function of the space craft. This function as well as the launcher is unknown yet. During the tests the mechanism is directly mounted to the adapter plate of the test facilities therefore the applied loads are worst cases for it.

To simulate the mass of the auxiliary tether a mass dummy with a mass of 370g, i.e. cots Kapton tether, is used.

4.2.1. Features to be Tested

This is a list of components to be tested. This list of features is applied for both tether designs.

Components	Features to be tested
Auxiliary tether reel mechanism with equipped tether	Sinusoidal vibration, investigate the dynamic loads of the mechanism
Auxiliary tether reel mechanism with equipped tether dummy	Random vibration, investigate the dynamic loads of the mechanism
Auxiliary tether reel mechanism with equipped tether dummy	Thermal vacuum, determine the structural properties of the mechanism under environment conditions.
Auxiliary tether reel mechanism with equipped tether dummy	Thermal vacuum, function test under environment condition.
Auxiliary tether reel mechanism with equipped tether dummy	Thermal vacuum, heat flow during motor operating.

Table 1: Features to be tested

4.2.2. Features Not to be Tested

This is a list of components NOT to be tested.

Components	Features not to be tested
E-motor	Thermal vacuum, separate function test under environment condition of the motor.
Auxiliary tether	Thermal vacuum, tether behaviour under environment conditions.
Auxiliary tether	Thermal vacuum, unreeling under environment conditions.

Table 2: Features Not to be tested

4.3. *Data Recording and Handling*

The following requirements are to be followed with respect to data acquisition and handling:

- Test measurements of sensor data and the environmental conditions shall be recorded by the operators of the test facilities
- All data have to be transferred in excel format

5. Vibration Tests

The vibration tests verify the developed design for the mechanism in addition the resistance to the dynamic loads.

5.1. *Resonance Search/Low Level Sine*

The natural frequencies of the test object are recorded during the resonance search runs, especially the first Eigenfrequencies.
The resonance search will be performed before and after the random vibration run in order to determine any shift of the structural parameters of the assembly caused by the random vibration loads.

Parameter	Value
Frequency range	5…2000…5 Hz
Acceleration	0.5 g
Amplitude (5…22 Hz)	0.5 mm … ± 1 mm
Sweep rate	± 1 oct/min
Axis	Axial and lateral
Recorded Data	Main resonance of each axis

Table 3: Resonance search test specification

5.2. *Sinusoidal Vibration Test*

The tests demonstrate the ability to withstand low frequency excitations during launch. They shall be conducted for all axes, 1 sweep-up, 2 octaves/min [AD02].

Frequency [Hz]	Qualification	Remark
5-21	11mm	No notching
21-60	20 g	
60-100	6 g	

Table 4: Sinusoidal vibration levels

5.3. *Random Vibration Test Levels*

The purpose of this test is to demonstrate the ability of the mechanism to withstand the random vibration during the launch [AD02].

Duration	Frequency [Hz]	Qualification
Vertical[b] 2,5 min/axis	20-100	+3 dB/octave
	100-300	PSD(M)[c] = 1,78 g²/Hz
	300-2000	-5 dB/octave
	Overall	31,93 g_{rms}
Lateral[b] 2,5 min/axis	20-100	+3 dB/octave
	100-300	PSD(M)[c] = (2/3)² × 1,78 g²/Hz = 0,79
	300-2000	-5 dB/octave
	Overall	21,27 g_{rms}

[b] Equipment vertical axis = perpendicular to fixation plane.
Equipment lateral axis = parallel to fixation plane.
[c] M = equipment mass in kg, PSD = Power Spectral Density in g²/Hz.

Table 5: Random vibration levels

With respect to the table above the PSD value is calculated:
PSD =0,12 g²/Hz × (M+ 20 kg)/(M + 1 kg) = 0,12 g²/Hz × 18,8

5.4. *Test Level Tolerances*

Sinusoidal vibration:
Acceleration, amplitude ± 10%
Frequency ± 2% from 10 Hz to 2000Hz
Sweep rate: ± 5%

Random vibration:
Power spectrum density (50 Hz or narrower)
20 to 500 Hz ± 1.5 dB
500 to 2000 Hz ± 3.0 dB
Overall g_{rms} ± 1.5 dB

Static force: ± 5.0%

6. Thermal vacuum Tests

Within the thermal vacuum test the reliability of the chosen material for the structure as well as the functionality of the mechanism shall be determined under worst case environmental conditions [AD02].

Important for the thermal vacuum test is the influence of the spacecraft, especially the heat conduction from the RU through the mechanical interface. These conditions are not defined at this moment, therefore if the values are available the qualification temperature range have to be adapt to this. The thermal conditions of the remote unite should be listed in the document D4.3 remote unit test plan. This document will be finished two month after the release of this document.

6.1. *Non-Operating Levels*

Determine the structural properties of the mechanism under thermal vacuum conditions.

Qualification Temperature Min [°C]	Qualification Temperature Max [°C]	Pressure [mbar]
-60	60	10^{-5} or less

6.2. *Operating Levels*

Demonstrate the ability of the mechanism to perform under worst case conditions.

Qualification Temperature Min [°C]	Qualification Temperature Max [°C]	Pressure [mbar]
-40	40	10^{-5} or less

6.3. *Test Level Tolerances*

Temperature:

From -50°C to +100°C	T_{Max} +3 and T_{Min} -3
Below -50°C or above +100°C	T_{Max} +4 and T_{Min} -4

7. Release Criteria

7.1. *Item Success/Fail Criteria*

Success:

- No visible damages
- Functionality of the mechanism after tests not affected
- No frequency shift greater than 5% is detected for the first Eigenfrequencies after the last resonance search

Fail:

- Visible damage
- The functionality failure, motor current consumption within of the 10% deviation

The following table shall be filled out after each test sequence.

Test Number	Damages	Functionality	Success/Fail Criteria