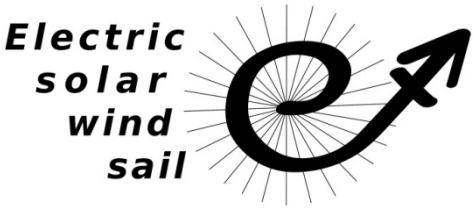

ESAIL D3.1.4
Tether Reeling Test Report
First Amendment

Work Package: **WP 3.1**

Version: **Version 1.0**

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List of Acronym and Abbreviation

DLR	German Aerospace Center (Deutsches Zentrum für Luft und Raumfahrt)
ESAIL	Electric Sail
PTA	Preliminary Test Assembly
ZARM	Center of Applied Space Technology and Microgravity

Reference Documents

[RD01]	Reeling Test Plan, D3.1.2, Version 1.0
[RD02]	Requirement specifications of the tether test reels, D3.1.1, Version 1.0

1. Scope of this Document

This report presents the results of the tether unreeling tests performed at DLR in November 2011. The tests are preformed to analyse the tether behaviour during the unreeling procedure and coinvestigates the performance of a chosen deployment concept.
The first issue in the test campaign is to investigate how the stacked tether layers influence the tether behaviour during unreeling. Therefore in the first test the preliminary test assembly is not equipped with a tether opening.
The second issue in the test runs is to examine the influence of a rounded edge at the reel on the unreeling behaviour.

2. Test Item Description

2.1. Heytether

The Heytether is a tether developed by the University of Helsinki. It is made up of a single 50 µm diameter basic wire and three 25 µm diameter auxiliary wires. The auxiliary wires are bonded to the base wire building loops. The Heytether is further described in the Reeling Test Plan [RD01]. In the test runs a Heytether with one auxiliary tether loop was used (Figure 1).

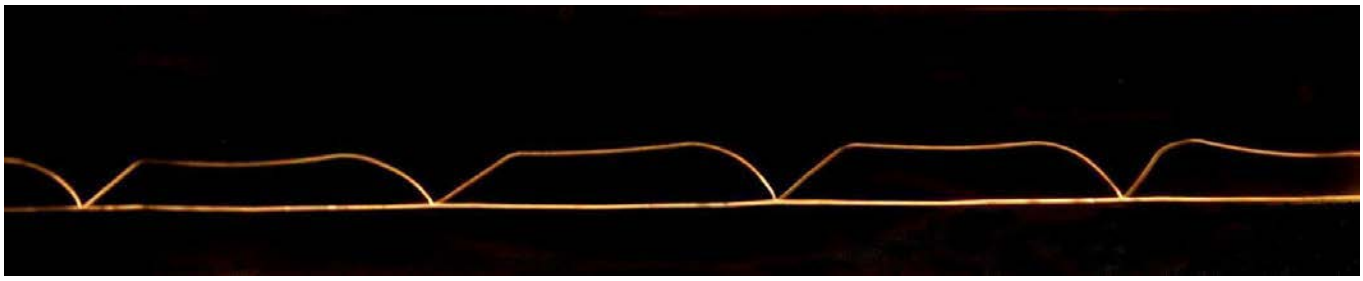


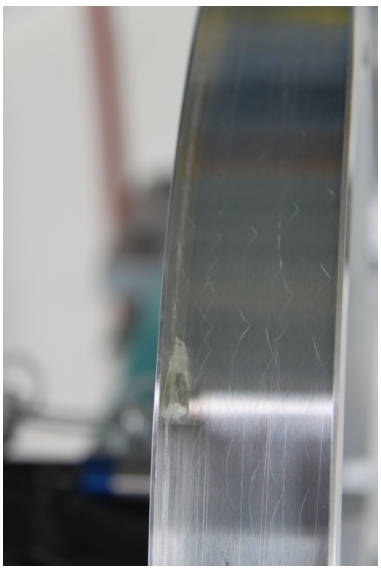
Figure 1: Heytether with one basic wire and one auxiliary tether loop

3. Test Setup

3.1. Preliminary Test Assembly

The PTA consists of a clamp, the e-motor and the tether reels (Figure 2). The clamp holds the e-motor and establishes the interface for mounting the PTA to the test facility. The e-motor is a Faulhaber DC-Micromotor, Series 1724 024 SR, connected to a Faulhaber planetary gear, Series 20/1, with a gear reduction of 415:1. [RD01].
For the unreeling test two different types of a reel with a diameter of one coil is 280 mm and the tether running surface is 30 mm (also seen in Figure 2). The reels differ in one rounded edge on the tether running surface (Figure 3). A detailed reel description is written in[RD02]. A tether opening was not used.

Figure 2: The PTA mounted on the test facility



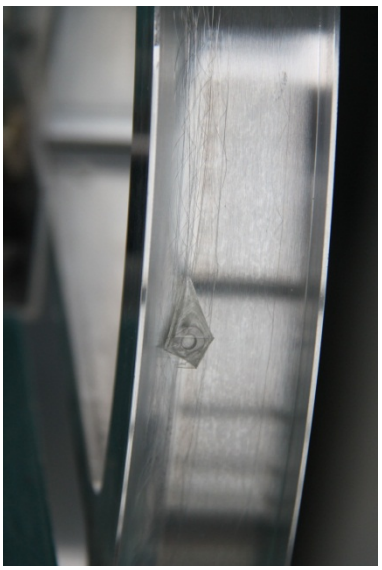


Figure 3: Normal reel (left) and rounded reel (right)

3.2. Test Facility

The test campaign is done in the ZARM laboratory building. This indoor facility is equipped with a staircase of about 12 m height. This height is needed to unreel the tether almost the whole length of 10 m. The PTA was mounted on a handrail which is approximately 13m over the ground. A table is positioned under the handrail.

3.3. Test Equipment

During the tests used equipment.

- **Camera**
  Canon EOS 500D, 15 Megapixel, Full HD Movie with 20 fps. The camera is used to document the tests procedure (further described in RD01).

3.4. Test Configuration

The PTA was mounted on the outside of the handrail. It was fixed with a screw clamp and backed with a wire cable. The e-motor was connected with a power supply, where the voltage can be adjusted (Figure 2).

4. Non Conformance Report

The non conformance report describes the condition of the delivered Heytether after unpacking and during the transmission from the transport reel to the PTA reel.

4.1. Tether Damages

The delivered Heytether had a length of 30 m. Each of the two testing reels was equipped with 15 m of tether. The tether was reviewed by visual inspection. Four damages were observed on the normal reel: two damages in the auxiliary wire in the loops and two broken welding spots. The tether on the rounded reel had four damages: three broken loops and one broken welding spot.

4.2. Possible Tether Damage Consequents

The possible consequents of the damage are listed and discussed in this chapter

Damage	Description	Possible consequents
Broken main tether	The main tether is broken.	The broken main tether can lead to an abbreviated tether length, if the auxiliary loop is not strong enough to avoid a complete disruption. An shortening of more than a half of the whole length can result in a test abort.
Broken auxiliary loops	The loop is broken between the two welding points.	The broken loops can get stuck into the tether opening or they can jam into the unreeling tether.
Broken welding	The loop is broken in the point where they are welding on the Heytether	Same as above, The nibble can also jam into another tether layer on the reel.
Broken neck	The loop is broken directly over the welding point.	Same as above.

5. Unreeling Test

The following tests are part of the Test Program Sequence T1 and T2 according to the classification in the Reeling Test Plan [RD01]. T1 includes four test runs with the normal reel: two with a low unreeling speed of approximately 6 mm/s and two with a high unreeling speed of approximately 12 mm/s. For both velocities the test was implemented with a guided and an unguided upreeling before the unreeling test. T2 consists of the same test runs but with the rounded edge reel. A detailed description of the different test runs can be found in the Reel Test Plan. The Release Criteria, which indicate a success or fail for the test run, are further recorded in [RD01].

5.1. Test Environments

5.1.1. Functional Requirements

Nr.	Features	Requirements
FR-01	10 m height	A height of 10 m shall be reach to unreel the whole length of the tether.
FR-02	Thermal	The thermal influence in the test facility shall be low.
FR-03	End mass	The end mass should be the same for every test run.

5.1.2. Features to be tested

This is a list of components to be tested.

Components	Features to be tested
Tether	Tether unreeling.
Tether	Behaviour of the tether during un- and upreeling.
Tether behaviour	Influence of different layer number on top of each other impact the reeling behaviour.
Tether behaviour	How the unreeling is influenced by the tether if they are side by side, tether guidance during the upreeling
Tether behaviour	How the unreeling is influenced by the tether if the upreeling is done without tether guidance.

5.1.3. Features not to be tested

This is a list of components NOT to be tested.

Components	Features to be tested
E-motor	Function of the motor
Tether	The conductivity of the Tether
Tether opening	Unreeling behaviour with equipped tether opening.

5.1.4. Motor Calibration

The used motor for the PTA is a brushless Faulhaber DC-Motor. The Motor is equipped with a Faulhaber planetary gear and has a reduction of 415:1. Due to not specified reasons the motor showed a wide spread of performance.
The first realized test campaign was T2. The needed potentials for the two unreeling velocities were measured during the first test (T2-1) and were calculated for the next tests. The calibration is shown below on the left side.
For the second four tests (T1-1 to T1-4) the unreeling speed was measured during the tests. The results for the needed supply voltages are listed below on the right side.

Speed	Calibration for T1	Calibration for T2
Low speed	1.2 V for 6 mm/s	2 V for 6 mm/s
High speed	3 V for 12 mm/s	4 V for 12 mm/s

The analysis of the documentation of tests T2-2, T2-3 and T2-4 showed a much higher unreeling speed as it was calculated. The velocities of test campaign T1 still differed from test to test, but they were about the same size.

5.2. Test Nr. T1-1 (Unreeling guided tether / low speed)

The test Nr. T1-1 was performed to investigate the tether unreeling behaviour during a 10 m unreeling on the normal reel. Beforehand the tether was wind up guided by hand (result shown in Figure 4).

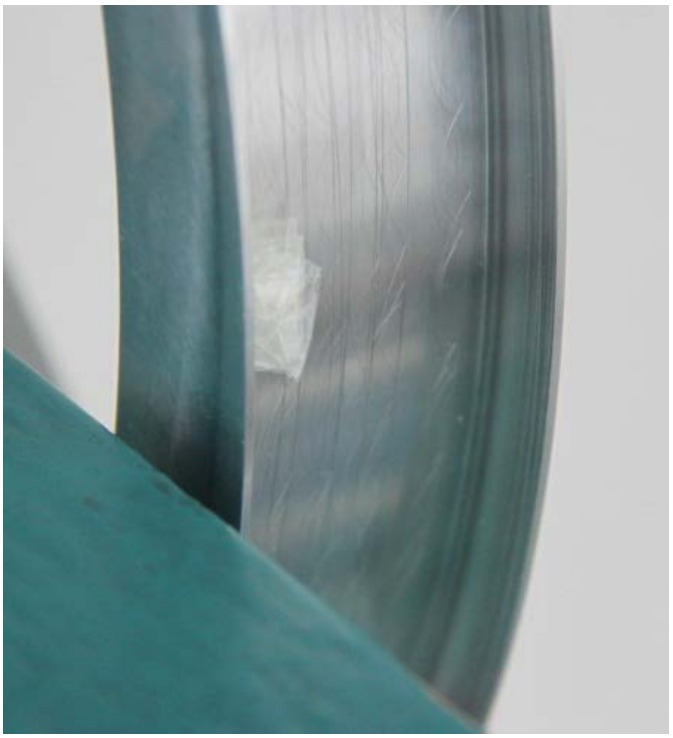


Figure 4: Guided tether on reel before test Nr. T1-1.

5.2.1. Tests Performance

The electric motor was operated at 1.2 V, which corresponds in an unreeling speed of 6.7 mm/s. By use of a stop watch the unreeling speed was recorded during the test.
The tether and the location where the tether leaves the reel were recorded on video during the unreeling process.

5.2.2. Tests Result

The tether was unreeled for about 29:30 minutes. The tether was unreeled 11 m to avoid contact of the end mass with the ground. The video documentation was stopped during the unreeling because the camera reached a critical level of operation.
The unreeling of the tether did not harm any tether loop and there were no problems during the reeling procedure.

Test Number	Date	Reeling Speed [mm/s]	End mass [g]	Unreeling behaviour	Tether damages	Success/Fail Criteria
T1-1	08.11.2011	6.7	0.05	Without problems	None	Success

5.3. Test Nr. T1-2 (Unreeling unguided tether / low speed)

In the second test the behaviour during the unreeling at low speed after an unguided upreeling was to observe. Due to the thermal lift the unguided upreeling tether was pulled on one side of the reel. The tether became reeled in one edge of the reel. This is shown in Figure 5.

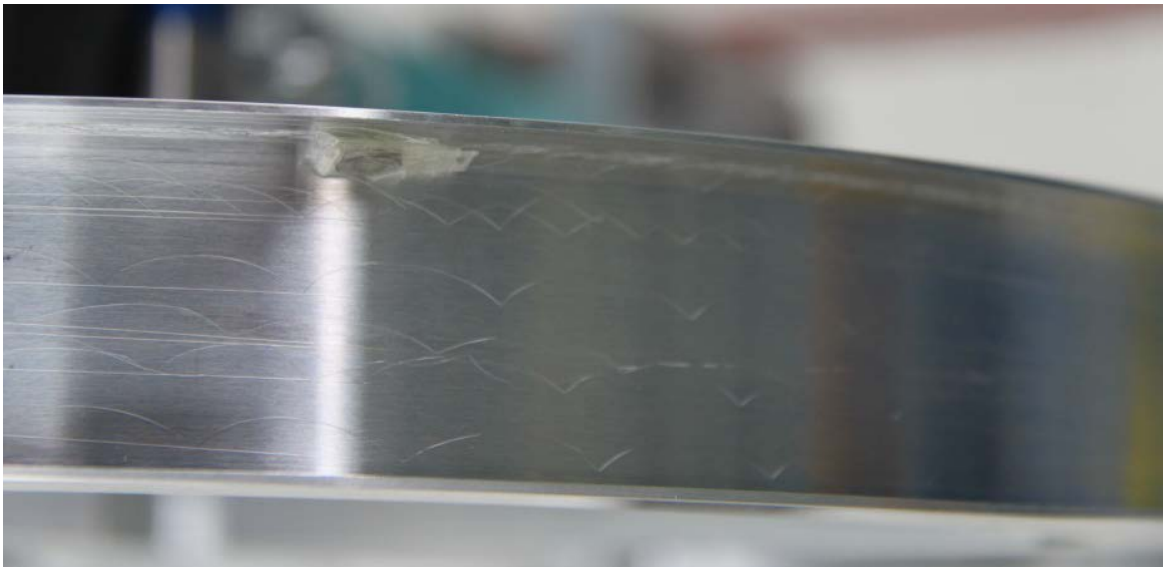


Figure 5: Unguided tether on reel before test Nr. T1-2.

5.3.1. Tests Performance

The test was performed similar to the test describe in chapter 5.2.1. The electric motor was also operated with 1.2 V, but the unreeling speed was about 5.3 mm/s. The unreeling speed was measured by a stop watch during the test.

5.3.2. Tests Result

The unreeling of the whole length took about 42 minutes. The unreeling length was about 11.5 m. The end mass has not touched the ground. Possible influences by this event can be excluded.
The unguided upreeling leads to stacked layers of the tether. Because of this the tether becomes slightly entangled and little tugs when the tether became loose occur. These small tugs repeat in the first half of the unreeling, when the unreeling tether is surrounded by several other coils. Five times the tether was stuck for nearly a quarter revolution. This leads to greater tugs. Nevertheless the unreeling was not prevented and the tether was not harmed.
The record of the camera was stopped after 11 minutes (reel got stuck by the security cable), 13:30 minutes (camera out of power) and 35 minutes (critical thermal level of the camera). The record ended after 40 minutes because the memory card was full. The last two minutes of the unreeling were not recorded but there was not any abnormal behaviour like tugs, etc.

Test Number	Date	Reeling Speed [mm/s]	End mass [g]	Unreeling behaviour	Tether damages	Success/Fail Criteria
T1-2	08.11.2011	5.3	0.05	Without greater problems; the tether experiences a few greater and many smaller tugs without interfering the unreeling	None	Success

5.4. Test Nr. T1-3 (Unreeling guided tether / high speed)

In test Nr. T1-3 the behaviour of the guided upreeled tether during the unreeling was investigated. The upreeled tether is shown in Figure 6.

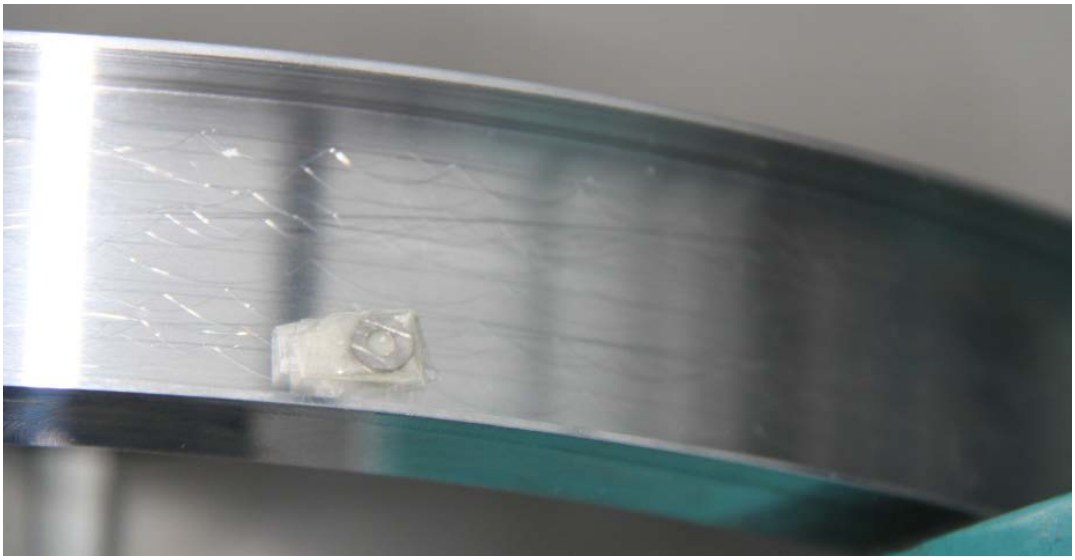


Figure 6: Guided tether on reel before test Nr. T1-3.

5.4.1. Tests Performance

The test was performed as the same as described in chapter 5.2.1. The difference is that the electric motor was now operated with 3 V. This resulted in an unreeling speed of 12.6 mm/s (measured by stop watch during test).

5.4.2. Tests Result

The unreeling of the tether succeeds without a problem. In this test the unreeling was stopped after 12.5 m tether length. The end mass was about 50 cm over ground so there was no disturbance from an end mass laying on the ground. The time for unreel the tether was about 17:45 minutes.

Test Number	Date	Reeling Speed	End mass	Unreeling behaviour	Tether damages	Success/Fail Criteria

		[mm/s]	[g]			
T1-3	08.11.2011	12.6	0.05	Without problems	None	Success

5.5. Test Nr. T1-4 (Unreeling unguided tether / high speed)

In this test the behaviour of the tether with a higher speed after an unguided upreeling is observed. As in T1-2 the tether was dragged to one side of the reel, too. The upreeled tether is shown in Figure 7.

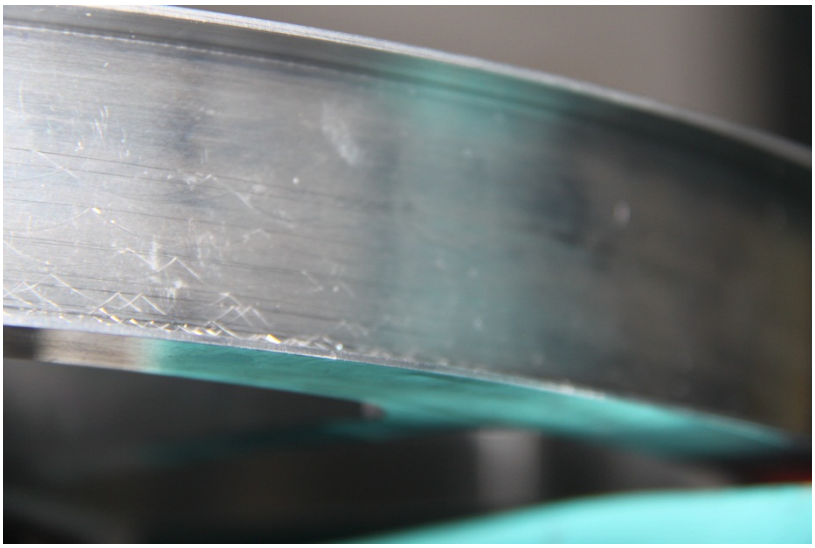


Figure 7: Unguided tether on reel before test Nr. T1-4.

5.5.1. Tests Performance

The test was performed as the same as described in chapter 5.4.1, but with unguided tether. The unreeling speed is about 14.2 mm/s. This was again measured by the stop watch during the test.

5.5.2. Tests Result

The unreeling of the tether was similar as in test Nr. T1-2, but this time the greater tugs did not occur. The unreeling was not further disturbed and passed off without other problems. The tether was unreeled for about 12 m to prevent the end mass hitting the ground. The test lasts about 14:45 minutes.

Test Number	Date	Reeling Speed [mm/s]	End mass [g]	Unreeling behaviour	Tether damages	Success/Fail Criteria
T1-4	08.11.2011	14.2	0.05	Without problems, but Tether becomes slightly entangled without interfering the unreeling	None	Success

5.6. Test Nr. T2-1 (Unreeling guided tether / low speed)

The test Nr. T2-1 was performed to investigate the tether unreeling behaviour during a 10 m unreeling of the rounded reel. Beforehand the tether was wind up guided by hand (result shown in Figure 8).

Figure 8: Guided tether on reel before test Nr. T2-1.

5.6.1. Tests Performance

The setup was the similar as in 5.2.1, with the following change: The electric motor was operated at 2 V, which resulted in an unreeling speed of 6.7 mm/s.

5.6.2. Tests Result

The tether was unreeled for about 38 minutes which results in a length of 15 m for the unreeled tether. During the unreeling the camera has stopped recording due to a critical level of operation. This causes a missing part in the video documentation.
The unreeling of the tether did not harm any tether loop and the existing damages did not influence the unreeling process or the other layers of the tether. There were no other problems during the reeling procedure.
The end mass has hit the ground, this do not influence the unreeling behaviour of the tether.

Test Number	Date	Reeling Speed [mm/s]	End mass [g]	Unreeling behaviour	Tether damages	Success/Fail Criteria
T2-1	01.11.2011	6.7	0.05	Without problems	None	Success, tether

						end mass hit the ground

5.7. Test Nr. T2-2 (Unreeling unguided tether / low speed)

The main focus in the second test is on the behaviour during the unreeling after an unguided upreeling. Due to the thermal lift the unguided upreeling tether was pulled on one side of the reel. Thus, the tether became reeled mainly on one position of the reel, which represents the worst case. This is shown in Figure 4.

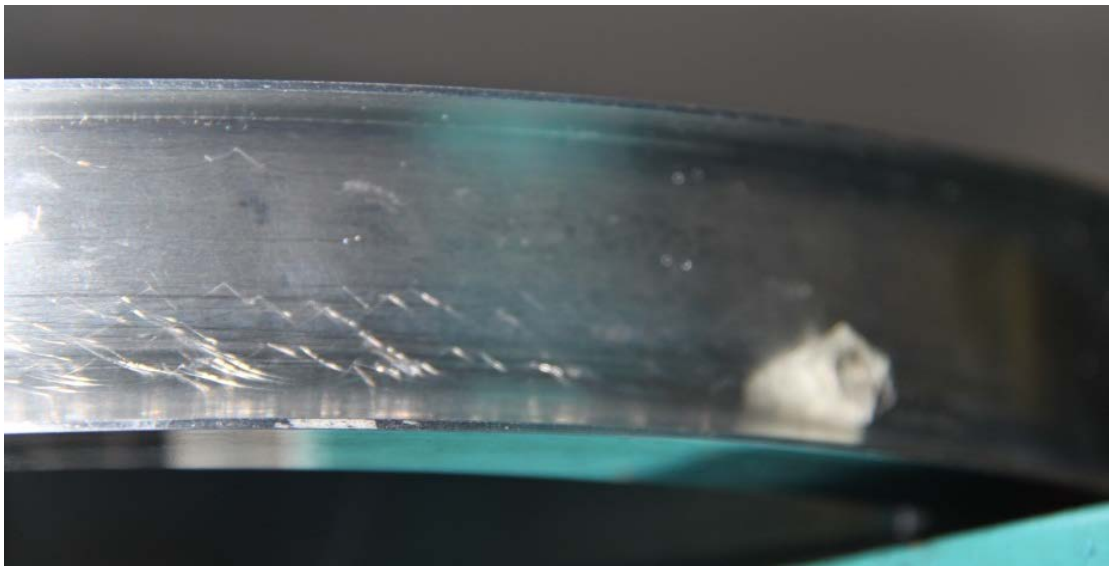


Figure 9: Unguided tether on reel before test Nr. T2-2.

5.7.1. Tests Performance

The test was performed similar to the test describe in chapter 5.6.1. The electric motor was also operated with 2 V, but in this test the unreeling speed was about 12 mm/s. The higher unreeling speed was detected by analysing the video material after the test.

5.7.2. Tests Result

The unreeling of the whole length took about 20 minutes. The end mass has touched the ground, the unreeling behaviour was not affected by that.
The unreeling process was done without major problems. Because of the unguided upreeling behaviour described above the auxiliary loops became slightly entangled under further layers of the tether. During the unreeling the tether became slightly stucked and it got loose in small tugs. Nevertheless the unreeling was not prevented and the tether was not harmed. In the first half of the test these tugs occur about every second loop, as there were several layers of tether on one position on the reel

Test Number	Date	Reeling Speed [mm/s]	End mass [g]	Unreeling behaviour	Tether damages	Success/Fail Criteria
T2-2	02.11.2011	14.6	0.05	Without problems,	None	Success, tether

				but Tether becomes slightly entangled without interfering the unreeling		end mass hit the ground, test with higher reeling speed

5.8. Test Nr. T2-3 (Unreeling guided tether / high speed)

In test Nr. 3 the behaviour of the guided upreeled tether during the unreeling was investigated. The upreeled tether is shown in Figure 5.

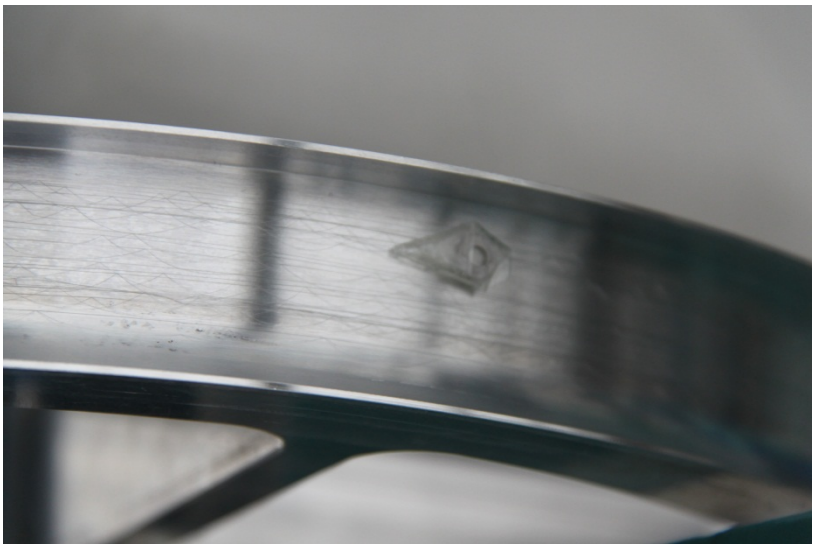


Figure 10: Guided tether on reel before test Nr. T2-3.

5.8.1. Tests Performance

The test was performed as the same as describe in chapter 5.6.1. The difference is that the electric motor is now operated with 4 V. This should lead to an unreeling speed of about 12 mm/s, but as described above the e-motor behaviour was not as it was expected. In this case it was about 35 mm/s. The higher unreeling speed was measured during the review of the documentation, too.

5.8.2. Tests Result

The unreeling of the tether succeeds without a problem. In this test the unreeling was stopped after 12 m tether length. The end mass was about 50 cm over ground to avoid possible disturbances when the end mass is not hanging freely. The time for unreeling the tether was about 6 minutes.

Test Number	Date	Reeling Speed [mm/s]	End mass [g]	Unreeling behaviour	Tether damages	Success/Fail Criteria
T2-3	02.11.2011	35	0.05	Without problems	None	Success, test with higher reeling speed

5.9. Test Nr. T2-4 (Unreeling unguided tether / high speed)

In this test the behaviour of the tether after an unguided upreeling is observed. The upreeled tether is shown in Figure 6.

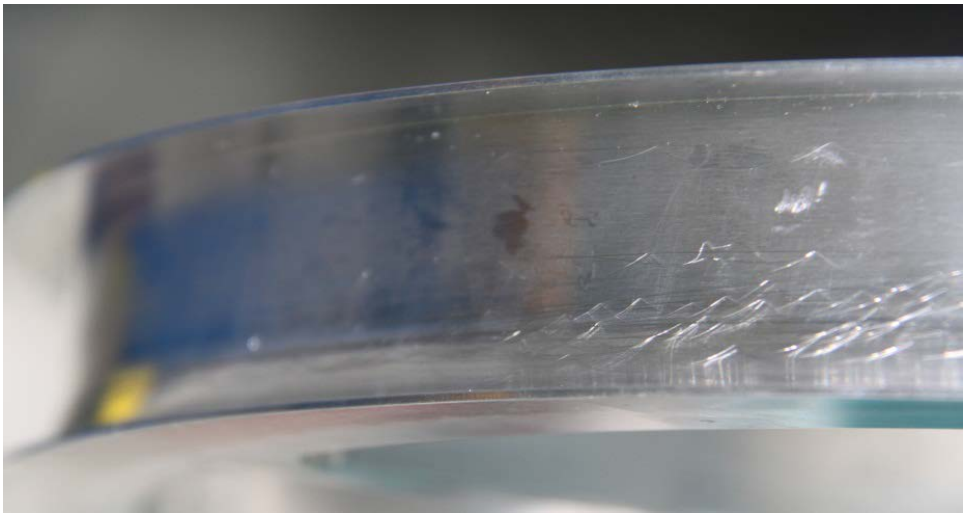


Figure 11: Unguided tether on reel before test Nr. T2-4.

5.9.1. Tests Performance

The test was performed as the same as described in chapter 5.6.1, but with an unguided tether. For the same reasons as above the unreeling speed is about 35 mm/s. This velocity was recognized by time measuring during the analysis of the video material.

5.9.2. Tests Result

During the unreeling the tether showed a similar behaviour as in test Nr. 2. The stacking of the tether causes little tugs about every other loop due to the sliding of the auxiliary loops under further tether layers. The unreeling was not further disturbed and passed off without other problems. Shortly after the end mass hit the ground (tether length of about 12 m) the unreeling was stopped. The test lasts about 6:30 minutes.

Test Number	Date	Reeling Speed [mm/s]	End mass [g]	Unreeling behaviour	Tether damages	Success/Fail Criteria
T2-4	02.11.2011	35	0,05	Without problems, but Tether becomes slightly entangled without interfering the unreeling	None	Success, tether end mass hit the ground, test with higher reeling speed

5.10. Conclusion

During the entire eight tests the tether was unreeled successfully for more than 10 m tether length. The guidance of the tether prevents the hooking of the tether. But neither the tether nor the unreeling itself becomes disturbed by this effect. Damages in the tether do not influence the unreeling; there were no further damages observed. Also the thermal bow and the resulting pressure during the test do not result in reeling problems. The thermal bow can be compare to an expected bow caused by the solar wind in space. Even the lower velocities do not harm the unreeling process.
The tests demonstrated the full functionality of the unreeling process even in worst case scenarios like the slow unreeling after an unguided upreeling.