# Tether Reeling Test Report

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## Approval Sheet

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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 |
| | |

# 1. Scope of this Document

This report presents the results of the tether unreeling tests preformed at DLR in February 2011. The tests are preformed to analyze the tether behaviour during the unreeling procedure and co investigates the performance of a chosen deployment concept.
The issue in the first test campaign is to investigate how the stacked tether layers influence the tether behaviour during un- and upreeling. Therefore in the first test the preliminary test assembly is not equipped with a tether opening.

# *2. Test Setup*

## 2.1. Preliminary Test Assembly

The preliminary test assembly is designed for testing of the Heytether unreeling behaviour. The PTA can be used in three different configurations: with the square, with the round and without specific tether opening.
In case of the square tether opening it is possible to change the width and the length of the tether opening.
In Figure 1 the three different possible PTA configurations are shown.

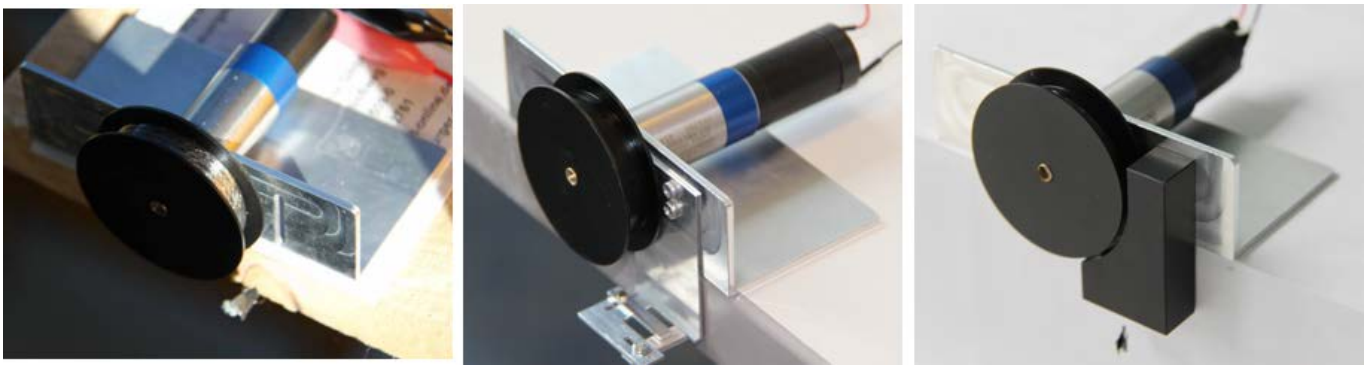

Figure 1: Different PTA configurations. On the left side without -, in the middle with the square - and on the right side with the round tether opening

The PTA comprise of:

- **The clamp**
  The clamp holds the e-motor, the tether opening and establishes the interface for mounting to different test facilities.
- **The e-motor**
  The used 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
- **The tether opening**
  To simulate the tether opening tow configuration are possible. The square- and round opening in both cases the distance between the motor axis and the tether opening is variable. Therefore it is possible to study the effect from different distances on the tether.
  - Square opening
    - Width variation

 

With the width variation it is possible to simulate different width tether openings, so the effect of the tether can study.

- Length variation

With the length variation it is possible to simulate different length tether openings, so the effect of the tether can study.

- Round opening

- **Tether reel**

The above mentioned parts of the PTA are shown in Figure 2.

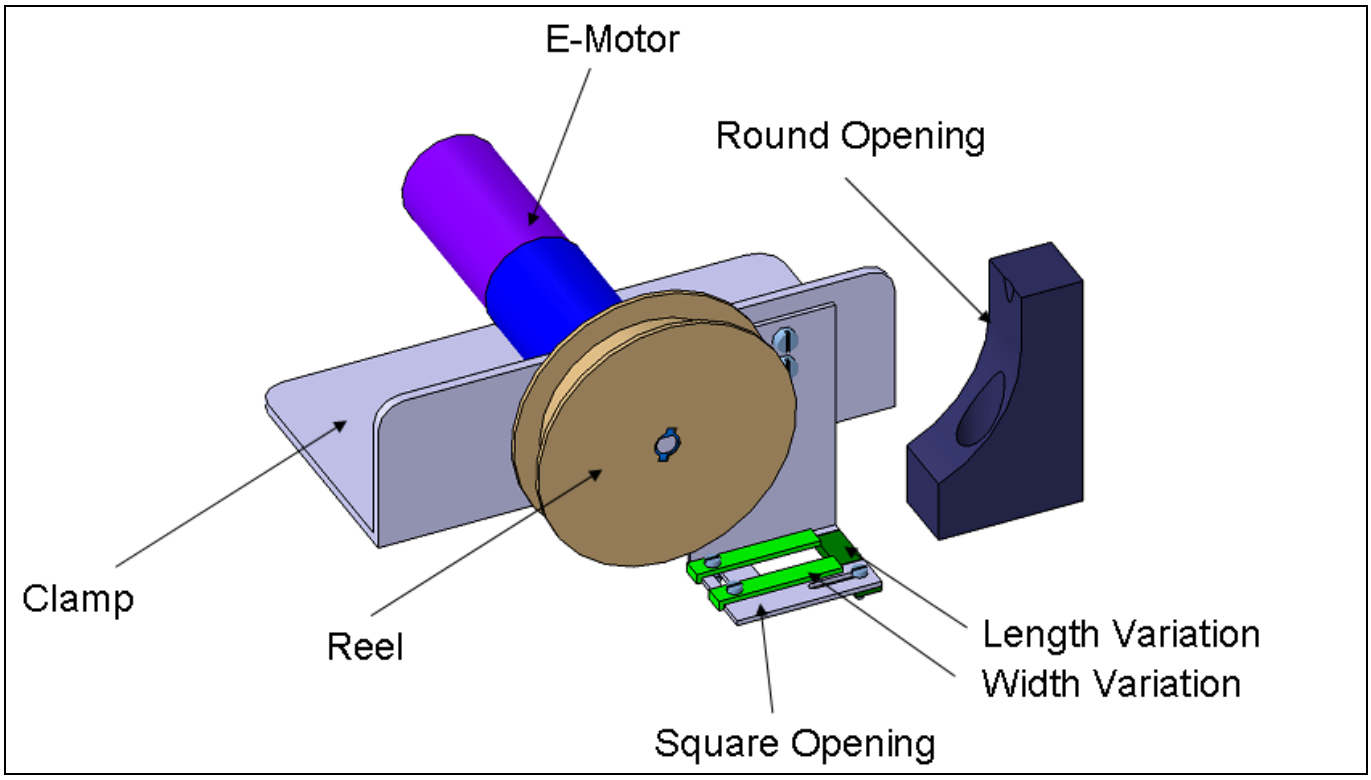


Figure 2: CAD -Model of PTA with several parts description

## 2.2. Test Facility

The first test campaign is done in the DLR rented Part of ZARM laboratory building. This indoor facility is equipped with a man carrying platform, with a possibility to mount the PTA, and the required overall height of 10 m. This height is needed to unreel the tether nearly the whole length.

## 2.3. Test Equipment

During the tests used equipment.

- **Laser Range**
  Laserliner, LaserRange-Master 40, measuring range 40 m, precision 3 mm. The Laser range is used to measure the height in which the PTA is positioned.

 

- **Camera**
  Canon EOS 500D, 15 Megapixel, Full HD Movie with 20 fps. The camera is used to document the tests procedure.
- **White Plate**
  The white plate is positioned on the ground below the tether to have a high contrast. With this plate it is possible to determine the tether position.

## 2.4. Test Configuration

The test configuration shows the position of the several equipments and the position on which the PTA is mounted.

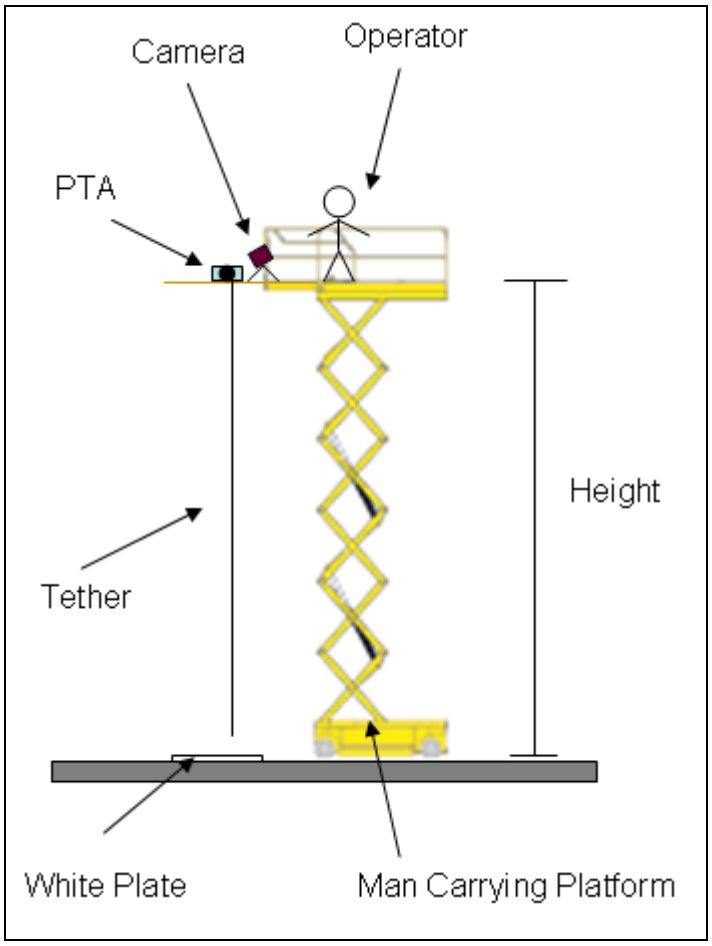


Figure 3: Test configuration

# 3. 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.

## 3.1. *Tether Damages*

The delivered Heytether is the first Heytether with a 10 m length. The Heytether has a main tether with 50µm diameter and auxiliary loops with a diameter of 25 µm. The auxiliary loops are bonded with supersonic on the main tether.
The tether was delivered on an aluminium wheel (tether running surface diameter 53 mm with a width of 26 mm.
The configuration of the inspection is show in Figure 4. At the beginning of the inspection the first 20 cm was unreeled and documented with a photo. In the next step the tether end is mounted on the PTA reel. After this the tether is unreeled in 20 cm steps from the transport reel and simultaneously upreeled on the PTA reel.

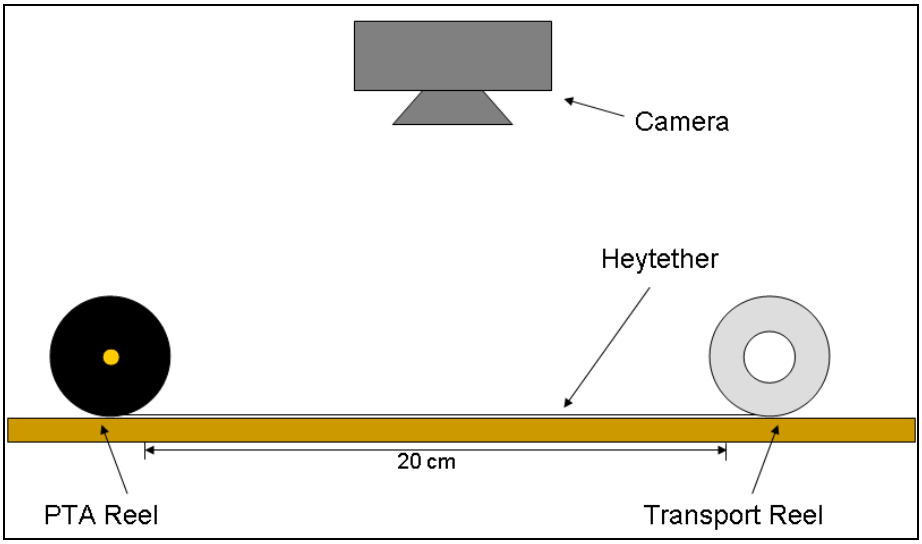


Figure 4: Configuration during the inspection of the tether

Unfortunately the tether disrupt during the inspection. But only the first 15 cm disrupt, therefore this don't has a negative effect of the whole tether length.
Due to the manual upreeling the number of stacked layers is about 5.The measured length of the tether reeled up on the PTA reel is 11 m. The above mentioned 10 m tether length is a value which was marked on the transport reel.
The investigation of the tether showed that neither the main tether, nor the auxiliary loops have bee damaged.
In the following figures the tethers condition is shown in an exemplary picture.

 

Figure 5: Heyteter 50 -100 cm.

## 3.2. *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 the tether length, if the auxiliary loop is not enough tow avoid a complete disruption. An abbreviation 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,<br>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. |

# 4. Unreeling Test

## 4.1. *Test Environments*

### 4.1.1. 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. |

### 4.1.2. 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 | How different layer number on top of each other influence 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. |

### 4.1.3. 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. |

### 4.1.4. 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.
To know which supply voltage is needed to have a reeling speed of 3 mm/s and 6 mm/s the tether reel was equipped with a reference point. With this pointer it was possible to measure the time for one revolution and results from this measurement the needed voltage is calculated.
The supply voltages are:

- 0.9 V for 3 mm/s
- 1.8 V for 6 mm/s

 

## 4.2. *Test Nr.1 (Full Length Deployment)*

The test Nr. 1 was performed to investigate in the tether unreeling behaviour during a 10 m unreeling as well as how different number of stacked layer of the tether influence this.

### 4.2.1. Tests Performance

The test is preformed in the ZARM Facility on a lifting platform. The PTA is mounted on a plate to have enough distance between the lifting platform and the unreeled tether. This is shown in Figure 6.

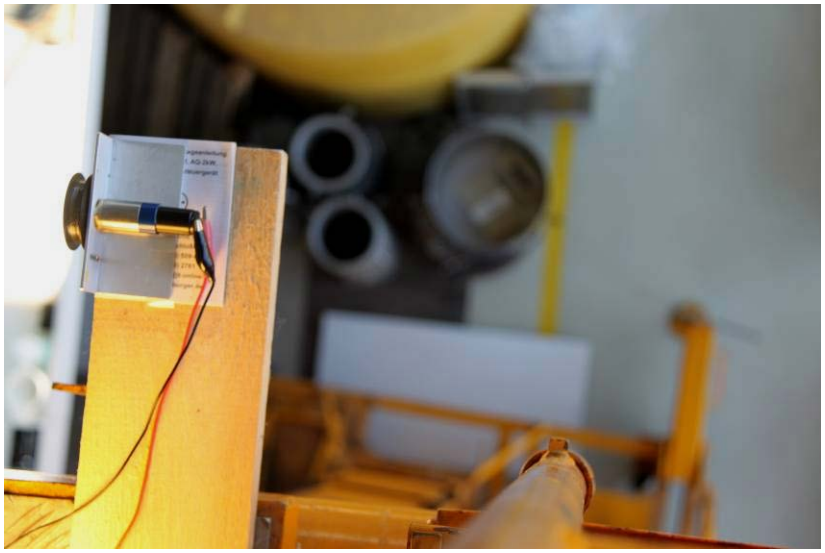

Figure 6: PTA position on the lifting platform.

Before the test run is started the platform is lifted in a height of 9 m ± 0.1 m. The height was measured with a laser range.
The un- and upreeling speed is 3 mm/s.
During the whole un- and upreeling process the tether reel and also the place where the tether leave the reel are recorded on video for documentation

### 4.2.2. Tests Result

The tether was unreeled for 41:06 minutes with this time value results a length of 7.5 m for the unreeled tether. The end of the unreeling after 41 minutes has two reasons:
The first was that the position of the small end mass on the end of the tether can not be detected so that it was not able to continue a safe unreeling process.
The Second was that the operating temperature of the camera reached a critical level of operation after 30 minutes.
During the unreeling it was observed that the tether made a small bow. This is shown in Figure 7; the bow of the tether is marked with a blue arrow. This bow results from the influence of a small thermal lift noticed at the ZARM Facility. It should be noted that during the whole unreeling process at the PTA mounting position no air flow was detected.
Like the unreeling the upreeling was done also with a speed of 3 mm/s but the camera reach a critical temperature and had an emergency shut down after 12 minutes of operation. Thus the rest of the upreeling procedure was not documented on video.

 

The un- and upreeling of the tether did not harm any tether loop and both un- and upreeling was done without problems during the reeling procedure.

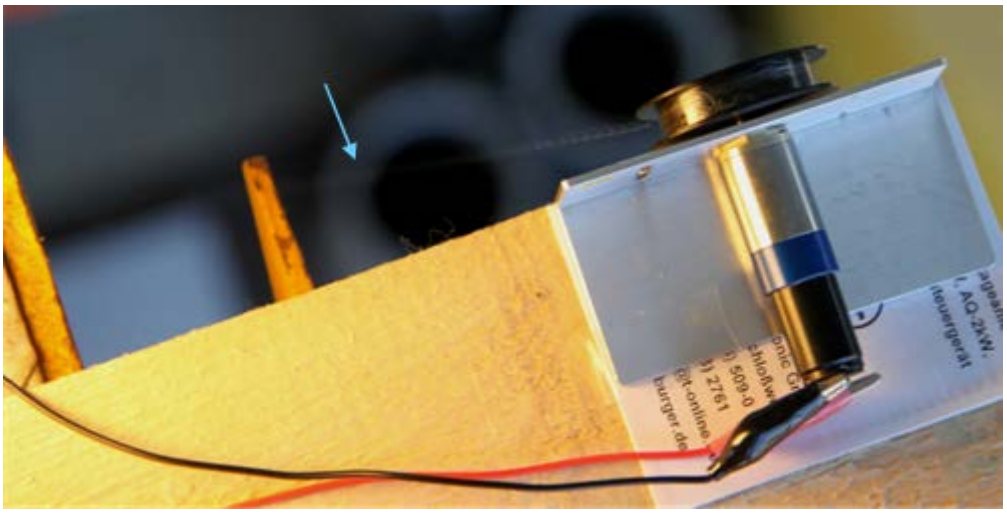

Figure 7: Tether bow under the influence of the thermal lift.

## 4.3. *Test Nr.2 (Upreeling without Guidance)*

The main focus in the second test is on the behaviour during the unreeling as well on the unguided upreeling of the tether.

### 4.3.1. Tests Performance

The test was performed similar to the test describe in chapter 4.2.1. But in this case two changes have been done.
The first is to raise the un- and upreeling speed to 6 mm/s. This is done to avoid the overheating of the camera again.
The second is, to permit the detection of the small end mass a white plate was positioned on the ground and for a better visual boundary of the tether end mass against the ground. The white plate is shown in Figure 6 in the lower middle of the picture.
The height of the platform was 9.2 m ± 0.1 m.

### 4.3.2. Tests Result

In this test the complete height of the lifting platform was used. That denotes that the end mass hit the ground. The unreeling of the whole length took 25:26 minutes. Due to the difference of the platform height and the tether length, it was not possible to stop the unreeling process at the same moment when the end mass hit the ground. Even with the increased visual contrast of the end mass, the test operator was not able to detect the moment of contact. Thus, the tether made a small loop on the ground, shown in Figure 8. This had no effect on the test results.
The unreeling process was done without problems, only a small bow formed again due to the thermal lift.
During the upreeling, then thermal lift influenced the tether I that way that it was pulled on one side of the reel. Thus, the tether became reeled mainly on one position of the reel. Due to the uneven surface of the reel and its soft material, the tether and the loops became catches up by the reel sidewalls and lifted over.

 

So the tether fall back downwards and a tug appeared on it. This tug occurred 20 times. The condition of the upreeled tether is shown in Figure 9.

Figure 8: Tether end mass hit the ground in test run two and creat a small loop.

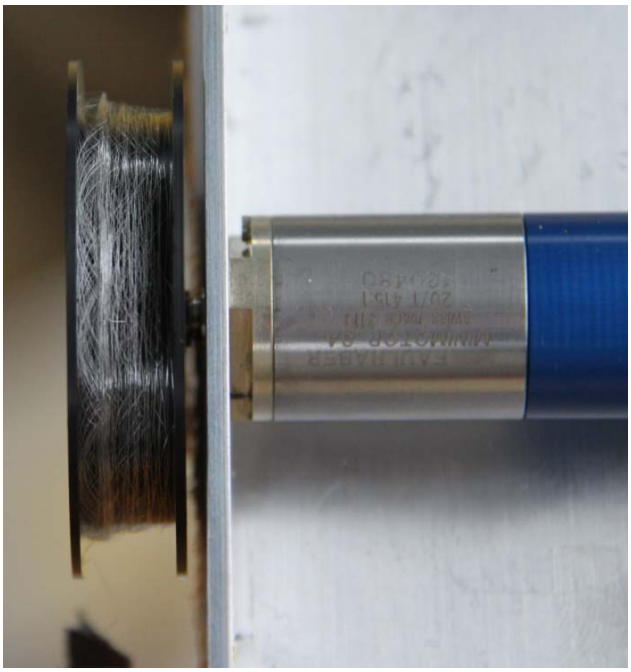

Figure 9: The upreeled tether after the second test run.

## 4.4. *Test Nr.3 (Upreeling with Guidance)*

In test Nr. 3 the behaviour of the tether during the unreeling and the upreeling with guidance was investigated. The unreeling in this case is more important to investigation if the many stacked layers, generated by the upreeling in test Nr.2, influenced the unreeling behaviour and if it lead to possible tether damages.

 

### 4.4.1. Tests Performance

The test was performed as the same as describe in chapter 4.3.1. The difference is that during the upreeling the whole PTA was manually skipped, so that the tether can fill the whole width of the running surface of the reel before the next stack layer will start.
The height of the platform for this test run was 9 m ± 0.1 m.

### 4.4.2. Tests Result

The unreeling of the tether succeeds without a problem. That shows that many stacked layers do not influence the unreeling behaviour. As the test before, the tether hit the ground, shown in Figure 10. The time for unreel the whole tether was 25:21 minutes. In this test run the tether has also a small bow caused by the thermal lift noticed in the indoor test facility.
In case of the upreeling the tether is guided, to have the tether side by side. Unfortunately with the manual guidance it was not possible to place each individual passage off the tether beside the next, but it has shown that during the upreeling the whole running surface was used. The upreeling behaviour of the tether was without a problem, but one welding spot is detached and results in a loop with a double length. It should be noted that the loop is not broken.
In Figure 11 the tether after the guided upreeling is shown.

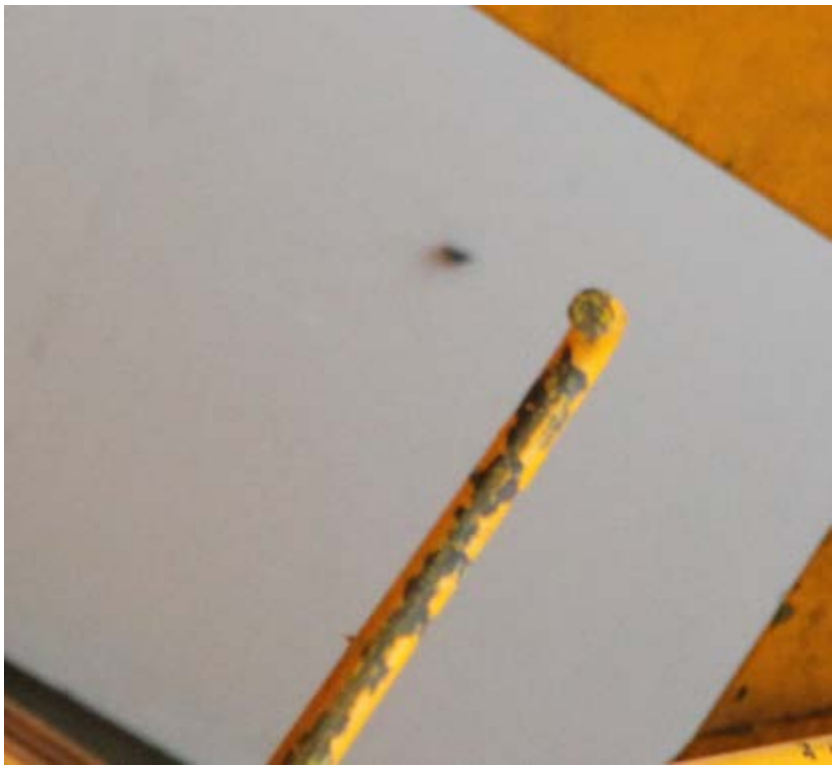

Figure 10: Tether end mass hit the ground in the third test run.

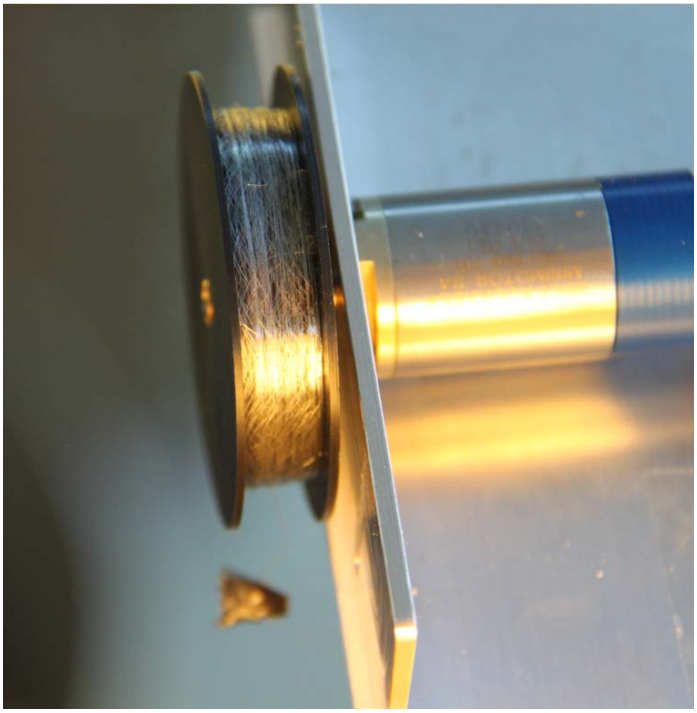

Figure 11: The upreeled tether after the third test run.

### 4.5. *Conclusion*

All the three test runs unreeled successful more than 7 m tether length. Further for all tests it can be conclude, that the different layer configurations, guided side by side or without guidance, has no influence of the unreeling behaviour of the tether. Also the thermal bow and the resulting pressure during the test do not result in reeling problems.

# 5. Release Criteria

## 5.1. *Item Success/Fail Criteria Unreeling Tests 1*

**Success:**

- If the tether was unreeled more than 50 %.

**Fail:**

- If the tether or the loops jammed into a other tether loop and avoid continuing the un- or upreeling

| Test Number | Reeling Speed [mm/s] | End mass [g] | Unreeling behaviour | Tether damages | Success/Fail Criteria |
|---|---|---|---|---|---|
| **1-1** | 3 | 0,057 | Without problems | None | Un- and upreeling successful |
| **1-2** | 6 | 0,057 | Without problems | None | Un- and upreeling successful |
| **1-3** | 6 | 0,057 | Without problems | One welding spot of a loop is detached but not broken. This results in a loop with double length. | Un- and upreeling successful |