Length Measurement of Deployed Electrodynamic Tether In DESCENT Mission

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Abstract

This paper will demonstrate two different methods used to measure the length of a deployed electrodynamic tether. The first method is a contact method that uses a designed circuit to determine the deployed tether length. The tether is coated with a non-conducting material at pre-determined intervals and an ADC will measure the change of voltage value between pre-determined lengths of the tether. The tether length will be determined by detecting the zero-voltage value time. The second method is a non-contact method using an LED-photodiode combination sensor (referred to as the detection system). Since the tether is aluminum, it has the tendency to reflect light. It was chosen at pre-determined intervals to have the tether coated with black paint in order to have the tether absorb light. The sensor will detect the difference between the portion of the tether that is painted black and the portion of the tether that is not painted. Then the deployed tether length will be obtained. The detailed introduction and comparison of the two methods will be presented in this paper and the results of the two methods is demonstrated by ground tests. Finally, the desired method used in the DESCENT mission will be presented.

Key words: DESCENT Mission, Electrodynamic tether deployment, Tether length measurement

1 Introduction

According to the US. Space Surveillance Network (SSN), the number of space debris objects is estimated to be greater than 17500 objects larger than 10 cm [1], which can be a threat to safety of spacecrafts. With the continuing growth in the number of spacecrafts, the probability of the collision between a spacecraft and orbital debris has increased. In order to prevent and mitigate the number of space debris, many compelling novel concepts have been presented. One of the most appealing technologies is the Electrodynamic Tether (EDT) technology, which has great potential in space-debris removal [2] because of the advantages of compact size, light weight, no propellant consumption and easy of operation [3]. The EDT system consists of one main satellite connected with a bare electrodynamic tether that produces a Lorentz force through electromagnetic interaction with the Earths magnetic field. Sometimes the other end of the tether can be connected to a sub-satellite. Based on the EDT technology, 12 space missions have been planned or operated to verify the feasibility of EDT in the past five decades [4]. One of the critical and difficult technologies is the successful deployment of the tether and the space experiments mainly focus on this aspect. One of the key parts of the mission requires the tether to be fully deployed. Thus, the deployment of the tether is tested multiple times.

The DESCENT mission aims to verify the ability of space junk deorbiting using a Lorentz force generated from an electrodynamic tether. The DESCENT mission consists of two 1U CubeSat (mother satellite and daughter satellite) connected by a thin 100m long aluminum tape tether. The tether will be deployed from the daughter satellite and the successful deployment of the tether is one of the fundamental performances for the on-orbit validation of the objectives of the DESCENT mission. Therefore, one of the key requirements of the mission is to be able to measure the post deployment length of the tether [5]. Among the conducted space tether missions, different tether length measurement methods have been presented. A length registration method by interruption of infra-red beams during deployment is employed in YES2 [6] and the data is detected by the optical loop detector. Then, the similar mechanism is designed and tested in a microgravity environment on the ground [7]. During the latest T-Rex mission in 2010, a method named "Inverse ORIGAMI" is employed [8] and the space flight result is compared with the tests on ground to verify the performance with high reliability. By comparing and analyzing those methods and consider the limited space, the DESCENT mission pursues a compact, accurate and simple easy of operation method to measure the deployed EDT length. This paper will demonstrate the contact method and the non-contact method used to measure the deployed tether length. The two methods were compared, and the non-contact method was chosen to be used in the DESCENT mission.

2 Description and Ground Test of the Two Methods

Due to the space and power limitations in the DESCENT mission, all the team members made an agreement to use a simple, easy of operation method with acceptable accuracy. The daughter satellite (Figure 1) is a 1U CubeSat with body-mounted solar panels. It will store a folded 100 m long tape Aluminum tether in a tether storage box (Figure 2). The tether will be deployed from the outlet of the box and the tether length measurement system is located right before the outlet. The driving requirement for the tether length measurement system is that the mission shall report the length of the deployed tether to within an accuracy of at least 5 m. To satisfy this requirement, the detailed description of the two methods are presented in this section and finally a comparison is done to validate the chosen method.

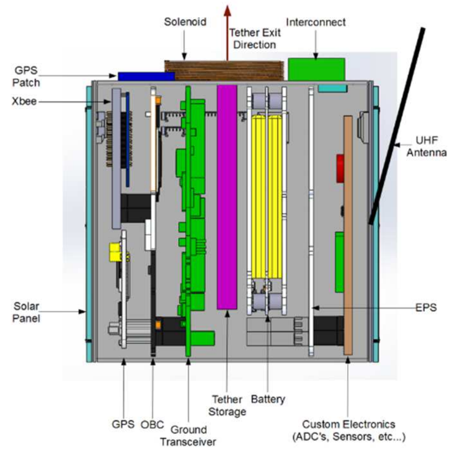

Figure 1. Top Level Block Diagram of Daughter Satellite

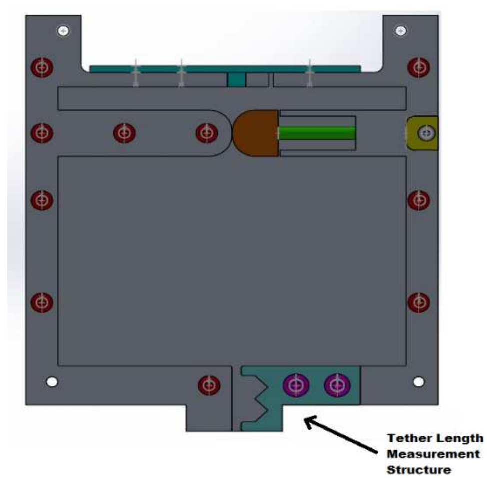

Figure 2. CAD model of tether storage box

2.1 The Contact Method

The contact method uses a designed circuit (Figure 3) to determine the deployed tether length. The tether is coated with non-conducting material at pre-determined intervals. The negative terminal is connected with a nail in the middle and the positive terminal is contact by the top of the tether through the probe. When the probe is in contact with the conducting aluminum tether, it will result in an open circuit and the voltage will be a non-zero value. When the probe is in contact with the non-conduct material, it will result in a closed circuit and the voltage will be zero. An ADC will be used to measure and store both the data of the voltage values and the sampling time between pre-determined lengths of the tether.

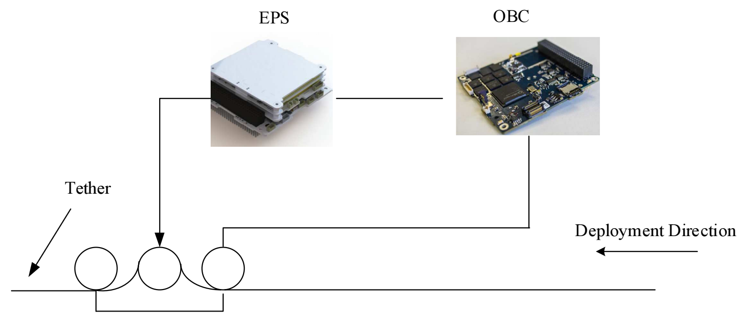

Figure 3. Circuit for measuring tether length

The CLYD SPACE Electric Power System (EPS) is a 5V power source that will be used to turn on the circuit and the On-Board Computer (OBC) will work as an ADC in the DESCENT mission. The tether will be deployed to a length of 100m and it will be coated with a non-conducting material (8cm long) at pre-determined intervals at every 5m (Figure 4). The length of the non-conducting material is 5m. There are 19 non-conducting material sections in the 100m tether. Then the velocities of every non-conducting material section can be calculated by:

$$v_{\mathrm{i}} = \frac{\Delta L}{\Delta t_i} \quad i = 1, 2 \ldots 19 \tag{2.1}$$

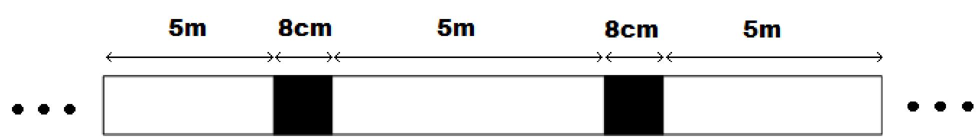

Figure 4. Coated tether segments (8cm long) with intervals at every 5m

The ground test result is shown in Figure 5. The detected voltage value "0" is clear and obvious and the tether length can be calculated based on the velocity and time.

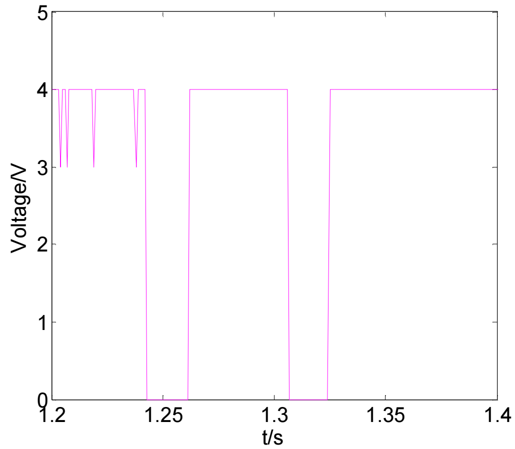

Figure 5. On-off voltage diagram of the deployed tether

2.2 The Non-Contact Method

The second method capable of measuring the length of the deployed tether is a non-contact method that consists of a Light Emitting Diode (LED) and a photodiode. The LED and photodiode combination are referred to as the detection system and it will be placed in front of the deploying tether at a distance of 3 to 5mm. Since the tether is aluminum, it has the tendency to reflect light. So, it was chosen at pre-determined intervals to have the tether coated with black paint in order to have the tether absorb light. The length of the pre-determined intervals and coated segment lengths are the same as the previous section (see Figure 4 for reference).

As the tether is being deployed the light from the LED will reflect from the aluminum surface of the tether and will then fall onto the photodiode. When the light from the LED encounters the dark portion of the tether, it will be absorbed due to the black paint. It is important to note that the LED is placed adjacent to the photodiode and a small division is placed between the two to avoid having light directly from the LED falling onto the photodiode. Figure 6 shows the configuration of the detection system. The division shown in Figure 6 will ensure that only reflected light from the tether will be received by the photodiode.

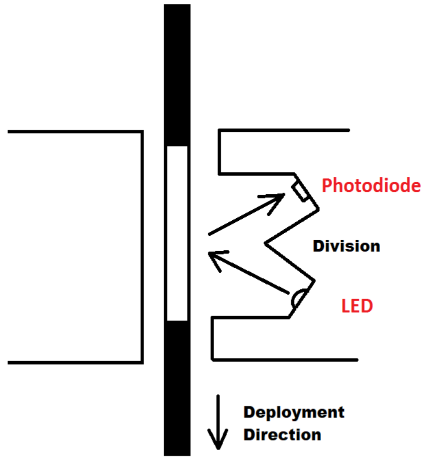

Figure 6. Placement of the LED and photodiode alongside the divider

Then, a test was conducted to see if the system is functional and practical. The testing equipment consisted of an Arduino Uno, a 1.2m long tether with 8cm intervals between painted and non-painted regions and a cell phone flashlight with an OPT101 photodiode was used as the detection system; which was then placed 2mm from the tether. The graphs from the test results show spikes for the reflected portions of the tether (Figure 7).

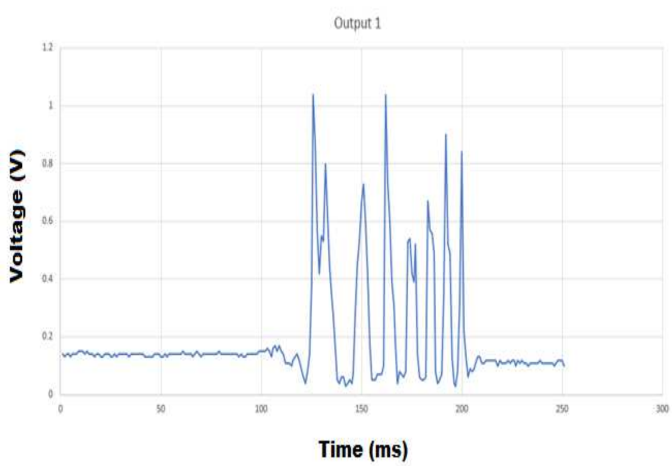

Figure 7. Spikes suggesting the reflected portions of the tether

In Figure 7 the voltage along the y-axis refers to the voltage obtained from the photodiode. To make the output look smooth, a second Arduino code was written such that any voltage reading below 0.2V should be given an output value of 0 and any voltage reading above 0.2V should be given an output value of 1. Figure 8 shows the new output with a smoother curve. From the spikes shown on the graphs the sample tether's length was successfully determined.

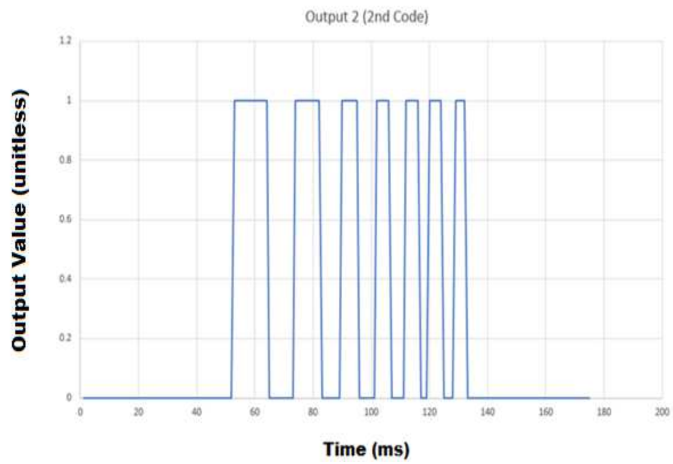

Figure 8. Modified output allowing for easier length determination

2.3 Comparison of the Two Methods

In this section both the contact and non-contact methods used to determine the length of the tether will be compared. First, the contact method has a very simple and clean design. It contains only 3 contact leads that contact with the deployed tether. The advantage of this design is that it does not require a complicated mechanical structure at the outlet of the tether storage box. In addition, the electrical connections are also simple as the center lead connects to the EPS and the end leads connect to the OBC. It does not require any additional circuitry or components. Therefore, it is a simple, light weight and efficient design. However, the contact method requires the leads to make direct contact with the deployed tether. This could be problematic as it can lead to jamming of the tether during deployment. Meanwhile, the direct contact between the tether and the leads means that there is a constant friction force. This could produce extra heat along the tether and can cause a delay in tether deployment time. On the other hand, the non-contact method is a more complicated design, as it requires a dedicated structure within the tether storage box. Furthermore, additional components and circuitry are needed to support this method. This leads to greater weight, complexity and increased points of failure. However, since it is a contactless method, there will be no contact between the deployed tether and the detection system. This means that there will be no friction or jamming caused by the system. One of the main requirements of the mission is to have the tether fully deployed so that the Lorentz force can be maximized, and the spacecraft can be deorbited in the targeted time. Therefore, the contactless method was chosen over the contact method as it will not prevent the tether from being deployed successfully. On the other hand, the contact method poses a risk of jamming and can lead to an unsuccessful deployment of the tether. To sum up, Table 1 shows the advantages and disadvantages of each method.

Table 1 Advantages & Disadvantages of Each Method

Method	Advantages	Disadvantages
Contact	-Does not require complex structure -Light weight -Few components & circuitry	-Generates a friction force -Can cause the deploying tether to jam
Non-contact	-No friction force generated -Does not cause deploying tether to jam	-Requires complex structure -More components and circuitry are required -Greater weight -Multiple points of failure

3 Conclusion

In conclusion, this paper presents and compares the performance of two-different EDT length measurement methods. The ground test results are analyzed, and it is verified that the two methods are able to measure the deployed EDT length with acceptable accuracy. After a comprehensive comparison of the two methods, the non-contact method was chosen to be adopted in the DESCENT mission. Further ground tests will be conducted and its performance in space will be presented in the future.

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