# Reel mechanism design, prototyping and test for tether release, retrieve and control

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## Abstract

The work presents a potential solution for the reel mechanism to pursue active space debris removal whenever a target-chaser tethered connection is considered. The mechanism here discussed is part of a larger system composed by a net, which has the role to capture a target satellite (e.g. Envisat) and a tether which connects the net to the chaser satellite: more specifically, the reel mechanism represents the mechanical interface between the tether and the chaser platform. The requirements definition process output is firstly presented; then several conceptual design solutions, which meet the requirements, are highlighted in order to find out a baseline design. In particular, a reel driven by a 150W electric motor controls the tether length (to support the chaser-target dynamics control) in terms of tether deployment and retrieval rate, while an electrodynamics brake accomplishes the fixed tether length whenever required. A level-wind supports the winding process in order to wind the tether as neat as possible. Furthermore, the most innovative device is a grip pulley; it is driven by an electric motor and its role is to keep the tether with a minimum level of tension in order to prevent tether jam inside the mechanism; to do that the pulley grabs the tether exploiting its flanges which bend one toward the other under the action of two pinch rollers.

## 1 Introduction

This work belongs to the broad research and technology development area focused on space debris remediation. Recently updated regulations such as ESA's own Requirements on Space Debris Mitigation for Agency Projects (applicable to all ESA missions), the French Space Operations Act and the United Nations' Outer Space Treaty require that more attention is paid to safeguarding Earth's orbital environment. The only way to preserve key orbits for future use is to shrink the current amount of debris in absolute terms, which asks for novel technologies and approaches for the removal of existing debris – remediation - and the design of new space systems which include a disposal strategy on board - mitigation – not to increase the debris population. As mentioned, the work presented in the paper belongs to the first branch, being part of the tethered-net based mechanism to grasp and de-orbit dead satellites. The net with four massive terminal bullets is thrown by means of pneumatic barrels, it travels until it reaches the target - here assumed of the Envisat –like class - and captures it; from the capture to the end of disposal the orbit energy dissipation is accomplished by the pulling from the chaser, transferred to the target through the tether, element representative of the two vehicles connection. The goal and the challenge of the work is to design a well suited mechanism (in particular a reel mechanism) devoted to control the dynamics of the chaser-target system by means of a control law, which shall drive the tether in terms of retrieval and deployment rate and support the stability of the dynamics of the stack, during its different mission phases. The chaser satellite is planned to be launched in 2020-2022, thus it is necessary to design and test the mechanism, which is a critical element of the payload, quite early in time to gain the correct technology readiness level to fly.

Reel mechanisms for terrestrial applications are a quite well established technology in many fields, such as in naval [1,2] building applications. Spools design moves to more and more clever and application driven design solutions starting from the fishing field [3,4], jumping on the textiles, and eventually ending with the aeromautical and space field; therefore to design a reel mechanism for active space debris removal payloads an investigation of the related art in different technological fields has been performed. That process was fundamental to identify potential technology spin-in in space sector and to deeply understand criticalities and key aspects of the mechanism. Mainly during nineties, NASA [5] and others space agencies were involved in space tethered missions; despite the other missions, TSS-1 and TSS-1R missions [6,7,8] are characterized by reel mechanisms asked to perform both the tether deployment and retrieval. In addition in some patents related to fishing reels it is possible to find many interesting different ways to face the deployment and retrieval of a wire. Thanks to this analysis many suggestion by industries experience have been identified[9]. Among others, one of the main underlined criticality stays in the need of a dedicated support to correctly rewind a cable. In the following the problem formulation and analysis is firstly discussed to address the mechanism design; the preliminary design and tradeoffs are then presented. The here proposed baseline is then presented in details. Some final comments on the design scalability are then offered together with remarks for the future work.

## 2 Problem formulation: functional analysis

The scenario here assumed as a reference to settle the mechanism design requirements is the active removal of a large size dead satellite, Envisat-like; therefore removal has to occur on an almost low Earth polar orbit; the overall mass to be removed is in the order of 8 tons for a volume envelope of 26m x 10m x 5m; a significant part of this envelope is due to the presence of an extended solar panel. The first step done to formulate the problem focused on the functionalities the mechanism has to accomplish during each of the mission phases strictly related to the net-based capture mechanism activation. A brief overview of those is given in the followings:

- **launch**: the mechanism is in a standby mode; tether is wounded on the reel; it shall prevent internal tether jam only.
- **pre-operational:** the mechanism is still in a standby mode; the tether is wounded on the reel.
- **Operational:**
  - *Net-Casting mode:* the net is cast to capture the target satellite and the mechanism starts being operational: it shall support the tether speed related to the net ejection dynamics not to affect the net deployment phase; the tether shall be slack thus the mechanism shall support the tether release even if a load/tension is not applied to the tether itself.
  - *Tether Control mode-power on:* once the target is captured the tether shall be tensioned to make the removal maneuver effective; the tether length shall be kept constant while the load experienced by the tether (static load) growths up to the operational level driven by the chaser main propulsion unit (baseline T=2700N).
  - *Tether Control mode-power off:* the removal phase may include ballistic arcs to be experienced by the stack, entailing the tether flexibility shall be considered to keep the two elements anchored at the end of the tether at a safe distance; to control this dynamics the mechanism shall be able to deploy and retrieve the tether according to a predetermined tether length control law and shall be designed according to the maximum dynamic load experienced. As far as the sizing scenario is considered, the $T_{max}$ =0.72N. The tether and net dynamics which size the mechanism here presented has been analyzed thanks to the numerical simulator for flexible systems dynamics analysis and sizing developed at Politecnico di Milano – Dipartimento di Scienze e Tecnologie Aerospaziali [10].

To improve its reliability the mechanism shall deploy and retrieve the tether without burying, snagging or fouling the tether in the process, and during the retrieval phase the tether shall be stored neatly to guarantee the mechanism to re-deploy the tether once it is retrieved. By taking advantage of the industrial and NASA experience, minimum levels for the tension the tether shall have during retrieval and deployment not to jam and jeopardize the mission has been here settled: 10N during retrieval and 2N during the tether deployment.

## 3 The tether control mechanism preliminary design: trade off and baseline

The reel has been ere identified as the core element of the entire mechanism to be designed. The reel is composed by a cylindrical core, the tether is wound up, and flanges, located at the cylindrical core extremes to prevent the tether to fall down from the core. The first design fork entails the drum surface features: either smooth or grooved depending on how the tether will be wound up the reel; a grooved solution is here proposed, to improve winding precision and rope stability.
Up to now the mechanism can be thought as a black-box characterized by a hole (called exit eyelet); so that the reel can be placed with different orientation with respect to the exit eyelet axis; for instance it could be placed with its axis parallel to the exit eyelet axis or with its axis perpendicular to exit eyelet axis. However the latter solution, because of its high reliability, is the common design, which could be found in some industrial reel mechanisms; for that reason, it has been chosen for our application. Once the primary reel axis orientation is fixed, two different design branches can be highlighted depending on the number of spools the mechanism is composed by: one reel or double reel mechanism. Analyzing the net casting phase we infer that "one reel mechanism" exploits only one reel, which can be active or passive. A passive winch means to have a reel free to

rotate around its axis during the casting phase so that any electric motors are not required; in that way the net departure itself pulls the tether uncoiling the reel, but in this manner the thrown tether experienced some resistance because of the reel inertia torque and friction, thus a device able to pull out the tether shall be designed. The active reel solution implies an electric motor that drives the reel during this phase with a velocity consistent with the tether velocity increasing mechanism complexity; a device to pull out the tether is always required to avoid tether jam.

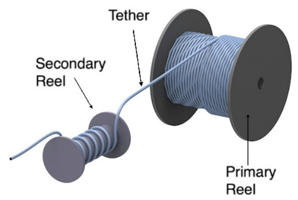


Figure 1: "double reel" design

“Double reel mechanism” exploits also a secondary reel which axis is aligned with box-eyelet axis as shown in figure 1 where only the tether necessary to fulfill net-casting phase is wound up on the core of the secondary reel. This spool is static and it works as the spinning fishing-reel [3,4] minimizing the resistance experienced by the thrown tether since the net motion is not affected by any inertia torque; however once the net reaches the target some tether could be left wound onto this secondary spool; for that reason it is necessary to think about a method to get back of this tether: the tether can be forced out the box until the static winch is cleared and then the tether, that is becoming slacker and slacker, could be simply retrieved exploiting a motorized primary reel. The presented solution increases the mechanism complexity and envelope and so it is discharged as baseline solution.
To avoid tether jam when a tether low-tension condition occurs, the tether shall be kept with a minimum level of tension, so that it is necessary to introduce a device to tension the cable. A pulley placed close to the exit eyelet may accomplish the task; this device shall be able to grab and so pull the tether on one hand and to assure the tether not to slide on the pulley surface on the other. The first concept (grip pulley) was exploited by TSS-1 engineers [8] and it exploits the bending capability of the flanges under the action of two pinch rollers to grab the incoming tether. Furthermore the second concept takes into account two pulleys which are pressed one to the other in order to grab the tether and so prevent its sliding. The exploitation of two pulleys increases the mechanism complexity with respect to one grip pulley mechanism; in addition the tether is squashed and it means a higher stress level experienced by the tether yarns. The motion of the pulley or pulleys can be caused by an independent motor or by gears coupled with the reel motor; the latter option is not very feasible because of the distance between the reel motor and the eyelet and then it is not possible to control them independently. Indeed the torque and angular speed of the pulley shall be coordinated with the reel ones, in order to guarantee the desired tether tension inside the box; hence a close loop control might be implemented to accomplish the goal. Furthermore this device can be the same devoted to pull out the tether during the net casting phase.
During maneuvers the mechanism is required to keep tether length constant, so that to accomplish the goal, it is possible to exploit the electric motor used to control the reel, but this may require the motor itself to be oversized in order to accomplish the blockage task. On the other hand a device devoted only to block the reel could be considered; the simplest one is a passive device like a pin, fixed to the mechanism structure, matches with an hole placed on the reel flange. This design solution is cheap and light, but it is a discrete coupling, because of the device works only if the pin matches perfectly the hole in the flange with a consequent concentrated load on the flange structure. This method can be exploited during launch, but it is not so optimal in case of mechanism failure, because of the perfect matching is not always guaranteed. Finally, electrodynamics brakes are used on reel mechanism for industrial application [11]; they are heavy but their power demand is not so demanding; in addition they could be designed to work as locking device when they are not fed, hence when electric power is no more available for some reasons, e.g. a failure, and at a later stage they can be disengaged when some current is supplied them in order to release the reel.
To conclude to perform close loop control system it is necessary to have real time information about tether speed and length and tether tension. The first two parameters can be known exploiting common sensor already mounted in the electric motors; while the tension applied to the tether can be measured by a tension meter.

## 4 Baseline selection and sizing

The baseline solution tries to maximize positive aspects while it tries to minimize the negative ones; it should be the most reliable one and so we tried to follow the simplest concept that satisfies all the requirements. Primary reel shall be driven by an electric motor both in the baseline solution and in the backup one since the primary reel is considered to be active at least in one mission phase (tether control). Even if the electric motor is mounted on the reel it can be switched off during the net casting phase, as considered for our baseline, in order to keep the mechanism behavior simpler. A level-wind device [12], to wind the tether as neat as possible, is considered for both the baseline solutions since it is one of the most fundamental devices in a reel mechanism. To keep the mechanism lighter and more reliable baseline design does not exploit the secondary reel during the net casting phase. The grip pulley is considered to be the tension device, this is because for the same requirement mentioned above this device allows us to have a more compact and reliable mechanism. The grip pulley can play also the role to pull out the tether during the casting phase and not only during the control one since the tasks are about the same; thus the device shall grab and pull out the tether thanks to an electric motor which drives it. The electrodynamic brake accomplishes two tasks at the same time: it works to maintain the reel fixed when it is required while it blocks the reel in case of failure. For that reason it is considered for both the baseline design.

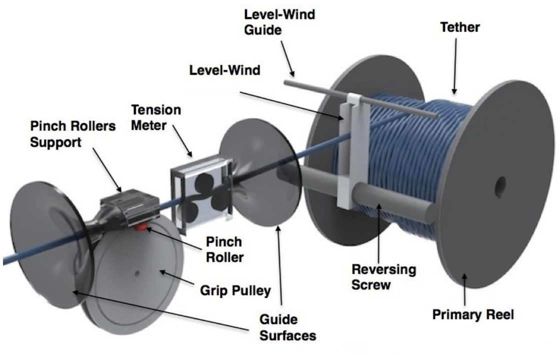


Figure 2: Reel Mechanism sketch

### 4.1 Primary Reel

The reel is constantly coupled with the tether, thus reel design shall be related to tether properties and behavior. The tether shall be wound onto the reel many times during the mission, thus the first step is to find out the minimum value the drum diameter shall have in order not to damage the tether that is a 8-strand braided rope made in Kevlar®; for this kind of rope there is no easy way to quantify pulleys and drum D/d ratio (reel drum diameter over tether diameter) that should be used for tether long-life, since this ratio depends on: tether material; pulleys and drum materials; rope construction; load; deployment/retrieval speed. As suggested by industries [9] we keep D/d greater than sixteen if a 100% margin is considered; in addition a good purpose is to have always a minimum of at least one full layer always wound upon the reel in order not to load the connection point between the rope and the reel. To size the reel we have to know how the different design parameters affect each others; in particular these parameters are: drum length and diameter; number of tether layers wrap on the reel drum; flanges diameter; occupied volume; reel drum thickness and central displacement and overall mass of the reel. They are all linked together, e.g. number of layers affects the pressure [9] experienced by the reel and it is one of the parameters the drum thickness [13] depends on. We choose to evaluate how the above-mentioned parameters vary as function of the drum length and diameter..

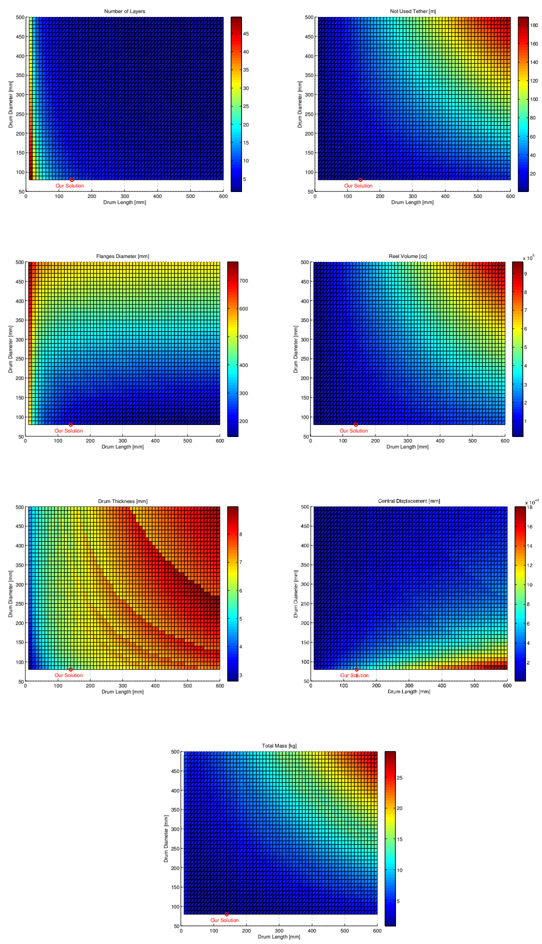

Figure 3: Sensitivity Analysis

Thus a sensitivity analysis (see Figure 3) exploiting a Matlab® code has been performed to have some feeling about the design parameters when the required tether length is imposed Among the infinite set of solution, the one which minimizes reel mass and envelope and maximizes the reliability is taken into account; it assures to have a compact device with a modest number of layers and a mass that is low enough; so that this design solution is a good trade-off between the infinite set of possible choices when Aluminum is the material.

Table 1 reel design details

| | | |
|---|---|---|
| Drum Length | 140 | mm |
| Drum Diameter | 80 | mm |
| Flanges Diam. | 198 | mm |
| Num. of Layers | 10 | - |
| Drum thickness | 5.6 | mm |
| Central Displ. | 0.0056 | mm |
| Not used tether | 7 | m |
| Mass | 1.05 | Kg |

4.2 **Level-Wind**

The level-wind carries out the role to let the tether to be uniformly distributed on the reel drum while the reel is rotating to wind up the tether. The sleeve has a mounted pin that has the role to mesh with the reversing screw (19.1mm pitch and 20mm in diameter) in order to move the level-wind back and forth when the screw is rotating driven by an electric motor. During the level-wind motion the tether is guided by the presence of the vertical elements which enter in contact with the tether itself; they have a wing like shape that respects the D/d ratio constraint. The pressure exercised by the tether on the surfaces generates a load that is the input for the level-wind electric motor sizing since the load in the direction of screw axis is $L=2T\sin(\alpha/2)$ where T is tether tension and $\alpha$ is the fleet angle; this parameter is affected by the relative distance between the level-wind and the guide surface where the tether is directed in the correct direction.

Pin is a really important device since it guarantees the level-wind to follow the screw pitch when the latter rotates because driven by an electric motor. So that the level-wind shall host this cylindrical pin by means of a cylindrical accommodation; in addition bearings could prevent both the accommodation surface and pin surface from abrasion because of the friction due to their relative motion. The overall margined mass is 0.43kg.

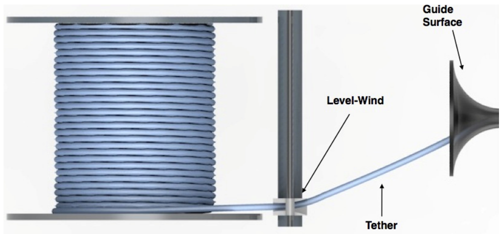


Figure 4: Level-Wind

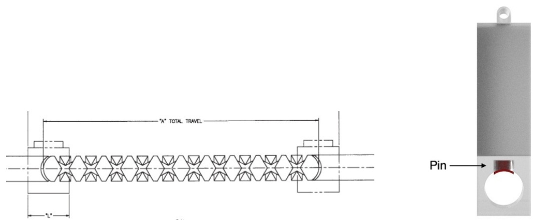


Figure 5: Reversing screw (left); Level-wind pin (right)

**4.3 Fleet Angle**

If we consider only tether behavior we have to consider a solution which exploits a fleet angle lower than 10deg which means to have very short primary reel drum or, if we maintain fixed the reel size, the tension meter and so the pulley as a consequence shall be placed very far from the level-wind increasing mechanism size. We decide to keep drum length equal to 140mm as it comes from previous analysis and so F is the only free parameter. Hence we have to remember we want a compact solution which guarantees at the same time tether safeguard against abrasion or other kind of failures due to the interaction with the mechanism surfaces. For that reason we have to perform a trade-off which leads to the choice of a fleet angle equal to 25deg; from Figure 7 we can infer that this kind of value implies limited bending surfaces size and it keeps the system sufficiently compact.

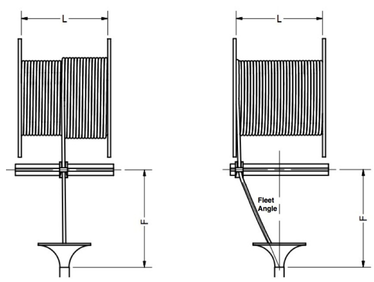


Figure 6: Fleet Angle

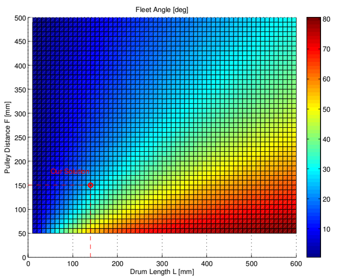


Figure 7: Fleet Angle sensitivity analysis

### 4.4 Tension Device

So that it is possible to design a grip pulley which plates bends completely under the load exercised by the pinch roller starting from TSS mission [8] experience and some U.S. Patent [14,15]. In Figure 8 it is possible to see the section view of such a device; in particular pinch rollers (1) act on the external part of grip pulley flanges (4) in order to bend them as shown figure 8. It is possible to see that when pinch rollers do not push against the flanges there is a gap between them; during the working condition the flanges bend to grab the incoming tether, but a little bit far away from the grabbing area the gap between the flanges allows the tether to enter end exit the grabbing area. Furthermore we can exploit a higher distance l of the point where tether grip occurs from the bending section (in proximity of the central drum (5)) in order to reach the same effect keeping the radius of curvature higher. Figure 8 (left) shows the vertical section of the grip pulley, we can see that an axial-symmetric wedge (2) is present; this wedge matches perfectly the groove (3) on the other flange during the working condition when the flanges approach each others to grab the tether (6) which lays perfectly on the wedge.

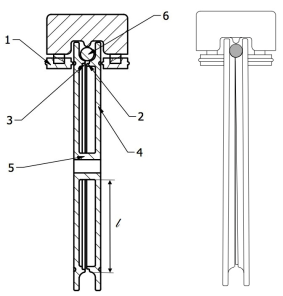


Figure 8: Grip Pulley section view (left), working condition (right)

The area of the pulley which enters in contact with the cable may be covered with some friction material in order to grip better the rope.The grip pulley we are sizing shall be able to control tether tension because of the friction force $F_f$ between tether surface and pulley moving plates; if we think that there is no sliding between these surfaces we can deal with static friction. The tension force the device is able to produce is proportional to the pressure $p_p$ exercised by the pulley surface onto the external surface of the tether; it is proportional to the friction coefficient $\mu_s$ and it depends on the value of the tether lateral surface $A_f$ that is grabbed, hence $F_{friction} = \mu_s \, p_p \, A_f$. Once the grip pulley grabs the incoming tether, to control the tension its motion shall be related to rotation of the primary reel through a close loop control system. For mass and inertia evaluation flanges have been considered 2mm thick, that is the minimum allowable to cover all the deflection range from less than 0.5mm up to 2.5mm; internal radius is 40mm while external about 50mm; internal drum is 10mm in diameter and 7mm wide.

### 4.5 Electric Motors

Primary reel is driven by an electrical motor, thus in order to go ahead in the choice of the electric motor for the reel we have to know what is the correct torque and velocity profile as a function of the time in order to evaluate the “effective torque” which is a fundamental parameter for the motor sizing. These data are not available yet since mission design is in phase-A, so that what we did is only a preliminary motor design thanks to some approximation; in particular, expert engineers suggest to consider the maximum torque that can be supplied by the motor as 3/2 of the nominal torque shown by the data-sheet; in this way it is possible not to oversize the motor while a proper margin on the motors lifetime that is related to their thermal properties keeps the system safer. The performance of the mechanism in terms of tether speed is fixed by the primary reel motor mechanical power, in addition, once the speed of the tether is evaluated the level-wind screw and pulley angular speed can be calculated as a consequence. Also the tension the tether experiences is fixed, so that the maximum torque the pulley and the level-wind motors have to supply are evaluated; so that the needed mechanical power can be evaluated in a simply way. As a preliminary constraint we fixed that value of the electric power available for the mechanism operation at about 300 W that is a reasonable data according to what has been define for this mission. Thus exploiting an iterative process it is possible to balance primary reel and grip pulley performances in order not to exceed the power limit; as a result a 150W Maxon® servomotor could be considered as primary reel motor. Thus level-wind motor exploits only 3W while the grip pulley motor 105W and the mechanism performance in terms of tether speed during tether retrieval is 4m/s.

### 4.6 Electrodynamic Brake

Electrodynamic brake principal parameter is the torque it has to supply to the load in order to maintain the primary reel with a zero angular velocity when tether tension reaches the peak value that is the so called static load. Thus, primary reel sizing lead to the knowledge of the total number of wound layer which is linked to the definition of the maximum distance of the upper layer from reel axis; this value multiplied with the maximum tether tension gives the required torque the brake has to supply for the worst case, since $\tau_{brake} = T_{static} R_{max}$ = 340Nm where $T_{static}$ is our case-study reaches 2700N; $R_{max}$ = 0.084m and a 50% of margin is applied, that value is three order of magnitude higher than the torque the electric motor has to supply during the retrieval mode; this proves that a brake dedicated to withstand this static torque is needed, so that satellite EPS shall supply 60W to the brake which mass is 7kg.

### 4.7 Structure

As first approximation we considered the mechanism structure composed by Aluminum panels with 5mm thickness in order to prevent the structure to fail under bearing loads and to consider some possible additional elements devoted to increase the overall structural stiffness, for that reason panels thickness has been properly margined (100%). Panels shall cover completely the mechanism in order to increase the mechanism torsional and bending stiffness while in figure 9 (left) the structure does not cover completely the mechanism in order to let possible to inspect the internal devices if it is required; total mass is then 4kg if guiding surface are considered made in Aluminum too. Otherwise the structure can be composed by two shells which couple each other through a male-female coupling. Each of the shell should host the elements which role are to support the elements the mechanism is composed by as depicted in figure 9 (right). Thanks to this solution the trumpets shape guide surfaces can be part of the stamps, in this way we minimize the cantilever element which can vibrate and so damage during launch with a consequent mission failure.

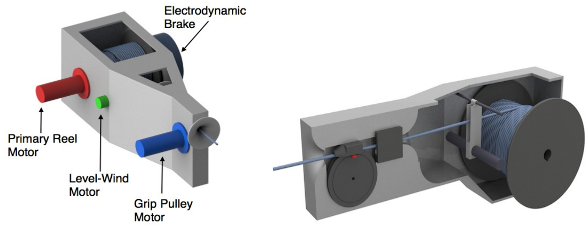


Figure 9: Mechanism Structure

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### 4.8 Mass & Power Budget

In figure 10 the circles highlight the possible working point during the tether deployment and the squares during the retrieval. Light-blue curve highlights the maximum performance of the mechanism since it is related to a 100% working condition of the reel electric motor.

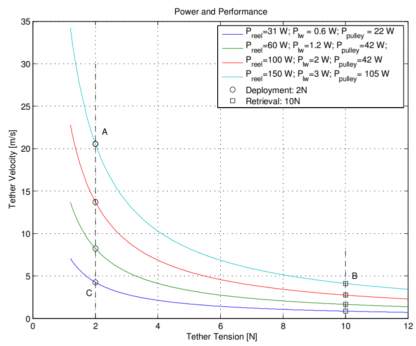


Figure 10: Primary Reel electric motor performance

Point B working condition allows the control law to exploit the highest tether speed during retrieval, in particular with a speed of 4m/s as already shown before. On the other hand working condition defined by point A leads to the maximum tether deployment speed up to 20 m/s. By the way if we want the mechanism to work at point A and B we shall exploit a tether control law with different saturation speed between the deployment and retrieval mode while the power demand is always the highest one. Thus if we want a lower power demand and the same saturation velocity (4 m/s) for the control law we can select Point C as working point during the deployment. Now the reel motor needs only 32W to control tether deployment at the considered speed; consequently also level-wind and pulley motors need a lower electric power.
Table 2 sums up the mass and power budget; the power demand has been considered during the control phase - retrieval mode to take into account the most demanding

situation.

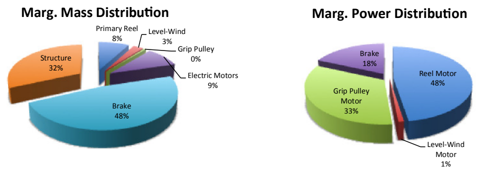


Figure 11: Mass & Power distribution

Table 2 Mechanism mass and power breakdown

| | Mass [kg] | Margin |
|---|---|---|
| Primary Reel | 1.23 | 5% |
| Level-Wind | 0.41 | 5% |
| Grip Pulley | 0.074 | 15% |
| Electric Motors | 1.43 | 30% |
| Brake | 7.4 | 5% |
| Structure | 4.9 | 50% |

| | Power [W] | Margin |
|---|---|---|
| Reel Motor | 165 | 10% |
| L-W Motor | 3.5 | 10% |
| GP Motor | 115.5 | 10% |
| Brake | 63.5 | 5% |

## 5 Design scalability

The input data for the sizing process are continuously changing since mission design is still in phase-A; thus, exploiting the sizing process depicted up to now, it is possible to define a rough mass and power budget related to a sensitivity analysis which keeps different data depending on: the class of the chaser thrusters, tether length and diameter. However this is not a problem for the design since the sizing process is always the same because the problem is scalable. The choice of a different chaser satellite implies different value of loads experienced by the tether during the mission lifetime; then the choice of deorbiting technique (V-bar maneuver or R-bar maneuver) affects the needed length and tether diameter. The maximum torque the motor shall supply to the system is inherently related to the dynamic load applied to the tether, therefore once motor class is fixed the tether is simply evaluated. The cases which consider short tether and so low dynamic loads are characterized by higher performances with respect to the cases which exploits longer tether. To conclude if the dynamic load is greater than 2N and 10N respectively during deployment and retrieval mode, the grip pulley is no more necessary and so its power demand shall not be taken into account in the power budget keeping the things simpler and simpler.

However, since the problems related to this mission are really demanding, the overall mechanism shall be composed by many devices which increase mechanism complexity; thus it is possible to think to design a mechanism following the reliability driver only. So that it is possible to highlight a really simple mechanism even if it can not answer correctly to all the defined requirements. This mechanism should be composed by the primary reel, which can be designed in the same way presented in this thesis, and a brake only. The reel is dedicated simply to store the tether, while the brake to block reel rotation (e.g. during the maneuver) and to slow down the speed of the deployed tether if it is required. As this kind of mechanism does not exploit the grip pulley, during the casting phase the net could experience some resistance, which can affect casting precision. Furthermore since motors are not taken into account in the design it is not possible to control the relative dynamics exploiting tether deployment and retrieval speed, but only keep the tether length engaging the brake. A comparison between the chosen design solution and the one just depicted is performed: keeping the above-mentioned margins our solution is: 16kg in mass with a peak power demand equal to 346W if a negative brake is exploited; on the latter solution has a mass equal to 13.5 kg and an overall power demand of 64W.

## 6 Final Remarks

The paper presented the preliminary design of a mechanism to control a tethered system to connect two different satellites, a chaser and a target, during the latter orbital removal. Some of the mechanism components have been studied deeply, such as the primary reel and the level-wind. The sizing process of these elements is almost complete despite some analysis about the technological process to manufacture them still should be performed. Once the final configuration for the tether is available it is possible to verify through tests if the D/d value considered in this thesis is too conservative or not; if it is, it shall be lowered since the lower D/d is, the smaller the mechanism envelope is, with a consequent mass saving. Motor sizing is lack since what it has been done should lead to a correct power and mass budget in terms of upper limits only. When a control law for tether control by means of the reel is available it is possible to verify the power and mass results, and, as it should be, to lower the power demand and mass related to the reel motor to get closer to the actual functioning of the mechanism. When the available electric power will be definitely fixed, it is possible to valuate if it is possible to consider the negative electrodynamic brake or if a positive one has to be selected since the available power is not sufficient to feed a negative brake when the motors are switched on. The grip pulley is the most critical and challenging device, with a complex functioning principle. What it remains to do is: perform a finite element analysis (FEA) to verify what is the actual bending capability of the designed pulley flanges and make a test campaign to evaluate the grip capability of such a device in order to find out which is the maximum level of tension the pulley can supply to the tether. It should be interesting analyze if the values chosen for tether minimum tension during retrieval and deployment oversize the problem or not. Furthermore the definition of a more suitable structure and its optimization has to be done thanks to a FEA since it has not been performed in this thesis. To do that it is important to know where the mechanism has to be attached onto the satellite structure; in this way it is possible to know which is the structural part loaded at the most, to be properly reinforced it. A problem the author notices deals with devices redundancy which is not present. Indeed it is possible only to increase the number of windings of the electric motors in order to keep the system more reliable; while the mechanical elements can not be duplicated. For that reason once mechanism design is enriched with a more detailed design of each element a test campaign shall start.

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