Review Article

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Preliminary Design of a Multi-Functional Textile based Tether for High Altitude Aerostat Systems

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Abstract
Lighter-Than-Air (LTA) technology based platforms like Tethered Aerostats have been used for several applications including surveillance, aerial photography, etc. Several challenges impede the successful mass commercialisation of such systems. One of the challenges faced during operation is the loss of altitude due to leakage of Hydrogen or Helium due to permeability issues resulting from the choice of envelope material. In order to reduce operational costs, a proposed methodology for developing a multi-functional tether is proposed. Conductive elements, including lightening protection cables, will be embedded into the tether structure. Also, the tether will have a passage for transport of the lighter than air gas or superheated steam (for a hot air aerostat system. This multi-layered tether structure will be manufactured using a 2D/3D braiding process. Braided structures present a lower susceptibility to breakage and have been proven to achieve higher load bearing capacities as compared to traditionally woven structures. Braiding also presents itself as a cost effective solution for high volume manufacturing currently being used by several other industries. This paper will present a preliminary design for the layout and manufacturing of this multifunctional tether structure.

Introduction
Tethered aerostats are classified as unmanned Lighter-Than-Air Systems. Aerostats have been actively applied to address several societal issues. These include aerial imaging, remote sensing, radar visual and infrared monitoring of international borders, airspace and movement on the ground, traffic monitoring and control, synthetic aperture astronomical telescopes, relaying electromagnetic signals, generation of wind power from the jet stream, and collection of solar power from above the cloud layer. Researchers have also proposed power generation using hybrid LTA based aerodynamic kite systems [1-14]. With a climate friendly trends towards adoption of renewable energy sources, there is a growing need for development of solutions for generation and transport of renewable energy souces.

The society has always been on a continuous quest for alternative means of generating electricity and one of the most important questions to be answered is 'How can we reduce the consumption while keeping the lights on?'. It has already been proved in practice that the single approach of simply installing solar and wind power capacity does not have a significant impact on reducing the carbon emissions and the effect is actually reversed in certain cases. Due to similar reasons and other technical considerations (improved capacity factor, availability of solar resource, lack of intermittency, irradiance levels and cooling of photovoltaic panels), the Space Farm concept provides a radical technological possibility to collect solar energy from high altitudes through a tethered buoyant platform filled with a lower than air density gas. Changing the environment of energy harvesting from ground to stratosphere offers a new perspective for the entire energy sector and can potentially inspire other ambitious ideas for future. Regarding the timespan of the project, early results will reflected in the first prototype of the platform, whereas the 1000 m model will serve as the overall aim for the duration of three years. The space farm concept is being currently investigated at ITA, Aachen Germany. Sub-scale trials are planned within the next year.

Aerostat System
An aerostat system consists of an aerodynamically shaped envelope which is attached to the ground station or winch via a tether. The envelope is connected by secondary tether like lines coming together at the confluence point. The weight of the aerostat system is balanced by the Lighter-Than-Air gas, typically, Hydrogen or Helium. In some cases, super-heated steam or hot air is also used a lifting gas. The total lift produced due to buoyancy and aerodynamic forces is balanced ny the self-weight of the aerostat, the tether drag force and the payload mounted onboard. A well-designed aerostat is tailored to carry a specific payload to a given operational altitude and has sufficient stability to maintain its position irrespective of changing wind directons.

Howver, several challenges impede the successful mass commercialisation of such systems. One of the challenges faced during operation is the loss of altitude due to leakage of Hydrogen or Helium due to permeability issues resulting from the choice of envelope material. In order to reduce operational costs, a novel concept for a multi-functional tether is proposed. This paper focusses on the material selection, manufacturing process and fabrication trials for the multi-layered, multifunctional tether.

Conceptual Tether Design, Materials Selection and Manufacturing Techniques

As discussed above, one of the key challenges is to develop an aerostat system that is capable of harvesting solar energy from operational altitudes upto 15km. In order to do so, a 'Space Farm' concept is developed. The main purpose of the Space Farm concept is to pave the way for innovative energy generating solutions and bridge the gap between ground and stratosphere floating power plants. The engineering expertise required to achieve this aim is heavily dependent on a multiple partner collaborative environment to meet at the crossroads of different disciplines and create a long-term renewable way of supplying the global energy needs. The space farm concept consists of three main elements namely, the solar canopy structure, multi-functional tether system and ground support equip-ment. The primary purpose of the solar canopy structure is to capture solar energy which is transferred back to the ground using the multifunctional tether system. The tether system comprises of a multi-layered structures consisting of load carrying members, electrical conductive element and a passage for transport of hydrogen, helium or hot air. The ground support system ensures the safe deployment and operation of the aerostat system. Details pertaining to the design of the tether system are provided in the next section.

Solar Canopy

The solar canopy consist of an inflatable shell structure with solar embedded cells on the surface. The envelope is made using light weight composite materials. The surface of the canopy structure is covered with thin textile based organic solar cells. The solar canopy also incorporates a textile sensor-based montitoring system to ensure that the optimal operational altitude is maintained as per requirement. Finally energy captured from the solar canopy is transferred to the ground using the multi-functional tether (Figure 1).

Figure 1: Schematic representation of Space Farm concept

Multi-functional Tether

Fibers have become indispensable in almost every technical application in the industry. Since the beginning of the 20th century, they are used worldwide industrially to replace already known technological applications such as steel and wood or improve them. Man-made fibers come in various forms of delivery, such as staple fibers, filaments or film strips. This flexibility allows for a wide range of applications. High-strength synthetic fibers have a significantly lower density, thus making them appropriate for usage in manufacturing of multifunctional tethers. The multi-functional tether consists of 3 main layers. The first layer consist of a load carrying member made using UHMW polyethylene (UHMW-PE) material. This inner most layer is made using UHMW-PE fibers. The next layer of the tether is made using electricially conductive fibers typically braided copper fibers. The adjacent layer also comprises of UHMW polyethelene UHMW-PE. Since UHMW polyethylene has a very low density, good insulation properties and high strength to weigh ratio, no significant impact to the overall weight of the tether system is observed. Finally, the other most layer is a load carrying member made using hybrid yarns (glass fiber and UHMW-PE). Figure 2 presents the schematic representation of the multi-functional tether design (Figure 2).

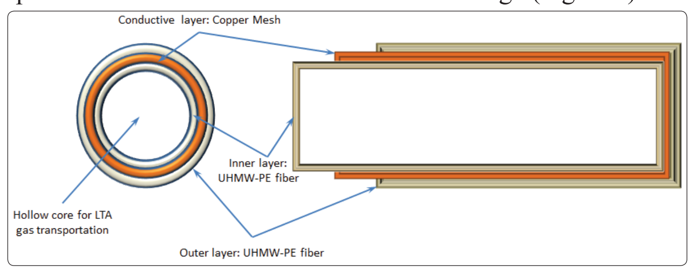

Figure 2: Comceptual representation of multi-functional tether design

Material Description

UHMW-polyethylene

Polyethylene fibers (PE) are organic chemical fibers. They belong to the class of polyolefins. Polyolefins are partial-ly crystalline thermoplastics. PE is prepared by the polymerization of ethene (C2H4). A special form are ultra high molecular weight polyethylene (UHMW-PE) (with a very high molecular mass M W ≥ 6 * 10 6 g / mol). This fiber is produced through a gel spinning process. This process is a modification of the solvent spinning process used for creating other polyethylene components. This special procedure is necessary since the polymer solution contains a high degree of crystallization compound (about 85%). The molecules are particularly long-chained elements con-nected by the gel spinning process. The long-chain molecules are arranged by extending in parallel to each other. Additional stretching and heat setting creates a special crystal structure. This particular crystal structure with the long-chain molecules is critical to the high strength of UHMW-PE. Table 1 provides an overview of the mechanical properties of UHMW-PE filament (Figure 3).

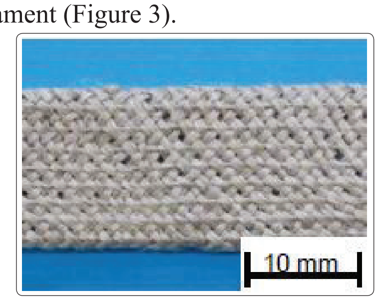

Table 1: Mechanical characteristics of a UHMW-PE filament material

Mechanical Characteritics (Value)	UHMW-PE
Modulus of Elasticity	172 kN/mm^2
Density	0.97 g/cm^3
Tensile Stregth	3300 N/mm^2
Elongation	4%
Maximum Operating Temperature	100° C

UHMW-PE filaments are characterized by a very low density of 0.97 g / cc from in contrast to other fibers. At the same time they have a very high strength and stiffness. This combination is usually not to be found in the field of plastic fibers. Additionally, it is chemically stable and has good electrical insulation. The filament is very abrasion resistant and has a very low water absorption.

Copper Mesh

Industrial grade copper fiber are incorporated into the tether system as a conductive element. This layer will be used for transferring the electrical energy captured by the solar canopy back to the ground storage system. Since UHMW-PE is a primary insulator, and is used on both surfaces of this copper mesh, there is no scope for leakage of electric charge (Figure 4).

Figure 4: Copper fiber processed using braiding technology

Manufacturing Trials and Results

In order to manufacture several elements of this tether, either 2D or 3D Braiding technology can be used. 3-D braid-ing is one of the more versatile processes for near-net shape manufacturing. Complex shapes of right angles and cylindrical components, as well as contoured shapes, can be produced with this technology. 2-D Braiding, on the other hand, is used to produce relatively simpler tubular structures. Multi-layered structures can also be produced using this technology. The principle of the braiding process is provided in (Figure 5).

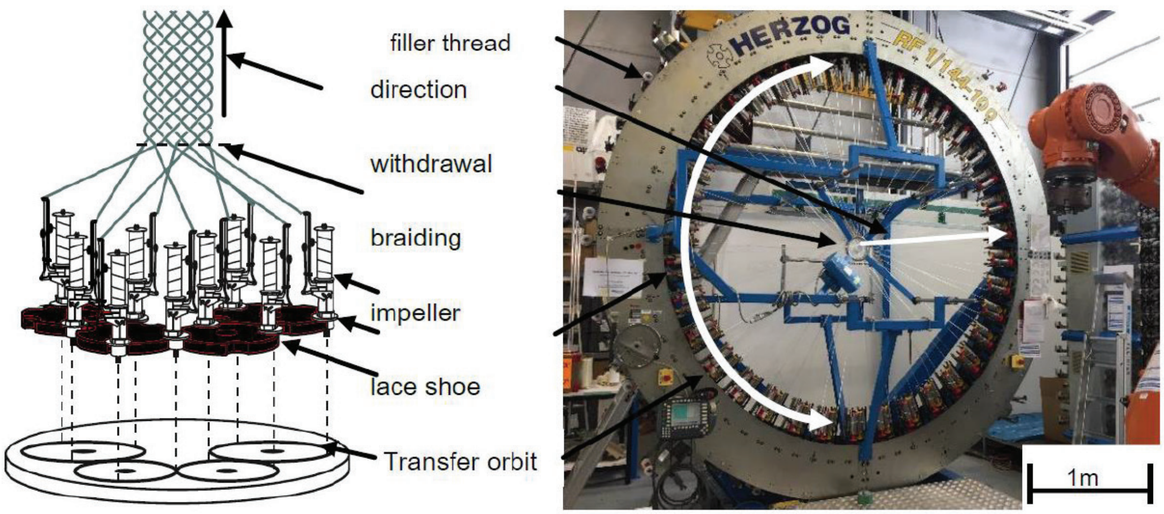

Figure 5: Principle of 2-D Braiding process

Manufacturing trials are carried out using the 2D Braiding machine at the Institut für Textiltechnik. Braiding of the outer layer of the tether system is carried out. Give time constraints and availability of internal resources, it was de-cided to produce a strucute with integral conductive elements. Trials are carried out 3 configurations of standing conductive yarns. The first configuration consisted of no standing yarns, the second configuration consisted of 2 standing yarns and the final configuration consisted of 4 standing yarns. The results, quality and reproducibility without defects, for each configuration were achieved. Figure 6 below shows the samples produced as a part of this project (Figure 6).

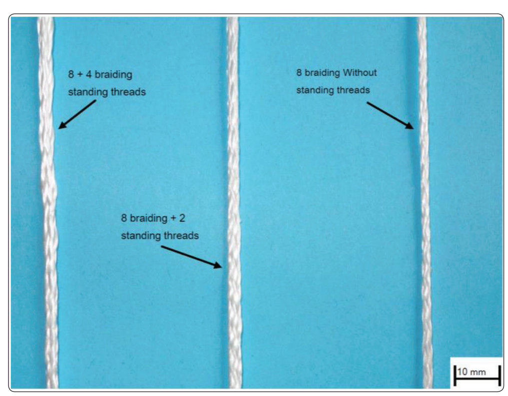

Figure 6: Copper fiber processed using braiding technology

Future work and Recommendations

In this paper elements of the multi-functional tether design are studied. Specifically, issues pertaining to material selection, manufacturing process identification, and fabrication trials are addressed as a part of this paper. The most critical layer i.e. the strength bearing layer of the tether was design and manufactured using 2D braiding technology. Futher work would investigate the manufacturing and assembly of all elements of the multi-functional tether.

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