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Method for electric solar wind sail tether production

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Abstract

We present a method to produce tether for the electric solar wind sail (E-sail) by bonding $25\mu m$ aluminium wires to a $50\mu m$ wire using an industrial semi-automatic ultrasonic wire bonder. We have used this method to create a 1.4 meter long two-wire tether structure with more than 100 wire-to-wire bonds. We tested 38 wire-to-wire bonds by destructive pull test and showed that they meet the 5g pull strength requirement of electric sail.

1. Introduction

The E-sail is a space propulsion concept that uses the dynamic pressure created by the solar wind to produce spacecraft thrust. The E-sail consists of a number of long, thin, conducting and centrifugally stretched tethers that are kept at high positive potential by an onboard electron gun [1].

The main requirements for the tethers are mechanical strength, conductivity and micrometeoroid tolerance [1]. Strength and conductivity-wise aluminium meets these requirements well. To improve the micrometeoroid tolerance and to extend the tether lifetime, a multiwire structure, fig. 1, was designed.

The tether consists of one continuous base wire and one or more continuous upper wires, that are bonded to the base wire. We call this design 'heytether'. We have been able to create heytether with two wires featuring a loop height of 3mm and an inter-bond distance of 10-15mm.

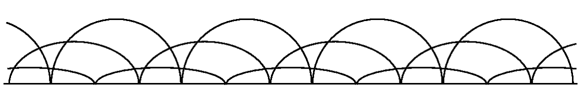

Figure 1: Illustration of heytether with one base wire and three upper wires.

2. Tether Factory

The tether factory is a custom made device that we have designed and produced. With the current tether factory we have created a two-wire tether structure by bonding a $25\mu m$ AlSi(1%) wire onto a $50\mu m$ AlSi(1%) base wire. The tether factory, fig. 2, guides the base wire from the wire spool into the tether factory, clamps the wire to fix it, induces tension into the wire and flattens a bonding site into it. Next the upper wire is bonded to the base wire with an ultrasonic bond method. Finally the clamps are released and the finished piece of tether is reeled onto a spool.

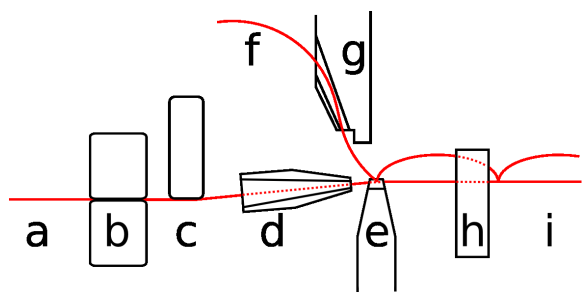

Figure 2: Schematic figure of the tether factory. a - base wire feed, b - first clamp, c - arm to create tension, d - capillary wedge to guide the wire, e - lower wedge with a groove serving as the bonding base, f - upper wire feed, g - upper wedge attached to the bonder, h - second clamp, i - finished tether.

2.1. Guiding the wire

The base wire is stored on a standard 2" spool. A teflon tube guided the base wire undamaged from the reel to the tether factory. A capillary bonding wedge, 2d, guided the base wire towards the lower wedge. This guide limits the base wire movement on the lower wedge.

2.2. Clamping and tensioning base wire

The base wire is clamped in two places inside the factory: before the tensioning arm, wire guide and bonding spot as well as right after the bonding spot (fig. 2b,h). The clamping fixates the wire and allows incuding tension into the fiber. To clamp the wire during the bonding process we use both a custom made clamp and a clamp employed in commercial wire bonders.

After clamping the wire, we lower an arm, fig. 2c, onto the wire to apply tension to the wire. To limit the tension and to deforming the wire, the wire slides under the first clamp when a force greater than a threshold value is applied.

At the bonding site, a fixed wedge ('lower wedge', 2e) with a ø50μm groove fixes the position of the base wire. This is done only after tension is applied to the wire.

2.3. Flattening base wire

To increase the flat area to bond to and in this way to improve the quality of the bonds, we create a flat area on the base wire. We do this by first turning in an arm from the side, over the top of the base wire and by then applying a downward force on the arm. This way a flat area is created on the base wire.

2.4. Wire to wire bonding

We use an industrial semi-automatic wire bonder to make the bonds. The upper wire that forms the heytether loops enters from the bonder spool to the upper wedge (fig. 2g). After clamping, tensioning and flattening the base wire we can bond the upper wire onto the flat area of the base wire. This wire is fixed in the groove of the lower wedge. One of these wire-to-wire bonds is shown in fig. 3. The core bond process is similar to the ultrasonic wire bonding technique commonly used in the microelectronics industry [2].

We tested 38 wire-to-wire bonds and average pull strength of $7.4 \pm 1.5g$ (one standard deviation) was seen. This shows that wire-to-wire bonds meet the 5g pull strength requirements of the electric sail.

2.5. Reeling the tether

After each bond is finished the clamps holding the base wire are released and the tether is moved to the next bonding position. The finished piece of tether is spooled on a plastic spool.

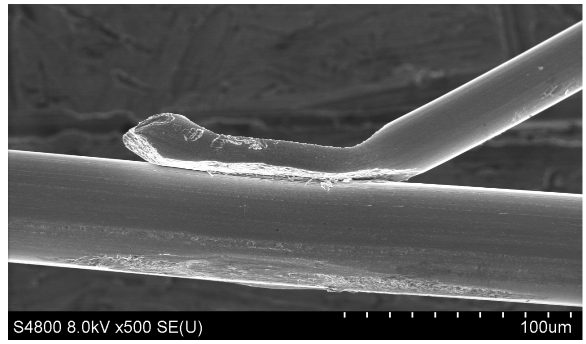

Figure 3: SEM image of a 25 μm wire bonded on a 50 μm wire.

3. Future development

We have proven the feasibility of this method to manufacture heytether for the electric sail by creating multiple samples exceeding 1 meter by length. To increase the efficiency of the method we next automate the tether factory. We will use AVR microcontrollers to control the electronic clamps fixing the wire and the motor spooling of the finished tether. Also the tension creation will be automated. We expect this semi-automatic operation mode to allow us to produce a continuous 10m long tether by the end of 2010.

We also work on methods to create the continuous four wire structure show in fig. 1.

4. Summary and Conclusions

A method to produce the tethers for the electric solar wind sail has been developed. Thin metal wires are bonded ultrasonically together to create a multi-wire heytether structure. The new tether factory that guides, clamps, induces tension, flattens and reels the wire has made this possible. We have shown that the wire-to-wire method is feasible for electric solar wind sail production.

References

[1] Janhunen, P. et. al.: Electric solar wind sail: Towards test mission, Review of Scientific Instruments, submitted, 2010.

[2] Harman, G.: Wire bonding in microelectronics : materials, processes, reliability, and yield, New York, McGraw-Hill, 1997.