

# ESAIL D21.1

## Tether factory (100 m)

Work Package: **WP 21**

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## 1. Introduction

The Electric Solar Wind Sail (E-sail) uses centrifugally stretched positively charged tethers to create thrust from the momentum flux of the solar wind. A full-scale E-sail should produce one newton of thrust from one hundred 20 km long tethers or from some other configuration featuring 2000 km total tether length.

For micrometeoroid resistivity, multifilament tethers are needed. In addition, the tethers must be electrically conductive, thin and strong enough to sustain the centrifugal force generated by the rotating E-sail.

The electric conductivity, density, and tensile strength of the Al(Si1%) bonding wire meet the requirements of the E-sail tethers. Also, Al-Al bonds are known to be reliable in long term use.

In this deliverable we present tether factory capable of producing 100 m of E-sail tether out of 25-50  $\mu\text{m}$  diameter Al wire.

## 2. Tether factory

An ultrasonic wire-to-wire bonding technique was developed to produce multifilament tether from 25-50  $\mu\text{m}$  diameter Al wires. In this process a specially designed wedge holds the 50  $\mu\text{m}$  base wire firmly in place during bonding while another customized wedge bonds the 25  $\mu\text{m}$  loop wire onto the base wire.

A custom 3-wire wedge was designed to produce 4-wire multifilament tether employing one bonder only (Fig. 1.). The 3-wire wedge permits us to bond three wires separately onto a single base wire. This wedge features three holes for the wires and grooves along the wire direction as well as large 51  $\mu\text{m}$  front and back radii in the foot to increase the strength of the bond neck.

To produce long, continuous multiline tethers we designed and implemented an automated tether factory (Fig. 2. and 6.). It employs an industrial 60 kHz ultrasonic wire bonder with the customized 3-wire wedge to produce a 4-wire tether. Automated tether production was first demonstrated with one wire attached to the 3-wire wedge to produce 2-wire tether and later 3-wires in the wedge to produce 4-wire tether. We bonded six bonds per minute in the tether production mode. That means 12 days continuous production time for 1 km tether.

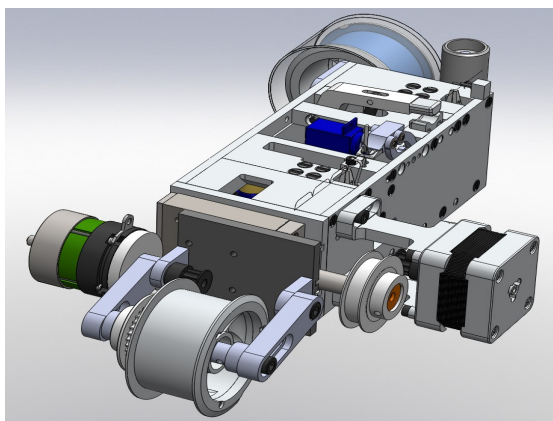


Figure 1. CAD drawing of the automated tether factory

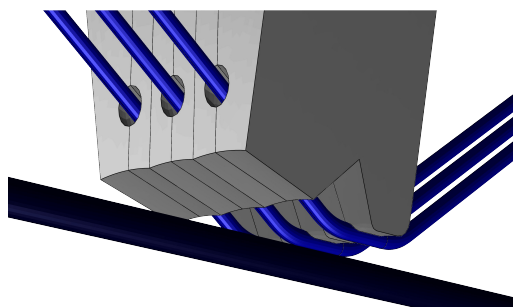


Figure 2. 3-wire wedge. Three 25  $\mu\text{m}$  diameter loop wires and 50  $\mu\text{m}$  diameter base wire.

### 3. Results

So far a 110 m long continuous 2-wire tether has been produced by bonding a 25 μm diameter loop wire to a 50 μm diameter base wire (Fig. 3.) Also we have produced a 13 m long 4-wire tether including three 25 μm diameter loop wires and 50 μm diameter base wire (Fig. 4. and 5.). All together 280 m 2- and 4-wire tether has been produced.

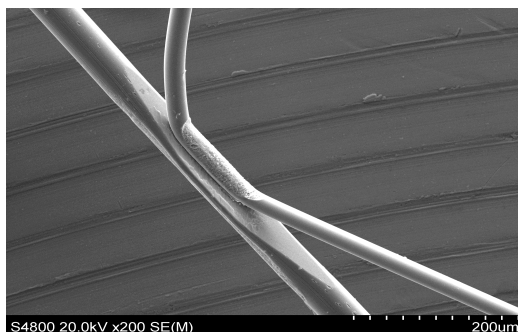


Figure 3. SEM image of the wire-to-wire bond

The measured bondability in 2-wire tether production was 99% and in 4-wire tether production the bondability was 96%. Bondability here means that the bonded wires remain attached after the bonding process before reeling.

Destructive pull testing serves as gold standard to assess the quality of the produced wire-to-wire bonds. We achieved  $11.6 \pm 0.8$  g maximum sustainable pull force for the produced wire-to-wire bonds. In the test 48 bonds were measured. The wires were pulled along the base wire direction.

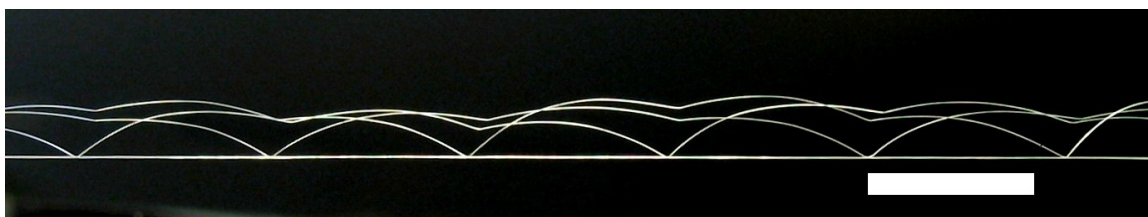


Figure 4. Photo of the 4-wire tether. White bar is 10 mm long.

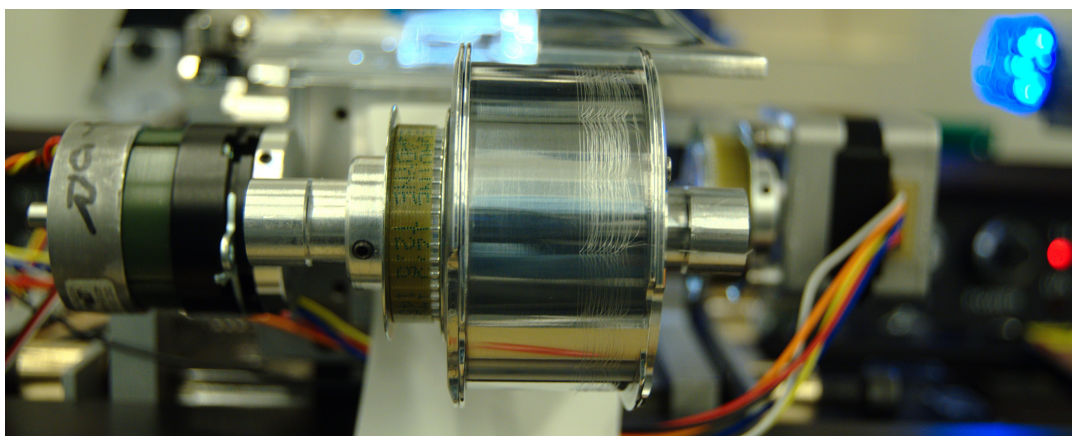


Figure 5. 4-wire tether on reel. The reel is 5 cm wide and has 5 cm radius

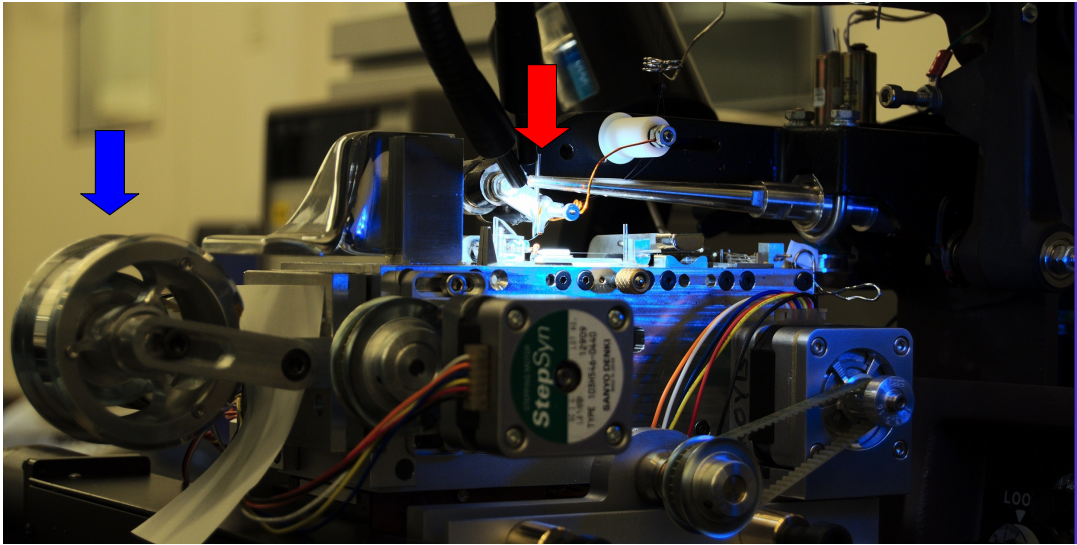


Figure 6. Tether factory in production. Blue arrow (left) shows the reel whereas red arrow (center) shows the bonding spot.