Cluster EFW boom deployment status report

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Background information

The EFW instrument comprises four boom units, each containing about 45 m of wire to be deployed by motors in each unit, see Figure 1. The length of deployment is monitored by two independent means. A potentiometer (see Figure 2) gives an analog measurement of the boom length and is contained in the spacecraft telemetry. A "click counter" gives a digital measurement of the boom length, and this value is also used by the EFW flight software when controlling the deployment. The click counter is actually a switch which goes on and off once during each half revolution of a measurement wheel which is driven by the cable. Each click corresponds to a distance of about 95.48 mm. Figure 3 shows the click counter for SC1, unit 1. The switch is here in the "off" position, with the wheel on the low portion of the cam. Figure 4 shows the click counter for SC1, unit 2. The switch is here in the "on" position, with the wheel on the high portion of the cam, and the spring is under tension. Of the 16 boom units on Cluster, 5 had the switch in the "off" position and 11 in the "on" position after refurbishment. The deployed length in mm/click has been calibrated individually for each boom unit, see Figure 5. The spread is partly due to real differences in the units, partly due to measurement uncertainties. The average value for all units is 95.48 mm/click, and this value is used in the boom length calculations below.

The overall plan for the EFW boom deployment is given in Table 1. The booms are deployed on four different occasions, up to a total deployed length of 42 m. The value of 42 m gives a margin of 1.5 m of wire remaining in each boom unit after final deoployemt. **It is suggested to increase this margin to 2.5 m and thus to deploy only to a final wire length of 41 m, which will give a sphere to sphere distance of 88 m.**

Spacecraft 2

1. Overview

First deployment: 2000-09-05

1. Booms 3+4 were deployed 30 clicks, 2.86 m; spin rate 15.04-14.95 rpm
2. Booms 3+4 were deployed 127 clicks, 12.13 m, spin rate 14.95-13.35 rpm
3. Booms 1+2 were deployed 30 clicks, 2.86 m; spin rate 13.35-13.27 rpm
4. Booms 1+2 were deployed 127 clicks, 12.13 m; spin rate 13.27-11.95 rpm
5. Spin-up 11.95-21.86 rpm

After this deployment, spheres are at 1.5 m + 15 m + 1.5 m = 18 m from s/c centre.
The Potentiometers show, for the 4 booms:
Before deployment: 1.37 m, 1.46 m, 1.46 m, 1.37 m.
After deployment: 16.28 m, 16.03 m, 16.48 m, 16.47 m.

(These values have been calibrated to include the spacecraft radius of 1.5 m, but not the extra 1.5 m of thin wire between hockey puck and sphere.)

Second deployment: 2000-09-12

1. Booms 3+4 deployed 210 clicks, 20.05 m; spin rate 21.84-14.33 rpm
2. Booms 1+2 deployed 52 clicks, 4.96 m; spin rate 14.33-13.58 rpm

After this deployment, spheres 1+2 are at 3 m + 20 m = 23 m from s/c centre, and spheres 3+4 are at 3 m + 35 m = 38 m from s/c centre.
The potentiometers show, for the 4 booms:
After deployment: 21.37 m, 20.97 m, 36.68 m, 36.53 m.

Third deployment planned for 2000-09-18

1. Booms 3+4 to be deployed 63 clicks, 6.02 m; spin rate 13.58-TBD rpm

NOTE: This is 1 m less than in the plan of 2000-04-22. This will increase the margin to end-of-wire from 1.5 m to 2.5 m.

This will bring spheres 3+4 to 3 m + 41.06 m = 44.06 m from s/c centre.
Potentiometers should show (predicted): 21.37 m, 20.97 m, 42.68 m, 42.53 m.

2. Performance/Problems

All deployments performed nominally. No missing clicks. Boom lengths agree with reduction in spacecraft spin rate and with s/c potentiometer readings.

3. Procedure for next (3rd) deployment

Use nominal deployment sequence, i.e., EFW software control, to deploy booms 3+4 63 clicks.
Set OBDH monitoring to stop deployment at current length + 6.5 m (6.02 m planned deployment length + 0.5 m margin), which is 2 m before end-of-wire.
Monitor clicks (and missing clicks) in real-time. Stop deployment if any missing clicks to assess situation. Clicks can be monitored with 10 s time lag, corresponding to 10 cm deployment. Missing clicks can be monitored with 40 s time lag, corresponding to 40 cm deployment.
Monitor potentiometer increase in real-time. Stop deployment if one potentiometer stops increasing. Potentiometer can be monitored with 10 s time lag, but with a resolution corresponding to appr 10-20 cm.
Monitor spin rate in real-time. Stop deployment if spin rate does not decrease as expected. Spin rate can be monitored with 30 s (TBC) time lag.

Spacecraft 1

1. Overview

First deployment: 2000-09-07

1. Booms 3+4 were deployed 30 clicks, 2.86 m; spin rate 15.14-15.04 rpm
2. Booms 3+4 were deployed 127 clicks, 12.13 m, spin rate 15.04-13.43 rpm
3. Booms 1+2 were intended to be deployed by 30 clicks
   Actually boom 1 was deployed 30 clicks, 2.86 m, and
   boom 2 was deployed 30+5 clicks, 3.34 m; spin rate 13.43-13.34 rpm
4. Booms 1+2 were intended to be deployed by 127 clicks.
   Actually boom 1 was deployed 127 clicks, 12.13 m, and
   boom 2 was deployed 126+33 clicks, 15.18 m; spin rate 13.34-11.71 rpm
5. Spin-up 11.71-21.77 rpm

After this deployment, spheres 1+3+4 are at 1.5 m + 15 m + 1.5 m = 18 m from s/c centre, and sphere 2 is at 1.5 m + 18.5 m + 1.5 m = 21.5 m from s/c centre.
The Potentiometers show, for the 4 booms:
Before deployment: 1.46 m, 1.37 m, 1.37 m, 1.37 m.
After deployment: 16.24 m, 19.69 m, 16.10 m, 15.98 m.

Second deployment planned for 2000-09-20

1. Booms 3+4 to be deployed 210 clicks, 20.05 m; spin rate 21.77-TBD rpm
2. Boom 1 to be deployed 52 clicks, 4.96 m; spin rate TBD-TBD rpm
3. Boom 2 to be deployed 52-37 = 15 clicks, 1.43 m; spin rate TBD-TBD rpm

This will bring spheres 3+4 to 3 m + 35 m = 38 m from s/c centre, and spheres 1+2 to 3 m + 20 m = 23 m from s/c centre.
Potentiometers should show (predicted): 21.24 m, 21.12 m, 36.10 m, 35.98 m

2. Performance/Problems

Deployments of spheres 3+4 performed nominally. No missing clicks. Boom lengths agree with reduction in spacecraft spin rate and with s/c potentiometer readings.

Deployment of spheres 1+2 performed with anomaly on sphere 2. The click counter in EFW instrument missed 5 clicks during first run (nominal 30 clicks) and 33 clicks during second run (nominal 127 clicks). EFW instrument controls both boom lengths so that the difference in clicks between the two unit remains less than or equal to 2. This means that motor 1 stopped several times in order for the clicks on unit 2 to catch up. This was noticed during the first motor run. A difference in the two potentiometer readings for unit 1 and 2 was also noticed. Given a) that the potentiometer is inherently less accurate than the click monitor, and b) that this deployment only should bring the booms out by 15 m, and thus there was ample margin to the end of wire, it was decided to increase the limit of the onboard monitoring of the potentiometer for boom 2 to 19.5 m for the second motor run. The deployment was stopped by the OBHD monitoring at 19.5 m, when a fraction of a click remained on unit 2 to the commanded value of 127 clicks. Subsequent analysis of spin rate, potentiometer readings, and a more careful inspection of the EFW science telemetry for evidence of missing clicks all showed in agreement that unit 2 had been deployed by approximately 3.5 meters extra.

An example of how the missing clicks are detected may be found in the accompanying Table 2 and Figure 6.

There was no detectable effect on the spacecraft nutation from the asymmetry between booms 1 and 2. The spin-up from 11.71 to 21.77 rpm performed nominally. Figure 7 shows additional evidence that boom 2 is longer, in that sphere 2 separated from the hockey puck about 10-15 s earlier than spheres 1, 3 and 4, due to the larger centrifugal force.

3. Procedure for next (2nd) deployment

Use nominal deployment sequence, i.e., EFW software control, to deploy booms 3+4 by 210 clicks to a length of 35 m.

Use a modified deployment sequence to deploy booms 1 and 2 to a length of 20 m. The suggested sequence is the following.

First deploy boom 2 by 15 clicks. Use EFW flight software control of the deployment. **(An advantage of using EFW software to deploy is the safety feature within the EFW instrument that will switch off deployment on a wire jam or an end-of-wire signal. Without this safety feature, the wire may be torn if it jams or reaches the end-of-wire state.)** Command deployment at time T of boom 2 only by 15 clicks. Follow this command by a deployment off command at time T+136.5 seconds (1438 seconds/(125+33) clicks x 15 clicks). In addition, set the OBDH monitoring to switch off deployment at 21.5 m (TBC, calculated as 19.69 m (value before deployment) + 1.43 m (planned deployment length) + 0.4 m (margin)).

When it has been verified that unit 2 has deployed to the nominal distance of 20 m, use the EFW software to deploy boom 1 only by 52 clicks.
Monitor clicks (and missing clicks) in real-time. Stop deployment if any missing clicks to assess situation. Clicks can be monitored with 10 s time lag, corresponding to 10 cm deployment. Missing clicks can be monitored with 40 s time lag, corresponding to 40 cm deployment.
Monitor potentiometer increase in real-time. Stop deployment if one potentiometer stops increasing. Potentiometer can be monitored with 10 s time lag, but with a resolution corresponding to appr 10-20 cm.
Monitor spin rate in real-time. Stop deployment if spin rate does not decrease as expected. Spin rate can be monitored with 30 s (TBC) time lag.

A topic for discussion is whether it might be wise to deploy first booms 1+2 to full length, and follow with booms 3+4 afterwards, if there should be a need for fine tuning to adjust all booms to equal length. This may be accomplished by interchanging the boom pairs 1+2 and 3+4 in the commissioning steps C, D and E. This will, however, have implications for the commissioning of other instruments (e.g., the WHISPER procedures are prepared for transmission on one boom pair and receeption on the other), and must be agreed on by all parties.