Space Tether Experiment on SFU

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Abstract

A plan for a space tether experiment(STEX) onboard the Space Flyer Unit(SFU) is discussed. The SFU is a reusable space platform now under development in Japan for advanced science and technology experiments. It will be put into an orbit of about 500 km altitude and be retrieved by the space shuttle after a 6-12 month mission. In the STEX, a tethered subsatellite of 40 kg is repeatedly deployed up to 10 km from the SFU. The major objective of the experiment is to establish the control methods for the space tether, including deployment, station-keeping, and retraction. The tethered subsatellite will also be used as a diagnostic package to study the large scale space environment surrounding a spacecraft. This paper describes the instruments we have designed and proposed as experimental scenarios for the STEX experiment.

1. Introduction

Applications of space tethers have been proposed in various fields of space technology and space science. A tether-elevator, a momentum transfer system, an electrodynamic power generator, and a wave transmitter are all potential applications(Ref.1). Tether systems can also be applied to atmospheric and aero-thermodynamic research. The examples of application of space tether are summarized in Table 1. Although it has a promising future, the technologies relating to its control have not been well established yet. Many control laws of space tethers have been proposed, but none of them has been verified in space. Establishment of these tether technologies is the first step towards its application.

Space Tether Experiment(STEX)(Ref.2) is one of the candidates for the experiments on Space Flyer Unit(SFU) Mission 2, although the mission has not been authorized yet. SFU is a reusable experimental platform for various kinds of space science and technology research(Ref.3). It is launched by an expendable vehicle or the space shuttle, and retrieved by the space shuttle. SFU Mission 1 is currently planned early in 1994. It has an octagonal modularized structure 4.46m in diameter and 3.07 m in height. The orbit is 500 km circular and the standard attitude is sun-oriented. It carries 1000 kg of payload in total. The total weight is about 4000 kg including payload. The average power to the payload is 850 watt typically. It is equipped with three-axis attitude control systems using a reaction control system, magnetic torquers and reaction control wheels. In the STEX experiment, we plan to deploy a tethered subsatellite up to 10 km in various directions with respect to the SFU. The objectives of the experiment are; 1) verification of the control laws of the space tether, including deployment, station-keeping, and retraction, 2) study of the spacecraft-generated environment on a large scale using a plasma diagnostic package on the tethered subsatellite.

A space tether experiment is planned in 1992 on the space shuttle(TSS-1; Tethered Satellite System-1), in which a tethered satellite will be deployed up to 20km from the orbiter(Ref.4). In the TSS-1, the deployment/retraction of the tethered subsatellite will be performed only once during a short mission period(~10 days). Although TSS-1 will be able to demonstrate the feasibility of space tether control for the first time, it is not sufficient to establish the space tether technologies. On the other hand, the mission period of the SFU is expected to be more than 6 months. The deployment

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and retraction of the tethered subsatellite will be tested repeatedly more than twenty times to establish the space tether technologies. In the experiment, the control laws to stabilize the tether system will be studied by applying an impulse to the subsatellite during the station-keeping phase.

Table 1 Potential Applications of Space Tethers

Space Transportation	Tether Elevator Momentum Transfer System
Orbit/Attitude Control	JxB Control Asteroid Swing-by
Mooring	Fuel Tank Power Generator Vertically-Connected Geosynchronous Satellites Space Walk、 Space Rescue
Power Generation	V x B Power Generation
Space Communication	ELF Communication
Observatory Platform	Multi-Satellite Observation(TSS-2,TSS-J) Astronomical Observation （VLBI) ELF Receiver （Long Antenna） Space Environment Monitor(STEX)
Experimental Platform	High-Quality Micro-Gravity Experiment Active Experiments Electrodynamic Tether(TSS-1) Experimental Target （Laser, Microwave Transmission)
Planetary Mission	Surface Sampler

2 STEX Configuration and Instrumentation

The basic concept of the STEX is illustrated in Fig.1.Two types of experimental configuration have been considered within the restriction of SFU capabilities, as shown in Fig.2. The tethered subsatellite must be deployed so as not to interfere with the SFU solar paddles. Configuration (a) allows the SFU to maintain a sun-oriented attitude, but the SFU is required to compensate a torque generated by the tethered system. In configuration (b), the tethered system does not give a torque to the SFU, but experiment time is limited because the sun-oriented attitude cannot be maintained.

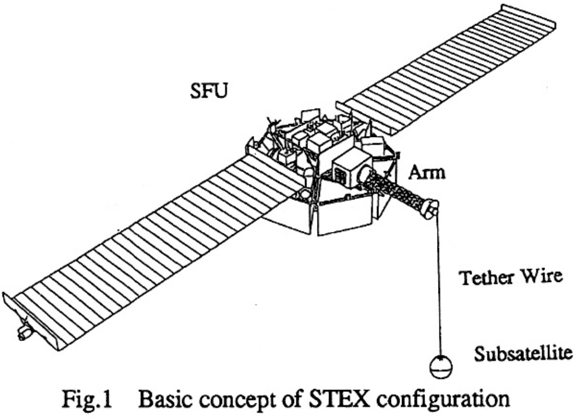

Fig.1 Basic concept of STEX configuration

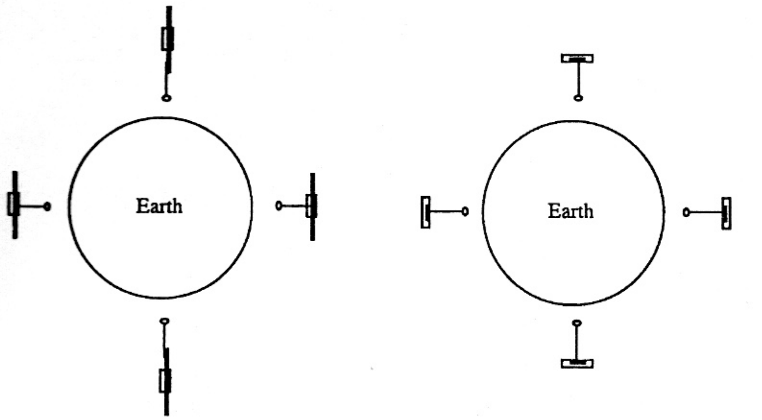

Fig.2 STEX experimental configuration

The STEX system is composed of three subsystems; an experiment control processor, a tether deployment/retrieval system and a subsatellite.

- Experiment control system
  - Data/command interface with the SFU Control and Data Management System(CDMS)
  - Electric power interface with the SFU bus power system(50 V typical)
  - Communication system with the tethered subsatellite(S-band telemetry and antennas)
  - Dedicated experiment processor
    - Experiment sequencer
    - Tether system control logics(deployment, station-keeping, retraction, stabilization)
  - Control logics are modified and edited by ground command and data uplink
- Tethered subsatellite deployment/retraction system
  - Tether wire(10 km, 0.5 mm ϕ , teflon-coated Kevlar)
  - Tether wire storage system
  - Tension controller (10 N max, 1.5 N nominal)
  - Deployment/retraction velocity control system (10 m/s max, 5 m/s nominal)
  - Subsatellite storage/extension system (latch, arm, charging system)
  - Tether subsatellite separation mechanism for emergency
  - The conceptual design of the deployment/retraction system is shown in Fig.3.
- Tethered subsatellite(40kg)
  - Communication system with SFU(S-band telemetry and antennas)
  - Subsatellite control system (telemetry and command, thruster control)
  - Power system (solar cells attached to the surface)
  - Batteries
  - 3-axis cold thruster system
  - IMU(Inertial Measurement Unit)
  - Environment diagnostic package(vacuum gauge, plasma density meter, wave receiver)

Experiment support systems on the SFU, such as TV cameras and Environment Monitoring System(EMS), are utilized in the STEX experiment. The EMS includes two vacuum gauges, a mass spectrometer, a plasma density meter, and two wave receivers. According to the current design, the total weight, power, and data rate required for the STEX are estimated as 200 kg, 100 watt on average(500 watt maximum), and 4000 bps, respectively.

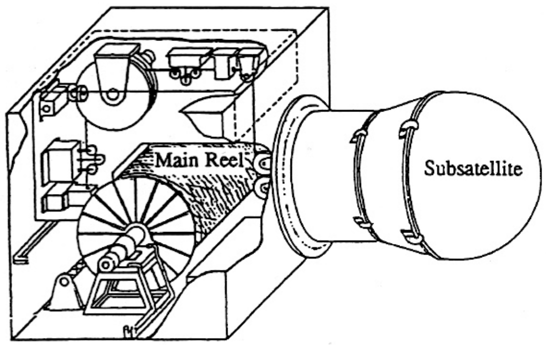

Fig.3 Tether subsatellite deployment/retraction system

3. Tether Control System

3.1. Control Scenario

A preliminary scenario for 10 km tether deployment, station-keeping, and retraction under gravity gradient has been investigated. The tether system can be stable if 3-axis thrusters on the subsatellite are fully operated. However, the operation of the thrusters needs to be minimized for future application because it is costly. In the scenario, the tether system is stabilized by the thrusters(thruster control mode) when the gravity gradient force is relatively small within 5 km from the SFU, and it is controlled by using the gravity gradient(tension control mode) when the subsatellite is more than 5 km from the SFU. The gravity gradient force reachs 0.7 N at 5 km separation. The feedback laws for swing control have been obtained by applying an optimum control theory to the linearized dynamic equations of the tether system, neglecting the air drag force(Ref.5). The out-of-plane dynamics are separated from the in-plane dynamics in this scheme. The proposed scenarios for deployment and retraction are shown in Figs.4 and 5, respectively. Several other scenarios using different control laws will be prepared for the experiment. The control system will be designed to transfer to the thruster control mode(safe mode) from the tension control mode at any time if the tension control should fail. The control laws will also be tested during the station-keeping phase by operating the thrusters to give an impulse to the subsatellite.

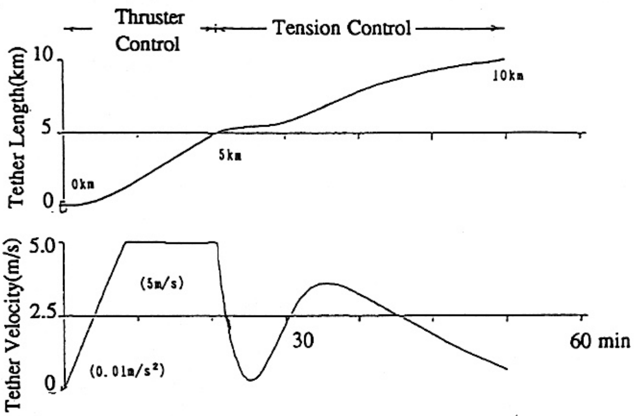

Fig.4 A control scenario for 10 km deployment

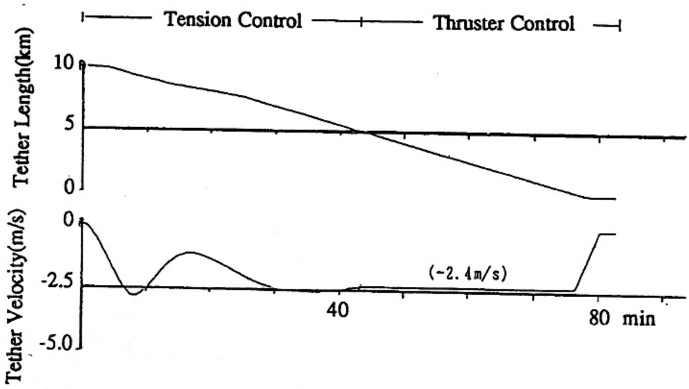

Fig.5 A control scenario for 10 km retraction

3.2 Control System

The control system is designed to realize the control scenarios in 3.1. Fig.6 shows the block diagram for the control system of tether deployment/retraction system. It consists of a reel drive subsystem and a grip pulley subsystem. The reel drive mechanism controls the tension of the tether. The grip pulley mechanism functions to prevent wire slackening inside the deployment/retraction system. Both subsystems interfere with each other, but their controllers are designed not to interact strongly. This scheme has been adopted from a stand point of simplicity and reliability. A laboratory test model(Fig.7) is now under development for system verification.

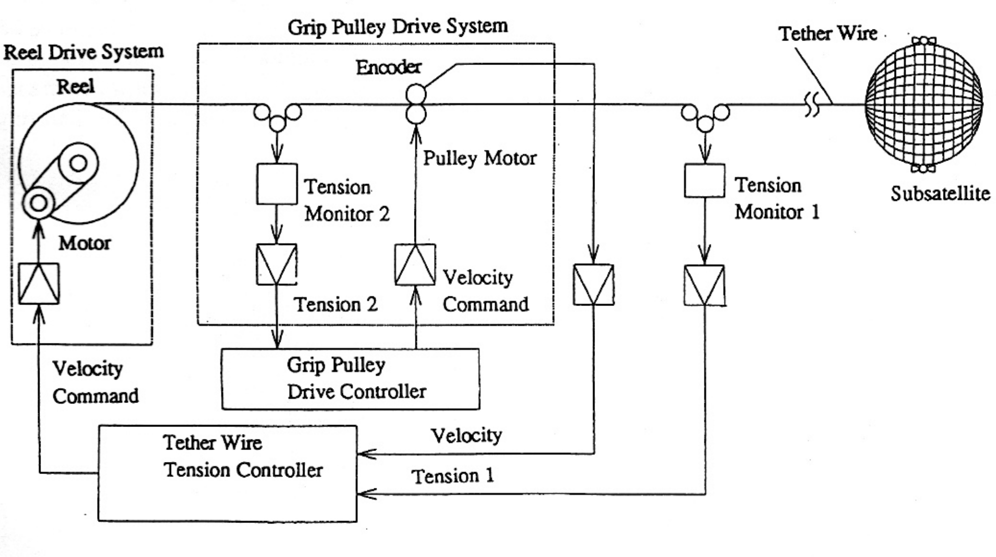

Fig.6 Block diagram of control system

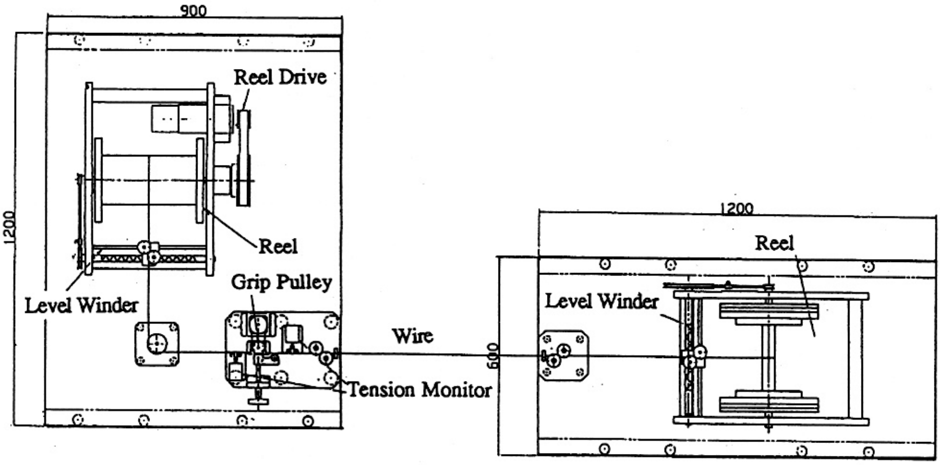

Fig.7 Laboratory system test model

4. Study of Spacecraft Environment

The space environment around a spacecraft is considered to be strongly modified by the spacecraft itself. The process includes gas/plasma interaction with a solid body at a high relative velocity more than the ion acoustic wave velocity. Plasma wake, collisionless shock structure, associated wave generation, and propagation of spacecraft disturbance are the major effects. The interaction scale is expected to extend greater than 100 times the scale of the spacecraft. The sounding of the spacecraft environment requires a diagnostic package extended beyond the spacecraft. The study of spacecraft environment is important in the fields of space physics and planetary science(Ref.6). In the PDP(Plasma Diagnostic Package) experiment on the space shuttle, a free-flying plasma diagnostic pakage was used to study the shuttle-generated space environment. It showed the existence of plasma wake on a large scale for the first time. The tethered subsatellite system will provide a powerful tool to study the spacecraft environment on a larger scale in a controlled manner. Fig.8 shows the model of spacecraft environment to be studied by the tethered subsatellite carrying a plasma diagnostic package.

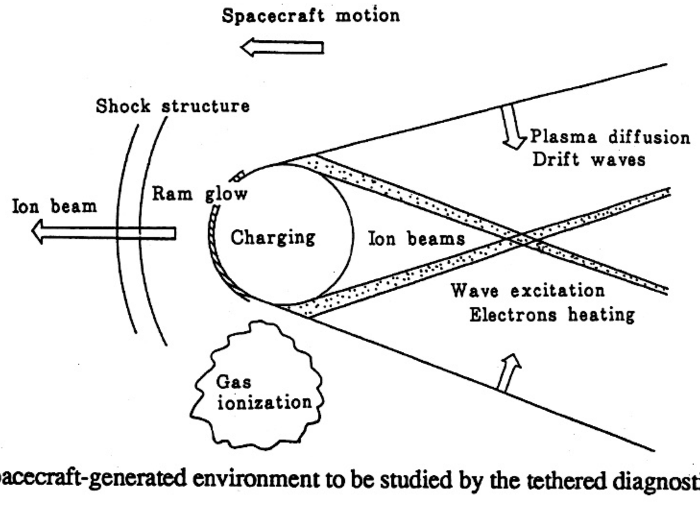

Fig. 8 Spacecraft-generated environment to be studied by the tethered diagnostic package

5. Experimental Scenarios

Experimental scenarios are generated considering mixed payloads for the SFU Mission 2. The experiment time is assumed to be totally 3 months for this experiment. 7 functional objectives(FOs) have been defined.

FO-1 Initial System Checkout(10 min)
: The function of the three subsystems are first tested and latch mechanisms in the deployment/retraction system are released.

FO-2 20 m Deployment/Retraction Test(120 min)
: The tethered subsatellite is deployed up to 20 m in 15 min, the position is kept for 90 min, and retracted in 15 min. The basic system functions, deployment, station-keeping, and retraction, are verified by instrument monitors and monitor TV cameras. The control software may be modified by ground command as required.

FO-3 100 m Deployment/Retraction Test(135 min)
: The tethered subsatellite is deployed up to 100 m in 15 min, the position is kept for 90 min, and retracted in 30 min. Potential control logics are tested for deployment, station-keeping, and retraction, and optimum logics are selected for the next-step experiment.

FO-4 1000 m Deployment/Retraction Test(210 min)
: The tethered satellite is deployed up to 1000 m in 15 min, the position is kept for 75 min, positioned in the cone region of 45 degrees for 90 min, and then retracted in 30 min. The selected control logics in the previous FO are confirmed.

FO-5 10,000m Tether Gravity Stabilization Test(360 min)
: Tension control mode is first tested. Using the selected control logics verified in the previous FOs, the tether satellite is deployed and positioned at the final target, 10km from the SFU. Control logics to stabilize the tether system are tested by applying an impulse to the subsatellite using the satellite thrusters.

FO-6 Satellite Charging(300 min)
: Before FOs-2～5, the subsatellite batteries are charged by the SFU power system.

FO-7 Preparation for Retrieval(10 min)
: The movable mechanisms are latched before SFU retrieval.

In FOs-2 to 5, environmental measurements are carried out simultaneously by the diagnostic package on the subsatellite and the Environment Monitoring System on the SFU. In case the microwave transmission experiment(METS) or the laser propulsion experiment(LPE) is one of the co-payloads in the SFU Mission 2, the tethered subsatellite could be used as a target satellite to study the microwave or laser power transmission in space(Refs.7 and 8).

6. Conclusion

An experimental plan for space tether experiment on the SFU has been discussed. The tether deployment/retraction mechanism is designed. Based on the results of the conceptual design, feasible experimental scenarios are developed. The experiment will establish the technologies to control a space tether by repeating deployment, station-keeping, and retraction. It will also provide useful data from a stand point of space science on the spacecraft-generated environment on a large scale. Further research will be required, as for (1) to develop the control laws with out-of-plane dynamics taken into consideration, (2) to find a reliable method to detect the exact position of the subsatellite, and (3) to verify the current design of the tether deployment/retraction system by using a laboratory test model.

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