NAL TR-1176T

ISSN 0389-4010
UDC 62-427:62-252:
677.052.485/677.022.93:
677.052.954

TECHNICAL REPORT OF NATIONAL AEROSPACE LABORATORY

TR-1176T

AN EXPERIMENTAL STUDY OF TETHER REEL SYSTEM — A LABORATORY MODEL —

YOSHIMURA Shoichi and OKAMOTO Osamu

August 1992

NATIONAL AEROSPACE LABORATORY

CHŌFU, TOKYO, JAPAN

AN EXPERIMENTAL STUDY OF TETHER REEL SYSTEM*
— A LABORATORY MODEL —

YOSHIMURA Shoichi*1 and OKAMOTO Osamu*1

ABSTRACT

A laboratory prototype model of a reel system has been made as the first step of an in-house hardware study of the tether system in space. The model is consisted of two main parts, i.e., a reel drum driving (RDD) unit (25 kg weight) and a power supply/signal processing (PSSP) unit (32 kg weight). The tether (0.8 mm in diameter and 300 m long) consists of a Kevlar fiber core and a nylon fiber jacket.

Following the preliminary functional test, a computer-controlled functional test has been carried out using a 32-bit personal computer as a control processor. The tests have shown that the stable operations of reel-out and reel-in are posible by tension control in both cases of a small tension (light end weight) and a high frequency input to the reel drum driving motor.

Keywords: tether, reel system, tension control

概　　　　要

宇宙基地などの大型有人母船から100～250m離れた小型ペイロード内で，10^{-4}～10^{-5}Gの微小重力レベルを実現することを目標とするテザーシステムについての検討を行っている。これまではシステムの概念検討及びその運動の数値シミュレーションを行ってきた。今回それと並行してシステムを構成する主要なサブシステムの一つである，テザーの繰り出し／巻き取り用リール機構の機能モデルの試作とその機能試験を実施した。

モデルはリールドラム駆動部(25kg)と電源／表示部(32kg)とから構成される。前者は，リール機構（ドラム，駆動用モータ，電磁ブレーキ，レベルワインダ），張力制御機構／計測装置（張力計），テザー長さ計測装置（エンコーダ），コネクタパネルから成り，それらが共通の架台に搭載されている。後者は，AC100V外部電源により駆動され，前者への電力／信号の供給，信号の受け取り，エンコーダのパルス信号から繰り出し／巻き取り速度信号を生成するなどの信号処理を行って外部に出力すると共に，前面パネルにそれらを表示する。また，切り替えスイッチにより，ローカル（オープンループモード）／リモート（閉ループモード）の両モードのいずれかで作動する。

テザーは直径0.8mm，長さ300mで，ケブラー繊維の芯線をナイロン繊維で被覆してある。

まずローカルモード（オープンループ）での基本機能試験により良好な作動を確認し，引き続いてリモートモードでのコンピュータ制御による機能試験を実施した。制御プロセッサには32ビットパーソナルコンピュータ（CPU：INTEL 80386 20MHz，浮動小数点演算用コ

*Received 19 June, 1992
*1Space Technology Research Group

プロセッサ：INTEL 80387 20MHz）を用いた。コンピュータ制御による機能試験においては，テザーの繰り出し／巻き取りの運動の空間を確保するために，10mの落差を持つ当所の無重力実験用落下塔施設を使用し，滑車を介して垂直下向きとしたテザーの先端には錘を付けて張力を発生させた。

実験により，テザーの張力の小さい場合（軽量の錘）の繰り出し，及びリールドラム駆動モータへの高周波数の正弦波入力による連続的な繰り出し／巻き取りが，張力制御機構を作動させることにより，テザーを弛ませることなく共に安定に行えることを確認した。

1. Introduction

There have been proposed and studied a lot of applications of space tether systems[1,2,3,4,5,6]. A study of the tethered microgravity laboratory (small satellite) deployed in the proximity of the large mother spaceship has been carried out in National Aerospace Laboratory (NAL). Target range of the microgravity level to be realized is $10^{-4} \sim 10^{-5}$ G. The numerical simulations of the dynamics of the mother spaceship/tether/satellite system have been in execution[7,8,9].

The hardware studies of the tether systems such as Tethered Satellite System (TSS) and Small Expendable-tether Deployer System (SEDS) have been reported. The former[10] is a joint program by U.S. National Aeronautics and Space Administration (NASA) and Italian National Space Plan of the National Research Council (PSN/CNR). The latter[11,12,13,14] is a program of NASA Marshall Space Flight Center. Hardwares of both tether systems have been already developed preparing for Shuttle based space test and Delta II (second stage) based space verification test respectively, although both tests are postponed so far partly because of a tragedy of Space Shuttle Challenger.

A tether reel system, just a laboratory prototype model, has been made in NAL as the first step of the in-house hardware study of the tether system preparing for the potential space verification test in the future.

Following the preliminary functional test, the computer-controlled functional test has been carried out using a 32-bit personal computer as a control processor.

2. Outline of the Tether Reel System

The model is consisted of two parts; reel drum driving (RDD) unit and power supply/signal processing (PSSP) unit. The outlines of them are described below.

2.1 Reel Drum Driving (RDD) Unit

The unit is 25 kg weight, 900 mm wide, 230 mm high, and 370 mm deep and, is consisted of ten main components ①~⑩ as shown in Fig. 1. They are mounted on the base table.

The reel drum (80 mm in diameter) is driven by a servomotor and is equipped with an electromagnetic brake. The specifications of servomotor and electromagnetic brake are shown in Tables 1 and 2 respectively. The DC servomotor outputs 0.637 N-m (6.5 kgf-cm) rated torque. Armature time constant of electromagnetic brake is 25 msec.

Level winder works in both operations of winding-off and winding-up synchronizing with the reel drum rotation.

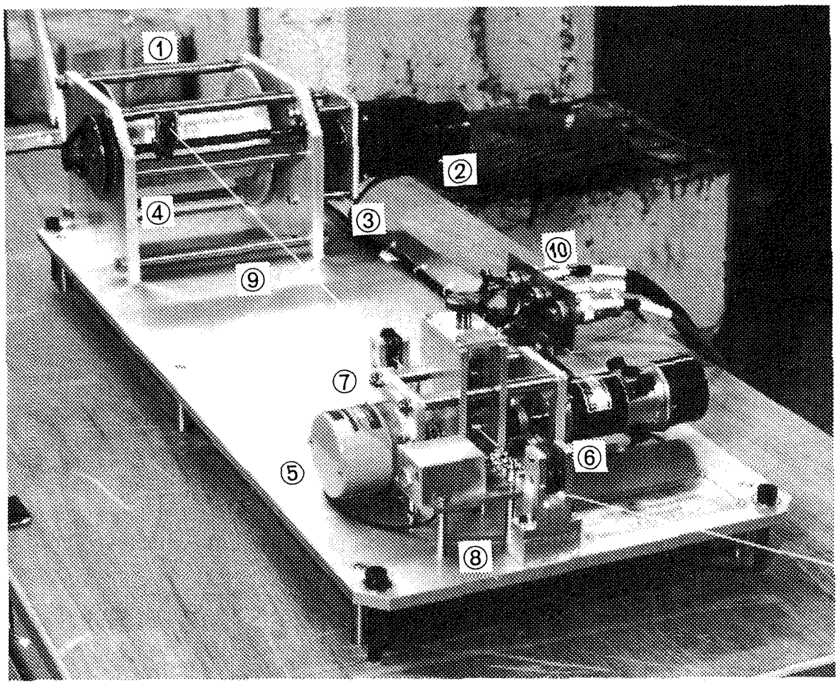
Two tension gauges are located in both sides

Table 1 Specifications of Reel Drum Driving Servomoter (TS3350E216)

Torque Constant	0.203 N-m/A (2.07 kgf-cm/A)
Voltage Constant	21.3 ± 10% V/1000 rpm
Rated Speed	3000 rpm
Rated Torque	0.637 N-m (6.5 kgf-cm)
Rated Input Power	200 W

Table 2 Specifications of Electromagnetic Brake (RNB0.2)

Braking Torque	1.96 N-m (0.2 kgf-m)
Input Power	10 W
Armature Time Constant	25 msec



① reel drum
② reel drum driving servomotor
③ electromagnetic brake
④ level winder
⑤ encoder
⑥ tension adjusting mechanism
⑦ tension gauge (reel drum side)
⑧ tension gauge (end mass side)
⑨ tether
⑩ connector panel and cables

Fig. 1 Reel Drum Driving (RDD) Unit

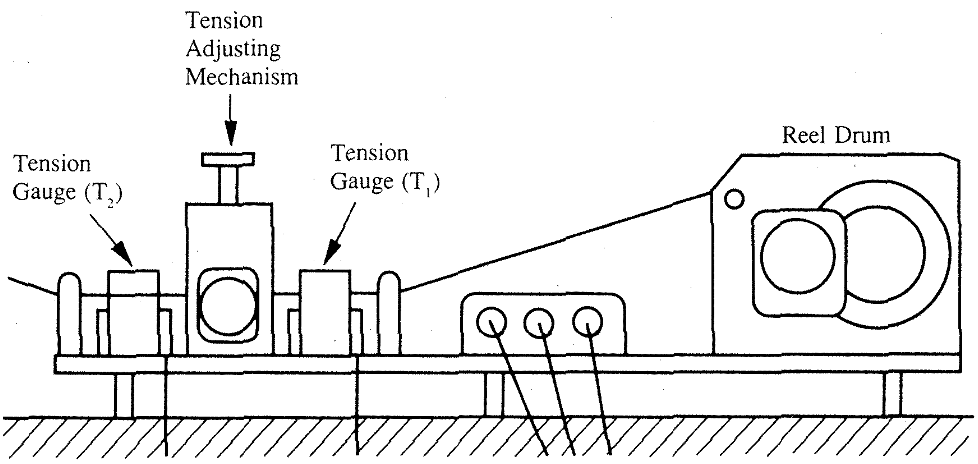


Fig. 2 Two Tension Gauges in Both Sides of TAM

of the tension adjusting mechanism (TAM) as shown in Fig. 2. They measure the tether tension T_1 in reel drum side and the tether tension T_2 in end mass side respectively. The specifications of load transducer are shown in Teble 3. The rated load is 196 N (20 kgf) and rated output is 3.5 mV.

The purpose of TAM is to avoid tether slack (to keep reel drum side tension T_1 positive) for the stable reel-out and reel-in and to control end mass side tension T_2 for the stable behavior of the end mass (small satellite). Schematic view of TAM is shown in Fig. 3 and explained briefly as follows.

Table 3 Specifications of Load Transducer (LU-20KSB34D)

Rated Load	1.96×10^2 N (20 kgf)
Rated Output	3.5 mV
Linearity	0.5% Readout
Hysteresis	0.5% Readout

Tether extending from the reel drum is wound once round the roller filling the shallow and narrow groove round the roller rim and pressed by another roller above and extends to the end mass. The roller is driven directly by tension adjusting servomotor, which is attached

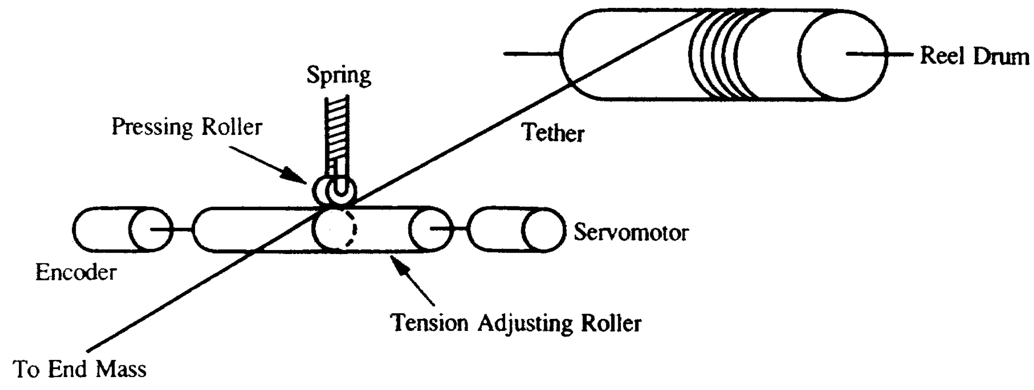


Fig. 3 Concept of Tension Adjusting Mechanism (TAM)

at the end of roller axis. Tension is adjusted by relative rotation of the roller and the reel drum. The specifications of TAM servomotor are shown in Table 4. The DC servomotor outputs 0.319 N-m (3.25 kgf-cm) rated torque.

An encoder attached at the other end of roller axis of TAM generates a pulse signal measuring tether length. The specifications of encoder are shown in Table 5. Resolution is 1000 counts per turn. The pulse signal is processed into tether length rate in PSSP unit.

The specifications of tether are shown in Table 6. Tether is consisted of Kevlar fiber core and nylon fiber jacket. It is 0.8 mm in diameter and 300 m long. The reel drum of this system could wind 2000 m long tether.

The connector panel has three kinds of receptacles. Three cables transmit the electric power and signals except for the tension signals between RDD unit and PSSP unit. The tension signals are transmitted to PSSP unit directly through two additional cables extending from tension gauges for the noise reduction of the very low output level signals mentioned previously.

Table 4 Specifications of Tension Adjusting Servomotor (TS3351E196)

Torque Constant	0.188 N-m/A (1.92 kgf-cm/A)
Voltage Constant	19.8 ± 10% V/1000 rpm
Rated Speed	3000 rpm
Rated Torque	0.319 N-m (3.25 kgf-cm)
Rated Input Power	100 W

Table 5 Specifications of Endoder (TS5107N132)

Resolution	1000 C/T
Open Collector	
Max. Allowable Output Voltage	40 V
Max. Allowable Sink Current	100 mA
Starting Torque	2.94×10^{-3} N-m (30 gf-cm) Max.
Moment of Inertia	3.0×10^{-6} kg-m^2 (30 g-cm^2) Max.

Table 6 Specifications of Tether (KW1516)

Core	Kevler 1500 denier x 1
Jacket	Nylon 140 denier x 16
Diameter	0.8 ± 0.2 mm
Break Strength	$\geq 9.80 \times 10^1$ N (10 kgf)
Length	300 m

2.2 Power Supply and Signal Processing (PSSP) Unit

The unit connected with RDD unit through five cables is 32 kg weight, 430 mm wide, 350 mm high, and 460 mm deep and is supplied with AC100V external electric power. The following six data are displayed in the front panel of the unit shown in Fig. 4; tether length (L, 5 digits), length rate ($\dot{L}$, 3 digits), input voltages (V_R, V_T, 3 digits respectively) for reel drum driving motor and tension adjusting motor, tensions (T_1, T_2, 3 digits respectively) in reel drum side and in end mass side.

The unit is able to be operated alternatively in two modes;

- local mode (open mode):

  Input voltages V_R for reel drum driving

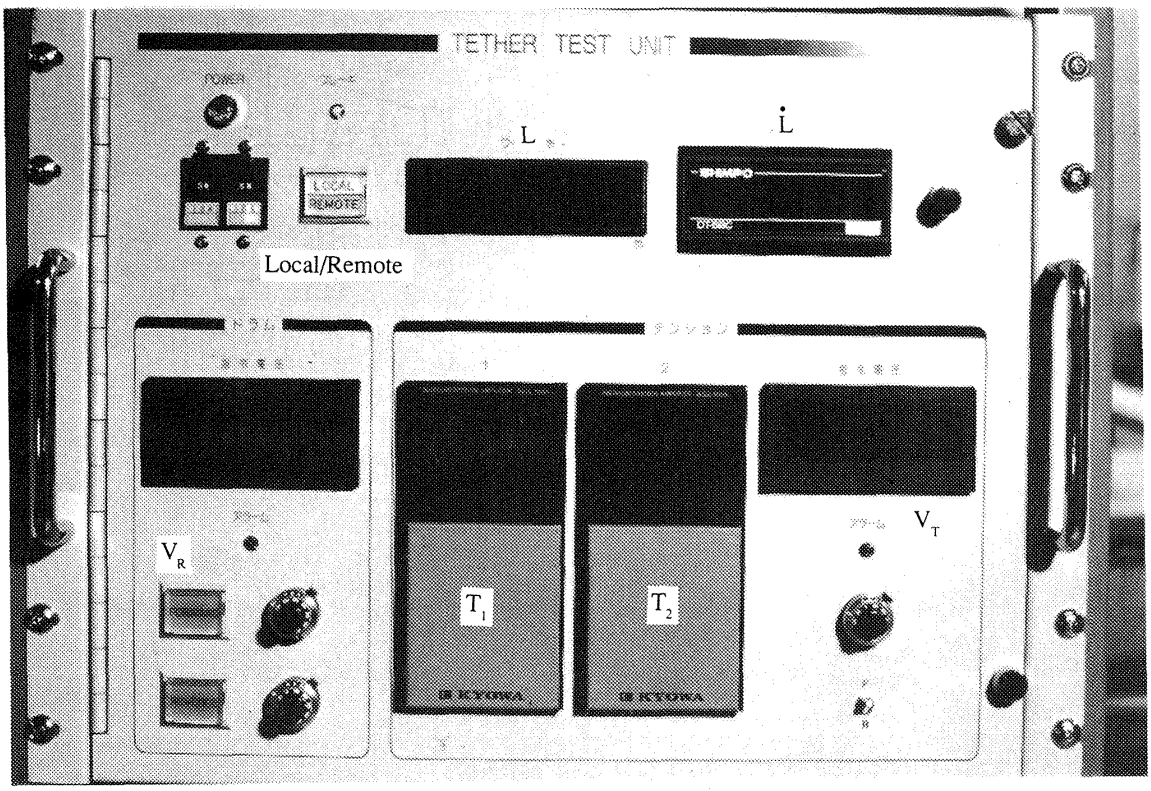


Fig. 4 Front Panel of Power Supply/Signal Processing (PSSP) Unit

motor and V_T for tension adjusting motor are specified manually by potentiometers in the front panel.

- remote mode (closed mode):
  V_R and V_T, which are generated externally, are inputted through external terminals (cable).

3. Preliminary Functional Test

The preliminary functional test has been executed in order to verify the fundamental function in local mode. The data displayed in the front panel of PSSP unit are read in the test.

3.1 Reel-Out and Reel-In Test

The test has been executed in order to verify the stable and repeating reel-out/reel-in and the function of electromagnetic brake. The test setup configuration shown in Fig. 5 includes another (dummy) reel drum system. It is implemented to wind up the tether reeled out and wind off the tether to be reeled in. The input voltage to the dummy reel driving servomotor is adjusted skillfully keeping the tether tension between the two reel drums in the moderate level (about 21 N) during the experiments. The previously measured 100/300 m long tethers are reeled out and reeded in at the constant rate of about 0.1 m/s. The reel-out/reel-in operations have been executed normally and the electromagnetic brake has also worked normally after each operation. The results are shown in Table 7. The length measuring error compared with the displayed figures shown in the front panel is below 1.0%.

The error level data in measuring length/rate at rather high rate have been also obtained using another setup configuration. In the configuration the tether hangs through the pulley which is located at about 10 m high as shown in Fig. 6. The previously measured 5/10 m long tethers are reeled out and reeled in at about 1.0 and 2.0 m/s with 2.1 kg end mass (end weight). The error levels compared with the displayed figures are shown in Table 8. The levels in the cases of 5 m long tether at 2.0 m/s have not been obtained because of the difficulty in

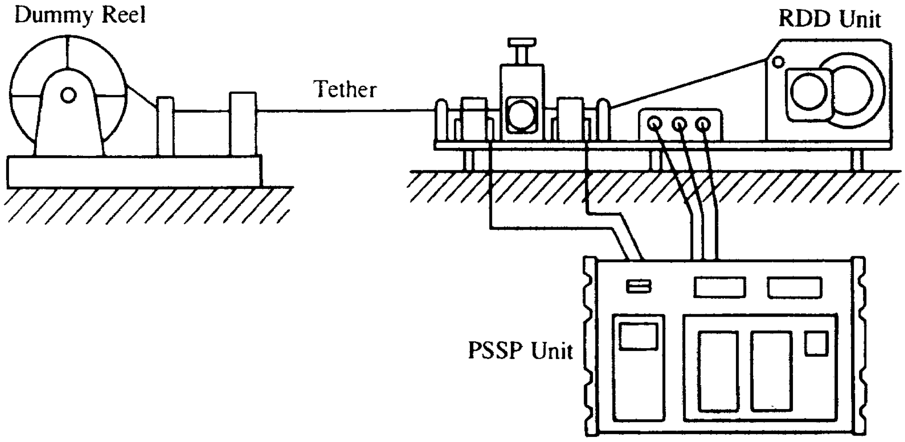


Fig. 5 Setup Configuration Including Dummy Reel for Preliminary Reel-out/Reel-in Test of Long Tether

Table 7 Preliminary Reel-Out/Reel-In Experiments

	Input Voltage V_R V / V_T V	Tether Length L m	Length Rate $\dot{L}$ m/s	Tension N T_1	Tension N T_2
Reel-Out	−0.14 ~ −0.17 / −2.00	300.04	0.10	12	21
	−0.14 / −4.26	100.00	0.09	21	23
	−0.14 / −3.50	98.17	0.09	22	23
	−0.14 / −3.30	100.50	0.09	22	24
Reel-In	+0.16 ~ +0.20 / +3.70	300.38	0.09	21	21
	+0.15 / +3.46	97.92	0.09	16	15
	+0.14 / +2.55	98.24	0.09	21	21
	+0.15 / +3.12	99.77	0.09	21	20

Table 8 Tether Length/Rate Measuring Accuracy at Rather High Rate

	Input Voltage V_R V ($\dot{L}$ m/s)	Tether Length Measurinng Accuracy % 5.0 m	Tether Length Measurinng Accuracy % 10.0 m	Length Rate Measuring Accuracy % 5.0 m	Length Rate Measuring Accuracy % 10.0 m
Reel-Out	−2.0 (~ 1.0)	2.5	2.9	3.4	3.3
	−4.0 (~ 2.0)	—	3.7	—	2.9
	Average	2.5	3.3	3.4	3.1
Reel-In	+2.0 (~ 1.0)	2.1	2.2	4.9	2.6
	+4.0 (~ 2.0)	—	1.8	—	3.9
	Average	2.1	2.0	4.9	3.3

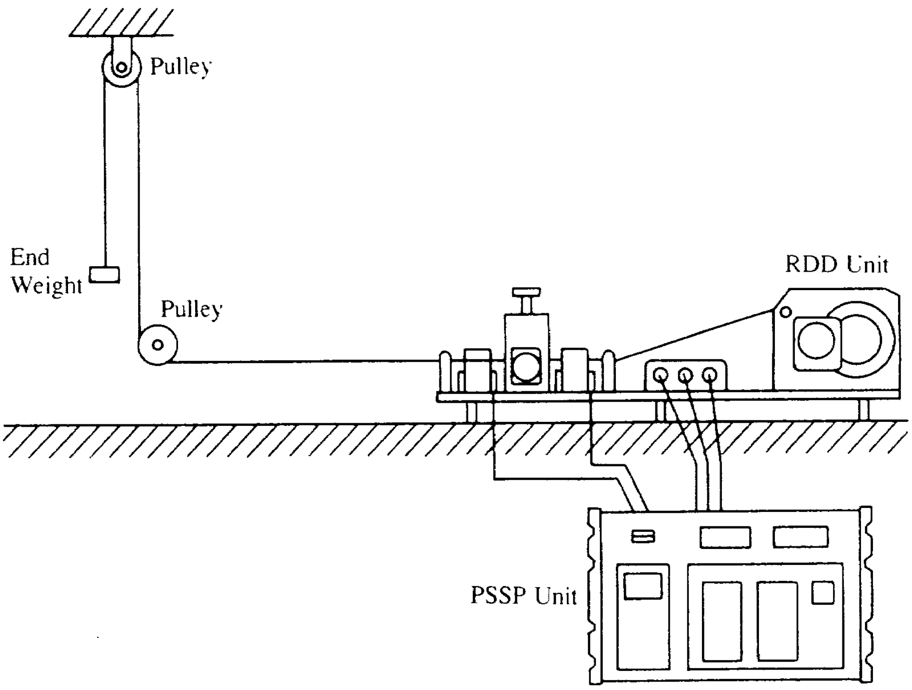


Fig. 6 Setup Configuration for Both Length/Rate Measuring Accuracy Test and Tension Adjusting Test

reading the displayed figures and the large variance in time measured by stopwatch. They are denoted by "—" in the Table. The accuracy is rather bad (in some case above 4%) compared with the data obtained at rather low rate of about 0.1 m/s.

This partly comes from the error in measuring short time manually by stopwatch. The short measuring time comes from tether stroke constraint restricted to only 10 m long or so. Another cause may come from the length measuring system itself. The tether may slip round the roller axis (see Fig. 3) at rather high rate.

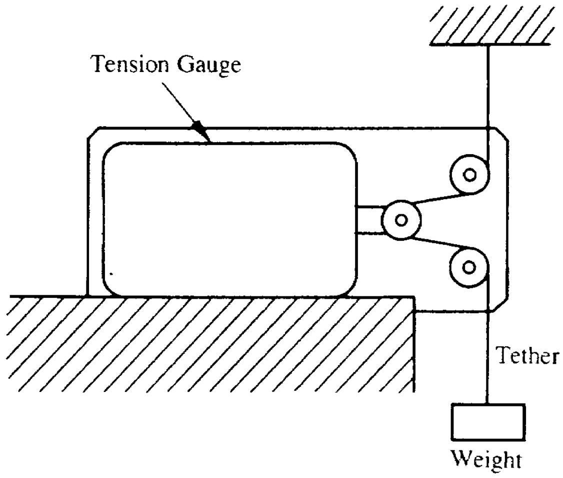


Fig. 7 Setup Configuration for Tension Gauge Calibration and Measuring Accuracy Test

3.2 Tension Measuring/Adjusting Test

Tension Merasuring Accuracy

Tension gauge accuracy has been measured after the calibration as shown in Fig. 7. The weight of end mass (end weight) is changed at every 0.5 kg in the range from 0.5 kg to 2.5 kg. The error levels compared with the displayed figures are shown in Table 9. They are below 1.0%.

Tension Adjusting Test

The tensions T_1 and T_2 have been observed inputting the tension adjusting motor driving voltage V_T at the reel drum driving motor driving voltage V_R of about 1.9 volts (roughly equivalent to 1.0 m/s). The test setup configuration is identical with one shown in Fig. 6.

The results are shown in Table 10. T_1 in reel drum side changes in a large amount and the effect of tension adjusting mechanism (TAM) is

Table 9 Tension Gauge Calibration/Measuring Accuracy

End Weight N (kg)	Tension Measuring Accuracy %	
	T_1	T_2
0.00 (0.0)	0.00	0.00
4.90 (0.5)	0.45	0.50
9.81 (1.0)	0.55	0.40
14.71 (1.5)	0.88	0.35
19.61 (2.0)	0.50	0.55
24.51 (2.5)	0.00	0.00

Table 10 Tension Adjusting Test with V_T Input

	V_R V ($\dot{L}$ m/s)	V_T V	Tension N	
			T_1	T_2
Reel-Out	-1.97 (1.09)	0.0 ↓ -3.62	28.15 ↓ 19.13	20.77 ↓ 20.79
	-1.83 (1.12)	0.0 ↓ -6.51	39.62 ↓ 32.88	20.86 ↓ 20.54
Reel-In	+1.95 (1.01)	0.0 ↓ -3.69	26.09 ↓ 47.77	20.73 ↓ 20.04
	+1.80 (1.04)	0.0 ↓ -6.70	37.84 ↓ 60.01	20.79 ↓ 23.89

evident. But T_2 in end weight side changes in a small amount. This comes from the fact that the tension (about 21 N) by the end weight is dominant in end weight side. This is inevitable in the tests executed on 1 G ground condition.

4. Computer-Controlled Test System Integration

4.1 Test System Integration

Fig. 8 shows the signal flow of the computer-controlled test system. A 32-bit personal computer with INTEL 80386 (20 MHz) processor and INTEL 80387 (20 MHz) floating arithmetic coprocessor is used as a control processor. An interface junction box is implemented between PSSP unit and the control processor. The junction box has the receptacles for the cables from PSSP unit and for the cables to the I/O interfaces (mentioned below). It has also several switches for the manual turn-off of servomotors and the manual turn-on of electromagnetic brake in an emergency and the monitoring terminals for all signals.

The signals from PSSP unit are read into the control processor as follows.

- Analog signals of tension T_1 and tension T_2 are read through 12-bit A/D converters after conditioned by amplifiers and filters.
- Digital signals (Binary Coded Decimal; BCD) of tether length L (4-bit x 5 digits) and length rate $\dot{L}$ (4-bit x 3 digits) are read through parallel digital input interface.
- Pulse signals (0.2 mm/pulse and 2.0 mm/pulse), which are modified in PSSP unit using the pulse signal from the encoder, are read through 16-bit counter for redundancy of length and length rate data.

The signals generated in the control processor are sent to PSSP unit and then to RDD unit as follows.

- Voltage V_R and voltage V_T are sent through 12-bit D/A converters.
- On-off signals of the electromagnetic brake for reel drum are sent through relay I/O interface.

As for the program driving the system, main routines are written in FORTRAN and subroutines driving I/O interfaces are in assembly language. Six signals (L, $\dot{L}$, T_1, T_2, V_R, V_T) obtained/generated are depicted in the graphics in real-time and the data including them are written sequentially in RAM disk of the control processor. A real-time control procedure works in 15 msec including graphic display handling time. The program is operated normally at the sampling interval of 100 or 50 msec. The data are stored fianlly in floppy disk at the end of

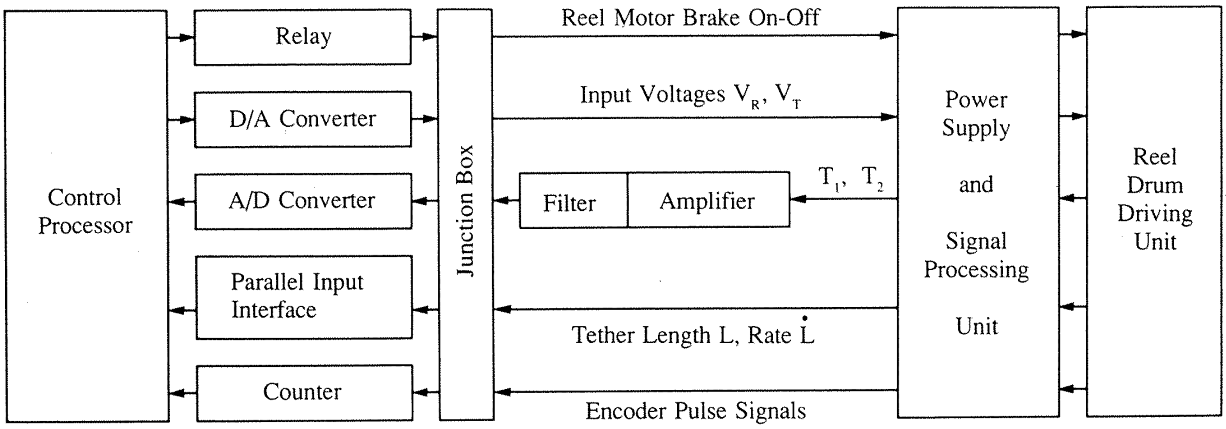


Fig. 8 Signal Flow of the Computer-Controlled Test System

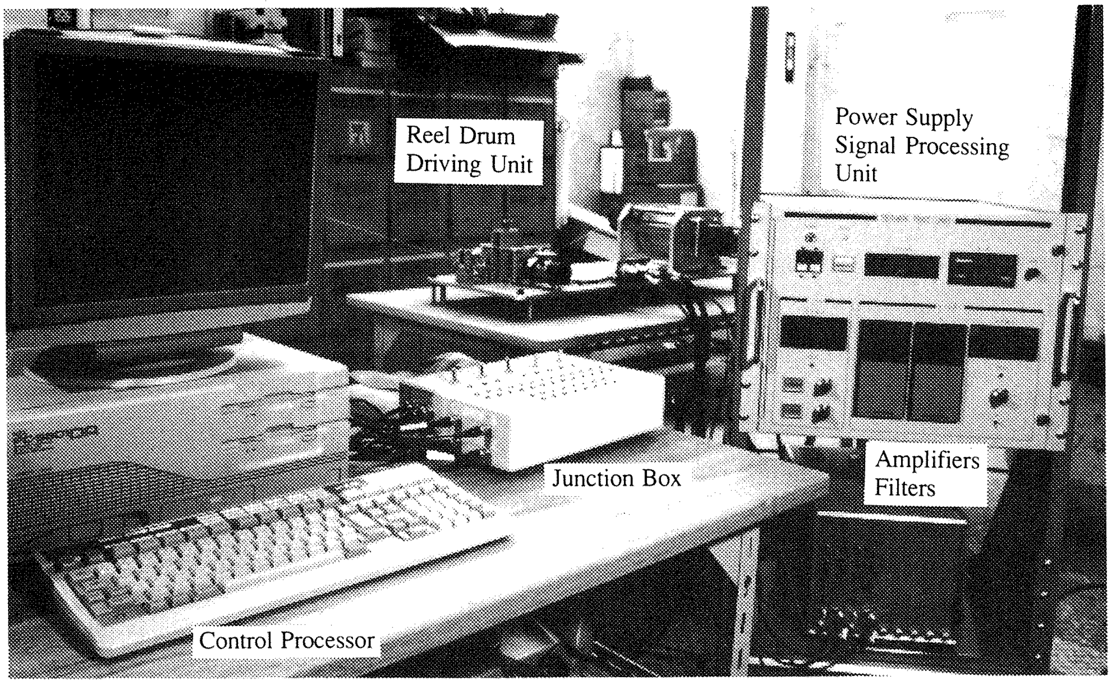


Fig. 9 Integrated Test System

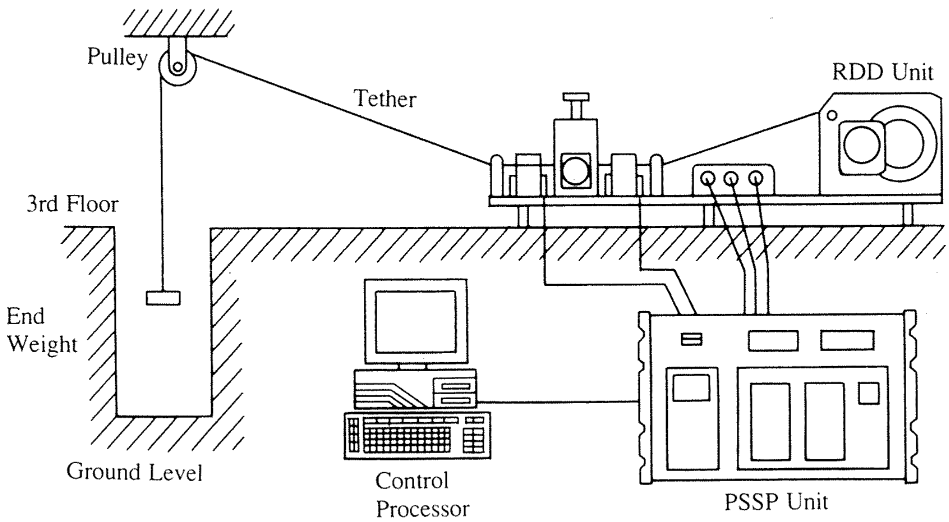


Fig. 10 Setup Configuration for the Computer-Controlled Test in Drop Tower

each experiment. Off-line graphic display is also available using the stored data. The integrated test system is shown in Fig. 9.

4.2 Test Facility

The test setup configuration is shown in Fig. 10. In order to secure the space for the tether reel-out/reel-in action, a drop tower in NAL (10 m head)[15] has been used in time-sharing with the microgravity experiments. The pulley of the drop tower is a new-made one with a low friction micro-bearing for the reel system test. Fig. 11 shows the RDD unit under experiments in the drop tower.

5. Computer-Controlled Test

Three kinds of tests have been carried out.

(1) reel-out/reel-in by the constant and sinusoidal V_R witout V_T

(2) stable reel-out in a small tension (light end weight) with V_T

(3) stable reel-out/reel-in by high frequency sinusoidal V_R with V_T

In (2) and (3), V_T command generated in the control processor has been determined by trial and error on the basis of the strategy as follows.

(a) to control tether length L and length rate $\dot{L}$ at the specified levels by V_R, which drives the reel drum motor

(b) to keep tension T_1 positive for stable reel-out/reel-in, i.e., to avoid the tether slack in reel drum side

(c) to control tension T_2 for stable behavior of end mass

5.1 Reel-Out/Reel-In by the Constant/Sinusoidal V_R without V_T

At the first step of the computer-controlled tests, reel-out and reel-in experiments by the constant and sinusoidal V_R without V_T have been executed.

As for the end weight hung from the tether end, one or two 500 gr weight(s) is/are laid on

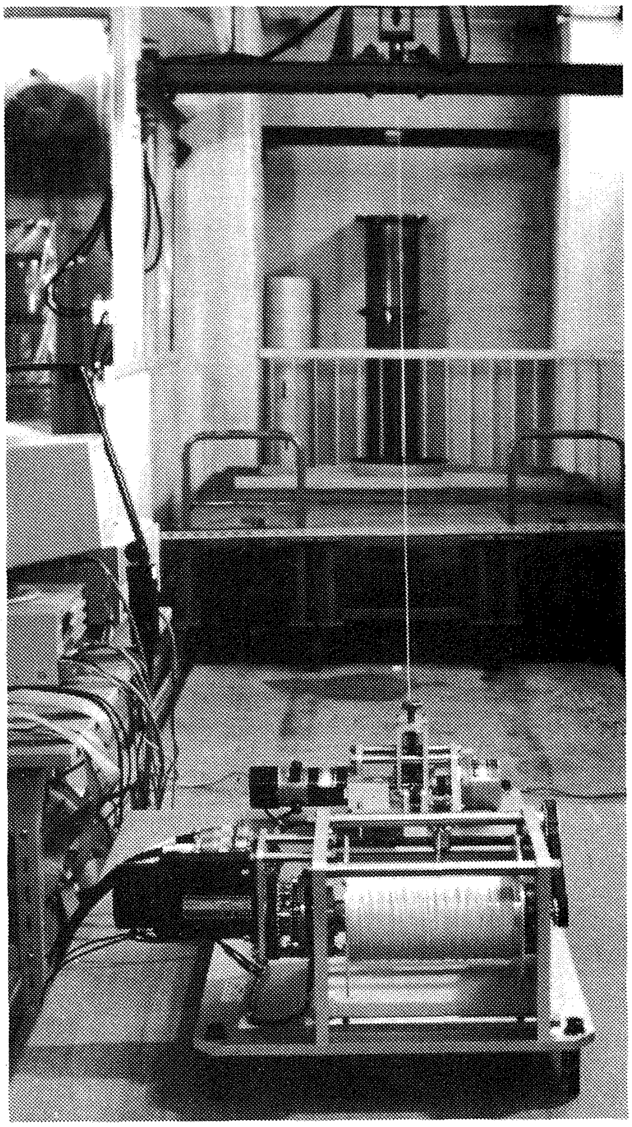


Fig. 11 Reel Drum Driving (RDD) Unit under Experiments in Drop Tower

200 gr scale, i.e., 700 gr or 1200 gr end weight. Either of them causes the tensions T_1 and T_2 enough for the stable reel-out without V_T input.

Figs. 12 and 13 show the histories of L, $\dot{L}$, V_R, T_1, and T_2 in the reel-out and reel-in operations with constant V_R input respectively. The numbers of end weights in these cases are increased at the initial and final phase respectively. In Fig. 12 T_1 takes very small value (approximately 0.43 N) at the initial phase (700 gr end weight). But stable reel-out continues without slack. In Fig. 13 T_1 is large enough for stable reel-in.

In both Figs. history of length rate $\dot{L}$ is rather noisy. The $\dot{L}$ depicted is the value calculated in the control processor using encoder pulse signal, but not the BCD 3-digit value read through parallel digital input interface. This comes from slow (long interval) generation of BCD 3-digit value of $\dot{L}$ in PSSP unit in low length rate of about 0.1 m/s. A tachometer-like sensor measuring the rate directly may be required to quickly obtain $\dot{L}$ data even in low length rate. This is one of the points for coming reformation of the model.

Fig. 14 shows the result of sinusoidal V_R

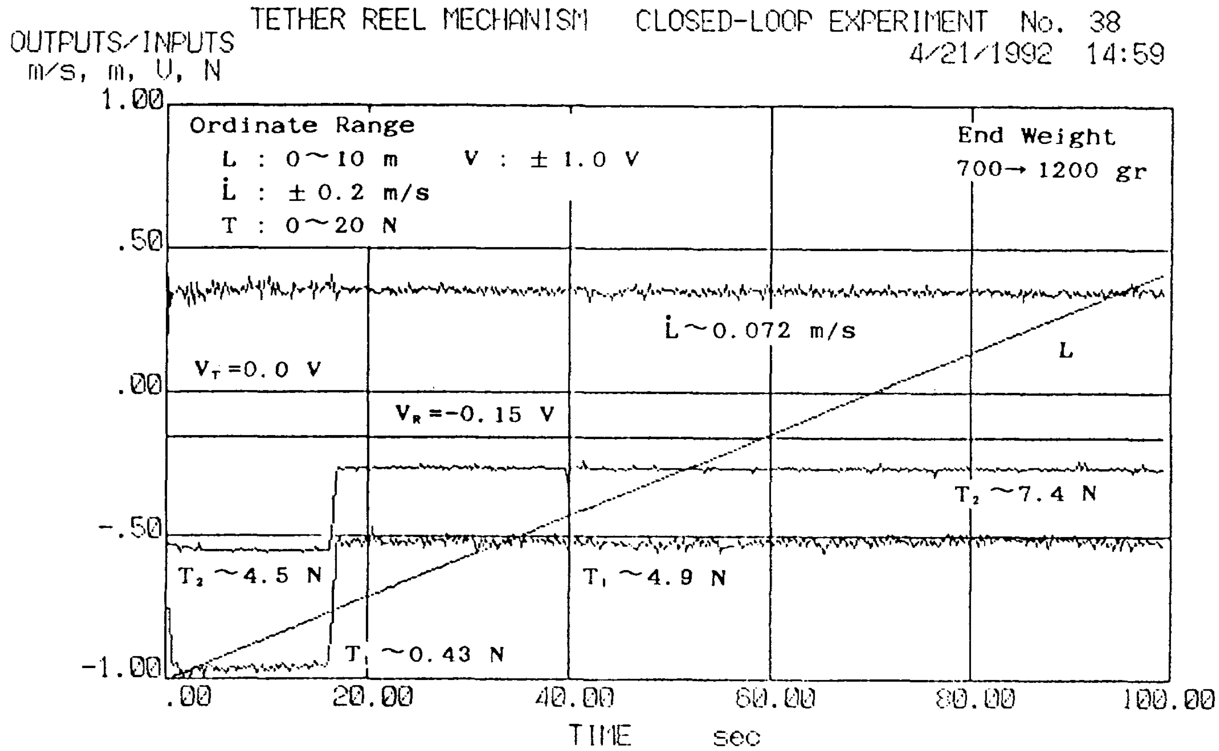


Fig. 12 Reel-Out Operation with Constant V_R and $V_T = 0$

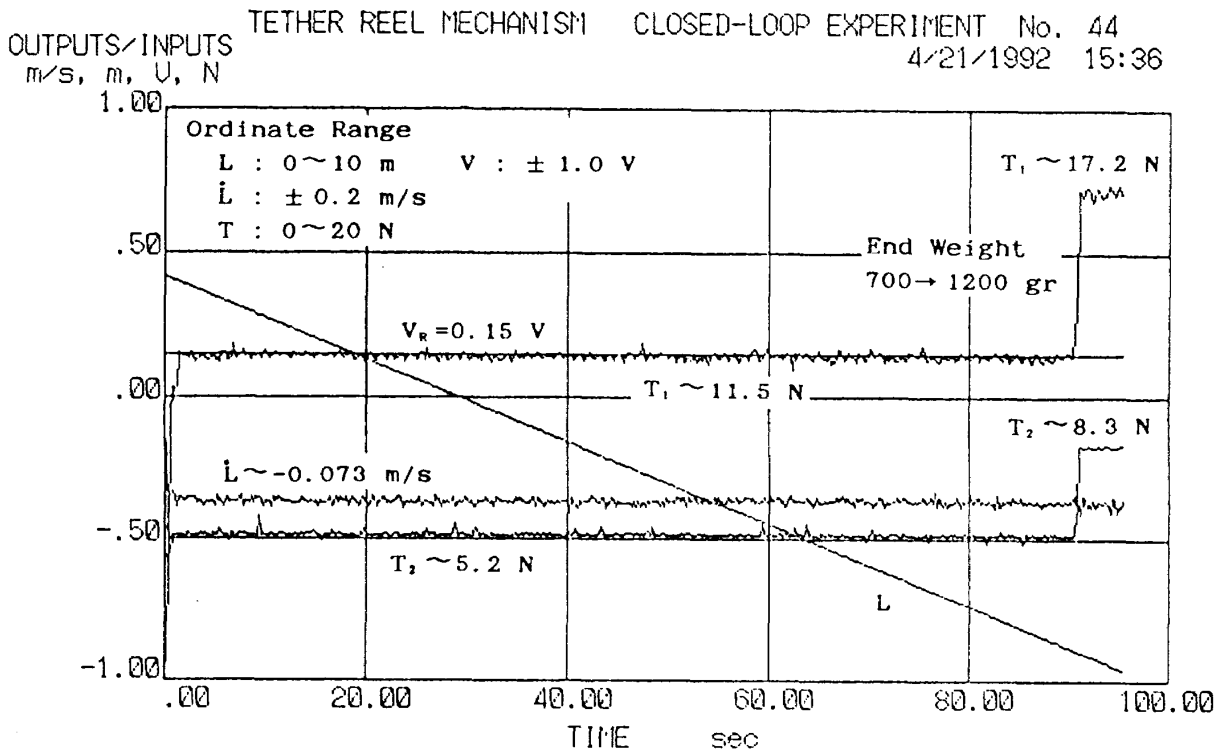


Fig. 13 Reel-In Operation with Constant V_R and $V_T = 0$

input (0.02 Hz) with 700 gr end weight. The repeating operation of reel-out/reel-in is stably executed changing drastically T_1 and slightly T_2.

5.2 Stable Reel-Out in a Small Tension (light end weight) with V_T

As observed in Fig. 14, T_1 changes drastically. It is large enough during reel-in phase and becomes small during reel-out phase. Therefore, the reel-out operation should be executed very carefully in order to avoid tether slack in reel drum side. This is especially true in case of light end weight (small tension).

In case of 200 gr end weight (scale only), no stable reel-out is possible because of tether slack in reel drum side without V_T input in remote mode, nor in local mode, where V_R and V_T are manually and continuously adjusted in real-time by potentiometers.

Then V_T input with gradually increasing V_R is introduced in remote mode as shown below;

$$V_T \equiv -3.0 \qquad (1)$$

$$V_R = \begin{cases} 1.0 - \exp(0.014t) & \text{for } 0 \le t < 10 \\ -0.15 & \text{for } t \ge 10 \end{cases} \qquad (2)$$

where t is time.

V_T input brings the boost in T_1 up to about 5 N and keeps reel-out operation with 200 gr end weight stable as shown in Fig. 15.

This strategy, Eqs. (1) and (2), has been applied also to the cases of 100 and 50 gr end weight reducing to the stable reel-out operation. Fig. 16 shows the result in the case of 50 gr end weight.

However, the application of Eqs. (1) and (2) to the case of 20 gr end weight has reduced to tether slack at about 75 sec later, although the stable reel-out had continued until then.

The tether has become slack in end weight side between tension gauge and tension adjusting roller (see Fig. 2), not in reel drum side. This slack has occurred due to imbalance in tether length going out through tension gauge and coming in from tension adjusting roller. Once this slack occurs, the small tension by light end weight (20 gr) cannot pull the tether

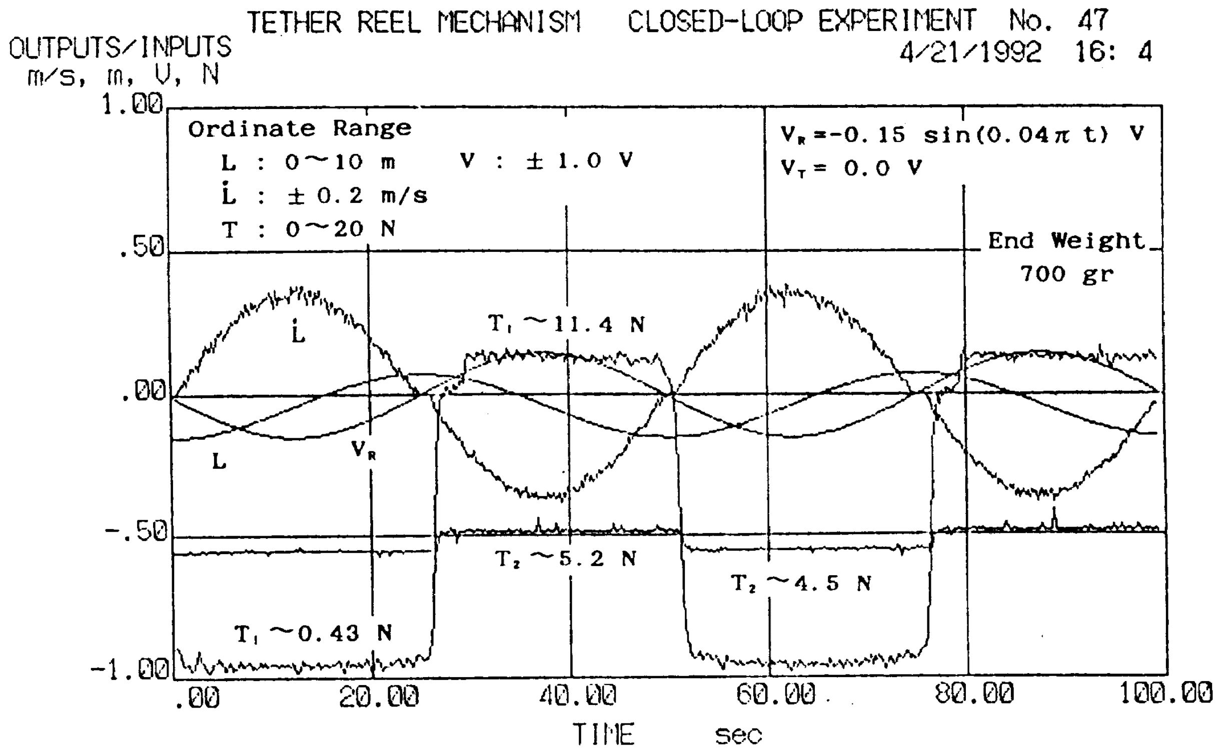


Fig. 14 Reel-Out/Reel-In with 0.02 Hz V_R and $V_T = 0$

through tension gauge overcoming the friction of three small pulleys shown in Fig. 7. Therefore, the amount of tether staying there continues to increase thereafter.

This is explained as follows. The sum of the pulley friction of drop tower, the weight of the slant tether portion between the pulley and tension gauge, and the friction of three small pulleys of tension gauge (see Fig. 7) sometimes becomes slightly larger than 20 gr end weight,

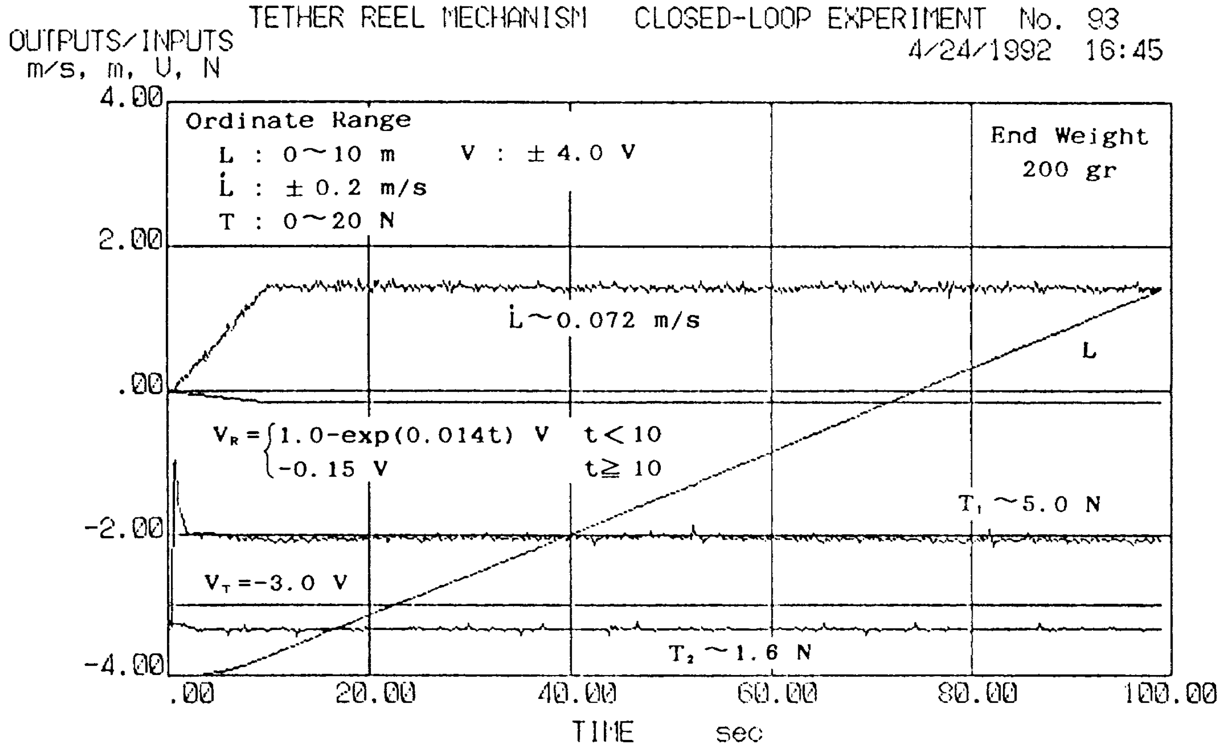


Fig. 15 Stable Reel-Out with V_T Input in 200 gr End Weight

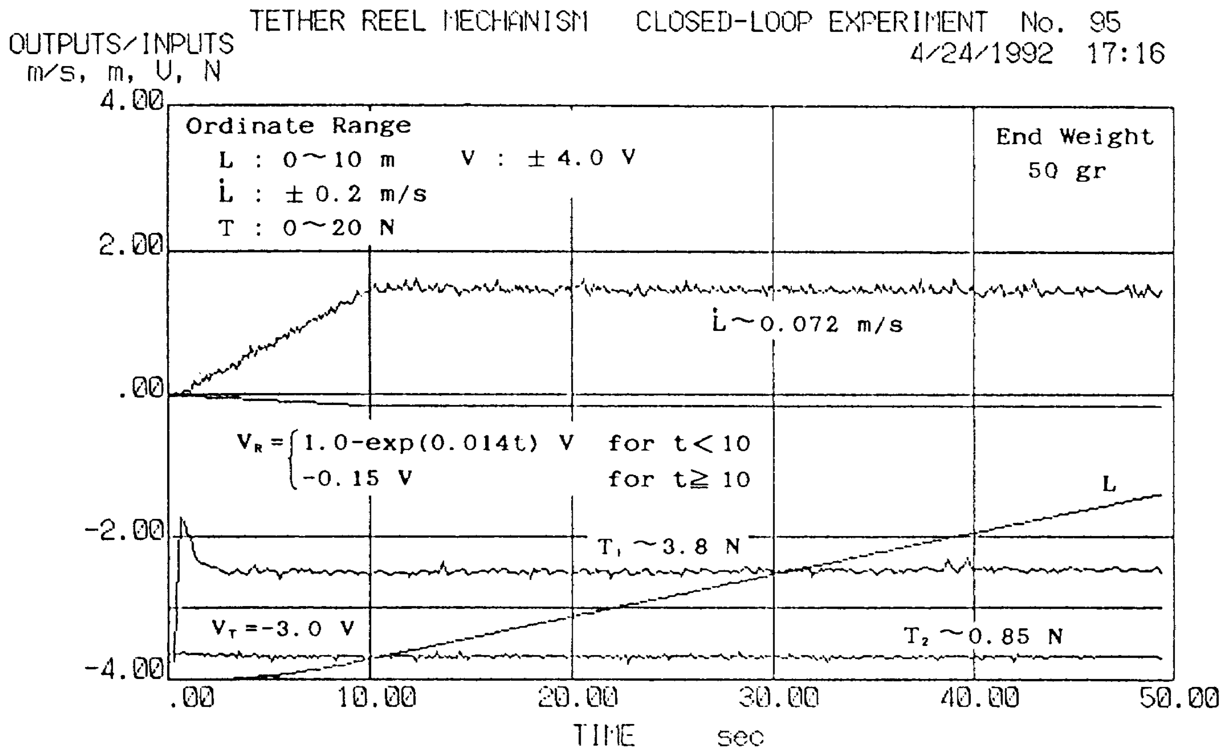


Fig. 16 Stable Reel-Out with V_T Input in 50 gr End Weight

although the pulley of drop tower is a new-made one for reel system test as mentioned previously. Another cause may come from the tether stiffness besides this explanation.

Then the smaller V_R input (equivalent to lower length rate)

$$V_R = \begin{cases} 1.0 - \exp(0.0095t) & \text{for } 0 \le t < 10 \\ -0.10 & \text{for } t \ge 10 \end{cases} \quad (3)$$

has been introduced. It has reduced to the rather

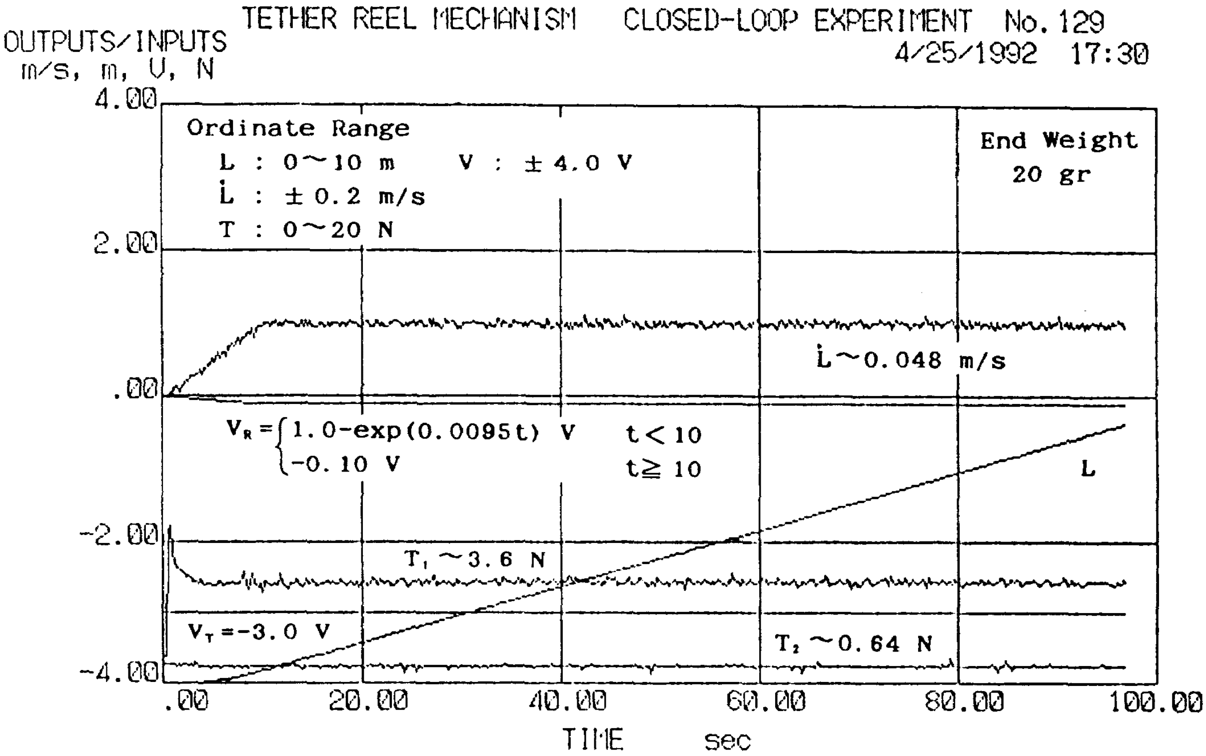


Fig. 17 Reel-Out by Smaller V_R Input with V_T Input in 20 gr End Weight

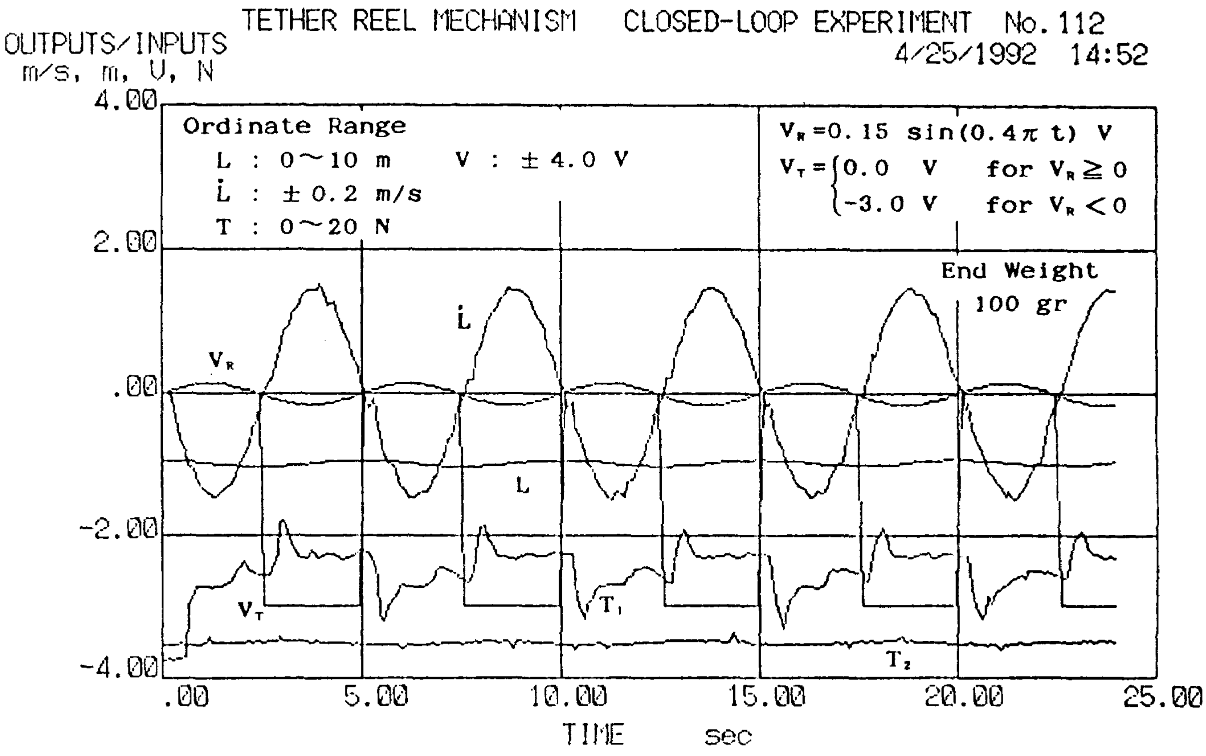


Fig. 18 Reel-Out/Reel-In with 0.2 Hz V_R and $V_T = 0$ in 100 gr End Weight

stable reel-out operation as shown in Fig. 17. But the reel-out operation has not been steadily stable, although it is not observed clearly in the Figure.

Therefore, this probably shows a limit on the lightest end weight (20 gr) in the test setup configuration shown in Fig. 10.

On the other hand, reel-in operations have been steadily stable, even in the case of 20 gr end weight.

5.3 Stable Reel-Out/Reel-In by High Frequency Sinusoidal V_R with V_T

The stable operation of reel-out/reel-in has been checked with sinusoidal V_R input up to 1.0 Hz for the cases of 200, 100, and 50 gr end weight. In each case the sinusoidal V_R input has been added after the tether being stably reeled out to the appropriate length according to Eqs. (1) and (2). The results have shown that the repeating reel-out/reel-in could be executed stably by sinusoidal V_R input up to 1.0 Hz.

Fig. 18 shows the result in the case of 0.2 Hz V_R input with 100 gr end weight and Fig. 19 shows the result in the case of 1.0 Hz V_R input with 50 gr end weight. Fig. 19 shows that T_1 is negative (slack) for about 0.5 sec at the initial phase. But this slack for very short period does not cause unstable operation and stable reel-out/reel-in continues thereafter.

6. Concluding Remarks

A laboratory prototype model of the tether reel system has been made as the first step of the in-house hardware study of the tether system. The model is consisted of two parts; reel drum driving unit and power supply/signal processing unit.

Following the preliminary functional test, the computer-controlled functional test has been carried out using a 32-bit personal computer as a control processor. The tests have verified the stable reel-out and reel-in operation by introduction of the tension control both in the case of a small tension (light end weight) and in the case at rather high frequency input to reel drum driving motor.

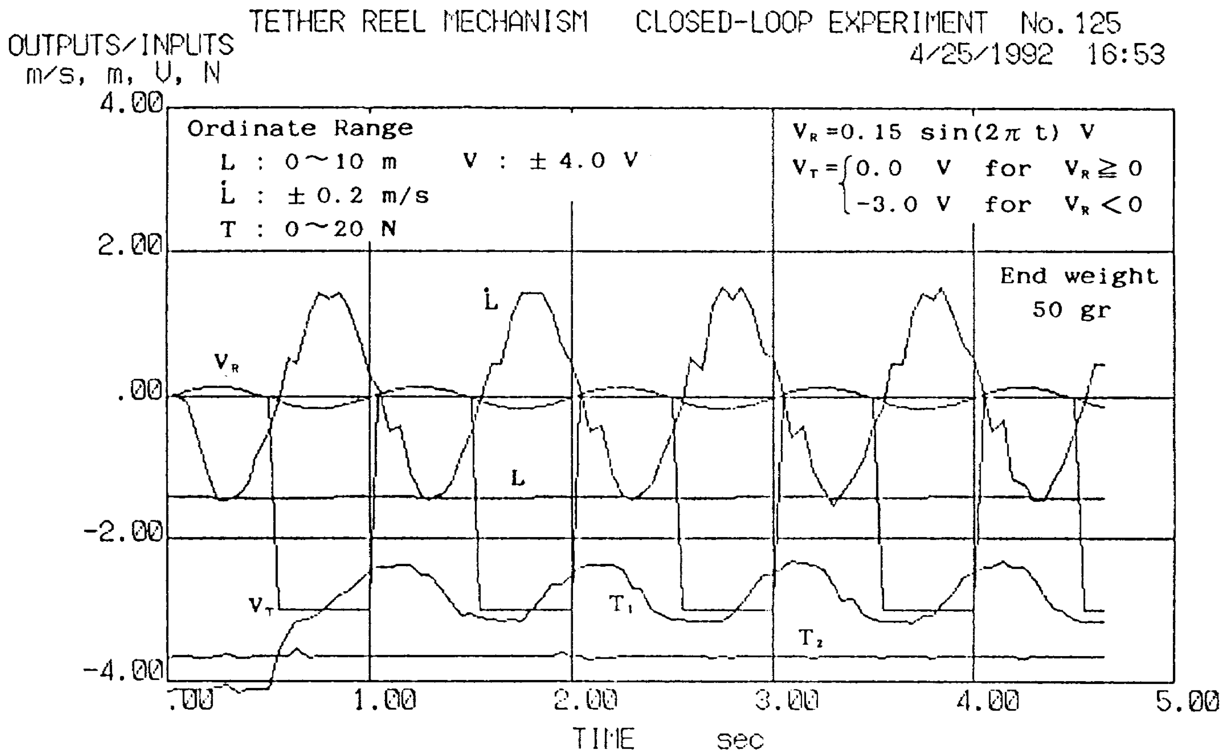


Fig. 19 Reel-Out/Reel-In with 1.0 Hz V_R and V_T = 0 in 50 gr End Weight

Through the tests some points to be reformed such as the measuring device of the tether length rate in low length rate have become clear. More study will be carried out including the reformation of the model.

References

1) A. Cron, compiler; Applications of Tether in Space – Volume 1, NASA CP-2364, Proceedings of a workshop sponsored by the NASA, Washington, D.C., and MSFC, Huntsville, Alabama, and held in Williamsburg, Virginia, June 15-17, 1983
2) A. Cron, compiler; Applications of Tether in Space – Volume 2, NASA CP-2365
3) A. Cron, compiler; Applications of Tether in Space – Volume 3, NASA CP-2366
4) W. Baracat, compiler; Applications of Tether in Space – Volume 1, – Volume 2, and Executive Summary, NASA CP-2422, Proceedings of a workshop sponsored jointly by the Italian National Space Plan, CNR, and NASA and held in Venice, Italy, October 15-17, 1985
5) The Report of the National Commission on Space; PIONEERING THE SPACE FRONTIER, May 1986
6) R. Kline-Schoder and J.D. Powell; Experiments with the KITE Attitude Control Simulator, AIAA-89-1576-CP, A Collection of Papers and Abstracts on the Third International Conference on Tethers In Space – Toward Flight, San Francisco, California, 17-19 May, 1989
7) Yoshimura, S. and Yamanaka, T.; On the Payload-Tether Technology Providing the Microgravity Circumstances in the Vicinity of the Space Station, Proceedings of the 15th International Symposium on Space Technology and Science, Tokyo, May 1986
8) Yoshimura, S. and Yamanaka, T.; On the Tether Technology Realizing a Microgravity Laboratory Deployed in the Proximity of the Large Mother Spaceship, Proceedings of the 16th ISTS, Sapporo, May 1988
9) Yoshimura, S.; Deployment and Station Keeping of the Tethered Microgravity Laboratory in the Proximity of the Large Mother Spaceship, Proceedings of the 17th ISTS, Tokyo, May 1990
10) D.S. Crouch; Shuttle Tethered Satellite System Development Program, AIAA-84-1106, AIAA/NASA Space Systems Technology Conference, 1984
11) J.A. Carroll and C.M. Alexander; The Small Expendable-tether Deployment System, Final Report on NASA SBIR to NASA MSFC, December 1987
12) J.K. Harrison, C.C. Rupp, J.A. Carroll, C.M. Alexander, and E.R. Pulliam; Small Expendable-tether Deployer System (SEDS) Development Status, AIAA-89-1550-CP, same in Ref. 6
13) J.M. Garvey and D.R. Martin; Delta II Secondary Payload Opportunities for Tether Demonstration Experiments, AIAA-89-1551-CP, same in Ref. 6
14) E.C. Lorenzini and J.A. Carroll; In-Orbit Experimentation with the Small Expendable-tether Deployment System, ESA (European Space Agency) Journal, Vol. 15, No. 1, January 1991, pp. 27-33
15) Ogiwara, S., Yoshiwara, S., and Azuma, H.; Improved Drop Tower Performance for Microgravity Environment Experiments, NAL TR-991, August 1988, in Japanese

TECHNICAL REPORT OF NATIONAL
AEROSPACE LABORATORY
TR-1176T

航空宇宙技術研究所報告1176T号（欧文）

平成4年8月発行

発行所　航空宇宙技術研究所
東京都調布市深大寺東町7丁目44番地1
電話三鷹(0422) 47-5911（大代表）〒182
印刷所　株式会社　東京プレス
東京都板橋区桜川2－27－12

Published by
NATIONAL AEROSPACE LABORATORY
7-44-1 Jindaijihigashi-Machi Chōfu, Tokyo
JAPAN

Printed in Japan