An Analytical Method for Tether Systems Composed of Rigid Bodies Introducing Linear Complementarity Problem

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Abstract

In recent years, the System with Rigid body and Extremely Flexible components (hereinafter called "SREF") is increasingly used in next-generation space crafts which have huge structures [1]. Previous studies have proposed effective methods for analyzing SREF motion, which based on an analogy between the state transitions of the SREF and the contact problem of rigid bodies. Ooshima et al. [2] proposed an efficient analysis method by solving linear complementarity problems for the state transitions of SREF, which include transitions in which the string is subjected to impact tension and transitions in which the tension is lost. In the proposed method, the mass is assumed to be a mass point which has planar motion, and good agreement is confirmed by analysis and experiment. However, since the masses constituting the SREF are not treated as rigid bodies, the effect of their moment of inertia on the motion is not considered. Thus, this paper investigates the effect of moment of inertia on dynamics in tether system using two-dimensional analysis and compare results of analysis and experiments.

The left side of Fig. 1 shows a fundamental model of the tether system. This fundamental model consists of one rigid body connected by one string, and is assumed to have planar motion. One end of String is connected to the ceiling and the edge of Body. The generalized coordinates of Body are the positions and angle in the inertial coordinate system, i.e., (x, y, φ). Body is assumed to have cylinder shape, masses of m, moments of inertia of J, and length L. Furthermore, the mass and bending deformation stiffness of String is assumed to be negligibly small and the stiffness in the direction of axial deformation is assumed to be sufficiently large, which means that its length is unchanged. The length of String is assumed to be l. Also, the diameter of Body is assumed to be negligibly small compared to its length. Body is subjected to the gravitational force mg as well as external forces f_x and f_y in the x and y directions and moment M, respectively. In addition, in the state where String is not slackened, the tension σ of String in the direction of ceiling is exerted on Body and the angle of the direction of the String from ceiling is given as θ as shown in Fig. 1. From right side of Fig.1, the relation between the generalized coordinates and the slack s is given by

$$s = l - d, d = \sqrt{(x_1 - L_1 \cos \varphi_1 /2)^2 + (y_1 - L_1 \sin \varphi_1 /2)^2} \quad (1)$$

Considering the complementarity associated with slack s and tension σ, parameters with respect to state transition are derived by Linear Complementarity Problem(LCP), which is proposed by our previous study[2]. Consequently, low cost calculation for analysis of SREF's motion is achieved.

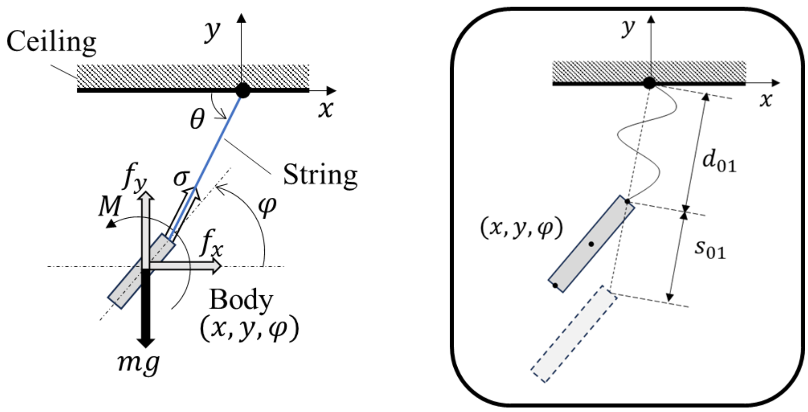

Figure 1: The left side shows fundamental model of a tether system which consists of one Body and one String. String connects Body and the ceiling. The right side shows the definition of slack between Body and ceiling.

In order to evaluate the motion of system analyzed by proposed method, this study configures three observation points on the Body 1 as shown in Fig. 2. Table 1 shows parameters used in analysis. These parameters are based on actual experimental setup. Fig. 3 shows the comparison of x-y displacement between the experiment and the analysis which uses fundamental model shown in Fig. 1.

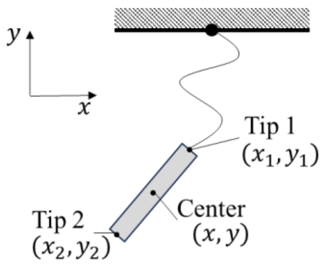

Figure 2: Configured observation points to evaluate the analyzed motion of system. Tip 1 indicates the point of Body that String is connected. Center indicates the center of gravity of Body. Tip 2 indicates the point of the opposite side from Tip 1 on Body.

Table 1: Analysis parameters.

Length of String [m]	1.710	Length of Body [m]	0.084
Coefficients of Restitution [-]	0.8	Mass of Body [kg]	0.132
Time step [s]	0.001	Integral time [s]	3.5

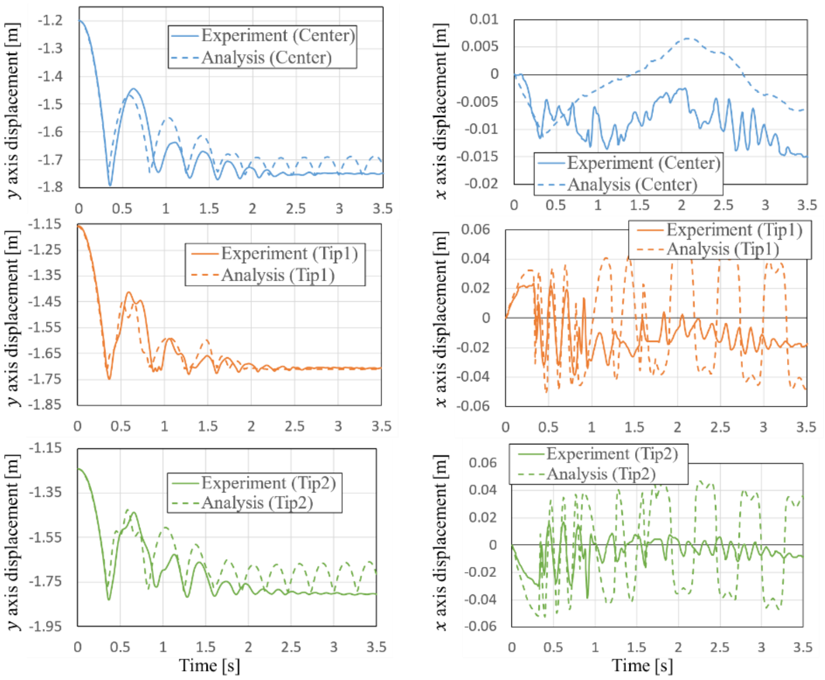

Figure 3: Comparison of x-y displacement between result of experiment and analysis. Graphs are lined in order of Center, Tip1, Tip2 from top to bottom. The left half of Fig. 3 indicates a comparison of y axis displacement and the other side indicates a comparison of x axis displacement.

From Fig. 3, qualitative agreement is observed in the comparison of y axis displacement. Similarly, qualitative agreement is observed in the comparison of x axis displacement in transient state ($t = 0 \sim 0.8$ s) of Tip 1 and Tip 2. This means the analysis method proposed by this paper is available for analyzing SREF motion which has influence of moment of inertia.

References

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[2] Ooshima, S. and Sugawara, Y.: Method for analysis of planar motion of system with rigid and extremely flexible components via analogy with contact problem of rigid bodies: Mechanical Engineering Journal, Vol.8, No.4, pp. 1-19, 2021.