Modelling centrifugal membrane deployment of solar sails with the discrete element method

Zixuan Xu[1], Daxu Zhang[1]*, Wujun Chen[1], and Fujun Peng[2]

[1] School of Naval Architecture, Ocean & Civil Engineering
Shanghai Jiao Tong University (SJTU)
Shanghai 200240, China
e-mail: daxu.zhang@sjtu.edu.cn, web page: http://www.sjtu.edu.cn/

[2] Shanghai Key Laboratory of Spacecraft Mechanism
Shanghai, 201108, China

ABSTRACT

Solar sails are a form of spacecraft propulsion using the radiation pressure (also called solar pressure) from stars to push large ultra-thin membranes to high speeds[1]. Japan Aerospace Exploration Agency (JAXA) successfully launched and deployed a solar sail "IKAROS" in 2010. Corresponding dynamic response was analyzed by using a spring-mass model[2].

In this paper, a DEM-based approach is proposed to perform the dynamic analysis of a small-scale solar sail. First, the membrane is discretised into a number of mass particles, with no physical contact between them. The particles can interact with each other via remote interactions. Contact law is determined so that strain energies of the model and the membrane coincide, and buckling effect is taken into account[3].

Then, in order to improve the accuracy, additional forces are added parallel to the mass particles to take account of velocity-proportional damping, crease stiffness and contact, air drag. The bending spring constant is determined to tune crease stiffness to actual membrane. Numerical results including deployment rate and phase difference of the membrane are obtained.

Finally, in order to validate the proposed approach, the predicted results of the centrifugal membrane deployment are compared with the experimental data and the spring-mass model results[2].

The dynamic response of solar sail is typically predicted by the finite element methods[4] and spring-mass system models[2]. This paper introduces a novel DEM-based approach to analyze the dynamic deployment of a solar sail membrane structure. It provides a new alternative approach to effectively analyze the dynamic deployment of solar sails or other membrane structures.

REFERENCES

[1] Solar sail (31 January 2015). Retrieved from http://en.wikipedia.org/wiki/Solar_sail

[2] Okuizumi, N., et al, Small-scale Experiments and Simulations of Centrifugal Membrane Deployment of Solar Sail Craft 'IKAROS', 52nd AIAA/ ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference, AIAA2011-1888, 2011.

[3] Thoeni K, Lambert C, Giacomini A, Sloan SW. Discrete modelling of hexagonal wire meshes with a stochastically distorted contact model. Comput Geotech 2013;49:158–69.

[4] Miyazaki, Yasuyuki, et al., "Conserving Finite Element Dynamics of Gossamer Structures and Its Application to Spinning Solar Sail IKAROS," 52nd Structures, Structural Dynamics and Materials Conference, 4–7 April 2011, Denver, Colorado.