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EVALUATION OF TRANSIENT RESPONSE OF SPINNING SOLAR SAIL WITH FLEXIBLE MEMBRANE BY EIGENFUNCTION ANALYSIS AND CONTINUUM ANALYSIS

Abstract

This study is about evaluation of transient response of large spinning membrane structures in space by two different methods, especially for spinning solar sails. A spinning solar sail IKAROS launched by JAXA has 14-meter-square sail and it is only 7.5 micro meters thin, which reduces the weight of the spacecraft and increases the efficiency of acceleration due to solar radiation pressure (SRP). The flexible sail membrane is pushed by the SRP and easily deforms, and is kept expanded with the centrifugal force generated by the spin motion. However, when the spacecraft changes its attitude using thrusters, for example, the membrane vibration is excited, and the control response including this vibration must be estimated in the actual operation. In order to estimate the motion of the membrane, a numerical method using multi-particle model is generally utilized which is called the continuum analysis in this study. In the multi-particle model, the membrane is modeled with many particles, springs, and dampers which simulate mass, stiffness, and attenuation respectively. This method is on the one hand useful for analysis of membrane vibration because it replaces the complex dynamics with simple equations of motion, but on the other hand, the calculation cost is high and it takes considerable amount of time for calculation because each propagation of force is calculated one by one. This study introduces the eigenfuntion analysis to solve this problem. By linearizing the equations of motion used in the continuum analysis, the natural vibration modes and natural frequencies of the whole spacecraft are derived, and the equations are expressed for every natural vibration mode or natural frequency. When the vibration is calculated, it makes it possible to focus only on the low-frequency modes which are generally dominant factors of the vibration, and to neglect the high-frequency modes. High-frequency modes are the major cause of the high calculation cost because the time width of each step of the numerical integration must be much shorter for high frequency motion. Therefore, the eigenfunction analysis can reduce the cost dramatically compared to the conventional continuum analysis. In this study, the transient response of the spinning solar sail is analyzed using both methods, and advantages and disadvantages are discussed. It is shown that the eigenfunction analysis is a good method to get approximate solutions in a very short time.