Analysis of Cable Dynamics for Ground Power Operated Gondola Type Space Elevator

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1. Introduction

A space elevator has been proposed as a future space transportation system. It is the concept of the space elevator to stretch a cable from the surface of the Earth by the centrifugal force of rotation, and to use it for transporting cargo into space.

Two types of the space elevator have been proposed, based on the operation method. One is a climber type, which is operated by self-climbing carriers that are called “climber”. Second is a gondola type, which is operated by stationary power via the cable. A lot of studies about the climber type have been carried out from 1990s. By contrast, the gondola type has not been studied well, because the gondola type has disadvantages such as the requirement of high mechanical strength for power source elements.

Therefore, in this report, we suggest Ground Power Operated Gondola Type Space Elevator, as shown in Fig.1, and consider its cable dynamics such as a method which is commonly used for the climber type. The greatest characteristic of the suggested space elevator is the circulating of the cable, which has an advantageous in maintenance of the cable.

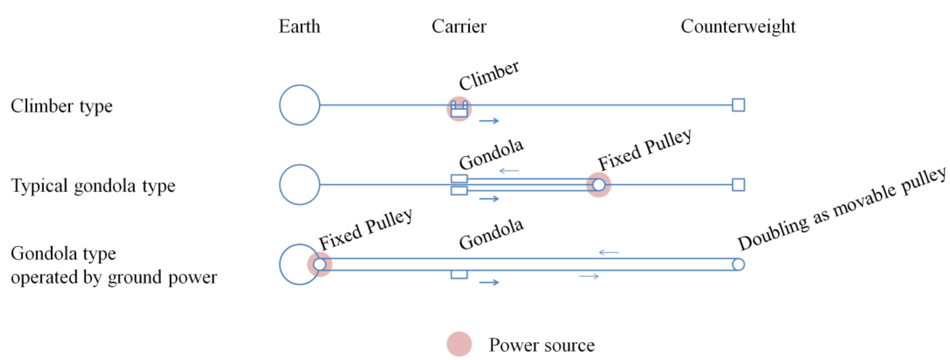

Fig.1: Comparison among three operation methods of space elevator

2. Numerical model

This cable analysis focuses on an initial stage of the space elevator construction and, thereby, we consider only essential facilities: a cable, carrier, top pulley which doubles as counterweight, and bottom pulley. We set the operating method as a gondola type, the material of the cable as carbon nanotubes, and the other parameters related to structures were referred from literatures [1].

The cable was modeled by spring-mass system, as shown in Fig.2. The cable was divided into 198 segments that have three physical quantities: a spring constant, mass and natural length. Basically, spring constants, masses and natural lengths were set as the same value in each segment. We added the mass of carrier at an arbitrary point and the mass of counterweight at the top point. Then, the spring constants of both top and bottom segments were set as variables. Catching and releasing cable by the pulleys were modeled by adjusting natural lengths of the next segments based on the angular velocity of the pulleys. The bottom pulley angular velocity was operated directly. The top pulley angular velocity was determined based on the integrated value of the difference between two springs' forces. When a mass point has reached to the top or bottom mass point less than a certain distance, that mass point was removed and a new mass point was added on the opposite segments. By this, we modeled both of stationary facilities and circulating cable including the carrier.

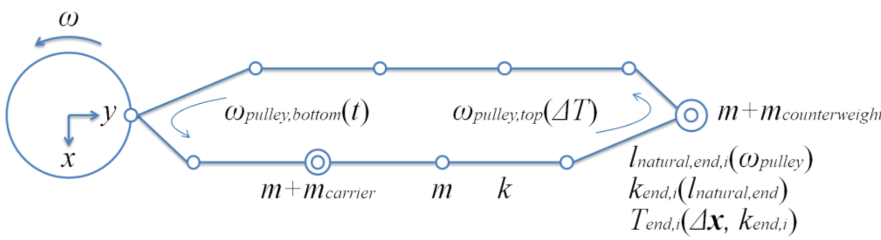

Fig. 2: Numerical model of Ground Power Operated Gondola Type Space Elevator

3. Simulation Results

Typical results of cable dynamics is shown in Fig.3. Figure 3 (a) is considered without the carrier mass. First, the cables start moving to the opposite directions. About 4.5 hours later, the displacement takes the maximum value that is about 515 km. After this, the cables begin to approach each other and, 7 hours later, the cables cross each other as shown in Fig.3 (a). Figure 3 (b) is considered with the carrier mass of 440 kg. It is confirmed that the carrier pulls down the lower cable a bit. However, it can be said that the effect of carrier mass for the entire behavior of the cable is limited.

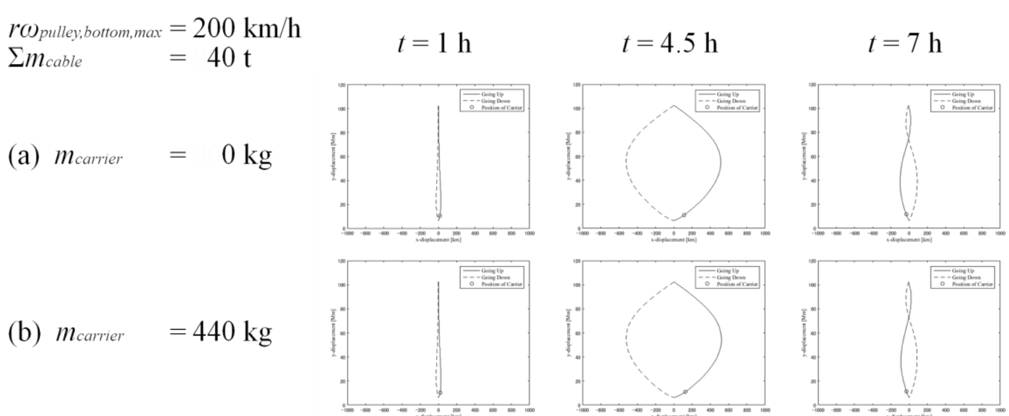

Fig. 3: Typical results of Ground Power Operated Gondola Type Space Elevator

4. Conclusion

We developed a model for simulating the cable dynamics of Ground Power Operated Gondola Type Space Elevator. Special emphasis of this report is the modeling of cable behavior on pulleys by an simple method and the analysis of cable behavior based on multibody dynamics. Thereby, we found some qualitative behavior: amplitude on the order of 100 km, cables' crossing, and limitedly effects of the mass of carrier.

References

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