Design and Optimization of a New Type of Active Hinge

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Abstract. This paper describes the design and optimization of a new type of active hinge, which has the potential application into solar panels for providing the panels with not only self-deploying/folding functions but also active vibration control capacity. The hinge was designed based on direct drive principle of interaction between electromagnet and permanent magnet. Excitated with current of certain time series and phase, the proposed hinge can achieve a ±180° working angle. The torque model of the hinge was established and a SQP optimal method was used for optimize the design parameters of the hinge. Simulation results show that the torque model matches consistently with the FEM analysis, and that it can effectively control vibration of low frequency in the solar panels.

1 Introduction

Solar panels are one of the most important structures for spacecraft. The deploying actions of the solar panels after the spacecraft launching into orbit were executed by elastic elements that can spring up from a fasten state, but would be never folded again. Meanwhile, a shock and vibration are rendered from the elastic part to the large structure when acting deploying movement, and would be propagated to the satellite or to the sensitive device in it[1]. This can be a great threat for the safety and stability of the spacecraft.

In previous studies, various structures and devices have been developed to handle this problem. They are commonly designed based on new type of intelligent materials and structures[2]. These types of intelligent materials and structures not only damage the integrity of the space structure but also increase the weight of the spacecraft additionally. Furthermore, all of them can do nothing to the folding of solar panels.

In this research, a new type of active hinge for solar panels is proposed and optimally designed. We focus on a ±180° working angle and high and changeable driving torque with a minimized volume, by which on one hand to realize the required deploying and folding movement actively, on the other to find a new way of active vibration control to deal with the current problem of low frequency, large amplitude vibration in large structure of spacecraft.

2 Concept design of the active hinge

The designing of this active hinge comes from a general idea of replacing the conventional elastic joints between the two panels with active hinges, which is shown in Fig.1(a). The conceptual design of the proposed new type of active hinge is showed in Fig.1(b). It is mainly composed of a stator and two moving magnetic type rotor. The stator of the hinge has six coils and each of them contains one magnetic yokes inside. The rotor is composed of one pair of magnet disks, which are symmetrical distributed aside the coils. Each of the disks has four permanent magnets and a steel yoke for a high uniform magnetic flux density.
The stator part is fixed to the housing. The four magnets in each disk are polarized either along the axial upward direction or downward direction (the polarity of the permanent magnets which are adjacent is opposite). A high and uniform magnetic flux density is formed at the air gap between the two magnetic plates.

Figure 1. (a) The schematic figure of two solar panels jointed by the active hinges; (b) basic structures of the proposed active hinge.


The six coils can be separated into three groups (EMI, EMII, EMIII) when driving the active hinge, which is shown in Fig. 2(a). In order to make the hinge work efficiently and steadily and achieve a ±180° working angle, the three groups of coils need to be excited according to certain time series and phase.

3 Modeling

To get the model of the total torque of the hinge, we assume that the two magnet plates are the stator, the coils move. Then we get the total torque [3] as:

\[ T_{\text{tot}} = 2iN_{\text{ac}} N_{\text{turn}} B_g R l_e \]  

Where: \( i \) the input current in the coils, \( N_{\text{ac}} \) the number of the coils, \( N_{\text{turn}} \) the number of turns for each coil, \( R \) the equivalent radius of the magnet plate, \( l_e \) the equivalent length of the each coil, \( B_g \) the magnetic flux density in the air gap. For a specific design all the parameters can be easily got except \( B_g \).

Fig. 2(b) shows the schematic of the hinge for modeling the flux density in the air gap. Because the permeability of the steel yokes is much higher than that of the air, so we assume that the steel yoke have infinite permeability (\( \mu = \infty \)). At the same time, we assume that the magnet is ideal which has a linear second quadrant demagnetization. Then we can transform the problem of finding the flux density in 3D space to a 2D one, which is shown in the left of Fig. 3(a). Considering the symmetry of the structure and that all the permanent magnet are identical, finally, the problem...
becomes to find the flux density model in these three regions in the right of Fig.3(a).

\[ \mu = \begin{cases} \mu_1 (\text{region1}) \\ -\mu_2 (\text{region2}) \\ 0 \quad (\text{region3}) \end{cases} \]  

Finally, we get the flux density in the air gap as:

\[ B_{gap}(x,y) = -4\mu_i M_s \sum_{n=1,3,5,...} \frac{(-1)^{n-1/2}}{(n\pi)^2} K(n,h,g,l) \cos \left( \frac{n\pi y}{l} \right) \cos \left( \frac{n\pi x}{l} \right) \]  

Where,

\[ K(n,h,g,l) = \cosh \left( \frac{n\pi g}{l} \right) - \sinh \left( \frac{n\pi g}{l} \right) \coth \left( \frac{n\pi}{l} (g-h) \right) \]  

Where, \( g \) is the gap height, \( t_m \) is the thickness of the magnet, \( h=g+t_m, l=\pi (R_1+R_2)/N_{pole}, R_1 \) and \( R_2 \) are the inner radius and outer radius of the magnet, \( N_{pole} \) is the number of magnets in each magnet plate.

4 Design optimization

In order to achieve high driving torque as well as minimize the volume of the hinge, a design optimization step is required. Fig.3(b) shows the design parameters of the proposed active hinge and the geometric constraints of the design parameters. With these factors, the equation of the objective function is determined as follows:

\[ f(R_1, R_2, t_m, gap) = \min \text{imize} \left( \frac{1}{T^2} \right) \]  

To optimize the design parameters, a sequence quadratic programming (SQP) method and the MATLAB optimization toolbox were used[4-5]. Other fixed parameters are as follow: the inner and outer diameter of the coils are 6mm and 14mm respectively, the current in the coils is 1.6A. Fig.4 shows the convergence of the design parameters used during the optimization of the proposed active hinge.

Figure 4. convergence of the design parameters.
5 Simulation and results

Finally, a FEM electromagnetic simulation and simulation of the hinge torque model were carried out based on the optimized parameters, which is shown in Fig.5(a). According to Fig.5(a), the simulation result of the torque model that we established matches consistently with the FEM analysis.

![Simulation results of the hinge torque based on model and FEM.](image)

To verify the effect of vibration control of the active hinge, a simulation was done. In the simulation, the solar panel was given a sine vibration excitation (0.15hz), the result of the simulation is shown in Fig.5(b). From the result, we can see that the hinge that we proposed can actively control the vibration of low frequency in the solar panels.

6 Summary

In this research, a new type of active hinge was proposed and designed. The hinge was designed based on direct drive principle of interaction between electromagnet and permanent magnet. Excited with current of certain time series and phase, the proposed hinge can achieve a $\pm 180^\circ$ working angle. The torque model of the hinge was established and a SQP optimal method was used for optimize the design parameters of the hinge. Simulation results show that the torque model matches consistently with the FEM analysis, and that it can effectively control vibration of low frequency in the solar panels. A prototype of this active hinge is about to be manufactured, more experiments will be done by that time.

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References


