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Study of Adaptive Variable Structure Attitude Control and Its Full Physical Simulation of Multi-Body Satellite Antenna Drive Control

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Abstract

On validating the feasibility of the antenna program, automatic or extreme tracking on the condition of mutibody dynamics, in order to overcome mutual disturbance caused by antenna driving, an adaptive variable structure control is adopted and solves the model uncertainty of feed-forward compensation in antenna pointing control effectively. This adaptive variable structure attitude control scheme reduces the attitude change caused by modeling error, and has capacity of attitude control with usual feed-forward compensation as well. The paper presents adaptive variable structure control system design method for large-scale satellite antenna and full physical simulation results.

1. Introduction

Besides other payloads, general modern satellites are equipped with mobile satellite communication antenna. When these antennas are driven, exterior interference torques (interference angular momentum) will be produced, and it will affect the precision of satellite attitude by acting on satellite body. The interference must be eliminated to keep attitude precision. Meanwhile, in order to verify nonlinear dynamics characteristic of body attitude caused by mutual coupling with antenna and solar battery array, and the feasibility of multi-body satellite compound control under flexibility interference, an antenna simulation system, which could realize testing ability of antenna frame driving system and compound control system under multi-body mechanics environment, is designed independently based on single axis air floating platform which is for full physical simulation of flexible structure satellite.

Antenna pointing control usually uses a flywheel feedforward compensation, that is, calculating exterior interference caused by antenna drive, then eliminating interferences by driving flywheel when driving antenna. This method will not increase feedback gain of attitude control system when constraining attitude change. But there exists another problem that new interference will be introduced because of mathematical model error during the driving interference calculation.

This adaptive variable structure attitude control scheme can effectively overcome the fatal problem exists feedforward compensation, and can modify modeling error according to attitude data change. Specifically speaking, the linear relationship of interference angular momentum, moment of inertia and other unknown parameters are used to estimate parameter. This adaptive variable structure attitude control scheme reduces the attitude change caused by modeling error, and has capacity of attitude control with usual feed-forward compensation as well. The paper gives out system design methods for adaptive variable structure control scheme suitable for satellite with a large-scale antenna, its numerical simulation examples and full physical simulation results [1].

According to the information of attitude change, this adaptive variable structure attitude control scheme estimates the unknown parameters contained in model, so it can be seen as a parameter estimation method. This approach has the following advantages: parameters approximate true value via attitude error feedback in online estimation, and the only one condition needed by estimating parameter is positive definiteness of mass matrix(This feature is always satisfied), not the value of mass matrix. This method not only updates parameters automatically, but also realizes ground monitor commendably, and has a very simple system structure for parameter estimation.

2. Interference model of antenna pointing control

This paper, takes full physical simulation for compound control of multi-body satellite antenna pointing on air bearing table as an example, derives the

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interference model of antenna pointing control, talks about the theory of adaptive variable structure attitude control scheme.

In order to simplify the model, the flexible interference is not considered. The dynamic model of air bearing table which is proposed by conservation of angular momentum is obtained as follows:

$$I\dot{\theta}+I_t\dot{\phi}+w=0 \quad (1)$$

where θ represents the attitude angle of air bearing table, ϕ represents a rotation angle of antenna, w represents the angular momentum of flywheel. In (1), $I_t\dot{\phi}$ represents the antenna angular momentum. I_t represents the moment of inertia of antenna relative to mass center of platform, and can be obtained by following equation:

$$I_t = I_{to} + m_t(a^2+b^2+2ab\cos(\phi)) \quad (2)$$

Where I_{to} represents the moment of inertia antenna relative to mass center of itself (it is a constant), m_t represents the antenna quality (it is a constant), a represents the distance between antenna shaft and mass center of platform. b represents the distance between antenna shaft and mass center of antenna.

In actual satellite stability control, rotation angle of antenna ϕ is relatively small. Then assume that $\cos\phi \approx 1$, and adequate compensation for outside interference is received. $I_t\dot{\phi}$ is proposed as a function of angle and velocity of antenna, and can be described as follows:

$$I_t\dot{\phi} = Y\alpha \quad (3)$$

Where Y represents the correlation matrix of ϕ and $\dot{\phi}$, α represents the vector related to inertia, quality, mass center location and other parameters of antenna. As above, the theory of online parameter estimation is to modify the estimate value of α, by using linear relationship between antenna interference angular momentum and unknown parameters of the vector α, according to simple estimation law, and manage to make estimate value close to true value. From (2) and (3), Y and α are expressed as:

$$Y = \begin{bmatrix} \dot{\phi} & \phi\dot{\phi} \end{bmatrix} \quad (4)$$

$$\begin{cases} \alpha_1 = I_{to} + m_t(a^2+b^2) \\ \alpha_2 = 2abm_t \end{cases} \quad (5)$$

3. Design for adaptive variable structure control scheme

3.1. control law and the parameters estimation

Suppose that $\hat{\alpha}$ is the estimate value of α, considering variable structure control law plus feedforward control. Let Switching surface is $s = c\dot{e}+e$, the flywheel angular momentum is:

$$w = -Y\hat{\alpha} + \varepsilon\,\mathrm{sgn}(s) + ks \quad (6)$$

where ε, k represent control gain of variable structure. Parameter estimation law is presented as .

$$\dot{\hat{\alpha}} = -PY^T\theta \quad (7)$$

where P represents positive definite symmetric estimate gain matrix. The parameter estimation law coupled with (6) is the adaptive variable structure control law.

For the full physical simulation system of the satellite antenna pointing control, by using parameter estimation law (7), $\hat{\alpha}$ represents the vector composed of two components, Y represents the 1X2 matrix. In the component of $\hat{\alpha}$, the items related to second order small scale $\phi\dot{\phi}$ almost don't change in fact.

3.2. The character of attitude control mode

By using this parameter estimation law, the attitude angle error θ is fed back, and will have indirect impact on attitude control system. Here a simple study of the impact is taken. According to parameter estimation law (7), $\hat{\alpha}$ can be expressed as follows, but firstly let the initial value of is .

$$\hat{\alpha} = \hat{\alpha}_0 - \int PY^T\theta dt \quad (8)$$

Substitute (8) into (6):

$$w = -Y\hat{\alpha}_0 + \int YPY^T\theta dt + \varepsilon\,\mathrm{sgn}(s) + ks \quad (9)$$

As antenna drive commands have a lot of restrictions on the matrix Y, correspondingly, the stability margin is not a problem if the gain P of parameter estimations law is set. The smaller P is, the longer time is required for parameter estimation. On the contrary, because the estimation law could calculate time for getting unknown parameters according to time constant of attitude control system, it will not have bad impact on the stability of the attitude control system, and could improve system precision.

4. Evaluation on control scheme

In order to confirm the effect of practical application of this adaptive variable structure attitude control scheme, the antenna drive physical experiments are conducted with satellite antenna pointing compound control full-physical simulation system. Each time the rotation of antenna is from -65 to 65, and then from 65 to -65. This kind of drive are repeated until the change of satellite attitude angle error and estimation parameter value are investigated clearly. Here the first and seventh antenna tracking acceleration command error figures are shown in fig.1 and fig.2.

These two figures show that when antenna track acceleration command signal the tracking error of antenna converge fast to $\pm 0.5^o$.

The antenna drive angle error change situations are also shown in figures. The seventh antenna drive angle error outlier decreases severely, the precision improves gradually, indicates that drive antenna repeatly can increase the estimation precision, and using flywheel can make interference angular momentum converge fast to improve antenna pointing precision.

5. Conclusion

In this paper, a control method to reduce interference of antenna driving to satellite body is studied. This method has advantages as follows: parameter estimation law could be improved by adding simple on-orbit parameter estimation law on general attitude control law. Even high-speed rotation antenna cannot influence attitude angel precision. So the time to rotate antenna can be shortened greatest and body attitude precision can be improved when adopting satellite antenna pointing control.

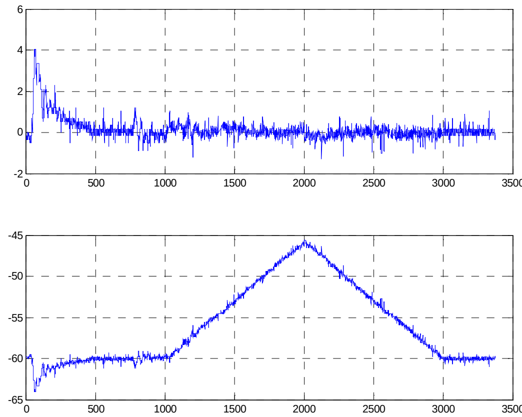

Figure 1 changes of attitude angle in the 1st drive antenna

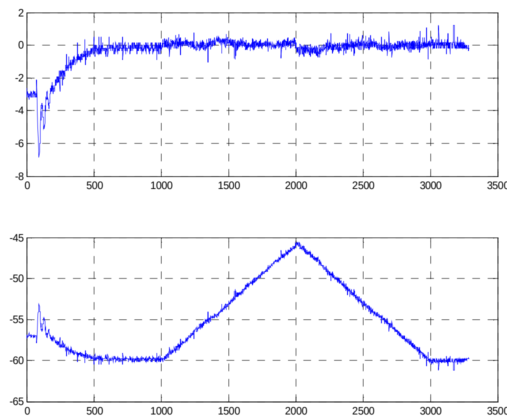

Figure 2 changes of attitude angle in the 7th drive antenna

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