Quantitative analysis of Satellite counterweight and Influencing Factors

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Abstract: Counterweight will increase with the use of more and more load equipment. More counterweights in satellite will reduce weight percentage of load equipment, consume fuel and short the lifetime of satellite on orbit. Firstly, this paper analyzes the relative factors with counterweight, and the relationships between them. That is, the relationships between counterweight and designed centroid from satellite layout, centroid error from product and computational error, installation scheme and error of 490N engine, as well as the disturbance torque value. Then the way to reduce counterweight is approached.

1. Introduction
Counterweights for some platform satellite stay high. From the date analyses of counterweight will increase with the use of more and more load equipment, such as deployable antennas. More counterweights in satellite will reduce weight percentage of load equipment, consume fuel and short the lifetime of satellite on orbit.

2. Mechanism analyses
If the thruster vector does not point instantaneous centroid during 490N engine igniting, disturbance torque is produced (thrust is a physical quantity that makes satellite rotate around its centroid). If disturbance torque exceeds the required value of control subsystem, more counterweights and adjusting engine pointing will be taken to meet that requirement. So, counterweight depends on satellite centroid, 490N engine thrust (attachment point, value and direction) and disturbance torque value. That is, counterweight is related to designed centroid from satellite layout, centroid error from product and computational error, installation scheme and error of 490N engine, as well as disturbance torque value.

3. Relationships between counterweight and various factors
3.1 Influence of satellite layout, product and computational error on eccentricity
Satellite layout is affected by many factors, so the satellite centroid is difficult to ensure no eccentricity. More serious eccentricity cost more counterweights (invalid weight) to align satellite centroid. Measurement value of satellite centroid is divided into designed centroid value, product from satellite layout and computational error. Computational error of quality characteristic is related with product error, and product error is main source of computational error. Secondary source of computational error is numerous fasteners, auxiliary materials of thermal and assembly which difficult to count.
3.1.1 Influence of satellite layout on eccentricity

(1) For example, maximum value of designed centroid from satellite layout is 24.0mm, product and computational error is 5.3mm. Maximum value of designed centroid from satellite layout is apparently higher than centroid error from product and computational error. Because satellite layout is limited by many factors, centroid value maybe large, while product and computational error is relatively limited.

(2) From these two aspects, maximum values of theoretical centroid of x coordinate are 24.0mm respectively. Maximum values of theoretical centroid of y coordinate are 13.6mm. This indicates that maximum value of x coordinate is apparently higher than the value of y coordinate, while the centroid value of y coordinate is relatively limited. To find out its cause, equipment and devices are mainly located at north and south panel, and the amount of which is nearly up to 500 sets. The amount and weight are basically balanced, so the total error is relatively limited (this will be explained in detail in the next section). Main reasons for serious eccentricity of x coordinate are those heavy and remote antennas and cameras from satellite centroid. Because counterweight can change centroid value of x and y coordinates, so simply take the maximum value of two directions. Maximum and average values of theoretical centroid are equal to 48.0kg and 19.0kg counterweights, respectively.

(3) Maximum and average value of centroid changing caused by product and computational error are 5.3mm and 3.2mm respectively, equaling to 10.6kg and 6.4kg counterweights.

3.1.2 Influence of product and computational error on centroid error

Influence of product and computational error is analyzed using model data in the last section. theoretical analysis and comprehensive consider is conducted then. In order to facilitate analysis, satellite is divided into three parts: generic product (subdividing into equipment and device, cable and waveguide, structure and thermal, solar array), big part outside the satellite such as antenna, camera etc., and propellant.

For general product, both weights of equipment and device in south and north panel are 550kg according to construction standard. Taking equipment of some satellite and weight error from construction standard for example, assume that the error of single sample is random distribution, and the total error (weight difference of north and south panel) is more than 3kg. Because per time the total error is different, so 100 times random sampling is in progress in this paper. The maximum error is 2.88kg. Assume that cable and waveguide affects counterweight of 1kg. For east and west antenna and camera, the counterweight needed is 10.6kg. For those propellant eccentricity caused by processing and installation technology of central column shell and tank, the maximum eccentricity of oxidant and fuel of some satellite equaling to 2.4kg and 2.9kg counterweights. The above-mentioned is based on that both propellant eccentricities are the maximum and at same direction.

(a) Error source and influence in the x-direction

(b) Error source and influence in the y-direction

Fig.1 source and influence of product and computational error

According to above analysis, influence factor of product is shown amply in figure 1. Theoretically, the influence factors of centroid error are east and west antenna, equipment and device, structure and
thermal, propellant. In the x direction, main factors are east and west antenna (62%, equaling centroid changing caused by 10.6kg counterweight), equipment and device (18%, 3kg), propellant (14%, 2.4kg), cable and waveguide (6%, 1kg) in sequence, of which the first three accounted for 96%. In the y direction, main factors are structure and thermal (47%, 7.5kg), equipment and device (19%, 3kg), propellant (18%, 2.9kg), solar array (10%, 1.5kg), cable and waveguide (6%, 1kg) in sequence, of which the first three accounted for 84%.

Take the maximum one, because counterweight can change centroid in the both x and y direction at the same time. So, east and west antenna, propellant errors are main factors that cause product eccentricity. Centroid error will reach a maximum when it is limit error. From preliminary theoretical hypothesis and analysis, the maximum product error equals counterweight of 17kg, which causes eccentricity of 8.5mm.

The influence of product error is analyzed above; the influence of computational error of quality characteristic will be analyzed then. According to some model rules, the maximum centroid errors in the x and y direction are both ±2mm. It will cost counterweight of more than 4kg to offset those errors.

3.2 Influence of installation scheme and error of 490N engine

3.2.1 Influence of installation scheme
Because the time of engine installation align is before quality characteristic test, so there is only computation value of quality characteristic at present.

The installation scheme of 490N engine (pointing and location) is divided into present method and optimism method. The difference between these two is thrust pointing. Present method will make the inclined angle of thruster vector and z axis approach to 0; while optimism method is based on the assuming that centroid computation value is dependable, and make the thrust vector to point centroid around during orbit transfer.

Next, the influence of installation scheme is analyzed through a calculation example. Assume that the eccentricities in the x and y direction are both 5.0mm.

| Disturbance torque Tx, Ty | Old method (counterweight 0Kg) | Optimism method (counterweight 30Kg) |
|--------------------------|-------------------------------|--------------------------------------|
| Maximum value            | -4.7                          | 0.8                                  |
| Minimum value            | -7.8                          | -0.8                                 |

It can be find out from disturbance torque value in tab 1 that more counterweight, more eccentricity, if present method is taken. When counterweight is 0, the disturbance torque reaches 7.8N.m. That will need nearly 30kg counterweight to minimize the disturbance torque (if the eccentricity of 5.0mm is about a single direction, that will need counterweight of 5000kg×5mm/1000mm=25kg). While the optimism method makes thruster vector to point to computational centroid nearby, so wherever the computational centroid is, there will be no more counterweight for the computational centroid, which is a key approach to achieve the target of non-counterweight. The actual centroid distributes a spherical region which center is computational centroid. So it is apparently rationality that thruster vector points to computational centroid.

3.2.2 Influence of installation error
In assembly error, because the position error of antennas etc. is small, so antennas etc. have less influence on the centroid and counterweight, on which main factor of influence is the installation error of 490N engine; In order to offset maximum installation error which technology requirement allows, it will cost counterweight of 4kg.
3.3 Summary
To avoid undervalue, for large counterweight, worse theoretical upper limit is chosen. To avoid overestimate, the average value of model is chosen. According to relationships between counterweight and design method, eccentricity of satellite layout, product and computational error, installation error of 490N engine, and total counterweight is shown in fig.2.

1) The maximum and average centroid values from satellite layout are 24.0mm and 9.5mm respectively, equaling counterweights of 48.0kg and 19.0kg respectively.
2) The maximum and average centroid values from product error are 8.5mm and 2.2mm respectively (average computational error is deducted), equaling counterweights of 17.0kg and 4.4kg respectively.
3) The maximum and average centroid values from computational error (in the x and y direction) are ±2.0mm and ±1.0mm respectively, equaling counterweights of 4.0kg and 2.0kg respectively.
4) The maximum and average counterweights using to offset 490N engine are 4.0mm and 2.0mm respectively.

![Fig.2 Relationships between counterweight and design method, eccentricity of satellite layout, product and computational error, installation error of 490N engine](image)

In summary, following conclusions are observed:
(1) In the worst condition: if present method is taken, total counterweight will be 51.6kg. This value is twice as much as the maximum counterweight of some model. If optimism method is taken, total counterweight will be 3.6kg.
For actual models, if weight allowance is large, a certain amount of counterweight is usually added to satellite to reduce disturbance torque value. If the disturbance torque is controlled among 2.2Nm (average value of models), it will need counterweight of 13.9kg, and the average counterweight value of 10 satellites is 12.7kg, both are in very good agreement, which also proved that the analysis method is reasonable and accurate.
(2) The influence from different design methods (installation scheme). If present method is taken, more eccentricity, more counterweight. If optimism method of minimising the disturbance torque (making the thrust vector to point centroid around) is taken, it will overcome the shortcomings of present method. Designed eccentricity itself will not add counterweight, which is the main way to reduce counterweight.
Model development for many years makes us accumulating certain data. The purposes of this paper are to mine relations and laws, and to enhance design level.
4. How to reduce counterweight

In summary, counterweight is decided by designed centroid of satellite layout, product and computational error, installation scheme and error of 490N engine, disturbance torque index. According to influence extent, installation scheme of 490N engine, designed centroid of satellite layout, centroid error from product error are three main factors to influence counterweight. Computational error of quality characteristic and installation error of 490N engine are two secondary factors, as well as the disturbance torque.

For main factors, satellite layout is limited by many factors, so it is hard to reduce designed centroid error. Control level of product error will not be remarkably improved. Installation scheme of 490N engine is the main factor, and also the breakthrough of improvement. So, optimism method is the key way to reduce counterweight.

For secondary factors, computational error and Installation error of 490N engine have little influence on counterweight, so reduce those errors only play a quite limited addition role in reducing counterweight. Otherwise, the disturbance torque is decided by configuration and performance of control subsystem, which this paper will not discuss, only suggested range for designing is present.

It can see that, if the optimization algorithm is taken, the ranges, The maximum component of disturbance torque is symmetry distribution, and tends to minimize, which realizes the target of optimization design. This method will reduce counterweight of satellite, save fuel and improve life on orbit.

5. Summary

In the case, counterweight stays high without action. Firstly, this paper analyzes the relative factors with counterweight, and the relation between them. Then, the way to reduce counterweight is approached. Finally, the optimization method is present.

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