

# Configuration Optimization and Force Analysis of Parallel Attached Platform for Satellite Docking

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**Abstract.** This paper makes use of the Stewart parallel mechanism acted as a parallel adjustment platform (PAP) on the satellite integrated assembly system, which is applied to carry on the adjustment of real-time high precision position and orientation for satellite integrated assembly. PAP's configuration optimization using optimization algorithm, which is designed to ensure the force on every limb in the workspace within the range of maximum value. The force of PAP's every limb is analyzed based on the screw theory, and is verified by the Adams software through simulation under the planning pathway, the result verifies the correctness of theoretical calculation. The research contents possess an important guideline significance for the structural design and performance optimization of PAP.

## 1. PREFACE

In order to ensure the precise adjustment of the attitude of the satellite integrated assembly, a more mature PAP can be used to assist the engineers to install the satellite. This parallel position adjustment platform adopts six degrees of freedom Gough-Stewart platform as the motion body, and it can achieve the position adjustment of the satellite moving along the X direction, Y direction and Z direction to  $\pm 50\text{mm}$ , and rotate around X, Y and Z to  $\pm 5^\circ$ . The overall space size of the PAP is controlled in  $2600 \times 2600 \times 1500\text{mm}$ .

The weight of the satellite is about 5T, which is relatively heavy. It requires that the adjustment mechanism has high positioning accuracy and stiffness. Due to the limited space, the layout of the adjusting mechanism should be tight. The parallel mechanism of Gough-Stewart platform has a good rigidity. The bearing capacity is great. The structure is symmetrical and so on. It is very suitable to adjust the position and position of the satellite as a PAP [1].

Scholars at home and abroad have many literatures about the parallel mechanism of Gough-Stewart platform, and the technology is relatively mature. However, there are few literatures on it as a parallel position adjustment platform for satellite assembly posture adjustment. GENG and HAYNES[2] use neural network to solve the dynamic problem of the Stewart platform. MCAREE and DANIEL[3] have found a robust, fast solution to the dynamics of the Stewart platform. ZHANG[4] has done some research on the semi physical simulation of space docking. Huang and other [5] people have given a number of ways to analyze the Stewart platform. KIM and CHUNG[6] analyzed the six degree of freedom parallel robot with a structured method. YIU[7] lists the advantages of many parallel robots.



In this paper, the basic parameters of the parallel position adjustment platform for satellite attitude adjustment are optimized by using the optimization algorithm. Based on that, the axial force of each branch of the parallel position adjustment platform in the working space is theoretically calculated and simulated.

## 2. Configuration and optimization of platform

### 2.1. Configuration of PAP

The PAP for satellite attitude adjustment uses a mature 6-UPS type Stewart parallel mechanism, which can be customized according to the requirements of the system. The height of the parallel position adjustment platform can be controlled by the branched chain movement. The 6 branches support the moving platform with high stiffness, which can meet the high stiffness requirement of the satellite attitude adjustment, and the structure is compact, the performance is advanced, and the positioning accuracy is high. The satellite integrated assembly system under the cabin and adjusting parallel platform is divided into general hoisting system, the satellite is composed of three parts, its structure diagram is shown in Fig. 1.

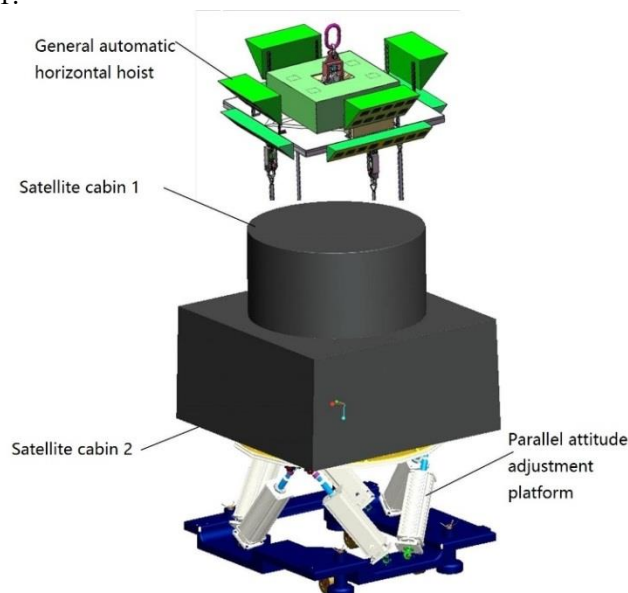


Figure 1. Schematic diagram of the structure of a satellite integrated assembly system

### 2.2. Configuration optimization of PAP

The mechanism diagram of the parallel attitude adjustment platform is shown in Fig. 2.

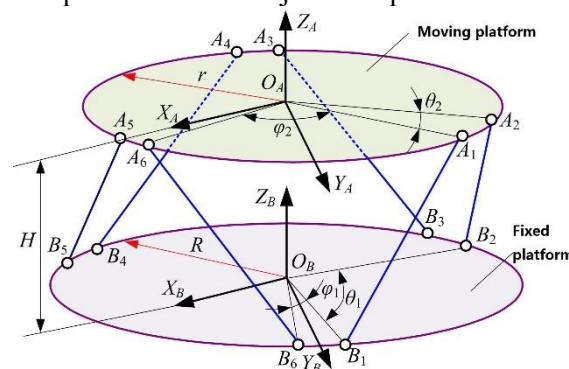


Figure 2. Mechanism diagram of parallel attitude adjustment platform

Among them,  $O_B-X_BY_BZ_B$  is a fixed platform coordinate system, and  $O_A-X_AY_AZ_A$  is a dynamic platform coordinate system. On the fixed platform, each Hooke hinge point  $B_i$  ( $i=1,2,\dots,6$ ) evenly distributed on the circumference of the radius  $R$ , and the hinges of each ball on the moving platform are  $A_i$  ( $i=1,2,\dots,6$ ) evenly distributed at the circumference of the radius  $r$ , and the hinge points 1, 3, 5 or hinges 2, 4, 6 are arranged in  $120^\circ$  equal intervals. The  $Y_B(Y_A)$  axis is equally divided into the angle of the hinge point  $B_1, B_6(A_1, A_6)$  and the coordinate origin  $O_B(O_A)$  line. The  $Z_B(Z_A)$  axis is perpendicular to the fixed (moving) platform, and  $X_B(X_A)$  satisfies the right rule of the right hand. The angle between  $B_1, B_6(A_1, A_6)$  is equal to the join angle of  $A_1$  ( $A_6$ ) and the center  $O_B(O_A)$  of the fixed platform. The angle between  $\theta_1(\theta_2)$  is the hinge angle  $B_1, B_2(A_1, A_2)$  and the connection angle of the center  $O_B(O_A)$  of the fixed platform. And  $\varphi_1+\theta_1=\varphi_2+\theta_2=2\pi/3$ .

According to the usual method, the attitude of the moving platform can be expressed by three Euler angles:  $\alpha$ ,  $\beta$  and  $\gamma$ , so the attitude transformation matrix of the moving platform relative to the moving platform can be expressed as:

$$\mathbf{T} = {}^B_A\mathbf{T}_{ZYX}(\alpha, \beta, \gamma) \quad (1)$$

The position vector of the Hooke hinge point of the fixed platform relative to the fixed platform coordinate system can be expressed as:

$$\begin{cases} \mathbf{B}_1 = R(\cos(\pi/2 - \theta_1/2) & \sin(\pi/2 - \theta_1/2) & 0)^T \\ \mathbf{B}_2 = R(\cos(\pi/2 + \theta_1/2) & \sin(\pi/2 + \theta_1/2) & 0)^T \\ \mathbf{B}_3 = R(\cos(7\pi/6 - \theta_1/2) & \sin(7\pi/6 - \theta_1/2) & 0)^T \\ \mathbf{B}_4 = R(\cos(7\pi/6 + \theta_1/2) & \sin(7\pi/6 + \theta_1/2) & 0)^T \\ \mathbf{B}_5 = R(\cos(11\pi/6 - \theta_1/2) & \sin(11\pi/6 - \theta_1/2) & 0)^T \\ \mathbf{B}_6 = R(\cos(11\pi/6 + \theta_1/2) & \sin(11\pi/6 + \theta_1/2) & 0)^T \end{cases} \quad (2)$$

Position vector of the platform the ball joint hinge point said in a moving platform coordinate system for  $O_B-X_BY_BZ_B$ :

$$\begin{cases} \mathbf{a}_1 = (r \cos(\pi/2 - \phi_2/2) & r \sin(\pi/2 - \phi_2/2) & 0)^T \\ \mathbf{a}_2 = (r \cos(\pi/2 + \phi_2/2) & r \sin(\pi/2 + \phi_2/2) & 0)^T \\ \mathbf{a}_3 = (r \cos(7\pi/6 - \phi_2/2) & r \sin(7\pi/6 - \phi_2/2) & 0)^T \\ \mathbf{a}_4 = (r \cos(7\pi/6 + \phi_2/2) & r \sin(7\pi/6 + \phi_2/2) & 0)^T \\ \mathbf{a}_5 = (r \cos(11\pi/6 - \phi_2/2) & r \sin(11\pi/6 - \phi_2/2) & 0)^T \\ \mathbf{a}_6 = (r \cos(11\pi/6 + \phi_2/2) & r \sin(11\pi/6 + \phi_2/2) & 0)^T \end{cases} \quad (3)$$

Position vector of the platform the ball joint hinge point said in a fixed platform coordinate system for  $O_A-X_AY_AZ_A$ :

$$\mathbf{A}_i = \mathbf{T}\mathbf{a}_i + \mathbf{P} \quad (i=1,2,\dots,6) \quad (4)$$

In the formula,  $\mathbf{P}=(P_x, P_y, P_z)^T$  is the position vector expressed in the fixed coordinate system of the coordinates of the coordinate system of the moving platform. The length of each branch rod length  $l_i$  of the parallel attitude adjustment platform can be expressed as:

$$l_i = |\mathbf{L}_i| = |\mathbf{A}_i - \mathbf{B}_i| \quad (i=1,2,\dots,6) \quad (5)$$

According to the actual work of satellite integrated assembly system, adjusting parallel platform platform radius need to cooperate with the size of the satellite cabin interface phase, taking into account

the system space requirements and convenient installation, adjusting parallel platform to determine the dynamic radius of  $r=1070\text{mm}$  platform. Optimization flow chart of configuration parameters of parallel attitude adjustment platform, as shown in Fig.3.

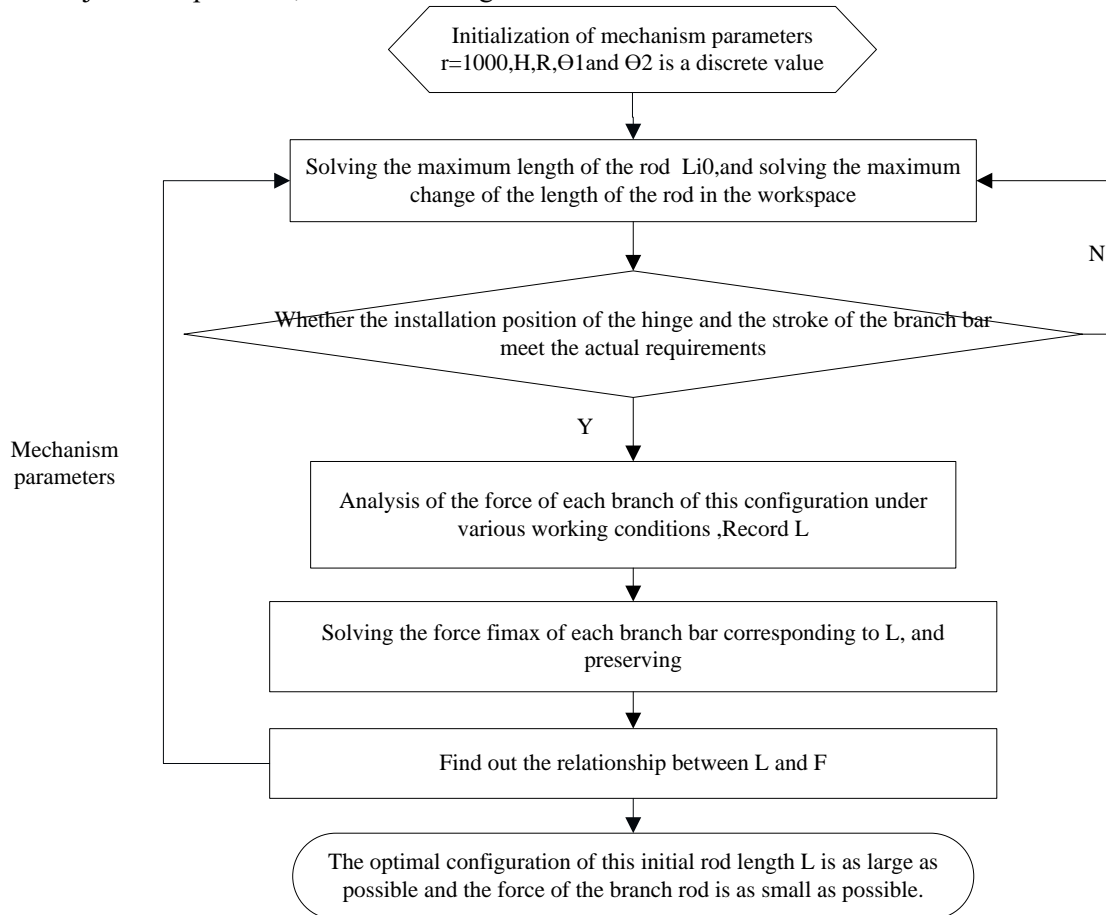


Figure 3. Flow chart of configuration parameter optimization

The parameters of the parallel attitude adjustment platform are optimized according to the calculation flow shown in Figure 3. The basic parameters of the configuration after the optimization are shown in Table 1.

Table 1. Configuration optimization parameters

$R/\text{mm}$	$r/\text{mm}$	$H/\text{mm}$	$\theta_1/^\circ$	$\theta_2/^\circ$	$\varphi_1/^\circ$	$\varphi_2/^\circ$
1100	1000	1070	105	12	15	108

### 3. Force analysis of PAP

#### 3.1. Static analysis of PAP

Based on the helix theory, the force analysis of the parallel connection can be obtained as the following equation [5]:

$$\mathbf{F} = \mathbf{G}_f^T \mathbf{f} \quad (6)$$

In the formula,  $\mathbf{F}=(f_x, f_y, f_z, m_x, m_y, m_z)^T$  is the six dimensional external force load vector of the moving platform,  $\mathbf{f}=(f_1, f_2, \dots, f_6)^T$  is the driving force vector of six branch legs,  $\mathbf{G}_f^T$  is the first order static influence coefficient matrix, which is in the form of:

$$\mathbf{G}_f^F = \begin{pmatrix} \frac{\mathbf{B}_1 - \mathbf{A}_1}{|\mathbf{B}_1 - \mathbf{A}_1|} & \frac{\mathbf{B}_2 - \mathbf{A}_2}{|\mathbf{B}_2 - \mathbf{A}_2|} & \dots & \frac{\mathbf{B}_6 - \mathbf{A}_6}{|\mathbf{B}_6 - \mathbf{A}_6|} \\ \frac{\mathbf{A}_1 \times \mathbf{B}_1}{|\mathbf{B}_1 - \mathbf{A}_1|} & \frac{\mathbf{A}_3 \times \mathbf{B}_3}{|\mathbf{B}_3 - \mathbf{A}_3|} & \dots & \frac{\mathbf{A}_6 \times \mathbf{B}_6}{|\mathbf{B}_6 - \mathbf{A}_6|} \end{pmatrix} \quad (7)$$

If  $\mathbf{G}_f^F$  is not singular, the formula (6) can be written as:

$$\mathbf{f} = \mathbf{G}_f^f \mathbf{F} \quad (8)$$

In the form,  $\mathbf{G}_f^f = (\mathbf{G}_f^F)^{-1}$ .

The formula (8) shows that when the load vector  $\mathbf{F}$  of the six dimensional external force on the moving platform is known, the axial tension pressure on the branches can be calculated. The external load on the moving platform of the parallel position adjustment platform for the satellite integrated assembly system is composed of two parts: one is the load vector caused by the self weight of the moving platform; the other is the load vector caused by the satellite's self weight. The two is the load vector caused by the self weight of the moving platform. According to the optimization design of adjusting parallel platform before, and according to the actual situation of the satellite integrated assembly system, after processing of the moving platform of  $f_d=2500\text{N}$  satellite gravity, gravity  $f_t=49000\text{N}$ , thus adjusting parallel platform total load  $F_s=51500\text{N}$ , using the formula (8) obtained by adjusting parallel platform of each branch rod in the working space within the scope of the theory of maximum stress  $f_m=16659\text{N}$ . The maximum force of the branch rod is an important parameter designed by the PAP of the satellite integrated assembly system.

### 3.2. Simulation and analysis of PAP

The 3D entity model in the Adams simulation environment of the satellite integrated assembly system is shown in Fig. 4.

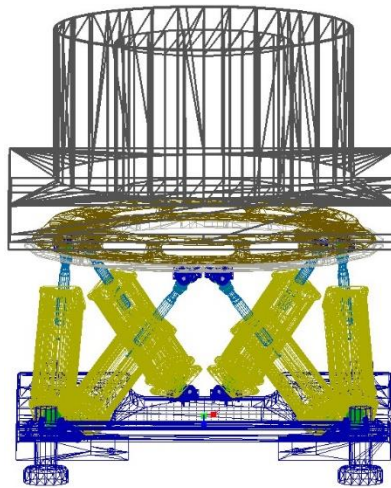


Figure 4. 3D solid model of Adams PAP

Before the simulation analysis, it is necessary to verify the accuracy of the model. In order to verify the accuracy of the constraints under Adams model and applied, for adjusting parallel platform for dynamic path planning for platform design as shown in Table 2.

Table 2. Motion parameters of the moving platform

Time interval	Motion parameters	Time interval	Motion parameters
0~5s	Moving -50mm along the $Z_A$	5~10s	5 degrees around the $X_A$
10~15s	5 degrees around the $Y_A$	15~20s	5 degrees around the $Z_A$
20~30s	Moving -50mm along the $X_A$	30~40s	Moving 100mm along the $X_A$

	Moving -50mm along the $Y_A$		
40~50s	Moving 100mm along the $Y_A$	50~60s	Moving -100mm along the $X_A$
70~80s	Moving -100mm along the $Z_A$	80~90s	Moving 100mm along the $X_A$
90~100s	Moving 100mm along the $Y_A$	100~110s	Moving -100mm along the $X_A$
110~120s	Moving -100mm along the $Y_A$	$\vdots$	$\vdots$
$\vdots$	$\vdots$	$\vdots$	$\vdots$
860~870s	-10 degrees around the $Z_A$	870~880s	10 degrees around the $X_A$
880~890s	10 degrees around the $Y_A$	890~900s	10 degrees around the $Z_A$

The parallel position adjustment platform moves in accordance with the above planned motion path in the Adams environment, and the force of each branch bar is measured in real time under the condition of precision assurance. The force of each branch of the parallel position adjustment platform simulated by Adams is shown in Fig.5~Fig.10. From Fig.5~Fig.10, we can see that the calculated values of the maximum force of the branches are consistent with the theoretical values, which indicates the correctness of the proposed parallel position adjustment platform model and the applied constraint conditions.

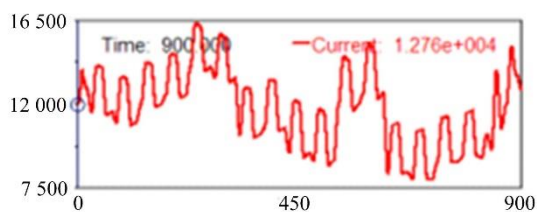


Figure 5. Branch 1 force curve

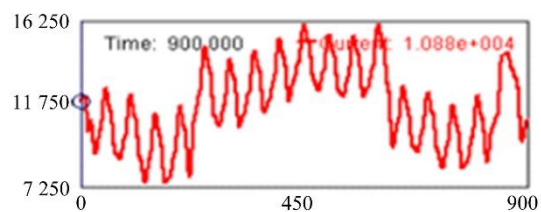


Figure 6. Branch 2 force curve

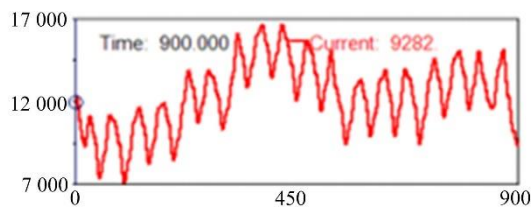


Figure 7. Branch 3 force curve

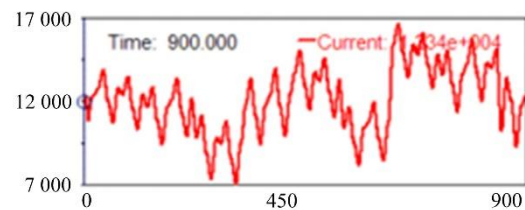


Figure 8. Branch 4 force curve

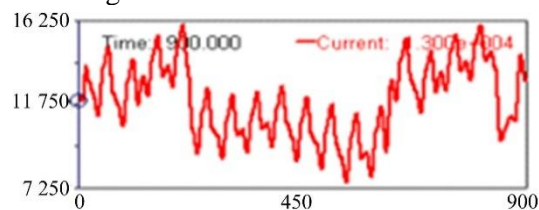


Figure 9. Branch 5 force curve

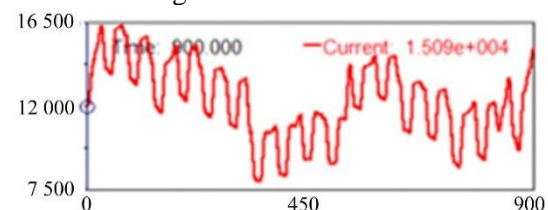


Figure 10. Branch 6 force curve

From Fig.5~Fig.10, we can see that within the range of motion planning, the force ranges of the branches of the parallel position adjustment platform are all within the maximum stress range of the branch bar, which indicates that the selection and design of the relevant parts of the machine body design part is in line with the requirements. At the same time, comparing the force on each branch rod, it can be seen that the force of the branch 3 and 4 is maximum and the maximum is 16659.50N, which is the most consistent with the theoretical branch rod.

#### 4. conclusion

(1) Optimize the configuration of the parallel position adjustment platform based on the optimization algorithm. Based on the principle that the initial rod length is as large as possible and the force of each



branch is minimum, the basic structural parameters of the parallel position adjustment platform satisfying the requirements of the satellite integrated assembly system are determined.

(2) The maximum force of branch bar is an important design parameter of parallel position adjustment platform. Based on screw theory and virtual simulation software, the theoretical analysis and simulation analysis of the force of the parallel platform are carried out, and the simulation results verify the correctness of the theoretical analysis.

## Reference

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