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Research on 6 DOF - Steward Platform mechanical Characteristics Analysis and Optimization Design

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Abstract***: This paper deals with the analysis mechanical characteristics of 6 DOF of Stewart Platform Modeling. The configuration of the sensor is based on the well known Stewart Platform manipulator. The key difference between other Stewart Platform based sensors and the one discussed in this paper is the use of a Stewart Platform in a near singular configuration. It is known in kinematics literature that a Stewart Platform at a singular configuration cannot resist some component(s) of externally applied force or moment. At near-singular configurations, a small applied force or moment in certain specific direction(s) can give rise to large forces in the links, resulting in mechanical magnification in link forces. The mechanical amplification enables us to achieve enhanced sensitivity along certain specific directions In order to find the optimal structure and guidance structure optimization design, in this paper used ANSYS software design and calculate two different forms of the platform model This paper presents the theory to obtain the Best result and design of a 6-6 Stewart Platform manipulator, results from finite element analysis of a hinge jointed Stewart Platform based sensor sensitive to externally applied force.***

Keywords: Stewart Platform, Ansys software, mathematical model, finite element analysis.

1. Introduction

In recent years, with the popularization of computer technology and computing speed continues to improve, finite element analysis in engineering design and analysis has been more widely appreciated, and has become an effective way to solve complex computational problems of engineering analysis. The finite element method is a systematic numerical calculation method for solving differential equations, as opposed to the traditional solution, it has the theory of complete and reliable, the physical intuitive meaning is clear, the problem-solving performance advantages, in particular, this method is adaptable form of specification. The design and mechanical analysis of the platform were done in Ansys software, allowing the system to be analyzed through a finite element analysis, while having the capability of viewing its kinematics and limits in physical motion. Overall conclusions for the paper are:

- The Stewart Platform design shows that the limits in the physical movement of the platform are sufficient for the medical application
- The establishments of the integral equation orthogonal function according to the variation
- principle or equation margin and the right principle, to establish the equivalent integral expression of differential equations initial
- Boundary value problem, which is the starting point of the finite element method.
- Using finite element equation: general finite element equations amended in accordance with the boundary conditions is closed with all pending unknown quantity equations, using appropriate numerical methods for solving function value of each node can be obtained.

2. The Unit Displacement Function

According to the basic idea of the finite element method, the elastomeric discrete finite combination units, node displacement as the unknown quantity. The actual distribution of displacements of the elastic body can be divided with the displacement distribution function within the cell to block approximately expressed. The displacement change in the unit can be assumed that a function to represent, this function is called a unit displacement function, or unit displacement mode. Elastic plane problems, the unit displacement function can be represented by a polynomial.

$$u=a_1+a_2x+a_3y+a_4x^2+a_5xy+a_6y^2+\dots$$
$$v=b_1+b_2x+b_3y+b_4x^2+b_5xy+b_6y^2+\dots \quad (1)$$

3 node triangular elements as shown in Figure 1, node I, J,M coordinates are (x_i,y_i), (x_j,y_j), (x_m,y_m), Nodal displacements were u_i, v_i, u_j, v_j, u_m, v_m. Six nodal displacements.

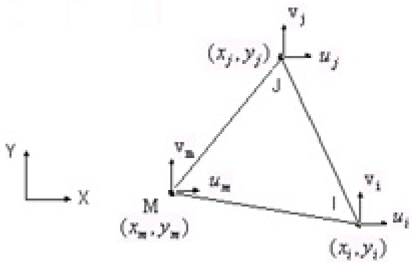

Figure 1: 3 node triangular elements

can only determine the six coefficients of the polynomial, so the 3-node triangular element displacement function as follows,

$$\left.\begin{aligned} u &= a_1+a_2x+a_3y \\ v &= a_4+a_5x+a_6y \end{aligned}\right\} \quad (2)$$

The three junction points on the coordinates and the displacement components are substituted into the formula (2) can be six undetermined coefficients with the node coordinates and the displacement components represented.

The horizontal displacement component and the node coordinating to (2) in the first type,

$$u_i = a_1 + a_2 x_i + a_3 y_i$$
$$u_j = a_1 + a_2 x_j + a_3 y_j$$
$$u_m = a_1 + a_2 x_m + a_3 y_m \qquad (3)$$

Written in matrix form,

$$\begin{Bmatrix} u_i \\ u_j \\ u_m \end{Bmatrix} = \begin{bmatrix} 1 & x_i & y_i \\ 1 & x_j & y_j \\ 1 & x_m & y_m \end{bmatrix} \begin{Bmatrix} a_1 \\ a_2 \\ a_3 \end{Bmatrix} \qquad (4)$$

Then

$$\begin{Bmatrix} a_1 \\ a_2 \\ a_3 \end{Bmatrix} = [\mathrm{T}]^{-1} \begin{Bmatrix} u_i \\ u_j \\ u_m \end{Bmatrix} \qquad (5)$$

That

$$\begin{Bmatrix} a_1 \\ a_2 \\ a_3 \end{Bmatrix} = \frac{1}{2A} \begin{bmatrix} a_i & a_j & a_m \\ b_i & b_j & b_m \\ c_i & c_j & c_m \end{bmatrix} \begin{Bmatrix} u_i \\ u_j \\ u_m \end{Bmatrix} \qquad (6)$$

Similarly, the vertical displacement of the component with the node coordinates substitute into the formula (2) of the second type, can be obtained,

$$\begin{Bmatrix} a_4 \\ a_5 \\ a_6 \end{Bmatrix} = \frac{1}{2A} \begin{bmatrix} a_i & a_j & a_m \\ b_i & b_j & b_m \\ c_i & c_j & c_m \end{bmatrix} \begin{Bmatrix} v_i \\ v_j \\ v_m \end{Bmatrix} = \frac{1}{2A} \begin{bmatrix} a_i & a_j & a_m \\ b_i & b_j & b_m \\ c_i & c_j & c_m \end{bmatrix} \begin{Bmatrix} u_i \\ u_j \\ u_m \end{Bmatrix} \qquad (7)$$

(7) Substituting back (2) after finishing can be obtained,

Available

$$\begin{Bmatrix} u \\ v \end{Bmatrix} = \begin{bmatrix} N_i & 0 & N_j & 0 & N_m & 0 \\ 0 & N_i & 0 & N_j & 0 & N_m \end{bmatrix} \begin{Bmatrix} u_i \\ v_i \\ u_j \\ v_j \\ u_m \\ v_m \end{Bmatrix} \qquad (8)$$

Among (which the)

$$N_i = \frac{1}{2A}(a_i + b_i x + c_i y)$$

(Subscript i, j, m rotation)

The displacement referred to as unit

$$\{f\} = \begin{Bmatrix} u \\ v \end{Bmatrix}$$

The unit nodal displacements denoted as

$$\{\delta\}^e = \begin{Bmatrix} \delta_i \\ \delta_j \\ \delta_m \end{Bmatrix} = \begin{Bmatrix} u_i \\ v_i \\ u_j \\ v_j \\ u_m \\ v_m \end{Bmatrix} \qquad (9)$$

The displacement function unit can be abbreviated as

$$\{f\} = [N]\{\delta\}^e \qquad (10)$$

The matrix [N] is called the morphology, (Ni) called morphological functions.

3. Unit Load Displacement

The finite element method for solving the object is a combination of the unit, external force acting on the elastic body, displaced to the corresponding node to become nodal loads. Load displacement to meet the static equivalence principle. Static equivalent load refers to the original load node is equal to the virtual work done on any virtual displacement. Virtual displacement of the unit can use the virtual displacement $\{\delta^*\}^e$ of the node Expressed as,

$$\{f^*\} = [N]\{\delta^*\}^e \qquad (11)$$

Node load

$$\{R\}^e = \begin{Bmatrix} X_i \\ Y_i \\ X_j \\ Y_j \\ X_m \\ Y_m \end{Bmatrix} \qquad (12)$$

Centralized (Concentration) force displacement Shown in Figure 2, any point concentrated force unit

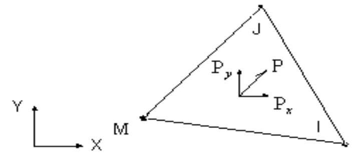

Figure 2: Force displacement

Can be obtained by virtual work equal

$$\{P\} = \begin{Bmatrix} P_x \\ P_y \end{Bmatrix}$$

$$\left(\{\delta^*\}^e\right)^T \{R\}^e = \left(\{\delta^*\}^e\right)^T [N]^T \{P\}$$

Since the virtual displacement is arbitrary,

$$\{R\}^e = [N]^T \{P\} \qquad (13)$$

4. The Distribution of the Surface Force Displacement

Provided in the unit from the edge of the distribution surface force $\{\overline{P}\} = [\overline{X}, \overline{Y}]^T$, Can get the same node load

$$\{R\}^e = \int_s [N]^T \{\overline{P}\} t ds \qquad (13)$$

5. Steward Motion Platform Mechanics Characteristic Analysis Process

Steward motion platform using the finite element method for the mechanical characteristics of the analysis process is shown in Figure 3

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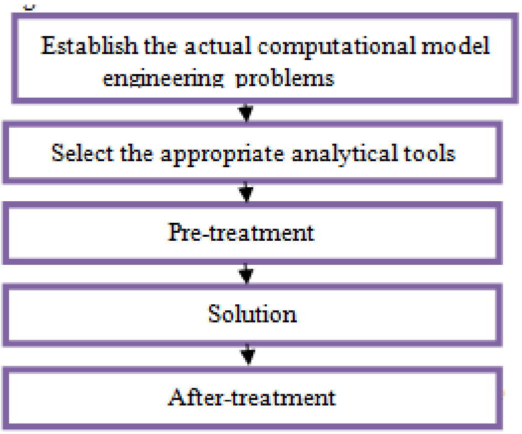

Figure 3: Finite Element Method

5.1 Steward Platform Finite Element Model

The Model material properties

(1) Model of the Moving and lower platforms made of cast iron

- Young's modulus: $1.85 \quad 10^{11}$ Pa
- Poisson ratio: 0.25
- The density of the material:$7.25 \quad 10^{3}$ kg/m3

(2) Model strut material for steel

- Young's modulus: 2.07×10^{11} Pa
- Poisson ratio: 0.30
- Material density: 7.8×10^{3} kg/m3.
- Dynamic platform model can be simplified as shown in Figure 4

Figure 4: Model and Meshing

6. Steward Motion Platform Mechanics Characteristic Analysis

In order to find the optimal structure and guidance structure optimization design, this paper ANSYS software design and calculate two different forms of the platform model element type (SOLID187): the rigid platform model and the middle hollow rigid body platform model them on the platform in the X, Y direction The limit position is inclined and the upper platform 15 degrees three cases of deformation and stress.

6.1 On Platform XY Limit Position

Figures (5), (6), (7), (8) respectively, for the strain and stress of the rigid body platform model on the platform in the X-Y direction limit position

6.1.1 Stewart Platform Model No. 1

Figures (5), (6) respectively, for the strain and stress of the rigid body platform model on the platform in the X, Y directions limits position.

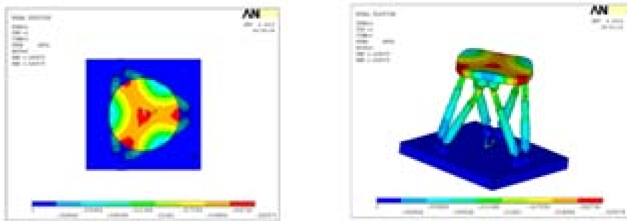

Figure 5: 6-DOF-Stewart Platform extreme conditions under deformation cloud picture

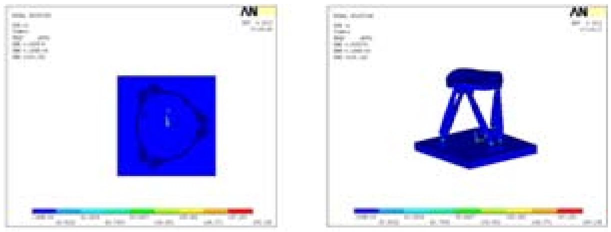

Figure 6: 6-DOF-Stewart Platform extreme conditions under stress cloud (SEQV-VON MISES STRESS)

6.1.2 Stewart Platform Model No. 2

Figures (7), (8) respectively, for the strain and stress in the X, Y-directions limit position on the platform in the middle of the hollow rigid body platform model.

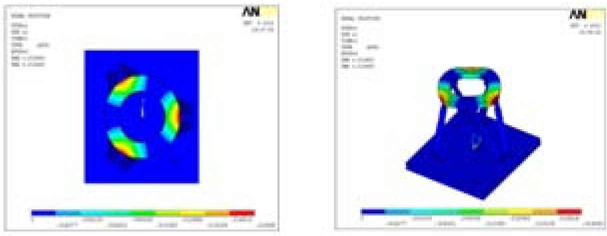

Figure7: Hollow rigid body -Stewart Platform model. Extreme conditions under deformation cloud picture

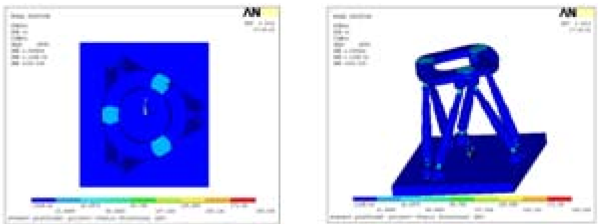

Figure 8: 6-DOF-Stewart Platform model. Extreme conditions under deformation cloud

6.2 On Platform Tilted 15 Degrees Limit Position

Figures (9), (10) were tilted 15 degrees limit position on the platform in the middle of the hollow rigid body platform model deformation and stress.

6.2.1 Stewart Platform Model No. 1

Figures (9), (10), (11), (12) respectively, for the strain and stress of the rigid body platform model on the platform tilted 15 degrees limits position.

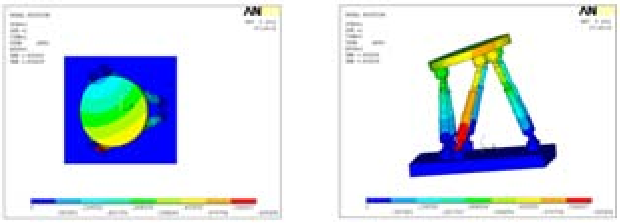

Figure 9: deformation cloud picture on the Stewart Platform tilted 15 degrees under extreme conditions

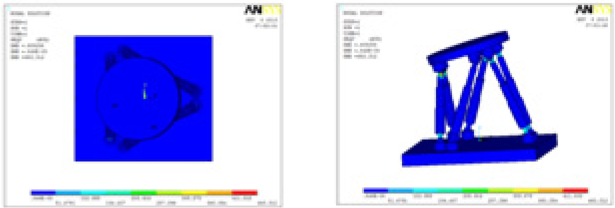

Figure10: 6-DOF-Stewart Platform on the platform tilted 15 degrees extreme conditions under stress cloud (SEQV-VON MISES STRESS)

6.2.2. Stewart platform model no. 1

Figures (11), (12) respectively, for the strain and stress of the hollow rigid body platform model on the platform tilted 15 degrees limits position.

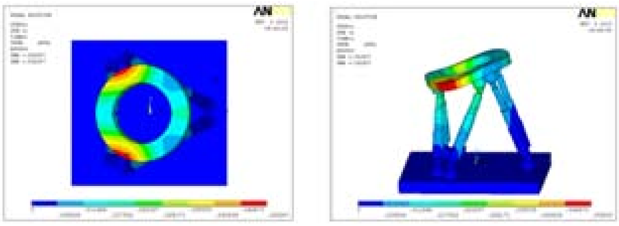

Figure 11: Hollow rigid body -Stewart platform model. On Platform tilted 15 degrees under Extreme conditions under deformation cloud picture

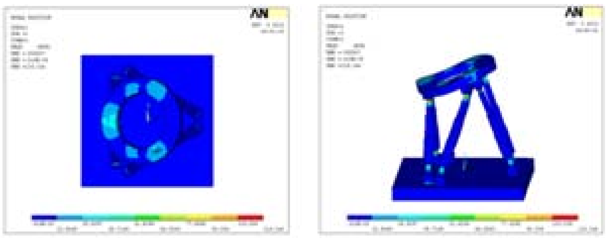

Figure12: Hollow rigid body -Stewart platform model on the platform tilted 15 degrees Extreme conditions under stress cloud (SEQV-VON MISES STRESS)

6.3 The Mechanical Characteristics: Conclusions

Rigid model and the middle hollow rigid model using ANSYS software the model material settings and boundary conditions are the same, in contrast, in the actual design of the structure, after the intermediate hollow rigid model. This design can either save raw materials; they can achieve the desired effect, economic and practical.

Table 1 Analysis of the three limit conditions of maximum deformation and the maximum stress value. Maximum deformation occurs in the middle of the upper platform cannot be considered, because under actual conditions, on the platform and the cockpit at the bottom, it will greatly improve its strength, struts as the weakest link, easy to lapse; maximum deformation with deformation in steel materials promise within. The maximum stress appears on the platform and strut hinged at. The maximum stress is far less than the yield limit of the steel. The platform with a rod is due to weak universal joints welded parts, it is recommended to use the ball hinge rotation Vice connected.

Table 1: Analysis of the three limit conditions of maximum deformation and the maximum stress value

Model	Position	Maximum Deformation \ mm	Maximum stress/MPa
The rigid body platform model	The platform in the X,Y directions	2.5576	168.162
	the platform tilted 15°	6.05258	463.312
Hollow Rigid body platform model	the platform in the X,Y directions	1.8693	83.3388
	the platform tilted 15°	5.22507	116.144

7. Recommendations

In this paper, the thorny issue facing the large car driving training, in conjunction with research based on virtual reality technology driving simulation system, focusing on driving simulation system of dynamic digital modeling platform, using the finite element theory Steward motion platform mechanical properties analysis using ANSYS software to establish the finite element model to analyze the dynamic mechanical properties of the platform and the conclusions are given, the optimal design of the motion platform provides a theoretical guidance and technical support ,design optimization of the Steward dynamic platform technology, to achieve a the driving simulation sensory numerical algorithm and verified.

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