ИССЛЕДОВАНИЕ ПРОЕКТИРОВАНИЯ ПЛАТФОРМЫ ДВИЖЕНИЯ С ИСПОЛЬЗОВАНИЕМ МЕХАНИЗМА HEXAPOD

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Аннотация: *в данной статье представлен результат расчета и проектирования платформы движения для симулятора пролета с использованием механизма Hexapod и других структурных элементов большого и престижного производителя Hexapod в мире, такого как Rexroth. Кинематика поведения Hexapod исследуется с применением программного обеспечения MATLAB с входными условиями, которые являются результатами решения обратной кинематики. Исследование показало, что результаты расчета и проектирования согласуются с симуляцией при обследовании кинематики Hexapod. Таким образом, этот результат может быть применен к новому проектированию и производству.*

Ключнвые слова: *платформа движения, обратная кинематика, Hexapod, Matlab.*

RESEARCH ON MOTION PLATFORM DESIGN BY USING HEXAPOD MECHANISM

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Abstract: *this paper presents the result of calculation and design of motion platform for a flight simulator by using Hexapod mechanism and other structural elements standard of large and prestigious Hexapod manufacturer in the world like Rexroth. The kinematics of Hexapod's behavior is surveyed by using MATLAB software with input conditions are the results of solving inverse kinematics. The study shows that the results of calculation and design are consistent with the simulation when survey the kinematics of Hexapod. Therefore, this result could be applied to new design and manufacturing.*

Keyword: *motion platform, inverse kinematics, Hexapod, Matlab.*

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1. INTRODUCTION

Nowadays, the Hexapod mechanism is widely used to make motion platform for training, experiment, and other useful purposes. One of the most important applications of the Hexapod mechanism is to simulate the movement of aircraft cockpits, cars, ships, etc… Thanks to these objects can create experimental conditions closed to reality, that facilitating the training process, saving money and ensure safety.

There are a variety of researches about Hexapod [1-4], but most of them are only concerned with modeling, calculating kinematics and dynamics. Thus, this paper focuses on research, calculating and design Hexapod mechanism and other structural elements standard of the flight simulator. After that, solving inverse kinematics and simulating the motion platform by SimMechanics tool on Matlab software.

2. RESEARCH AND DESIGN THE MOTION PLATFORM

2.1. Select Hexapod mechanism type for motion platform

Figure 1 shows the most commonly seen configurations of Stewart platform for Hexapod mechanism.

In this paper, choosing the 3-3 type because it reduces the complexity in calculating of kinematics and dynamics. In addition, it also relieves the mass of motion platform.

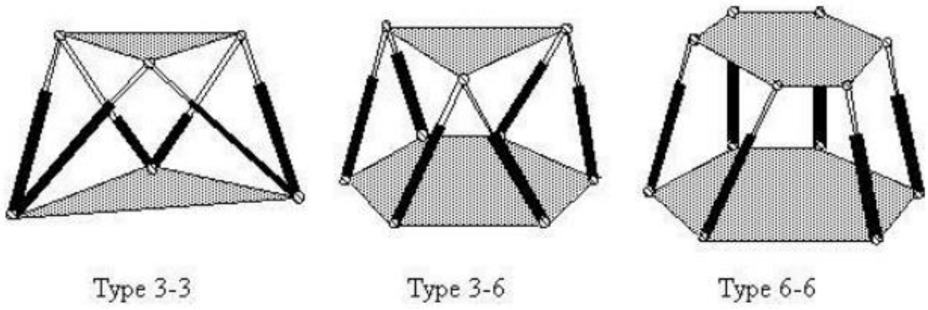

Fig. 1. Three types of Hexapod with Index Denoting the Number of Connection Vertices on the Base and the Platform

2.2. Select Actuator

There are many types of actuators such as piezoelectric, hydraulic, pneumatic and electromechanical actuators. This paper chooses electromechanical actuator type due to its high precision and high load requirements for motion platforms, so almost large industrial manufacturers in the world use that of study, calculating, design [5]. Some Hexapod manufacturers may be listed as MOOG and Thomson and Rexroth of the Bosch Group.

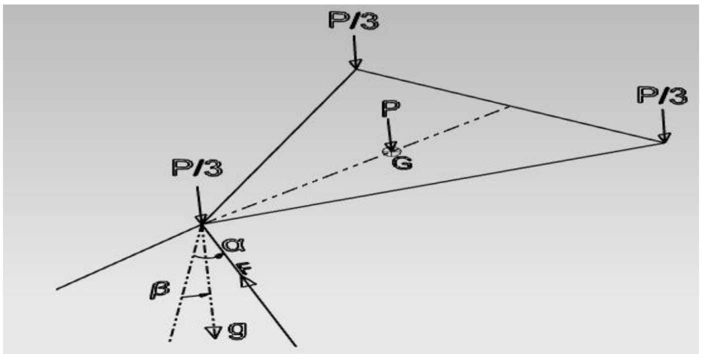

Fig. 2. Diagram for calculating axial force

Due to the use of the ball screw in the electromechanical actuators, the maximum axial load acted on the screw of the actuator is the most important parameter of input condition. Its schematic calculation is based on figure 2. Assume P is the external load placed on the platform of Hexapod. The position of P can be placed to G point which is the centroid of motion plate. F is the axial load acted on the screw of the actuator. α is the angle between a actuator and the projection of the gravitational acceleration vector g on the plane containing two legs. β is the angle between the plane containing the two actuators and the acceleration vector g.

By using the balance of force and torque, the axial force acting on each actuator of Hexapod is:

$$F = \frac{P}{6.\cos\alpha.\cos\beta} \quad (1)$$

where, in this motion platform design for flight simulator, the fixed load is equal to $P = 70000\,(N)$, $0^o < \alpha < 55^o$ and $-30^o < \beta < 30^o$ to ensure the principle of geometry in the simulation. Therefore, $F_{\max} \approx 23487\,(N)$ when $\alpha = 55^o; \beta = 30^o$

According to the reference [6], this paper chooses an electromechanical actuator named EMC HD 085-MSK 071 from Rexroth Company of Bosh Group. Some technical data is listed in table 1.

Table 1. Technical data of EMC HD 085 – MSK 071

Information	Diameter of Screw drive x pitch d_0 x $p(mm)$	Belt ratio i	Max Axial force $F_{\max}(N)$	Torque $M_p(Nm)$	Mechanical efficency η
Value	40 x 10	1,5	44000	53,6	0,87

After design, calculating and referring to the standard of structural elements. This results in the structure and geometry dimensions of the ball screw in the electromechanical actuator.

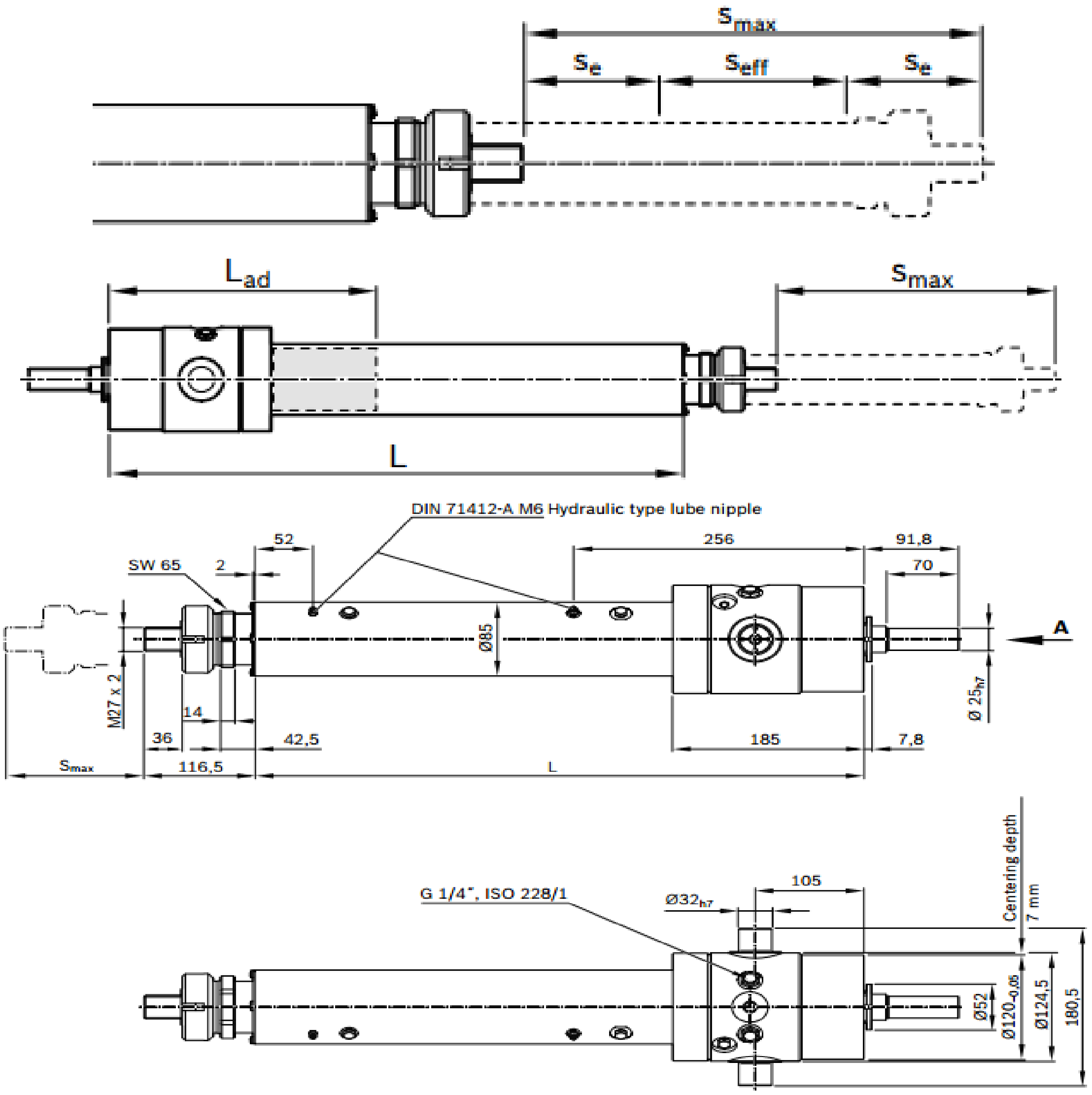

Figure 3. Dimensions of ball screw of electromechanical actuator

Here, $S_{eff} = 260\ (mm)$ is the effective operating stroke; $S_e = 2.p = 20\ (mm)$ excess travel to both ends of the effective operating stroke; L is the length of the actuator which is at the lowest positon of the actuator; $L_{ad} = 350\ (mm)$ is the length at the original position of the nut which is not yet working.

2.3. Design the other parts of the actuator

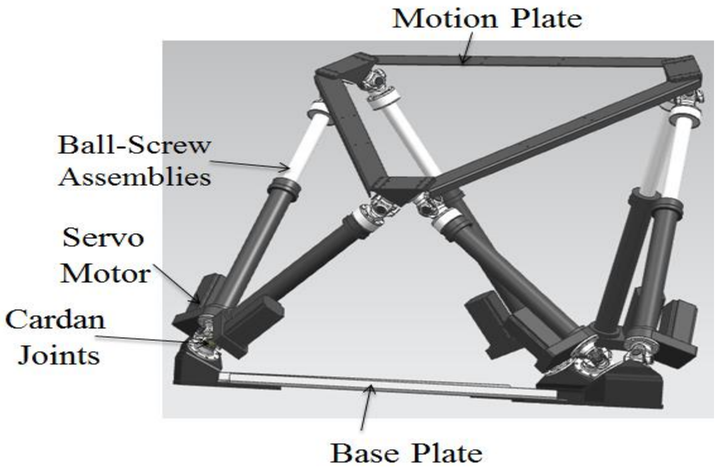

Fig. 4. The overall design model of Hexapod

In figure 4, other structural components consist of Cardan joints, flanges, base plate, motion plate, bolts, nuts, etc… Which are designed to fit the technical data and dimensions of the actuators.

3. SURVEY THE KINEMATICS OF HEXAPOD

3.1. Inverse kinematics

Inverse kinematics is used to determine the values of the joints in order to ensure the given motion of the Hexapod closes to flight training process. Inverse kinematics is so important for the control system. This paper uses the analytics method to calculate the inverse kinematics.

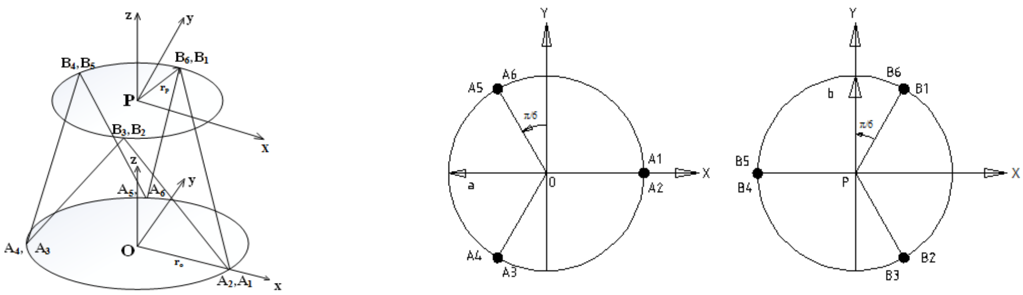

Fig. 5. The schematic diagram of the Hexapod

Inverse kinematics equation is $A_iB_i = OP + {}^oR_P.PB_i - OA_i$ (2)

where ${}^OR_P$ is the rotation matrix of the moving platform with respect to the base platform coordinate system is obtained. Thus, the rotation matrix is given according to [7]. When the position and orientation of the moving platform $X_{P\text{-}O} = [d_x\ \ d_y\ \ d_z+h]^T$ (3) are given, the length of each actuator A_iB_i is computed as the following.

$$l_i^2 = (d_x - B_{xi} + A_{xi}r_{11} + A_{yi}r_{12})^2 + (d_y - B_{yi} + A_{xi}r_{21} + A_{yi}r_{22})^2 + (d_z + h + A_{xi}r_{31} + A_{yi}r_{32})^2 \quad (4)$$

here, A_{xi} and B_{xi} is the coordinate matrix of the corresponding node points. h is the original height of the Hexapod when it is the lowest position; r_{ij} is the indexes of the rotation matrix ${}^OR_P$

3.2. Survey motion of the Hexapod by using Matlab software

a. Input Parameters

Input parameters for modeling and surveying motion of the Hexapod are the values which detailed mention in section 2 of this paper. The smallest and the largest operating stroke of the actuators are $l_{\min} = 856\,(mm), l_{\max} = 1156\,(mm)$, respectively. The radius of the circle which crosses through the centers of upper and lower Cardan joints are $R = 750\,(mm); r = 504{,}5\,(mm)$, correspondingly. The original height of the Hexapod is $h = 516{,}19\,(mm)$. We survey kinematics behavior when the Hexapod moves up and down only along the Z-axis following equation $x = 0; y = 0; z = 0{,}05\sin(\pi t + \pi / 2) + 0{,}51619\ (m)$.

b. Model Hexapod by SimMechanics tool in Matlab software

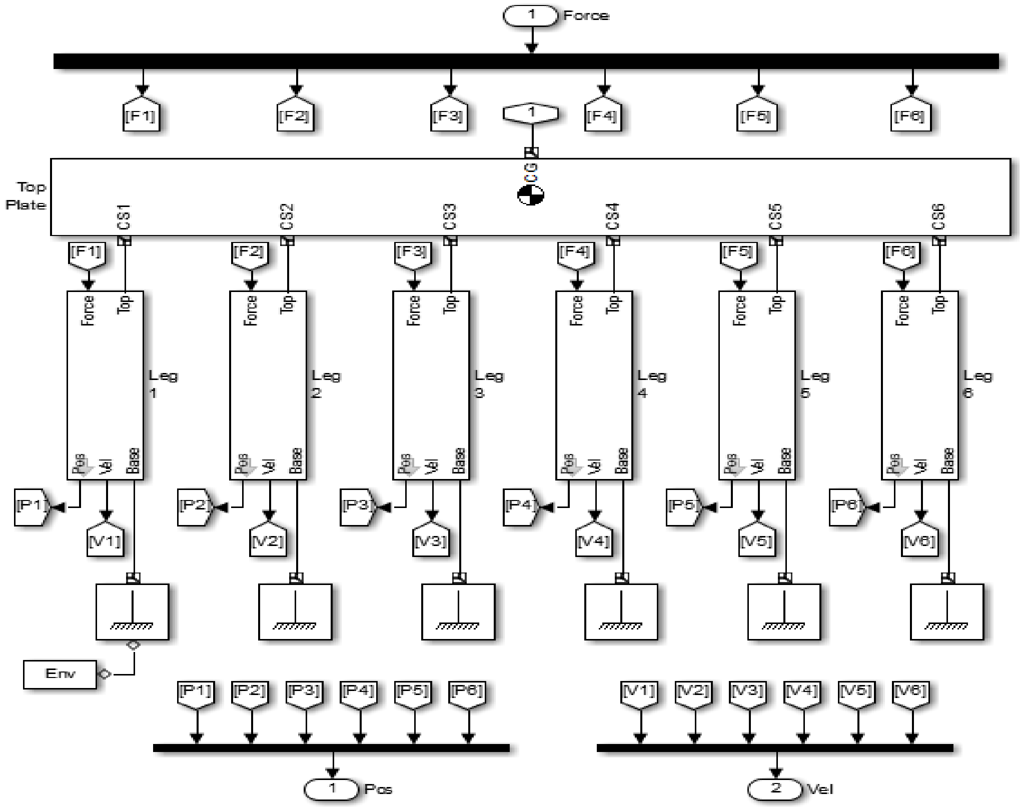

Fig. 6. Hexapod model by SimMechanics tool in Matlab

The base plate and the moving plate are linked to actuators by Cardan joints. Each actuator contains 2 parts join together by prismatic joint. Modeling of Hexapod by SimMechanics is shown in figure 6.

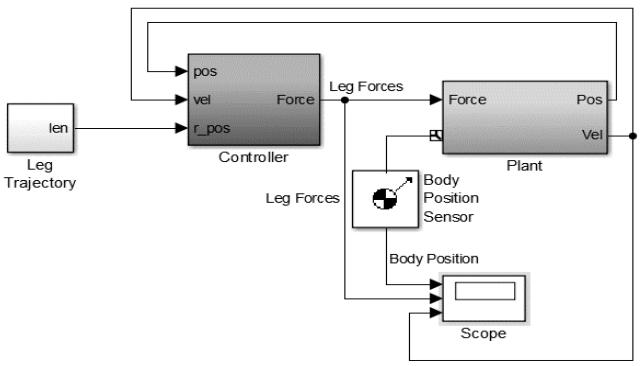

Fig. 7. Simulink model for the control system

Simulink model for the control system of the Hexapod is shown in figure 7, which is used to survey motion and kinematics behavior of the Hexapod.

c. Simulation Result

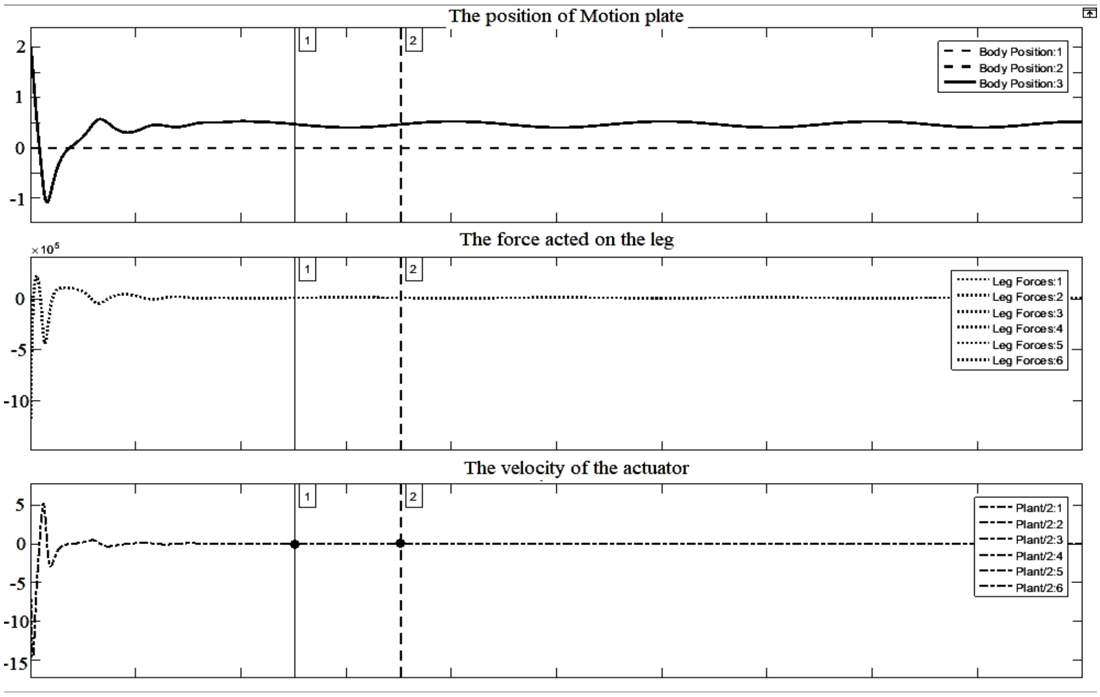

Fig. 8. Graphs describe the position of moving plate, the force acted on the leg and the velocity of the actuator

Some graphs about the position of moving plate, the forces to control and change the length of the actuators, the velocity of each actuator.

In figure 8, it can be clearly seen that the position of moving plate follows input parameters, its position in the x and y-axis is zero. It only moves along the Z-axis, depending on the input equation when surveying. The driving force and the travel velocity of 6 actuators are the same. These results are fairly with the actual design and input data when surveying. The smallest and largest driving force values are $1,482.10^4\ (N)$ and $2,055.10^4\ (N)$. The smallest and largest moving velocity values are $-3,806.10^{-2}\ (m/s)$ and $3,579.10^{-2}\ (m/s)$.

4. CONCLUSION

The research achieves some results. Firstly, addressing the design the motion platform for flight simulator using Hexapod mechanism and the other standard elements of large and prestigious Hexapod manufacturers in the world like Rexroth, Thomson. Secondly, solving Hexapod inverse kinematics and surveyed kinematics behavior which serviced the control system of the Hexapod. The research shows that the results of calculation and design are consistent with the simulation when surveying the kinematics of Hexapod. Therefore, the result of this paper could be applied to new designs and manufacturing.

We can develop more some researches from this result such as calculating and durability for the entire design, calculating workspace of Hexapod, surveying forward kinematics and calculation Hexapod dynamics and research more intensively about control problem as design in this paper.

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