Improved Sliding Mode Variable Structure Control of Robot Manipulators with Flexible Joints based on Singular Perturbation

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Abstract. This paper discusses the kinematics analysis method of six link mechanism based on virtual prototype technology and Adams. Firstly, the kinematics mathematical model of the six-bar linkage is deduced. Then, based on the design and development process of virtual prototype technology, the virtual prototype model of the six-bar press is established in ADAMS software. Finally, the kinematics simulation analysis is carried out for the model. The proposed method provides a reference for the parametric and optimal design analysis of the multi bar linkage of the mechanical press.

Keywords: Kinematics analysis, Virtual prototype, six bar linkage, ADAMS.

1. Introduction

Stamping processing is inseparable from stamping equipment. Mechanical press is the most widely used type of stamping equipment. It accounts for more than 50% of the total number of all stamping equipment [1]-[2]. Press is important process equipment in stamping processing. Mechanical press is a key product in mechanical industry. It is widely used in stamping processes such as blanking, bending, blanking, stretching and folding. It is necessary key equipment for motorcycles, automobiles, household appliances, instruments and instruments, light industry, tractors, aircraft, national defense industry, chemical industry and electronic industry [3]-[5].

The process of stamping is the process of material separation or plastic deformation. The movement speed of the stamping die determines the flow speed of metal separation or deformation, that is, the movement speed of the transmission mechanism of the press affects the flow speed of metal separation or deformation. In the actual stamping production, we should not only produce parts that meet the specifications, but also improve the production efficiency [6]-[7]. Theoretically speaking, improving the working speed of the transmission mechanism of the press is the simplest solution to improve the production efficiency. Therefore, the working speed of the transmission mechanism will be a very important process parameter, which must be considered when designing the transmission mechanism of the press [8].

The factors affecting the quality of stamping workpiece include the properties of materials and the stamping performance of press. Therefore, simply improving the forming speed to improve the production efficiency will have a bad impact on the quality of workpiece [9]. This is a very contradictory question. After people's research, it is found that replacing the general crank connecting rod press with multi connecting rod press can alleviate some defects of this problem, so the technology of multi connecting rod press appears. The multi-link transmission mechanism in the mechanical press can achieve higher production efficiency and prolong the service life of the die without changing the working speed [10]-[11].

With the rapid development of industry, the popularization and application of computer in CAD/CAM/CAE also puts forward higher requirements for the service performance of multi-link press. It is very necessary to improve the working efficiency of multi-link press and obtain better

service performance at the same time. With the help of virtual prototype development technology [12]-[13], drawing on the experience and methods of foreign advanced multi-link mechanical press design, and on the basis of the original multi-link mechanism structure, through the parametric design and optimization analysis of the size of its working mechanism [14], a more stable and efficient transmission mechanism is developed. The acceleration and speed of the working mechanism in the working process, Smaller and more stable. The multi-link mechanical press suitable for modern manufacturing is of great significance to the development of China's industrial technology [15].

2. Derivation of Kinematic Equation of Six-link Pressure Mechanism

In order to improve the motion characteristics of the above sliding block, make the speed stable during stretching and the full load working area longer, people have come up with a way to change the structural form of the press by changing the transmission structure of the press. Based on the crank slider press, it is transformed into six bar, eight bar and ten bar mechanisms. The main feature of multi bar mechanism is that it is suitable for deep drawing process[16]. The press of this kind of mechanism can maintain a stable and low speed within the working stroke, but try to be fast at other times.

The transmission mechanism of mechanical press adopts multi-link mechanism, and its advantages are as follows [17]

(1) The sliding block speed of the multi-linkage press is stable when stretching, which can well meet the requirements of the stamping process, reduce the impact load of the die and prolong the service life of the die;

(2) The multi-link press has high speed in idle travel, which greatly improves the production efficiency;

(3) Compared with the traditional crank connecting rod press, the multi connecting rod press has a long working area and can realize full load stamping work. It is especially suitable for deep drawing process, and there is no need to use multiple drawing process;

(4) Compared with the press driven by crank and connecting rod mechanism, under the same technical parameters, the overall size of the multi connecting rod press is small, the structure of the press is compact and the weight of the machine is light, which has reference significance for the production of large press;

(5) The multi-link press is suitable for multi station drawing forming of high-strength steel;

(6) Multi-link press can improve the production efficiency of progressive die.

The core problem in the design of multi-link press is the problem of bar system. Because the number of rods of multi-link mechanism is usually large, and the change of rod length will certainly have an impact on the motion of multi-link mechanism, the motion of multi-link mechanism is relatively complex. As the most important working mechanism in the transmission mechanism of mechanical press, the design level of multi-link mechanism directly affects the working efficiency and performance of mechanical press. Therefore, using advanced design methods and optimization methods to produce and manufacture multi-link mechanism has become increasingly important. At present, the optimal calculation method is often used to obtain the best parameters of each rod length of multi-link mechanism and achieve the expected goal.

Six link Press - Elbow bar press. Main uses: it is mainly used for punching, blanking, forming and other main stamping processes of thicker steel plates. It is generally used for stamping work with large process force, such as blanking, stretching, punching, etc. of large truck girder in one stamping process.

The principle of the six bar press is shown in Fig. 1. When the crank AB rotates at a uniform speed, the slider moves up and down in a reciprocating straight line. As shown in the Fig., the mechanism is composed of a rocker slider mechanism and a crank rocker mechanism, in which rocker CD, rocker CE, slider and frame form a rocker slider mechanism, and crank AB, connecting rod BC, rocker CD and frame form a crank rocker mechanism. From the motion diagram of the mechanism, it can be

seen that the mechanism has 5 moving parts, 7 low pairs, but no high pairs. The intersection of rod 2, rod 3 and rod 4 is a composite hinge, so its degree of freedom can be obtained as follows:

$$F = 3n - 2Pl - Ph = 3 \times 5 - 2 \times 7 - 0 = 1 \tag{1}$$

There is a prime mover in the mechanism, which is equal to the degree of freedom of the mechanism, so the mechanism has definite motion.

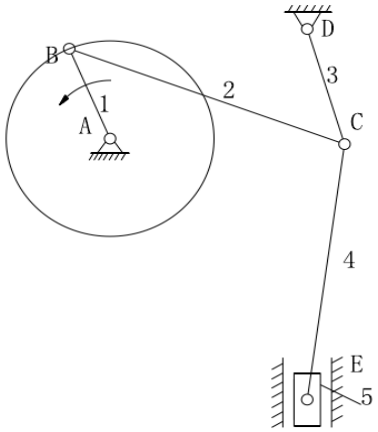

Figure 1. Six link pressure mechanism

According to the principle of closed vector method, it is known from Fig. 1

$$l_3 + l_4 = s \tag{2}$$

By projecting each vector on the X and Y axes, we can get

$$l_3 \cos\theta_3 + l_4 \cos\theta_4 = 0 \tag{3}$$

$$l_3 \sin\theta_3 + l_4 \sin\theta_4 = s \tag{4}$$

After the terms of equation (3) and equation (4) are shifted, the squares are added and eliminated θ_3 to obtain

$$l_3^2 = (l_4 \sin\theta_4 - s)^2 + (l_4 \cos\theta_4)^2 \tag{5}$$

Decompose the above formula to obtain

$$2l_4 \sin\theta_4 s = s^2 + l_4^{\,2} - l_3^{\,2} \tag{6}$$

After shifting the terms of equation (4) and equation (5), add the squares and eliminate θ_4 to obtain

$$l_4^{\,2} = (l_3 \sin\theta_3 - s)^2 + (l_3 \cos\theta_3)^2 \tag{7}$$

Decompose the above formula to obtain

$$2l_3 \sin\theta_3 s = s^2 + l_3^{\,2} - l_4^{\,2} \tag{8}$$

After finishing, the angular displacement θ_4, angular velocity ω_4, angular acceleration α_4 of rocker 4 and the displacement s_1 equation of slider 5 are obtained as follows:

$$\theta_4 = \arccos(\frac{l_3 \cos\theta_3}{l_4}) \tag{9}$$

$$\omega_4 = \frac{d\theta_4}{dt} = \frac{\omega_3 l_3 \sin\theta_3}{l_4 \sin\theta_4} \tag{10}$$

$$\alpha_4 = \frac{d\omega_4}{dt} = \frac{(l_3\alpha_3 \sin\theta_3 + \omega_3^2 \cos\theta_3 - l_3 l_4 \omega_3 \omega_4 \cos\theta_4 \sin\theta_3)}{l_4 \sin\theta_4} \tag{11}$$

$$s_1 = l_3 \sin\theta_3 + l_4 \sin\theta_4 \tag{12}$$

Where, s_1 - sliding block displacement;

θ_4 - angular displacement of rocker 4;

ω_4 - angular velocity of rocker 4;

α_4 - angular acceleration of rocker 4.

It is known that l_1 represents the length of the AB rod, l_2 represents the length of the BC rod, l_3 represents the length of the CD rod, and l_4 represents the length of the de rod.

Derive equation (12) from time to obtain the velocity equation:

$$v_s = \frac{ds}{dt} = \omega_3 l_3 \cos\theta_3 + \omega_4 l_4 \cos\theta_4 \tag{13}$$

Where, v_s - speed of sliding block;

θ_3 - angular displacement of rocker 3;

ω_3 - angular velocity of rocker 3.

Derive equation (13) from time to obtain the acceleration equation

$$a_s = \frac{dv}{dt} = l_3\alpha_3 \cos\theta_3 - l_3\omega_3^2 \sin\theta_3 + \alpha_4 l_4 \cos\theta_4 - \omega_4^2 l_4 \sin\theta_4 \tag{14}$$

Where, a_s - acceleration of sliding block, unit: m/s2.

3. Virtual Prototype Modeling of Six- link Press based on ADAMS

Virtual prototype technology can test the performance at the early stage of product design, and test the virtual product at the design stage, rather than the expensive test of physical prototype. It can meet the design objectives as much as possible, shorten the development cost, save the development cycle

and greatly improve the development efficiency. This paper introduces the method of three-dimensional modeling of the mechanism using ADAMS software, and carries out kinematic simulation analysis of the working mechanism of the six link press with the dynamic simulation analysis software ADAMS. In the product development stage, through virtual experiment and test, it can help the designer find defects and put forward improved methods, which lays a foundation for the optimization of the model.

Virtual prototyping technology is an advanced manufacturing technology based on intelligent design technology, simulation engineering, concurrent engineering and network technology, supported by computer modeling and simulation technology. With the help of the virtual prototype technology, the final production scheme can be improved and the product can be predicted repeatedly before the virtual prototype technology.

The virtual prototype design process is carried out according to ADAMS software, and the kinematics analysis is carried out for the working mechanism of six link press. The design process of virtual prototype using ADAMS software is shown in Fig. 2.

(1) Create model.Creating a mechanical system model includes: creating components (or parts), applying constraints and drives to components, and defining forces acting on components. A component is a geometric body with some physical characteristics such as moment of inertia, mass and volume.

(2) Test and verify the model.During or after the creation of the model, the model is simulated and tested, and the simulation verifies the correctness of the model. The verification model includes simulation analysis, animation playback, measuring characteristics and drawing curves. The validation model includes: comparing the experimental data with the data curve.

(3) Perfect model and iterative simulation.On the basis of verifying the preliminary correctness of the model, parameterize the model, and further improve and perfect the model by modifying the parameters and automatically modifying the model.

(4) Optimization design. Adams can find out the best design variables suitable for the model through various optimization design schemes. Optimization design includes: study the influence of design variables on experimental design analysis and the degree of optimization design and analysis.

Fig. 1 is the structural diagram of the press with six bar crank mechanism, and the size of the slider is $50mm \times 50mm \times 50mm$. Wherein, crank $l_1 = 163$mm, connecting rod $l_2 = 868$mm, connecting rod $l_3 = 404$mm, connecting rod $l_4 = 414$mm.

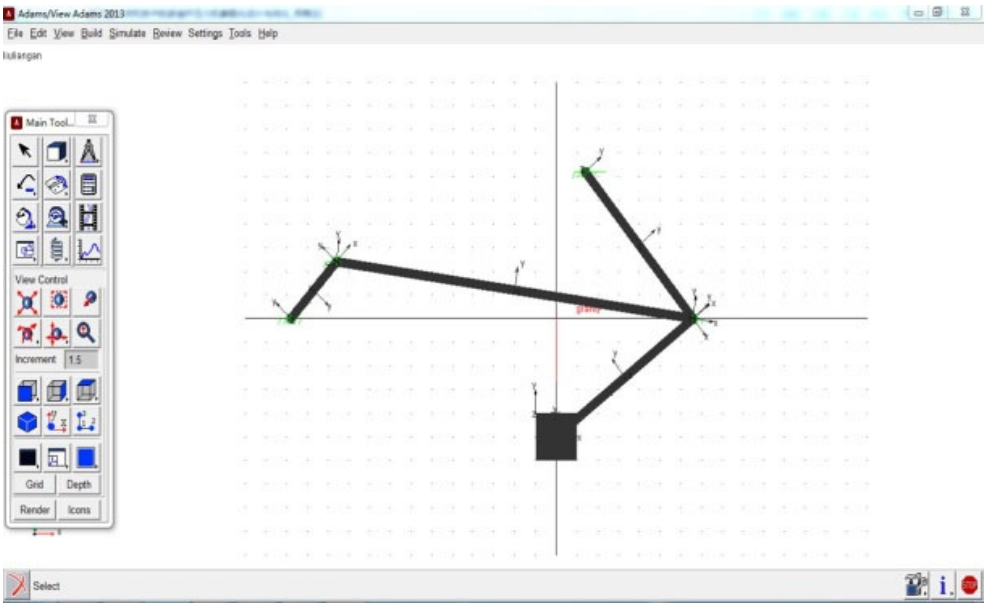

Figure 2. geometric model of six bar press

Create the coordinates of points a, B, C, D, e and f respectively, take the width of each rod = 30mm and the thickness = 20mm, input the length of each rod, and the virtual prototype model of the mechanism is shown in Fig. 2.

Add constraints and drives Add motion pairs and drives to the model according to the actual motion state of the components. The motion pairs are used to define the relative motion relationship between the components. After the setting is completed, the kinematics analysis of the physical prototype can be carried out. Except that the sliding block and the frame are connected by a moving pair, other components are connected by a rotating pair, and ab is fixed with the earth.

In ADAMS, the function of driving is to make further constraints on the degrees of freedom of the kinematic pair without constraints. Therefore, one or more drives need to be applied, and the number of drives must be equal to the number of degrees of freedom, so a selective drive should be added. Click the rotation drive button on the main toolbar, and the rotation speed is set to 30 ° per second. Select the rotation pair in the graphics area with the mouse, and the rotation drive is created on the rotation pair. The prototype model of multi linkage mechanism is established, as shown in Fig. 3.

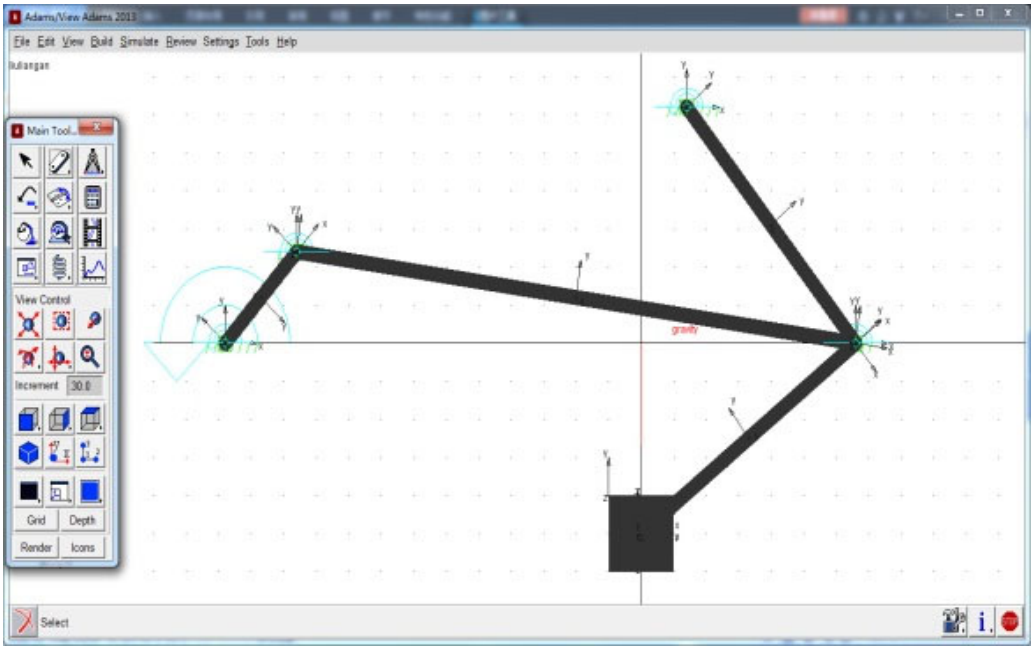

Figure 3. Virtual prototype model of six link press

ADAMS software provides a very powerful parametric modeling function. After establishing the three-dimensional model, in order to design the ideal motion characteristics of the mechanism. The key variables are determined according to the demand analysis. In the simulation analysis, the change of the median value of these design variables will lead to the automatic updating of the multi rigid body virtual prototype model. If the kinematics analysis is to be carried out according to the predetermined parameters, the determined parameters should be set in advance. Adams can simulate automatically, which can facilitate the observation of the next prototype. The performance of the automatic simulation prototype can change different parameter values.

During parametric modeling, ADAMS / view provides four methods for mechanism parameterization:

(1) Parameterized point coordinates;

(2) Use design variables;

(3) Parametric motion mode;

(4) Use parameter expression; Parametric expression is the most basic way of model parameterization.

4. Kinematics analysis based on ADAMS

It is of great significance to parameterize the virtual prototype model. By changing any point, the parameters associated with it will also change. Then the designer can easily modify the relative motion relationship between the models and optimize the model. Parametric module is a very important module in dynamic simulation software ADAMS.

After completing the design research process, the kinematic characteristics of each iteration simulation are derived. Through the analysis of each simulation result, the designer can get the following contents:

(1) The influence of parameter variables on the objective function;

(2) The best value of parameter variable;

(3) The sensitivity of parameter variables is the sensitivity of the change of design variable value to the performance of the prototype.

Experimental design is the analysis of the design variables that affect the performance of the prototype when the changes of multiple design variables occur at the same time. Including the experimental design of the establishment of the design matrix, such as test results and statistical analysis. The original experimental design (DOE) is used for the above physical tests, but the tests are also very effective. The use of experimental design can not only enhance the credibility of simulation results, and test results can be faster than test factors, but also help users better understand and optimize the performance of mechanical system.

In general, DOE in ADAMS is to arrange a set of test procedures and test results and statistical analysis tools to measure the performance test, the output in the manufacturing process, or the quality of virtual prototype.

Doe generally has the following five basic steps:

(1) Select the factor set to be investigated by the system, and then design a method to measure the response of the system;

(2) Determine the value of the factors and change the factors to investigate their influence on the test results;

(3) Record the performance of each test system;

(4) Analyze which factors have the greatest impact on the system performance.

After the components of the six bar press are created and constraints and drives are added, the virtual prototype model of the multi link mechanism is created. Start simulation analysis.

(1) Simulation model.The process of simulation model is to click the interactive simulation controls tool button in the main toolbox, expand the option area, select end time and set its value to 30, select steps and set its value to 1000, and click the start or continue simulation tool button to start model simulation.

(2) Post processing of test results. ADAMS software completes the post-processing of the simulation analysis results through the postprocessor module, and completes the following work through the post-processing of the three-dimensional model: further debugging the virtual prototype; Verify and verify the simulation analysis results; The data curves obtained after simulation can be compared and analyzed; Compare the advantages and disadvantages of different schemes by analyzing the data curve; You can edit and compare the data curves obtained after simulation. After the simulation analysis, the motion characteristic curves of displacement, velocity and acceleration of the slider are obtained through measurement, as shown in Fig. 4-Fig. 6.

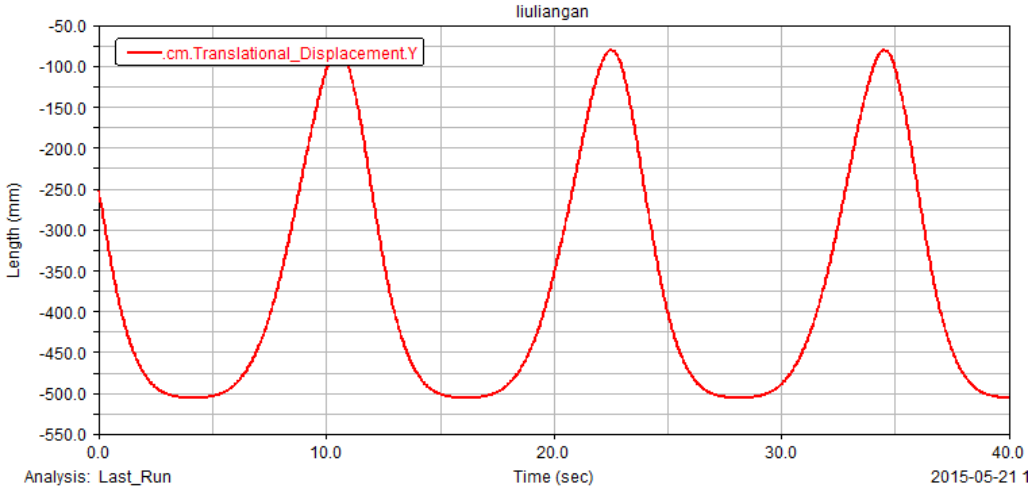

Figure 4. Displacement curve of sliding block

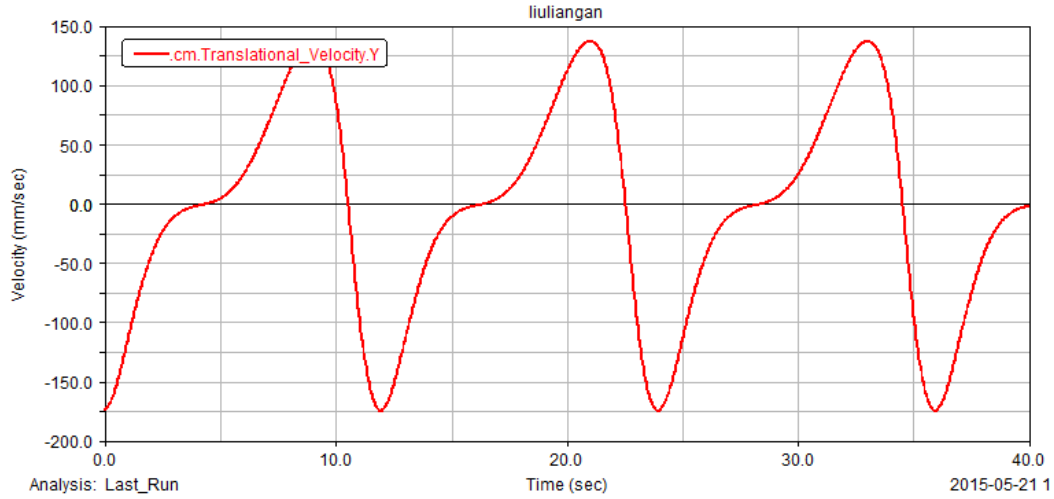

Figure 5. Slider speed curve

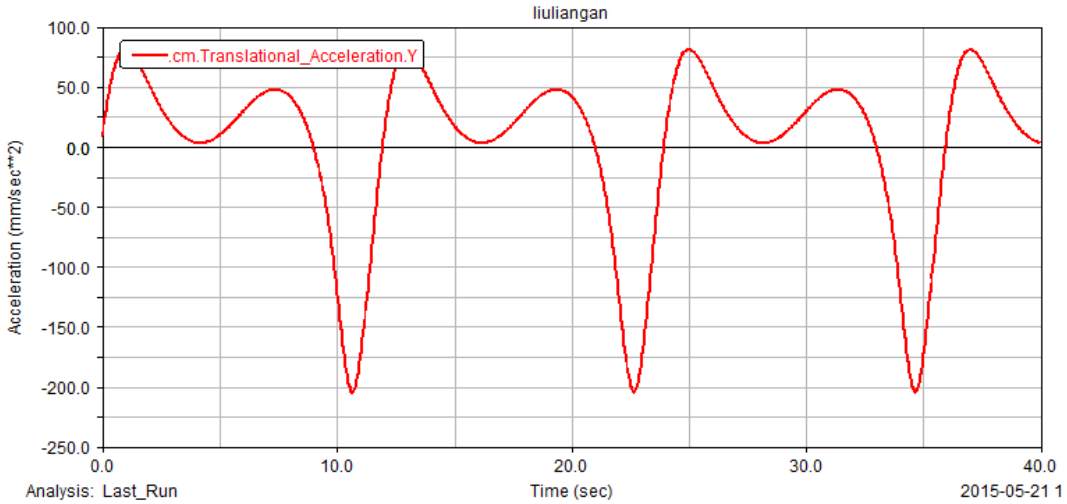

Figure 6. Acceleration curve of slider

It can be seen from the displacement curve of the slider that the working pressure angle of the six bar press is relatively large, which prolongs the working time of the stamping process and helps to reduce the impact load in the stamping process; It can be seen from the speed curve of the slider that the speed in the working area is almost constant, the six bar mechanism close to the lower dead center of the slider has better low-speed characteristics, and the lifting speed curve of the slider is asymmetric. It is analyzed that the stamping speed is slow and the return speed is fast, which is more

suitable for the stamping process requirements of "fast slow faster" movement. It can be seen from the acceleration curve of the slider that the working efficiency is high when working at full load for a longer time.

5. Conclusion

This paper discusses the kinematics analysis method of six link mechanism based on virtual prototype technology and Adams. Firstly, the kinematics mathematical model of the six bar linkage is deduced. Then, based on the design and development process of virtual prototype technology, the virtual prototype model of the six bar press is established in ADAMS software. Finally, the kinematics simulation analysis is carried out for the model. The proposed method provides a reference for the parametric and optimal design analysis of the multi bar linkage of the mechanical press.

Acknowledgment

Thank you to all the members of the laboratory and the reviewers for this project.

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