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Procedia Engineering 81 (2014) 1639 – 1644

Procedia Engineering

www.elsevier.com/locate/procedia

11th International Conference on Technology of Plasticity, ICTP 2014, 19-24 October 2014, Nagoya Congress Center, Nagoya, Japan

# Dimensional synthesis for multi-linkage of high-speed mechanical press

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**Abstract**

In order to improve the performance and solve problems produced under the high speed operation of the high-speed mechanical press, a comprehensive optimal mathematic model of main transmission mechanism of high-speed mechanical press was established. The model takes minimum of crack length and maximum of stamping angle as the evaluation index. In the meantime, the optimal model was established with MATLAB. The optimization result shows that the stamping angle of mechanism is increased by 56.2%, maximum speed of main slider is increased by 21.5% in the return stage, and acceleration of main slider is decreased by 69.5% near the bottom dead position. The displacement curve is more smooth in the near of bottom dead center. The optimized mechanism is beneficial to abundant deformation of material in the process of stamping, and to improve the dynamic precision of the bottom dead center.


Selection and peer-review under responsibility of the Department of Materials Science and Engineering, Nagoya University

*Keywords*: High-speed press;Multi-linkage;Optimizationdesign;Motion path

## 1. Introduction

In recent years, with the rapid development of electronics, communications and automobile industries, market demand of stamping parts is increasing rapidly. In order to meet this demand, all countries are devoting to improve the speed of press constantly [1,2]. However, how to solve effect of the high speed on the geometric parameters

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Selection and peer-review under responsibility of the Department of Materials Science and Engineering, Nagoya University
doi:10.1016/j.proeng.2014.10.204

optimization, improve the working performance of the press and make it work efficiently has became an important research topic for the scholars all over the world. At present, more research works on transmission mechanism of high-speed press had been done by the Switzerland's BRUDERER and America's MINSTER companies [3,4].

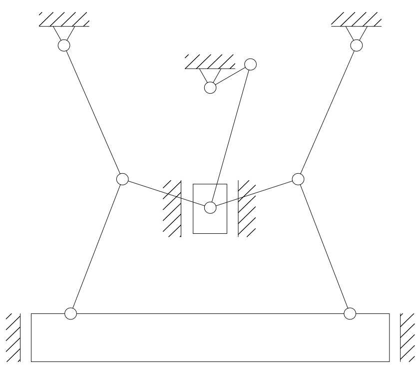
In recent years, taking the slider speed and it's fluctuation near the bottom dead position, speed and acceleration error, and pressure angle or transmission angle of the mechanism as the evaluation index, the optimization of the inner sliding block mechanism of eight-linkage press was studied by the domestic scholars by using the genetic algorithm, sequential quadratic programming, and step search arithmetic, et al. The research improved the efficiency of design, but the object of study is low speed transmission mechanism of press [5-8].

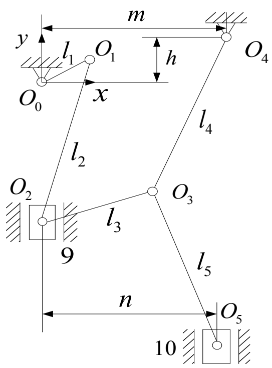
The relationship between the motion and the geometric parameters of the linkage is intricate and nonlinear, so it would be difficult to find a set of geometric parameters which satisfies all constraints [9]. At present, multi-linkage mechanism of high speed press is still complicated, design theory is still not perfect and the performance is low. All of those need solving. Therefore, the key question of mechanism optimization design of high speed press is to find an appropriate evaluation index.

In order to enhance working performances of press, reduce the difficulty of subsequent design and get the optimal working curve, the minimum length of crank and maximum stamping angle is defined as evaluation index in this paper, according to performance requirements of multiple linkage high speed mechanical press.

## 2. Establishment of mechanism model

Transmission mechanism principle diagram of multiple linkage high speed press is shown in Fig. 1(a). The mechanism is mainly composed of rack, crank-slide mechanism, tie rods, toggle mechanism and main slider. The crank is uniform circular motion during the runtime. Then the connecting lever allows guide rail to be traced out by the secondary slider in vertical direction. The vertical motion of secondary slider makes tie rods bobbing up and down, so that toggle mechanism move sideways. Finally, the reciprocating motion of main slider is achieved along guide rail in vertical direction.


(a)



(b)

$l_1$-crank; $l_2$-side link; $l_3$-tie rod; $l_4$-upper toggle link; $l_5$- lower toggle link; 9- secondary slider; 10-main slider; $m$-horizontal distance between top toggle link joint point and rack joint point; $h$-vertical distance between top toggle link joint point and rack joint point; $n$-width dimension of main slider

Fig. 1. Transmission mechanism principle diagram of multiple linkage high speed mechanical press.

## 3. Optimization design of multiple linkage press

### 3.1. Design variable

The unilateral transmission mechanism and coordinate system is shown in Fig. 1(b) which is established for illustration easily. The coordinate origin $O_0$ is rotation center of crank $l_1$ .The right is positive direction of x-axis, and the upward is positive direction of y-axis.

Through the analysis of unilateral transmission mechanism motion as shown in figure 1(b), we can know that the geometric parameters that determine mechanism motion of multi-linkage mechanism are length of crank $l_1$, length of side link $l_2$, length of tie rod $l_3$, length of upper and lower toggle link $l_4$ and $l_5$, positional parameter of main slider articulated point *n*, positional parameter of upper articulated point *m* and *h*. Therefore, the number of independent design parameter is eight, and design variable defined as:

$$X = (x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8)^T = (l_1, l_2, l_3, l_4, l_5, m, n, h)^T .$$

Then, the objective function and constraint function will be given, according to modeling sequence.

### 3.2. Objective function

The performance of main slider is crucial important to the precision of work-piece under the high-speed operation situation. How to determine evaluation index of transmission mechanism reasonably is very import to get perfect output of motion, and meet stamping process needs.

The operation precision of crank impacts the precision of bottom dead center, and this part generates thermal deformation easily. Because force is the main factor which will influence the thermal deformation on crank, and the length of crank is proportional to the force, the length of crank is optimized to reduce the effect on the crank and enhance kinematic accuracy of main slider. Through kinematics analysis of the press machine, the deformation time of parts will be increased with the stamping-angle increased in stamping process. In addition, the deformation of parts is more efficient and the force of mechanism is more uniform according to actual operating condition and kinematic analysis of press. Meanwhile it is beneficial to decrease the impact force and to improve the robustness of the mechanism and the quality of parts [10].

In conclusion, the optimization goal is to decrease the force of crank and increasing stamping-angle, and all objective function is normalized in this paper and then accumulated as multi-objective function. The problem that dimension is inconsistent and gap of magnitude is bigger is solved. Multi-objective function of multi-linkage mechanism is

$$f(x) = {l_1}/{l_c} + {\varphi_c}/{(\varphi_e - \varphi_s)} , \tag{1}$$

where $l_1$ is the length of crank, $l_c$ is the expected length of crank which is 30mm, $\varphi_c$ is the expected value of stamping angle which is $120^\circ$, $\varphi_e$ and $\varphi_s$ is corresponding crank angle at the beginning and end of the stroke of nominal pressure. The difference between $\varphi_e$ and $\varphi_s$ is stamping angle. The $l_c$ and $\varphi_c$ is given by kinematics analysis and practical experience.

### 3.3. Constraint function

There are many mechanism parameters matched to a given multi-bar linkage mechanism of high speed press. Mechanism parameters should be determined based on the comprehensive consideration of the following, such as stroke of main slider, length of each rod, movement interference， total height and transmission angle of mechanism etc. Based on this, engineering constraint conditions are established as follows[11-13].

Because of the limitation of structure dimension of fuselage and practical needs from assembly, length of each rod and their relative position parameter should be constrained. The inequality constraint condition is:

$$g_{1i}(x) = x_{i\min} - x_i \le 0, g_{2i}(x) = x_i - x_{i\max} \le 0, (i = 1, \cdots, 8) . \tag{2}$$

In order to improve force condition of mechanism, ensure normal operation and force-transfer characteristic of multi-linkage mechanism and reduce force on crank and spindle, the pressure angle on articulated point must satisfy constraint.

$$g_3(x) = \varphi - \varphi_{\max} \le 0 , \tag{3}$$

where $\varphi_{\max}$ is maximum allowable value of pressure angle. Generally, the value is $40^{\circ} \sim 45^{\circ}$. The $\varphi$ is pressure angle of each link.

When the position of main slider is bottom dead center, pose of rod $l_3$ can't be horizontal in order to realize expected function and rationality of design.

The value of angle between rod $l_3$ and horizontal direction is minimum with reference to Fig. 1(b), when the position of main slider is bottom dead center. Reference to Fig. 2 and position relation of all points, the equation is obtained:

$$z^2 = m^2 + (h + l_2 - l_1)^2 , \tag{4}$$

$$\tan\theta_1 = \frac{m}{h + l_2 - l_1}, \cos\theta_2 = \frac{z^2 + l_3^2 - l_4^2}{2 \cdot l_3 \cdot z} . \tag{5}$$

Because pose of rod $l_3$ can't be horizontal, the constraint of pose is established, according to formula (4~5).

$$g_4(x) = 0.5\pi - (\theta_1 + \theta_2) \le 0 . \tag{6}$$

In order to adapt pair clearance and deformation of rod, mechanism run reliably and do not appear singular configuration, the point $O_3$ must locate at the left hand of a connecting line between point $O_4$ and point $O_5$.

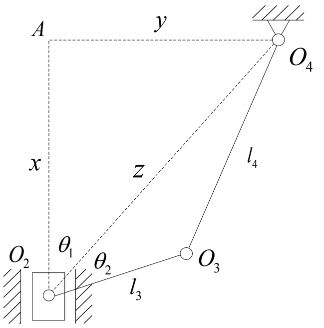



Fig. 2. Constraint diagram of rod $l_3$.

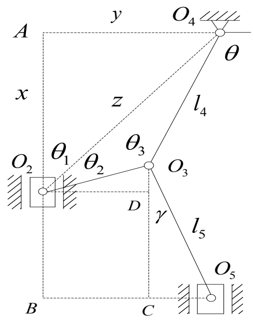



Fig. 3. Constraint diagram of rod l4 and l5.

The rod $l_4$ and $l_5$ tend to be collinear with the reference of Fig. 1(b) and Fig. 3, according to the allocation of all rods in mechanism, when the position of main slider is bottom dead center. The state of rod $l_4$ and $l_5$ should be constrained so that rod $l_4$ and $l_5$ is not collinear.

According to the position relation of all points, the equation is obtained.

$$\cos\theta_3 = \frac{l_4^2 + l_3^2 - z^2}{2 \cdot l_3 \cdot l_4} , \tag{7}$$

$$\sin\gamma = \frac{n - l_3 \cdot \sin\theta_4}{l_5} . \tag{8}$$

The constraint is established, according to formula (4~8).

$$g_5(x) = \cos\gamma + \cos(\theta_1 + \theta_2 + \theta_3) \le 0 . \tag{9}$$

*3.4. Optimization result*

Taking a developing transmission mechanism of high-speed mechanical press for example, the geometric parameters and motion parameters of multi-bar linkage which considered multi-objective optimization design process is designed according to its main technique requirement. Meanwhile, comparision of the high-speed linkage press with the slider-crank mechanical press (which the length of crank is 10 mm) is given .The main technical parameters are depicted as follows: nominal pressure is 600 kN, nominal pressure stroke is 3 mm, main slider stroke is 20mm and maximum operation frequency of main slider is 1000 spm.

According to the above main technical parameters, the optimization program is written in MATLAB. The optimization program is shown in Fig. 4. The optimal solution is searched with step-search method. The optimization results show that geometric parameter of all rods and location parameter set is:

$$X^{*} = (35, 276, 200, 380, 300, 240, 315, 173)^{T}$$

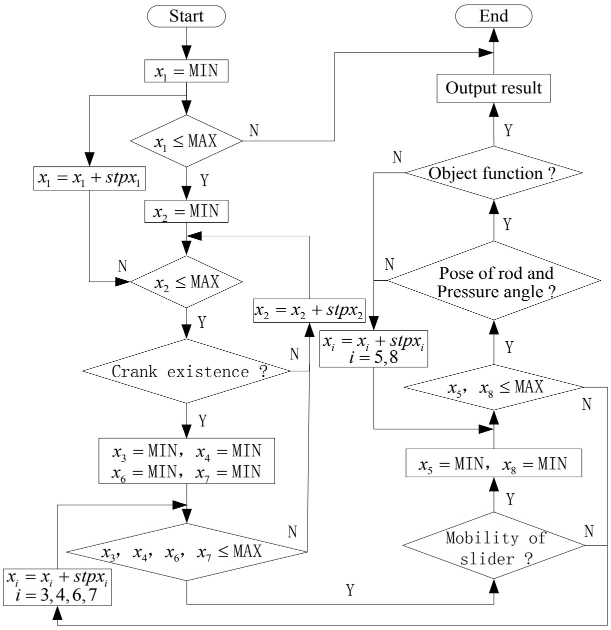



Fig. 4. Flow chart of optimization.

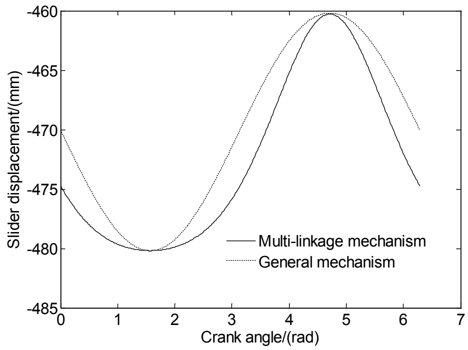



Fig. 5. Displacement curve.

Through kinematic analysis, curve of kinematic is obtained, as shown in Figs. 5-7.

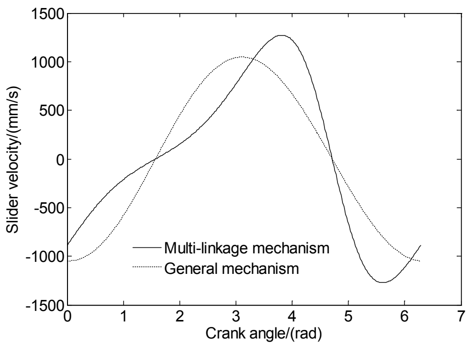



Fig. 6. Velocity curve.

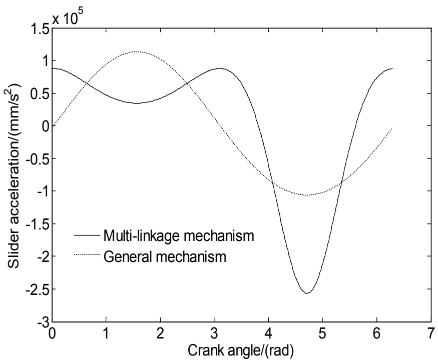



Fig. 7. Acceleration curve.

In Fig. 5, the stamping angle of multi-linkage mechanism is about 56.2% larger than stamping angle of general mechanism. The deformation time of parts is increased with the increasing of stamping angle. Moreover, it is beneficial to full deformation of material, and making the force of mechanism very uniformly.

In Fig. 6, we can know that the slope of velocity curve of multi-linkage mechanism is smaller than slope of general mechanism between 0 and $\pi$. In the meantime, velocity fluctuating is smaller, the speed is lower when upper mold contact strip, impact and noise is decreased. The maximum speed of main slider of multi-linkage mechanism is about 21.5% larger than maximum speed of general mechanism. The maximum value appears between $0.5\pi$ and $1.5\pi$ which is return stage, so return time is short.

In Fig. 7, the acceleration of main slider of multi-linkage mechanism is about 69.5% smaller than acceleration of general mechanism in the near of bottom dead center. Thus, inertia force of mechanism is smaller, design difficulty of dynamic balance is reduced, and kinematic accuracy of main slider is improved. But the acceleration of main slider is larger relatively in the near of top dead center. To a certain extent, the impact of mechanism is increased in stamping stage. In the meantime, the figure embodies relationships of the crank length and the acceleration of main slider indirectly and the motion characteristic of the mechanism is embedded.

## 4. Conclusion

The transmission mechanism of multiple linkage high speed press is given by analysis. Length of crank and stamping angle are used as the evaluation index of mechanism performance. Then, a multi-objective optimization mathematical model of the mechanism is established. The results show that the length of crank is reduced, and then force and fever of crankshaft is reduced. Meanwhile it is beneficial to improve running speed of mechanism. The stamping angle appears about 56.2% larger within the nominal force stroke limit. Displacement curve is smooth. So, it is favorable to full deformation of material and blanking.The maximum speed of main slider is about 21.5% larger. The acceleration of main slider is about 69.5% smaller in the near of bottom dead center .

## Acknowledgements

This work was financially supported by the National Science and Technology Major Project of China (Grant No. 2013ZX04002-082), Jiangsu Province Science and Technology Support Project (Grant No. BE2012174).

## References

[1] Zhao Shengdun, Zhang Xuelai, Gao Changyu et al,2005. Investigation on Inertial Force Balance Assembly Units and Their Dynamic Charact-eristics of A High Speed Press. China Metal Forming Equipment & Manufacturing Technology,40(4):27-30.

[2] Azpilgain Z,Ortubay R, Blanco A, et al, 2008. Servo-mechanical press: a new press concept for semi-solid forging. Diffusion and Defect Data: Part B Solid State Phenomena, 141/142/143(3): 261-266.

[3] Wen Qingpu, 2009. The Advantages of Bruderer High Performance Stamping Technology//The Fifth China International Metal Form Conference. Beijing: Confederation of Chinese Metal Forming Industry, 35-56.

[4] Hong D K, Woo B C, Kang D H, 2008. Application of fractional design for improving performance of 60W transverse flux linear motor. Journal of Applied Physics, 103(7):1-3.

[5] Mo Jianhua Zhang Zhengbin Lv Yan, et al,2011. The Simulation and Optimization of Triangle Toggle Rod Transmission Mechanism for Servo Press. China Metal Forming Equipment& Manufacturing Technology,1:21-24.

[6] Chen Yueyun, 2008.On Dynamic Performance Analysis and Design of A Multi-link Servo Mechanical Press.Shanghai: Shanghai Jiao Tong University.

[7] Yang Chunfeng, Zhang Sheng, Li Yunpeng et al ,2013.optimization design for six-bar linkage of mechanical press.Journal of Dalian University of Technology,53(1): 64-70.

[8] Li Chuye, Sun Caixia, Zheng Huien,2011.Performance optimization of multi-linkage mechanism based on ANSYS. Forging & Stamping Technology,36(6):80-83.

[9] Bai Yunjun, 2012.Key Technologies and Experimental Research on Heavy-Duty Servo Mechanical Presses with Parallel Topology.Shanghai: Shanghai Jiao Tong University.

[10] Xie Jia, Zhao Shengdun, Liang Jintao,2012. Variable Sequential Combination Response Surface Methodology for Press rod System Optimization.Journal of Xi'An Jiaotong University, 46(5):57-62.

[11] Shang Wanfeng, Zhao Shengdun, Shen Yajing, 2009. A flexible tolerance genetic algorithm for optimal problems with nonlinear equality constrains. Advanced engineering informatics, 23(6): 253-264.

[12] Song Qingyu,Li Jian,Yin Wenqi,2012.Mechanical Press Six-link Mechanism Design Based on Multi-objective.Transactions of the Chinese Society of Agricultural Machinery, 43(4): 225-229.

[13] Peng Yuhai,2013.Analysis on the Motion Characteristics of Drawing Press Working Mechanism Based on the Virtual Prototype. Machinery Design & Manufacture, 3: 211-213.