10th International Conference on Axiomatic Design ICAD 2016

Optimization design of guiding device on hydraulic press column based on Axiomatic Design Theory

Hui-lin Qu[a], Yi-xiong FENG[a, *], Yi-cong Gao[a], Jian-rong Tan[a]

State Key Laboratory of Fluid Power and Mechatronic Systems, Zhejiang University, Hangzhou 310027, China
* Corresponding author. Tel.: +0-000-000-0000; fax: +86-571-87951273. E-mail address: fyxtv@zju.edu.cn

Abstract

During the lower speed precision stamping process, the slide block may jitter or crawl because of the unbalance friction on the guide device, which will influence the quality and precision of the workpiece. Therefore, it is necessary to optimize the guiding device on hydraulic press column. Axiomatic design plays a very important role in the optimization design of mechanical products, and it provides a basic scientific framework for the research and design by mapping different domains and refining design process. In this paper, we analyze the guiding device on a large tonnage hydraulic press, and we create the axiomatic design framework of guiding device on hydraulic press column by mapping and refining layer by layer. Through the analysis of the coupling, we optimize the structure of guide device and improve the lower speed precision stamping conditions of hydraulic press

Keywords: a*xiomatic design; design optimization; guiding device*

1. Introduction

Axiomatic design (AD) was proposed by Suh of Massachusetts Institute of Technology in 1990, which is now considered as a design method that addresses the fundamental issues in mechanical design, software design, system design, business planning, etc[1]. The theory provides a basic scientific framework for designers through rational analysis to improve the design level[1-3]. Designers can make a comprehensive analysis of design requirements, solutions and process. The design consists of four domains: customer attributes(CA_s), functional requirements(FR_s), design parameters(DP_s), process variables (PV_s)[1-5]. In the process of product design, the two neighbouring domains are closely related by a certain mapping relationship between them. Furthermore, Axiomatic Design prescribes the independence axiom and the information axiom. The independence axiom maintains the independence of functional requirements. And the information axiom minimizes the information content[6].

The mapping process between two neighbouring domains in axiomatic design can be described by mathematical formulas, which is a certain mathematical relationship. For example, the relationship between functional requirements and design parameters can be expressed in Formula 1[7].

$$\{FR\} = [A]\{DP\} \qquad (1)$$

Where [A] is a design matrix, which characterizes the product's design formula. In the design, we should ensure that the design matrix [A] is a diagonal matrix or triangular matrix [1]. Otherwise, the design has couplings, which make the design unreasonable, and therefore it needs to be decoupled or uncoupled. During the design process, it is difficult to make each level of the design matrix completely uncoupled sometimes, but we should strive to achieve the quasi-coupling design at least.

Many scholars have more in-depth researches on the axiomatic design. Kulak et al. provided a recognizable overview of literature on AD principles from the past 20 years and introduces a novel classification scheme covering 63 papers[8]. F Wang et al. optimized the design of the compressor reed valve group through the axiomatic design, and the prototype test proved that the optimization is good[9]. Roohnavazfar et al. presented an optimization design of

torque motor by using zigzagging process and axiomatic design theory[10]. KL Mao arrived at the best scheme to realize great power transmission by comparing the flexible pin even-loading system and sun gear floating system based on the axiomatic design theory[11]. XF Cheng et al. verified the effectiveness of the axiomatic design method by optimizing the design of a disk brake[12].

After years of development, Axiomatic Design has been widely applied in different fields of engineering design. Especially it is widely used in the optimization design of mechanical structure[13]. Compared to the other design methods, axiomatic design not only can cover from conceptual design to manufacture, but also can provide a framework to address existing design issues that make the design unreasonable. After analysis in the process of top-down decomposition of mechanical structure, we usually make some decoupling analysis of the existence of the coupling design to address issues of the mechanical structure optimization design. What's more is that the independence axiom and the information axiom can ensure high robustness and reliability to the product.

At present, there are some common problems including jittering or crawling of the slide block on the large tonnage hydraulic press, which may influence the workpiece's quality and the service life of the press. The jittering and crawling are caused by the unbalanced friction [14]. In this paper, we optimize the design of the guiding device on hydraulic press column based on axiomatic design theory. After decomposing the existing guiding device from the perspective of functional design, we find the coupling design in the device design. By redesigning, we optimize the design of the guiding device on hydraulic press column by conducting a decoupling design.

2. Analysis of guiding device on hydraulic press column based on axiomatic design

During the lower speed precision stamping process, the slide block descends at a very low speed in order to ensure the quality of the thin wall component. The structure of hydraulic press is shown in Fig 1. Nowadays, the sliding guiding structure is widely used in the guiding devices on large tonnage hydraulic press which will cause jitter or crawl because of the unbalance friction on the four sets of guiding devices. It may lead to the appearance of the surface rupture and the coarse grain of the workpiece. So we need to analyse the existing guiding device on hydraulic press column in detail to finish the optimization design. The structure of the slide block and guiding device are shown in Fig 2. The four sets of guiding devices are distributed symmetrically with sliding friction pair. Every set of guiding device is composed of a pair of guiding blocks which are installed on the slide block and the column separately.
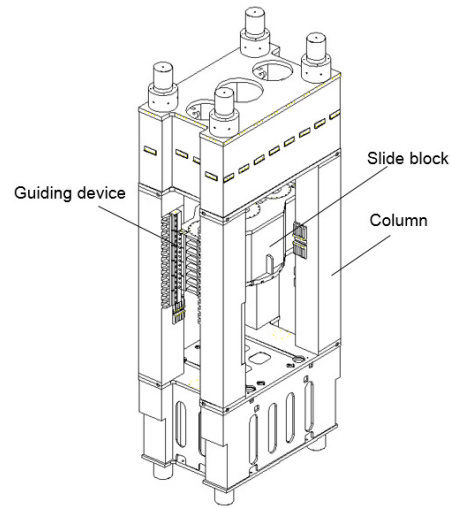

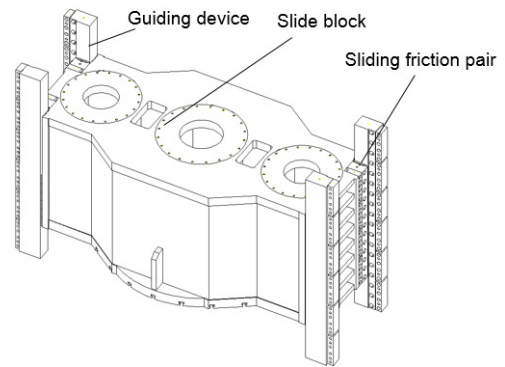Fig.1. The structure of hydraulic press

Fig.2. The structure of slide block and guiding device

2.1. Analysis of existing guiding device on hydraulic press column

The structure of the existing guiding device on hydraulic press column is shown in Figure 3. The slide block can ensure the vertical stability of descending and ascending through the guide device. The slide block may jitter or crawl because of the unbalance friction on the four sets of sliding friction pairs.
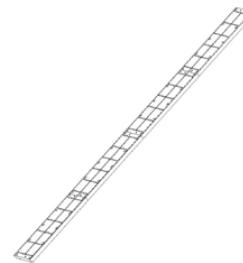

Fig.3. The structure of sliding friction pair

Design analysis based on axiomatic design theory:

FR_1-Keep the motion vertical between slide block and column, DP_1- Guiding device in vertical direction;

FR_2-Stabilize the horizontal limitation of the slide block, DP_2-Close contact symmetrical guiding device on four column;

FR_3-Stabilize the movement of the slide block, DP_3- Four sets of guiding devices with very small or similar friction value;

FR_4-Ensure the guiding device replaceable, DP_4-Detachable guiding device.

The design formula is as follows:

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \\ FR_4 \end{Bmatrix} = \begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \\ DP_4 \end{Bmatrix} \quad (2)$$

1 indicates strong dependency. 0 indicates no dependency. The realization of FR_1 depends on both DP_1 and DP_3. The realization of FR_3 depends on DP_1, DP_2 and DP_3. DP_2 influences FR_2 and FR_3. The guiding device defines the horizontal limitation of the slide block by the close contact. While the close contact will increase the friction value, which will influence the stability of the slide block. During the descending process, the friction on the four columns is unbalanced, which will cause the slide block jitter or crawl. So it needs to be redesigned from the customer attributes to achieve optimal design.

2.2. Optimization design improvement of guiding device

In view of the above coupling design, we need to decouple the design by optimizing the existing structure. By analysing the customer attributes, we determined the functional requirements and proposal design parameters layer by layer according to the independence axiom and information axiom. The axiomatic design framework of the optimization of the guiding device is as follows:

Customer attributes: CA_1-The products produced by the hydraulic press are of good quality and accurate size; CA_2-The hydraulic press should have a long service life.

Functional requirements and Design parameters: According to the axiomatic design framework, we map the customer attributes into functional requirements, and then we make sure FR_S and DP_S in every detail.

(1)First level decomposition: FR_1-Ensure the normal motion of the slide block. DP_1-Guiding device on hydraulic press column.

FR_2-Ensure the guiding device can be replaced. DP_2-Detachable column guiding device.

The guiding device comprises a guide block on the column and a guide block on the slide block. And the guide blocks are fixed by bolt connection. We get the first level design formula by analysing the relationship between functional requirements and design parameters:

$$\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \end{Bmatrix} \quad (3)$$

(2)Second level decomposition: FR_{11}-The guiding device limits the horizontal direction of slide block. DP_{11}-Four sets of symmetric guiding devices. FR_{12}- The guiding device enables the slide block to move in the vertical direction. DP_{12}-Guiding device installed in vertical direction. Four sets of symmetric guiding devices are symmetrically distributed on four columns and slide blocks. The second level design formula is as follows:

$$\begin{Bmatrix} FR_{11} \\ FR_{12} \end{Bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{Bmatrix} DP_{11} \\ DP_{12} \end{Bmatrix} \quad (4)$$

(3)Third level decomposition: FR_{111}-The guiding device can limit the front and rear direction of slide block. DP_{111}-The columns and slide block's guiding blocks are installed in the front and rear direction. FR_{112}- The guiding device can limit the left and right direction of slide block DP_{112}- The columns and slide block's guiding blocks are installed in the left and right direction. The design formula is as follows:

$$\begin{Bmatrix} FR_{111} \\ FR_{112} \end{Bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{Bmatrix} DP_{111} \\ DP_{112} \end{Bmatrix} \quad (5)$$

FR_{121}-The guiding device runs smoothly. DP_{121}-Four sets of guiding devices with balanced friction. FR_{122}- Guide device runs without obstacles. DP_{122}-Four sets of guiding devices with smooth contact plane. The design formula is as follows:

$$\begin{Bmatrix} FR_{121} \\ FR_{122} \end{Bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{Bmatrix} DP_{121} \\ DP_{122} \end{Bmatrix} \quad (6)$$

(4)Forth level decomposition: FR_{1211}- The numerical difference of the friction force between the four sets of guiding devices is very small. DP_{1211}- Four sets of guiding devices with small friction difference. FR_{1212}-The friction value of four sets of guiding device is very small. DP_{1212}-Four sets of guiding devices with very small friction value. The design formula is as follows:

$$\begin{Bmatrix} FR_{1211} \\ FR_{1212} \end{Bmatrix} = \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix} \begin{Bmatrix} DP_{1211} \\ DP_{1212} \end{Bmatrix} \quad (7)$$

Process variables: Use the guiding devices with rolling friction pair instead of the ones with sliding friction pair. Install the new guide blocks on the columns by bolt connection.

The level structure of the FR and DP in the optimization design is showed in Fig 4.
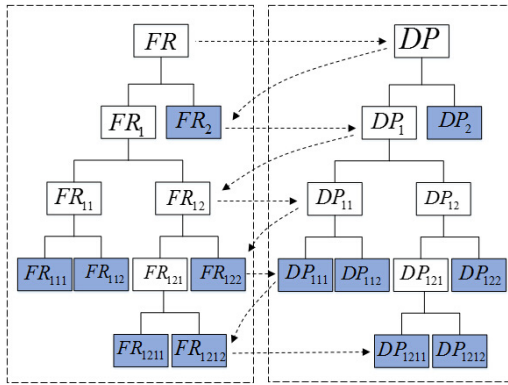
Fig.4. The level structure of the FR and DP in the optimization design

The guiding device adopts rolling friction to ensure the very small friction value and the small friction difference among the four sets of guiding devices. The structure of rolling friction pair is showed in Fig 5.
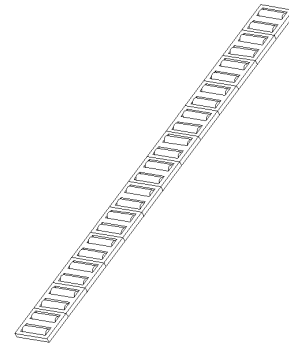

Fig.5. The structure of rolling friction pair

2.3. The result analysis

In the result of the decomposition of the hydraulic machine column guiding device, there are 5 sub functional requirements and 5 leaf design parameters. And we get a 5×5 design matrix finally. The relationship between the functional requirements and design parameters of each sub item is shown in Table 1. 1 indicates a strong effect between FR and DP, while 0 indicates a weak effect between FR and DP.

Table 1. The optimized design of the guiding device on hydraulic press column

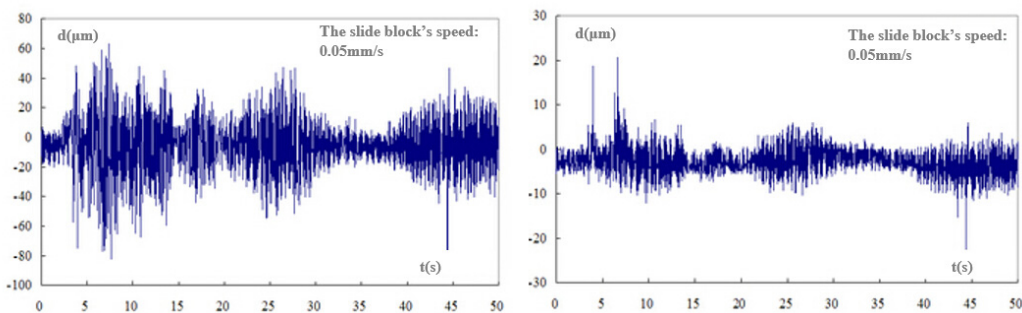|	DP_{1212}	DP_{1211}	DP_{122}	DP_{112}	DP_{111}
FR_{1212}	1	0	0	0	0
FR_{1211}	1	1	0	0	0
FR_{122}	0	1	1	0	0
FR_{112}	0	0	0	1	0
FR_{111}	0	0	0	0	1

Fig.5. The vibration results of slide block

We've carried out some experiments by changing the guiding device to validate our design. The left picture in Fig.5 is the vibration result of the slide block contacting sliding friction pair. The right picture in Fig.5 is the vibration result of the slide block contacting rolling friction pair. Obviously, the amplitude of the slide block contacting rolling friction pair is smaller than the one contacting sliding friction pair. Compared with the existing design, the optimized guiding device greatly reduces the friction between the slide block and column by using the rolling friction pair, which can eliminate

the jitter and crawl phenomenon. What's more, the optimized guiding device can limit the horizontal position of the slide block well. The optimization design is finished through the axiomatic design theory.

3. Summary and conclusion

The guiding device after optimization can provide better balanced frictions, which can make the movement of slide block smoother. In this paper, we optimize the design of the guiding device on hydraulic press column based on axiomatic design theory by changing sliding friction pair to rolling friction pair. The amplitude caused by jittering and crawling is proved to be smaller after optimization through experiment. Axiomatic Design is well applied in the optimization design of guiding device. However, in this design, there are still some quasi coupled design, which needs further research. What's more, during the process of stamping, there are still some problems about the production, such as sheet's wrinkling, hydraulic system's noise, material consuming body, which need further optimization. In the next phase, we will address the above issues based on axiomatic design theory. Through the analysis of blank holder, hydraulic circuit and machine body, we will optimize the structures of the key parts of the press to solve the above problems..

Acknowledgements

References

[1] Suh N P. Axiomatic Design Theory for Systems[J]. Research in Engineering Design, 1998, 10(10):189-209.

[2] W Albano L D, Suh N P. Axiomatic approach to structural design [J]. Research in Engineering Design, 1992, 4(3):171-183.

[3] Suh N P. Axiomatic design: advances and applications [M]. New York: Oxford University Press 2001.

[4] Liu X P, Soderborg N. Improving an existing design based on axiomatic design principles [C]. First International Conference on Axiomatic design, Cambridge, 2000.

[5] Xi Chen, Zhiwu Li, Zhiping Fan, Xiaoyang Zhou, Xiao Zhang. Matching demanders and suppliers in knowledge service: A method based on fuzzy axiomatic design[J]. Information Sciences,2016.

[6] Yuri Borgianni,Dominik T. Matt. Applications of TRIZ and Axiomatic Design: A Comparison to Deduce Best Practices in Industry[J]. Procedia CIRP,2016,39.

[7] Gyung-Jin Park. Teaching conceptual design using axiomatic design to engineering students and practitioners[J]. Journal of Mechanical Science and Technology,2014,283.

[8] Kulak O, Cebi S, Kahraman C. Applications of axiomatic design principles: A literature review[J]. Expert Systems with Applications, 2010, 37(9):6705-6717.

[9] Feng Wang, Xueyuan Peng. Axiomatic design of the valve assembly of compressor reed valve [J]. Fluid machinery, 2011,06:38-42+12.

[10] Roohnavazfar M, Houshmand M, Zarandi R N, et al. Optimization of design parameters of a limited angle torque motor using analytical hierarchy process and axiomatic design theory[J]. Production & Manufacturing Research An Open Access Journal, 2014, 2(1):400-414.

[11] Mao K L. Application of Axiomatic Design Theory in Multi-Planetary Gear Transmission Design[J]. Applied Mechanics & Materials, 2014, 536-537:1306-1309.

[12] Xianfu Cheng, Renbin Xiao. Optimization design method based on axiomatic design and its application [J]. Transactions of the Chinese Society for Agricultural Machinery, 2007,03:117-121.

[13] Park G J. Teaching conceptual design using axiomatic design to engineering students and practitioners[J]. Journal of Mechanical Science & Technology, 2014, 28(3):989-998..

[14] Zhineng Wang, Minghui Huang, Jinjing Xie, Kan Deng, Xinjiang Lu. Large forging press's low-speed stable operation rules[J]. Journal of Central South University (NATURAL SCIENCE EDITION), 2014, 10:3379-3385..