Application of TRIZ Theory in the Design of Cross Arm Rotating Clamping Mechanism

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Abstract. In order to solve the problem of the stainless steel pipe falling off during the debugging process of the cross arm rotating clamping mechanism, the TRIZ theory is applied to the innovative design of the mechanism. Firstly, the problem description, causal analysis and function analysis are carried out, then the invention principle and separation principle of conflict resolution theory and the standard solution of substance-field analysis model are used to solve the design problem. After feasibility evaluation, the optimization schemes such as changing the clamping direction and increasing the shape of the clamping rubber bulge are obtained. The optimized cross arm rotating clamping mechanism is applied to the stainless steel tube automatic packaging production line, which solves the problem of the stainless steel tube falling off, and provides a reference for the design of similar clamping mechanism.

1. Introduction

To reduce the labor costs and improve the packaging efficiency of stainless steel pipes and the automation level of enterprises, an automated packaging line of stainless steel pipes was developed [1-2]. The overall production line consists of six modules: material discharging, stacking, winding, paper folding, taping, and palletizing. The cross arm rotating and clamping mechanism is located in the stacking module, and its main function is to clamp a layer of 10 stainless steel pipes from the discharging section to the stacking platform. After 10 layers of pipes are stacked, stainless steel pipes are then placed in the winding section and transported forwards. In the commissioning process, there is a certain probability that clamped pipes fall off from the cross arm rotating and clamping mechanism. Therefore, stainless steel pipes that fall off must be manually picked up and then placed onto the stacking platform, which reduces the level of automation and increases the labor intensity of workers. To completely solve this engineering problem, the paper applied the Theory of Inventive Problem Solving, known by the acronym TRIZ to improve the design of the cross arm rotating and clamping mechanism for stainless steel pipes. TRIZ is a comprehensive theoretical system [3] consisting of various methods and algorithms for solving technical problems and achieving innovation.
development. TRIZ theory has been promoted and practiced in recent years since it was developed by G. S. Altshuller et al. It has been widely applied at home and abroad in mechanical equipment [4-5], medical equipment [6], automotive industry [7], system design [8], and innovation education [9-10]. In this case, we first used TRIZ theory to describe the problem and conduct the cause-effect analysis and functional analysis and then comprehensively synthesized the invention and partitioning principles of the conflict resolution theory as well as the standard solution of the substance-field analysis model. Through concretizing the general solution into the engineering solution of the problem, and finally the optimal solution is applied to the actual production after the feasibility evaluation.

2. Structure and Operating Principle of the Cross Arm Rotating and Clamping Mechanism

The cross arm rotating and clamping mechanism mainly consists of cross arms, clamping elements, clamping cylinders which drive clamping elements, rotating shaft, reducer and stepper motor, as shown in Figure 1. The stepper motor drives the rotating shaft and the two fixed cross arms to rotate through the reducer. The two cross arms are made of 50 mm × 50 mm × 4 mm square pipes and connected together by welding. A clamping cylinder is fixed at the end of each cross arm and a clamping element is fixed at each cylinder for clamping stainless steel pipes and the specifications of stainless steel pipes to be clamped are 1380 mm × 18 mm × 10 mm. The clamping elements are made of rubber. When cross arm 1 rotates to the horizontal position (position shown in Figure 1), clamping cylinder 1 and clamping element 1 on both sides at the corresponding position are pushed out to clamp a layer of 10 stainless steel pipes placed on the material discharging section and then cross arm 1 starts to rotate. When cross arm 1 turns 90°, cross arm 2 rotates to the horizontal position, clamping cylinder 2 and clamping element 2 at the corresponding position start to clamp a layer of 10 stainless steel pipes. When cross arm 1 turns to 180°, the cylinder at both sides of the cross arm at the corresponding position loosens and places the layer of stainless steel pipes onto the lifting plate of the stacking platform. At the same time, the clamping cylinder on the other side of cross arm 1 rotates to the horizontal position, continues to clamp a layer of 10 stainless steel pipes in the discharging section, and starts the next cycle until 10 layers are stacked.

3. Problem Analysis

3.1 Problem Description

In the commissioning process, stainless steel pipes clamped by the cross arm rotating and clamping mechanism fall off. This problem mainly occurs in the following two situations: (1) when a cross arm
at a horizontal position is clamping steel pipes, steel pipes clamped by the other cross arm fall off; (2) clamped steel pipes at the uppermost end of cross arms are most likely to fall off. At present, this problem is mainly solved by replacing the clamping element material to increase the friction between clamping elements and stainless steel pipes. However, the problem has not been completely solved.

3.2 System Function Analysis
The system components of the cross arm rotating and clamping mechanism are cross arm 1, clamping cylinder 1, clamping element 1, cross arm 2, clamping cylinder 2, clamping element 2, and super system components such as organic frame, bearing seat, motor, reducer, shaft, etc. The system acts on the stainless steel pipes that are clamped or being clamped. Figure 2 is the functional model of the cross arm rotating and clamping mechanism. It can be concluded that clamped steel pipes fall off for two direct reasons: (1) the friction of clamping element 2 on the clamped stainless steel pipes is not enough, which causes the clamped stainless steel pipes to fall off, and it is functioned as being insufficient. (2) the reacting force of stainless steel pipes that are being clamped on clamping element 1 and clamping cylinder 1 causes the clamping cylinder 1 to vibrate. The vibration transfers to clamped stainless steel pipes through cross arm 2, clamping cylinder 2, and clamping element 2, causing the clamped stainless steel pipes to fall off, and it is functioned as being harmful.

3.3 Causal Analysis
The causal analysis of the cross arm rotating and clamping mechanism is shown in Figure 3. The key problems that cause the insufficient friction of clamping elements and the vibration of the clamping position are: (1) insufficient friction coefficient of the clamping elements; (2) insufficient rigidity of cross arms; (3) insufficient clamping force of the clamping elements; (4) large reacting force of steel pipes on the cylinders. By further analysis of problems (3) and (4), we can get a pair of physical contradictions: the cylinder bore must be both large and small. The reason why the cylinder bore is large is because cylinders need to provide enough clamping force for stainless steel pipes, and the reason why the cylinder bore must be small is because this can reduce the vibration generated when stainless steel pipes are being clamped.
Fig. 3 Causal analysis of the cross arm rotating and clamping mechanism

4. Problem Solving

4.1 Technical Contradiction

For the key problem (2) of the cross arm rotating and clamping mechanism, the rigidity of cross arms is insufficient, and the cross arm needs to be replaced with a more rigid material or a larger square pipe, which will increase the cost and cause other problems such as the increase of the load on the rotating shaft and the increase of the deformation of the rotating shaft. Therefore, the key problem (2) is not considered for the time being, and the TRIZ tool is used to discuss the key problem (1), which is the insufficient friction coefficient of clamping elements.

If the surface shape of clamping elements (12) is changed, it will lead to a decrease in its manufacturability (32). Four recommended invention principles were obtained by checking the contradiction matrix: No.1 splitting, No.32 change of color, No.17 dimensional change, and No.28 mechanical system substitution. No.1 splitting and No.17 dimensional change are chosen to solve the technical contradiction. The specific solution is: A clamping element is split into two pieces, one with a large friction coefficient and the other made of the elastic material. At the same time, flat clamping elements are designed with a bulged surface so that the bulged part can reach into the cross-section of steel pipes.

4.2 Physical Contradiction

Through the causal analysis of the cross arm rotating and clamping mechanism, it can be seen that the cylinder bore must be both large and small. This physical contradiction is solved by using the principle of spatial separation and partitioning. That is, the action of pushing out the clamping elements by the cylinder to clamp stainless steel pipes is split into two actions: one is a cylinder being pushing out and the other is a finger cylinder clamping stainless steel pipes. The specific solution is: A TN cylinder is used to push out a finger cylinder at both ends of each cross arm. When clamping stainless steel pipes, a TN cylinder pushes out a finger cylinder and the gripper on the finger cylinder clamps the stainless steel pipes from the vertical direction. In this way, the forces on both cylinders are relatively small and a smaller model of cylinders can be chosen, which reduces vibration.

4.3 Substance-Field Analysis

According to the substance-field analysis of TRIZ theory, a substance-field analysis model is established, as shown in Figure 4 (a). In the model, F is the mechanical field, substance S1 is the object of actions, stainless steel pipes, and substance S2 is the clamping element. Through the previous system functional analysis, it can be concluded that certain problems exist in the mechanism: the friction of clamping elements on the clamped stainless steel pipes is insufficient, which causes the
clamped stainless steel pipes to fall off, that is, the acting force of S2 on S1 is insufficient; When clamping stainless steel pipes, the reacting force of stainless steel pipes on the clamping elements and clamping cylinder causes the cross arm to vibrate. The vibration is transmitted to the clamped stainless steel pipes, causing the clamped stainless steel pipes to fall off, that is, the acting force of S2 on S1 is harmful. In TRIZ theory, the substance-field model provides 76 standard solutions. In this design, the standard solution methods in S1.2.3 are applied to introduce substances to eliminate the harmful effect and S2.2.2 to increase the degree of division of substances to solve the above problems, and get a new substance field model, as shown in Figure 4 (b).

![Substance-field model of the cross arm rotating and clamping mechanism](image)

**Fig.4 Substance-field model of the cross arm rotating and clamping mechanism**

According to the above-mentioned substance-field analysis, the following solution can be obtained: The clamping mechanism from the horizontal direction can be used to clamp the end surface of stainless steel pipes and from the upper and lower vertical directions to clamp the upper and lower surface of stainless steel pipes. At the same time, elastic materials are placed between the clamping element and the clamping cylinder at the horizontal direction to absorb vibration. The foam sponge can be used as the elastic material.

### 4.4 Determination of the Final Solution

After comparative analysis, the solution derived from the physical contradiction, i.e., installing finger cylinders on the TN cylinder to clamp stainless steel pipes, requires two sets of power sources, which is easy to cause instability of the whole mechanism. At the same time, a total of eight finger cylinders are required, which also greatly increased the cost. Therefore, this solution has not been used. The final solution obtained by comprehensively considering the technical contradiction and substance-field analysis is shown in Figure 5 (a), (b). That is, the clamping mechanism is used to clamp the stainless steel pipes from the horizontal direction and vertical direction. The clamping element on the horizontal direction is split into two pieces: one is made of rubber and the other foam sponge. Meanwhile, the flat rubber plate is designed to have bulges on the surface, so that the plate can be stuck into the cross-section of stainless steel pipes, as shown in Figure 5 (c). The improved cross arm rotating and clamping mechanism is then applied to the automated packaging production line. The mechanism is running stably and no stainless steel pipe fall off during the clamping process, which meets the technical indicator required by enterprises (the packaging speed is 2 boxes / min).
5. Conclusion
In this paper, TRIZ theory is used to conduct a causal analysis of the problems and methods such as technical contradiction, physical contradiction, and substance-field analysis are used. The problem that stainless steel pipes fall off during the commissioning process of the cross arm rotating and clamping mechanism is solved by the following measures: clamp pipes from both the horizontal and vertical directions and increase the bulging areas of the rubber plate.

The optimized cross arm rotating and clamping mechanism is applied to the automated packaging production line, no stainless steel pipe falls off obviously during the clamping process, and the equipment operates stably. The application of TRIZ theory to the design and optimization of the automated production line has good economic values, and lays a good foundation for the subsequent promotion and use of automated packaging production lines.

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