Innovative design of side mould structure based on TRIZ theory

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Abstract. In order to meet the requirements of domestic prefabricated buildings and PC production lines, taking the side mould structure as the research object, an innovative design of the side mould structure based on TRIZ theory is proposed. The tools of TRIZ's nine-screen method and conflict matrix are used to complete the innovation of the plugging device for the side mould reinforcement hole, and by using steel wire connection, the aluminum alloy sealing device can complete synchronous action and solve the problem of reinforcement hole leakage. Through the object field analysis tool in the TRIZ theory, to establish the function related to the existing system or new technology system problems, the double rocker mechanism is used to make the reset action and the demolding action of the side mould sealing device complete in a linked manner, to realize the design of the demoulding device and the side mould fixing device. The calculation and verification of the side mould structure verify that the side mould stiffness meets the production requirements, and improves the accuracy and placement accuracy of the side mould.

1. Introduction
As the country promotes the industrialization of housing, PC (precast concrete) production technology has also ushered in huge challenges. Different from abroad, the domestic PC board's ribbing requirements have brought a very serious slurry leakage problem to the side module. This problem adds labor intensity to the cleaning work of the mold table and the side mould itself[1]. The same die table can produce multiple PC components at the same time, so the negative effect of the steel hole leakage on the cleanliness of the die table working surface will affect the accuracy of the die setting and the beat, working efficiency of the relevant stations, and even increase the production cost[2].

At present, most of the side moulds in production use permanent magnets to be fixed on the mold table, and combined with the binding force of concrete, it leads to increased mold removal resistance when the side moulds are removed. In order to overcome the resistance of demoulding, in actual production, violent methods such as heavy hammering are used to remove the side mould, which causes the side mould to deform to a certain extent, seriously reduces the service life of the side mould, and even affects the quality of the product[3].

The straight bar sealing device and stirrup sealing device designed by China No.22 Metallurgical Group Co., Ltd. respectively solve the problem of slurry leakage at the position of the straight bars and stirrups of the wall PC components. Li Bin et al. proposed a demoulding mechanism composed of a link mechanism that can be embedded in the side mould, which can supply a sufficiently large...
demolding force. This article takes the TRIZ theory as a guide to innovate the design of the steel bar sealing device, demoulding device and fixing device of the PC component side mould to improve the production efficiency and automation of the PC production line.

2. Design of side mould plugging device
At present, most of the raw materials used for the side mould body are section steel, and the use of angle steel is more common. In order to meet the requirements for ribs, the side mould body is used to open small holes, which will cause the problem of leakage of reinforcement holes. In this regard, the “nine screen method” introduced in TRIZ theory is used for resource analysis, transforming the current edge mode system, using the system itself, subsystems, super systems, and their past and future resources to analyze and find available resources[4]. As shown in Figure 1, the "nine-screen method" is used to analyze the relevant factors such as the process flow, materials used, and working environment of the main body of the side mould. Based on the structural system of Jiugongge and the resources shown, various possible solutions are obtained Program and evaluation[5].

Figure 1. Nine screen method to analyze the main body of the side mode

Through the analysis of each resource and comprehensive consideration of achievable factors, two solutions are obtained:

(1) Use the subsystem to get the program A, that is, use different types of angle steel, hereinafter referred to as the angle steel dislocation type program.

(2) Using the super system to get the plan B, that is, use the robot to put the steel bar sealing device into the steel bar hole to block.

The angle steel dislocation scheme is to use two different types of angle steel together, because the outside of the right angle of the angle steel is a right angle and the inside is a circular arc. The cross-sectional shape brings great limitations to this solution, that is, the right angle and the circle It is impossible to complete cooperation between arcs. In this regard, instead of the angle steel used for sealing, a sealing strip formed of aluminum alloy is used to block the reinforcement holes on the side mould to solve the existing limiting factors.

Considering the shape of the aluminum alloy plugging device, the specific technical issues related to the aluminum alloy plugging device can be abstracted as a general problem. Querying 39 general engineering parameters and the contradiction matrix table can summarize the problem as improving the weight of a stationary object, resulting in an increase in the length of the object, as shown in the available contradiction matrix table in Table 1 below. The available invention principles are: No. 1 division, No. 10 pre-operation, No. 29 pneumatic and hydraulic structure, No. 35 parameter change[6].

Table 1. Principles of invention that can be used to resolve conflicts

| Improvement | Object weight |
|-------------|---------------|
| Deterioration | No.1, No.10, No.29, No.35 |
Based on the empirical analysis of the plugging device for reinforcement holes, the solution of the principle No. 1 of the invention is adopted. The entire aluminum alloy side mould sealing strip is divided into aluminum alloy sealing sliders corresponding to the number of reinforcement holes, excess aluminum alloy material is removed, and each aluminum alloy sealing slider is blocked by a fixing frame. Fixed in the corresponding position, the main body of the side mould and the aluminum alloy sealing slider are shown in Figure 2. This solution ensures that each reinforcement hole can be blocked to avoid the problem of slurry leakage, while meeting the requirements of reducing weight.

Use a thin steel wire rope to connect each aluminum alloy sealing slider together, so that the aluminum alloy sealing slider can complete the sealing work in one operation, and the mechanism used can be a crank rocker or a double rocker mechanism. Figure 3 shows the four-bar mechanism (part) for plugging.

Figure 2. side mould body and plugging device

3. Structural design of mold removal device

The side mould is demolished after the concrete is solidified, and the destructive and violent nature of the mold demolishing method will prevent the mold demolition function of the side mould robot from performing well. Aiming at these problems that occur during demoulding, the TRIZ theory can be used to construct a structural bridge. The first step in the construction of the structural bridge is the analysis of the object field. To complete the dismantling of the side mould, three basic factors are required, namely two substances S1, S2 and a field F. The side mould itself is the bearer during the demolding process, and the mold-setting robot is the sender during the demolding process. The two can be used as S1 and S2 in the system respectively, so this demolding function still lacks a field F. To complete the incomplete object model, a field F must be added to complete the object model. Considering the current design of the side mould, working environment, mechanical state, preliminary design of the sealing device, etc., a lever device can be provided to amplify the magnetic force on the magnet chuck.

Through the analysis of the system's object field, the incomplete object field model lacking "field F" completes the object field model using the action of magnetic field and mechanical field force. The lever design determined based on the analysis of the object field can amplify the magnetic attraction of the magnet on the mold-setting robot, and achieve the mold-removing function of the side mould by overcoming the mold-removal resistance[7]. The lever used in the mold removal design can be made into a rocker, so the double rocker mechanism can be used to reset the side mould sealing device (the purpose is to expose the steel hole when the mold is removed) and the lever mold removal action in a linked manner Completed at the same time. In a side mould unit, the four-bar mechanism adopts a symmetrical arrangement. Due to the traction of the steel wire rope, the symmetrically arranged aluminum alloy block slider and the mold removal device can achieve interlocking[8]. The specific structure is shown in Figure 4.

Using permanent magnets to fix the side mould on the mold table, the magnetic force becomes a harmful effect when the mold is removed, thus forming another object field model-a complete model with harmful effects. Among them, the side mould itself acts as the bearer, the permanent magnet acts as the sender of the fixed action, and the magnetic force effect of the permanent magnet acts as the field. The three can be regarded as S1, S2, and F in the system, respectively. In order to prevent this
harmful effect, a third substance S3 needs to be added. The substance S3 may not be an entity or some measure. Through the analysis of the material performance of the permanent magnet, a soft magnetic material can be added to the bottom of the permanent magnet to solve it. The permanent magnet and the base of soft magnetic material can just form a magnetic base, so the magnetic base can be used to directly replace the permanent magnet in the fixing of the side mould, which will effectively reduce the resistance of demolding and at the same time play the role of fixing the side mould. The specific construction steps of the complete model with harmful effects are shown in Figure 5.

Figure 4. The specific structure of the demoulding device

Figure 5. Steps to build a complete model with harmful effects

4. Calculation and verification of the edge mode structure
The function of the U-shaped sheave is to wind or reserve the steel wire rope, and its outer diameter and groove depth need to be combined with the sliding displacement of the steel hole sealing device and the design of the wire rope diameter. Taking a steel wire rope with a diameter d1 of 2 mm as an example, the groove depth h of the U-shaped sheave can be taken as 4 mm, and the displacement x of the steel bar blocking slider can be taken as 15 mm. As shown in Figure 6, the swing angle range of the rocker at the steel bar sealing device is 0°~63.73°.

Figure 6. The maximum swing angle of the rocker
According to the dimensions and formula (1) given above, the outer diameter D1 of the U-shaped wheel is 32.971mm, and the upward roundness D1=33mm.
Regardless of whether the mold is set manually or by the robot, the side mould needs to be lifted onto the mold table to be fixed. However, in the process of lifting and placing, if the rigidity of the side mould body is not enough to cause excessive bending deformation, it will cause damage to the reinforcement hole sealing device, demoulding device, fixing device, etc. on the side mould, and even affect the following Placement accuracy. Therefore, it is necessary to check the rigidity of the side mould. According to the description of "Minimum Thickness of Concrete Protective Layer" in GB50010-2010 "Code for Design of Concrete Structures", the thickness \( c \) of the reinforced concrete protective layer of the floor of civil buildings with a design period of 50 years may be 20 mm.

According to the calculation of the reinforcement of the floor slab, the rebar spacing in the floor slab \( d_2 = 200 \text{mm} \) and the diameter of the steel bar \( \varphi = 8 \text{mm} \) are used as an example for verification. The main material of the side mould adopts L100*80*6 unequal angle steel, the length \( l \) is 2200mm, and the U-shaped slot is opened on the angle steel to meet the requirements of the exposed steel bars, then the distance between the center of the reinforcement holes at both ends of the side mould and the edge of the side mould for:

\[
D_2 = \frac{\varphi}{2} + c = \frac{8}{2} + 20 = 24 \text{mm}
\]  

(2)

Because the short side of the angle steel is cut, the rigidity of the angle steel will be reduced. The short side of the angle steel may be reduced from the original 80mm to 36mm. The cross-sectional characteristics are calculated from the cross-sectional shape of the angle steel, and the required moment of inertia \( I \) is 6.026 cm\(^4\).

The main body of the side mould and the arrangement of the plugging device, the demoulding device and the fixing device of the reinforcement hole can be simplified into a uniform load. The mass of the main body of the side mould is calculated according to the theoretical mass of this type of angle steel 8.350 kg/m, and the result is multiplied by a safety factor of 2.0 to obtain the total mass of the side mould.

\[
m_{\text{side mould}} = m_{\text{Theoretical value}} \times l = 18.37 \text{kg}
\]

(3)

\[
m_{\text{side mould}} = m_{\text{Body}} \times 2.0 = 36.74 \text{kg}
\]

(4)

When the side form is lifted, it can be reduced to the form of simply supported beam, and the uniform load on it is:

\[
q = \frac{mg}{l} = 163.66 \frac{N}{m}
\]

(5)

The deflection curve equation and end section angle of the bending deformation of the side mode are obtained from this:

\[
\omega = -\frac{ql^3}{24EI} \left( l^3 - 2lx^2 + x^3 \right)
\]

(6)

\[
\theta_A = -\theta_B = -\frac{ql^3}{24EI} = -5.74 \times 10^{-3} \text{ rad}
\]

(7)

According to formula (6), the maximum deflection of the side mould is obtained:

\[
\omega_{\text{max}} = -\frac{5ql^3}{384EI} = 3.94 \text{mm}
\]

(8)

According to the analysis of the obtained results, the bending deformation of the side mould is not large, so the rigidity of the side mould meets the production requirements.

5. Conclusion

This article takes PC component side mould as the research object and innovates the side mould structure based on TRIZ theory. The aluminum alloy sealing device is used to connect the steel wire
rope to complete the sealing operation of the steel bar hole, so as to solve the problem of the side mould leakage. The innovative design of the side mould demoulding device and the fixing device respectively uses the incomplete model and the harmful complete model in the object field model; the combination of the magnet suction cup and the lever of the end effector of the mold-setting robot is used, and the magnetic base is used to replace the permanent magnet to fix the Side mold on the mold table, the two act synchronously to overcome the demolding resistance and effectively extend the service life of the side mould. The innovative design of the side mould structure based on the TRIZ theory uses a double rocker mechanism to combine the reinforcement hole sealing device and the mold removal device to realize the linkage operation. The calculation and verification of the side mould verify that the stiffness of the side mould meets the production requirements, which has reference value for the research of PC component side mode.

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