Optimal design of concrete automatic distribution system for digital manufacturing

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Abstract. Concrete distribution system is an important production equipment to realize the development of prefabricated buildings. In order to realize the development of building industrialization and residential industrialization, considering the problems of intelligent and low automation of concrete distribution system, by perfecting the structural design of automatic distribution system, it is oriented towards digitalization. Manufacture, analyze and select the control of the opening of the distribution valve and the parameters of the distribution shaft, and put forward measures to optimize the overall mechanical structure of the distribution hopper of the distribution machine; establish the relationship model of the hopper moving speed of the concrete distribution machine, the speed of the spiral distribution shaft and the thickness of the distribution, to complete the optimal design of the motion parameters of the concrete distribution system. Based on the finite element analysis of the supporting beams, the feasibility and effectiveness of the overall optimal design of the concrete automatic distribution system were verified.

1. Introduction
With the development of the construction industry, the traditional on-site construction method in the construction industry has gradually transformed into a prefabricated method of "factory production and on-site installation", realizing the transition from semi-manual and semi-mechanized to modern concrete production [1]. In the production process of PC components (prefabricated concrete components) of prefabricated buildings, the concrete distribution system plays a vital role. The current distribution production process is mostly realized by manually inputting the distribution area, and the degree of automation and production efficiency are low. The process from CAD drawings to automated and intelligent cloth has not yet been fully realized.

At present, prefabricated buildings are entering a period of rapid development, and the demand for PC components is showing an explosive growth trend. For the problems faced by PC components in production methods and development processes, there are different domestic and foreign automatic distribution systems for PC components. The study. The production technology and production equipment of PC components are relatively mature in some developed countries, and the production process has basically realized intelligent control, factory and standardized production; compared with foreign automatic precision cloth distribution systems, domestic distribution of PC components is automatic. The research of the system is still in the exploratory stage. Although some enterprises have produced relatively perfect product equipment, the concrete distribution system is still a combination
of man and machine, which makes it difficult to realize the automatic and intelligent production mode of the distribution system[2].

The concrete distributing machine uniformly pours the concrete on the mold table where the side mold has been placed according to the performance requirements of the PC components such as the strength during the construction process. This paper is directed to the digitally-manufactured concrete automatic distribution system. It is improved on the basis of the traditional distribution machine structure, and further improves the distribution machine structure model. It optimizes the design of the distribution machine flow rate and distribution shaft speed to improve the production efficiency and production environment of prefabricated components.

2. Structural design of concrete distribution system

The digital automatic cloth distributing system is a concrete cloth distributing mechanism that applies intelligent robots in the industry to the production process of PC components. The use of the digital automatic cloth distribution system improves the efficiency of pouring concrete prefabricated components, accelerates the process of prefabricated construction, and saves various construction resources to the greatest extent. As the core equipment of the entire PC production line, the concrete distributing machine must accurately control the amount of material discharged, otherwise it will cause the entire PC component to be abandoned or the concrete to overflow to the mold table to cause waste of materials and affect subsequent work; to prevent the distribution of concrete if it is uneven, the placement position of the distributing machine should be ensured to avoid the difficulty of vibrating due to too small pouring range[3].

The concrete distributing machine is equipped with several measuring mechanisms on the distributing port, and its structural composition includes the concrete vibrating mechanism and the concrete distributing device, the distributing measuring and positioning mechanism, the X and Y direction motion driving device, the Z direction lifting mechanism and the spiral distributing device. Control system, etc. According to the requirement that the size of the bottom mold is 9m×4m and two components can be produced at the same time, the effective moving range of the distribution system of the distribution machine is designed to be 6m×10m[4]. The overall mechanical structure of the concrete distributor is shown in Figure 1.

![Figure 1. Schematic diagram of the overall structure of the cloth machine](image)

The effective volume of the hopper of the concrete automatic cloth distributor is 2.5m³. Based on the calculation of production capacity and a certain security room project (when a specific project is involved, it may change within a certain range due to the form of component splitting). It is 2.0m³/block, which meets the amount of concrete needed for the primary distribution of the production line. The distribution hopper adopts a V-shaped funnel design, which is suitable for concrete of different slump models, while reducing the deformation of the concrete distribution hopper[5]. During the distribution process, the lifting and lowering functions can be used to complete the rise and fall. After the concrete in the distribution bucket is used, the concrete transport trolley moves above the distribution bucket, and the concrete in the vehicle is poured into the distribution bucket when the
initial set capacity is reached. After that, the cloth hopper will drop to the distance set by the concrete slump to complete the cloth distribution process. The structure diagram of the cloth hopper is shown in Figure 2.

According to the on-site construction distributing technology, the concrete distributing machine can flexibly adjust the walking and distributing speed. The distributing speed is the rotation speed of the spiral distributing shaft, and its feeding volume is uniform and stable, which is convenient for the calculation of accurate feeding volume and ensures that the control accuracy of concrete materials is not greater than 0.01, the cloth thickness accuracy is ±2mm; the concrete cloth valve opening and closing device is installed at the lower part of the side of the cloth hopper, under the rotation of the spiral cloth shaft, according to the required cloth thickness, the opening degree of the cloth valve can be controlled to realize the cloth effective control of accuracy[6~7]. The opening and closing device of the concrete cloth valve is shown in Figure 3.

3. Optimal design of concrete distribution system parameters

To realize the automatic distribution of concrete, it is necessary to not only quantify the concrete in the distribution bucket, but also consider how the concrete is output. This system selects the distribution shaft of the concrete distributing machine as the research object, and establishes the relationship model of the moving speed of the hopper of the distributing machine, the speed of the distribution shaft and the thickness of the distribution. The key index that determines the performance of the spiral cloth shaft is the spiral productivity[8]. The main parameters that affect its size are the spiral speed, spiral outer diameter, and pitch. According to the technical parameter table, the distribution speed of the distribution shaft is 0~25r/min, the distribution width of the distribution machine is 1.5m, the distribution power is 4kw, and the distribution shaft length is 1.15m. Through the analysis of the above parameters, the initial value of the pitch is $s = 0.8D$ based on the results of the spiral kinematics analysis.

Establish the relationship model between the moving speed of the cloth bucket, the speed of the cloth shaft and the thickness of the cloth as follows:

(1) The concrete slump of the experimental data is based on $H_t$, and the concrete slump measured in actual production is $H_c$, then the concrete slump coefficient of the test is $\frac{H_c}{H_t}$. (Slump is between 100~150)

(2) Assume that the volume of concrete pushed out once by the rotation of the cloth axis is $W_0$ ($s$ is the lead of the spiral cloth axis is 12cm, $R$ is the outer radius of the spiral cloth axis is 7.5cm, $r$ is the inner radius of the spiral cloth axis is 2.5cm), According to the formula:

$$W_0 = \pi \left( R^2 - r^2 \right) \frac{k}{r} = 0.0019 m^3 / r \quad (1)$$

There are many factors that affect the volume error. In this section, the slump of concrete is mainly considered. The slump of the concrete when the introduced volume is $W_0$ is $H_t$. When $X<1$, it means
that the actual measured $H_c$ is smaller than the theoretical slump $H_t$ at this time, and the volume pushed out by the distribution axis is less than that of $W_0$. On the contrary, the volume pushed out by the distributing shaft is more than that of $W_0$. It is stipulated that the correction coefficient of the concrete volume pushed out by one rotation of the distribution axis is $\theta$, then the actual pushed-out volume $W_1$ is:

$$W_1 = (1 + \theta)W_0$$

(2) When the slump coefficient $X < 1$, $\theta$ is a negative value, and when the slump coefficient $X > 1$, $\theta$ is a positive value.

(3) Assuming that the concrete material falls on a fixed width mold table, its width is set to $d$ (considering that the factory generally takes a width of 10 cm when verifying the rationality).

(4) Assuming that the vibration link is omitted after the concrete cloth, the thickness of the cloth is uniform, and the height is $h$ everywhere.

On the basis of confirming that the above four assumptions are established, the moving distance of the concrete distribution hopper is $L$ (cm) within a certain time, and the total blanking volume of the distribution machine is:

$$V_{\text{Total, Capacity}} = hLd = (1 + \theta)W_0Xn_{\text{cloth, shaft}}t$$

(3) Take the different frequency corresponding to the speed $n$ of the distribution shaft for speed measurement. It is known that the reduction ratio of the reduction motor of the distribution shaft is $k_1$, the rated speed is $n_{01}$, and the factory power frequency is 50Hz. When the frequency is $f_1$, the rotation speed of the distribution shaft is:

$$n_{\text{cloth, shaft}} = \frac{n_{01}}{60k_1} \cdot \frac{f_{\text{Axis, 1}}}{50}$$

(4) The speed of the hopper moving speed $v$ is corresponding to different frequencies for speed measurement. It is known that the reduction ratio of the hopper moving reduction motor is $k_2$, the rated speed is $n_{02}$, the factory electrical frequency is 50Hz, and the moving roller radius of the hopper cart is 12.5, when the frequency is $f_1$ The moving speed of the hopper is:

$$v_{\text{Hopper}} = 2\pi \cdot \frac{n_{02}}{60k_2} \cdot \frac{f_1}{50} \cdot r_{\text{Roller}}$$

(5) By changing the rotation speed $n$ of the spiral distribution shaft and the moving speed $v$ of the distribution bucket, the volume of the material distributing unit of the distribution machine per unit time is the distribution productivity of the concrete distribution machine $\eta$:

$$\eta = \frac{V_t}{t} = \frac{(1 + \theta)W_0Xn + hdv}{t}$$

(6) The cloth shaft reducer adopts the model K37-49.79/Y0.55-4/M4/R/A, its reduction ratio is 49.97, the motor rated speed is $n_{01}=1390r/min$, and the factory power is 50Hz, when the frequency is $f = 30Hz$, the speed of the cloth shaft $n=16.39r/min$. The reduction ratio of the hopper moving reduction motor of the concrete placing machine is 44.32, the rated speed of the motor is $n_{02}=1420r/min$, the power frequency of the preform factory is 50Hz, and the radius of the moving roller of the hopper trolley is $r=12.5cm$, then when the frequency is $f=30Hz$ When the hopper moving speed $v$ hopper$=0.252m/s$. Under the assumption that the cloth opening width $d$ is 10cm, the cloth efficiency of the concrete placing machine $\eta=0.1061m^3/min$; if the actual cloth width $d=15cm$, the cloth efficiency $\eta=1.376m^3/min$. According to the data reference materials, if the cloth mold table is 4m×9m and the cloth height $h$ is 12cm, the cloth time $t=3.14min$, and the design cycle of the PC component production
line is 15min, and the average production time per station is about 5min. Therefore, the optimized spiral distribution shaft structure improves the production efficiency of precast concrete components.

4. Checking the strength of the supporting beam of concrete distribution system

The guide rail support beam of the concrete automatic distribution system needs to bear greater force, and at the same time, the distance between the guide rails is longer. Therefore, the finite element analysis of the guide rail support beam of the distribution machine is required, and the static beam analysis and calculation of the support beam model based on the finite element software. The material of the guide rail supporting beam of the distributor is ordinary carbon steel Q235, and a load of 32000N is applied on the upper surface, and constraints are imposed according to the actual situation, and then the force and deformation of the guide rail supporting beam are analyzed, and the grid is generated. The stress and displacement are calculated, and the corresponding conclusions are drawn from the stress cloud diagram and deformation cloud diagram of the support beam. The specific finite element analysis results of the guide rail support beam are shown in Figure 4.

![Stress analysis of supporting beam](a)
![Support beam displacement analysis](b)

Figure 4. Finite element analysis results of guide rail support beam

Through the stress analysis and displacement analysis of the guide rail support beam, it can be seen that the maximum amount of displacement (that is, the most dangerous change) of the guide rail support beam is 1.89456mm, and the position where the maximum displacement occurs (that is, the guide rail support beam is the most dangerous place) in the middle of the support beam of the guide rail, the yield force of the material less than Q235 is 282685049N/m², which is far less than the yield limit of the ordinary carbon steel Q235 material. Based on the finite element analysis of the support beams of the guide rails, the rationality of the design of the support beams of the concrete automatic distribution system is verified, so that it can effectively increase the load bearing of the distribution machine and meet the requirements of the system.

5. Conclusion

This article takes the PC components of the prefabricated building as the background and faces the digital manufacturing technology to realize the optimal design of the concrete automatic distribution system. According to the overall scheme design of the concrete automatic distribution system model, the installation position of the components and the main parameters of the distribution system are determined, the selection and design of the opening method and structure of the distribution valve are completed, and the parameter optimization design of the spiral distribution axis of the distribution bucket is completed. Through the analysis of flow control, rotation speed control and supporting beam strength during cloth distribution, the optimized design scheme is verified, which has reference value for the research of concrete automatic cloth distribution system.

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