Structural design of spiral blade of concrete mixer truck

Zhao lu-yan*, Li Pengb, Liu Fu-xiu

(Ocean Engineering College, Guilin University of Electronic Technology, Beihai, Guangxi, 536000, China)

*aemail: zhaoluyan@guet.edu.cn, bemail:lip@guet.edu.cn, cemail: lpwr@163.com

Abstract. This article takes a concrete mixer truck actually produced by an enterprise as an example. According to the functions of the three-part spiral blades of the front cone, cylinder, and tail of the mixing drum, combined with theoretical knowledge, the Pro/E software is used to realize the re-realization of the blade spiral design. A spiral line that is more in line with actual working conditions is derived, which provides a theoretical basis for the design and modeling of spiral blades of concrete mixer trucks.

1. Introduction
As the core component of the concrete mixer truck, the spiral blade of the mixing drum has a direct impact on the mixing performance and discharge performance of the tank. How to ensure the homogeneity and non-segregation of concrete, and to ensure continuous and rapid feeding and discharging of materials, has an important relationship with the spiral line type and spiral angle parameters.

2. Linear design of the mixing drum spiral
According to the requirements of GB/T26408-2011, the mixer truck in our country is in a right-handed mixing mode, so the spiral blade needs to be left-handed. At present, there are two types of curves commonly used in the mixing drum of concrete mixer trucks, Archimedes spiral curve and logarithmic spiral curve.

Archimedes spiral curve, that is equal pitch spiral curve. The characteristic of the curved blade is that the pitch of the blade spirally surrounding the drum wall in the direction of the axis of the mixing drum remains unchanged, but the helix angle of the blade changes inversely proportional to the diameter of the cross section of the mixing drum. If the rise angle of the blade curve is selected according to the working requirements of the mixing section, the spiral rise angle of the blade entering the discharge section will become larger and larger with the shrinkage of the mixing section, which is contrary to the results of the previous analysis. Therefore, the discharge performance may be deteriorated; If the blade helix angle is selected according to the work requirements of the discharge section, the blade helix angle of the mixing section will be too small, and the mixing quality may not be guaranteed. Therefore, when the Archimedean spiral curve is used as the blade curve, it is easy to take into account the situation of mixing and unloading performance.

Logarithmic spiral curve, that is, spiral curve with equal angle of rise. The spiral angle of this blade is always constant, but the pitch changes proportionally with the diameter of the mixing drum. Although the blade spacing in the discharge section is smaller than that in the mixing section, the design is appropriate Does not affect the discharge performance. It is easier to take into account the
performance requirements of mixing and unloading by adopting this kind of spiral curve blades and selecting a moderate spiral angle. It is used more in large-capacity mixer trucks.

The mixing and discharging performance of the mixing drum is closely related to the helix angle and helix angle of the spiral. The mixing drum is placed at a certain angle, as shown in Figure 1. $\alpha$ is the helix angle of the blade curve around the axis of the mixing drum, and there is a relationship between it and the spiral angle: $\alpha + \beta = 90^\circ$. The larger the helix angle, the better the mixing performance, but the worse the discharge performance. With the increase of the helix angle, the friction force of the concrete sliding along the blades increases accordingly. After reaching a certain level, it is easy to cause the siltation of the concrete on the blades, which will hinder the movement and reduce the mixing efficiency, especially in the unloading conditions. Blockage caused by siltation will make unloading difficult. When tends to $\alpha=90$ degrees, that is, the blade is approximately parallel to the stirring axis, at this time, the blade has almost no axial displacement effect on the concrete like a self-falling mixer, and thus loses discharge. However, in order to avoid the accumulation of the front cone and improve the discharge performance, the helix angle at the small end should be reduced, but the helix angle should not be too small. When the helix angle is small, the blade is almost perpendicular to the mixing axis, and the concrete is axially in the rotating mixing drum. The movement is very small, which is similar to only sliding along the tangential direction of the leaf. In this case, not only the stirring effect is weak, but also the actual discharge capacity is not available.

Based on the above description, the spiral is divided into three segments, and each segment of the spiral should meet the following requirements:

- The front cone spiral blade is mainly to achieve the mixing function, and the spiral rise angle should be increased as much as possible under the premise of meeting the material decline. However, in order to avoid the front cone accumulation and improve the discharge performance, the spiral rise angle at the small end should be reduced.

- The cylindrical section is the transition section between mixing and discharging, which plays a guiding role and takes into account the mixing and mixing functions. Generally, in order to improve the mixing performance, the helix angle of the tip of the spiral blade can be appropriately increased. In order to improve the discharge performance, the spiral blade should have a certain angle with the axis of the mixing drum. This included angle is equal to the complementary angle of the half cone angle of the front cone.

- The back cone spiral blade realizes rapid discharge and has a certain mixing effect to avoid segregation during discharge. The closer to the outlet, the larger the spiral angle, that is, the small helix angle, can improve the discharge performance of the mixing drum.
3. Derivation of the spiral equation formula

Fig. 2 is a schematic diagram of spiral calculation cone, according to the spiral equation:

\[
\begin{align*}
    x &= \rho \cos \theta \sin \alpha \\
    y &= \rho \sin \theta \sin \alpha \\
    z &= \rho \cos \alpha \\
    \rho_1 &= (d_1/2 \sin \alpha) \exp \theta \sin \alpha / \tan \beta
\end{align*}
\]

(1)

Among, \(\alpha\) is the half cone apex angle; \(\beta\) is the helix angle; \(\theta\) is the helix rotation angle; \(\rho_1\) is the initial pole diameter. When \(\rho_1\) is a fixed value, equation is an equiangular logarithmic spiral; when \(\beta\) is a variable, equation is an equiangular logarithmic spiral, \(\beta\) can be changed according to a variety of functional relationships. The value range of \(\theta\) is \(0 \leq \theta \leq \tan \beta \cdot \ln \left(\frac{d_1}{d_2}\right)/\sin \alpha\).

When \(\beta\) is a variable, equation (1) is a non-equal-angle logarithmic helix. The disadvantage is that the helix angle cannot be changed according to the given functional relationship, and the helix angle cannot be controlled. In order to accurately control the change of helix angle, make the helix meet the design requirements. Need to re-derive the logarithmic spiral formula.

The geometric relationship in Fig. 2 is:

\[
\begin{align*}
    d \rho / dl &= \cot \beta \\
    dl &= r d\theta \\
    r &= \rho \sin \alpha
\end{align*}
\]

Organized:

\[
d \rho / \rho \sin \alpha d\theta = \cot \beta
\]

(2)

First, discuss the situation when it is a constant. After finishing formula (2) and integrating on both sides, we get:

\[
\ln \rho = (\theta + \theta_0) \cot \beta \sin \alpha
\]

(3)

In the formula, \(\theta_0\) is the integral constant, find from the boundary conditions: When \(\rho = \rho_1\), \(\theta = 0\), bring \(\rho\) into Equation (3) to get \(\theta_0 = \ln \rho_1/((\cot \beta \sin \alpha))\), Then the formula (3) can be expressed as:

\[
\rho = \rho_1 \exp(\theta \sin \alpha / \tan \beta)
\]

(4)

When \(\rho = \rho_2\), get \(\theta = \theta_{\text{max}}\), at the same time, bring \(\theta_0 = \ln \rho_1/((\cot \beta \sin \alpha))\) into equation (3) to get:

\[
\theta_{\text{max}} = \tan \beta \ln(\rho_2/\rho_1)/\sin \alpha = \tan \beta \ln(d_1/d_2)/\sin \alpha
\]

(5)

Equation (4) is the polar coordinate equation of the spiral on the frustum when \(\beta\) is a constant, which is a logarithmic spiral, and equation (5) is the maximum helix angle of the spiral.
If $\beta$ changes linearly with $\theta$, $\beta$ can be expressed as

$$\beta = \beta_1 + \frac{(\beta_2 - \beta_1)\theta}{\theta_{\max}}$$  \hspace{1cm} (6)

Bring the formula (6) into the formula (2) to sort and integrate on both sides to obtain:

$$\ln \rho = \frac{\theta_{\max} \sin \alpha}{\beta_2 - \beta_1} \ln[\sin(\beta_1 + \frac{(\beta_2 - \beta_1)\theta}{\theta_{\max}})] + c$$  \hspace{1cm} (7)

Using boundary conditions, $c$ can be obtained:

$$c = \ln \rho_1 - \frac{\theta_{\max} \sin \alpha}{\beta_1 - \beta_2} \ln(\sin \beta_1)$$  \hspace{1cm} (8)

Substituting formula (8) into formula (7), we obtain the equilateral angle logarithmic spiral polar coordinate equation when $\beta$ changes linearly with $\theta$:

$$\rho = \rho_1 [\frac{1}{\sin \beta_1} \sin(\beta_1 + \frac{(\beta_2 - \beta_1)\theta}{\theta_{\max}})]^{\theta_{\max} \sin \alpha / (\beta_2 - \beta_1)}$$  \hspace{1cm} (9)

When $\theta = \theta_{\max}$, get $\rho = \rho_2$, bring into formula (7) together with $C$ to get the maximum helix angle:

$$\theta_{\max} = \frac{(\beta_2 - \beta_1) \ln(\rho_2 / \rho_1)}{\sin \alpha \ln(\sin \beta_2 / \sin \beta_1)} = \frac{(\beta_2 - \beta_1) \ln(d_2 / d_1)}{\sin \alpha \ln(\sin \beta_2 / \sin \beta_1)}$$  \hspace{1cm} (10)

After derivation, the equilateral angle logarithmic spiral equation expressed by truncated cone parameters can be expressed as:

$$\begin{cases}
  x = \rho_1 \cos \theta \sin \alpha \\
  y = \rho_1 \sin \theta \sin \alpha \\
  z = \rho_1 \cos \alpha \\
  \rho_1 = (d_1 / 2 \sin \alpha)(\sin \beta / \sin \beta_1)^{\theta_{\max} \sin \alpha / (\beta_2 - \beta_1)}
\end{cases}$$  \hspace{1cm} (11)

Through the above parameterized equations, the relationship parameter expressions are written in the Pro/E software, and the blade spiral CAE model is designed through the hybrid scanning function, as shown in Fig. 3.

![Fig. 3 CAE model of blade helix](image)

4. Conclusion
The paper takes a concrete mixer truck actually produced by an enterprise as an example. According to the functional characteristics of the three-part spiral blades of the front cone, cylinder and tail of the mixing drum, combined with theoretical knowledge, the spiral equation is re-introduced and the Pro/E
software is used. Realize the re-modeling and design of the blade helix. A spiral line that is more in line with actual working conditions is derived, which provides a theoretical basis for the design and modeling of spiral blades of concrete mixer trucks.

References

[1] Maria Cristina Valigi, Silvia Logozzo, Mirko Rinci. Wear resistance of blades in planetary concrete mixers. Design of a new improved blade shape and 2D validation [J]. Tribology International, 2016, 96.

[2] An Lin Wang, Fan Li, Peng Yu Zan. The Method of Parametric Design of Mixing Blades Based on Subdividing Functions [J]. Advanced Materials Research, 2011, 1335.

[3] Chandratilleke G R, Yu A B, Steewart R L, et al. Effect of blade rake angle and gap on particle mixing in a cylindrical mixer, Power Technology, 2009, 303-311.

[4] Li Z. Bleeding model of fresh concrete in still state [J]. Journal of Structural and Construction Engineering, 2012, 77(679): 1357-1366.

[5] Gabriel Fedorko, Jan Kral, Jan Kral, Ivica Ristovic, Vieroslav Molnar. Determination of Calculation for the Shape of Blades Trace in the Concrete Mixer Truck [J]. Procedia Technology, 2015, 19.

[6] Sun Li, Chen Nan, Liu Yongchen. Optimization Design for Auxiliary Frame Oblique Support of Concrete Mixer Truck [J]. International Journal of Earth Sciences and Engineering, 2016, 9(4).

[7] Yu Liang Chen, Yong You Du, Zhao Huan Jia, Wei Zhao. Design of Digital Display Control Devise System for Concrete Mixer Truck [J]. Applied Mechanics and Materials, 2011, 1245.