Research on anti-swing control of tower crane with lifting weight swing function

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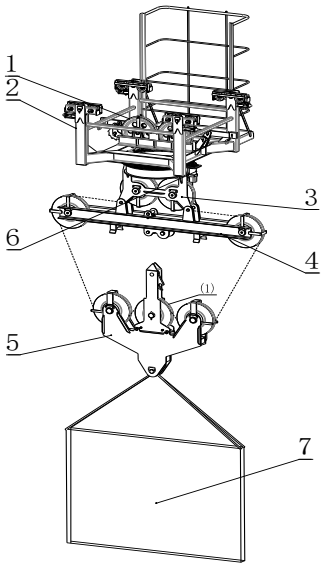
Abstract. In order to ensure the accurate positioning of the assembly building, a swing trolley with swing function is designed. In order to solve the swing angle difference generated in the process of adjusting and positioning of the swing trolley, a simplified model is established to analyze the force and establish the relationship between the angular acceleration of the lower lifting beam and the angle of the swing. Secondly, the kinematic analysis is carried out for the rotating pendulum trolley, and its motion model is analyzed under uniform acceleration braking, uniform speed running and uniform deceleration braking. Finally, the angle difference of the rotating pendulum is gradually increasing in the case of different angular acceleration by example. And the variation of the rotating pendulum angle difference in different processes, laying the foundation for subsequent control studies.

Keywords: Tower crane; swinging trolley; angular position difference; control.

1. Introduction

Assembled buildings are currently strongly promoted by the national strategy, which has also seen significant modifications in construction equipment, particularly the tower crane, which has high criteria [1]. It is essential to guarantee that the lifting equipment type building can be positioned steadily while tower cranes are in use. The swing trolley developed [2] for the precise positioning of the assembly building has a rotary function that, in contrast to the traditional luffing trolley, enables the lower part of the swing trolley to achieve plus or minus 90° rotation in accordance with the actual construction requirements on the presumption of meeting the up and down lifting and horizontal luffing, and swinging to realize the process of adjusting the posing, as shown in Figure 1.

Because the slewing support of the slewing trolley may be positioned in an attitude adjustment and the steel wire rope's elasticity allows the heavy object to swing back and forth freely, the tower crane with slewing function differs from a standard tower crane. Based on this, a kinematics analysis of the swing angle yielded the results of this study. This study is based on the kinematic analysis-generated swing angle. Additionally, the swinging motion of the swinging trolley is examined in order to create a model and offer fresh control strategies for the eventual halting of the upper slewing support and the consequent swinging of the lower lifting weight. to serve as a guide for enhancing the placement and posture-adjustment of equipped buildings' operational effectiveness. Studying the stable pendulum control of tower cranes with swinging functions is therefore practical.



1. Guide pulley;2. Small car frame;3. Rotating frame;4. Support beam;5. Lifting beam;6. Slewing support;7. Heavy loads.

Figure 1. Example of a figure caption.

2. Rotating pendulum trolley motion characteristics analysis

2.1. Model of the spinning pendulum cart simplified

As a typical under-driven mechanical system, the tower crane system's swing function is made more complex by the system's own internal workings as well as changes to the external environment. Since the tower crane's swing function differs from that of a standard tower crane in that the swing trolley's slewing bearing can be adjusted for posture and the wire rope's flexibility makes it easy for the weight to produce the swing's front and back, conducting a stable swing analysis is important from a practical standpoint.

The author assumes the following assumptions in order to simplify the study and take into account how the tower crane swing placement actually functions.

(1) When creating the mechanical model, the motion of the trolley mechanism is not taken into account to simplify the study.

(2) Do not factor in the wire rope's elastic deflection or the impact of air resistance when calculating the mass of the wire rope.

A simple mechanical model of the system is established based on the upper swing trolley movement of the rotational support posture of the force condition, as shown in Fig. 2 and 3.

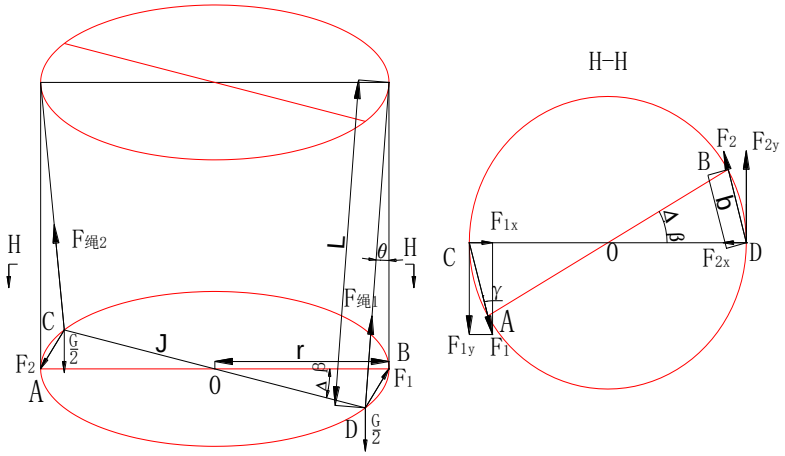


Figure 2. Simplified mechanical model of rotating pendulum trolley.

In Fig. 2, the wire rope L, which denotes the wire rope's length, connects the lifting weight to the slewing support of the swing trolley at both ends. The lower lifting beam and the weight are driven to follow the upper swing trolley slewing bearing throughout the swinging motion due to the different angular acceleration of the upper and lower, which results in the angular difference between the upper and lower rotation and the swing angle. The weight swings as a result of the rope's pulling force which produces the torque of the swing in the tangential direction of the cutting force in the plane of the weight.

2.2. Force analysis for systems

Tower cranes with the ability to swing out play a significant part in the placement process as prefabricated components. A very intricate non-linear system is used to place the tower crane's swing, and flexible connections are used to distribute the crane's weight among the trolley. Additionally, the crane weight achieves plus or minus 90° rotation placement using the bottom swing trolley swing mechanism.

According to Fig. 2, the lower lifting beam follows the upper swing support beam's uniform acceleration movement because of the lower two wire rope's different angular acceleration and the upper swing mechanism's creation of an angular difference, which allows the component's gravity and the tension of the two wire rope to balance.

$$F_1 = F_2 = \frac{mg}{2\cos\theta} \tag{1}$$

The cutting force necessary for the lifting beam and weight movement, as well as the rotating movement of the top support beam of the rotary trolley is

$$F_1 = F_2 = \frac{1}{2} mg \tan\theta \tag{2}$$

Based on the geometric relationship shown in Fig. 2. It is possible to discern the link between and.

$$\gamma = \frac{\pi}{2} - \frac{\pi - \Delta\beta}{2} = \frac{\Delta\beta}{2} \tag{3}$$

$$\begin{cases} \dfrac{b}{\sin\Delta\beta} = \dfrac{r}{\sin\left(\dfrac{\pi-\Delta\beta}{2}\right)} = \dfrac{r}{\cos\gamma} = \dfrac{r}{\cos\dfrac{\Delta\beta}{2}} \\ \dfrac{b}{L} = \sin\theta \end{cases} \tag{4}$$

Then

$$\sin\theta = \frac{r\sin\Delta\beta}{L\cos\dfrac{\Delta\beta}{2}} \tag{5}$$

So it can be found that

$$\tan\theta = \frac{r\sin\beta}{\sqrt{(L\cos\dfrac{\beta}{2})^2 - (r\sin\beta)^2}} \tag{6}$$

The component of the cutting force in the tangential direction provides the momentum in the motion of the spinning pendulum as

$$F_{1y} = F_{2y} = \frac{1}{2} mg \tan\theta\cos\gamma = \frac{1}{2} mg \tan\theta\cos\frac{\Delta\beta}{2} \tag{7}$$

The two forces F_{1y} and F_{2y} together constitute the moment, then the moment of momentum to the z-axis is

$$J_2\varepsilon = \sum M(F) \tag{8}$$

Then

$$J_2\varepsilon_2 = F_{1y} \cdot 2r = mgr\tan\theta\cos\frac{\beta}{2} \tag{9}$$

So the relationship between the angular acceleration of the lower lifting beam and the rotation angle difference is shown as follows.

$$\varepsilon_2 = \frac{mgr^2 \sin\Delta\beta\cos\frac{\Delta\beta}{2}}{J\sqrt{(L\cos\frac{\Delta\beta}{2})^2 - (r\sin\Delta\beta)^2}} \tag{10}$$

The meaning of each parameter is shown below.

m--mass of the lower lifting beam and the lifting weight; --mass of the lower lifting beam and the lifting weight

r --the radius of rotation of the lower lifting beam

J --The rotational inertia of the lower lifting beam and the lifting weight

L --the length of the lifting wire rope between the upper and lower rotating beams

ε_2--Angular acceleration of the lower lifting beam.

θ-- lower lifting beam deflection angle.

Δβ-- lower lifting beam and the upper support beam rotation angle difference.

3. Kinematic analysis of rotating pendulum trolley

Due to the complexity of the lower lifting beam's angular acceleration expression and the upper support beam's uniform acceleration, which drives the lower lifting beam's movement, see Fig. 3 for this paper's study of the lower lifting beam's angular acceleration linearization.

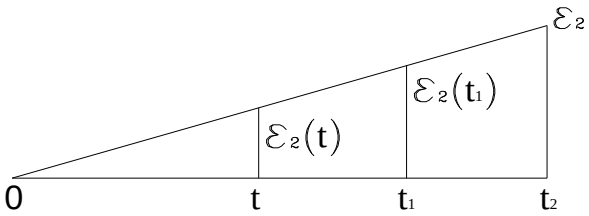


Figure 3. Lower lifting beam rotational angular acceleration model.

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The meaning of each parameter is shown below.

t_1—the acceleration time of the upper support beam

t_2--the acceleration time of the lower lifting beam

t_2- t_1 --the difference between the acceleration time of the upper support beam and the lower lifting beam

ε_1-- the angular acceleration of the upper support beam.

ω_1—the angular velocity of the upper support beam, $\omega 1 = \varepsilon_1 t_1$.

ε_2--the angular acceleration of the lower lifting beam.

According to the acceleration model of the lower lifting beam in Fig. 3, the acceleration of any point can be described as

$$\varepsilon_2(t) = \frac{\varepsilon_2 t}{t_2} \tag{11}$$

The angular velocity of the lower lifting beam at any given moment is indicated below.

$$\omega_2(t) = \int \varepsilon_2(t) dt = \int \frac{\varepsilon_2 t}{t_2} dt = \frac{\varepsilon_2 t^2}{2t_2} + c \tag{12}$$

When t=0, $\omega_2(t) = 0$, we can get c=0, substitute into (11) to get

$$\omega_2(t) = \frac{\varepsilon_2 t^2}{2t_2} \tag{13}$$

The angle of the lower lifting beam at any instant may be calculated by integrating the angular velocity of (12) at any point.

$$\beta_2(t) = \int \omega_2(t) dt = \int \frac{\varepsilon_2 t^2}{t_2} dt = \frac{\varepsilon_2 t^3}{6t_2} + c \tag{14}$$

When t = 0, θ=0, it is possible to obtain c = 0. Substitute in (13).

$$\beta_2(t) = \frac{\varepsilon_2 t^3}{6t_2} \tag{15}$$

Relate the angular acceleration of the lower lifting beam to the kinematic modeling

$$J_2 \frac{\varepsilon_2 t}{t_2} = \frac{mgr^2 \sin\Delta\beta \cos\frac{\Delta\beta}{2}}{\sqrt{(L\cos\frac{\Delta\beta}{2})^2 - (r\sin\Delta\beta)^2}} \tag{16}$$

At this point, the whole swing trolley swing attitude is divided into three stages, and the following analysis is made.

3.1. Uniform acceleration start

The upper support beam at any time, are related to the lower rotation angle acceleration of the beam.

When, at this time, the upper support beam to uniform acceleration to start, the lower lifting beam with the acceleration, at this time the lower lifting beam did not reach the maximum swing angle, the upper and lower beam rotation angle difference, and the relationship between the start time.

$$\beta_2(t) + \Delta\beta = \frac{1}{2}\varepsilon_1 t^2 \tag{17}$$

Substituting (14) and (15) yields

$$\frac{mgr^2 \sin\Delta\beta \cos\frac{\Delta\beta}{2} t^2}{6J_2\sqrt{(L\cos\frac{\Delta\beta}{2})^2 - (r\sin\Delta\beta)^2}} + \Delta\beta = \frac{1}{2}\varepsilon_1 t^2 \tag{18}$$

3.2. Uniform motion

When $t_1 < t < t_2$, the upper support beam rotation at a constant speed, the lower lifting beam first increases to the maximum swing angle and then back to swing, at this time in any time, the upper and lower beam rotation angular position difference Δ are with the lower rotation beam angular acceleration relationship is as follows.

$$\beta_2(t)+\Delta\beta=\frac{1}{2}\varepsilon_1 t_1^2+\omega_1(t-t_1) \tag{19}$$

Where $\omega_1(t)=\varepsilon_1 t_1$, substituting (14) and (15) yields.

$$\frac{mgr^2\sin\Delta\beta\cos\frac{\Delta\beta}{2}t^2}{6J_2\sqrt{(L\cos\frac{\Delta\beta}{2})^2-(r\sin\Delta\beta)^2}}+\Delta\beta=\frac{1}{2}\left(\varepsilon_1 t_1^2+2\varepsilon_1 t_1(t-t_1)\right) \tag{20}$$

3.3. Uniform deceleration brake

The upper support beam decelerates uniformly until it stops.

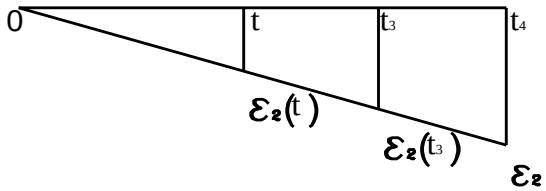


Figure 4. Lower lifting beam rotational angular acceleration.

The meaning of each parameter is shown below:

t_3 - the upper support beam deceleration time;

t_4 - the lower lifting beam deceleration time.

According to the acceleration model of the lower lifting beam in Fig. 4, the acceleration of any point can be described as in:

$$\varepsilon_2(t)=\frac{\varepsilon_2 t}{t_4} \tag{21}$$

When $t_2 < t < t_3$, at this time, the upper support beam starts with uniform deceleration; in the t_3 moment, the upper support beam deceleration stop. At this time, the lower lifting beam with the deceleration has not completely stopped, the upper and lower beam rotation angle difference Δ and the relationship between the braking time.

$$\beta_2(t)+\Delta\beta=\frac{1}{2}\varepsilon_1 t_1^2+\omega_1(t_2-t_1)+\omega_1(t-t_2)-\frac{1}{2}\varepsilon_1(t-t_2)^2 \tag{22}$$

Substituting $w_1(t)=\varepsilon_1.\ t_1$and (14) and (15) yields

$$\frac{mgr^2\sin\Delta\beta\cos\frac{\Delta\beta}{2}t^2}{6J_2\sqrt{(L\cos\frac{\Delta\beta}{2})^2-(r\sin\Delta\beta)^2}}+\Delta\beta=\frac{1}{2}\varepsilon_1 t_1^2+\varepsilon_1 t_1(t_2-t_1)-\frac{1}{2}\varepsilon_1(t-t_2)^2 \tag{23}$$

When $t_3 < t < t_4$, the upper support beam stops the movement, and the lower lifting beam continues to decelerate until it stops. At this time in any time, the upper and lower beam rotational angular position difference Δ are with the lower rotation beam angular acceleration relationship is as follows.

$$\beta_2(t)+\Delta\beta=\frac{1}{2}\varepsilon_1 t_1^2+\omega_1(t_2-t_1)-\frac{1}{2}\varepsilon_1(t_3-t_2)^2 \tag{24}$$

Substituting $w_1(t)=\varepsilon_1 . t_1$and (14) and (15) yields

$$\frac{mgr^2\sin\Delta\beta\cos\frac{\Delta\beta}{2}t^2}{6J_2\sqrt{(L\cos\frac{\Delta\beta}{2})^2-(r\sin\Delta\beta)^2}}+\Delta\beta=\frac{1}{2}\varepsilon_1 t_1^2+\varepsilon_1 t_1(t_2-t_1)-\frac{1}{2}\varepsilon_1(t_3-t_2)^2 \tag{25}$$

4. System simulation and analysis

In order to study the effect of different parameters on the angle of the rotating pendulum, the following parameters are set for its study. It is assumed that the initial relevant parameters of the tower crane model with rotating pendulum function are m=200kg, g=9.8m/s^2, J2=0.6kg.s^2, r=0.5m, ε=1rad/s^2; the initial rope length is L (0) = 80m.

4.1. Changes in the lower lifting beam's angular acceleration and their effects on the swing angle

Other parameters given values, changing the angular acceleration of the lower lifting beam, the relationship between the two can be obtained as shown in Fig. 5.

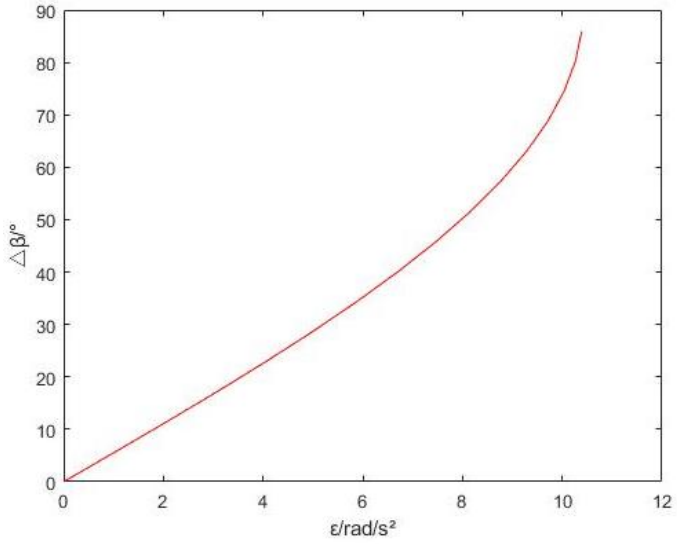


Figure 5. Angular acceleration of the lower lifting beam and the angular position difference between the upper and lower rotational pendulum.

You can see that as the lower lifting beam angle increases, the upper and lower beam swing angle difference gradually grows, but not by more than 90 degrees. As a result, you must choose an appropriate upper support beam acceleration to prevent a dangerously large upper and lower swing angle difference.

4.2. Motion process simulation and analysis

(1) In the uniform acceleration start-up phase, assuming t_1=3s, the angular position difference between the upper and lower crossbeam rotations with time can be obtained, as shown in Fig. 6.

With the change of time, the angular velocity of the upper support beam reaches the maximum at this time, and the angular position difference of the upper and lower beam swing Δβ gradually increases, reaching $\Delta\beta_{max}$=15.69° at this time.

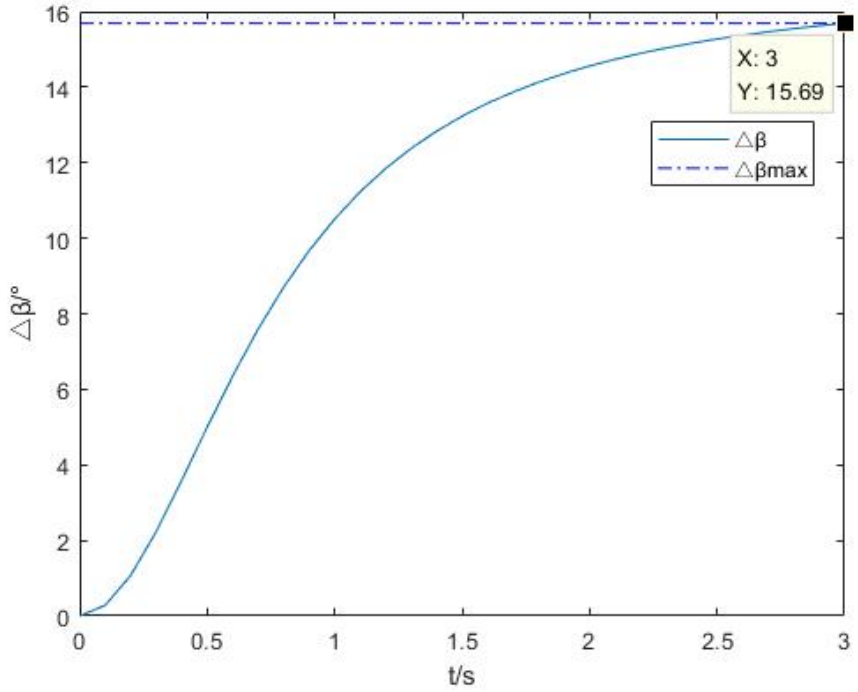


Figure 6. The time variation of the angular position difference between the upper and lower beam rotational pendulum during uniform acceleration.

(2) In the uniform velocity stage, assuming t_2=10s, the angular position difference between the upper and lower beam rotations with time can be obtained as shown in Fig. 7.

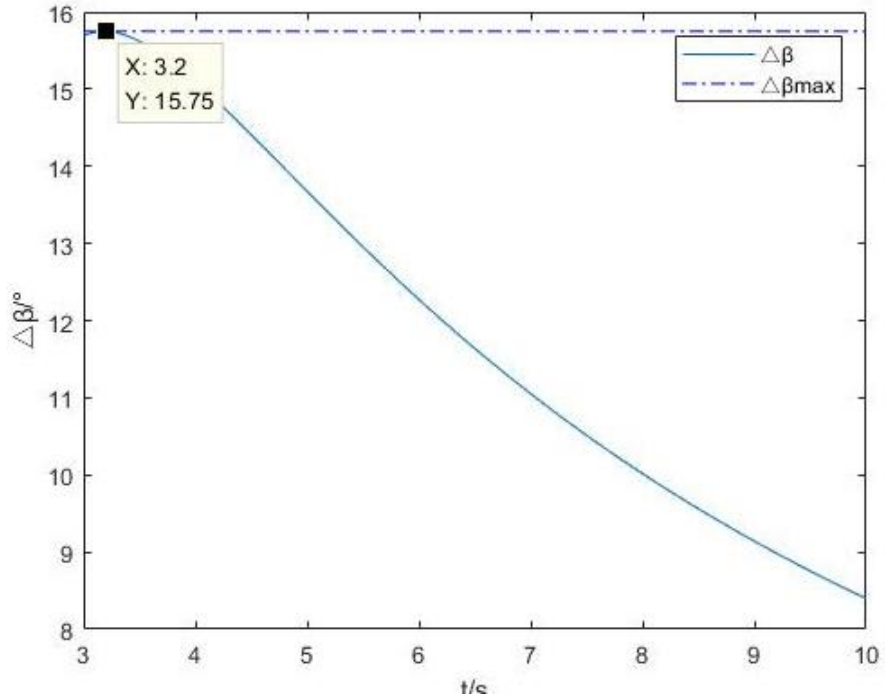


Figure 7. The time variation of the angular position difference between the upper and lower beams of the rotational pendulum at constant speed.

With the increase of time, the angular velocity of the upper support beam remains unchanged, and the angular position difference of the upper and lower beam swing Δβ first increases to 15.75° and then decreases, reaching $\Delta\beta_{max}$=15.69° at this time.

(3) Uniform deceleration and braking, assuming t_3=40s, the angular position difference of the upper and lower beam swing with time can be obtained as Fig. 8.

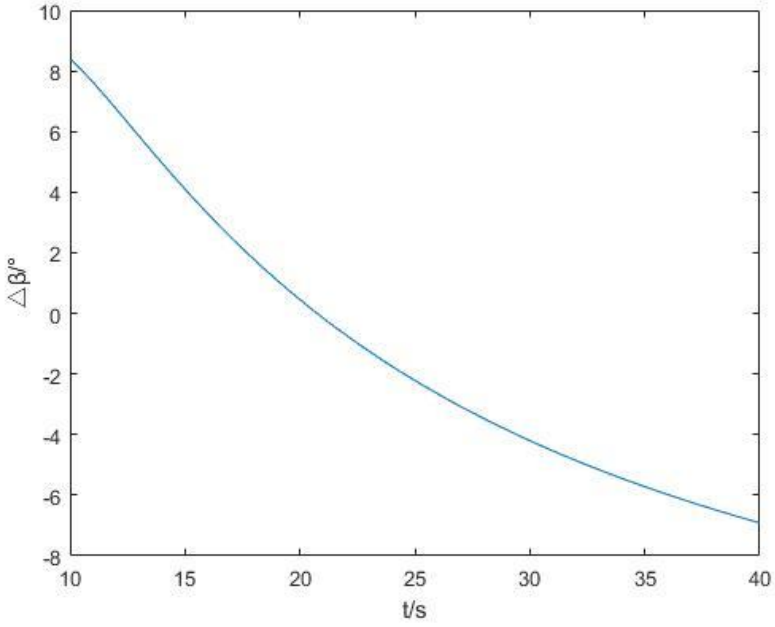


Figure 8. Time variation of the angular position difference between the upper and lower beams of the rotational pendulum during uniform deceleration.

With the increase of time, the upper support beam decelerates and brakes evenly, and the upper and lower beams swing angle difference Δβ gradually decreases to 0. Then the lower lifting beam over the upper support beam continues to decelerate, and the upper and lower beams swing angle difference Δβ increases in the opposite direction, as shown in Figure 9.

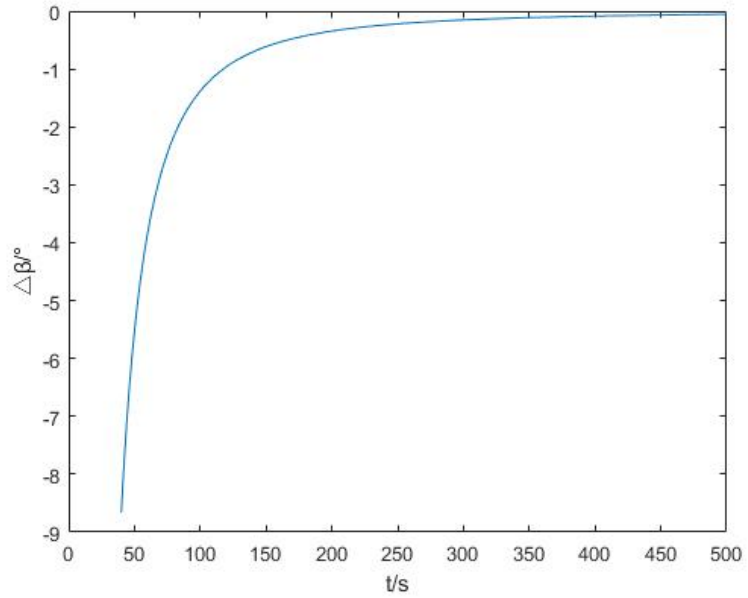


Figure 9. Time variation of the angular position difference between the upper and lower beams of the rotational pendulum when stopping.

When the upper support beam stops, by the upper and lower beam swing angle position difference Δβ, gradually swing to the left, about 500s close to 0, so controlling the time after stopping the swing can avoid accidents, is of practical significance.

5. Conclusion

The study on the anti-swinging control technique of lifting weight greatly benefits from establishing the kinematic model of the tower crane swinging system with weight swinging function. In this paper, through the force analysis of the rotating pendulum trolley model, followed by the establishment of kinematic equations, the study of the upper support beam in the state of acceleration, constant speed, deceleration, the upper and lower crossbeams rotating pendulum angle difference with time of the relationship between the angle of the relationship, according to the simulation results, in the anti-swing control research should focus on the impact of the trolley acceleration (deceleration) speed on the upper and lower crossbeams rotating pendulum angle difference.

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