Study on safety detection method of anti-tilt lifting operation of crane

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Abstract. Crane is an important equipment in engineering construction. Its anti-overturning stability is directly related to the safe operation of crane equipment. With the development of China 's social economy, ensuring the anti-overturning stability of crane equipment in work has become an important issue. This paper analyzes the anti-overturning stability of the crane, describes the model in detail, and discusses the system design. Then, the method and principle of crane anti-overturning detection are explained, and multi-sensors are used to monitor and calculate the maximum lifting weight according to ZMP theory. Finally, the simulation verification is carried out. The proportional scaling model of the crane is used to set multiple different rotation angles and calculate the corresponding maximum lifting weight. The results show that compared with the estimated value of the traditional vector method, the maximum lifting weight calculated by the ZMP method based on the swing angle is more accurate and can effectively prevent the crane from overturning.

Keywords: overturn-preventing; ZMP theory; sensor monitoring.

1. Introduction

Crane is an important equipment in engineering construction. Its anti-overturning stability is directly related to the safe operation of crane equipment and the safety and stability of engineering construction[1]. With the development of China 's social economy, crane equipment is widely used in industry and construction industry and plays a huge role. How to ensure the anti-overturning stability of crane equipment in work has become an important issue in front of us[2]. Crane is a kind of special equipment, which is widely used in industry, construction industry and logistics transportation industry, and plays a very important role. In the process of use, the safety and reliability of the equipment are directly related to its stable operation and the size of the accident risk. Therefore, we must focus on the anti-overturning stability of the crane equipment.

Zhang Yunsheng et al.carried out research topics and practical value. During the stress period, the instantaneous dynamic load was subjected to continuous static force, and the performance could be strengthened by means of model, moment inequality, coefficient method[3], and fixed weight method. Liu Jie et al.found that due to overload, overturning will occur. The stability safety factor method was studied for the crane model to enhance the anti-overturning stability[4]. Zhou Xueyong et al.analyzed the stability of the crane through the method of mechanical engineering, and obtained the parameters of the wind force and the motion state of the crane on the ground in real time to achieve the effect of monitoring[5]. Cheng Wei et al.developed an intelligent crane remote monitoring system, which can effectively prevent the occurrence of overturning accidents. The main height of the crane, the length of the boom, the influence of external wind force, overload weight and other parameters were analyzed. An algorithm to prevent overturning was selected for calculation, and the above parameters were integrated to predict the maximum lifting capacity. From the point of view of improving the material of the crane[6], Wu Bo et al.analyzed the accident of the balance arm of the crane, and found that the mechanical properties of the boom on the balance arm were not qualified, and there was a great instability when the impact load was received. Therefore, the structure and material of the balance arm were improved[7].Li Jin and others put forward the theory of zero moment, which means that when the center of mass of the crane falls within a certain range, it will not overturn. Therefore, it is very important to find the zero moment

point in this critical state[5]. The relationship between the coordinate of the center of mass and the mass of each part of the crane is established. The influence of the luffing angle and lifting angle of the crane on the force is analyzed, and the calculation expression is put forward.

In the daily work of the crane, the analysis of anti-overturning factors has a great influence. Therefore, this paper establishes a crane hoisting model based on zero moment point theory, analyzes the influence of crane swing, luffing and rotation, gives the calculation method of zero moment point coordinate, the calculation method of rotation angle and the maximum lifting weight, and puts forward the stability detection method.

2. Lifting stability dynamic model

In practical applications, the crane is in an unstable environment, affected by the external wind, itself through the boom to bear a certain weight of goods, as well as the weight of the crane itself. The crane is divided into two parts, and two masses are set respectively, that is, the mass m1 of the crane body and the mass m2 of the boom part. Due to the influence of these resultant forces, it is impossible to determine whether the crane will capsize due to overload. Therefore, it is necessary to calculate the maximum lifting weight. The force analysis of the crane is carried out, and the maximum lifting weight is inferred by calculating the position coordinates of the zero moment point where the moment will not overturn.

During the construction, the crane rotation will often start and stop, and the lifting weight will also rise and fall, resulting in inertial force and swing. If ZMP falls on the overturning edge, the swing inertia force of the lifting weight causes ZMP to move outward, resulting in the overturning of the whole machine. In order to analyze the influence of the swing motion of the lifting load, a dynamic model is established. Take the rotation center as the origin. The rotation angle α is positive clockwise ; the positive direction of the x-axis is the direction of the vehicle head ; the positive direction of the y-axis is to the left,As shown in Figure 1.

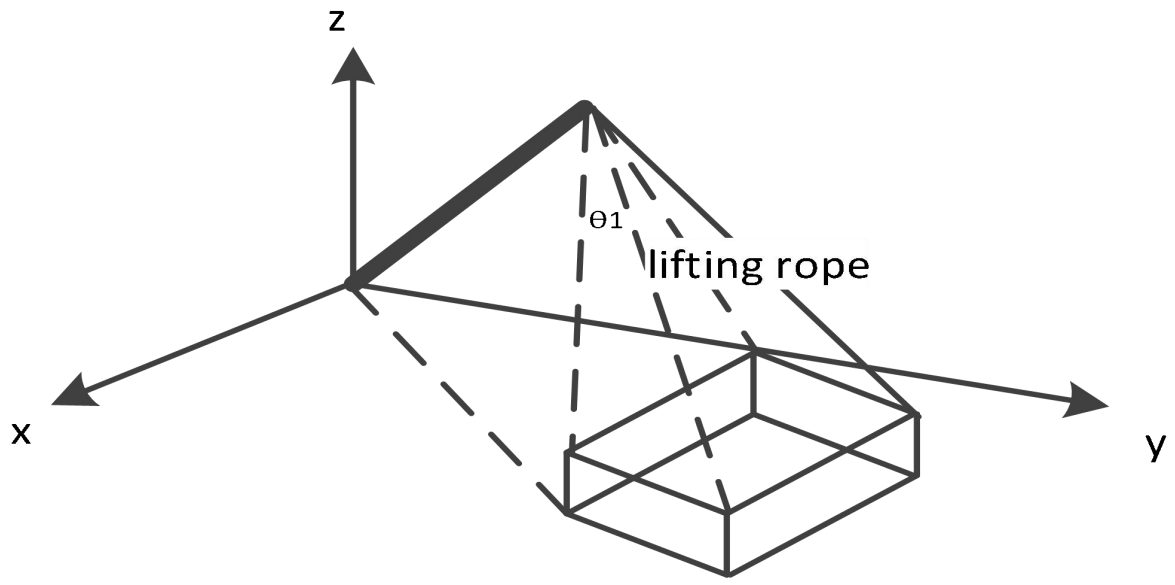

Fig. 1 Crane rotation diagram

The force analysis of the crane is carried out, and the Lagrange equation can be obtained like Formula (1-2):

$$d(\frac{\partial L}{\partial （\theta_1 + \dot{\Delta\theta})}) / dt - \frac{\partial L}{\partial(\theta_1 + \Delta\theta)} = 0 \quad (1)$$

$$d(\frac{\partial L}{\partial(\theta_2 + \dot{\Delta\theta})}) / dt - \frac{\partial L}{\partial(\theta_2 + \Delta\theta)} = 0 \quad (2)$$

Where L is the Lagrange operator θ_1、θ_2 which are the tangential $\Delta\theta$ and longitudinal swing angles respectively, and is the angular offset caused by wind force. When the swing angle is simplified to be infinitely small, the following dynamic model is obtained as Formula(3-4):

$$\ddot{\theta}_1 = \frac{l_b \dot{\alpha}^2 \cos\beta}{l} - \frac{g}{l}\theta_1 + \ddot{\alpha}\theta_2 + 2\dot{\alpha}\dot{\theta}_2 + \dot{\alpha}^2\theta_1 \quad (3)$$

$$\ddot{\theta}_2 = \frac{l_b \dot{\alpha}^2 \cos\beta}{l} - \frac{g}{l}\theta_2 - \ddot{\alpha}\theta_1 - 2\dot{\alpha}\dot{\theta}_1 + \dot{\alpha}^2\theta_2 \quad (4)$$

Where lb is the length of α （ t ） ,β the boom, the rotation Angle and working Angle are respectively, g is the gravity acceleration. L is the length of the wire rope.

The zero moment point ZMP is an important index to judge the stable state of the crane, and it is the critical point of whether the crane capsizes. If ZMP falls on the support surface of the crane, the system remains stable, otherwise it will capsize. Therefore, the state of the crane can be detected by finding the ZMP method.

ZMP can ensure stability in the support surface. The coordinate system is established with the intersection of the rotary axis and the ground as the origin, and the centroid coordinates of each part are obtained. The centroid coordinates and mass are substituted into the calculation of the coordinates of ZMP on the x and y axes.

The coordinate value of the zero moment point is calculated as Formula(5-6):

$$x = \frac{\sum_{i=1}^{2} m_i(\ddot{z}_i + g)x_i - \sum_{i=1}^{2} m_i \ddot{x}_i z_i}{\sum_{i=1}^{2} m_i(\ddot{z}_i + g)} \quad (5)$$

$$y = \frac{\sum_{i=1}^{2} m_i(\ddot{z}_i + g)y_i - \sum_{i=1}^{2} m_i \ddot{y}_i z_i}{\sum_{i=1}^{2} m_i(\ddot{z}_i + g)} \quad (6)$$

The mass of each part of the crane is mi, the coordinate of the center of mass is (xi, yi, zi), and g is the acceleration of gravity.

3. The principle of anti-overturning detection method

Due to the unbalanced force, the object cannot meet some limiting conditions, and the support point crossing the vertical line of gravity will capsize. When the bottom edge is raised, it will be unstable but not necessarily overturned. When the center of gravity exceeds the support point, it will overturn. The center of gravity action line has a large overturning rate due to the rotation of the main arm. All-round combination of rated weight meter and height operation, lifting items is not greater than the rated weight is not overloaded ; do not lift objects with unclear weight ; can not be inclined to pull and inclined to lift, do not change the balance weight ; control the braking condition and pay attention to the weight and size. The instability of the crane leg is also an important factor leading to overturning. As a key component of the crane supporting the ground, the stability of the leg is directly related to the overall safety of the crane. However, in actual operation, due to the different hardness of the ground contacted by the legs, such as backfill soil, gravel land, mud land, terrain edge, drainage canal and other hollow sites, even the cement land may also sink, resulting in uneven force of the legs, which in turn causes the crane to capsize. Therefore, when carrying out crane operations, it is necessary to ensure that the legs are supported on a flat and solid ground. Generally, auxiliary materials such as sleepers and steel plates should be used to increase the bearing capacity and stability of the ground. At the same time, it should also be avoided near the excavation foundation or various buried objects.

In the truck crane, the length sensor, the angle sensor and the rotation angle sensor can measure the arm length, the luffing angle and the rotation angle, and the maximum lifting weight is calculated according to the ZMP theory. The lifting weight sensor can measure the actual lifting weight and compare it with the maximum lifting weight. Brake when the measured lifting weight is greater than the maximum lifting weight to avoid overload to ensure stability. The inclination sensor monitoring technology can realize the early warning and effective monitoring of the collapse safety accidents caused by improper operation or other external forces during the lifting and landing of the tower crane. In the application of tower crane anti-overturning monitor, there is the figure of inclination sensor. The anti-overturning monitoring instrument can monitor artificial omissions, such as bolt loosening inspection, tower body lateral verticality inspection, mechanism integrity inspection, unlicensed personnel operation, etc. Its working principle is simply to use machine vision technology to monitor the tilt deformation of the tower body caused by various reasons. The equipment on the market is usually composed of an inclination angle measuring device and an inclination angle display alarm.The inclination angle measuring device is composed of a closed container, an inclination sensor and a signal processing circuit board. It is installed on a main limb of the slewing bearing of the tower crane and is mainly used to measure the inclination angle of the tower body. When the inclination angle sensor detects that the inclination angle is greater than a critical state, it can alarm in time, so as to effectively prevent the occurrence of overturning accidents.

The measured lifting weight is Qr, the maximum lifting weight is Qmax, and the ratio is the overturning degree S. Two masses are set respectively, namely the mass of the main body of the crane m1 and the mass of the boom part m2 as Formula 7.

$$S = \frac{Q_r}{Q_{\max}} = \frac{Q_r}{m_1 \sin\beta + m_2 \sin\alpha} \tag{7}$$

4. Simulation verification

Considering the experimental conditions, it is difficult to carry out the real experiment of truck crane. Therefore, the proportional scaling model is used to verify the experiment. The arm length of the model is 200 mm, the variable angle is 45 °, and the rotation angle is 0 ° ~ 20 °. The

identification weight is installed in the vertical direction of the hook, and the weight is gradually increased until it is unstable.

The traditional vector analysis method and the ZMP method used in this paper are used to estimate the effective lifting weight of the crane. The results are shown in Figure 2. Through simulation analysis : the swing of the lifting weight has a great influence on the maximum lifting weight of the crane, and the maximum lifting weight decreases with the increase of the swing angle. It can be seen that the error between the ZMP method and the actual value is smaller and the accuracy is higher, which proves the effectiveness and feasibility of the method proposed in this paper.

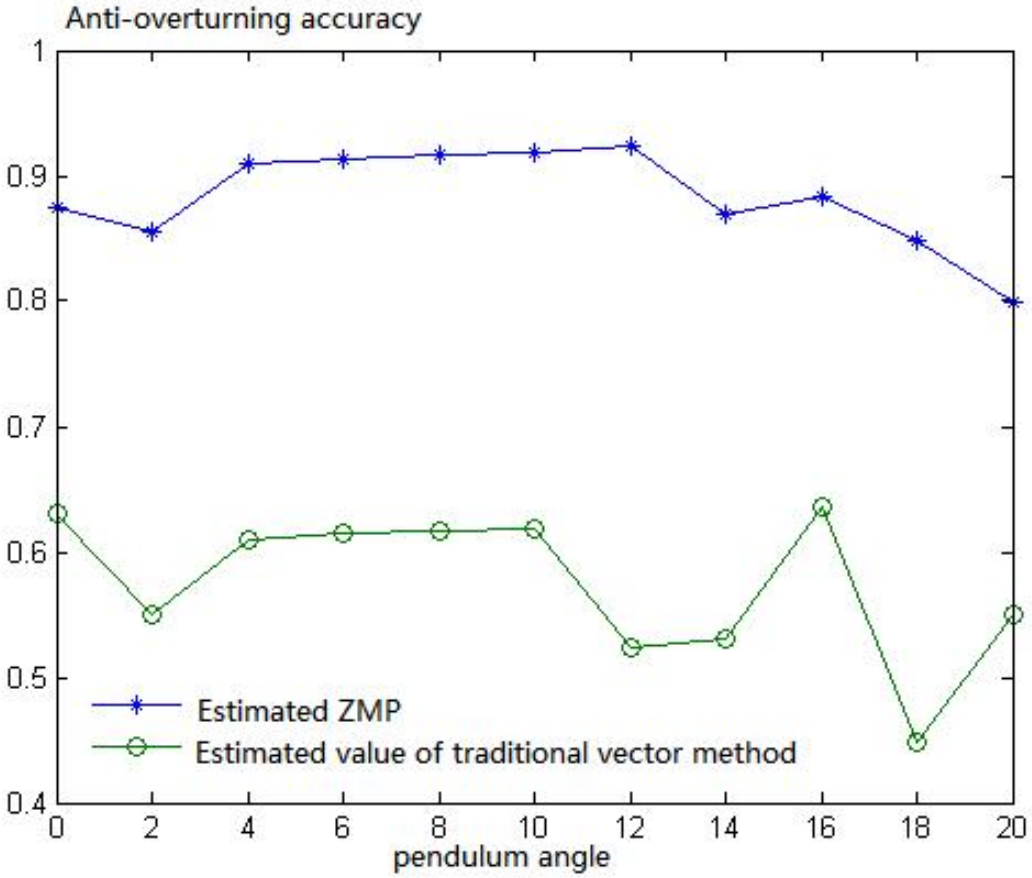

Fig. 2 Simulation comparison of two methods

5. Conclusion

Based on the mechanical model of the crane, this paper analyzes the calculation method of the swing angle, finds the critical maximum lifting weight to prevent the crane from overturning by means of the zero moment point ZMP method, calculates the value of the ZMP coordinate point position according to the data of multiple angle sensors, and derives the maximum lifting weight by substituting it into the formula. Comparing the measured lifting weight with the maximum lifting weight can determine whether the crane will capsize. Finally, the detection method is simulated and analyzed. The traditional vector estimation method and ZMP estimation method are used to calculate the maximum lifting weight respectively. The experimental results show that the maximum lifting weight calculated by ZMP method is more accurate, which is helpful for crane anti-overturning and has important guiding value for practical engineering application.

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