Research on Power Calculation Method of High Speed Rotary Device under Wind Loads Crystals

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Abstract. The wind load has a great influence on the power of large rotary devices working outdoors. In the power calculation formula of the rotary devices, the static air pressure is often used as the wind resistance of the whole device. But in fact, the rotating device bears the dynamic wind pressure during the rotation. This method of calculation will lead to large deviation. Based on this, this paper emphatically studied the dynamic wind load of the rotating device under rotation, and gave a more accurate formula for the calculation of the rotating power. This formula solves the problem of power calculation of the rotating device in high speed rotation. It can be widely used in all kinds of rotating devices.

1.Introduction

The rotating mechanism is widely used in all kinds of mechanical devices, such as tower crane, port machinery, rotating antenna and so on[1]. When calculating the power of rotating devices working in door or the devices with small integral size and slow speed, the wind load change is not considered. So the traditional power calculation formula of the rotary mechanism only considers the static wind load. With the development of modern society, the rotating devices are required to be worked under strong wind, and the rotating speed is also required to be faster. At this time, the wind load under the rotational state cannot be ignored.It becomes the main resistance of the rotating mechanism.

In the calculation formula applied in engineering machinery, the stationary wind load is taken as the wind load of rotary device[2]. But in fact, the rotating devices bear dynamic wind pressure in the process of rotation. So the calculated result obtained by this method are less than that in the true condition, when the speed is fast, the error is large. In the calculation formula applied in antenna, dynamic windresistance

resistance is obtained through the method that static wind resistance is multiplied by the dimensionless coefficients[3], and the results are often larger than the measured data. When the static wind resistance is zero, this result is not consistent with the actual situation.

In order to solve this problem, this paper considered the static and dynamic wind load conditions and gave the accurate calculation formula of dynamic wind load. Finally, the accuracy of the formula is verified by an example.

2.The mathematical model of the power calculation of rotary device

Calculating the driving force is the first step to calculate the power of the rotary device. The composition of rotary resistance moment M_{sw} is as follows:

$$M_{SW} = M_f + M_S + M_W + M_P \quad (1)$$

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M_{sw} —rotary resistance moment； M_f —frictional resistance moment； M_S —the resistance moment caused by the incline of the rotary platform； M_W —the resistance moment caused by wind pressure； M_P —the resistance moment caused by inertia.

Power calculation of rotary mechanism:

$$W = M_{SW} w \quad (2)$$

W —rotary drive power； w —angular velocity.

2.1. The rotation resistance torque without wind load. The frictional resistance moment of the rotary devices can be determined by the following formula, and the force diagram is shown as Figure 1.

$$M_f = 0.5\mu k(N_1 + N_2)D_0 \quad (3)$$

The resistance model is shown in Figure 2. According to the model, the calculation formula is shown as follow:

$$M_S = (P_Q R + G_b r - G_1 l_1)\sin\gamma \sin\varphi \quad (4)$$

G_1 —Weight load of rotary platform; G_b —Weight load of the upper part of the rotary

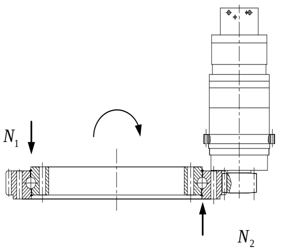

Fig 1 friction resistance

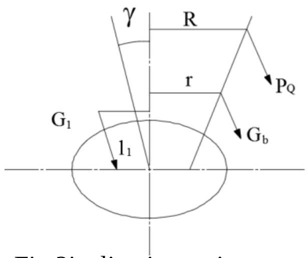

Fig 2inclination resistance

The rotating torque caused by inertia is composed of two parts[4], the calculation formula is shown as follow:

$$M_P = \frac{n}{9.55t}\left[\frac{G_b R^2}{3g} + \frac{4G_1 l_1^2}{3g} + i^2 K J_1 \eta\right] \quad (5)$$

2.2. The resistance torque caused by wind pressure. The wind load include the wind pressure while the device is at rest and the wind pressure while the device is rotating.

When considering the wind pressure under the rotating state, the resistance is caused by external wind load and by the rotating of rotary device under windless condition. As the rotating devices are generally symmetrical about the central axis of the rotation $e \approx 0$, the coupling relationship between the two kinds of resistance can be ignored[6].In order to facilitate the calculation, the two resistances can be treated independently.

$$q = 0.613v^2\,;$$

$$p = CK_n q\,;$$

$$M_{Wz} = qC(A\sin\alpha\sin\beta)\cdot e\cos\beta \quad (6)$$

q —wind pressure； A —the area of upwind surface； r —the distance from centroid to the center of rotation； C —wind force coefficient;e—eccentricity

Equivalent wind resistance moment:

$$M_{W1}=\frac{2\int_0^{\frac{\pi}{2}}M_{Wz}d\varphi}{\pi}=\frac{qC\,\text{Aesin}\,\alpha\sin 2\beta}{2}\ (7)$$

In the windless condition, due to the rotation of the rotating device, the wind load which is opposite to the rotation direction. The front view of rotating device is shown as figure 3. The force diagram of arbitrary cross section is shown as figure 4.

According to the location of the center of rotation, the force condition can be divided into two kinds of situations: $x_0 < h_0\cos\alpha$ and $x_0 > h_0\cos\alpha$

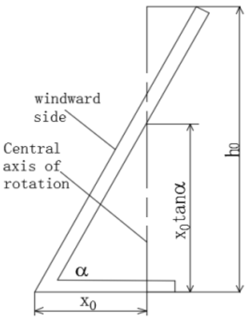

Fig.3 front view of rotating device

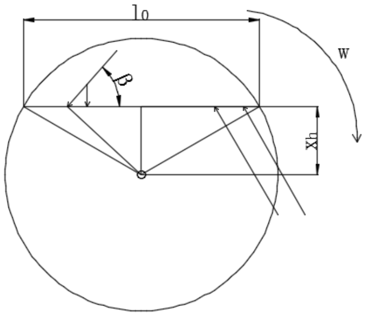

Fig.4 vertical view of rotating device

x_0 is the distance between the gyration center and the base of rotation device

a). When the gyration center $x_0 < h_0\cos\alpha$, the wind load is divided into two kinds of situations: $0 < h < x_0\tan\alpha$ and $x_0\tan\alpha < h < h_0$

While $0 < h < x_0\tan\alpha$:

$$R_h=\sqrt{(x_0-h\cot\alpha)^2+(\frac{l_0}{2})^2}\ (8)$$

Because the relative wind load is symmetry in any cross section while rotating without wind outside. $0 < l < 0.5l_0$ At a height of h of arbitrary cross section, the distance from the windward side to the midpoint of the windward side is l , the distance of any point in the cross section to the rotation center: $R_l=\sqrt{l^2+{x_h}^2}$, the relative speed of any point in the cross section:

$$v_l=wR_l\,;$$

$$\sin\beta=\frac{l}{\sqrt{l^2+{x_h}^2}}\ (9)$$

Wind pressure at this point:

$$q_l=0.613w^2(\text{l}^2+\text{x}_h^2)\ (10)$$

The torque of wind resistance without wind:

$$M_1=2\int_0^{x_0\tan\alpha}\int_0^{\frac{l_0}{2}}p_l\cdot R_l\cdot\sin\beta\cdot dhdl\ (11)$$

While $h > x_0\tan\alpha$:

$$x_h=h\cot\alpha-x_0\,;$$

$$M_2=1.226CK_nw^2\int_{x_0\tan\alpha}^{h_0}\int_0^{\frac{l_0}{2}}(l^2+{x_h}^2)\cdot l\cdot dhdl\ (12)$$

The total torque of wind resistance without wind:

$$M_{W2} = M_1 + M_2$$

$$= N(\frac{1}{24}h_0^3 l_0^2 \cot^2\alpha - \frac{1}{8}x_0 h_0^2 l_0^2 \cot\alpha + \frac{1}{8}x_0^2 h_0 l_0^2 + \frac{1}{64}h_0 l_0^4) \quad (13)$$

While $N = 1.226CK_n w^2$

b). When the gyration center $x_0 > h_0 \cos\alpha$:

$$M_{W2} = 2\int_0^{h_0}\int_0^{\frac{l_0}{2}} p_l \cdot R_l \cdot \sin\beta \cdot dhdl$$

$$= N(\frac{l_0^{\,3}}{24} + \frac{x_0^{\,2} l_0^{\,2}}{8} - \frac{l_0^{\,2} x h_0 \cot\alpha}{4} + \frac{l_0^{\,2} h_0^{\,2} \cot^2\alpha}{8}) \quad (14)$$

The total torque of wind resistance:

$$M_W = M_{W1} + M_{W2} \quad (15)$$

3.Application examples

The design parameters of a large scale mobile turntable are as follows:

$\alpha=70^\circ, w = 6\text{r}/\min, \text{l}_0 = 15.18m, h_0 = 16.352m, \text{G} = 80t,$

$D = 2m, e = 0m$

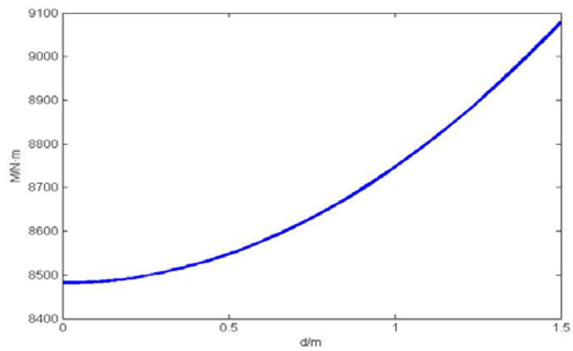

Fig 5 Wind load resistance torque at different distances

All design parameters are calculated in the formula (1):

$M_f = 9049N\cdot m, M_s = 1360N\cdot m, M_p = 3200N\cdot m$

The wind load is depended by the distance between the central axis of rotation and the centroid axis of the windward side. The wind load of different distance torque as shown in figure 5.From Figure 5, the minimum value of the wind load resistance torque is: $M_W = 8500N\cdot m, M_{SW} = 22KN\cdot m, P = 13.8Kw$ Wind tunnel test results from the literature [5] shows that the dynamic wind torque is $8250N\cdot m$. When this data is calculated in the formula (17), the rotary power of the device is $13.5Kw$. Using the calculation formula of literature [1], the rotary power of the device deserve to be $9.1Kw$. While using the calculation formula of literature [7], the rotary power of the device deserve to be $17.4Kw$. Compared with other computational methods, the formula of wind resistance, given in this article, is much more accurate.

4.Conclusion

(1)In this paper, the condition of the wind load of the rotating device in the rotating state was studied. Static and dynamic wind pressure were taken into account. By introducing the wind load, under windless situation, caused by the rotation of the rotary device, this paper deduced the formula of dynamic wind resistance torque.
(2)This formula solve the problem of power calculation of rotating device at high speed, and can be widely applicable to all kinds of rotary device.
(3)Finally, it is proved that the formula has higher accuracy through Citing an application example.

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