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A New Algorithm of Determining the Winch Braking Torque in Safe Working Condition

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Abstract: According to quality modulus of lifting winch (hoist) mentioned by the article 432 of coal mine safety regulations, using hoist mechanical brake power balance equation, derived relationship of maximum static torque multiples K, safe braking deceleration and quality modulus M. On the basis of detailed analysis, Obtained: (1) The range of the inclined shaft, shaft hoisting system quality modulus M meeting the relevant provisions, (2) The basis and results of the four division of big, normal, small, smaller of inclined shaft, shaft hoisting system quality modulus M, Using the software of MATLAB, study corresponding variation of different inclination angles between K and M. The examples illustrated that the brake mode determined by quality modulus is feasible.

Key words: Hoist, quality modulus, brake deceleration, braking torque

INTRODUCTION

The article 432 of coal mine safety regulations (abbreviation regulations) indicates “when hoist common brakes and hoist insurance brakes are working, the ratio of the braking torque generated by actual lifting maximum static load rotational torque than the K value is not less than 3. when the overloading insurance brake braking deceleration of the smaller hoist quality modulus exceeds the limits specified in this regulation Article 433, the Insurance brakes appropriate to reduce the value of K, but not less than 2. Sinking period, the value of K of the winch lifting material shall not be less than 2” (China Legal Publishing House, 2011). Hoist with a smaller mass modulus is mentioned (Zhang and Qiu, 2010). How much is the hoist quality modulus belongs to the smaller? What is the relation between the modulus M and the K?

On the promise of following the regulations requirements, by analyzing, elaborate the internal relations of quality modulus M and the maximum static torque multiple K and given the hoist quality modulus interval division method, with it, determine the braking torque and braking mode. And then, realize the purpose of enhancing the working safety of hoist (Zhao and Chen, 2013; Wang *et al.*, 2012; Tian *et al.*, 2012).

RELATION OF THE QUALITY MODULUS AND BRAKING TORQUE OF HOIST

Hoist quality modulus M is the ratio of the total displacement quality of the hoist system and the actual maximum static pressure of the hoist wire rope:

$$M = \frac{\sum m}{F_s} \quad (1)$$

The article 432 of regulations imposes the provisions of the hoist safety braking deceleration (China Legal Publishing House, 2011), refer to the Table 1.

In the Table 1, $\alpha_c = g (\sin \beta + f_1 \cos \beta)$

α : Nature speed reduction, $m \sec^{-2}$

g : Gravity acceleration (9.81), $m \sec^{-1}$

β : The dip of shaft, ($^\circ$)

f_1 : Rope end load running drag coefficient, generally 0.010~0.015

The momentum balance equation of mechanical brake hoist system (Sun and Zhou, 1995; Xia and Hao, 1987):

$$M_d = M_z + M_j \quad (2)$$

where:

M_d : Hoisting system dynamic moment or the moment of inertia, Nm:

$$M_d = \sum \max R \quad (3)$$

R : Hoist roll radius, m

a : Hoist braking deceleration, $m \sec^{-2}$

Here, the upward strain deceleration α_s , the down ward strain deceleration α_x

M_z : The hoisting system braking torque, Nm

Brake torque should meet the Regulation, that is:

$$M_z = KM_j, \text{ (generally } K = 3) \quad (4)$$

M_j : The static resistance from the hoist, Nm:

$$M_j = F_{jc} R \quad (5)$$

the static resistance is taken "+" when upward hoisting, taken "-" when downward

The Eq. 3, 4, 5 are substituted in Eq. 2, Dynamic equilibrium equation can be expressed as:

At the time of upward hoisting:

$$\sum ma_s R = KF_{jc} R - F_{jc} R \quad (6)$$

At the time of downward hoisting:

$$\sum \max R = KF_{jc} R - F_{jc} R \quad (7)$$

The quality modulus M of the Eq. 1 substituted the total quality of the displacement $\sum m$ and the maximum static tension difference F_{jc} , the Eq. 6, 7 should be.

At the time of upward hoisting:

$$\alpha_s M = K + 1 \quad (8)$$

At the time of downward hoisting:

$$\alpha_x M = K - 1 \quad (9)$$

According to Table 1, the Eq. 8, 9 can be summarized the relation at different inclination between the K and the M when the safety brake, as shown in Table 2.

According to the Table 2, select the dip $15^\circ \leq \beta \leq 30^\circ$ to discuss. Let be $K = \alpha_c M - 1$, $K = 0.3 \alpha_c M + 1$, make the curve of the relation $K = f(M)$, when the safety brake, as shown in Table 2.

In Fig. 1, the Maximum static torque multiples K meeting the Regulation requirements of braking deceleration are $0.3 \alpha_c M + 1 \leq K \leq \alpha_c M - 1$ considering the article 432 of coal mine safety regulations defined

Table 1: All machinery deceleration at the hoist safety braking time $m \sec^{-1}$

Operating state	Dip β		
	$\beta < 15^\circ$	$15^\circ \leq \beta \leq 30^\circ$	$\beta > 30^\circ$
Upward strain heavy load	$\leq \alpha_c \leq \alpha_c \leq 5$		
Downward strain heavy load	$\geq 0.75 \geq 0.3 \alpha_c \geq 1.5$		

Table 2: Relation at different inclination between the K and the M

Operating state	Dip β		
	$\beta < 15^\circ$	$15^\circ \leq \beta \leq 30^\circ$	$\beta > 30^\circ$
Upward strain heavy load	$K \leq \alpha_c M - 1$	$K \leq 5M - 1$	$K \leq \alpha_c M - 1$
Downward strain heavy load	$K \geq 0.75 M + 1$	$K \geq 0.3 \alpha_c M + 1$	$K \geq 1.5 M + 1$

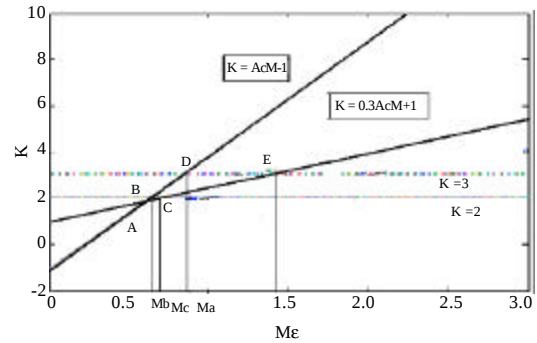


Fig. 1: Curve of the maximum static torque multiples K the quality modulus M

minimum value, identify the M_B , M_C , M_D , M_E . Feature points and the Fig. 2 is divided into five sections (Fig. 2-8), From the Fig. 1:

- **(0, M_B):** Corresponds to $0.3 \alpha_c M + 1 \leq K \leq \alpha_c M - 1$, in the interval $(0, M_B)$, all of the value M and K do not meet the requirement $K \geq 2$
- **[M_B , M_C):** Corresponds to $0.3 \alpha_c M + 1 \leq K \leq \alpha_c M - 1$, In the interval $[M_B, M_C)$, all of the value M and K meet the requirement $K \geq 2$
- **[M_C , M_D):** Corresponds to $0.3 \alpha_c M + 1 \leq K \leq \alpha_c M - 1$, in the interval $[M_C, M_D)$, all of the value M and K meet the requirement $K \geq 2$
- **[M_D , M_E):** Corresponds to $0.3 \alpha_c M + 1 \leq K \leq \alpha_c M - 1$, In the interval $[M_D, M_E)$ all of the value M and K do not meet the requirement $K \geq 2$ and the parts of that meet the requirement $K \geq 3$
- **[M_E , ∞):** Corresponds to $0.3 \alpha_c M + 1 \leq K \leq \alpha_c M - 1$, In the interval $[M_E, \infty)$, all of the value M and K do not meet the requirement $K \geq 3$

In summary, the quality modulus M can be divided into four interval $(0, M_B)$, $[M_B, M_D)$, $[M_E, \infty)$. According to the equation related to the Fig. 2:

$$M_B = \frac{3}{a_c}, M_D = \frac{4}{a_c}, M_E = \frac{20}{3a_c}$$

get the characteristic interval:

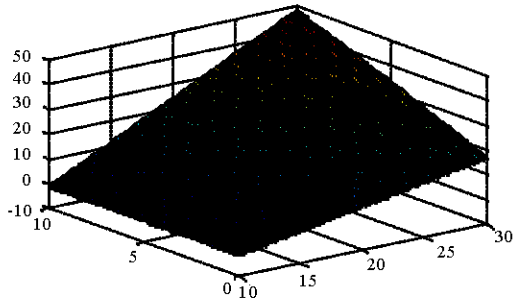


Fig. 2: Dip corresponding to upward strain heavy load ($f = 0.01$ $10^\circ < \beta < 30^\circ$) three-dimensional map of the largest static torque multiples and the quality modulus

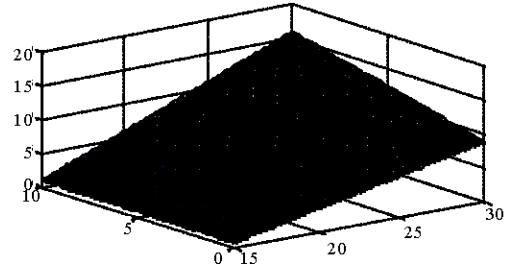


Fig. 5: Dip corresponding to downward strain heavy load ($15^\circ < \beta < 30^\circ$ $f = 0.01$) three-dimensional map of the largest static torque multiples and the quality modulus

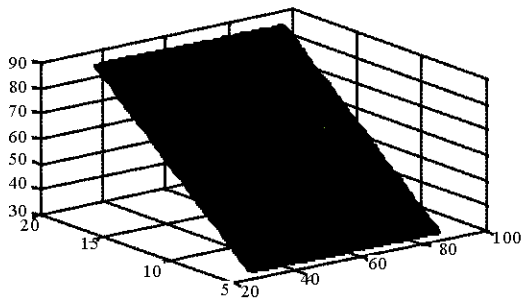


Fig. 3: Dip corresponding to upward strain heavy load ($\beta > 30^\circ$ or shaft) three-dimensional map of the largest static torque multiples and the quality modulus

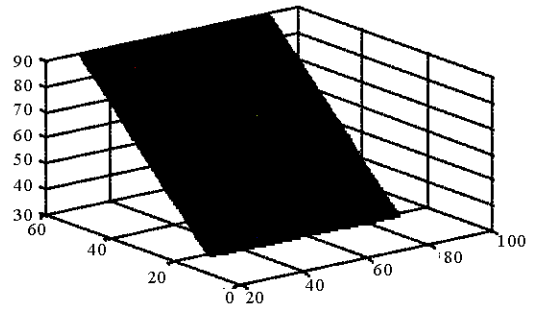


Fig. 6: Dip corresponding to downward strain heavy load ($30^\circ < \beta$ or shaft) three-dimensional map of the largest static torque multiples and the quality modulus

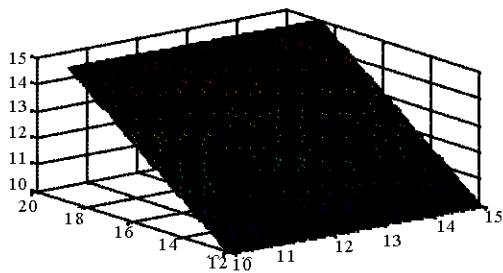


Fig. 4: Dip corresponding to downward strain heavy load ($10^\circ < \beta < 15^\circ$) three-dimensional map of the largest static torque multiples and the quality modulus

$$\left[\frac{3}{a_c}, \frac{4}{a_c}\right)$$

may be referred to the smaller quality modulus. For the unified call, the characteristic interval: the small quality modulus:

$$\left(0, \frac{3}{a_c}\right)$$

the smaller:

$$\left[\frac{3}{a_c}, \frac{4}{a_c}\right)$$

the normal:

$$\left[\frac{4}{a_c}, \frac{20}{3a_c}\right)$$

the big:

$$\left(0, \frac{3}{a_c}\right), \left[\frac{3}{a_c}, \frac{4}{a_c}\right), \left[\frac{4}{a_c}, \frac{20}{3a_c}\right), \left[\frac{20}{3a_c}, \infty\right)$$

The quality modulus M in the interval:

$$[\frac{20}{3a_c}, \infty)$$

Because the small quality modulus hoist can't meet the Regulation requirement, the hoist quality modulus is not less than:

$$\frac{3}{a_c}$$

Simultaneously, when $\beta < 15^\circ$: In the small quality modulus interval:

$$(0, \frac{3}{a_c})$$

in the smaller:

$$[\frac{3}{a_c}, \frac{4}{a_c})$$

in the normal:

$$[\frac{4}{a_c}, \frac{8}{3})$$

in the big:

$$[\frac{8}{3}, \infty)$$

the hoist quality modulus is not less than:

$$\frac{3}{a_c}$$

when $\beta > 30^\circ$ and shaft in the small quality modulus interval (0, 0.60), in the smaller [0.60, 0.80), in the normal [0.80, 1.33), in the big [1.33, ∞) the hoist quality modulus is not less than 0.60.

Relationship of the quality M and brake mode: Figure 1 shows:

- **Big quality modulus hoist:** According with $0.3\alpha_c M + 1 \leq K \leq \alpha_c M - 1$, $K \geq 3$ and the greater the modulus the greater the value of. then, select the value K in inequality within, the first step braking can meet the regulation requirement
- **Normal quality modulus hoist:** According with $0.3\alpha_c M + 1 \leq K \leq \alpha_c M - 1$, $K > 2$. Then, select the value K in inequality within, the first step braking can meet the regulation requirement when $K \geq 3$, the second

step braking can meet the regulation requirement when $K < 3$, that is to say the first step braking can meet the Deceleration requirement, the second step braking can meet the maximum static torque multiples, the both can meet the Regulation related requirement

- **Smaller quality modulus hoist:** According with $0.3\alpha_c M + 1 \leq K \leq \alpha_c M - 1$, $K < 3$. Then, select the value K in inequality within, behoove $K \geq 2$, the second step braking prescription can meet the Regulation related requirement
- **Small quality modulus hoist:** Being inconsistent with the Regulation act

Using MATLAB, write the hoist braking parameter K, β and M calculation program at different inclination, the results of the proceedings shows the corresponding relationship and the law between the parameters of the braking process. As shown in the following figure and the Table 3.

- **Upward strain heavy load:** When $f = 0.01$ and $10^\circ < \beta < 30^\circ$, the program as follows:

```
>> clear all
```

```
>> x = linspace (10,30,100),
```

```
>> m = linspace (0,10,100),
```

```
>> [A,B] = meshgrid (x, m),
```

```
>> K= (9.8*(sin(x*pi/180)+0.01*cos(x*pi/180)))*m-1,
```

```
>> mesh (A, B, K),
```

```
>> surf (A, B, K)
```

When $\beta > 30^\circ$ or shaft, $K = 5M - 1$:

```
>> clear all
```

```
x = Linspace (30, 90, 100),
```

```
m = Linspace (0, 10, 100),
```

```
[A, K] = Meshgrid (x),
```

```
>> m = (K+1)./5,
```

```
mesh (A, m, K),
```

```
surf (A, m, K)
```

Table 3: Safe braking deceleration corresponding to different inclination values

The dip	Drag coefficient			
	Upward strain heavy load ($a \leq$)		Downward strain heavy load ($a \geq$)	
	0.01	0.015	0.01	0.015
10	1.7982633009	1.8465188808	0.75	0.75
11	1.9661276187	2.0142273507	0.75	0.75
12	2.1333930349	2.1813222673	0.75	0.75
13	2.300085989	2.3477527321	0.75	0.75
14	2.4659235581	2.5134680486	0.75	0.75
15	2.631087373	2.6784177385	0.78932621189	0.80352532154
16	2.7954497332	2.8425515563	0.83863491996	0.85276546689
17	2.9589605724	3.0058195054	0.88768817171	0.90174585162
18	3.1215700835	3.1681718528	0.93647102504	0.95045155583
19	3.2832287341	3.3295591443	0.98496862023	0.99886774329
20	3.4438872814	3.4899322198	1.0331661844	1.046979666
21	3.6034967873	3.6492422282	1.0810490362	1.0947726685
22	3.7620086332	3.8074406421	1.12860259	1.1422321926
23	3.9193745348	3.9644792727	1.1758123604	1.1893437818
24	4.075546557	4.1203102844	1.2226639671	1.2360930853
25	4.2304771282	4.2748862098	1.2691431385	1.2824658629
26	4.3841190551	4.4281599633	1.3152357165	1.328447989
27	4.5364255368	4.5800848565	1.360927661	1.374025457
28	4.6873501794	4.7306146115	1.4062050538	1.4191843834
29	4.8368470097	4.8797033754	1.4510541029	1.4639110126
30	4.9848704896	5.0273057344	1.4954611469	1.5081917203
>30	5	1.5		

- **Downward strain heavy load:** When $K \geq 0.75M+1$ and $10^\circ < \beta < 15^\circ$, the program as follows:

```

>> clear all

>> x = Linspace (10,15,100),

m = Linspace (0,10,100),

>> [A, K] = Meshgrid (x),

>> m = (K-1)/0.75,

>> mesh (A, m, K)

>> surf (A, m, K)

When  $15^\circ < \beta < 30^\circ$ ,  $f = 0.01$  and  $k = 0.3AcM+1$ :

>> clear all

x = Linspace (10, 30, 100),

m = Linspace(0, 10, 100),

[A, B] = Meshgrid (x, m),

K = 0.3*(9.8*(sin(x*pi/180)+0.01*cos(x*pi/180)))*m+1;
mesh (A,B,K) surf (A, B, K)

```

When $30^\circ < \beta$ or shaft:

>> clear all

x = Linspace (30, 90, 100),

m = Linspace (0, 10, 100),

[A, K] = Meshgrid (x),

>> m = (K-1)/1.5,

>> mesh (A, m, K),

>> surf (A, m, K)

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EFFECT OF QUALITY MODULUS IN ENGINEERING PRACTICE

A mine auxiliary shaft hoist uses the 2JK-2.5/30 inclined shaft double hook trip lifting system.

System parameters: Hoist roll radius $R = 1.25$ m, the lifting maximum total load $m = 3000$ kg, the inclined shaft lifting dip length $L = 620$ m (the rope full-length 750 m), the

wire rope resistance coefficient $f_2 = 0.20$, the mine car dead weight $m_z = 1920$ kg, the head sheave deflection quality $m_t = 1100$ kg, the wire quality per meter $m_p = 2.492$ kg m^{-1} , the dip $\beta = 23^\circ$, the hoist deflection quality $m_j = 12000$ kg, the bunching group resistance coefficients $f_1 = 0.015$, the motor deflection quality $m_d = 11314$ kg.

According to calculation, the lifting system deflection quality:

$$\sum m = m + 2m_z + 2m_p L + 2m_t + m_j + m_d = 36092 \text{ kg}$$

The wire rope maximum static pressure difference:

$$F_{jc} = Mg(\sin\beta + f_1 \cos\beta) + 2m_z g f_1 \cos\beta + m_p L g (\sin\beta + f_2 \cos\beta) - 2m_p x g \sin\beta$$

When $m = 3000$ kg, $x = 0$ m (heavy load bottom-hole), that the maximum static pressure difference $F_{jc} = 21117$ N

The lifting system quality modulus:

$$M = \frac{\sum m}{F_{jc}} = 1.7092$$

When the inclined shaft dip $\beta = 23^\circ$, the small, smaller, normal and big modulus intervals are (0, 0.7567), [0.7567, 1.0090], [1.0090, 1.6816], [1.6816, 8) in order, according to the calculation results, the hoist maximum quality modulus, the interval of the value K of this hoist is [3.03, 5.78] (that is $0.3\alpha_c M + 1 \leq K \leq \alpha_c M - 1$), use the first braking can meet the related Regulation requirements.

Practically choose $K = 4$, according to the calculation results, the braking torque M_z is that:

$$M_z = K R F_{jc} = 105.59 \text{ KN}$$

Adjust the auxiliary shaft disc brake and station hydraulic, when the measured braking torque achieve the calculated value, according to the measured results, the upward strain heavy load deceleration is 3.11 m sec^{-2} , the results are less than 3.965 m sec^{-2} and the downward is 1.84 m sec^{-1} , its value is more than 1.189 m sec^{-2} , the both can meet the Regulation requirements (Yang *et al.*, 1996).

CONCLUSION

- The hoist quality modulus M interval meeting the Regulation is determined: When $\beta \geq 30^\circ$, its is $M = 3/\alpha_c$; when $\beta > 30^\circ$ and shaft is $M \geq 0.60$
- Based on the Regulation requirements, according to the analysis results, the hoist quality modulus can be divided into 4 kinds, respectively small, smaller, normal and big
- According to the quality modulus interval, the brake mode and range of static torque multiple may be rapidly and accurately determined
- By the project example Verification, the article using method has a guiding role when reasonably choosing the value K in its practical application

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