Vibration Analysis of The End Conveyor Discharge Arm

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***Abstract*-End conveyor is widely used in large open-pit mine, in order to gain the three diagonal elastic deformations of supporting elements as well as the discharge arm vibration model, by making reasonable assumptions. The discharge arm system is simplified to single degree of freedom model, using the geometric invariant principle for three diagonal elastic deformation of supporting elements, and by the Laplace transform method gets the vibration model of the discharge arm system. To this, for reprint conveyor performance provides effective basis for smooth work.**

Keywords-materials; vibration; transport

I. INTRODUCTION

End conveyor used in open-pit mine, is supported by three diagonal elastic supporting elements and the discharge arm, which is composed by lattice truss basic body. Belongs to ultral twice statically inclined support extended end lattice column [1], in its upper installation of belt conveyor, can realize the function of reproduced transport. As shown in figure 1. When the materials have a certain kinetic energy in the discharge arm, cause its vibration, increases the dynamic load of the components; To highlight the dynamic load characteristics, its simplified into single degree of freedom vibration model [2].

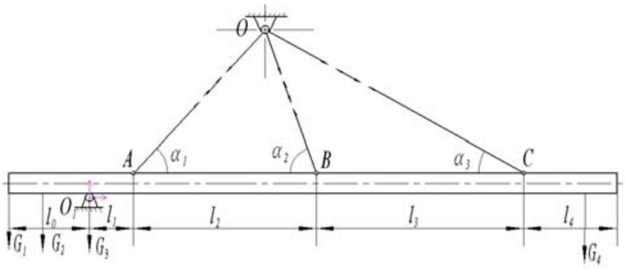

FIGURE I. FIGURE I. CONVEYOR MECHANISMS DIAGRAM

II. ELONGATION FOR ELASTIC ELEMENT

The assumptions for calculating the elongation of elastic element:

1) Discharge arm is regarded as a homogeneous rigid body;

2) Material as a uniform distribution on the discharge arm, material quality m01=390kg/m, the quality of the conveyor belt m02=190kg/m.

3) Discharge arm as rigid body, A point to boundary, such as controlled beam, the moment of inertia J1，J2. Under the influence of disturbing force, the vibration of the discharge arm Angle is θ .

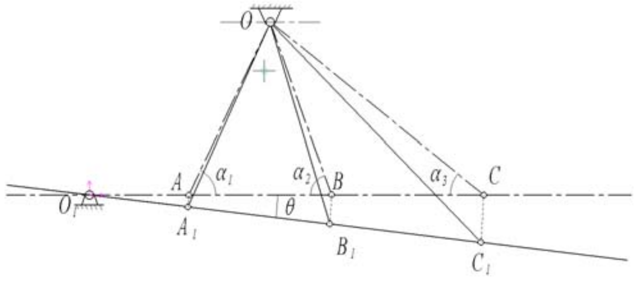

FIGURE II. ELASTIC DEFORMATION OF CONVEYOR MECHANISMS

Three elastic: OA, OB, OC, elongation, respectively, to OA_1, OB_1, OC_1. the deformation is shown in figure 2.

According to the principle of geometric constant, obtains its elongation, respectively

$\angle O_1AA_1 = \theta$, in ΔOAA_1

$$\beta_1 = \angle OAA_1 = \alpha_1 + 180° - \angle O_1AA_1 = \alpha_1 + 180° - (180° - \theta)/2 = 90° + \alpha_1 + \theta/2$$

According to the law of cosines, there is

$$l_{OA1}^2 = l_{OA}^2 + (l_1\theta)^2 - 2l_{OA} \cdot (l_1\theta)\cos\beta_1$$

$$l_{OA1} = \sqrt{l_{OA}^2 + (l_1\theta)^2 + 2l_{OA} \cdot (l_1\theta)\sin(\alpha_1 + 0.5\theta)}$$

$$\Delta l_{OA} = l_{OA1} - l_{OA} = l_{OA}(\sqrt{1 + \frac{(l_1\theta)^2 + 2l_{OA} \cdot (l_1\theta)\sin(\alpha_1 + 0.5\theta)}{l_{OA}^2}} - 1)$$

For， $l_{OA} = 19.76m \approx 4l_1 = 4 \times 5\,m$

$$\therefore x = \frac{(l_1\theta)^2 + 2l_{OA} \cdot (l_1\theta)\sin(\alpha_1 + 0.5\theta)}{l_{OA}^2} \le |1|$$

$$\Delta l_{OA} = l_{OA1} - l_{OA} = l_{OA}(1+\frac{1}{2}\frac{(l_1\theta)^2 + 2l_{OA}\cdot(l_1\theta)\sin(\alpha_1+0.5\theta)}{l_{OA}^2} - 1) \quad (1)$$
$$\approx l_1 \cdot \sin\alpha_1 \cdot \theta$$

By the same token, then obtained,

$$\beta_2 = \angle OBB_1 = \alpha_2 + \angle O_1BB_1 = \alpha_2 + (180° - \theta)/2 = 90° + \alpha_2 - \theta/2$$

$$l_1 + l_2 = 5 + 18.36 = 23.4m, \quad l_{OB} = 14.86 \approx 15m$$

$$\Delta l_{OB} = l_{OB1} - l_{OB} = l_{OB}(1+\frac{1}{2}\frac{((l_1+l_2)\theta)^2 + 2l_{OB}\cdot((l_1+l_2)\theta)\sin(\alpha_2-0.5\theta)}{l_{OB}^2} - 1)$$
$$\approx (l_1+l_2)\cdot\sin\alpha_2\cdot\theta$$

$$l_1 + l_2 + l_3 = 5 + 18.36 + 21.6 = 45m, \quad l_{OC} = 30.32m, \alpha_3 = 27°,$$

Make

$$x = \sqrt{1 + \frac{((l_1+l_2+l_3)\theta)^2 + 2l_{OC}\cdot((l_1+l_2+l_3)\theta)\sin(\alpha_3-0.5\theta)}{l_{OC}^2}},$$

Get θmax=0.5°, and the relevant data into the expression of x, x=0.135<1, the series expansion are available, and namely,

$$\Delta l_{OC} = l_{OC1} - l_{OC} = l_{OC}(1+\frac{1}{2}\frac{((l_1+l_2+l_3)\theta)^2 + 2l_{OC}\cdot((l_1+l_2+l_3)\theta)\sin(\alpha_3-0.5\theta)}{l_{OC}^2} - 1)$$
$$\approx (l_1+l_2+l_3)\cdot\sin\alpha_3\cdot\theta$$

A. Discharge Arm and The Discharging Arm Material

1) The kinetic equation of discharge arm

$$T_1 = \frac{1}{2}J_1\dot{\theta}^2 + \frac{1}{2}J_2\dot{\theta}^2 \quad (2)$$

$$J_1 = \frac{1}{3}m_1 l_0^2 \quad (3)$$

$$m_1 = \frac{m\cdot l_0}{l_0+l_1+l_2+l_3+l_4} \quad (4)$$

$$J_2 = \frac{1}{3}m_2(l_1+l_2+l_3+l_4)^2 \quad (5)$$

$$m_2 = \frac{m}{l_0+l_1+l_2+l_3+l_4}\cdot(l_1+l_2+l_3+l_4) \quad (6)$$

The kinetic energy equation of concentration quality body on the discharge arm

$$T_2 = \frac{1}{2}\frac{G_1}{g}(\dot{\theta} l_0)^2 + \frac{1}{2}\frac{G_2}{g}(\dot{\theta} l_5)^2 \quad (7)$$

The kinetic energy equation of the material on the discharge arm

$$T_3 = \frac{1}{2}(J_3 + J_4)\dot{\theta}^2 \quad (8)$$

$$J_3 = \frac{1}{3}m_3 l_0^2 \quad (9)$$

$$m_3 = m_{01}l_0 \text{ (kg)} \quad (10)$$

$$J_4 = \frac{1}{3}m_4(l_1+l_2+l_3+l_4)^2 \quad (11)$$

$$m_4 = m_{01}(l_1+l_2+l_3+l_4) \text{ (kg)} \quad (12)$$

The kinetic equations of the conveyor belt on the discharge arm

$$T_4 = \frac{1}{2}(J_5 + J_6)\dot{\theta}^2 \quad (13)$$

$$J_5 = \frac{1}{3}m_5 l_0^2 \quad (14)$$

$$m_5 = m_{02}l_0 (kg) \quad (15)$$

$$J_6 = \frac{1}{3}m_6(l_1+l_2+l_3+l_4)^2 \quad (16)$$

$$m_6 = m_{02}(l_1+l_2+l_3+l_4)(kg) \quad (17)$$

$$m = m_1+m_2+m_3+m_4+m_5+m_6 \quad (18)$$

B. The Potential Energy of The Discharge Arm

Take the equilibrium position of discharge arm to position of zero potential energy in the system, the discharge arm in tiny Angle theta (θ) place. Then, potential energy changes, which refers system relative to the amount of in position of zero potential energy[3],

$$V = \frac{1}{2}k_1(\theta l_1)^2 + \frac{1}{2}k_2(\theta(l_1+l_2))^2 + \frac{1}{2}k_3(\theta(l_1+l_2+l_3))^2$$

$$k_1 = k_{OA} = \frac{E_{OA}F}{l_{OA}} \quad (19)$$

$$k_2 = k_{OB} = \frac{E_{OB}F_{OB}}{l_{OB}} \quad (20)$$

$$k_3 = k_{OC} = \frac{E_{OC}F_{OC}}{l_{OC}} \quad (21)$$

$$J_7 = \frac{G_1}{g}l_0^2 + \frac{G_2}{g}l_5^2 \quad (22)$$

Plug into the Laplace equation,

$$\frac{d}{dt}(\frac{\partial T}{\partial \dot{\theta}}) - \frac{\partial T}{\partial \theta} + \frac{\partial V}{\partial \theta} = 0 \quad (23)$$

$$\frac{d}{dt}(\frac{\partial T}{\partial \dot{\theta}}) = (J_1+J_2+J_3+J_4+J_5+J_6+\frac{G_1}{g}l_0^2+\frac{G_2}{g}l_5^2)\ddot{\theta}$$

$$\frac{\partial V}{\partial \theta} = (k_1 l_1^2 + k_2(l_1+l_2)^2 + k_3(l_1+l_2+l_3)^2)\theta$$

Vibration equation for,

$$J\ddot{\theta} + K\theta = 0$$

From it,

$$J = (J_1+J_2+J_3+J_4+J_5+J_6+\frac{G_1}{g}l_0^2+\frac{G_2}{g}l_5^2) \quad (24)$$

$$K = (k_1 l_1^2 + k_2(l_1+l_2)^2 + k_3(l_1+l_2+l_3)^2) \quad (25)$$

Make $\omega_0^2 = K/J$,

The form of differential equations, $\theta = e^{rt}$, and its solutions

$$\theta = C_1 \cos\omega_0 t + C_2 \sin\omega_0 t$$

$$A = \sqrt{C_1^2 + C_2^2}, \tan\alpha = C_1/C_2$$

$$\theta = A\sin(\omega_0 t + \alpha) \qquad (26)$$

Natural frequency,

$$\omega_0 = \sqrt{K/J} \qquad (27)$$

The initial conditions,1) $t = 0, \theta = 0$;2) $t = 0, \dot{\theta} = \dot{\theta}_0$.

By the initial conditions 1), there is $\alpha = 0$, By the initial conditions 2), there is:

$$A = \dot{\theta}_0 / \omega_0 .$$

Vibration equation for,

$$\theta = \frac{\dot{\theta}_0}{\omega_0} \sin\omega_0 t \qquad (28)$$

III. EXAMPLE CALCULATION

The basic parameters of the conveyor:

The Weight of the discharge arm m=38362 kg, the material Weight m01=390 kg/m , the Weight of the belt m02=190 kg/m;

G_1=35000N, G_2=140000N, G_3=80000*N*, G_4=53000N, take θ=0.5°, t_1=3s, t>t_1=3s;

$$\alpha_1 = 46°, \ \alpha_2 = 70°, \alpha_3 = 27°;$$

$$l_0 = 5m, l_1 = 5m, l_2 = 18.36m, l_3 = 21.6m, l_4 = 6.6m,$$

l5=2.55m, l6=5m;

$$l_{OA} = 19.76m, l_{OB} = 14.86m, l_{OC} = 30.32m;$$

By formula (1) can be obtained:

$$\Delta l_{OA} = l_1 \cdot \sin\alpha_1 \cdot \theta = 5\sin 46^\circ \cdot \frac{0.5^\circ}{57.3} = 0.031385\text{m}$$

According to the geometric constant principle can be obtained:

$$\Delta l_{OB} = 0.1469m, \ \Delta l_{OC} = 0.2825\text{m}$$

By formula (3), (4), (19) can be obtained:

$$J_1 = \frac{1}{3} m_1 l_0^2 = \frac{1}{3} \times 3391.3 \times 5^2 \approx 2.8261 \times 10^4 \text{kgm}^2$$

The other parameters of end conveyor calculation methods are same as above, as shown in table (1).

TABLEI. CONVEYOR EXAMPLE CALCULATION PARAMETERS

Name	Numerical	Formula number	Name	Numerical	Formula number
m_1 (*kg*)	3391.3	(4)	J_4 *kgm*^{2}	1.782×10^7	(11)
m_2 (*kg*)	34971	(6)	J_5 *kgm*^{2}	7.92×10^3	(14)
m_3 (*kg*)	1950	(10)	J_6 *kgm*^{2}	8.7×10^6	(16)
m_4 (*kg*)	20108.4	(12)	J_7 *kgm*^{2}	1.78535×10^5	(22)
m_5 (*kg*)	950	(15)	J *kgm*^{2}	5.7751×10^7	(24)
m_6 (*kg*)	9796.4	(17)	k_1 KN/m	3.44×10^5	(19)
m (*kg*)	71167.1	(18)	k_2 KN/m	4.344×10^4	(20)
J_1 *kgm*^{2}	2.8261×10^4	(3)	k_3 KN/m	2.129×10^4	(21)
J_2 *kgm*^{2}	3.1×10^7	(5)	K KN/m	6.76×10^7	(26)
J_3 *kgm*^{2}	1.625×10^4	(9)	ω_0 rad/s	1.082	(27)

By formula (24) shows that the vibration equation (29).of discharge arm system

$$\theta = \frac{\dot{\theta}_0}{\omega_0} \sin\omega_0 t = \frac{\dot{\theta}_0}{1.082} \sin 1.082t \ \text{(rad)} \qquad (29)$$

The vibration equation of discharge arm system is shown as follows:

$$\theta = -4.76 \times 10^{-8} \sin 1.082t + 5.15 \times 10^{-8} t \ \text{(rad)}$$

IV. CONCLUSION

By the above discussion and calculation, the following conclusions can be concluded:

It is reasonable to simplify the discharge arm system as linear single degree of freedom vibration system in the process of the material fall on the discharge conveyor arm. The determination of the model assumptions and system of generalized degrees of freedom is consistent with the actual situation and the calculated results.

Discharge arm system is super quadratic statically indeterminate system, and using geometric invariant principle to calculate the three oblique elastic supporting elements of deformation. And the deformation results consistent with the actual mechanism and working conditions.

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