

Research on the Vibration of Rolling Mill

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Keywords: Rolling mill, Vibration pattern, Self-excited vibration, Finite element method

Abstract. In this paper a horizontal vibration problem in strip rolling was studied; dynamic model was established; the mechanism of self-excited vibration was analyzed. The main reason of surface quality of strip is self-excited vibration. A vertical natural frequency and vibration mode of the rolling mill are obtained by finite element method. It lays the theoretic foundation for future researches on rolling mill vibration.

Introduction

In the production of the strip rolling mills, the mill vibration makes the equipment wears easily. It is easy to have vibration pattern, sometimes even leads to rupture. This phenomenon is common and need to be resolved in rolling production[1,2]. The vibration pattern appears frequently. It makes the strip surface quality and accuracy fail to meet the product requirements. And it also leads to the vibration patterns on the roll surface, which increases the number of roll changing, increases business costs, and reduces production efficiency[3,4].

Therefore, the study of rolling mill vibration is important to improve product quality and promote enterprise efficiency. Vibration pattern is the result of torsion vibration, vertical vibration, and horizontal vibration coupling through the rolling interface.

A dynamic model of rolling process was established in this paper. The conditions and mechanism of the self-excited vibration was shown. The self-excited horizontal vibration of strip was studied. Finite element analysis method of vertical vibration of the rack was introduced.

Self-excited vibration of strip rolling

The mechanical model of friction self-excited vibration of the object (negative damping vibration) is shown in Fig.1 [5,6,7]. Friction F , objects quality m , stiffness coefficient k , equivalent viscous damping coefficient c , conveyer belt speed v_0 , displacement of objects x , speed \dot{x} , minimum speed v_m .

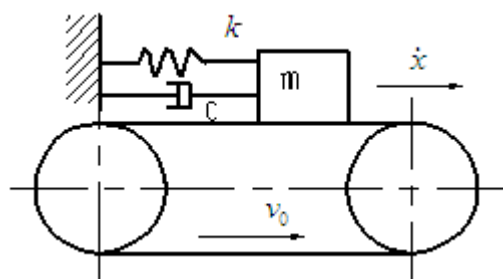


Fig.1. Mechanical model of friction vibration

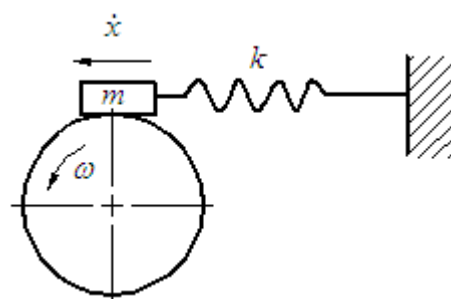


Fig. 2. Model of the level of vibration strip

During the strip rolling process, at the roll gap, the volatility of the friction leads friction self-excited vibration to be a typical self-excited vibration, according to principles of friction and wear [5-9], the relationship between the relative sliding speed and friction as:

$$F = f(v_0 - \dot{x})$$

In which $\dot{x} \leq v_0$, Taylor series expanded to $F = f(v_0 - \dot{x})$ by \dot{x} power at v_0 as :

$$f(v_0 - \dot{x}) = f(v_0) - f'(v_0)\dot{x} + \frac{f''(v_0)\dot{x}^2}{2!} + \dots$$

As a result of a slight vibration of the object, the motion differential equation is:

$$m\ddot{x} + c\dot{x} + kx = f(v_0 - \dot{x})$$

$$m\ddot{x} + c\dot{x} + kx = f(v_0) - f'(v_0)\dot{x} + \frac{f''(v_0)\dot{x}^2}{2!} + \dots \quad (1)$$

Without considering the second order above or vibration- irrelevant constant, the equation (1) will be expressed as:

$$m\ddot{x} + [c + f'(v_0)]\dot{x} + kx = 0 \quad (2)$$

where $c > 0$, when v_0 is in the left unstable region [4], characteristic curve slope $f'(v_0) < 0$.

If $|f'(v_0)| > c$, the equation (2) became:

$$m\ddot{x} - [f'(v_0) - c]\dot{x} + kx = 0$$

Order $[f'(v_0) - c] / m = 2\xi P$, $k / m = P^2$ then into:

$$\ddot{x} - 2\xi P\dot{x} + P^2x = 0 \quad (3)$$

The solution:

$$x = Ae^{3Pt} \sin(P\sqrt{1-\xi^2} \cdot t + \phi) \quad (4)$$

Where, P is the natural frequency, t is the time, A is the amplitude, ϕ is the initial phase angle.

Equation (4) shows that, when time increases, x will increase exponentially, the amplitude of the vibration increased, the system becomes unstable. As x increases, the velocity increases simultaneously. When the amplitude reaches a certain level, F would step in a stable right side. At this time, characteristic curve $f'(v_0) > 0$, the negative damping turned into positive damping.

The solution:

$$x = Ae^{-3Pt} \sin(P\sqrt{1-\xi^2} \cdot t + \phi)$$

Positive and negative damping so again, so the system will remain stationary amplitude vibration. When $[c + f'(v_0)] = 0$, system is equivalent to amplitude free vibration without damping.

Self-excited vibration strip

Mechanical model of the work roll rolling roll band during strip rolling process was built. Rolling vibration equation is established. The level of self-excited vibration of the vibration is studied[8,9].

The simplified model of a continuous strip mill in 1700 F7 rack is shown in Fig.2.

In which, working roll diameter $D = 700$ mm, rolling and the friction coefficient of the roll is $\mu = 0.1 - 0.0005v$, the roller and rolling the relative velocity is $v = 1300$ m/min, plate width is 1 m, No. 3 steel material, height before rolling is $H_0 = 4$ mm, the absolute amount of reduction is 3 mm. In the 1300 m/min rolling speed flutter occurs, initial disturbance displacement is 500 % mm, rolling temperature is 1000°C.

Calculate the average rolling force.

$$p_c = n_\sigma \sigma \quad (5)$$

where, p_c is the rolling force per unit area, MPa ; σ is the deformation resistance, MPa ; n_σ is the external resistance coefficient, take $n_\sigma = 1.2$;

Determine the deformation resistance σ .

$$\text{Rolling speed } v = 1300 \text{ m/min} = 21.7 \text{ m/s}$$

$$\text{Contact arc length } L = \sqrt{R\Delta h} = \sqrt{350 \times 3} = 32.4 \text{ mm}$$

$$\text{Deformation velocity } u = \frac{21700}{32.4} \times \frac{3}{4} = 502 \text{ s}^{-1}$$

According to the values t and u from [5] look-up table is $\sigma = 190 \text{ MPa}$.

From the equation (5), obtained: $p_c = 190 \times 1.2 = 228 \text{ MPa}$

$$P_0 = F_0 \cdot p_c \quad (6)$$

$$F_0 = b_c L = 3.24 \times 10^{-2} \text{ m}^2$$

Into the equation (6), Obtained: $P_0 = 7387200 \text{ N}$

where, P_0 is the rolling force, N ; F_0 is the rolling contact area with the roll, m^2 ; b_c is the deformation of the rolling average width of the region, m ; L is the length of deformation zone, m .

The quality of rolling (Deformation zone).

$$m = \rho V = \frac{(1+4) \times L}{2} \times \rho = 0.6318 \text{ kg}$$

$$k = \frac{EA}{L} = 9.26 \times 10^7$$

Friction between the contact surfaces.

$$F = 2P_0(0.1 - 0.0005\dot{x}) = 7387.2\dot{x} + 1317137$$

$$F = m\ddot{x} + kx = 0.6318\ddot{x} + 1.5 \times 10^{12}x$$

$$0.6318\ddot{x} + 1.5 \times 10^{12}x = 7387.2\dot{x} + 1317137$$

$$\ddot{x} + 146565368x - 11692\dot{x} = 2084737$$

The general form of equations:

$$x(t) = Ae^{-(c/2m)t} \sin(w_d t + \varphi) + B \quad (7)$$

$$\text{where, } w_d = \sqrt{\frac{k}{m} - \left(\frac{c}{2m}\right)^2} = 10601$$

$$B = \frac{2084737}{1.46 \times 10^8} = 0.0142$$

From the equation (7), finishing the strip deformation vibration displacement of the region:

$$x(t) = Ae^{5846t} \sin(10601t + \varphi) + 0.0142 \quad (8)$$

$$\dot{x} = A \times 5846 e^{5846t} \sin(10601t + \varphi) + A e^{5846t} \times 10601 \times \cos(10601t + \varphi) \quad (9)$$

When $t = 0$, $x = x_0 = 0.5$ mm, $\dot{x} = 0$

Into (8) and (9), order is:

$$\dot{x} = A \times 5846 \sin \varphi + A \times 10601 \times \cos \varphi$$

Obtained: $\varphi = -61^\circ$ or $\varphi = 119^\circ$

$$x = x_0 = 0.5 = A \sin \varphi + 0.0142$$

Obtained: $A = 0.5552$

Finishing (8), obtained:

$$x(t) = 0.5552 e^{5846t} \sin(10601t - 61) + 0.0142 \quad (10)$$

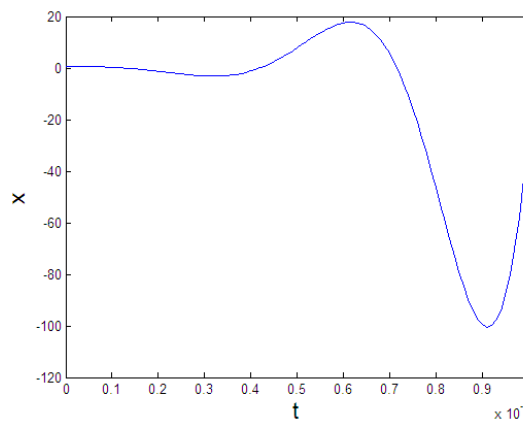


Fig.3 The amplitude changes with time

In equation (10) and Fig.3, they show the amplitude changes with time.

However, the relative velocity of the point of contact increased the value of the friction and the amplitude reduced, which in turn the relative velocity reduced, the relative velocity, friction in turn increase the amplitude in turn increases circulation to reproduce.

This is typical of the self-excited vibration caused by friction; system itself appears positive and negative damping which affects only the relative velocity conversion.

Rolling direction of the self-excited vibration levels will cause the roll between the rolling and the relative displacement, it leads to tension fluctuations before and after rolling. Rolling force will fluctuate; the vibration pattern on the strip surface would appear.

Calculating of the rolling mill vibration using finite element method

The top ten order vibration mode of 1700 Mill F2 rack is analyzed by FEM, and the model natural frequencies and mode shapes were obtained.

According to the actual situation of vibrations, the tenth-order modal expansion was calculated to get the natural frequency and vibration rack type, as shown in Table 1.

Table 1 The natural frequency of the rack

Order	1	2	3	4	5
Natural Frequency(Hz)	13.389	16.138	29.008	75.513	84.335
Order	6	7	8	9	10
Natural frequency(Hz)	87.898	90.409	94.742	96.197	103.13

The fifth-order vibration mode is shown in Fig.4. It indicates that its vertical vibration mode shape for the frame.

The vertical vibration mode shape for the frame is bigger than the other mode deformation. The fifth-order vibration mode of the rolling mill vibration is the most important.

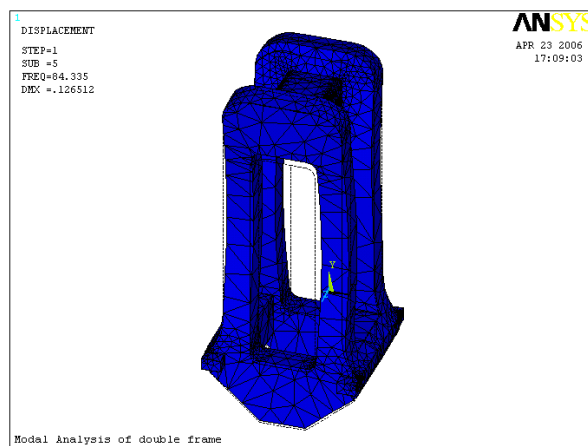


Fig.4 The fifth-order vibration mode screenshot

Conclusions

The mechanism of the level of vibration was analyzed to study vibration pattern of the steel surface. The vibration model was built and the vibration quantitatively was analyzed. The horizontal vibration displacement was obtained by the real product. The level of vibration mill is self-excited vibration which leading to tension fluctuations and affecting the rolling force change. Self-excited vibration levels changed to vertical vibration excitation, resulting in self-excited vibration of the vertical mill which influences surface quality of steel. Vibration of the rolling mill is analyzed by FEM. Vertical natural frequency and vibration mode were analyzed which is useful for future researches of vibration mill.

References

- [1] Taniguchi repair the Yin pass on translation, Daquan Vibration Engineering, Mechanical Industry Press, Beijing, 1983 112-114
- [2] Jiang Weixing, steel rolling machinery and equipment, Metallurgical Industry Press, Beijing, 1981, 89-92
- [3] Chen Peilin, Wang Ze Ji, Wang Chen, strip surface vibration pattern of the world iron and steel, Shanghai, 2002 (4) 21-25
- [4] Jue Zhong and Huaping Tang. A certain number of vibration problems of fast mill. Journal of Vibration, Measurement & Diagnosis, 2002, 22(1): 1-8.
- [5] Hofman w. et al, Furui K, Iida H. Reduction of chatter Marks During Skin Pass Rolling of Steel Strips. MPT International, 1998 (1): 98-100.
- [6] Hou Zhuang AI, Jiuhui Li, Dechen Zhang and Feng Han. Analysis of dynamics behavior of belt steel mill by rub Vibration theories, 2006, 29(2): 155-158.
- [7] Xiaobin Fan, Yong Zang, Yongtao Wang, Yifan Liao and Zhijian Huang. The rolling Interface Friction Characteristic of CSP and its Effect with Rolling Mill Vibration, 2006, 10: 92-98.
- [8] Yongtao Wang, Yong Zhang, Diping Wu and Qin Qin. Study on Vibration Mechanism of CSP Mill caused by chatter Marks. Iron and Steel, 2008, 43(2): 68-72.
- [9] Full Permanent Xin, Shi Gaoyi, friction and wear theory, Zhejiang University Press, Hangzhou, 1988, 78-81