The Sensitivity Analysis of Inherent Frequency of Roll Mill’s Main Drive System

Hou Dongxiao
School of Control Engineering, Northeastern University at Qinhuangdao, Qinhuangdao 066004, China
houdongxiao1982@163.com

Abstract: In order to avoid the beat vibration of rolling mill, taking F1 rolling mill of 1780 tandem mill as an example, a twelve DOF branched torsional vibration model of main drive system of F1 rolling mill was constructed. Then the inherent frequency of the rolling mill and the corresponding vibration modes of every inherent frequency were calculated. Meanwhile, the sensitivity of first and second inherent frequency with the change of equivalent rotational inertias and torsional stiffness of rolling mill were analyzed, and the most sensitive parameters which influence on first and second inherent frequency were found out. The result shows that the equivalent inertias of upper and lower work rolls and equivalent stiffness of upper and lower joint shaft of drive system were most sensitive parameters, which are easier to change first and second inherent frequency of drive system. The research will provide theory reference for adopting proper mechanical parameters in equipment design.

1. Introduction
In recent years, as the increase of rolling speed and rolling product quality, the vibration of rolling mill become more frequently. The vibration of rolling mill not only affects the surface quality of products and the precision of control, severe vibration may lead to serious accidents, such as strip break and equipment damage. Vibration has become the major bottleneck in productivity and strip yield. For avoiding vibration, many theory models and control methods are proposed [1-2]. Consider the influence of the nonlinear friction damping, a single DOF torsional vibration model is constructed, and the vibration characteristics were analyzed [3]. Based on finite element model, the spatial vibration which include vertical, horizontal, axial, reverse, cross and swinging vibration were analyzed [4].

In this paper, a twelve DOF branched torsional vibration model of F1 rolling mill of 1780 tandem mill was constructed, and the inherent frequency and vibration modes were obtained. Then the sensitivity of first and second frequency with the change of equivalent rotational inertias and stiffness were analyzed, it will provide theory reference for designing drive system of rolling mill.

2. The torsional vibration model of F1 rolling mill of 1780 tandem mill
According to the actual mechanical structure of F1 rolling mill of 1780 tandem mill, a twelve DOF branched torsional vibration mechanical model of the main drive system can be constructed as Figure 1.
The torsional vibration mechanical model of main drive system of F1 rolling mill

The parameters of the mechanical model in Fig.1 are shown as Table 1.

| rotational inertia (kgm^2) | torsional stiffness (N.m/rad) |
|---------------------------|-------------------------------|
| J_1 (Motor)               | 9895.6                        |
| J_2 (Motor coupling)      | 1013.8                        |
| J_3 (gear reducer)        | 1543.7                        |
| J_4 (The main coupling(left)) | 138.0556                   |
| J_5 (The main coupling(right)) | 136.6309                  |
| J_6 (Gear base)           | 87.0458                       |
| J_7 (upper joint shaft(left)) | 24.2059                   |
| J_8 (upper joint shaft (right)) | 18.2076                 |
| J_9 (upper work roll)     | 229.6021                      |
| J_10 (lower joint shaft(left)) | 24.2059                   |
| J_11 (lower joint shaft(left)) | 18.2076                 |
| J_12 (lower work roll)    | 229.6021                      |

Based on the Lagrange equation, the dynamic equation in Fig.1 can be expressed as

\[
[J][\ddot{\theta}] + [K][\dot{\theta}] = [F]
\]

(1)

Where, J and K are the matrix of rotational inertia and torsional stiffness, respectively. F is the matrix of external force.

3. The inherent frequency and vibration mode of drive system of F1 rolling mill

Based on MATLAB, the inherent frequency of drive system of F1 rolling mill can obtained from Eq. (1), and it is shown as Table 2.

| \omega_1 | \omega_2 | \omega_3 | \omega_4 | \omega_5 | \omega_6 | \omega_7 | \omega_8 | \omega_9 | \omega_10 | \omega_11 |
|----------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|-----------|
| 18.3     | 20.9     | 60.3     | 82.6     | 149.8    | 188.8    | 190.1    | 197.7    | 223.4    | 238.5     | 295.7     |

The corresponding vibration mode of every inherent frequency are shown as Figure 2.
If the first inherent frequency of drive system is close to the second inherent frequency, the beat vibration easier to arise. The first and second inherent frequencies may change with the change of rotational inertia and stiffness of drive system. When design a new rolling mill, it should select proper mechanical parameters and the beat vibration will be avoided in the design stage.

4. The sensitivity of inherent frequency of drive system of F1 rolling mill

4.1. The sensitivity of inherent frequency with the change of rotational inertias

The change of every rotational inertia of drive system may change the inherent frequency, it has different sensitivity chart for every rotational inertia. The sensitivity comparison chart of the first and second inherent frequency with the change of rotational inertia are shown as Figure 3(a) and Figure 3(b), respectively. Where the abscissa axis is rotational inertia of $J_1$ to $J_{12}$ which range from 90% to 110%.

In Figure 3, It is found that $J_9$ and $J_{12}$ are more sensitive to change first and second inherent frequency, so adjusting $J_9$ and $J_{12}$ are easier to change the first and second inherent frequency in mechanical design. Others rotational inertias are less impact on the change of the first and second inherent frequency.

Because of upper and lower structure of the drive system is symmetrical, the sensitivity charts of inherent frequency are same when varying $J_9$ and $J_{12}$. Figure 4 is sensitivity Comparison chart of first and second inherent frequency with the change of $J_9$. 

Figure 2. The vibration mode of the corresponding frequency of drive system of F1 rolling mill
Figure 4. The sensitivity Comparison chart of the first and second frequency with the changes of $J_9$

In Figure 4, it could found that the first and second inherent frequency have different change tendency. Where $J_9$ is equivalent rotational inertia of upper working roll, it may be changed as rolling mill wears off. When $J_9$ is equal to 220 kg.m$^2$, the first inherent frequency is close to the second inherent frequency, and the beat vibration may arise in this situation.

4.2. The sensitivity of inherent frequency with the change of torsional stiffness

The inherent frequency of drive system also vary with the change of torsional stiffness. The sensitivity chart of the first and second inherent frequency with the change of torsional stiffness are shown as Figure 5(a) and Figure 5(b), respectively.

Figure 5. The sensitivity comparison chart of first and second inherent frequency with different stiffness from $K_1$ to $K_{11}$

In Figure 5, the abscissa axis is torsional stiffness from $K_1$ to $K_{11}$ which range from 90% to 110%, it is found that $K_7$ and $K_{10}$ are more sensitive for varying the first and second inherent frequency. Where $K_7$ and $K_{10}$ are equivalent torsional stiffness of upper and lower joint shaft, respectively.

Figure 6 is sensitivity comparison charts of first and second inherent frequency with the change of $K_7$. It is found that the first and second inherent frequency has different change tendency with the change of $K_7$. The equivalent stiffness $K_7$ may vary with the change of length, diameter or another mechanical structure size of the upper joint shaft. When $K_7$ is equal to 5.2e10 N.m/rad, the first inherent frequency is close to the second inherent frequency, then the beat vibration arises.
5. Conclusion

(1) According to the actual mechanical structure, a twelve DOF branched torsional vibration model of main drive system of F1 rolling mill is constructed.

(2) The inherent frequency and the corresponding vibration mode of every inherent frequency were obtained by means of MATLAB.

(3) The sensitivity of first and second inherent frequency in different rotational inertias and torsional stiffness were analyzed, and it is found that rotational inertias of the upper and lower working rolls, the torsional stiffness of upper and lower joint shaft are more sensitive to the first and second inherent frequency. Based on the results, it could provide theoretical way for avoiding beat vibration in design of drive system of rolling mill.

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