Vibration characteristics analysis of a 20-high Sendzimir mill with localized defect on the working roller

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Abstract. The working roller associating with local defect of the twenty-high roll mill not only significantly affects the mill performance, but also reduces surface quality of the strip steel. In this paper, the roll mill model with local defect on the working roller is established. The dynamic rolling process is simulated using the Finite Element Analysis. Effects of the local defect on the vibration characteristics of the roll mill and the surface quality of the strip steel are presented. The calculated results are validated using experimental data.

1. Introduction
The 20-high Sendzimir mill has the characteristics of thin rolled production, fast rolling speed, large rolling tension and small diameter working roll [1], which has been used widely in producing cold rolled stainless steel strip and become one of the most important equipment in the stainless steel strip production[2,3]. In the rolling process, the working roller directly contacts with the strip surface and is easy to suffer from local defects due to the large force and high temperature. The mill performance and the surface quality of the strip steel are thus negatively affected. However, it is difficult to monitor fully the vibration characteristics of the roll mill and the surface quality of the strip steel, due to the bad working condition, complex inner structure and various disturbing factors. The theoretical model and finite element simulation provide a new method to solve this problem.

A lot of research work has been done on the rolling process of the mill recently [4-17]. However, these works mainly focus on the deflection of the rolls, strip shape control, arrangement of the rolls, rolling force and the friction behavior between the rolls. Study on the vibration characteristics of the roll mill and the surface quality of the strip steel with localized defect on the working roller is limited.

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Although the generation of the local defect has been elaborated in the view of material microstructure, the effects of the defect on the vibration response of the mill has not been presented [1,18,19].

In this paper, the vibration characteristics of a 20-high Sendzimir mill with localized defect on the working roller is studied. The three-dimensional finite element model of the roll mill is established, including the first intermediate rolls, the working rolls and the strip and the explicit dynamic finite element method is used for calculation. Effects of the local defect on the vibration characteristics of the roll mill and the surface quality of the strip steel are presented. The calculated results are compared with experimental results and good agreement is obtained.

2. Model description

2.1. The working roller with local defect
Figure 1 shows the shape and position of the localized defect on the working roll. The defect has the shape of cube with a length \(L\) and a rectangular cross-section with width \(B\) and depth \(H\). The distance between the left end of the defect and the left end of the working roller is \(D\). The parameters are specified as \(L=50\text{mm}\), \(B=23\text{mm}\), \(H=5\text{mm}\), \(D=100\text{mm}\) in this study. Table 1 shows the parameters of the rollers and the working condition of a 20-high Sendzimir mill.

![Figure 1. The shape and position of the localized defect on the working roll.](image)

| Items                     | Amount  |
|---------------------------|---------|
| Working roller            |         |
| Diameter /mm              | 63.5    |
| Length /mm                | 1440    |
| Speed /(r/min)            | 3770.59 |
| Diameter /mm              | 102     |
| First intermediate roller |         |
| Length /mm                | 1578    |
| Rolling force /KN         | 2706    |
| Length /mm                | 1000    |
| Strip                     |         |
| Width /mm                 | 1246    |
| Thick /mm                 | 1.3     |
| Tension /ton              | 45.9    |

2.2. Finite element modelling
Figure 2 shows the established finite element model for the dynamic analysis of the rolling process. The first intermediate rollers, the working rollers and the strip are included for calculation. The second
intermediate rollers and the backup rollers are eliminated due to the large stiffness and slight deflection during the rolling and to save computation time. The deformable first intermediate rollers and the working rollers were modelled using 3D solid element SOLID164 and the thin strip was modeled using 2D shell element SHELL163. The Coulomb friction law with a constant friction coefficient and a critical slipping force was adopted to account for the friction process taking place between the rollers and between the working rollers and the strip. Constant rotating speed was applied along the center axis of the two working rollers (S) respectively. The same rolling tension force was applied on the nodes at two edges of the strip along the rolling direction. The nodes lying at the center line of the underneath first intermediate rollers Q and R were constrained from moving in all directions. The decomposed rolling force according to the angle between the rollers was applied on the nodes at the center line of the up first intermediate rollers O and P. The elastic material parameters for the rollers are Young’s modulus $E=210\text{GPa}$, Poisson’s ratio $\nu=0.3$ and density $\rho=7830\text{kg/m}^3$, and the Young’s modulus for the strip is $E=200\text{GPa}$ with same Poisson’s ratio and density.

![Figure 2. The finite element model for the dynamic rolling process.](image)

### 2.3. Validation of the finite element analysis

To establish confidence in the FEA program for contact problems, a three-dimensional FEA simulation of the first intermediate roll in frictionless contact with the working roller was performed, as shown in Figure 3. The parameters used for calculation were Young’s modulus $E=210\text{GPa}$ and Poisson’s ratio $\nu=0.3$. Five different radial forces were employed for calculation as $F=232.5\text{KN}$, $310\text{KN}$, $387.5\text{KN}$, $465\text{KN}$ and $542.5\text{KN}$. The results were compared with the Hertz elastic theory [20] and are shown in Table 2. It can be seen that a difference of only 5% is found.

![Figure 3. Sketch diagram of the contact deformation between rollers.](image)
Table 2. Comparison between the FEA results and Hertz theory solution (in mm *10^-3).

| Radial load F (KN) | 232.5 | 310 | 387.5 | 465 | 542.5 |
|--------------------|-------|-----|-------|-----|-------|
| Hertz theory       | 5.5   | 7.1 | 8.7   | 10.3| 11.9  |
| FEA                | 5.3   | 7.0 | 8.8   | 10.5| 12.3  |
| err /%             | 4.05  | 2.81| 0.51  | 0.39| 2.08  |

3. Results and discussion
The finite element model is solved using the explicit dynamic method and the displacement, velocity and acceleration responses of the rollers during the rolling process are obtained for both with and without local defect on the working roller.

3.1. Vibration responses
Figure 4 and Figure 5 show the vibration responses of the first intermediate roller P for normal working roller and working roller with local defect respectively. It can be seen that the vibration responses oscillate more rapidly due to the local defect. The local defect will also induce a more rapid oscillation of the other rollers and affect the vibration characteristics of the roll mill. The surface quality of the strip will thus be negatively affected.

![Figure 4](image1.png)
**Figure 4.** Vibration responses of the first intermediate roller P (without local defect): a) displacement, b) velocity and c) acceleration.

![Figure 5](image2.png)
**Figure 5.** Vibration responses of the first intermediate roller P (with local defect): a) displacement, b) velocity and c) acceleration.
3.2. Stress distribution on the strip surface

Figure 6 shows the Von Mises stress distribution on the strip surface for both with and without local defect on the working roller. It can be seen that a concentrated stress is observed at region B on the strip surface when the localized defect on the working roller is in contact with the strip. However, no concentrated stress can be observed for a normal working roller. The concentrated stress on the strip surface will further reduce the surface quality of the rolled strip.

![Figure 6. The Von Mises stress distribution on the strip surface during the rolling process: a) working roller without defect and b) working roller with local defect.](image)

4. Experimental validation

To validate the accuracy of the numerical results, an experimental measurement was performed. Figure 7 shows the experimental setup for a 20-high Sendzimir mill. The acceleration response at the saddle of the backup roller above the first intermediate roller O was collected using a BK accelerometer attached to the housing near the backup roller, as shown in Figure 8. The vibration signals passed through an amplifier and were then put into the Dewetron-501 data collector for storage and analysis. The rolling force is 433.3 ton and the milling speed is 192.3 m/min for data collection. The entry thickness and exit thickness of the strip are 1.3mm and 1.182mm, respectively. The back tension is 45.9 ton and the front tension is 47.9 ton.

![Figure 7. Experimental setup.](image)
Figure 8. Sensor location.

Figure 9 shows the experimental frequency spectrum of the acceleration response, together with the corresponding numerical results from the first intermediate roller O. It can be seen that the characterized frequency 26.25Hz, which equals to the rolling speed/working roller perimeter, is observed from the experimental measurement. A very close characterized frequency 24.94Hz is also observed from the numerical result. The accuracy of the established finite element model and the numerical results are supported.

Figure 9. Comparison of the frequency-amplitude responses between the FEA and experimental result: a) experimental result and b) numerical result.

5. Conclusions
The effects of the working roller with a localized defect on the vibration characteristics and the surface quality of the strip are studied using the explicit finite element analysis approach. The following conclusions of this study can be drawn:
1) The performance of the Sendzimir mill and the surface quality of the strip are significantly affected by the local defect on the working roller during the rolling process.
2) The explicit finite element analysis is a reliable approach for simulating the dynamic rolling process of the roll mill.

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