Rolling Process Analysis of Working Rollers of Cold Rolling Mill Based on ANSYS

Kun Shi*, Gang Zheng and Jianhua Hang
Xi’an University of Technology, Xi’an, Shaanxi, China

*Corresponding author email: shikun@xaut.edu.cn

Abstract. Aiming at the complex changes of the working rollers and rolled pieces in the rolling process of a cold rolling mill, this paper built a finite element model of the working rollers and rolled pieces based on ANSYS, and analyzed the rolling process of working rollers by using the transient algorithm of structural dynamic equation. The stress-strain situation and rolling force curve of working rollers and rolling pieces were obtained. The results revealed the characteristic change process of working rollers and rolled pieces in the rolling process, which laid the foundation for further realizing the precise control of the rolling process of cold rolling mill.

1. Introduction
Rolling is the subsequent key process of steel production, which involves elastic deformation and plastic deformation. The characteristic change of working rolls and strip steels in rolling process is a complex change process [1]. Scholars at home and abroad have done a lot of research on the rolling. Cavaliere et al [2] used Hermitian beam element to develop one-dimensional finite element model to calculate the elastic deformation of roll system. Montmitonnet [3] adopted the semi theoretical and semi numerical finite element model. The influence function method is still used in the calculation of the bending deformation and the contact flattening between rolls, which is very complex. Bambach et al [4] derived a fluid-dynamics model to describe high-volume steel rolling processes. The steel rolling was modeled as a particle game where each particle corresponds to a piece of steel at a certain production stage. Based on a stochastic interpretation of the particle game, a kinetic equation was derived as well as fluid-like limiting equations under suitable scaling of time. Liu et al [5] used the influence function method to calculate the roll system deformation. Dong Li et al [6] used the recurrence method to calculate the deflection and longitudinal stiffness of the roll system. But the recurrence formula was complex and the physical meaning was not clear. Yu et al [7] carried out the finite element numerical simulation of roll deformation, and analyzed the influence of rolling pressure, strip width and roll configuration on roll deflection.

At present, in view of the rolling problem of cold rolling mill, the analytical model was established to solve the elastic-plastic change of cold rolling mill structure, which not only involved a large amount of calculation, but also involved many assumptions and had a large deviation from the actual results. The calculation of the finite element was based on the actual size of the roll. The simulation process was closer to the real situation, which was more instructive for the analysis of rolling problems. In order to have a further understanding of the complex change process of work roll and strip in the process of strip rolling, the actual parameters of working roll of a multi roll rolling mill were used to establish its rolling model, analyzed the rolling process, and obtained the stress-strain results and rolling force curve of work rolls and rolled piece.
2. Finite Element Model of Working Roller of Cold Rolling Mill

Because the material of the roller is linear elasticity and the rolled piece is elastic-plastic, the forming process of the elastic-plastic is nonlinear. The contact between the linear elasticity and the elastic-plastic is also nonlinear. The rolling process of the upper and lower work rollers to the rolled piece is highly nonlinear.

The rolled piece material is steel Q235, and the size parameters and material performance parameters are shown in Table 1 and Table 2. The constraints are imposed on the thickness direction and width direction of the rolled piece.

| Table 1. Size of the rolled piece |
|----------------------------------|
| Width(mm) | Thickness(mm) | Length(mm) |
| 950       | 4             | 300        |

| Table 2. Material performance parameters of the rolled piece |
|-------------------------------------------------------------|
| Elastic modulus(MPa) | Density (kg/m³) | Poisson's ratio | Yield stress (MPa) | Tangent modulus (MPa) |
| 2.03E+5             | 7850           | 0.3            | 235                | 6100                 |

The material of working rollers is 9Cr2M, and the size and material performance parameters of working rollers are shown in Table 3 and Table 4.

| Table 3. Size of working rollers |
|----------------------------------|
| Diameter(mm) | Length(mm) |
| 63.5         | 1444        |

| Table 4. Material performance parameters of working rollers |
|-------------------------------------------------------------|
| Elastic modulus (MPa) | Density (kg/m³) | Poisson's ratio |
| 2.36E+5              | 7810           | 0.3             |

Considering the strengthening characteristics of the material, the material of the rolled piece was defined as bilinear isotropic hardening model (BIS0), which used bilinear to express the stress-strain curve. Therefore, the stress-strain curve has two slopes, elastic slope and plastic slope, which are generally used for the large strain problem of the initial isotropic materials and is very suitable for the forming of strip steel in this study. The material of the roller was defined a linear elastic model.

In the finite element model of working roller of cold rolling mill, the solid element of solid186 was used for the rollers and the rolling piece, conta174 was used for the contact surface, targe170 was used for the target surface, and surface effect element surf154 was used for applying the tension. The contact between the rollers and the rolling piece was set as the friction contact type. Because the rolling piece and the rolls are always in contact with each other, normal Lagrange contact algorithm was used, which can quickly get convergence solution.

The boundary condition of the rolling piece was set to release only z-axis translation without friction support, and the rollers were set to release only two degrees of freedom, Y-axis translation and z-axis rotation. The rolling model of the working rollers was solved after applying tension, reduction, friction, speed and other parameters. Tension rolling was used in cold rolling, which could not only reduce rolling pressure and energy consumption, but also ensure flatness of plate. Table 5 shows some parameters of the rolling process.

| Table 5. Parameters of rolling process |
|---------------------------------------|
| Angular velocity of rollers (rad/s)   | Pretension stress(MPa) | Posttensional stress(MPa) | Static friction | Dynamic friction |
| 3rad/s                               | 42.3                    | 42.3                       | 0.3             | 0.15             |
3. Rolling Process Analysis

3.1. Theoretical Basis of Finite Element Dynamic Analysis
The previous metal forming problems mostly use the display dynamics analysis, which requires a very small time increment to ensure the stability of the end discrete in the time domain. However, the time increment step of the implicit algorithm can be relatively large and reach the goal of closing. The steps of convergence condition can guarantee the correctness of the result \[8\]. Therefore, the implicit algorithm of transient dynamics can be used to simulate the strip forming process of rolling. The implicit algorithm requires that the load step be divided into several sub steps. If there are too many sub steps, the calculation time will be long, and the number of sub steps will be too small. Then it will lead to no convergence of calculation results. Therefore, ANSYS needs to set the initial number of sub steps, the maximum number of sub steps and the minimum number of sub steps. When the program starts to run, the software will operate according to the initial number of sub steps. When it is judged that the calculation result is not convergent, the number of sub steps will be increased. If the convergence accuracy is enough, the number of sub steps will be reduced. If it does not converge after a certain number of sub steps, the program will report an error.

3.2. Rolling Process Analysis
According to the implicit algorithm of transient dynamics, the parameters are adjusted continuously, and the acceptable rolling shape results are obtained by simulation. Figure 1 shows the equivalent stress distribution diagram of the working rollers and rolled pieces at the end of rolling. It can be seen from the figure that the equivalent stress of the rolled piece is different at different times. Especially when the rolled piece is in the rolling position, the equivalent stress is greater than the buckling strength of the rolled piece. At the same time, there is a stress release link in the rolled area, which results in the stress value slightly less than the stress value during rolling.

![Figure 1. Equivalent stress cloud diagram of rolling](image)

3.3. Analysis of Working Rollers
Figure 2 shows the equivalent elastic strain of the working roller in the rolling process. The strain of the working roller in the width direction is relatively uniform. But the strain at both ends of the working roller is relatively large. The two ends of the rolled shape are thinner than the middle.

![Figure 2. Equivalent elastic strain of working rollers](image)

3.4. Analysis of Rolled Piece
The plastic residual strain of the rolled piece is the deformation result of the unrecoverable part of the rolled piece after rolling. From the strain cloud chart in Figure 3, the strain of the rolled piece is basically 0.1754, which is relatively uniform. According to the relationship between the strain of the rolled piece and the deformation, the deformation of the rolled piece is 0.7016mm when the thickness of the rolled piece is 4mm. The actual reduction of the rolled piece is about 17.54%, which is close to the set value. And it can be clearly seen that the strain at both ends of the rolled piece is large.

![Figure 3. Plastic residual strain of rolled piece](image)

3.5. Analysis of Rolling Force

Figure 4 shows the curve of the maximum rolling force along the width direction during rolling. It can be seen from the curve that it takes a certain time for the rolled piece to enter the rollers’ gap at the beginning. Then, the rolling force begins to increase. When the rolling ends at the end of nearly 2s, the rolled piece gradually leaves the working roller, and the rolling force also decays to zero under the inertia. At the same time, the rolling force fluctuates greatly. It may be that the grid of rollers and rolling piece is not enough dense, or the contact damping setting is unreasonable.

![Figure 4. Curve of the rolling force](image)

4. Conclusion

This paper uses ANSYS to realize the rolling process simulation of work roller and rolling piece. In the process of analysis and modeling, it is necessary to establish the material model of rolling piece and work rollers, divide the mesh of two roll model, define contact type and contact algorithm, set boundary conditions and loads, and resolve the model by the structural dynamics method of transient dynamics algorithm. In particular, the mesh of contact area should be sufficiently fine.

The calculation results are basically in line with the actual situation of rolling. The results revealed the characteristic change process of working rollers and rolled pieces in the rolling process, which laid the foundation for further realizing the precise control of the rolling process of cold rolling mill.

Acknowledgments

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