Available online at www.sciencedirect.com

ScienceDirect

JOURNAL OF IRON AND STEEL RESEARCH, INTERNATIONAL. 2015, 22(11): 996-1001

Plate Shape Control Theory and Experiment for 20-high Mill

Zheng-wen YUAN[1,2], Hong XIAO[1,2]

(1. National Engineering Research Center for Equipment and Technology of Cold Strip Rolling, Yanshan University, Qinhuangdao 066004, Hebei, China; 2. College of Mechanical Engineering, Yanshan University, Qinhuangdao 066004, Hebei, China)

Abstract: Roll flattening theory is an important part of plate shape control theories for 20-high mill. In order to improve the accuracy of roll flattening calculation for 20-high mill, a new and more accurate roll flattening model was proposed. In this model, the roll barrel was considered as a finite length semi-infinite body. Based on the boundary integral equation method, the numerical solution of the finite length semi-infinite body under the distributed force was obtained and an accurate roll flattening model was established. Coupled with roll bending model and strip plastic deformation, a new and more accurate plate control model for 20-high mill was established. Moreover, the effects of the first intermediate roll taper angle and taper length were analyzed. The tension distribution calculated by analytical model was consistent with the experimental results.

Key words: 20-high mill; roll flattening; finite length semi-infinite body; boundary integral equation method; plate shape control

The 20-high cold rolling mill, which has rolls arranged as cluster, is widely used in thin strip rolling process. In the past years, some researches on 20-high mill have been made to improve the quality of the plate shape. The roll deformation and plate shape can be obtained by finite element analysis (FEA) and analytical model. FEA can be used to calculate roll deformation accurately[1], but it is difficult for online calculation due to its time-consuming. Compared with FEA, the analytical model can greatly shorten the calculation time and the calculation accuracy is acceptable.

Roll deformation theory is the core part of plate shape control theories, which includes roll flattening and roll bending deformation. Foppl formula[2] and semi-infinite body model[3] are the most popular analytical models in the roll flattening calculation. With Foppl formula as the roll flattening model, Yu et al.[4] established a roll deformation model of 20-high mill. Coupled with the metal plastic deformation, the effects of the first intermediate roll shifting and taper, AS-U-ROLL, tension, work roll crown and the second intermediate non-drive roll crown on strip edge drop were analyzed. Cho and Hwang[5] deduced an analytical model for predicting plate shape of 20-high Sendzimir mill. The model, which was developed on the basis of the predictions from finite element simulation, was applied to the analysis of roll deformation in a 20-high Sendzimir mill under some special conditions, such as rigid outer rolls and without roll shifting, etc. A numerical model for plate shape prediction of 20-high Sendzimir mill is established by Shin et al.[6], which is based on the contact element method, and the effects of AS-U-ROLL and first intermediate roll were considered. A numerical model based on the contact element method and Foppl formula for the prediction of plate shape for 20-high mill was obtained by Shin et al. Wang et al.[7] investigated the effect of different AS-U-ROLL control schemes on the plate shape defects in 20-high mill rolling process using the semi-infinite body model as the roll flattening model. A simulation model for predicting the shapes of cold-rolled strips in 20-high Sendzimir mills was developed by Hara et al.[8]; by this model, improvement of quarter buckles was shown difficult merely by conventional shape control actuators.

However, contact position and roll flattening are very complicated because the rolls of 20-high mill are arranged as cluster. The current roll flattening model cannot obtain accurate result for 20-high mill. Foppl formula is derived based on the assumption of ignoring the strain along the axial direction, which leads to the low-precision of Foppl formula. Semi-infinite body model is derived based on Boussinesq solution[9]. In the semi-infinite body model, the effects of shear stress and normal stress along the axial direction are considered. However, since the roll barrel has a finite length, the roll flattening calculated by semi-infinite body model has a great deviation from actual situation, especially near the barrel edges.

In the past years, some improvements have been done to increase the accuracy of the calculation, such as

Foundation Item: Item Sponsored by National Natural Science Foundation of China (51474190); Natural Sceince Foundation of Hebei Province of China (E2015203311)
Biography: Zheng-wen YUAN, Doctor; **E-mail:** yzwysu@ysu.edu.cn; **Received Date:** June 20, 2014
Corresponding Author: Hong XIAO, Doctor, Professor; **E-mail:** xhh@ysu.edu.cn

Berger[10], Zhou[11,12] and Hacquin[13]. But most modified semi-infinite body models were based on the result obtained by FEA, which is practical, and there were too many assumptions and lack theoretical support. In this paper, the deformation of a finite length semi-infinite body under the distributed force was obtained based on boundary integral equation method. The results were used in roll flattening calculation of strip rolling mill and more accurate roll flattening results were predicted. Based on the roll flattening model, a new roll deformation model of 20-high mill was deduced. Coupled with the strip plastic deformation, more plate shape value was obtained.

1 Establishment of Roll Flattening Model Based on Finite Length Semi-infinite Body

The displacement field of a finite length semi-infinite body under the distributed force $t_3(Q)$ is shown in Fig. 1. The length of the finite length semi-infinite body is L along X_1-axis and infinite along X_2-axis and X_3-axis positive direction.

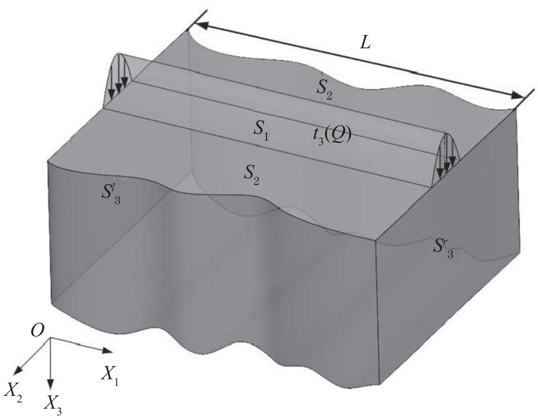

Fig. 1 Finite length semi-infinite body under the distributed force

In order to solve the problem in Fig. 1, the boundary integral equation is established as Eq. (1)[14].

$$C_{ij}(P)u_j(P)+\int_S t_{ij}^*(P,Q)u_j(Q)\mathrm{d}S=\int_S u_{ij}^*(P,Q)t_j(Q)\mathrm{d}S \tag{1}$$

where, P is load point; $C_{ij}(P)$ is a function about Kronecker symbol; $u_j(P)$ is the displacement of P in j direction; Q is field point position vectors; $u_j(Q)$ and $t_j(Q)$ are displacement vector and traction vector; S is the boundary; and $t_{ij}(P,Q)$ and $u_{ij}(P,Q)$ are fundamental solutions for the tractions and displacements in j direction of Q due to a unit load in i direction of P.

Eq. (1) can be derived by Betti reciprocal theorem, which is applicable for both surface and internal points. The fundamental solutions can be chosen from Kelvin solution or Mindlin solution in the isotropic case. In this paper, Mindlin solution[15] was used.

Considering the rolling actual situation and roll barrel contact feature, Eq. (1) can be dispersed and simplified as Eq. (2)[16].

$$\begin{aligned}u_3(P_i)=&\sum_{j=1}^{n}\int_S u_{33}^*(P_i,Q)T_j(X_2)\mathrm{d}S-\\&u_1(P_1)\int_{S^l} t_{31}^*(P_i,Q)f'(X_2,X_3)\mathrm{d}S-\\&u_1(P_n)\int_{S^r} t_{31}^*(P_i,Q)f'(X_2,X_3)\mathrm{d}S-\\&u_3(P_1)\int_{S^l} t_{33}^*(P_i,Q)f(X_2,X_3)\mathrm{d}S-\\&u_3(P_n)\int_{S^r} t_{33}^*(P_i,Q)f(X_2,X_3)\mathrm{d}S\\&(i=1,2,\cdots n)\end{aligned} \tag{2}$$

where, $f(X_2,X_3)$ and $f'(X_2,X_3)$ are the lateral surface displacement decay functions, and the detailed derivation process is shown in Ref. [16].

Based on FEA, it is concluded that the displacement decay law is related to the distance from action points of force and the contact arc length ($2b$). Considering all the factors and the simulation results of FEA, the lateral surface displacement decay functions are expressed as follows.

$$f(X_2,X_3)=0.258\cdot\left(\ln\frac{1\,000b}{b+\sqrt{X_3^{\,2}+(1.8X_2)^2}}\right)^{0.7} \tag{3}$$

$$f'(X_2,X_3)=0.055\cdot\left(\ln\frac{1\,000b}{b+\sqrt{X_3^{\,2}+(1.56X_2)^2}}\right)^{1.5} \tag{4}$$

Based on Eqs. (2)–(4), the roll flattening can be obtained. The new model is compared with semi-infinite body model, Foppl formula and FEA. The result shows that the flattening calculated by the new model is more close to FEA than the other models[16].

2 Establishment of Plate Shape Control Model

2.1 Establishment of roll deformation model

Based on the new roll flattening model, a new 20-high mill roll deformation model can be established. The roll deformation of 20-high mill includes roll bending deformation, roll flattening deformation among rolls, and roll flattening between work roll and strip. Considering the complexity of 20-high mill roll deformation, the roll barrels of 20-high mill are divided into a series of equal units. The load and deformation of each unit are analyzed separately. The 20-high mill deformation discrete model is shown in Fig. 2, in which $\boldsymbol{P}_j$ is the rolling force of unit j, and $\boldsymbol{q}_j$, $\boldsymbol{q}_j'$ and $\boldsymbol{q}_j''$ are pressure between rolls of the first, second and third layers, respectively.

The 20-high mill rolls are set as a cluster, as shown in Fig. 3. In order to analyze roll deformation, force analysis should be carried out for the special structure of rolls, and then the force equilibrium, deflection deformation, torque equilibrium, and displacement coordination function can be established. In Fig. 3, α_1–α_7 are the angles between rolls center connection and horizontal line, and e is eccentricity.