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Structure parameters and function of hydraulic elastic bulging roller①

LI Wei-min(李纬民), LIU Zhu-bai(刘助柏), ZHAO Chang-cai(赵长才), LIU Guo-hui(刘国晖)
(School of Mechanical Engineering, Yanshan University, Qinhuangdao 066004, P. R. China)

[Abstract] The fundamental principle and method of the determining of structure parameters for the hydraulic elastic bulging roller were discussed. The relationship among crown of roller, hydraulic pressure and thickness of roller sleeve was studied. Aluminum was chosen as experimental material to accomplish the dynamic load experiment. The hydraulic elastic bulging roller exerts good effect on shape control and therefore has a broad application prospect in engineering.

[Key words] hydraulic bulging roller; shape control; structure parameters
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1 INTRODUCTION

On the view of geometry, weather the shape is perfect depends upon change of crown occurred in the rolling process. If the stretching of the rolling stock in the rolling process is neglected, geometrical dependence of perfect shape can be expressed as[1]:

$$C_h = \frac{h}{H} C_H \qquad (1)$$

where C_h is the exit crown of sheet metal, H is the entrance thickness of sheet metal, h is the exit thickness of sheet metal, C_H is the entrance crown of sheet metal. Eqn. (1) shows that the exit crown of sheet metal must be less than the entrance one, so that perfect shape can be obtained. Therefore, it is necessary that the structure of rolling mill and technological control system should be able to reduce the crown of sheet metal.

If the elastic recovery of the rolled sheet metal is ignored, its exit crown will be decided completely by the loaded roll gap. The appearance of the gap should consequently suit to the exit crown of sheet metal decided by Eqn. (1). The responses of roll system to the rolling load and technology, i.e. elastic bending, elastic squash, thermal expansion, wear and the original shape of roller are five essential factors for forming the gap. Among them, the influences of elastic deformation and the thermal crown are the largest, therefore, they play an important role in changing the roll gap. If the shape of roll gap is satisfied with Eqn. (1) only by adjusting roller crown, the latter should be just equal to the elastic deformation (bending deflection and squashing) caused by rolling force. Under practical rolling condition, rolling force is linear with roller crown corresponding to good sheet shape[2]. The relationship is called perfect shape curve (the solid line in Fig. 1).

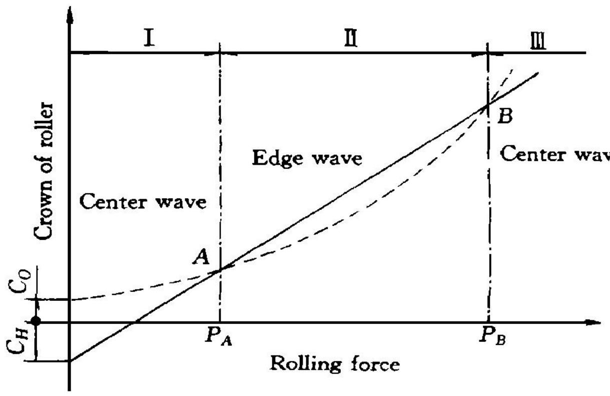

Fig. 1 Perfect shape curves

A part of heat transformed by deformation energy of rolling stock and friction work produced between roller and sheet metal in rolling process can be pass to the cylinder system, so the thermal crown appears. In the state of stable rolling, the relationship between rolling force and thermal crown can be approximately expressed as exponential function (the dashed line in Fig. 1), where C_0 is the original crown of roller. To a certain extent, thermal crown can compensate for the elastic deformation of the roller. Because of this compensation, even if no adjusting measurement is adopted, sheet metal shape will be good, when the needed rolling force corresponds with the point A or B, the intersecting points of perfect shape curve and thermal crown curve.

If the rolling force is in area II, the sheet metal has edge wave, because the actual crown of the roller constituted by initial crown and thermal crown is less than the necessary value to guarantee high quality. If the force is in area I and III, all are opposite to the force in area II. To get good shaped sheet metal with any permissive load, the roller and its control system should have the ability to modulate its crown. Many researches such as hydraulic bending roller technology, HC rolling mill with cross movable middle

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roller[3], continue variable crown CVC rolling mill[4] and the PC rolling mill with crossing working roller and back-up roller were put forward[5,6]. The mathematical model for shape control when aluminum plate being rolled on HC rolling mill was also presented[7]. All these achievements stimulated the development of shape control.

All above mentioned techniques are beneficial to shape control in different aspects, but each also has its own shortage, especially in rolling mill improvement and on-line shape control.

In the early 1980s, Japanese Sumitomo Metal Industries Ltd developed a new shape control technology, which is hydraulic elastic bulging roller[8], also called VC (variable crown) roller, and its crown can be changed momentarily. The IC roller technology in America is a similar one[9], it is not only suitable for on-line shape control with high shape control ability and high responding speed, but also convenient for rolling mill improvement; and now it has been used in Japan, America, etc. Ref. [10] gives an elementary static load experiment. According to a Key Program of the 9th Five-year Plan of China, a pair of back-up hydraulic bulging rollers was developed by the authors, its structure parameters and function are studied and dynamic load experiments based on Al.

2 HYDRAULIC ELASTIC BULGING ROLLER SYSTEM AND ITS WORKING PRINCIPLE

Hydraulic elastic bulging roller is a crown variable system, its crown can be changed or modulated instantly according to the demand of products. Its working principle is shown in Fig. 2. Hydraulic elastic bulging roller consists of an arbor and a sleeve. High-pressure oil can flow into the oil chamber between the axis and the sleeve through high speed rotating joint. Under the high hydraulic pressure, the sleeve bulges and leads to the corresponding crown. By modulating the hydraulic pressure, the crown of sleeve can be changed continuously. Consequently the roller bending deformation can be adjusted at the same time, so the shape can be controlled. It is a strict interference fit between the sleeve and the arbor at the two ends along certain length so the pressurized oil can be sealed up very well. On the other hand the working torsion can be transmitted and the general rigidity of roller can be ensured.

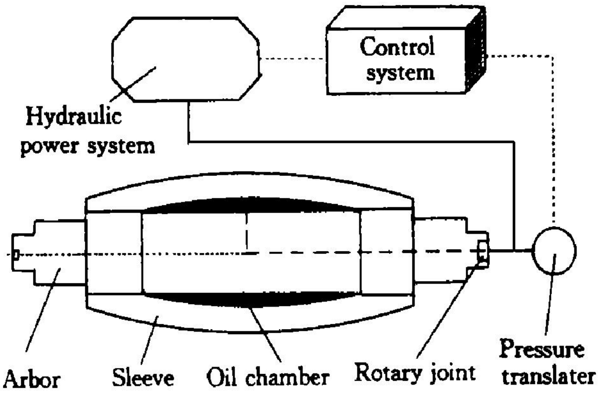

Fig. 2 Structure principle of hydraulic elastic bulging roller

3 STRUCTURE PARAMETERS OF HYDRAULIC ELASTIC BULGING ROLLER

The dynamic load experiment was carried out on the 4-roller mill in rolling lab of Yanshan University. The original back-up roller is substituted by the new made hydraulic elastic bulging one, so its install dimension and the sleeve outer diameter are equal to the original one's. Under this situation, the optimum overlapped value and the sleeve thickness are two important parameters for hydraulic elastic bulging roller.

3.1 Finite-element model

Without rolling load, hydraulic elastic bulging roller is an axis symmetric problem. Fig. 3 gives the FEM simulation model.

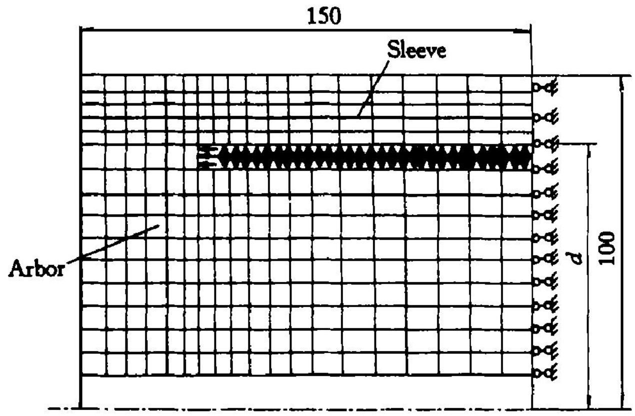

Fig. 3 FEM discrete model of hydraulic elastic bulging roller

The mechanical properties of the simulated material 70Cr3Mo is given:

$E = 2.058 \times 10^5$ MPa

$\mu = 0.28$

where E is elastic modulus and μ is Poisson's coefficient. This simulation belongs to statically indeterminate problem. It is supposed the point P_1 belongs to arbor and P_2 belongs to sleeve before installation, then P_1 and P_2 become one communal point P between sleeve and arbor after installation, so the deformation harmony conditions for the two points are

$$\text{Radial: } \delta = u_2 - u_1 \tag{2}$$

$$\text{Axial: } v_1 = v_2$$

where δ is unilateral overlapped value; u_1 is radial displacement of point P_1 and u_2 radial displacement of point P_2; v_1 is axial displacement of point P_1 and v_2

axial displacement of point P_2.

The introduction of this condition is convenient to calculate stress, strain and displacement, etc, with any load condition.

3.2 Calculation for designing roller sleeve thickness

When deciding the roller sleeve thickness, two factors must be considered. One is the demanded crown for controlling shape offered by sleeve under high hydraulic pressure, the other is sleeve strength and rigidity. Under certain pressure, the thicker the sleeve is, the less the crown will be, which will weaken the shape control ability. On the other hand, if the sleeve is too thin, the rigidity will be too small to guarantee good shape. The relationship between maxim crown and the thickness under 500 MPa hydraulic pressure is given in Fig. 4.

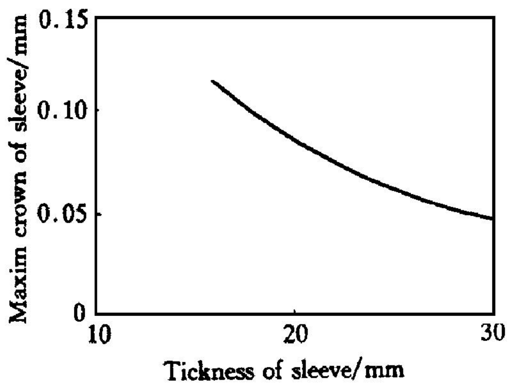

Fig. 4 Relationship between maximum crown and thickness under 500 MPa hydraulic pressure

It can be seen that along with the increase of thickness, the crown will decrease approximately linearly. So the thickness can be decided according to the shape control demand. In the experiment, the thickness is 20 mm and the calculated crown is 0.085 mm.

3.3 Decision of optimum overlap

The optimized overlap between axis and sleeve when installing should meet three demands. First, it should seal up high-pressure oil strictly. Second, transmit torsion. And third, there is no relative radial displacement between contact pair points so the bending rigidity of the hydraulic bulging roller can be equal to solid roller under peak rolling load and highest pressure. To meet the three demands, enough overlap is needed. Considering processing, the heating temperature of sleeve determined by overlap value should be lower than its temper temperature after quenching, otherwise the needed hardness cannot be got.

4 HYDRAULIC ELASTIC BULGING ROLLER STATIC LOAD PROPERTIES

By using self-made FEM program, based on the new developed hydraulic bulging roller, the geometric model shown in Fig. 3 was simulated. Crown distribution of hydraulic elastic bulging roller under different hydraulic pressures is calculated and the result is given in Fig. 5.

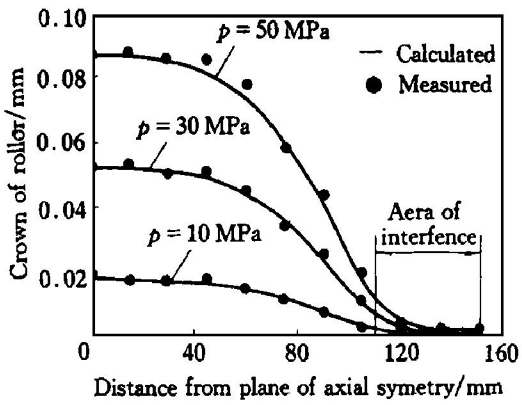

Fig. 5 Relationship between crown of roller and hydraulic pressure

The length of unilateral interference fit is 40 mm, and the sleeve thickness is 20 mm. It is clear that under high pressure, the crown axial distribution is similar to the cosine curve. So the crown can be used to compensate elastic deformation by controlling the pressure. When the pressure is 50 MPa, the relative error between the calculated and metrical value is only 0.46%.

5 DYNAMIC LOAD EXPERIMENT ON HYDRAULIC ELASTIC BULGING ROLLER

To get its actual shape control effect, the dynamic load experiment on rolling Al plate was carried out. All the 2 mm thick plates were rolled to be 1 mm thick, 200 mm wide with good shape. The experiment was carried out on the 4-roller mill with hydraulic elastic bulging back-up roller.

Under different hydraulic pressures, the plate was rolled with same reduction. The thickness both in the center and the edge of the plate were measured. The crown were calculated and the shape were checked. When oil pressure p = 0, there is edge wave obviously and the absolute crown is about 12 μm (as shown in Fig. 6(a)). With increasing pressure, the crown decreases and the shape becomes better and better. When the pressure is 10 MPa, the absolute crown is about 0.5 μm, the plate surface is even, good shape is obtained (as shown in Fig. 6(b)). Along with increase of pressure, crown will appear oppositely, plate has center wave. The higher the pressure is, the higher the center wave is. When p = 25 MPa, the shape is shown in Fig. 6(c). Accordingly, the shape changes from edge wave to even until at last it becomes center wave. It is obviously that the hydraulic elastic bulging roller exerts strong ability to

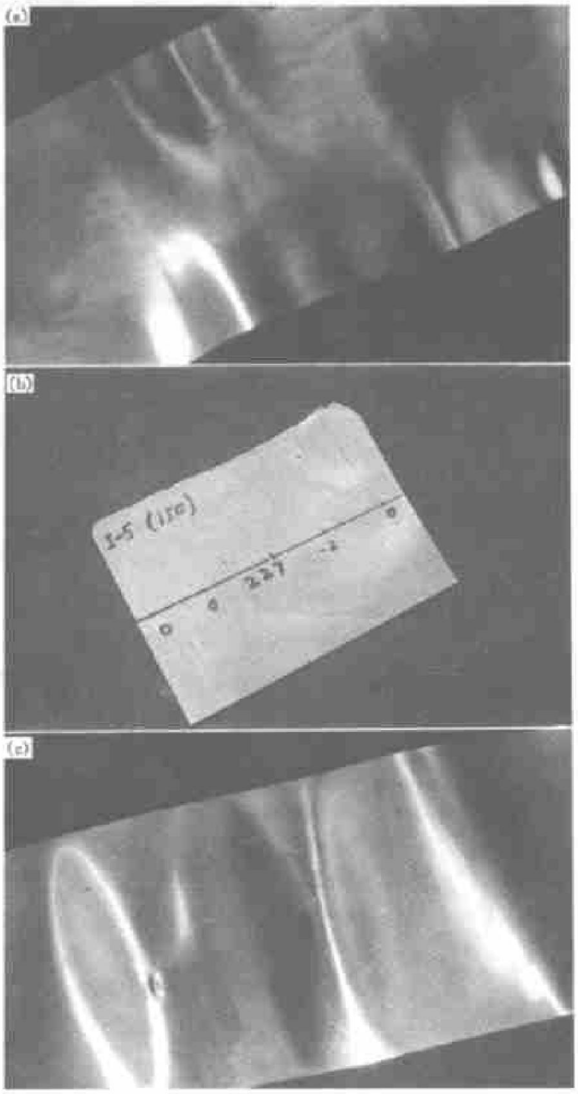

Fig. 6 Macrostructures of plates under different hydraulic
(a) $\bar{p} = 0$; (b) $\bar{p} = 10$ MPa; (c) $\bar{p} = 25$ MPa

control shape.

Owning to the instant variable hydraulic pressure and the elastic response of the hydraulic elastic bulging roller, the technology can be used especially for on-line shape control.

6 CONCLUSIONS

1) Hydraulic elastic bulging roller exerts good effect on shape control.

2) The overlap between axis and sleeve should seal up high-pressure oil strictly and transmit rolling load. And the heating temperature of sleeve determined by overlap should be lower than its temper temperature.

3) The dynamic load experiment proves that the crown properties with dynamic load of the self-developed hydraulic elastic bulging roller can meet the demand of shape control for rolling Al plate.

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