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INFLUENCE OF PROCESS PARAMETERS ON THE FORMING MECHANICS PARAMETERS OF THE THREE-ROLL SKEW ROLLING FORMING OF THE RAILWAY HOLLOW SHAFT WITH 1: 5

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This paper presents the new technology applied in a three-roll skew rolling railway hollow shaft. The three-roll skew rolling forming simulation is conducted in railway hollow shaft with 1: 5. The rotation condition of the three-roll skew rolling is deduced and the rolling force and rolling torque are calculated and validated. The influence of process parameters on mechanics parameter is analyzed, from which it concludes that the mechanics parameters of the skew rolling are obviously smaller than those acquired by the cross-wedge rolling when rolling the same size of the railway hollow shaft. The results of this study lay a theoretical foundation for the realization of accurately forming the three-roll skew rolling railway hollow shaft with short process and low cost.

Key words: three-roll skew rolling, railway hollow shaft, rotation condition; process parameters, mechanics parameters

INTRODUCTION

Now, the development of the railway industry is of great significance to the sustainable development of the world. In china, according to experts' predict that in 2 020 the number of high-speed rail train inventory will reach 8 000 and 1 million high-speed rail axles will be demanded [1-2]. At present, the hollow axle is mainly produced by free forging and wedge rolling. The core technology of precision forging is mainly mastered by developed countries. The cross wedge rolling method has the advantages of significantly improving the productive efficiency and material utilization compared with the free forging method[3].

Railway shaft is a large shaft part with the maximum diameter of φ 222 mm and the maximum length of 2 356 mm. If the train axle is produced by the method of cross wedge rolling, the die diameter will reach about φ 3 000 mm and wedge rolling mill height will exceed 9 000 mm. Such a large machine and a mold that require huge investment are impossible to be implemented, as they will lead to difficult production and inconvenient operation. While the three-roll skew rolling can solve the above problems [4-5].

PRINCIPLE AND INNOVATION

In this paper, based on the technology of reducing hollow diameter by three-roll skew rolling and the technology of profiled spiral rolling axle, a new technology of the three-roll skew rolling is proposed. The process consists of three movements: 1) The roller rotates around its own axis; 2) The roller moves along the radial direction of the workpieces, which reaches the purpose of controlling the roller spacing; 3) The workpieces are axially moved under the traction of the clamp so that the workpieces can extend axially. The process by synchronously controlling the radial movement of the roller and the axial movement of the rolling piece achieves the rapid rolling cross-section stepped shaft of the three-roll skew rolling. Within a reasonable range when rolling different products, there is no need to change the roller. What we should do is to simply change the workpiece as well as the roller path, so the equipment is very versatile.

FEM AND SIMULATION PROGRAM

Due to the large size and long simulation time of railway hollow shaft, so this paper takes railway hollow shaft with 1: 5. Using the theory of relative motion, the axial feeding motion of the roller replaces the axial movement of the rolling piece. The roller movement composes of the roller rotation, axial feed and radial feed. workpieces are rotated driven by the roller; the rolling direction is from left to right. The finite element model (FEM) is shown in Figure 1.

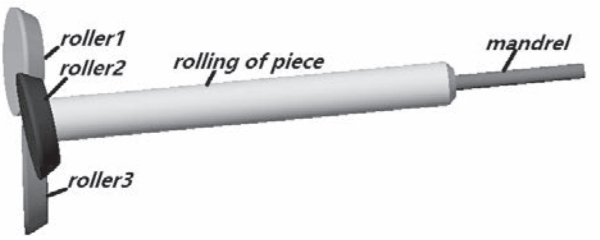

Figure 1 FEM of three-roll skew rolling hollow shaft

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This paper has designed 22 sets of single-factor finite element simulation. As shown in Table 1, studying the influence of seven process parameters of the three-roll skew rolling hollow shaft on rolling mechanics parameters, which includes the feed angle α, the toe angle β, the length L of the roller forming zone, the roller rotation speed r, the axial velocity v of the workpiece, roller radius R and the temperature T.

Table 1 **The process parameters**

	Reference	Change
T / °C	1 150	950/1 000/1 050/1 100
r / rpm	60	30 / 90
L / mm	4	3 / 5 / 6
α / °	30	25 / 35 / 40
β / °	7	5 / 6 / 8
R / mm	50	25 / 37,5 /62,5
v / mms^{-1}	20	10 / 30 / 40

THEORETICAL CALCULATIONS AND VERIFICATION OF ROLLING MECHANICS PARAMETERS

As shown in Figure 2, the lateral force F_X, the axial force F_Y and the radial force F_Z can be directly derived by the Simufact13.3. The process of deducing rolling force and torque calculation is as follows according to the stress of the roller and the rolling piece in Figure 3.

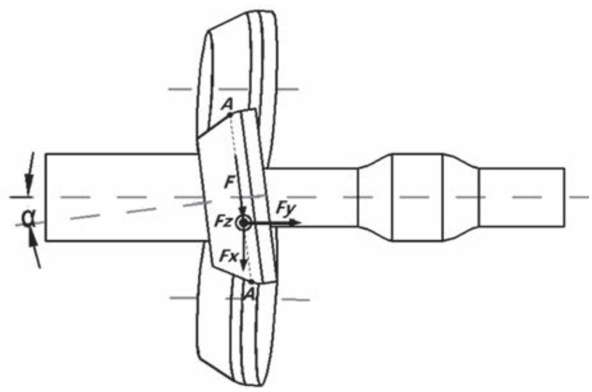

Figure 2 Rolling force diagram

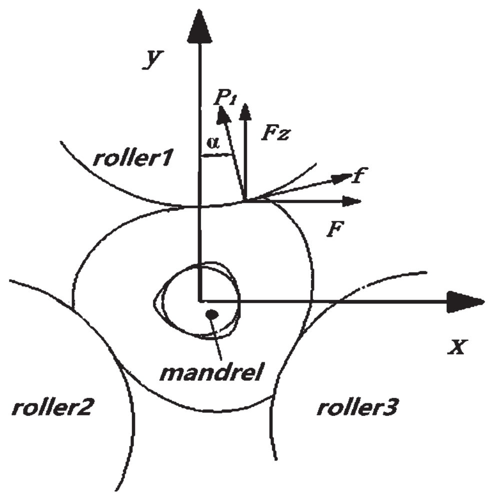

Figure 3 Rolling force diagram in A-A

Figure 4 Finite element results diagram

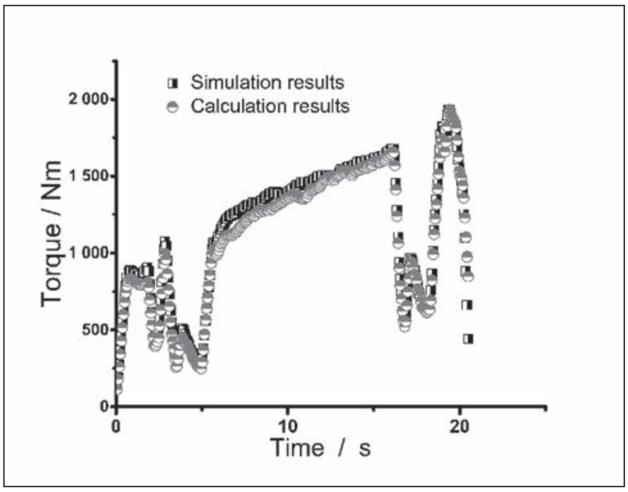

Figure 5 Comparative results diagram

$$F = Fx \cdot \cos\alpha + Fy \cdot \sin\alpha \qquad 1$$

$$F = f \cdot \cos\gamma - P_1 \cdot \sin\gamma \qquad 2$$

$$F_z = f \cdot \sin\gamma + P_1 \cdot \cos\gamma \qquad 3$$

$$f = \mu \cdot P_1 \qquad 4$$

Synchronous 1, 2, 3, 4 available rolling force P1:

$$P_1 = \sqrt{\frac{F_z^2 + F_x^2 cos^2 \propto + F_y^2 sin^2 \propto + F_x F_y sin2 \propto}{\mu^2 + 1}} \qquad 5$$

So the rolling torque T is:

$$T = 3f \cdot D/2 = 3\mu \cdot P_1 \cdot D/2 = \qquad 6$$

$$= \frac{3\mu D}{2}\sqrt{\frac{F_z^2 + F_x^2 cos^2 \propto + F_y^2 sin^2 \propto + F_x F_y sin2 \propto}{\mu^2 + 1}}$$

Under the conditions of the process parameters in reference, the finite element simulation result show in Figure 4, the rolling torque derived from the software and that acquired by the theoretical calculation are compared. The comparison results are shown in Figure 5 from which it can see that the overall error of the compared figures is less than 10 %, thus it demonstrates that the calculation formula 5 - 6 of rolling force and rolling torque derived in this paper has high reliability.

THE RULE OF EFFECT OF PROCESS PARAMETERS ON MECHANICS PARAMETERS

The process parameters include feed angle α, toe angle β, the length of the roller forming zone L, roller rotation speed r, roll radius R, the axial velocity of the workpiece v and temperature T, which is the main factor that affects the rolling mechanics parameters of the three-roll skew rolling.

Under the condition of process parameters in reference, the overall change tendency of the exploration

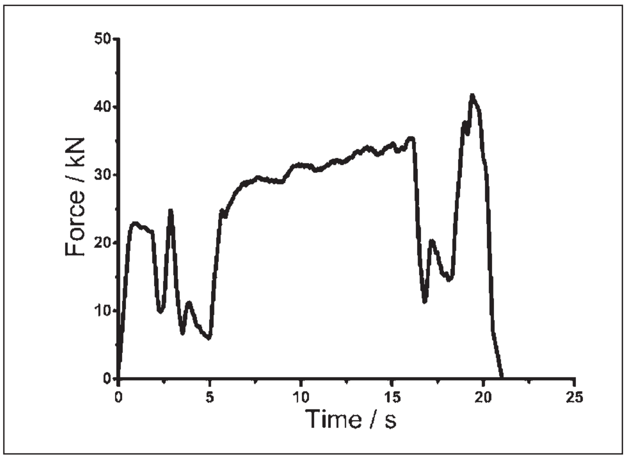

Figure 6 Rolling force

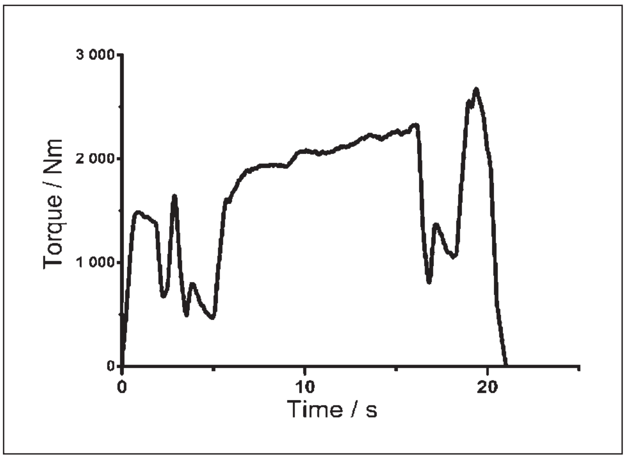

Figure 7 Rolling torque

mechanics parameters is selected. The rolling force in Figure 6 is calculated according to equation 5.

It can see from the Figures 6 - 7 that the changing trend of rolling force and the three-roll skew rolling hollow axle torque are basically same as time goes by. Due to the effect of the left end of the workpiece on the roller, the rolling mechanics parameters tends to rise gradually from left to right. The roller undergoes the process from bite to the rolling at the shaft section with different section shrinkage ratios, so the wave trough will appear. The changing process of mechanics parameters is basically same, so the maximum mechanics parameter can be selected for discussing the influence of the process parameters on the mechanics parameters.

Figure 8 shows the trend of the maximum of five kinds of mechanics parameters (lateral force, axial force, radial force, rolling force and torque) under different process parameters. Figure 8 a shows that within a reasonable range rolling mechanics parameter is inversely proportional to temperature. Figure 8 b shows that with the increase of the roll rotation speed, the mechanics parameter has declined. Figure 8 c shows that

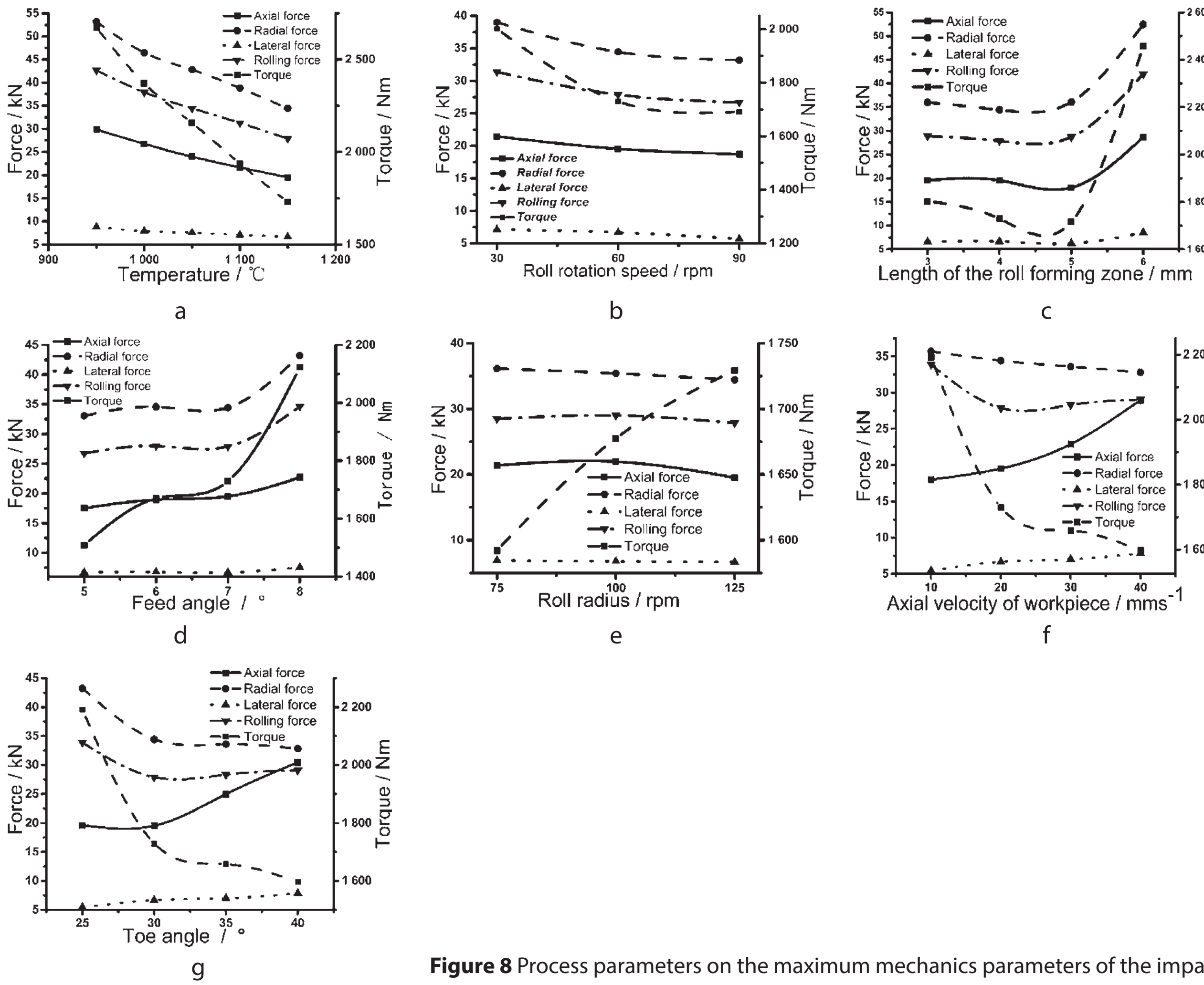

Figure 8 Process parameters on the maximum mechanics parameters of the impact

when the length of the forming zone is 3 - 5 mm, the mechanics parameter changes within 5 %. However, when the forming zone length is increased to 6 mm, the mechanics parameters obviously increase by about 45 %. Figure 8 d shows that when the feed angle is 5 - 7 °, the change of the mechanics parameters is not obvious . But when the feed angle is 8 °, the mechanics parameter has been obviously increased. Figure 8 e shows that the change of the mechanics parameter is less than 10 % with roll radius. Figure 8 f shows that as the axial velocity of workpiece changes from 10 mm / s to 40 mm / s, the variation range of radial force, lateral force and rolling force does not exceed 10 %, the axial force increases by more than 40 % and the growth rate of torque is more than 28 %. Figure 8 g shows the Axial and lateral forces increase as the toe angle mounts, the radial force, the rolling force and the torque decrease as the toe angle increases.

From the above analysis it can conclude that rolling hollow shaft with 1: 5 requires such optimum process parameters as temperature of 1 150 °C, feed angle of 7 °, roll radius of 62,5 mm, forming zone length of 5 mm, axial speed of 20 mm / s and toe angle of 30 °. Under the condition of the above optimum process parameters, by using the three-roll skew rolling technique, have the maximum radial force of 34,42 kN, the axial force of 19,53 kN, the lateral force of 6,665 kN and the torque of 1 729,30 Nm, Such figures are much smaller than those acquired by using the multi-wedge cross wedge (MCWR) rolling technique including the maximum radial force of 3 000 kN, the axial force of 300 kN, lateral force of 20 kN and torque of 14 kN · m [3].

CONCLUSION

Through the simplification of the shape of the roll, the improvement of the movement mode of the roll and the rolling piece, it realizes the rapid and accurate rolling of the variable cross-section stepped shaft of the three-roll skew rolling. Without replacing the mold, it can roll axles with different sizes, greatly improving the versatility of the equipment; and it deduces and verifies the correctness of the theoretical formula about rolling force and rolling torque.

By exploring the influence of technological parameters on the mechanics parameters, the optimum technological parameters are obtained. Under the same condition, the mechanics parameters of the three-roll skew rolling are obviously smaller than those acquired by the cross wedge rolling, which means the abrasion of the roll can be effectively reduced in the process of skew rolling and the rolling mill can conduct the lightweight construction, increasing its service life.

Acknowledgements

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Note: The responsible translator for the English language is Q. Q. Yan, Ningbo, China.