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EFFECT OF FEED RATE ON FORMING QUALITY OF CROSS WEDGE ROLLING OF GEAR SHAFT TEETH

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In order to improve the forming quality of cross wedge rolling of gear shaft teeth, this paper adopts the single factor research method and uses DEFORM - 3D software to carry out the finite element simulation of the rolling process with different feed rate dies.The results show that the total feed rate of 2,75 mm is the most appropriate, and the tooth top defect of rolled piece gear can be repaired under this condition. The feed rate in the first stage is more important than that in the other stages, and the suitable range of it is 1,0 mm - 1,2 mm.

Key words: cross wedge rolling; gear; feed rate; forming quality; finite element simulation

INTRODUCTION

Gear shaft is a common transmission part in machinery, and its strength has a great influence on the life of the whole machine. At present, the machining process of gear shaft tooth is mainly based on cutting, which not only has low machining efficiency, but also has low material utilization rate. Cross wedge rolling is an advanced manufacturing technology, which is widely used in shaft parts forming. Using cross wedge rolling process to process gear can improve material utilization and processing efficiency, make gear tooth profile more easily to obtain continuous and reasonable metal flow line, which will greatly improve the forming quality of gear.

Yu Jie of Beijing University of Science and Technology analyzed the influence of mold tooth shape, position of tooth blank relative to mold, initial shape of blank and rolling temperature on forming tooth shape [1].Ying Fuqiang of Zhejiang University of Technology studied the effects of rolling temperature, tooth number and modulus on tooth forming quality, and obtained the order of the importance of each factor [2]. Zhang Yao of Shandong Jianzhu University studied the influence of gear shaft parameters on gear forming quality, and proposed solutions to some problems [3].

In summary, the current research on the influencing factors of gear cross wedge rolling mainly focuses on the parameters such as mold design and tooth number. There are few studies on the influence of gear feed on the forming quality of gear cross wedge rolling. Therefore, this paper summarizes and sorts out four feed rates with large differences in trends. Combined with DEFORM - 3D software, the method of changing feed rate to improve gear forming quality is proposed.

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ESTABLISHMENT OF FINITE ELEMENT MODEL

In this paper, the gear with modulus m = 2 mm, tooth number z = 20, pressure angle α = 20° is taken as the research object. The three-dimensional modeling is carried out by SolidWorks. After assembling the position relationship between the die and the rolled piece in SolidWorks, the STL file is exported and imported into the DEFORM - 3D software to construct the finite element model, as shown in Figure 1 below.

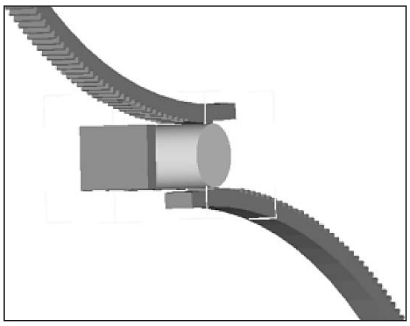

Figure 1 Finite element model of gear cross wedge rolling

Mould design

The gear cross wedge rolling forming die is generally composed of 4 - 6 stages, and the number of teeth in each stage should meet the following formula:

$$z = \frac{z_1}{2} + 1$$

where z_1 is the number of teeth required for rolling gears, and z = 11 in this paper.

In the design of gear cross wedge rolling forming die, according to the size of the gear, the parameters of the die are determined as Table 1 shows:

Table 1 **Die design parameters**

modulus/m	tooth number/z	pressure angle/α	tooth number in each stage/z	tooth pitch/p
2	323	20°	11	2π

Considering the factors such as the amount of workmanship, the final diameter of the rolled piece is 40,5 mm.

Process parameters setting

(1) The rolled piece material is steel AISI - 1 045, the blank temperature is set to 1 150 °C, and the ambient temperature is set to 20 °C.
(2) The grid is tetrahedral, and the number of grids is 100 000.
(3) The friction coefficient between the die and the rolled piece is 1.
(4) The rotation speed of the upper and lower dies is equal, 0,1 r/s, and the direction is opposite.

SIMULATION EXPERIMENT ANALYSIS

According to the analysis of previous scholars and the calculation of relevant empirical formulas [1-4], the single factor method was used to study. Four groups of experiments were taken, and the total feed rate of each group was 2,5 mm. The feed rate of each stage is as Table 2 shows:

The initial tooth profile height contains the first stage feed.

The results of the above tests are shown in Figure 2:

Under the condition of No. 1 test, the gear tooth top of the rolled piece is not smooth enough, showing the shape of left low and right high. This is due to the insufficient first-stage feed rate in the die design, as shown in Figure. 3. The die rolled into the rolled piece is very shallow, which makes the tooth of the die rolled into the rolled piece unable to drive the rotation of the rolled piece, leading to the slip of the rolled piece at the initial stage and the uneven surface of the rolled piece. In the post stage, it is still unable to make the whole gear of the die rolled into the rolled piece, so the gear tooth top of the rolled piece cannot be corrected. Therefore under the condition of Experiment 1, the obtained gear forming quality is not good enough.

In No. 2 test conditions, the results show that concave center appears on the top of individual gear teeth and tooth top is still not smooth enough. This is due to the asynchronous phenomenon of the rolled piece on the split teeth of stage 1 and stage 2, as shown in Figure. 4, that is, the position of the rolled piece rolled into by the die in stage 2 is not located in the groove position rolled out on the rolled piece in stage 1. The rolled gear is also not filled with the die, so it has no repair effect on the tooth top of the rolled piece. Therefore, under the condition of Experiment 2, the obtained gear forming quality is also not good enough.

Table 2 **Die feed design of each group**

	Initial tooth height	stage1	Stage2	Stage3	Stage4	Stage5	Stage6	total feed rate
1	2,25	0,25	0,25	0,5	0,5	0,5	0,5	2,5
2	2,5	0,5	0,5	0,5	0,5	0,5	/	2,5
3	3,0	1,0	0	0,5	0,5	0,5	/	2,5
4	3,2	1,2	0,6	0,3	0,2	0,2	/	2,5

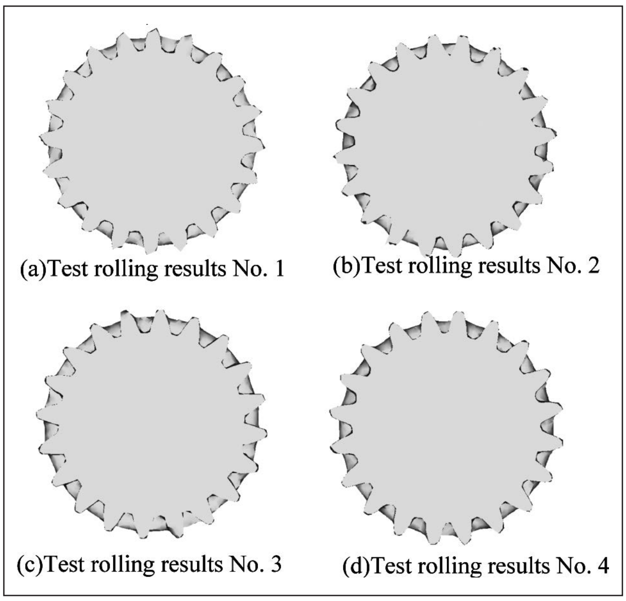

Figure 2 Figure of rolling results of four groups of tests

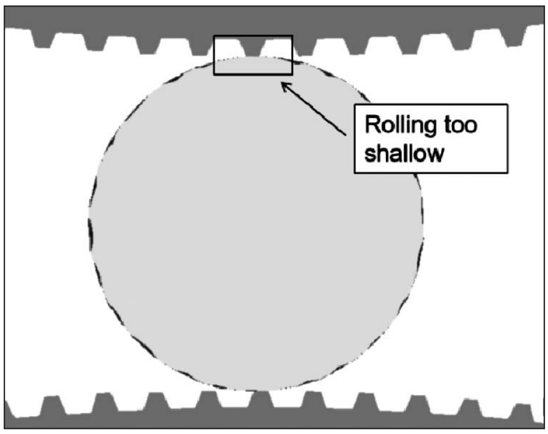

Figure 3 Rolling Process of Test 1

Under the condition of No. 3 test, compared with No. 1 and No. 2 test, the final gear forming quality has been greatly improved. In the rolling process, the residual space between the rolled piece gear and the die

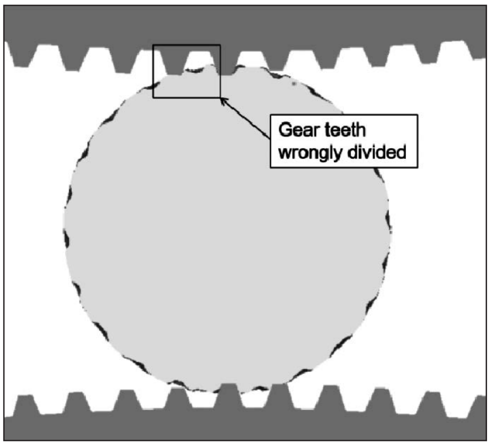

Figure 4 Rolling Process of Test 2

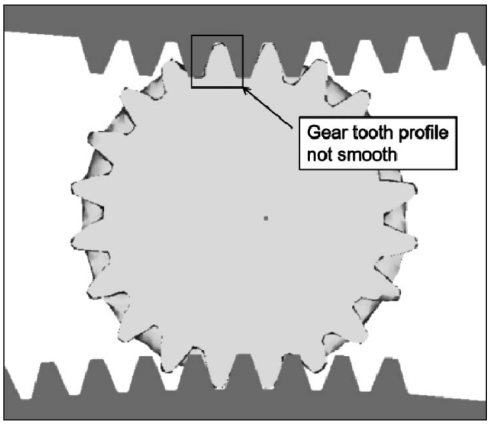

Figure 5 Rolling Process of Test 3

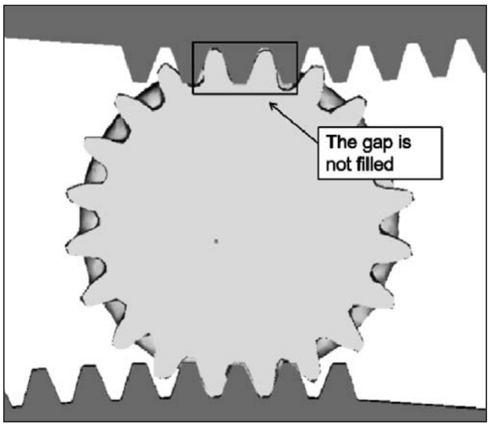

Figure 6 Rolling Process of Test 4

gear is small, so there is no obvious tooth top tilt and concave surface, and the tooth profile is relatively clear. As shown in Figure 5, however, the profile of the individual teeth of the rolled piece is not smooth, which does not reach the expected involute profile shape. This is due to the lack of correction of the final stage mold on the gear shape.

In No. 4 test conditions, the overall forming quality of the final rolled gear is relatively good, and some of the tooth tops have slight inclination and no concave surface. The tooth profile is smoother than that of Nos. 1, 2 and 3.As shown in Figure 6, the main reason for the slight inclination of some tooth tops may be that the rolled piece gear does not properly fill the gap between the mold gear because of insufficient feed , which makes the mold not contact with the tooth top and tooth top cannot be modified.

IMPROVEMENT OF PROCESS PARAMETERS

In the above four comparative tests, it can be seen that the feed rate in the rolling stage is particularly important. The large feed rate in the No. 3 and No. 4 tests plays a greater role in spliting tooth and improving the quality of the tooth top of the rolled piece than the small feed rate in the No. 1 and No. 2 tests. Therefore, based on the feed data of No. 3 and No. 4 tests, the parameter improvement design is carried out. The parameters of the improved die are as Table 3 shows:

Table 3 **Improved mold feed rate**

Initial tooth height	stage1	stage2	stage3	stage4	stage5	total feed rate
2,95	1,2	0,75	0,4	0,2	0,2	2,75

While increasing the feed rate, the total height of the gear must be kept unchanged, so the purpose must be achieved by reducing the die height before the rolling stage. Based on the experience of No.3 and No.4 test, the feed rate of 1,0 mm - 1,2 mm in the rolling stage has little difference on the total forming quality. 1,2 mm is selected as the rolling feed rate in the first stage in the improved test.On the basis of the total feed rate of 2,75, the feed rate at the other stages was fine-tuned with reference to Experiment 4.The results of the improved test are as Figure 7 shows:

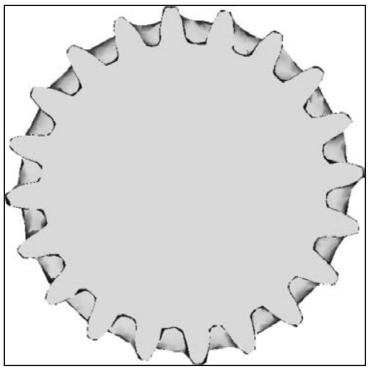

Figure 7 Rolling Process of Improved Test

It can be seen from Figure. 7 that on the basis of an increase of 0,25 mm in the total feed rate, the gear forming quality has been greatly improved, the uneven defect of the tooth top has been corrected, and the tooth profile is clearer and smoother, which is closer to the standard tooth profile.The test shows that the proper total feed rate can correct the gear tooth top defect, and the proper first stage feed rate can not only ensure the correct tooth division, but also lay the foundation for the subsequent rotation of the rolled piece.Therefore, in the actual process and production, the total feed rate and the first stage feed rate should be given priority to avoid the forming defects of the rolled piece and improve the forming quality.

CONCLUSIONS

(1) When using the single factor method to study the influence of feed rate on the forming quality of gear cross wedge rolling, it can be concluded that the selection of total feed rate and the feed rate in the first stage is the most important. On the basis of ensuring that the correct total feed rate and the first stage feed rate are selected, the influence of the selection of other stages feed rate is not great.

(2) Taking the gear with modulus of 2 as an example, in order to ensure that the rolled piece gear can fill the gap between the gears of the die and achieve the purpose that the die can correct the tooth top defects of the rolled piece gear, the total feed rate about 2,75 mm is the most appropriate; in order to ensure the correct tooth division and the part of the die rolled into the rolled piece enough to drive the rolled piece rotation, the first stage of the feed rate should select about 1,0 mm - 1,2 mm.

Acknowledgments

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Note: The responsible translator for English language is X.G.Chen, Ningbo, China