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NUMERICAL ANALYSIS OF INTEGRATED FORMING PROCESS OF DIAGONAL ROLLING AND PIERCING OF FLANGE NUTS

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In this paper, Simufact FE software is used to establish a simulation model of three-roll diagonal roll piercing integrated forming flange nut blanks, elaborate its process principle, analyze its forming process through numerical simulation. The law of load change, equivalent plastic strain distribution and wall thickness uniformity during the piercing process and diameter reduction process were investigated, and verify the feasibility of this forming process for manufacturing flange nut blanks.

Keywords: alloy steel, three-roller diagonal rolling, flange nut, perforation, numerical simulation

INTRODUCTION

As one of the basic components of fasteners, nuts are used in the automotive, aviation and railroad industries with the advantages of a wide range of products and easy disassembly. Compared to hexagon nuts, flange nuts have a simpler production process and better forming results due to their special flange face structure. At present, the manufacturing process of flange nuts is mostly based on stamping, forging welding and cold heading forming. The following problems often occur when forming by the above process: high scrap rate, poor flatness, folding defects in the inner hole [1]. With the increase in demand for non-standard size large diameter flange nuts from enterprise, innovative manufacturing processes, improved flange face forming quality and improved material utilization are the issues that need to be addressed for such flange nuts.

As a near-net forming process, three-roller diagonal rolling is widely used in the forming of rotary parts because of its high efficiency, energy saving and material utilization. For the oblique rolling and piercing process, Wang et al. [2]conducted an experimental and numerical simulation study on the three-roll oblique roll piercing of pipe billets to derive the causes of tail ring and bearing failure in forming. Ding X.F. [3]and Zhu H.Z. [4]numerically studied the three-roller oblique rolling and piercing process for seamless steel tubes of magnesium and titanium alloys, respectively, and obtained reasonable process parameters for forming seamless steel tubes of magnesium and titanium alloys by oblique rolling. In the diagonal rolling reduction process, Pater [5]confirmed the applicability of this technique for the production of hollow shafts by numerical simulations. Zhang et al. [6] conducted an experimental and numerical simulation study of a three-roll obliquely rolled hollow shaft and verified that the three-roll obliquely rolled process can reduce the diameter of the equidistant hollow shaft. Aleshchenko [7]studied the process of reducing and plugless rolling in a three-roll spiral mill and used FE software to analyze the effect of increasing reduction on metal forming and geometric changes when reducing billets of different wall thicknesses in an experimental industrial mill. Ye et al. [8]introduced a new process of integral forming of hollow shaft profile and bore, which was deeply analyzed and verified the feasibility of this process by numerical simulation.

Although a wealth of research has been conducted by many scholars on oblique roll piercing and reduction processes, most of them are for tubular long-axis workpieces. In this paper, we will combine three-roll piercing and reduction techniques to manufacture rotational parts with short shafts. The forming mechanism of flange nuts manufactured by this process is described, and the changes of stress-strain field and wall thickness uniformity of the rolled parts during the forming process are analyzed to verify the feasibility of the process.

PRINCIPLE OF FLANGE NUT THREE-ROLL DIAGONAL ROLLING AND PIERCING PROCESS

Three-roller diagonal piercing process refers to the successive deformation of a solid billet through two sets of rolls to obtain the desired shape. The whole continuous rolling process includes feeding the billet, piercing section, continuous rolling section and diameter reduction section. The key influence on the shape of the rolled part is the piercing section as well as the reduction section. The principle of the piercing process is that three barrel-shaped rolls with a feeding angle (roll cen-

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terline and workpiece rolling line deflection angle) of θ are distributed in space in a positive triangle, and rotates around its own axis with the same speed. The friction between the roll and the workpiece drives the workpiece along the rolling line, and the perforation process is carried out after meeting the top bar. The reducing section consists of three conical rolls with α feeding angle, which not only provide forward power during the forming process of the workpiece, but also feed radially to the workpiece while the conical rolls are in rotational motion, playing the role of reducing the diameter. The movement of the rolling process is divided into the following three kinds:

1) Two sets of rolls rotational movement around its own axis.
2) The relative movement of the workpiece and the top bar.
3) Tapered roll radial feed movement.

The process principle is shown in Figure 1.

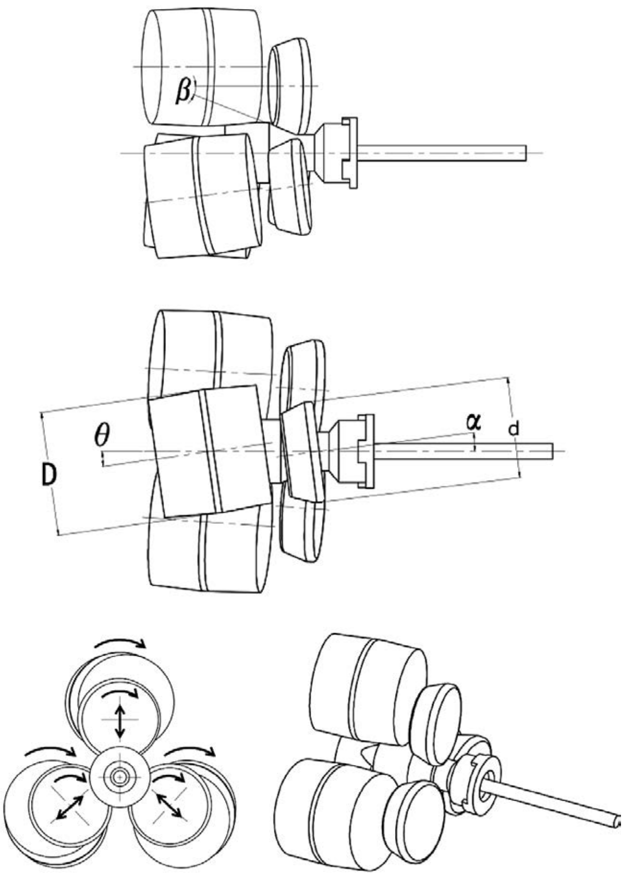


Figure 1 Schematic diagram of the principle of three-roll diagonal rolled perforated flange nut

FE SIMULATION OF FLANGE NUT THREE-ROLL OBLIQUE ROLLING PIERCING

The flange nut part diagram studied in this paper is shown in Figure 2. The diameter D of the barrel roll is 160 mm, the inlet cone and outlet cone are both 3°, the diameter of the hole throat is 72 mm. The large diameter d of the conical roll is 130 mm, β= 20°. The diameter of

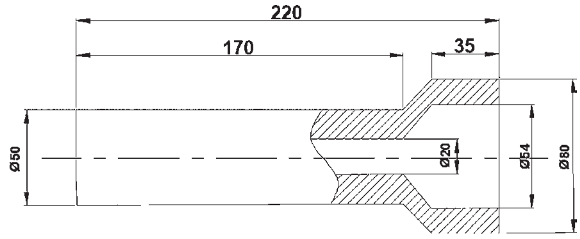


Figure 2 Flange nut parts diagram

the top bar is 52 mm, the length is 85 mm, and the forward extension is 15 mm.

Simufact software was used for FE simulation, and the simulation model is shown in Figure 3. The billet is defined as an elasto-plastic body, the material is set to 42CrMo, the material model and parameters are selected from the Simufact database, and the rolling temperature is 1 200 °C. The rollers, pusher, top bar and chuck are defined as rigid bodies, the temperature of the rolls and top bar is 150 °C. The feeding angle of the barrel roll is 8°, the rolling angle is 0°, and the roll speed is 25 r/min. The tapered roll feed angle is 7° and the roll speed is 55 r/min. The friction factor between the roll and the workpiece is 0,5, and the friction factor between the top bar and the workpiece is 0,1. The ambient temperature is 20 °C and the thermal conductivity of the roll to the blank is 15 000 W/ (m^2K).

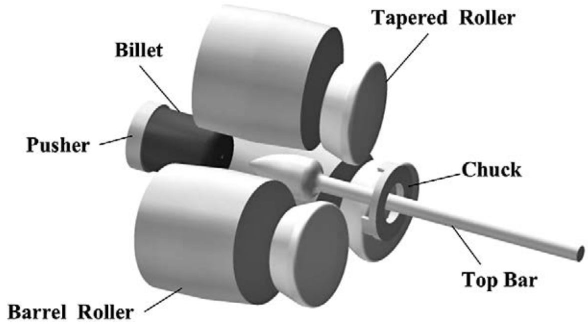


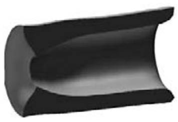
Figure 3 Simulation model diagram

ANALYSIS OF FE SIMULATION RESULTS

Table 1 shows the changes in the shape of the workpiece during the rolling process. The piercing stage is from initial piercing to stable piercing, and the billet is processed into a rough tube through this process. The reduction stage is from radial reduction to stable rolling, and the blank is passed through this process to get the flange nut blank with flange face. During steady rolling, the workpiece flares out at the end of the inner hole. From the final forming results, the overall shape meets the design requirements and there are no machining defects of slippage, workpiece collapse or distortion [9], which means that the integrated process of three-roll diagonal rolling and piercing is feasible for processing such flange nuts.

Figure 4 shows the radial load of the two sets of rolls and the axial load of the top bar. At the beginning of the

Table 1 **Rolling process**

Process	Perforation Stage
0 %	
10 %	
25 %	
50 %	
75 %	
100 %	

workpiece bite, the radial load of the barrel roll gradually increases, and the trend slows down when it reaches the piercing stage I, while the top head starts to receive axial load. The peak radial load of the barrel roll occurs at the end of the workpiece and the end of the roll flush. When the top bar penetrates the workpiece, the axial force of the top head starts to decrease. Reaching the II diagonal rolling-reducing stage, two sets of rolls act on the workpiece at the same time, the tapered rolls are subjected to radial load. At this stage, the piercing is basically completed and the axial load on the top head tends to 0. The radial load of tapered rolls increases with the increase of radial feed depth when reducing

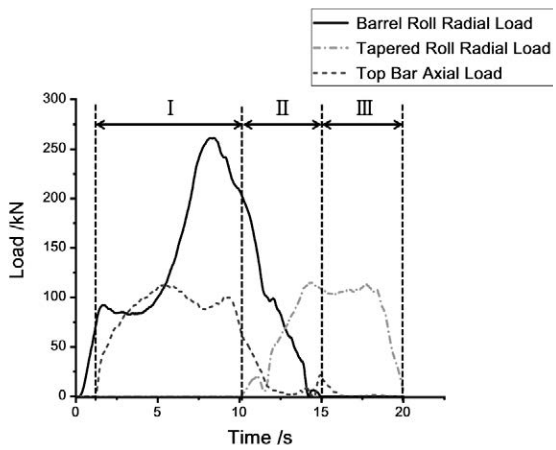


Figure 4 The radial load acting on the roll and the axial load on the top bar

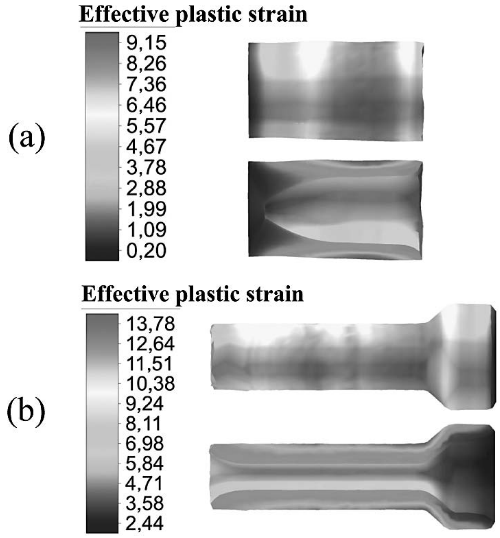


Figure 5 (a) Equivalent plastic strain diagram of flange nut perforation process (b) Equivalent plastic strain diagram of flange nut reduction process

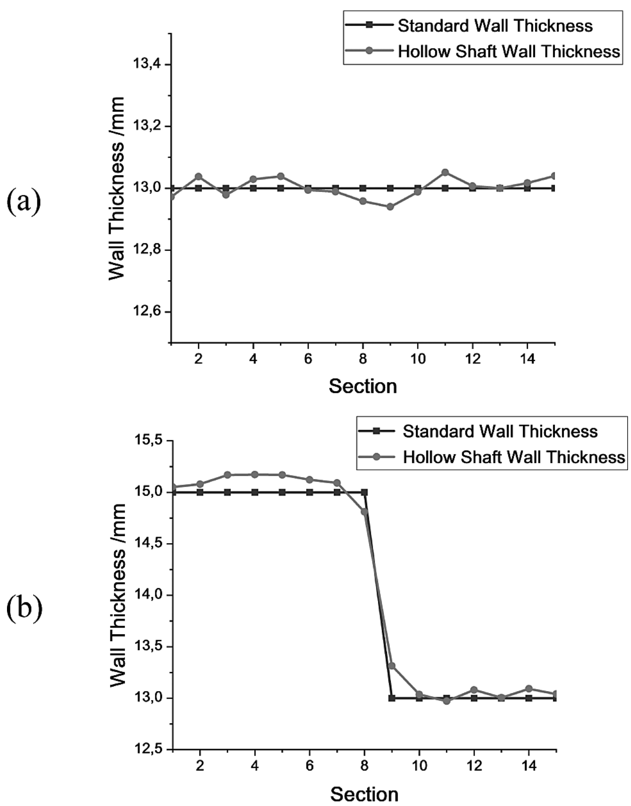


Figure 6 (a) Uniformity of wall thickness of the burr pipe at the perforation stage (b) Uniformity of blank wall thickness at the reduction stage

the diameter, the load variation tends to be smooth after the completion of the diameter reduction in III.

The equivalent effect variation at stable perforation is shown in Figure 5 (a). The equivalent effect between the outer surface of the workpiece and the inner hole is laminar distribution, and the roll shoulder contact part of the maximum strain, gradually decreasing to the axis, which is due to the workpiece is mainly subject to roll friction so that the metal for circumferential flow. The equivalent plastic strain of the flange nut blank after the reduction is completed is shown in Figure 5 (b). The maximum strain appears at the maximum reduction, which is consistent with the rolling strain law.

The solid billet is formed into a blank tube after a three-roller oblique rolling perforation process, and the wall thickness uniformity of the blank tube is an important criterion to measure the quality of the perforation forming. Nodes are selected uniformly on the pierced blank tube and the wall thickness is measured, the results are shown in Figure 6 (a). In Figure 6 (b) the wall thickness after perforation is surrounded by a uniform linear variation in wall thickness in the reduced section, decreasing with increasing diameter of the outer surface of the workpiece cross-section. The comparison of wall thickness and design dimensions in the numerical simulation can be obtained from the three-roller diagonal rolling process to obtain the overall ideal wall thickness dimensions of the flange nut blank, with good wall thickness uniformity.

CONCLUSIONS

Based on the above study, the following conclusions can be drawn:

- Three rolls inclined rolling can be used to form hollow shaft parts and can also be applied to make flange nut blanks.
- The three-roller diagonal piercing process can form rotary parts of various sizes by changing the movement of the tapered roll and the size of the top head. It has a high degree of versatility.
- The strain fields in the perforation and reduction stages are characterized by a stratified distribution. The perforation depth of the perforation stage affects the radial load of the roll, and the size of the reduction stage affects the radial load of the tapered roll.
- The wall thickness uniformity of the hollow parts manufactured by the three-roll oblique rolling method is in accordance with the design dimensions, the accuracy needs to be improved by optimizing the process parameters, and the machining allowance at both ends of the blank awaits further study.

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Note: The responsible translator for English language is F. Lin, Ningbo, China