Producing various shafts by novel flexible skew rolling in multiple-freedom mill

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Abstract. This paper presents a new method in shafts manufacturing including flexible skew rolling process (FSR), multiple-freedom mill (DRM-80) and a new type of roller, by which can produce various shafts with same rollers via programming different movements. In order to explore industrial application, four typical shafts — preforms of valve and railfrog, the shafts of truck and train were produced in FSR experiments, and their forming defects were summarized and presented.

1. Introduction

The shaped shafts are the basic near-net components in axisymmetric profiles manufacturing and die-forging billets pre-forming, which are widely used on automotive and railway industry [1, 2]. Nowadays, these shafts are generally manufactured by open die forging, radial forging or cross-wedge rolling. On the one hand, open die forging and radial forging can form various shafts with same hammers but belong to large intermittent deformation, which result in massy loading and low precision. On the other hand, cross-wedge rolling belongs to continuous-regional deformation that have the advantages of less loading, precision manufacturing, but their rollers have large-size dimensions and merely used in one shape shaft producing which significantly increases the cost of mould designing and manufacturing.

In order to combine the advantages of less loading, precision manufacturing and flexible production, a lot of intelligent studies have been performed and several flexible rolling processes were proposed, which can be summarized as axial-feed rolling process[3], copy skew rolling process [4] and CNC skew rolling process [5]. Nevertheless, both these existent processes, in which a chuck is needed to axially draw the billet that results in the following limitations: 1) a considerable amount of chucking allowance is indispensable that reduce the material utilization; 2) the drawing force of the chuck is very huge that increases the complexity of the equipment; 3) the maximum length of the rolling shaft is limited by the chuck stroke.

2. FSR process and DRM-80 mill

In this paper, a novel flexible skew rolling (FSR) with two rollers is proposed as shown in Fig. 1, whose device are mainly consists of two tapered rollers and two tube guides. Both two rollers have three degrees of freedom — circumferential rotating $N_0$, skew-angle adjustment rotating $W_0$ and radial feeding $V_0$. On the condition that the position of the rolling workplace is restricted by two tube guides, FSR process can flexibly form various shafts with same rollers by programming the motions ($N_0, V_0, W_0$) of the roller motions, and its procedure can be divided into four stages:

- Radial rolling: two levelled rollers have the motions of $N_0$ and $V_0$, two rollers bite into the workpiece;
• Rollers inclining: the skew angle increase to the target value $\beta$ by the angle adjustment rotating $W_0$;
• Skew rolling: two rollers are inclined with invariant skewing angle $\beta$ and have the motion of $N_0$, then the workpiece rotates circularly and moves axially;
• Rollers levelling: two rollers have the motions of $V_0$ and $W_0$, back to the original state.

Fig.1. The flexible skew rolling (FSR) process: (a) schematic diagram; (b) process stages

According to the above analysis, two rollers in FSR process need three degrees of freedom ($N_0, V_0, W_0$). However, all the existing skew rolling mill (e.g., piercing mill, ball rolling mill, skew rolling mill) cannot meet the requirements.

Hence, a new type of multiple - freedom FSR mill was invented and constructed. Fig. 2 shows the laboratory flexible skew rolling mill, which named as DRM-80. This mill mainly consists of two roller, two rotation systems, two angle adjusting systems and an axial feeding system. All these power systems are directly driven by electric servo motor and controlled by a servo drives in PLC language, thus the main body of this mill is compactness with a overall dimensions of 1.8 m×1.7 m×1.6 m. Moreover, two arm-stands with a C-shaped structure is used in the frame design, which directly improved the stiffness of the mill. The total power is about 70 kW, the the maximum roller diameter is 350 mm, but the maximum billet diameter up to 80 mm, so we can look forward to this new type of mill may have a promising potential in industry because its compactness structure, high strength and precision control.
3. Producing various shafts with same rollers

To verify the flexibility of this novel process, feasibility experiments were performed on the DRM-80 mill with the FSR roller at the University of Science and Technology Beijing, China. The initial billet is C45 steel with a diameter of 60 mm. Prior to rolling, the billet was preheated to 1050°C in an electric tube furnace, then immediately transferred into the workspace of the DRM-80 mill. The movements of rollers were designed and programmed based on the shape of the target shaft. During every rolling stage, these movements were controlled in the operation panel by the servo program.

In the reason that FSR process is a relatively new technique, the study of roller design is a critical work. Hence, a number of feasibility tests have been made during earlier researches. The FSR roller is a symmetrical structure that can be divided into sizing zone in the middle and forming zone on both sides. Since a larger forming angle is required in the FSR process to relieve the trend of central cracking, some pockmarks are used in FSR rollers to improve rolling conditions. The forming zone surface was knurled by hatching knurling with the size of 2 mm. Besides, because the roller stands a large rolling force at a high temperature (exceed 1000°C), the value of HRC hardness is greater than 50 and the roller was made of hot-die-material H13 and heat treated between rough lathing and precise grinding process. The geometry parameters of two roller are: overall diameter $D_0 = 340$ mm, overall length $L_0 = 100$ mm, sizing width $L = 25$ mm and forming angle $\alpha = 20^\circ$.

The geometries and physical photograph are detailedly displayed in Fig 3. Notably, the size of FSR is relatively small and their shape is very simple, which take obvious advantage in the roller designment and fabrication, and in favor of industrial application.
As displayed in Fig. 4a, four typical shafts were successfully manufactured which includes the train axles, truck drive shafts and the forging preforms of valve, railroad switch. By the feasibility experiments, we can get the conclusions that: 1) the FSR method is flexible and feasible; 2) DRM-80 mill is well designed and debugged, whose technical specifications are sufficient; 3) the shape of roller is reasonable, but its parameters need to be optimized in the future research.

Meanwhile, there are some defects evidently appearing in FSR products. The knurl pockmarks remain on the step-surface because the rollers were knurled by hatching knurling on the tapered forming zone surface. The shallow helical grooves, which are formed by the stage of skew rolling, are obvious presented on the bar surfaces. The side cavity is on the edge of the product. These defects are named and summarized in Figure 4b, of which central cracks, pockmarks, surface threads, and side cavity are the most noteworthy limitations. These defects limit the application of FSR process and need to be solved in future studies.

4. Conclusions
A novel FSR technique including flexible skew rolling process, multiple-freedom mill and FSR roller for flexible forming shafts has been proposed and verified through experiment. Four typical shafts of train axles, truck drive shaft, valve preforms and railfrog preforms were successfully manufactured, but there are some defects (i.e., central cracks, pockmarks, surface threads, and side cavity) appearing in FSR products, which limit the application of FSR process that need to be solved in future studies.

The FSR process can flexibly form various shafts with same rollers by programming different motions. The multiple-freedom FSR mill has the characteristics of compactness structure, high strength and precision control. And the corresponding rollers have a simple shape in small size. Both these integrated innovations may take the advantages of flexible rolling, less loading, high efficiency and compact equipment in shaft manufacturing.

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