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Influence of roller distribution modes on spinning force during tube spinning

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ABSTRACT

The eccentric force exerted on the mandrel by the rollers has important influence on the forming precision of tubular workpieces during tube spinning, which is closely related to the roller distribution mode. In this study, the deformation characteristics and spinning forces were investigated during tube spinning with different roller distribution modes. According to the simulation results, the contact zones under the rollers were analyzed and the spinning forces applied by various rollers were obtained. The results show that the stress distribution exhibits non-periodic change along circumferential direction and the spinning forces of various rollers are different because the non-uniform distribution of the rollers leads to different contact zone areas under the rollers. The variation of spinning forces of the rollers causes the unbalanced load exerted on the mandrel, thus the mandrel deviates from the neutral axis, which is verified by the deflection measurement of the mandrel end in the spinning experiment. Although the spinning forces of the rollers on the same side are different, four-roller spinning can keep the balance of the mandrel. In addition, stagger spinning with nonuniformly distributed three rollers is newly proposed to achieve the balance of the mandrel, increasing the flexibility of traditional two-roller spinning machine.

1. Introduction

Tube spinning is an excellent process to produce seamless thin-walled tubular workpieces in the diameter range from a few millimeters to several meters [1,2]. During tube spinning, the rollers advance spirally over the tube blank resting on a rotating mandrel and apply compressive force to the surface of tube blank, causing the metal to flow axially through reducing wall thickness. Since the spinning process localizes plastic deformation to small zones, the working force reduces greatly compared with other plastic forming processes, such as forging and extrusion. Owing to high productivity and low consumption of materials and energy, tube spinning has gained wide application in automobile, aviation, aerospace and weapon industries.

During tube spinning, the roller distribution modes, usually including two-roller, three-roller and four-roller spinning (see Fig. 1), have important effect on the forming quality of tubular workpieces since they influence the load exerted on the mandrel by the rollers. Xue et al. [3] stated that unbalanced load imposed on the mandrel aggravated the circular runout and eccentricity of the mandrel, thus influencing the forming process of tube spinning and decreasing the forming precision of as-spun tubular workpieces, such as wall thickness uniformity and circularity of as-spun tubular workpieces. Usually, tubular workpieces are mainly formed by the spinning machines with symmetrically distributed two rollers and uniformly distributed three rollers around the mandrel, wherein the three-roller spinning machine is better for manufacturing relatively large-diameter tubular workpieces since the mandrel fixed on the chuck of the two-roller machine is more prone to deviate from the equilibrium position, compared to the three-roller machine, due to less constraint exerted by the rollers as well as large dead weight of the mandrel. However, the three-roller machine is not appropriate for forming conical parts, indicating the relatively narrow application domain than the two-roller spinning machine in producing rotationally symmetric workpiece. Therefore, the modes of non-uniformly distributed three rollers and symmetrically distributed four rollers (see Fig. 1) have been successively put forward based on the two-roller spinning machine in spinning practice, which seems possible to balance the mandrel and only need minor modification for the two-roller spinning machine, significantly improving the flexibility

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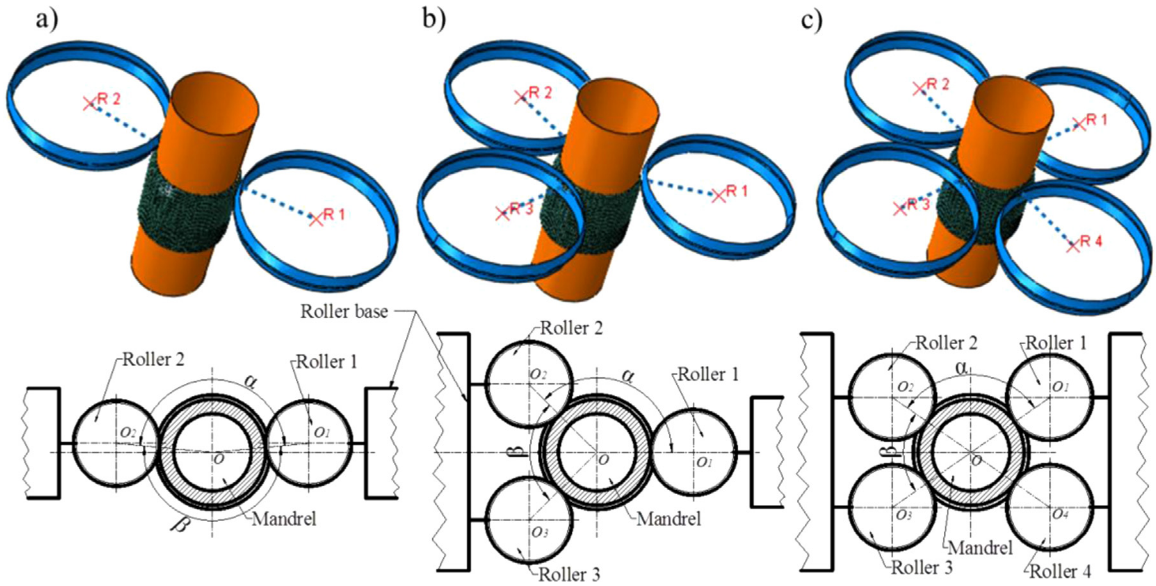

Fig. 1. Schematic diagram and FEA model of various roller distribution modes in tube spinning: (a) two-roller spinning, (b) three-roller spinning, and (c) four-roller spinning.

of the two-roller spinning machine. Although the above spinning modes in the two-roller spinning machine have been applied in spinning practice, there is no detailed study on the resultant spinning force exerted on the mandrel in various roller distribution modes up to day, which actually influence the forming precision of as-spun tubular workpiece to a great extent.

Earlier researchers proposed a few analytical models to study the spinning process, which primarily involves the spinning power, force and torque, such as Kobayashi and Thomsen [4], Thamasett [5], Hayama and Kudo [6], Chen et al. [7] and Ma [8]. In recent years, more detailed research on the spinning processes was conducted mostly based on the Finite Element Analysis (FEA) since it could give more detailed solutions for complex spinning deformation. Quigley and Monaghan [9] established an enhanced FE model by domain decomposition to enable the simulation of conventional spinning process by parallel processing techniques. Yoshihara et al. [10] conducted the finite element analysis of the spinning process of domed shape and obtained the proper spinning scheme to control wall thickness by optimizing the roller feeding path. Wang and Long [11] analyzed the evolution of wall thickness and the stress distribution of local forming zone during multi-pass conventional spinning, revealing the wrinkling failure mechanism at the flange area. With regard to tube spinning, Li et al. [12] studied the displacement distribution during backward spinning using elastic–plastic FEM and revealed the deformation characteristics of backward tube spinning. Xu et al. [13] conducted the rigid-plastic FE simulation on the tube spinning process, and the deformation region around the rollers were divided into different stress–strain zones, by which the defect formation mechanisms were revealed reasonably. Hua et al. [14] modeled a spinning process of Hastelloy C alloy tube by the ANSYS software and some phenomena occurring during tube spinning were simulated successfully. Xia et al. [15] studied the neck spinning process of non-axisymmetric tube with uniform distribution of three rollers, and the spinning forces were analyzed to optimize the machine design and the processing parameters. Roy et al. [16] proposed an analytical model of the contact interface between the roller and workpiece in tube spinning, calculated the contact interface profile in detail and obtained the change of the contact area with the spinning process variables. However, the previous studies were mainly focused on the deformation mechanism and spinning force of single roller during tube spinning and no systematic study was reported concerning the influence of roller distribution modes on the spinning force until now.

Table 1
Tube blank, tool and process parameters adopted in the FEA models.

Parameter	Value
Tube blank length, L (mm)	100
Tube blank thickness, t_0 (mm)	4, 6, 9
Mandrel diameter, D_m (mm)	100
Roller diameter, D_r (mm)	200
Front angle of roller, α_ρ (deg)	20
Nose radius (mm)	5
Rotation speed of mandrel, n (rpm)	120
Feed rate, f (mm/r)	1
Reduction, ψ (%)	10–50
Roller number	2, 3, 4

In this paper, we established different elasto-plastic FEA models corresponding to various roller distribution modes by the software ABAQUS/Explicit and analyzed their effects on the tube spinning process. The reliability of the FEA models was verified through comparing with the analytical, experimental and other FEA results. The difference of the spinning forces of various rollers were revealed, resulting from different contact areas under the corresponding rollers. The resultant force imposed on the mandrel was analyzed during tube spinning with different roller distribution modes, which was traced successfully by experimental examination of the deflection of the mandrel end. In addition, a stagger spinning process with non-uniformly distributed three rollers was newly put forward based on the two-roller spinning machine.

2. FEA models and experiment design for tube spinning

2.1. Establishment of FEA models for tube spinning with different roller distribution modes

In this paper, the elasto-plastic FEA models for backward tube spinning with three roller distribution modes were established using the ABAQUS/Explicit module, i.e. two-roller spinning, three-roller spinning and four-roller spinning, respectively, as indicated