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Analysis of motion between rolling die and workpiece in thread rolling process with round dies

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ABSTRACT

Exploring the motion characteristics in thread rolling process under varied center distance between rotation axes of workpiece and rolling die is important for accuracy evaluation and process control, and provides a basis for further study on motion compatibility condition in the thread and spline synchronous rolling process. The motion characteristics between the die and workpiece under varied center distance in the thread rolling process were investigated. Related mathematical models in the rolling process, such as the rotation angle and the angular velocity for workpiece, the transmission ratio, and the axodes of workpiece and die, were established. The results indicated that: (1) the relationship between rotation angle of workpiece and rolling time is approximately linearly dependent, transmission ratio almost presents the same change as angular velocity of workpiece; (2) the cross sections of the axodes of workpiece and rolling die are similar to Archimedes line, where the polar radius reduces with the reduction of center distance; (3) however, the changes of the angular velocity of workpiece, the transmission ratio, and the axodes are closely related to the shape of tooth profile.

1. Introduction

Threaded shaft parts are the key components used for power transmission in machinery industry or for fastening critical components of such as pressure vessel systems. Thus, the performance requirement of thread shaft components is of considerable importance in methods used in the design and manufacture of such component. Comparing with cutting processes, manufacture of thread by cold rolling brings proven advantages of efficient utilization of material, short processing time, increased strength of material, good surface quality of rolled thread. As a result the rolling process has been used widely [1–3]. Especially, the application of rolling process has been further developed by use of the thread and spline synchronous rolling process reported in the study [4], which provides an approach to plastic form thread and spline on the different portions of shaft part.

The thread rolling process and spline rolling process with round dies are both based on the principle of cross rolling. In the rolling process, multi shafts rotates under high-speed combining feed-in motion of rolling die(s), and the complex motions couple with multi-pass local plastic deformation. Thus the uncoordinated motion between workpiece and rolling die may result in not only poor quality but also a failed thread. Zhang et al. [5–7] analyzed the rotatory condition at divide-tooth stage of spline rolling process based on considering frictional moment, and investigated the motion characteristics at form-tooth stage of spline rolling process. Comparing with spline rolling process, the thread rolling process is more stable, but the relative slip is prone to

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occurrence at initial rolling stage and can result in the uncoordinated motion. Pater et al. [8] presented that a vortex cavity in screw face may be caused by kinetic associated with the hot thread rolling process with three round dies. In the thread and spline synchronous rolling process [4], the coordination of motion between thread meshing and spline meshing play an important role in pitch error and forming accuracy. The motion characteristics in thread rolling process are a key question for research on motion compatibility condition under multi-axis running and multi-meshing type.

However, up to now, most research on thread rolling has been carried out focusing finite element modeling of the rolling process [9–11], surface hardening after rolling [9,12], influence of processing parameter [13,14]. Little research is focused on motion characteristics in thread rolling process where the center distance between the rotation axes of workpiece and rolling die changes continuously. Given the errors of misalignment including cross angle and center distance, the meshing and contact of enveloping surfaces were analyzed by Litvin and Hsiao [15], and the analysis of worm-gear drive (with Archimedes' worm) indicated that the transmission error is a periodic function. Considering a given error of misalignment and a predesigned parabolic function of transmission error, a method to modify the geometry of worm-gear drive was developed by Seol and Litvin [16]. Dooner and Santana [17] also developed a method to modify tooth profile of gear pairs, where the shaft displacement or deflection was considered. Under a certain errors of misalignment including cross angle and center distance, Bair and Tsay [18] studied the contact and motion for ZK-type dual-lead worm-gear drive and presented that the contact and motion are sensitive to the errors of misalignment. Thus, it appears that there are not sufficient reports in the literature on spatial meshing analysis under continuously varied center distance.

The motion characteristics between the workpiece and rolling die in the thread rolling process under the condition of continuously changed center distance were analyzed in the present study. Condition of tangency of thread rolling die and workpiece before rolling was solved and the mathematical model of rotation angle of workpiece in the rolling process under the condition of continuously changed center distance was established. The angular velocity of workpiece in the thread rolling process was solved based on discretized interval of rolling time. Then the models about the transmission ratio and the axodes in rolling process under varied center distance were developed. Application of the developed models to investigate the rolling processes of thread with involute helical profile and Archimedes helical profile were carried out, respectively.

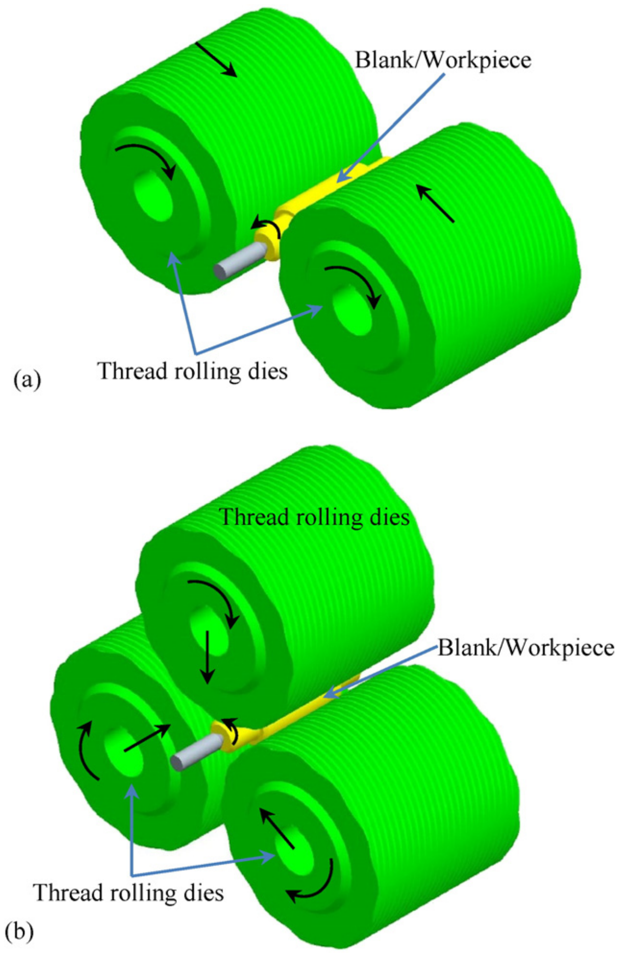

Fig. 1. Sketch of thread rolling process with round dies: (a) two rolling dies; (b) three rolling dies.