Journal of Materials Processing Tech. 259 (2018) 141–149

Contents lists available at ScienceDirect

Journal of Materials Processing Tech.

journal homepage: www.elsevier.com/locate/jmatprotec

Investigation on gear rolling process using conical gear rollers and design method of the conical gear roller

Tao Wu[a], Guangchun Wang[a,*], Jin Li[b], Ke Yan[a]

[a] Key Laboratory for Liquid-Solid Structural Evolution and Processing of Materials (Ministry of Education), Shandong University, Jinan, Shandong 250061, PR China
[b] School of Mechanical and Electrical Engineering, Shandong Jianzhu University, Jinan, Shandong 250101, PR China

ARTICLE INFO

Keywords:
Gear
Rolling
Conical gear roller
Structure design

ABSTRACT

A type of gear rolling process using conical gear rollers was firstly proposed in this study. Different with the cylindrical gear rollers used in the traditional gear rolling process, the roller which looks like a conical gear with different tooth profile along the axial direction was adopted in the rolling process. Besides, the radial feed applied on the roller in traditional rolling process was replaced by the axial feed applied on the blank. The proposed rolling process was divided into three stages, *viz.*, tooth graduation, tooth forming and tooth finishing. According to the function of the roller in each stage, the structure of the conical gear roller was designed. Importantly, the detailed formulas to calculate the essential parameters of the gear roller's tooth in tooth forming stage were established, such as the diameter of addendum circle, the radius of addendum tip, the pressure angle, and the cone angle. Through the numerical simulation, the variation and forming mechanism of the tooth profile at different stages were analyzed. The results revealed that the proposed process achieves better uniform tooth graduation and refining of the tooth profile, which increase the forming accuracy of the tooth to some extent in rolling process. Moreover, the experimental device was developed and the feasibility of the conical gear rolling process was verified.

1. Introduction

Gears are widely used as mechanical components which play the role of transmitting motion and power. The forming precision and quality of gears are of great importance to improve the performance of mechanical equipment. Cutting is a traditional method to produce gears, and it can be used to produce most of the gears. Based on the type and size of gear, the selection of an appropriate cutting process can improve the productivity and forming precision. However, the gear cutting is a way of material removal, which causes a large amount of material waste.

The rolling process is another economic alternative method of producing highly exact gears, which has attracted much attention from researchers all over the world. Based on the principle of gear meshing, the roller should be designed to have similar shape of the gear. During the rolling process, the gear roller contacts and extrudes blank with a feed in the radial direction. The materials at the outer part of the blank gradually form the tooth shape through its generating motion with the gear roller, as shown in Fig. 1. This kind of precision forming technology has many advantages, such as high material utilization, high productivity and small forming force. The formed gears also have better mechanical properties than those obtained from cutting process.

However, the complexity of gear rolling process brings great difficulty to the theoretical analysis, parameter calculation and numerical simulation. It is difficult to find a reliable and effective solution to avoid defects in the gear rolling process. In practical production, the process parameters of gear rolling are mainly determined based on the experiences, as well as trial and error methods. It not only lacks scientific basis, but also wastes raw materials and prolongs the production cycle (Klepikov and Bodrov, 2003).

In recent years, the research on gear rolling have been carried out by means of experimental or numerical methods. (Kamouneh et al. (2007a, b) studied the involute helical gear rolling process by means of numerical simulation, and explained the enhancement of gear rolling by analyzing changes in grain on the surface of the gear. Neugebauer et al. (2007a, b, 2008) firstly designed a gear roller with variable pitch, established the rolling model, and came to a conclusion that the forming accuracy could be improved by 50%. Pater et al. (2011) simulated the rolling process with DEFORM-3D, proved the feasibility of the gear rolling process, and analyzed the distribution of the temperature field, stress field and rolling force during the rolling process. Yu et al. (2011) presented a method which formed the shaft and the teeth

* Corresponding author.
E-mail address: wgc@sdu.edu.cn (G. Wang).

https://doi.org/10.1016/j.jmatprotec.2018.04.034
Received 7 November 2017; Received in revised form 28 March 2018; Accepted 20 April 2018
Available online 22 April 2018
0924-0136/

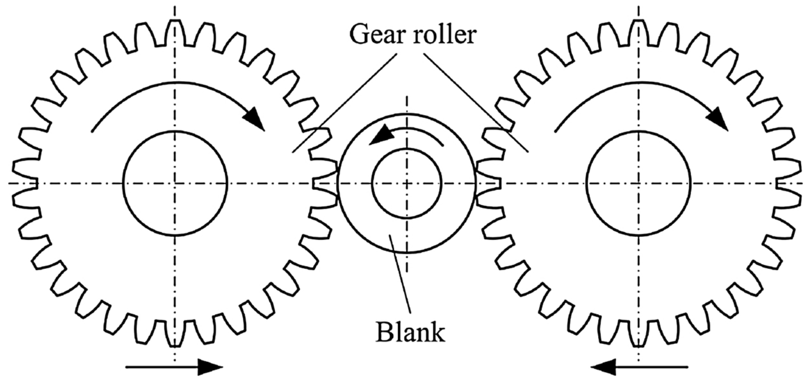

Fig. 1. Schematic diagram of gear rolling.

at the same time. Alireza and Melander (2013) provided a method using finite element simulation as a tool to evaluate gear quality after gear rolling. Kadashevich et al. (2015) investigated the thermal distribution and geometric deviations in gear rolling. Brecher et al. (2015) employed regression analysis to design the optimization of gear hobbing processes with different gear specifications based on numerical simulations. Li et al. (2016, 2017) discussed the slipping phenomenon and the formation mechanism of rabbit ear in gear rolling using numerical simulation and experimental methods.

In traditional gear rolling process, a standard gear is always used as the roller to extrude the blank with a feed in radial direction. In this way, the radial clearance could not be cut out because of the shortage of working depth, which results into a larger dedendum circle in the objective gear and a lower dimensional precision. Moreover, the rabbit ear defect cannot be avoided.

In the present study, to solve the aforementioned problems in traditional gear rolling process, a novel method is firstly proposed by a rolling feed in the axial direction instead of the radial direction in the traditional methods. The conical gear roller with different pitches in axial direction is shown in Fig. 2. The distance between the axis of roller and blank remains constant, and the rotation speed ratio of roller to blank is always unchanged during the whole rolling process. The rolling process is divided into three stages. In the first tooth graduation stage, the blank is pushed into the die along axial direction through an entry angle structure, and then the uniform tooth graduation is realized. In the second tooth forming stage, the blank is formed with gear roller which looks like a conical gear, afterwards the forming tooth shape will get larger and larger along axial direction. In the last tooth finishing stage, the size of the gear roller's addendum decreases to the standard size gradually along axial direction, while blank changes into meshing motion with the gear rollers, and the outer achieves the objective gear tooth eventually. Based on the above three deformation stages, the design methods and formulas of gear roller structure parameters in each stage were presented in this paper. Moreover, the paper verified the rationality of the proposed process and design through the method of numerical simulation and experiment.

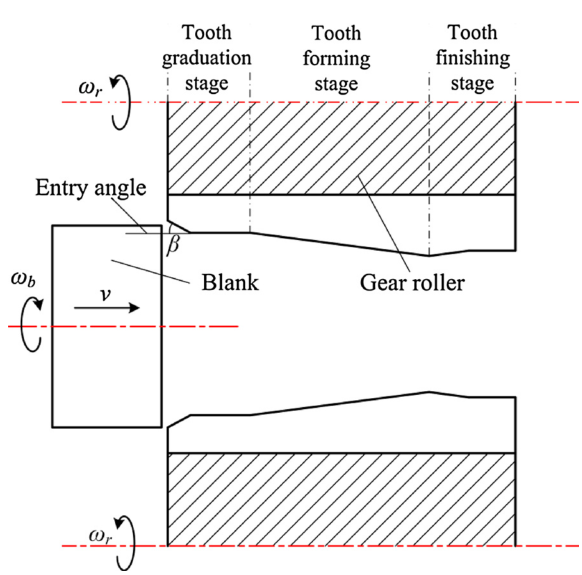

Fig. 2. Schematic diagram of the conical gear rolling method.

2. Design method of conical gear roller

In order to ensure the forming precision, the tooth number of gear roller should be as much as possible. Considering the space limitations, the distance between the axial centers of paired gear rollers is supposed to be less than the one of rolling equipment. The maximum tooth number of $z_{\max}$ can be obtained by Eq. (1) (He, 2001), and the result should be translated to integer.

$$z_{\max} = (c_{\max} - 2h_0 - dz)/m - (3 \sim 5) \tag{1}$$

where, $c_{\max}$ is the maximum distance between the axial centers of the paired gear roller, h_0 is the whole dedendum depth of the objective gear, d_z is the diameter of the objective gear, m is the module.

The structural parameters of the conical gear roller are respectively determined according to the three different deformation stages.

In the first tooth graduation stage, an entry angle structure is designed in order to ensure that the blank extrudes into the die successfully. The radius of addendum circle at the entrance r_a', the blank's radius r_z, and the distance between the axial center of gear roller and blank a should meet the relationship of $r_a' + r_z < a$. The blank's radius r_z can be determined by equal volume of the blank before and after rolling process. Besides, there is a minimum feed in order to realize uniform tooth graduation, which means that the addendum circle of the gear roller has a minimum radius. The minimum radius of addendum circle is calculated as follows:

$$\begin{cases} r_{a2} \geq \sqrt{a^2 + r_z^2 - 2ar_z \cos\frac{\beta}{2}} \\ \beta = \frac{360}{z} \end{cases} \tag{2}$$

where, r_{a2} is the minimum radius of addendum circle in tooth graduation stage, β is the radius angle corresponding chord length of blank, z is the tooth number of the objective gear.

In the second tooth forming stage, the roller is designed as conical shape with teeth which have increasingly higher addendum along axial direction. The gear roller can be divided into large and small end face which are called heel and toe in bevel gear, respectively. The toe connects with the roller in tooth graduation stage. The radius of the addendum circle and the tooth profile at heel should be determined.

In order to rolling the clearance on the objective gear, the