Cold Rolling of Zigzag-Toothed Gears*

(Improvement of Material Flow by Arranging the Teeth in Zigzags)

Shigeaki TSUTSUMI**, Shigekazu TANAKA***
and Shinko SENDA**

A new type of cylindrical gear which is called a zigzag-toothed gear is proposed. This type of gear has the same cross-sectional profile as a conventional spur gear, and a tooth trace which is arranged in zigzags on a cylindrical surface. A special configuration, such as a zigzag-toothed gear, improves the material flow in gear rolling so that there is a more precise form of tooth. In rolling this type of gear, the axial flow of material, which seems to be indispensable to complete the gear rolling but never appears in the rolling of conventional gears, is induced. Additionally, this type of gear has the advantage of maintaining good conditions for the lubricant and the ability to support some thrust load.

Key Words: Forming, Gear, Machine Element, Component Rolling

1. Introduction

At the present time, most cylindrical gears are produced by some removing processes such as hobbing, shaving or grinding. The introduction of a deformation process to the manufacture of gears will offer high productivity and low working cost. Though attempts have been made to forge a gear, it is difficult to fill a gear-profiled die with material because of the frictional constraint on the transverse planes. On the other hand, there are many difficulties in controlling the material flow in a conventional plunge-type gear rolling because a few teeth of the die penetrate a workpiece successively to generate the involute teeth. In order to overcome these difficulties, several new forming processes have been proposed ⁽¹⁾⁻⁽⁴⁾. In this paper, a new idea of controlling the material flow in gear rolling to improve the accuracy of tooth form by changing the configuration of a product is introduced and the possibility of it is examined.

In the processes of component rolling, the combi-

nation of material flow and die arrangement varies in many ways⁽⁵⁾, and the selection of it seems to hold a key to obtaining a product without any geometrical defect. For example, in the rolling of a thread or a worm gear, of which the required accuracy is assured in general, axial and radial flows of material appear, while circumferential and radial flows appear in the plunge-type rolling of a gear. Hence, the teeth of defective form obtained in the gear rolling process seem to be related closely with the lack of axial flow of material, and therefore it is expected that the accuracy is improved by arranging the configuration of a product so that the axial flow of material is induced.

In this study, a new type of cylindrical gear named the zigzag-toothed gear, which is suitable for application of the rolling process, is proposed, and its forming process is investigated experimentally utilizing a conventional rolling system.

2. Concept of the Zigzag-Toothed Gear

Figure 1 shows a new type of gear which has the same cross-sectional profile as a conventional spur gear, and a tooth trace arranged in zigzags on a cylindrical surface. When rolling this type of gear, the axial flow of material appears. The axial flow seems to be indispensable to complete the gear rolling but

* Received 12th July, 1989. Paper No. 88-0724B

** Nagoya University, Furo-cho, Chikusa-ku, Nagoya, 464-01, Japan

*** Shizuoka University, 3-5-1, Johoku, Hamamatsu, 432, Japan

never appears in the rolling of the conventional type of gear. Hereafter, the type of gear shown in Fig. 1 will be referred to as the "zigzag-toothed gear".

The rolling of the gear can be performed by either flat dies which consist of racks shifted by half a pitch from one another or toothed roller dies as shown in Fig. 2.

When a tooth of a rolling die for a conventional gear indents the surface of a workpiece with rotation, most of the displaced materials flow in a circumferential direction to generate a gear tooth, but some of them fall into a kneading state. On the other hand, all the adjoining parts of an indenting tooth of a die for a zigzag-toothed gear are depressions of the die, and therefore, an additional axial flow may appear. Appearance of an axial flow has a great effect on constituting good conditions to get a precise form of tooth because the harmful component of the circumferential flow is replaced with an axial one.

Additionally, this type of gear has the ability to support some thrust load and the advantage of maintaining good conditions for lubrication as oil is

held in the depressions.

3. Apparatus and Procedure of Experiment

Experiments were carried out by a converted thread rolling machine with two roller dies. The components of the roller dies for a zigzag-toothed gear are shown in Figs. 3(a) and (b). Dies (a) and (b) are set up alternately to compose the roller die for the zigzag-toothed gear as shown in Fig. 2 and

Fig. 1 Zigzag-toothed gear

Fig. 2 Roller die for rolling of zigzag-toothed gear

(a) Toothed roller die (1)

(b) Toothed roller die (2)

(c) Tooth profile of die

Fig. 3 Components of roller die (m : module)

their locations are fixed by pins through holes ①. Each of the roller dies in Figs. 3(a) and (b) is 144 mm in diameter of pitch circle and 4 mm in thickness, and the teeth have the pressure angle of 20° and a module of 2.0 mm. Figure 3(c) shows a tooth form of the die. Because an addendum of a die corresponds to a dedendum of a product, an addendum of $1.25 \times (\text{module})$ and a dedendum of $1.0 \times (\text{module})$ are employed in these dies. The tip of the die tooth has a corner radius of 0.6 mm to allow material flow without stagnation at the root of a tooth and to avoid scouring of the finished surface. At a different time, the dies were rearranged into a spur gear using holes ②, the result of which can be compared with zigzag-toothed gears.

Figure 4 shows the working area of the experimental apparatus. In order to prevent a product from expanding in the axial direction, a roller die has two side plates which are 169 mm in diameter and are located at both sides of toothed roller dies. The profile of a blank is shown in Fig. 5, and aluminium A 1050 F was used as the work material. The dimensions of the blank are chosen so that the displaced material fully fills the space enclosed by the die and the side plates at the completion of a rolling. In order to get the required number of teeth with complete form, the blank has leading parts 3.5 mm in width on both sides, and their diameters are decided so that their circumferential length can be divided into equal parts by the

Fig. 4 Experimental apparatus

Fig. 5 Blank for gear rolling

foot-step of the die teeth. In the rolling process, machine oil (60%) and gas oil (40%) were used for lubrication, and the blank was coated with fluorotelomer of dispersoid. The other experimental conditions are tabulated in Table 1.

4. Experimental Results

4.1 Forming example

Figure 6 is a zigzag-toothed gear obtained by rolling and Fig. 7(a) is its cross-sectional profile. As can be seen, the teeth are well formed. Figure 7(b) is the conventional gear rolled under the same forming condition as the gear in Fig. 7(a).

Figure 8 shows normal reaction and position of die plotted against number of turns of a workpiece. Small arrows in Fig. 8 indicate the pulsation observed in normal reaction, and their magnitude for the zigzag-toothed gear is half the conventional one. The reduction of pulsation is preferred for the accuracy of a product.

Figure 9 shows the forming process of teeth. In the rolling of a zigzag-toothed gear, the position of the tooth does not move on the blank surface throughout the process. In the rolling of a conventional gear, the tooth position drifts at some stage of rolling. Although Fig. 9 might be an extreme case, there is little doubt that the zigzag-toothed gear is superior to

Table 1 Experimental conditions

Rolling machine	Maximum rolling force : 196KN Revolving speed of dies : 0.92 rpm Nominal penetration rate 0.8 mm/0.5rev.
Product	Gear (Module:2)
Blank	Material : aluminium A1050F
Lubricant	Machine-oil (60%)+Gas-oil (40%) Fluorotelomer

Fig. 6 Zigzag-toothed gear obtained by rolling

(a) Zigzag-toothed gear

(b) Conventional gear

Fig. 7 Cross-sectional profile of rolled gears

(a) Zigzag-toothed gear

(b) Conventional gear

Fig. 8 Normal reaction and position of die

(a) Zigzag-toothed gear

(b) Conventional gear

Fig. 9 Forming process of teeth

the conventional gear with respect to the division of teeth.

4.2 Material flow in a workpiece

The appearance of axial flow of material in rolling of a zigzag-toothed gear was confirmed by the split-plug method shown in Fig. 10. The split plug, so called here, is a small cylinder turned from an aluminium bar of the same material as the test specimen so as to make the workpiece material uniform as a whole when it is buried diametrically in a specimen. The plug, 10 mm in diameter, is split into halves by a meridian plane, and on one of the parting planes, square grid lines of 0.2 mm spacing are scribed with a diamond needle. The fitting scheme of the plug is shown in Fig. 10. In the experiment, after a prescribed number of turns of the specimen, the plug was removed and the whole image of the deformed section was observed.

Figure 11 shows the experimental results of the split plug. Figure 11(a) is a photograph obtained from the plug which is split in the meridian plane of a work, and as can be seen, material flow in the axial direction is observed beneath the root surface of teeth.

Fig. 10 Split plug for detecting material flow

Figures 11(b) and (c) present the photographs obtained from the plugs which are split in the circumferential direction. From the observation of a vertical line centered in a tooth, it will be found that the material flows more symmetrically in a zigzag-toothed gear than in a conventional gear, and the zigzag-toothed gear is proved to be superior to the conventional gear with respect to the accuracy of teeth.

5. Conclusions

A new type of gear which is suitable for the rolling process has been proposed and produced on trial. The material flow in a workpiece was observed and the following results were obtained.

(1) The zigzag-toothed gear is introduced to improve the material flow of a workpiece in the gear rolling with the idea of changing the configuration of a product. It is confirmed that this type of gear can be easily produced by the rolling process.

(2) By employing the zigzag-toothed gear as a product, the axial flow of material, which is not utilized in the conventional gear rolling, is surely induced. It is expected that a precision gear of this type will be produced by the rolling process.

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(a) Zigzag-toothed gear (meridian plane)

(b) Zigzag-toothed gear (Cross-sectional plane)

(c) Conventional gear (Cross-sectional plane)

Fig. 11 Example photographs of deformed grids

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