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Performance analysis of generated hypoid gear based on measured tooth flank form data

Ryohei Takeda [a], Masaharu Komori [a,*], Tatsuya Nishino [a], Yukihiko Kimura [a], Takayuki Nishino [b], Kenji Okuda [b], Shinji Yamamoto [b]

[a] Kyoto University, Department of Mechanical Engineering and Science, Kyoto daigaku-Katsura, Nishikyo-ku, Kyoto-shi, Kyoto 615-8530, Japan
[b] Mazda Motor Corporation, 3-1, Shinchi, Fuchu-cho, Aki-gun, Hiroshima 730-8670, Japan

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ABSTRACT

A method for predicting and analyzing the tooth contact pattern, vibration, and strength of a generated hypoid gear is needed to achieve a low-noise design and adequate quality control. However, it is not easy to analyze the performance of a generated hypoid gear because the tooth flank form is complicated and has a significant influence on the overall performance. In order to solve this problem, in this research, a method for analyzing one of the gear dynamics excitations and contact condition of a generated hypoid gear that considers the measured tooth flank form is proposed. The contact pattern and transmission error are measured experimentally and are compared with the analysis results. It is confirmed that the result from the proposed analysis method agrees with the experimental result.

1. Introduction

Hypoid gears have advantages over spiral bevel gears due to their strength and smooth rotation, and thus, they are widely used in rear-wheel drive and four-wheel drive vehicles. Recently, engine and road noise in vehicles has been improved, and therefore, better noise and vibration quality are demanded for hypoid gears. Moreover, the load carrying capability must be increased in order to transmit higher torques. To meet these requirements, performance analysis technology is necessary.

For hypoid gears, a lot of research has been conducted on theoretical tooth geometry [1–5]. Since CNC-controlled bevel and hypoid gear cutting machines and grinding machines were developed, much research related to CNC control has been conducted [6–9]. As for the analysis of real tooth flank form, Kin [10] studied spur gear adding the measured data to theoretical involute surface and interpolating them. And Zhang et al. [11] made unloaded tooth contact analysis of non-generated hypoid gear based on the measured tooth flank form data by CMM using similar approach with Kin. Most of it deals with the final drives of non-generated face mill hypoid gears for automobiles, of which the manufacturing method is rather simple. On the other hand, recently, cases that require a generated hypoid gear wheel instead of a non-generated one have increased. For example, these days, multipurpose four-wheel drive vehicles are very popular. In the case of a four-wheel drive system based on a front-wheel drive vehicle, a hypoid gear with a low ratio is used in the transfer gearbox. And in many applications the gear ratio becomes less than 2.5, and in that case, it is difficult to use non-generated cutting such as Formate® or Helixform® on such wheels. In that case, a generated hypoid gear must be used. In generated hypoid gears, the wheel tooth flank form becomes very complicated, and not much research has been reported on them. There is a report [12], in which the influence of misalignment to path of contact, minimal separation along the potential contact line and tooth contact pressure distribution are studied on generated spiral bevel

* Corresponding author. Tel./fax: +81 75 383 3587.
E-mail address: komorim@me.kyoto-u.ac.jp (M. Komori).

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gear with mismatched surface. But these studies are for the theoretical pinion surface and not using the actual tooth flank form. And tooth contact pattern and transmission error are not studied. Therefore, in this research, a method for analyzing the gear dynamics excitation and contacting condition of a generated face mill hypoid gear is developed.

During manufacturing of a generated hypoid gear, a lapping process is used after gear tooth cutting and heat treatment. If gear tooth grinding is used, lapping is typically performed afterward. The gear dynamics excitation of a hypoid gear is largely affected by any small waviness of the tooth surface. For that reason, to accurately analyze the dynamic performance of a hypoid gear, detailed information on the tooth flank form must be considered. In the case where lapping is used, the tooth flank form of the hypoid gear after lapping becomes different from that after gear tooth cutting based on gear tooth cutting theory. Therefore, it is difficult to accurately analyze an actual gear set using tooth cutting theory. Also, analysis of the tooth flank form after heat treatment and lapping is required. There are few studies of analysis of hypoid gear using measured tooth flank form [11,13]. In the study [11], pinion tooth form measurement is made on machine setting base, but it is not suitable to analyze the tooth flank form after heat treatment or lapping accurately. And those studies use tooth flank form measurement data of 5×9 grid points, but they are not sufficient to get detailed information of the tooth flank form after heat treatment or lapping.

The authors have presented an analysis method for the generated face mill hypoid gear tooth geometry based on conjugate tooth flank theory and developed a tooth flank scanning measurement method in the previous report [14]. This was then used to obtain detailed information on the tooth flank form of a generated face mill hypoid gear. In this research, a performance analysis method for a generated face mill hypoid gear that utilizes tooth flank form data obtained from the scanning measurement and takes the small waviness of the tooth flank form into account is developed. By comparing the result of the analysis with that of the experiment, the effectiveness of the proposed method is confirmed.

2. Introduction of theoretical and conjugate tooth flank form and composite deviation

2.1. Theoretical tooth flank form

The purpose of this research is to predict the gear dynamics excitation and strength of generated face mill hypoid gears by measuring the tooth flank form and analyzing the tooth contact condition using the measured data. To achieve this, it is desirable to use a reference surface with an ideal contact condition for the gear performance. The gear set with tooth flank forms conjugate to each other has tooth contact on the full tooth flank form and has no transmission error. Then, the conjugate tooth flank form can be described as the ideal tooth contact condition. For this reason, in this research, the conjugate tooth flank form is used as the reference surface. Specifically, the reference surface of the wheel is defined as the surface derived from the envelope of the gear cutter and that of the mating pinion at the conjugate surface of the wheel [15].

2.2. Calculation of theoretical tooth flank form for generated face mill hypoid gear

Recently developed CNC-controlled hypoid pinion cutting machines do not have the mechanical devices (such as eccentric angle and cradle) that old mechanical machines have, but the relative motion of the cutter and workpiece duplicates that of old mechanical machines. Therefore, this research is done based on the Gleason No. 106 generator shown in Fig. 1.

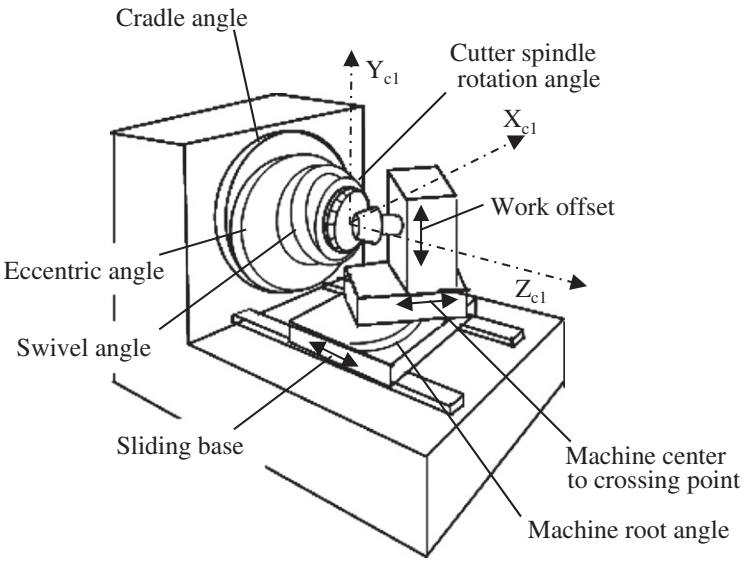

Fig. 1. Hypoid gear generator.