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Influence of waveform components derived from the transmission error of a face gear pair on a fishing reel based on tactile sensibility

Tetsuo Inoue[a,*], Syuhei Kurokawa[b]

[a] Department of Reel Development, Shimano Inc., 3-77 Oimatsu-cho, Sakai-ku, Sakai, Osaka 590-8577, Japan
[b] Department of Mechanical Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka, Fukuoka 819-0395, Japan

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ABSTRACT

This paper discusses the relationship between the rotational sensation of the handle of a fishing reel and the transmission error (TE) using a vibration-generating machine. A vibration based on gear-pair engagement in a fishing reel occurs when the handle of the reel rotates. The vibration is transmitted to the tips of the fingers via the handle. When a large vibration is present, the angler feels discomfort. It is widely accepted that the rotational sensation in the handle depends on the amplitude of the TE at a particular speed in terms of the mesh frequency of the gear pair, and the TE includes the harmonics of the mesh frequency and different wave patterns. The TE waveform is subdivided into unit TEs with the time defined as the individual tooth-to-tooth mesh period. The TE units can be classified into several specific shapes. The variation in these unit TEs affects the sensation of the angler. In this study, a vibration-generating machine is introduced to simulate vibration in commercial products. The relationship between the TE of the classified patterns and the rotational sensation in the handle was investigated using the vibration-generating machine. The vibration patterns were classified into six types of fluctuation components, and the influence of each type was investigated. The results confirmed that the amplitude and waveform fluctuations significantly influenced the rotational sensation of the handle. Moreover, we discovered that the mesh frequency is the most significant influencing factor for the rotational sensation in the handle.

1. Introduction

Face gears are commonly used in fishing spinning reel mechanisms (Fig. 1) because a face gear pair (Fig. 2) displays high performance in terms of the rotational sensation in the handle of a fishing reel. The rotational sensation affects and determines the value of the fishing reel. A vibration based on the gear-pair engagement occurs when the handle of the reel rotates. The vibration is transmitted to the tips of the fingers via the handle. When this vibration is large, the angler experiences discomfort, and accurate information from a fish or the water cannot be transmitted to the tips of the fingers via the fishing line. Therefore, a vibration such as this results in considerable devaluation of the reel. In the present study, the rotational sensation is defined as a comfortable or an uncomfortable sensation. This paper discusses the evaluation method of the rotational sensation.

In response to the findings of this study, a method to improve the rotational sensation by implementing a modification of the face gear teeth is proposed [1]. The rotational sensation is widely accepted to strongly depend on the amplitude of the transmission error (TE) at a particular speed in terms of the mesh frequency of a gear pair mounted on the reel [2]. The result indicates that the rotational sensation will improve if the accuracy of the tooth flank is improved. However, we need to introduce a high-accuracy machine tool, which results in increased production costs. In a previous study [2], 10 sample face gears were manufactured to evaluate the rotational sensation. However, face gear samples are very expensive. Therefore, experiments such as those performed in those studies cannot be frequently carried out.

On the other hand, many studies have been performed that evaluate the tactile sensibility of a human finger [3]. These studies report on the phenomenon of the velvet-hand illusion [4]. A nonlinear relationship is widely accepted to exist between the tactile sensibility of a finger and the vibration frequencies [5,6]. According to one study [7], frequencies at approximately 200 Hz result in the highest sensibility in terms of human sensation.

In addition, four types of receptors are present under the skin of the tip of a finger [7–10], namely, “Meissner’s corpuscle,” “Pacinian corpuscle,” “Merkel’s disk,” and “Ruffini ending.” These receptors and the dermal plexuses of the nerve fibers have been described in terms of the skin of the palm within the epidermis and dermis in a human and a rhesus monkey in a handbook of physiology [10]. The Meissner’s

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[*] Corresponding author.
E-mail address: inotet@sic.shimano.co.jp (T. Inoue).

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Fig. 1. Spinning reel.

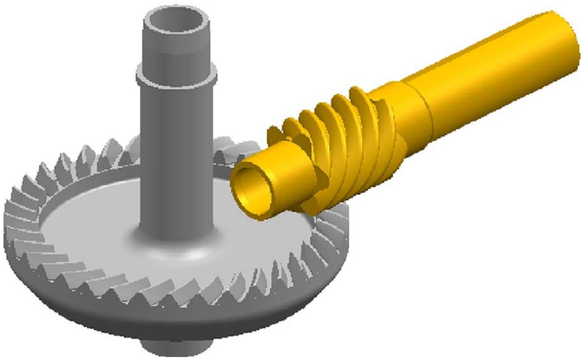

Fig. 2. Face gear pair.

corpuscle responds to the speed of the stimulus. The Pacinian corpuscle [11,12] responds to the acceleration of the stimulus. The Merkel's disk responds to the speed and displacement of the stimulus. The Ruffini ending responds to the displacement of the stimulus. Moreover, the Pacinian corpuscle is the most sensitive to vibration, which contributes to part of the acceleration sensor [7]. If the rotational sensation in a fishing reel is defined as a vibration and the tip of the fingers feel the vibration via the Pacinian corpuscle, the sensation should change according to the vibration frequency. In reality, we can confirm that the rotational sensation changes when the rotational speed of the handle changes. This phenomenon suggests that the tip of the fingers feel the rotational sensation via the Pacinian corpuscle. If the sensation is improved by controlling the frequency, we can possibly reduce the large capital investment in improving the tooth-flank accuracy.

However, the reported sensibility only considered the relationship between the mesh frequency and the amplitude in terms of a sine wave vibration. By comparing the sine wave with the measured TE waveform, we found that the TE waveform was not similar to the sine wave. When the TE waveform of each tooth was individually observed, the waveform was not consistent for all the teeth. Hence, the measured TE waveform of a gear pair includes many frequencies and different wave patterns. The result shows that other nonlinear relationships might exist other than simply that of the amplitude of a sine wave and the mesh frequency.

In the case of the acoustic sensibility of a human being, reports have been presented about the relationship between acoustic sensibility and the sounds emitted by a gear pair [13,14]. The sound was classified into four types, namely, loudness, sharpness, roughness, and fluctuation strength. However, no report on the relationship between the tactile sensibility of a human finger and the vibration generated by a gear pair is available. First, we carried out pattern classification of the measured TE waveforms, and the relationship between the classified patterns and rotational sensation was investigated. To evaluate the rotational sensation, a vibration-generating machine (vibration simulator) was introduced to simulate the vibration, instead of using commercial products. After the verification of this vibration simulator, the relationship between the rotational sensation in the reels and their TE waveforms and that between the TE of the classified patterns and the rotational sensation were investigated using the vibration simulator.

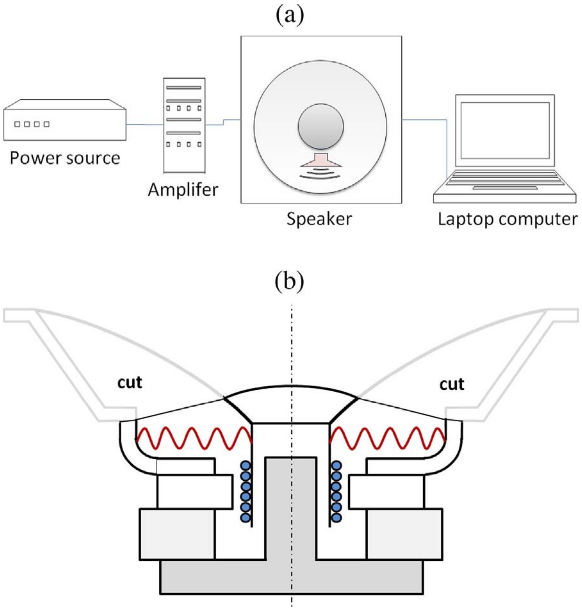

Fig. 3. Vibration simulator.
(a) Configuration of the vibration simulator.
(b) Schematic drawing of the cross-sectional view of the speaker.
(c) Determination of the vibration using a finger.
(d) Installation location of the acceleration sensor.

2. Introduction of vibration simulator

2.1. *Configuration of the vibration simulator*

Under normal conditions, the rotational sensation is evaluated by human judgment using commercial reel products. Therefore, many sample reels are required. Therefore, the vibration simulator, which can evaluate a true vibration without noise, was introduced. Fig. 3(a) shows the system configuration. This system includes the basic equipment consisting of a speaker (VISATON WS25E–8 ohm) [15], an amplifier, a power source, and a personal computer (PC). A speaker whose outer diameter of the diaphragm is 23 cm was selected to determine the characteristic of the sound pressure level in the low-frequency band. The fluctuation of the sound pressure level against the frequency of the speaker was within ± 10 dB from 20 to 2000 Hz. In particular, the fluctuation of the frequency range from 30 to 300 Hz was within ± 2 dB, which represents a stable frequency characteristic. Fig. 3(b) shows the schematic drawing of the cross-sectional view of the speaker. In addition, the periphery of the diaphragm was removed from the speaker, retaining only the innermost 8 cm. This was done to prevent the hand from touching the outer periphery of the diaphragm as doing so reduced the accuracy of judgments made. Even if the vibration was changed by the removal of a part of the diaphragm, calibration was still performed using the acceleration sensor, as presented in Section 2.2. In this section, we confirm the stability of the frequency, and the amplitudes of the vibration are calibrated by adjusting the volume of the PC. In other words, this vibration simulator is a system that produces the specified frequency in a reliable manner.

The vibration data-set and the vibration data-output programs are