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Calibration method for magnetically self-aligned multiball pitch artifact and accuracy upon reassembly

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ABSTRACT

The vibration/noise of gears is influenced by micrometer-order tooth pitch deviation, and therefore advanced quality control is needed in the gear manufacturing process using measuring instruments. The accuracy of the pitch measuring instrument is verified using a master gear or artifact, but its accuracy is not sufficiently high, and its manufacture is difficult. In our previous report, a novel pitch artifact named the magnetically self-aligned multiball pitch artifact, in which elements with simple geometries are aligned spontaneously by a magnetic force, was proposed for the calibration of pitch measuring instruments. The parts comprising the artifact, which consist of balls, a cylinder, and a plane, have simple geometries and can be manufactured with accuracies on the order of several tens of nanometers. Therefore, this artifact can also have high accuracy. In addition, because it undergoes self-alignment by a magnetic force, it has the advantage of easy assembly. An appropriate calibration method for this artifact using a coordinate measuring machine is proposed, and the accuracy of the artifact is evaluated in this report. The repeatability of pitch measurements when the artifact is disassembled and reassembled is investigated, and the results show high repeatability. A measurement experiment using a pitch measuring instrument is performed. These experiments verified that the calibration and measurement of the proposed pitch artifact are possible with high repeatability.

1. Introduction

Low vibration and noise are necessary for geared power transmissions used in vehicles and other mechanical devices. Tooth flank deviation on the order of micrometers affects gear vibration and noise [1–3]. Therefore, quality control of the teeth through measurements is important in the gear manufacturing process. Numerous studies on measuring methods for gears [4–7] have been reported. A specialized measuring machine for gears [8–10] or a coordinate measuring machine (CMM) [11] is often used in the actual manufacturing process. A specialized measuring machine that uses a tactile probe sensor is popular, particularly in mass-production industries.

High-precision measuring instruments are necessary for quality control of gears. Generally, a high-precision artifact is used to verify the accuracy of the gear measuring instruments. In principle, the accuracy of the gear measuring instrument cannot exceed the accuracy of the artifact used to calibrate it. Thus, a high-precision artifact is necessary.

The measured pitch between the teeth of a gear is important, as are the profile form [12–15] and lead form measurements [15–17]. In many industries, a master gear [18,19], which has a shape similar to that of a common gear, is used to evaluate the pitch measurement accuracy of the instrument. However, the master gear does not have high accuracy, because its reference surface is geometrically complex and difficult to manufacture. Some artifacts specialized for the evaluation of pitch measurements (pitch artifacts) have been proposed to solve this problem [20–27]. It is thought that the accuracy of these pitch artifacts is higher than that of master gears, but the feasible level of accuracy is limited because advanced manufacturing techniques are necessary. Therefore, it may be difficult to accomplish higher accuracy. In addition, high manufacturing costs are also problematic.

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To solve this problem, a magnetically self-aligned multiball pitch artifact, in which elements with simple geometries, consisting of balls, a cylinder, and a plate, are magnetically attracted to each other, has been proposed [28,29]. This artifact is composed of elements with simple forms that can be manufactured with high accuracy; therefore, highly accurate pitch is feasible. In addition, the elements are assembled spontaneously by magnetic forces and thus can be manufactured easily and at a low cost. Furthermore, because the magnet can generate the attractive force without contact, machining of each element, i.e., the balls, cylinder, and plate, is not necessary. Consequently, the form deterioration of each element is kept to a minimum.

However, a calibration method for the magnetically self-aligned multiball pitch artifact has not yet been established. In particular, in this artifact, the balls and the cylinder are fixed by spontaneous self-alignment resulting from a magnetic force; therefore, it must be determined whether the balls and the cylinder are stably fixed during the calibration measurement. Furthermore, an appropriate calibration measurement method must be established. In this paper, regarding the calibration method of the magnetically self-aligned multiball pitch artifact using a CMM, an experimental investigation is conducted, and the feasibility of the calibration measurement is verified. The appropriate conditions for the calibration measurement are clarified, and the pitch artifact is calibrated using the proposed method. Since this artifact undergoes spontaneous self-alignment by a magnetic force, high repeatability is expected even after the disassembly and reassembly of the artifact. Therefore, the repeatability of the pitch after disassembly and reassembly of the artifact is investigated. In addition, a measurement experiment for this artifact using a pitch measuring instrument is conducted. The measurement results using the pitch measuring instrument are compared with those using a CMM, and the repeatability of the measurement is evaluated. Through these investigations, the calibration measurement method for this artifact is established, and its feasible level of accuracy is determined.

2. Background and development of magnetically self-aligned multiball pitch artifact

2.1. Background

In general, the pitch of a gear is measured using a specialized measuring machine for gears, which is called a pitch measuring instrument in this report. A high-precision pitch artifact is used to evaluate the accuracy of the target pitch measuring instruments. The pitch of the pitch artifact is highly accurate, and its pitch value is calibrated using a more accurate measuring instrument. The difference between this calibrated pitch value and the pitch value measured by the target pitch measuring instrument is regarded as the error of the target instrument. The accuracy of the target pitch measuring instrument is calibrated in this way.

In many cases, a master gear is used to inspect and calibrate the pitch measuring instrument. The master gear has a shape similar to that of a gear; that is, it has a geometrically complicated reference surface. Therefore, master gears are difficult to manufacture with high accuracy. In principle, the accuracy of the pitch measuring instrument cannot be better than the accuracy of the artifact used to calibrate it. Thus, the accuracy that the pitch measuring instrument can ensure is limited if the instrument is calibrated using a master gear.

A pitch artifact with a higher accuracy than the master gear is necessary to solve this problem. Sammartinia et al. proposed a pitch artifact [24] in which gauge blocks are fixed around the circumference at a certain interval. In this artifact, the surface of the gauge block, which is used as a reference surface, is a highly precise plane, whereas that of the master gear has a complex form. Therefore, this artifact can provide more precise reference surfaces than the master gear. However, it is necessary to fix the gauge blocks in the target positions and postures with high accuracy to realize a high-precision pitch. This process requires advanced manufacturing techniques and takes a long time, making it difficult to accomplish ultrahigh precision. The manufacturing cost of the pitch artifact is high, which inhibits its widespread use for quality control in factories.

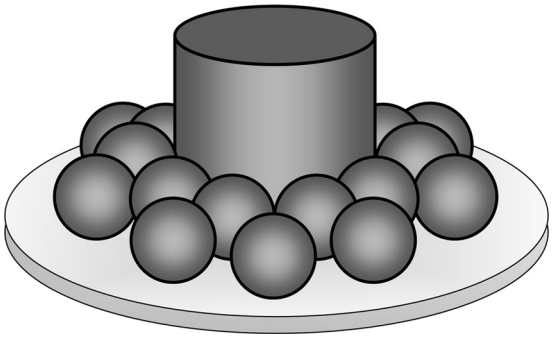

Fig. 1. Structure of multiball artifact [28].

To solve these problems, a novel pitch artifact satisfying the following three conditions is necessary:

(1) Highly accurate angular pitch
(2) Simple manufacturing process
(3) Low manufacturing cost.

2.2. Proposed magnetically self-aligned multiball pitch artifact

2.2.1. Fundamental structure

In a previous study, we proposed a novel pitch artifact called a "multiball artifact," which is shown in Fig. 1 [28]. The multiball artifact is composed of a combination of balls, a cylinder, and a plane. The center cylinder is surrounded by balls on a plane. The balls, cylinder, and plane are in contact with their neighboring elements. The cross section of the artifact is shown in Fig. 2. The stylus tip of the pitch measuring instrument is in contact with the balls at reference points *A* and *B* when the pitch (angular pitch) is measured. This pitch artifact can realize arbitrary angular pitches by changing the diameter of the balls and that of the center cylinder.

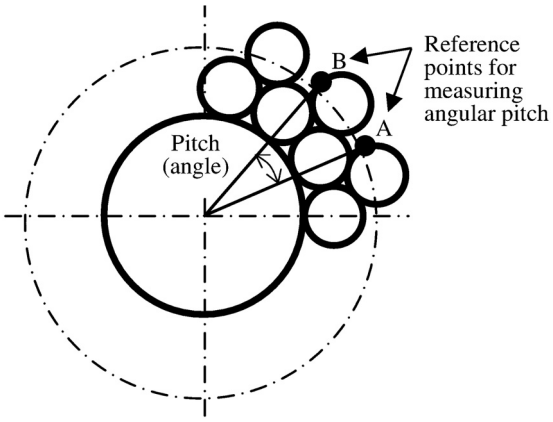

Fig. 2. Contact points of stylus tip in the angular pitch measurement of the multiball artifact [28].