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Magnetically self-aligned multiball pitch artifact using geometrically simple features

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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 instrument. The accuracy of the pitch measuring instrument is verified using a master gear or artifact, but its accuracy is not sufficiently high, and its manufacturing is not easy. In our previous report, a novel high-precision pitch artifact composed of simple-shape parts ("multiball pitch artifact") was proposed for the calibration of pitch measuring instruments. Simple-shape parts such as balls, cylinders, and planes can be manufactured with several-ten-nanometer-order accuracy. Therefore, this artifact can also have high accuracy. In this study, a magnetically self-aligned multiball pitch artifact is proposed in which the simple-shape parts are assembled with high precision using magnetic force without any special assembly technique. The artifact is designed and manufactured. A measurement experiment using a pitch measuring instrument is performed, and it is verified that the proposed pitch artifact is fundamentally valid for calibration.

1. Introduction

Gears and splines are often used for power transmission in vehicles and other mechanical devices. Nowadays, low vibration/noise is required for geared power transmissions. The gear vibration/noise is influenced by the tooth flank deviation of micrometer order [1–3], and therefore, advanced quality control of the teeth by measurement is necessary in the gear manufacturing process. There are many reports on measuring methods for gears [4–7], but in the actual manufacturing process, a specialized measuring machine for gears [8–10] or a coordinate measuring machine (CMM) [11] is used. The specialized measuring machine for gears that uses a tactile probe sensor is popular, particularly in mass-production industries, because it is easy to use and allows for high-speed measurement.

The accuracy of the gear measuring instruments is very important for the quality control of gears. In order to verify the accuracy of the gear measuring instruments, an artifact of high accuracy is used in most cases. In principle, the accuracy of the gear measuring instrument does not exceed the accuracy of the artifact used to calibrate it. Thus, ultrahigh accuracy is demanded for the artifact.

In gear measurement, the measurement of the pitch between teeth is important as well as the profile form [12–15] and lead form measurements [15–17]. In many factories, a master gear [18,19], which has a similar shape to that of a common gear, is used to evaluate the pitch measurement accuracy of the instrument. However, the accuracy of the master gear is not high because its geometrically complicated reference surface is difficult to manufacture. In order to solve this problem, some types of artifacts specialized for the evaluation of pitch measurement (called pitch artifacts) have been developed [20–27]. It is thought that the accuracy of those pitch artifacts is higher than that of the master gears in terms of pitch, but the feasible accuracy would be limited because advanced manufacturing techniques are needed. Therefore, it might be difficult to satisfy the requirement of higher accuracy. In addition, high manufacturing cost is also a problem.

In order to solve this problem, a magnetically self-aligned multiball pitch artifact using geometrically simple features is proposed in this research. This artifact is composed of simple-formed elements such as balls, a cylinder, and a plate that can be manufactured with high accuracy; therefore, highly accurate pitch is feasible. In this artifact, the simple-formed elements are assembled spontaneously by magnetic force. Therefore, it can be manufactured easily and at

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low cost. In this paper, fundamental experiments are performed in order to investigate whether the balls are aligned spontaneously by magnetic force. A magnetic circuit suitable for the pitch artifact is designed, the structure of the pitch artifact is examined, and a prototype of the pitch artifact is manufactured. The attractive force applied to the composing elements is evaluated in the prototype artifact, and its practicality is analyzed. Based on these experiments, the magnetically self-aligned multiball pitch artifact is designed and manufactured. A pitch measurement experiment of the manufactured magnetically self-aligned multiball pitch artifact is performed using a pitch measuring instrument, and the validity of the proposed pitch artifact is evaluated.

2. Background and proposed pitch artifact

2.1. Background

Typically, the pitch of a gear is measured using a specialized measuring machine for gears, which is called a pitch measuring instrument in this report. In order to evaluate the accuracy of the target pitch measuring instruments, a pitch artifact of high accuracy is used. The pitch of the pitch artifact is manufactured with high accuracy, and its pitch value is calibrated using a more accurate measuring instrument. The deviation between this calibrated pitch value and the measured pitch value using the target pitch measuring instrument is regarded as the error of the target instrument. The target pitch measuring instrument is calibrated based on this deviation.

Currently, an artifact called a master gear is used for the inspection and calibration of the pitch measuring instrument. The master gear has a shape similar to that of a gear; therefore, it is difficult to manufacture with high accuracy due to its geometrically complicated reference surface. In principle, the accuracy of the pitch measuring instrument does not exceed the accuracy of the artifact used to calibrate it. Thus, the accuracy is limited when the pitch measuring instrument is inspected and calibrated using the master gear.

In order to solve this problem, a pitch artifact with a higher accuracy than the master gears is required. Fig. 1 shows an example of the currently proposed pitch artifact [24]. The gauge blocks are fixed around the circumference at certain intervals. The surface of the gauge block is a highly precise plane, whereas that of the master gear is a complex form. Therefore, it can provide more precise reference surfaces to the pitch measuring instrument than the master gear. However, to realize a highly accurate pitch, it is necessary to fix the gauge blocks in the target positions and postures accurately. This process requires advanced manufacturing techniques and is time-consuming. Therefore, it will be difficult to obtain ultrahigh precision. In addition, for the final verification of the accuracy of the manufactured artifact, it is necessary to calibrate its geometrical features using more precise measuring instruments, such as a well-calibrated CMM. Because of the above factors, it is difficult to lower the manufacturing cost and to supply the pitch artifact at an affordable price. This prevents its widespread use for quality control in factories.

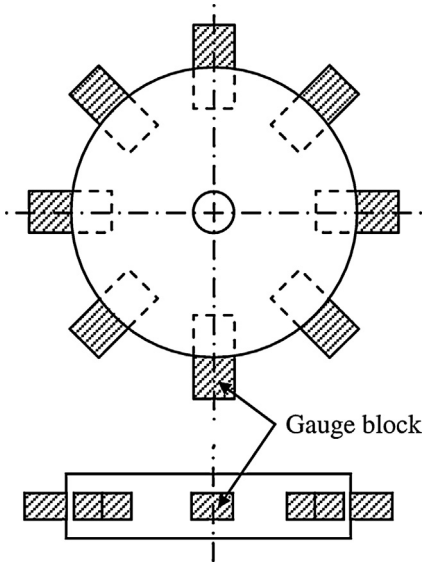

Fig. 1. Previously proposed pitch artifact with gauge blocks [24].

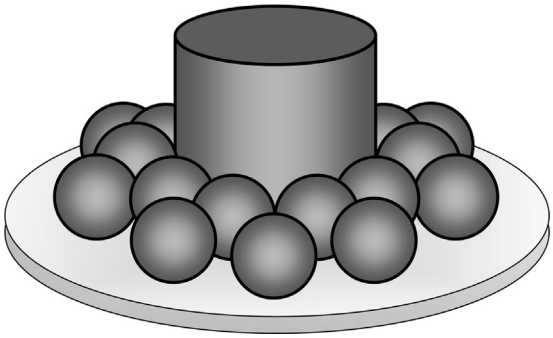

Fig. 2. Structure of multiball artifact [28].

In this research, a novel pitch artifact is developed to solve these problems. The aim of the developed pitch artifact is to satisfy the following four conditions:

(1) A highly accurate angular pitch is achieved.
(2) The manufacturing is easy, and advanced manufacturing techniques are not required.
(3) The manufacturing cost is low.
(4) The calibration process can be simplified.

It would be ideal to develop a pitch artifact that satisfies all of the above four conditions. If this is too difficult, condition (1) should be considered the top priority, and conditions (2) to (4) should be satisfied if possible as long as condition (1) is ensured.

2.2. Proposed pitch artifact

In a previous report [28], we proposed a novel, highly precise pitch artifact called a "multiball artifact," which is composed of a combination of balls, a cylinder, and a plane. As shown in Fig. 2, the center cylinder is surrounded by multiple balls on a plane. The balls, cylinder, and plane contact the neighboring elements. Fig. 3 shows the cross section of the artifact. The stylus tip of the pitch measuring instrument comes into contact with the outer balls at reference points A and B in the measurement of the pitch (angular pitch). This pitch artifact can be accommodated to arbitrary angular pitch and measurement circle diameter by changing the diameter of the balls and that of the center cylinder.

The proposed multiball artifact has the following characteristics:

(1) The balls, cylinder, and plane come into contact with each other; therefore, the positions of all these elements are determined automatically, and then, the positions of the reference surfaces for the pitch measuring instrument are also fixed. The manufacturing and assembly of this artifact are easy because advanced techniques are not necessary. For example, in the case of the artifact for small gears, it is difficult to manufacture