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Spring-force self-aligned multiball pitch artifact

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ABSTRACT

Gear noise is influenced by pitch deviation of micrometer order, and, therefore, the pitch of gears is inspected in manufacturing processes using measurement instruments. Master gears or artifacts are used to evaluate the accuracy of the pitch measurement instrument, but their accuracy is not sufficiently high and they are not easy to manufacture. In a previous study, the concept of a novel high-precision pitch artifact composed of simple components was proposed for the evaluation of the accuracy of pitch measurement instruments. Simple components, such as balls, cylinders, and planes, can accomplish an accuracy on the order of several tens of nanometers. Therefore, this artifact can be realized with high accuracy. In the present study, we propose a spring-force self-aligned multiball pitch artifact, in which simple components are assembled using spring force. The design of the artifact is discussed, and the artifact is manufactured. Measurement experiments using a coordinate measurement machine and a pitch measurement instrument are carried out, and the proposed pitch artifact is demonstrated to be fundamentally valid for accuracy evaluation.

1. Introduction

Geared power transmission is often used in vehicles. Recently, lowering the vibration/noise of gears for geared power transmissions is becoming increasingly important. The gear vibration/noise is influenced by micrometer-order tooth flank deviation [1–3]. Therefore, the inspection of gears using a measurement instrument is necessary in the gear-manufacturing process. As such, there have been a number of studies on measurement methods for gears [4–7]. In particular, a specialized measurement device for gears [8–10] or a coordinate measuring machine (CMM) [11] is often used for the inspection of gear quality.

A high-precision gear-measurement instrument is required in order to accurately evaluate gear quality. In order to verify the accuracy of gear-measurement instruments, a high-accuracy artifact is used in most cases. In principle, the accuracy of the gear measurement instrument does not exceed the accuracy of the artifact used to calibrate the instrument. Thus, an ultrahigh-accuracy artifact is needed.

Measurement of the pitch between teeth is one method of evaluating gear quality [12–17] and is important for reducing gear noise. 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 sufficiently high because it has a geometrically complicated reference surface and its manufacture is difficult. In order to solve this problem, artifacts specialized for the evaluation of pitch measurement (called pitch artifacts) have been developed [20–27]. It is thought that these pitch artifacts have higher pitch accuracy than master gears, but their practical accuracy would be limited because their manufacture is difficult. Therefore, higher accuracy might be difficult to realize. Moreover, such artifacts are costly to manufacture.

In order to solve this problem, the present authors have proposed a multiball artifact, in which elements with simple geometries, such as balls, a cylinder, and a plate, are in contact with each other and produce the desired pitch [28]. This artifact is composed of elements with simple forms that can be manufactured with high accuracy. Therefore, a highly accurate pitch is feasible. In addition, the artifact can be manufactured easily and at low cost. Based on this concept, the authors have proposed a magnetically self-aligned multiball pitch artifact, in which simple-shaped elements are assembled spontaneously and are held in contact with

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each other by magnetic forces [29,30]. However, the strong magnetic force used in this method might affect the measurement results for this artifact, depending on the measurement instrument. Thus, in the present study, a novel method to keep the balls, cylinder, and plane in contact with each other without a magnetic force is discussed. A spring-force self-aligned multiball pitch artifact is proposed, in which the balls, cylinder, and plane are kept in contact with each other by a pushing force generated by springs. The artifact is designed and manufactured, and measurement experiments are performed using a CMM and a pitch measurement instrument in order to evaluate the validity of the artifact.

2. Background and multiball artifact

2.1. Background

In many cases, pitch measurement for a gear is performed using a specialized machine referred to herein as a pitch measurement instrument. A high-accuracy pitch artifact is used to evaluate the accuracy of the target pitch measurement instrument. The pitch artifact is manufactured with high accuracy, and its pitch value is calibrated using a measurement instrument with even higher accuracy. The deviation between this calibrated pitch value and the pitch value measured using the target pitch measurement instrument indicates the error of the target instrument. The target pitch measurement instrument considered herein is calibrated based on this deviation.

In industry, an artifact called a master gear is used for the inspection and calibration of the pitch measurement instrument. The shape of the master gear is similar to that of a gear and the master gear is manufactured by grinding. Due to its geometrically complicated reference surface, it is difficult to realize a high-accuracy master gear. In principle, the accuracy of the pitch measurement instrument cannot exceed that of the artifact used to calibrate the instrument. Thus, the accuracy of the pitch measurement instrument is limited when it is inspected and calibrated using a master gear.

A pitch artifact with an accuracy higher than that of the master gear is required in order to solve this problem. As such, a specialized pitch artifact was proposed [24] in which the gauge blocks are fixed around the circumference at certain intervals as shown in Fig. 1. The gauge block has highly precise planes, whereas the surface profile of the master gear is complex. Therefore, a specialized pitch artifact can provide more precise reference surfaces than the master gear. However, it is necessary to accurately fix the gauge blocks at the target positions and postures. This requires advanced manufacturing techniques and is time consuming. Therefore, it is difficult to obtain ultrahigh precision and, at the same time, lower the manufacturing cost.

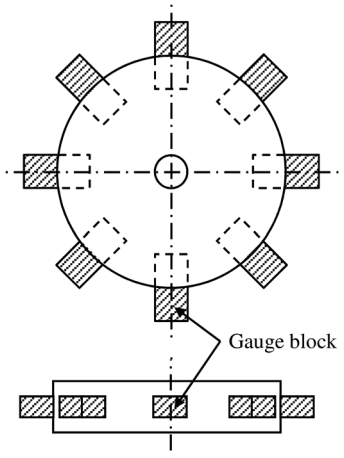

Fig. 1. Previously proposed pitch artifact with gauge blocks [24].

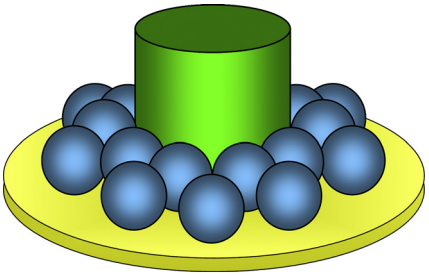

Fig. 2. Structure of the multiball artifact [28].

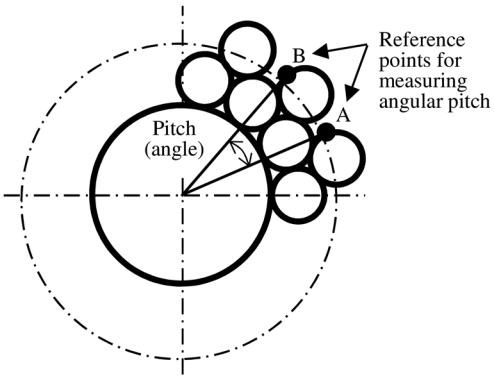

Fig. 3. Contact points of the stylus tip in the angular pitch measurement of the multiball artifact [28].

2.2. Multiball artifact

In a previous report [28], the present authors proposed a novel, highly precise pitch artifact called a multiball artifact, as shown in Fig. 2. The multiball artifact is composed of a combination of balls, a cylinder, and a plane, and the center cylinder is surrounded by multiple balls on a plane. The balls, cylinder, and plane contact the neighboring elements. A cross section of the artifact is shown in Fig. 3. The stylus tip of the pitch measurement instrument contacts the outer balls at reference points A and B when the pitch (angular pitch) is measured. This multiball artifact was demonstrated to realize an arbitrary angular pitch and measurement circle diameter by changing the diameter of the balls and the diameter of the center cylinder.

The multiball artifact has the following characteristics:

(1) The balls, cylinder, and plane contact each other. Therefore, the positions of these elements are determined automatically. Then, the positions of the reference surfaces for the pitch measurement instrument are also fixed. The multiball artifact is easy to manufacture and assemble because advanced techniques are not necessary. For example, in the case of small gears, it is possible to manufacture this pitch artifact precisely, whereas manufacturing small master gears is difficult.
(2) The accuracy of the balls, cylinder, and plane determines the accuracy of the artifact. All of these elements can be manufactured with 10-nm-order accuracy. For instance, the sphericity of the highest grade (grade 3) of steel balls is within 80 nm, according to ISO 3290 [31] and JIS-B 1501 [32]. Moreover, these highly precise products are manufactured as standard products and so are readily available. The high precision of the individual elements results in the high accuracy of the artifact.