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Extending the Benefits of Elemental Gear Inspection

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Irving Laskin

[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

It may not be widely recognized, that most of the inspection data supplied by inspection equipment following the practices of AGMA Standard 2015 and similar standards, are not of Elemental accuracy deviations but of some form of Composite deviations. This paper demonstrates the validity of this “Composite” label by first defining the nature of a true Elemental deviation and then, by referring to earlier literature, demonstrating how the common inspection practices for Involute, Lead (on helical gears), Pitch, and in some cases, Total Accumulated Pitch, constitute Composite measurements. The paper further explains how such measurements often obscure the true nature of the individual deviations. It also contains suggestions as to some likely source of the deviation in various gear manufacturing processes and how that deviation may affect gear performance. It further raises the question of the likely inconsistencies of some of these inspection results and of inappropriate judgments of gear quality, even to the point of the rejection of otherwise satisfactory gears. Finally, there are proposals for modifications to inspection software, possibly to some inspection routines, all to extending the benefits of the basic Elemental inspection process.

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Introduction

The gear industry, here in the USA and internationally, has adopted two systems of specifying and measuring the accuracy of gears. One is composite inspection, which recognizes that the inspection measurements are the result of a combination of accuracy deviations, generally derived when the test gear is engaged with some form of master gear. The other is generally labeled as *elemental inspection*, or sometimes as *analytic inspection*. This inspection system looks at individual *elements* of gear accuracy or, at least, attempts to do so, all as part of *analyzing* the complete nature of the gear's accuracy. This paper deals only with the system of elemental inspection, especially as performed by modern, computer controlled, inspection equipment. Not only is the inspection process, itself, computer controlled but also the processing and reporting of the inspection results. This makes possible additional or alternate data processing with results reported in a form that clarifies or enhances current forms of inspection data reporting.

AGMA documents

Current USA practice in elemental inspection closely follows a pair of AGMA documents. AGMA 915-1-A02 [1], describes a variety of tangential measurements, many adopted for use in so-called elemental inspection. The second, ANSI/AGMA 2015-1-A01 [2], defines the elemental version of a gear accuracy classification system based on selected tangential measurements described in the AGMA 915-1 document. This specification of accuracy classifications introduces tolerances for each specified elemental measurement. These tolerances, in effect, do determine whether the test gear meets specifications and, upon failure to do so, will lead to rejection and scrapping or rework. If the test gear came from some kind of molding process, the rework could extend into the molding tool.

The system of elemental gear accuracy defined in [2] lists the following 8 items, along with the general inspection procedures which provide the measure-

ment data for each. These will be reviewed in groups later in this paper.

- 1) Single pitch deviation
- 2) Cumulative pitch deviation
- 3) Profile, total
- 4) Profile slope
- 5) Profile form
- 6) Helix, total
- 7) Helix slope
- 8) Helix form

There is another set of AGMA documents which treats composite inspection radial measurements (see [3] [4]), but these measurements are not directly connected to the elemental measurements discussed here. There is one exception in [3], dealing with the subject often called "hidden runout" treated later in this paper.

Objectives

The objectives of elemental inspection are three-fold:

- 1) to compare the inspected gear to the gear accuracy specifications, which may have been stated individually or as a group by accuracy class.
- 2) to indicate what in the gear manufacturing process has caused the departure from ideal gear geometry
- 3) to help identify the effect of the elemental condition on the performance of the gear

In meeting all these objectives, elemental inspection has demonstrated its benefit to the gear designer, the gear manufacturer, and the user of the gear.

The objective of this paper is to examine the elemental inspection process as defined by the referenced AGMA documents, to indicate where and in what way it may be improved in meeting the above objectives, and to propose changes that will provide such improvements. Success in this effort can be recognized as extending the benefits of elemental gear inspection.

Definitions

Although the following terms are used in the AGMA documents, their definitions are generally by inference rather than by readily located statements. The definitions given here conform to the general usage of the terms, inside and outside of gear technology. They are generally in agreement with their use in the AGMA documents, with the possible exception of the use of elemental, as will be noted later.

Deviation: the dimensional departure from the geometry of the ideal gear, as defined, directly or by inference, in the gear specifications, including any design modifications, such as *tip relief* or *face crown*, introduced by the gear designer.

Elemental: any component of gear accuracy which cannot be further reduced to sub-components and, as such, may be present alone or in combination with other elemental components. Elemental components are often associated with a single source in the manufacturing process and have an individual effect on gear performance.

Composite: any gear accuracy designation applying to a combination of elemental components.

Gear manufacture

Gear accuracy definitions and measurements are independent of the method of gear manufacture. However, each manufacturing method may produce its own set of typical accuracy deviations requiring its own set of measurement procedures. For example, wide-faced gears made by the powder metallurgy (P/M) process tend to have a hollow condition in its face width, namely, a smaller diameter at its face center with a larger diameter near the end faces. This will be revealed in the helical inspection trace. Any inspection for profile should then be made at the face-located larger diameters because it is these gear sections which will interact with a non-crowned mating gear on the parallel shaft. It is the responsibility of the gear designer to specify such inspection locations.

It is important to recognize that each manufacturing method may also bring its own set of typical accuracy deviations. In the measurement and data analysis methods in use for one specific accuracy deviation, another type of the accuracy deviation may insert itself. This could result in a composite

measurement rather than a true elemental measurement. Such a condition, in the form of “eccentricity of mounting”, is mentioned in [1], clause 7.5, and will be further discussed below.

Runout

Runout is applied to a variety of individual elemental accuracy deviations, each associated in some way with a varying distance of individual gear teeth, or tooth spaces, from the datum center of the gear. None of these individual elemental deviations are listed directly as part of elemental inspection requirements but their presence often enters into almost all of the other inspection procedures. The effect of some kinds of runout on the results of these inspection procedures will be given extensive treatment in this paper as part of an effort at clarification and enhancement of the coverage in the AGMA documents.

Three types of runout will be discussed:

- 1) eccentricity, in which the center of the ring of gear teeth, which may itself be close to ideal shape, is offset from the datum center of the gear, the one center used for all gear measurements and likely to be used in the mounting of the gear in its application.
- 2) out-of-round, in which the shape of the ring of gear teeth is not round, so that even if no eccentricity is present, measurements from all teeth or tooth spaces would not be constant
- 3) “hidden runout”, a condition in which eccentricity in the gear was present in an earlier step of manufacture but, in some later step of manufacture, was modified so as to “hide” one of its negative features from some inspection processes.

Eccentricity

Regardless of the method of gear manufacture, there are likely to be cases in which the inspected gear has some degree of eccentricity. Examples of some of these are given below:

In the case of a machined gear, it is common practice to locate the gear blank by its datum center in the form of a through-hole. Manufacturing variation in the size of the hole, especially when several gears are stacked on a single arbor matched to the size of the *smallest* possible hole, will introduce eccentricity between the hole's datum axis and the