A Proposed Pre-Finish Cylindrical Gear Quality Standard

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It is quite common to specify a gear class for in-process quality requirements, usually calling for a lower quality class than is required for the finished gear quality. Although it is appropriate to have lower expectations for a pre-finish gear condition, it is not appropriate to subject the pre-finish gear to the same level of scrutiny as a finished gear. Gears in a pre-finish condition may have large feed scallops or generating flats, which are desirable for productivity and may be conducive to the finishing process. However, such features will be evaluated as errors when subjected to the full analysis as required by the finished gear class inspection. Therefore, the use of a finished gear quality specification is not recommended or even appropriate for pre-finish gear quality evaluation, even if the quality class has been adjusted to pre-finish expectations. Additionally, in-process requirements often require non-zero target helix and profile slopes, which necessitate a new method of analysis to determine the achieved quality class. Therefore, a pre-finish evaluation method and standard is proposed. This proposed standard would not make any recommendations regarding the required quality for any application. The intent is to establish standard pre-finish quality classes for typical finishing operations, which only include the inspection elements that are important to properly evaluate pre-finish gear quality as it applies to the finishing operation.

Introduction

It is quite common to reference a gear class for in-process quality requirements. For example, a gear may need to meet ANSI/AGMA/ISO 1328 Class 6 when it is finished, but to control the in-process quality, the pre-finish hobbing quality may be specified at a lower quality, such as Class 8. (ANSI/AGMA/ISO 1328 is the current AGMA standard, replacing the older 2015, 2000-A88, and 390 quality class specifications.) Although it is appropriate to have lower expectations for a pre-finish gear condition, it is not appropriate to subject the pre-finish gear to the same level of scrutiny as a finished gear. The ANSI/AGMA/ISO 1328 gear quality specification, which is intended to be applied to a finished gear, covers numerous parameters, including: helix (slope, form, and total), profile (slope, form, and total), and pitch (single and cumulative). However, many of these quality characteristics are so drastically affected by typical pre-finish conditions that they should not even be applied. To illustrate this issue, consider a pre-grind hobbing operation where a large feed rate is used, which produces rather significant feed scallops on the tooth flanks. Such scallops are not only typical, but are often desirable. Features such as helix slope, profile slope, and cumulative pitch (if properly measured)—likely unaffected by feed scallops—are considered important features to evaluate pre-grind quality. However, features such as helix total and form, profile total, and form will be negatively impacted by the feed scallop, which may cause the gear to fail pre-finish specifications even with lowered pre-finish expectations (see Figs. 1, 2 and 4). Therefore, the use of a finished gear quality specification such as ANSI/AGMA/ISO 1328 is not recommended or even appropriate for pre-finish gear quality evaluation — even if the quality class has been adjusted to pre-finish expectations. In addition, in-process requirements often require non-zero target helix and profile slopes, and a method of analysis is required to handle this. Therefore, a pre-finish evaluation method and quality standard is proposed.

Goals of this proposed pre-finish standard:

- Provide a standard method of evaluation for pre-finish quality.
- Reduce the evaluated parameters to those that directly impact final gear quality for the given finishing process.
- Avoid penalizing evaluated quality for inherent, typical, and often desirable pre-finish geometries (such as feed scallops, generating flats, thread-to-thread induced pitch errors, intentional off-lead conditions, leaning profiles, etc.).
- Promote a common understanding of typical pre-finish characteristics and how they affect evaluated quality.
- Reduce in-process costs by eliminating unnecessary and overly restrictive tolerances.
- Create pre-finish quality classes for the most common finishing operations.

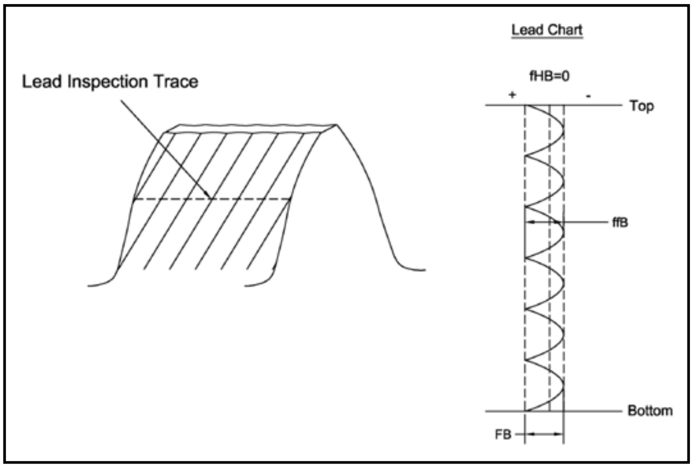

Figure 1 **While it is often desirable to have a significant hobbing feed scallop, such scallops will negatively impact helix total and form errors. There should be a minimal effect on lead slope unless there are not enough scallops to construct a decent best-fit line.**

This proposed standard would not make any recommendations regarding the required quality for any application. The intent is to establish standard pre-finish quality classes for typical finishing operations, which only include the inspection elements that are important to properly evaluate pre-finish gear quality as it applies to the finishing operation. It would be the responsibility of the manufacturing/process engineer, quality engineer, or other responsible individual to establish the required pre-finish quality class for their application.

The intent of this standard is not to create a rigid pass/fail evaluation system. Because the gears that would be evaluated according to this standard are still in an unfinished state, the final pass/fail decision cannot necessarily be made. However, as would be expected, the likelihood of producing an acceptable gear through the finishing process decreases with increased pre-finish errors. Therefore, this standard should be viewed as a manufacturing tool and not a strict quality standard.

Since the various finishing processes have different pre-finish quality requirements, it makes sense to establish different criteria for the pre-finish conditions of each finishing process. The five most common finishing processes are grinding, shaving, honing, rolling, and skiving (hard hobbing), and guidelines would be provided for each. These guidelines are based on the existing ANSI/AGMA/ISO 1328 tolerances and tolerance classes (with certain elements excluded), and also with some newly defined elements that may be important to pre-finish quality but are not currently covered in the finished gear standard.

Elements included in ANSI/AGMA/ISO 1328:

- Helix slope (individual teeth): $fH\beta$
- Helix slope tolerance: $fH\beta T$
- Helix form: $ff\beta$
- Helix form tolerance: $ff\beta T$
- Helix total: $F\beta$
- Profile slope (individual teeth): $fH\alpha$
- Profile slope tolerance: $fH\alpha T$
- Profile form: $ff\alpha$
- Profile form tolerance: $ff\alpha T$
- Profile total: $F\alpha$
- Single (individual) pitch: fp
- Cumulative pitch: Fp

NEW elements NOT included in ANSI/AGMA/ISO 1328:

- * Runout: Fr
- Average helix slope (mean): $fH\beta m$
- Helix slope variation (difference from high to low $fH\beta$): $\Delta fH\beta$
- Helix slope upper tolerance limit: $fH\beta Tmax$
- Helix slope lower tolerance limit: $fH\beta Tmin$
- Helix slope target (nominal): $fH\beta nom$
- Helix slope error (difference from nominal): $fH\beta'$
- Average helix slope error: $fH\beta m'$
- Average profile slope (mean): $fH\alpha m$
- Profile slope variation (difference from high to low $fH\alpha$): $\Delta fH\alpha$
- Profile slope upper tolerance limit: $fH\alpha Tmax$
- Profile slope lower tolerance limit: $fH\alpha Tmin$
- Profile slope target (nominal): $fH\alpha nom$
- Profile slope error (difference from nominal): $fH\alpha'$
- Average profile slope error: $fH\alpha m'$

New Elements Defined:

***Runout* (*Fr*).** Technically, runout is not a newly defined element; however, it is not a required element under ANSI/AGMA/ISO 1328 because gears do not typically function with double-flank contact. Because gear finishing processes typically do use double-flank contact and can be significantly affected by pre-finish radial runout, it is important to include runout in certain pre-finish evaluations. Therefore, runout is included in this proposed pre-finish standard.

Average helix slope (*fHβm*) is the numeric average (mean value) of all measured individual tooth helix slope values (including sign) per flank.

Example: four (4) $fH\beta$ values: -4, 2, 7, -1

$$fH\beta m = (-4 + 2 + 7 - 1) / 4 = 1$$

Helix slope variation (Δ*fH*β) is the difference between the maximum and minimum (including sign) of all measured individual tooth helix slopes per flank.

Example: four (4) $fH\beta$ values: -4, 2, 7, -1

$$\Delta fH\beta = 7 - (-4) = 11$$

In-process helix slope. It is quite common to require an off-lead condition, where zero helix slope is not the ideal condition in the pre-finish state. This is most often done to compensate for subsequent distortion in heat-treatment, where the two most common helix changes that occur are tapering and unwinding of the helix. To allow for this desirable off-lead condition, the target left and right flank $fH\beta$ values may be offset from zero, with each flank possibly having different target helix slopes. Therefore, the upper and lower $fH\beta T$ tolerance limits are calculated from the target $fH\beta$ instead of zero. As a result, several new elements must be defined to allow for a non-zero target helix slope.

Target helix slope (*fH*β*nom*) is the target (nominal) in-process helix slope ($fH\beta$). This value is set by the manufacturing/process engineer, quality engineer, or other individual responsible for the finishing process. The target helix slope value should be chosen to optimize the conditions for the finishing process. Target values may be different for each flank, denoted with a LF or RF preceding $fH\beta nom$ (i.e., LF $fH\beta nom$). If the left flank and right flank have different target helix slopes, then the part orientation and flank designations need to be clearly identified.

Helix slope tolerance (*fH*β*T*) is the helix slope ($fH\beta$) tolerance per ANSI/AGMA/ISO 1328.

Helix slope, upper limit (*fH*β*Tmax*) is the upper tolerance limit for helix slope.

$$fH\beta Tmax = fH\beta nom + fH\beta T$$

Helix slope, lower limit ($fH\beta Tmin$) is the lower tolerance limit for helix slope.

$$fH\beta Tmin = fH\beta nom - fH\beta T$$

Helix slope error ($fH\beta'$) is the difference between the target helix slope ($fH\beta nom$) and the measured helix slope ($fH\beta$) value

Example: $fH\beta nom = -20\mu m$ and $fH\beta = -17\mu m$

$$fH\beta' = -17-(-20) = 3\mu m$$

***Note*:** The use of prime (') in any element identifies that value as an error value (difference from target), and not a raw measurement value.

Average helix slope error ($fH\beta m'$) is the numeric average (mean value) of all measured individual tooth helix slope error values (including sign) per flank.

Example: four (4) $fH\beta'$ values: -4, 2, 7, -1

$$fH\beta m' = (-4+2+7-1)/4 = 1$$

Average profile slope ($fH\alpha m$) is the numeric average (mean value) of all measured individual tooth profile slope values (including sign) per flank.

Example: four (4) $fH\alpha$ values: -10, 5, -5, -2

$$fH\alpha m = (-10+5-5-2)/4 = -3$$

Profile slope variation ($\Delta fH\alpha$) is the difference between the maximum and minimum (including sign) of all measured individual tooth profile slopes per flank.

Example: four (4) $fH\alpha$ values: -10, 5, -5, -2

$$\Delta fH\alpha = 5-(-10) = 15$$

In-process profile slope. It is quite common to target a non-zero profile slope, where zero profile slope is not the ideal condition in the pre-finish state. This is often done either to compensate for distortion in heat treatment, or to improve meshing conditions with the finishing tool. To allow for this desirable non-zero profile slope condition, the target $fH\alpha$ value may be offset from zero. Therefore, the upper and lower $fH\alpha T$ tolerance limits are calculated from the target $fH\alpha$ instead of zero. As a result, several new elements must be defined to allow for a non-zero target profile slope.

Target profile slope ($fH\alpha nom$) is the target (nominal) in-process profile slope ($fH\alpha$). This value is set by the manufacturing/process engineer, quality engineer, or other individual responsible for the finishing process. The target profile slope value should be chosen to optimize the conditions for the finishing process. Target values may be different for each flank, denoted with an LF or RF preceding $fH\alpha nom$ (i.e., LF $fH\alpha nom$). If the left flank and right flank have different target profile slopes, then the part orientation and flank designations need to be clearly identified.

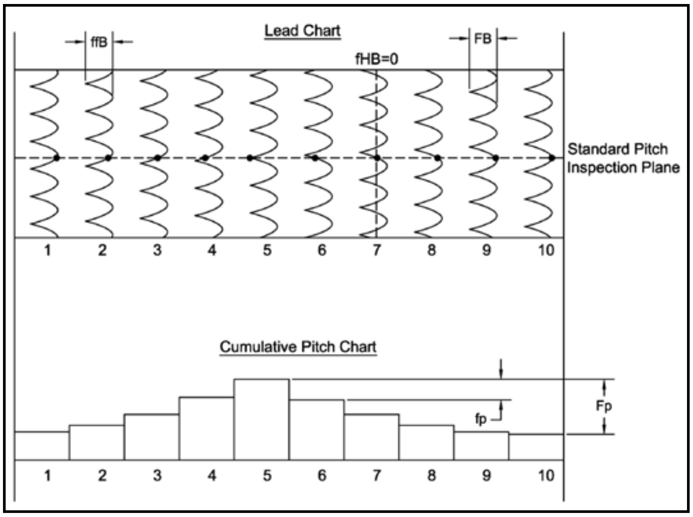

Figure 2 It is obvious that hobbing scallops will directly affect helix total and form errors. But helix slope error can also be affected — especially when the number of feed scallops on the face width is very low — or if a best-fit evaluation is not used. What may *not* be obvious is that pitch inspection can also be affected by feed scallops (as shown); checking pitch in a fixed plane will traverse the feed spiral, including inducing erroneous cumulative and single pitch errors (as well as calculated runout).

Profile slope tolerance ($fH\alpha T$) is the profile slope ($fH\alpha$) tolerance per ANSI/AGMA/ISO 1328.

Profile slope upper limit ($fH\alpha Tmax$) is the upper tolerance limit for profile slope.

$$fH\alpha Tmax = fH\alpha nom + fH\alpha T$$

Profile slope lower limit ($fH\alpha Tmin$) is the lower tolerance limit for profile slope.

$$fH\alpha Tmin = fH\alpha nom - fH\alpha T$$

Profile slope error ($fH\alpha'$) is the difference between the target profile slope ($fH\alpha nom$) and the measured profile slope ($fH\alpha$) value.

Example: $fH\alpha nom = 10\mu m$ and $fH\alpha = -5\mu m$

$$fH\alpha' = -5-(10) = -15\mu m$$

Average profile slope error ($fH\alpha m'$) is the numeric average (mean value) of all measured individual tooth profile slope error values (including sign) per flank.

Example: four (4) $fH\alpha'$ values: -4, 2, 7, -1

$$fH\alpha m' = (-4+2+7-1)/4 = 1$$

Proposed pre-finish quality classes

Five (5) pre-finish quality classes are proposed to cover the most common finishing operations:

1. Pre-grind "PG"
2. Pre-shave "PS"
3. Pre-hone "PH"
4. Pre-roll "PR"
5. Pre-skive (pre-hard hob)"PSk"

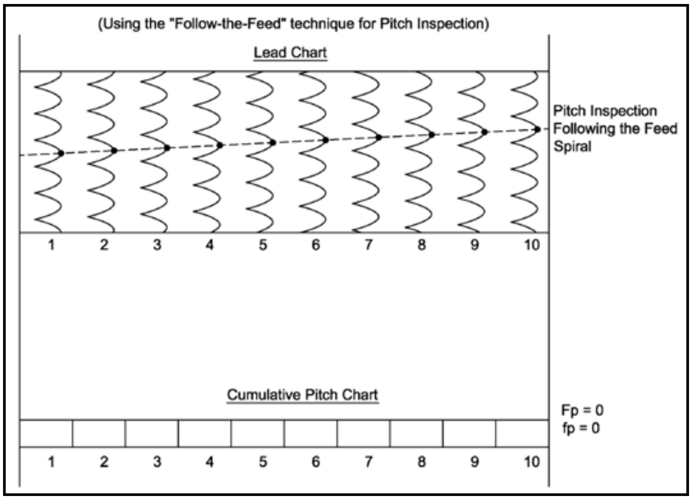

Figure 3 By following feed spiral during pitch inspection, scallop depth is not factored into cumulative or single pitch errors (or calculated runout). Caution must be exercised with this inspection method for gears with significant crown or taper, as the pitch evaluation finishes one scallop above or below from where it started, which may show a mismatch from start to end.

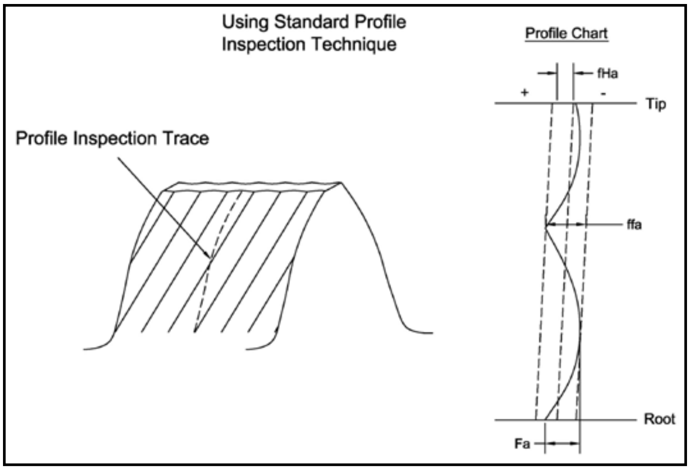

Figure 4 The standard method of measuring involute profile on a hobbed helical gear will traverse one or more hobbing scallops. Scallop depth will factor directly into evaluated profile total and form errors, and may falsely induce a profile slope error, depending on how the best-fit line is constructed for partial scallops traversed. Note: Spur gears are typically not affected by this because the scallop angles are nearly parallel to the profile inspection trace.

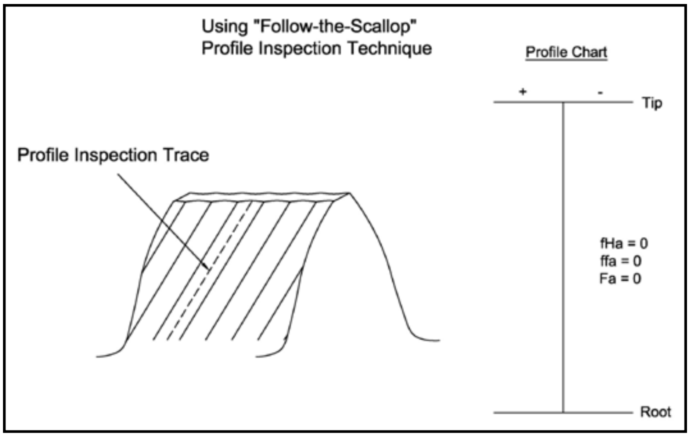

Figure 5 By following the scallop angle on a hobbed helical gear, the profile inspection does not include scallop geometry in the quality evaluation. This is important because scallop geometry should not be confused with profile quality, especially for a pre-finish quality evaluation.

The tolerances for each pre-finish class generally follow the equivalent ANSI/AGMA/ISO 1328 quality class (i.e. pre-finish class PG8 tolerances generally follow ANSI/AGMA/ISO 1328 class 8), but with a modified scope. ANSI/AGMA/ISO 1328 includes tolerance classes 1–11. However, classes 1–5 are rather high precision to be included in a pre-finish standard. Therefore, pre-finish classes have been limited to classes 6–11.

Each pre-finish quality class includes specific elements required to meet the defined pre-finish quality class number. All other elements are excluded from evaluation, unless specifically added to the requirements. For example, the pre-grind quality class does not include helix form, but this can be added separately to the pre-finish quality requirements (i.e., class PG9, plus helix form (*ff*β) 18µm max.) if deemed necessary by the responsible manufacturing/process engineer, quality engineer, or other responsible individual.

As this is currently in the proposal stage; all elements and proposed tolerances given below for each pre-finish quality class are open for discussion and change.

Pre-grind (class PG6– PG11)

- Average helix slope error (*fH*β*m*') (average of inspected *fH*β' values)
  - The tolerance for *fH*β*m*' is equal to *fH*β*T* per ANSI/AGMA/ISO 1328, using the same class number.
  - Helix slope variation (Δ*fH*β) (difference between max and min *fH*β values) (Tolerance = 2 × *fH*β*T*? (TBD))
  - Average profile slope error (*fH*α*m*') (average of inspected *fH*α' values). Note: If significant hobbing scallops are present, measurement should follow the feed scallop angle (Figs. 4 and 5).
- Cumulative pitch. Note: If significant hobbing scallops are present, measurement must follow the feed spiral (Figs. 2 and 3).

Pre-shave (class PS6– PS11)

- Average helix slope error (*fH*β*m*') (average of inspected *fH*β' values)
  - The tolerance for *fH*β*m*' is equal to *fH*β*T* per ANSI/AGMA/ISO 1328, using the same class number.
- Helix slope variation (Δ*fH*β) (difference between max and min *fH*β values) (Tolerance = 2 × *fH*β*T*? (TBD))
- Average profile slope error (*fH*α*m*') (average of inspected *fH*α' values). Note: If significant hobbing scallops are present, measurement should follow the feed scallop angle (Figs. 4 and 5).
- Profile form. Note: If significant hobbing scallops are present, measurement should follow the feed scallop angle (Figs. 4 and 5). (Tolerance = TBD)
- Cumulative pitch. Note: If significant hobbing scallops are present, measurement must follow the feed spiral (Figs. 2 and 3).
- Runout. Note: If significant hobbing scallops are present, measurement should follow the feed scallop angle (Figs. 4 and 5). The tolerance for runout (*FrT*) is defined as 90% of the cumulative pitch tolerance per ANSI/AGMA/ISO 1328.

Pre-hone (class PH6– PH11)

- Average helix slope error ($fH\beta m'$) (average of inspected $fH\beta'$ values)
- The tolerance for $fH\beta m'$ is equal to $fH\beta T$ per ANSI/AGMA/ISO 1328, using the same class number.

- Helix slope variation ($\Delta fH\beta$) (difference between max and min $fH\beta$ values)
  - ($\Delta fH\beta T = 2 \times fH\beta T$? (TBD))
- Helix form to limit scallop height? Maybe.
  - $ff\beta T$ = (TBD)
  - Average profile slope error ($fH\alpha m'$) (average of inspected $fH\alpha'$ values). Note: If significant hobbing scallops are present, measurement should follow the feed scallop angle (Figs. 4 and 5).
- Profile form. Note: If significant hobbing scallops are present, measurement should follow the feed scallop angle (Figs. 4 and 5). (Tolerance = TBD)
- Cumulative pitch. Note: If significant hobbing scallops are present, measurement must follow the feed spiral (Figs. 2 and 3).
- Runout. Note: If significant hobbing scallops are present, measurement should follow the feed scallop angle (Figs. 4 and 5). The tolerance for runout (FrT) is defined as 90% of the cumulative pitch tolerance, per ANSI/AGMA/ISO 1328.

Pre-roll (class PR6–PR11)

- Average helix slope error ($fH\beta m'$) (average of inspected $fH\beta'$ values)
- The tolerance for $fH\beta m'$ is equal to $fH\beta T$ per ANSI/AGMA/ISO 1328, using the same class number.
- Helix slope variation ($\Delta fH\beta$) (difference between max and min $fH\beta$ values) (Tolerance = $2 \times fH\beta T$? (TBD))
- Helix form ($ff\beta T$)
- $ff\beta T$ = (TBD)
- Average profile slope error ($fH\alpha$m') (average of inspected $fH\alpha'$ values). Note: If significant hobbing scallops are present, measurement should follow the feed scallop angle (Figs. 4 and 5).
- Profile form. Note: If significant hobbing scallops are present, measurement should follow the feed scallop angle (Figs. 4 and 5).
- Cumulative pitch. Note: If significant hobbing scallops are present, measurement must follow the feed spiral (Figs. 2 and 3).

Runout. Note: If significant hobbing scallops are present, measurement should follow the feed scallop angle (Figs. 3 and 4). The tolerance for runout (FrT) is defined as 90% of the cumulative pitch tolerance, per ANSI/AGMA/ISO 1328.

Pre-skive/pre-hard-hob (class PSk6– PSk11)

- Average helix slope error ($fH\beta m'$) (average of inspected $fH\beta'$ values)
- The tolerance for $fH\beta m'$ is equal to fHβT per ANSI/AGMA/ISO 1328 using the same class number.
- Helix slope variation ($\Delta fH\beta$) (difference between max and min $fH\beta$ values) (Tolerance = $2 \times fH\beta T$? (TBD))
- Average profile slope error ($fH\alpha$m') (average of inspected $fH\alpha'$ values). Note: If significant hobbing scallops are present, measurement should follow the feed scallop angle (Figs. 4 and 5).
- Cumulative pitch. Note: If significant hobbing scallops are present, measurement must follow the feed spiral (Figs. 2 and 3).

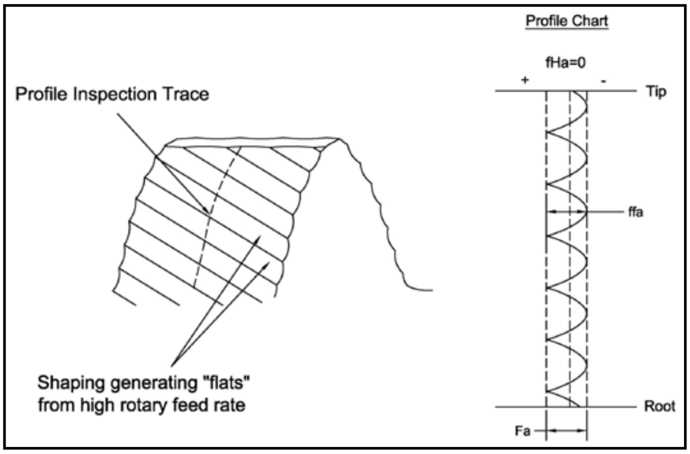

Figure 6 Using a high rotary feed rate during shaping may be desirable for optimizing productivity; but this can leave significant generating flats that are similar to hobbing scallops, yet are more pronounced in the profile direction. Such generating flats will influence profile inspection, causing significant total and form errors, but should have minimal effect on profile slope. Note: Hobbed gears with a low teeth-to-thread ratio can also exhibit similar generating marks on the profile.

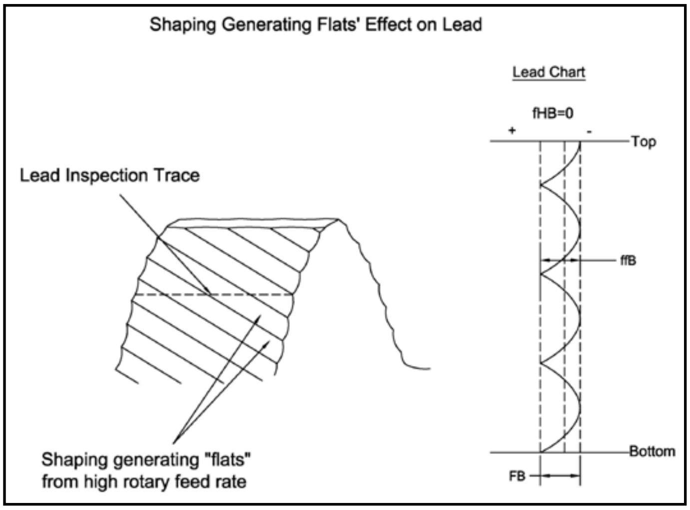

Figure 7 Using a high rotary feed rate during shaping may be desirable for optimizing productivity, but this can leave significant generating flats similar to hobbing scallops. Because these generating flats may cross the tooth flank diagonally, they can also appear on lead traces.

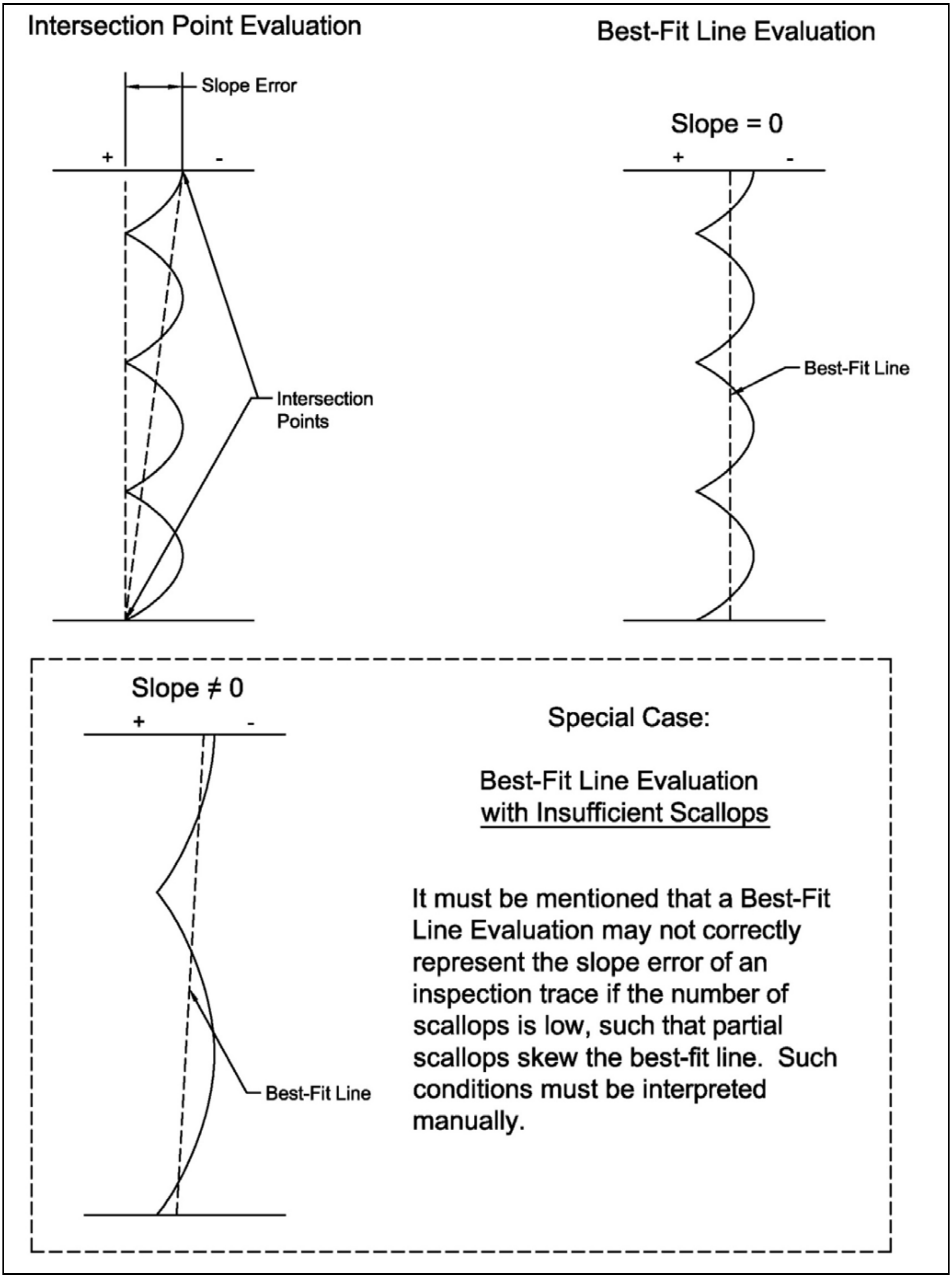

Figure 8 It is extremely important to use a best-fit evaluation for slope deviation, as illustrated above. The use of a simple intersection point evaluation may incorrectly induce slope error and slope variation from tooth to tooth, depending on where the inspection trace crosses the evaluation zone lines.

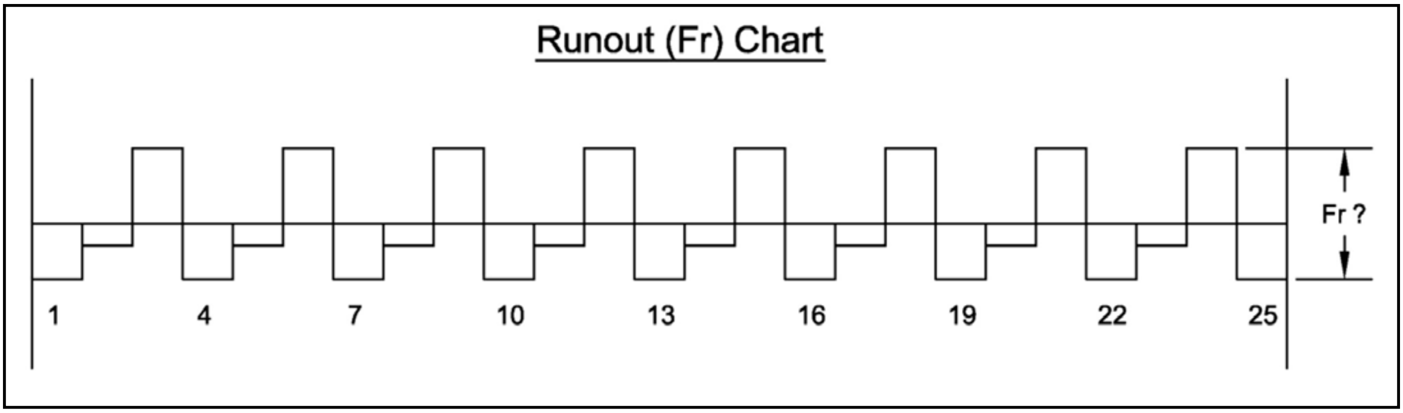

Figure 9 This example shows a gear with *no actual runout*. However, because it was cut with a 3-thread hob, an analytical inspection machine will interpret errors induced by the hob's thread-to-thread errors as runout (*Fr*). Note: The above chart could just as equally represent individual pitch (*fp*) or cumulative pitch (*Fp*) error of a gear cut with a 3-thread hob, and may not accurately represent true spacing errors.

Best Practices for Properly Evaluating Typical Pre-Finish Gears

- ***Scallops and generating flats are not "errors."*** On pre-finish gears, scallops and generating flats are expected—and often desirable—geometric features. As such, they should not affect the evaluated quality (Figs. 1, 2, 4, 6 and 7).
- ***Use the "follow-the-feed" technique for pitch inspection***. Hobbing produces a feed scallop that inherently spirals up or down the gear face width, with the scallops repositioned incrementally from tooth to tooth. One full revolution of the gear reveals that the scallop has spirally advanced according to the process feed rate (distance per gear revolution). A problem arises when a standard pitch inspection is performed on such a gear, especially with large pre-finish feed scallops. If the pitch inspection is performed in a simple plane, then each tooth's pitch measurement will be taken in a different relative location within the scallop as the scallops incrementally advance (Fig. 2). If left uncorrected, the pitch measurement will display the topography of a feed scallop, superimposed on top of the actual gear pitch results. To correct for this, the pitch measurements can be incrementally advanced along with the feed scallop so that all pitch measurements are taken in the same relative location within each scallop. This technique is often called "follow-the feed" (Fig. 3).
  Special case note: When "follow-the-feed" pitch inspection is used in conjunction with an intentional off-lead condition, a phantom pitch error component will appear, due to the fact that the feed spiral is progressing along a leaning helix; after completing the pitch inspection of all teeth, the inspection probe has progressed one full scallop above or below where it began. This will appear as a small pitch error per tooth around the gear, but it will appear as a large pitch error from last tooth to first tooth, with the phantom pitch error being equal to the helix difference from one scallop to the next. Because analytical inspection machines use pitch inspection results to calculate runout, evaluated runout will also have a phantom component as well.
- ***Use the "follow-the-scallop" technique for profile inspection.*** The generated scallop produced by hobbing typically follows a scallop angle that is not perpendicular to the root. This effect is much more pronounced on helical gears. Because a standard profile inspection trace will simply follow up the tooth in a single plane, the profile measurement may traverse partial or multiple feed scallops. As a result, the profile inspection chart will reveal the topography of the scallops traversed, superimposed on top of the actual profile measurement (Fig. 4). To eliminate the scallop geometry from the profile inspection, the profile inspection trace can be taken at the scallop angle so that the entire profile trace is performed at the same relative location within the scallop. This technique is often called "follow-the-scallop" (Fig. 5). Because the scallop angle on spur gears is usually perpendicular to the root, this technique is generally not necessary for spur gear profile inspection.
- ***Use best-fit lines for evaluating profile and helix slope.*** When analyzing either profile or helix for slope, it is important to use a best-fit line (or curve). If the slope is determined by simply identifying the intersection points of the actual trace and the evaluation lines, the presence of large feed scallops or generating flats will artificially induce slope error and slope variation from tooth to tooth (Fig. 8).

If there are enough scallops present between the evaluation lines, then a best-fit line should accurately represent the overall trace. However, in special cases where there are very few scallops present, the best-fit line may be skewed.

- ***Beware of profile evaluation range***. For a pre-finish gear, it may be necessary to modify to the evaluated range of the profile inspection. There are two primary reasons for this. First, a semi-topping pre-finish cutter may transition from flank to tip chamfer below the finished gear's required EAP (end of active profile). However, after more stock has been removed in the finishing process, the tip chamfer fall-off should be above the EAP, as required. Therefore, in the pre-finish state, the upper evaluation line may need to be adjusted below the required EAP to avoid evaluating the tip chamfer fall-off as profile error. Second, a pre-finish cutter may produce an undercut that begins above the TIF (true involute form) or SAP (start of active profile) diameter. Similar to the upper evaluation line, it may be necessary to adjust the lower evaluation line above the required TIF or SAP to avoid evaluating undercut as profile error.
- ***Be aware of hob thread-to-thread error's effect on runout and pitch errors***. Analytical gear inspection machines usually measure the left and right flank indexes and then calculate a runout chart and runout value based on how the center distance of a theoretical ball or pin would vary within all spaces around the part. Gears cut with multiple-thread hobs often have a regular tooth spacing error that repeats in a pattern that matches the number of threads in the hob. This regular pattern will usually also appear on a calculated runout chart, and the cyclical highs and lows will also be included in the

reported runout value (Fig. 9). However, calculated runout induced by hob thread-to- thread is not true runout, does not function as true runout, and will not affect finishing processes in the same way that true runout would. Eliminating this effect from calculated runout is important because it is not productive to be chasing a runout problem that does not exist, and the use of multiple-thread hobs should be encouraged (when appropriate), and not penalized, for optimizing productivity. Therefore, a solution is needed to remove such cyclical highs and lows from calculated runout. Possible solutions include, but are not limited to:

- Apply a low-pass filter to the index values prior to calculating runout.
- Apply a low-pass filter to the runout chart.
- Determine the cyclical pattern and subtract its effect from the calculated runout value.
- Perform a lead scan for each tooth's pitch measurement to take an average of all represented hob threads on each flank.

Note that the hob's thread-to-thread errors will also appear as individual pitch error (*fp*) as well as cumulative pitch error (*Fp*). If the number of hob threads is not evenly divisible into the number of gear teeth, and they do not share a common multiple, then the pitch errors reported by an analytical inspection machine will not accurately represent true spacing errors. This is due to the fact that all hob threads will be represented on each flank (in preceding or subsequent feed scallops), given sufficient face width.

Special case: helical gears with very few teeth. Hobbed gears with very few teeth often have pronounced generating flats. These generating flats will appear as scallops on the profile trace. (Note: A profile inspection turns a curve into a straight line. Interestingly, flats that are present on the profile will appear as curves or "scallops" on a profile inspection.) On helical gears, the relative position of these generating flats ("scallops") will change from tooth to tooth—just as feed scallops progress from tooth to tooth. As a result, a pitch inspection of the gear done at a constant diameter will traverse these "scallops" and the index chart will show the topography of the "scallop" progression, in a manner nearly identical to the phenomenon shown in Figure 2, even if a slow feed rate is used and actual feed scallops are not visible. This will lead to phantom pitch and runout readings. At this time, no solution is offered for this phenomenon. This is mentioned purely for informational purposes.

Evaluating Profile and Helix with Modifications

Gears are frequently designed with intentional modifications in order to improve their rolling characteristics. Profiles may have crown, tip relief, and root relief, which deviate from the perfect involute to compensate for tooth deflections under load. Similarly, helix crown or edge reliefs are often specified to avoid edge contact. However, these intentional modifications may be measured as errors if they are not handled properly in inspection. ANSI/AGMA/ISO 1328 illustrates how profile and helix deviations should be measured as they relate to "design profile" and "design helix." This is pertinent to this proposed pre- finish standard due to the fact that pre-finish gears will often have different modifications than the finished gear, or may have no profile or helix modifications whatsoever. This is due to the possibility that the prescribed modifications may be intended to be achieved with the finishing process, or that different modifications are desired in the pre-finish state due to changes that may occur during heat treatment. Therefore, the in-process "design profile" and "design helix" used for evaluation in the pre-finish state may differ from the final gear requirements and should be defined by the responsible manufacturing/process engineer, quality engineer, or other responsible individual.

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