Gleason-M&M Precision Systems CORPORATION

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Standard Practices
Gleason - M&M Calibration Laboratory

GENERAL

The Gleason - M&M Calibration Laboratory (Lab) provides services based on the following Standard Practices unless the Customer and the Lab have agreed to different procedures. Lab Customers are strongly encouraged to review the quotation and this information concerning Standard Practices in detail before issuing purchase orders for calibration or inspection services.

SCOPE OF WORK

The Lab has set limits upon its scope of standard work. Quotations for calibration or inspection services within this scope can usually be prepared according to a standard price list. When requested calibration or inspection services are beyond this scope, the Lab may either decline to quote or provide a special quotation according to the particulars of the application.

The Lab's scope of standard operations is summarized by the following categories and size limits. For a listing of A2LA-accredited measurements, see *SCOPE OF ACCREDITATION TO ISO/IEC 17025-1999 for the GLEASON - M&M PRECISION SYSTEMS CALIBRATION LABORATORY, Certificate Number: 2054.01*, available on-line at www.Gleason.com or upon request from Gleason - M&M Precision Systems.

Standard Categories

Test pieces are organized according to the following general categories.

Artifacts:

Fellows lead master
Fellows involute master (new style; 1, 4.5, & 14 inch base circle)
Other helix and involute masters, within the size limits
Pitch artifacts, within the limits

Master Gears:

External or internal involute gears, helical or spur

Go/No-Go Gages (Plugs and Rings):

External or internal involute splines (full or sector), helical or spur

Tapered Master Plugs:

External involute splines (full and sector), helical or spur

Standard Size Limits

Test pieces meeting the following criteria will be considered standard:

Maximum test diameter, externals or internals	250 mm (9.8 inches)
Maximum external diameter, SIP measurements	125 mm (4.9 inches)
Minimum internal diameter, SIP measurements	10 mm (0.4 inches)
Maximum internal diameter, SIP measurements	125 mm (4.9 inches)
Minimum base diameter, involute testing	5 mm (0.2 inches)
Minimum test diameter, helix & pitch testing	5 mm (0.2 inches)
Maximum base diameter, involute artifacts	356 mm (14.0 inches)
Maximum base diameter, all other	225 mm (8.9 inches)
Minimum minor diameter, internals	20 mm (0.8 inches)
Minimum bore size (mounting on center)	7 mm (0.3 inches)
Maximum bore size (mounting on center)	125 mm (4.9 inches)
Maximum length (between centers)	280 mm (11.0 inches)
Maximum face width	100 mm (3.9 inches)
Maximum weight	10 kg (22 lbs.)
Module, finest	1.0 module (24 DP)
Module, coarsest (master gears & spline gages)	5.0 module (5 DP)

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Maximum helix angle	42°
Minimum involute roll angle	3° (less for larger base diameters)
Maximum involute roll angle	42°
Maximum tolerance (potential deviation)	35 µm (0.0014 inches)
Maximum tolerance for involute & helix reference artifacts	5 µm (0.0002 inches)
Minimum diameter, spherical probe tip	0.5 mm (0.020 inches)

LAB MEASUREMENT SERVICES

The Lab provides five measurement services:

1) Inspection Service

Description: Usually applicable when test pieces are beyond the Lab's A2LA accredited scope of measurements or when traceability of results are not required. Test results are reported without statement of traceability or associated A2LA-accredited measurement uncertainty. Results may be compared to tolerance values provided by Customer and differences highlighted. Determination of compliance is not stated or inferred.

Required Data: Specified nominal geometry including, at a minimum:

normal pitch (module / diametral pitch)
normal pressure angle
helix angle

Data must be on hand before testing procedures commence. In the absence of required data, the Lab may recommend its Reverse Engineering Service to establish nominal values for testing.

It is strongly recommended that the following data also be provided. When this information is not provided, the Lab will use default values and procedures unless directed otherwise by the Lab Technical Manager.

measurement system, inch / metric (Lab default is metric)
reference axis definition, if other than mounting centers
number of teeth
face width
major and minor diameters
tooth thickness or dimension over/under pins with specified pin size, when appropriate
start of helix analysis (distance from end faces)
start of involute analysis (diameter, roll angle, or roll length) or
start of involute analysis, a.k.a. form diameter, TIF, SAP (diameter, roll angle, or roll length)
end of involute analysis (diameter, roll angle, or roll length)

Measurement Uncertainty: Not stated

Traceability: Not reported

Reports Provided: Inspection output sheets

2) Accredited Inspection Service

Description: Applicable only when test pieces are within the Lab's A2LA accredited scope of measurements. Intended for production test pieces that will not be used to carry forward the chain of traceability. Test results are reported along with statements of traceability and associated A2LA-accredited measurement uncertainties, where appropriate. Results may be compared to tolerance values provided by Customer and differences highlighted. Determination of compliance is not stated or inferred.

Required Data: Specified nominal geometry including, at a minimum:

normal pitch (module / diametral pitch)
normal pressure angle
helix angle

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Data must be on hand before testing procedures commence. In the absence of required data, the Lab may recommend its Reverse Engineering Service to establish nominal values for Measurement Service testing.

It is strongly recommended that the following data also be provided. When this information is not provided, the Lab will use default values and procedures unless directed otherwise by the Lab Technical Manager.

measurement system, inch / metric (Lab default is metric)
reference axis definition, if other than mounting centers
number of teeth
face width
major and minor diameters
tooth thickness or dimension over/under pins with specified pin size, when appropriate
start of helix analysis (distance from end faces)
start of involute analysis (diameter, roll angle, or roll length) or
start of involute analysis, a.k.a. form diameter, TIF, SAP (diameter, roll angle, or roll length)
end of involute analysis (diameter, roll angle, or roll length)

Measurement Uncertainty — Stated for each A2LA-accredited parameter measured

Traceability — Evidence provided by listing calibrated standards and equipment used

Reports Provided — Inspection Report provides measurement results and description of test procedures and conditions, including at a minimum:

instrument model
software version
ambient temperature limits
reporting temperature, after correction
test piece mounting conditions and orientation
specified nominal geometry values
reference axis definition, if other than mounting centers
test locations, if other than default (mid face width, pitch diameter)
direction of measurement (tolerancing) for each parameter observed
tooth / space testing method used (if appropriate)
conventions flank naming, including specified reference face
conventions for use of algebraic signs in test results
NIST traceable reference information
data filtering applied (if appropriate)
test date
technician
Gleason - M&M test number
general condition of the test piece

3) Reverse Engineering Service

Description: Development of representative nominal geometry values including pitch (module or diametral pitch) pressure angle and helix angle from observations of sample test piece(s). Reverse engineering observations of tooth flank geometry are limited to base diameter and lead derived from regression analysis of selected test trace regions. This analysis is affected by manufacturing deviations of the example test piece(s), modifications of the involute or helix geometry, and selection of the actual extent of the analysis region. There are an infinite number of combinations of gear parameters that will produce the same base diameter or lead. Those produced by the reverse engineering process are representative of the gear(s) observed, within the stated limitations, but are not unique.

Required Data — None. When available, mounting center distance and number of teeth in the mating gear can help refine the resulting values.

Test Procedure — Find a set of nominal geometry values using the Gleason - M&M "Unknown Gear" program or, when required, special calculations at the direction of the Lab Technical Manager.

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Documentation — Listing of nominal values

4) Accredited Calibration Service

Description: Applicable only when test pieces are within the Lab's A2LA accredited scope of measurements. Intended for master test pieces that will be used to carry forward the chain of traceability. Test results are reported along with statements of traceability and associated A2LA-accredited measurement uncertainties. Results may be compared to tolerance values provided by Customer and differences highlighted. Determination of compliance is not stated or inferred.

Required Data — Specified nominal geometry including, at a minimum:

normal pitch (module / diametral pitch)
normal pressure angle
helix angle

Data must be on hand before testing procedures commence. In the absence of required data, the Lab may recommend its Reverse Engineering Service to establish nominal values for Measurement Service testing.

It is strongly recommended that the following data also be provided. When this information is not provided, the Lab will use default values and procedures unless directed otherwise by the Lab Technical Manager.

measurement system, inch / metric (Lab default is metric)
reference axis definition, if other than mounting centers
number of teeth
face width
major and minor diameters
tooth thickness or dimension over/under pins with specified pin size, when appropriate
start of helix analysis (distance from end faces)
start of involute analysis (diameter, roll angle, or roll length) or
start of involute analysis, a.k.a. form diameter, TIF, SAP (diameter, roll angle, or roll length)
end of involute analysis (diameter, roll angle, or roll length)

Measurement Uncertainty — Stated for each A2LA accredited parameter calibrated

Traceability — Evidence provided by listing calibrated standards and equipment used

Reports Provided — Calibration Report provides measurement results and description of test procedures and conditions, including at a minimum:

instrument model
software version
ambient temperature limits
reporting temperature, after correction
test piece mounting conditions and orientation
specified nominal geometry values
reference axis definition, if other than mounting centers
test locations, if other than default (mid face width, pitch diameter)
direction of measurement (tolerancing) for each parameter observed
tooth / space testing method used (if appropriate)
conventions flank naming, including specified reference face
conventions for use of algebraic signs in test results
NIST traceable reference information
data filtering applied (if appropriate)
test date
technician
Gleason - M&M test number
general condition of the test piece

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5) Compliance Service

Description:

Test results will be derived according to Customer-specified measurement and analysis methods then compared with Customer-specified tolerances to establish compliance to specifications. Test results may be reported along with statements of traceability and associated A2LA-accredited measurement uncertainties, where appropriate. **Compliance Service is only available for parameters for which the Lab has A2LA-accredited measurement uncertainties.**

When determining Compliance in the absence of specific Customer instruction to the contrary, documented in their purchase order and acknowledged by Gleason - M&M, the Lab will follow "guard banding" practice as recommended by *ISO/TS 14253-1:1998, Geometrical Product Specifications (GPS) - Inspection by measurement of work pieces and measuring equipment - Part 1: Decision rules for proving conformance or nonconformance with specifications*. Accordingly, the tolerances will be reduced by the U_{95} measurement uncertainty for the given measurement parameter before comparison with test values to determine compliance with specifications.

Whenever the Customer-specified analysis requires application of a band-fitting method, the measurement result is inherently limited to an observation of either an "in band" or "out of band" condition. In all such cases, an accept/reject decision is inferred and Compliance Service methods shall be applied. In the absence of specific Customer instruction to the contrary, documented in their purchase order and acknowledged by Gleason - M&M, this is implemented by uniform reduction of the width of the specified band by the U_{95} measurement uncertainty for the given measurement parameter. Compliance Service with the standard guard banding method cannot be properly implemented when tolerance band design includes regions where the width of the band is less than or equal to the U_{95} measurement uncertainty. It may not be possible to properly implement Compliance Service with standard guard banding when tolerances are provided in the form of non-uniform band-fit specifications due to incompatibility with the available validated software.

In all cases, measurement uncertainty is taken into consideration when carrying out Compliance Service.

Required Data

Specified nominal geometry including, at a minimum

measurement system, inch / metric (Lab default is metric)
reference axis definition, if other than mounting centers
number of teeth
normal pitch (module / diametral pitch)
normal pressure angle
helix angle
face width
major and minor diameters
tooth thickness or dimension over/under pins with specified pin size, when appropriate
start of helix analysis (distance from end faces)
start of involute analysis (diameter, roll angle, or roll length) or
start of involute analysis, a.k.a. form diameter, TIF, SAP (diameter, roll angle, or roll length)
end of involute analysis (diameter, roll angle, or roll length)
direction of measurement (tolerancing) for each parameter observed
an unambiguous specification of the analysis for each parameter observed must be provided,
(may be provided, when appropriate, by reference to established national standard),
other data as may be available per application

Data must be on hand before testing procedures commence.

Measurement Uncertainty

Stated for each A2LA-accredited parameter observed

Traceability

Evidence provided by listing calibrated standards and equipment used

Reports Provided

Compliance Report provides a statement of test piece compliance to specifications, as provided by Customer, and description of test procedures and conditions, including at a minimum:

instrument model
software version

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ambient temperature limits
reporting temperature, after correction
test piece mounting conditions and orientation
specified nominal geometry values
reference axis definition, if other than mounting centers
test locations, if other than default (mid face width, pitch diameter)
direction of measurement (tolerancing) for each parameter observed
tooth / space testing method used (if appropriate)
conventions flank naming, including specified reference face
conventions for use of algebraic signs in test results
NIST traceable reference information
data filtering applied (if appropriate)
test date
technician
Gleason - M&M test number
general condition of the test piece

Measurement results may also be reported.

FITNESS FOR USE

The Gleason - M&M Calibration Lab does not provide opinions concerning fitness for use of any test pieces.

TEST PROCEDURES, all Services except Reverse Engineering

In the absence of specific Customer instruction to the contrary, documented in their purchase order and acknowledged by Gleason - M&M, and within the Lab's scope of standard work for the given test piece, the following standard measurement practices will be carried out as appropriate:

Involute profile and helix

Measurements are made on the Lab's Gleason - M&M 3515 instrument. Test pieces are measured on both flanks of four teeth approximately 90° apart. For sector Plugs and Rings, measurements are made on available teeth, excluding the outside flanks of last teeth in the sector. For center-relieved gears, both sections are measured for involute profile and helix deviations. Each feature of involute and helix reference artifacts is tested at multiple mounting locations on the instrument and the average value reported. Analysis methods are described in detail under "ELEMENTAL TEST RESULT ANALYSIS METHODS" below. Involute profile and helix slope deviation measurements of reference artifacts are adjusted for test piece temperature. Measurement methods follow AGMA 915-1-A02.

Pitch

Measurements are made on the Lab's Gleason - M&M 3515 instrument. Test pieces are measured on both flanks of all teeth. Sectors are not tested for pitch parameters. For center-relieved gears, both sections are measured for pitch deviations. Pitch reference artifacts are tested at multiple mounting locations on the instrument and the average value reported. Analysis methods are described in detail under "ELEMENTAL TEST RESULT ANALYSIS METHODS". Measurement methods follow AGMA 915-1-A02.

Dimension over/between pins (DOP)

Measurements on external test pieces are made on the Lab's SIP 550M instrument using calibrated gage pins, and when required by the three-pin method, a calibrated spanning gage block. DOP measurements on internal spur test pieces are made using calibrated gage pins and calibrated gage blocks. **DOP measurement of internal helical test pieces is not available.** DOP is measured in two places, approximately 90° apart, with the average value reported. The Lab can only measure DOP of external helical test pieces with odd numbers of teeth by the three-pin method. In some cases it may not be possible to implement the three-pin method, owing to significant helix modification or limitations of axial pitch and face width. Sectors are tested at one location, where possible. DOP measurements may be adjusted for test piece temperature, material compression, and actual (calibrated) pin sizes. Measurement methods follow ANSI/AGMA 2002-B88 (R1996).

Tip diameter (outside or inside)

Measurements on external test pieces are made on the Lab's SIP 550M instrument, and when required, using calibrated gage pins. Tip diameter measurements on internal test pieces are made using calibrated gage pins and calibrated gage blocks.

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Accredited measurement of the tip diameter of helical test pieces with odd numbers of teeth is not available. Tip diameter is measured in two places, approximately 90° apart, with the average value reported. Measurements of external test pieces with odd numbers of teeth can only be made using the one-pin method. Associated calculations require DOP measurements by the two-pin or three-pin method. Measurements of internal test pieces with odd numbers of teeth can only be made using the one-pin method. Associated calculations require DOP measurements by the two-pin method. Sectors are tested at one location, where possible. Tip diameter measurements may be adjusted for test piece temperature, material compression, and actual (calibrated) pin sizes.

Bore diameter

Measurements of external master gear bores are made on the Lab's SIP 550M instrument. Bore diameter is measured in two places, approximately 90° apart, with the average value reported. Bore diameter measurements may be adjusted for test piece temperature and material compression.

MEASUREMENT UNCERTAINTY

All measurement processes exhibit limitations upon consistency and accuracy of reported results. The Lab has carried out extensive studies of their measurement processes, leading to statistical estimations of their U_{95} measurement uncertainties. These estimations have been made following the methods outlined in various standards, technical reports, information sheets, and other documents published by ISO, AGMA, NIST, and others. Measurement results reported with U_{95} measurement uncertainty values can be expected to be valid within the stated limits 95% of the time.

When carrying out the Compliance Service, the Lab is required by *ISO/IEC 17025-1999* to take the associated measurement uncertainty into consideration. Accordingly, in the absence of specific Customer instruction to the contrary, documented in their purchase order and acknowledged by Gleason - M&M, the tolerances will be reduced by the U_{95} measurement uncertainty for the given measurement parameter before comparison with test values to determine compliance with specifications.

TRACEABILITY

Traceability of elemental gear geometry measurements, i.e. involute, helix, and tooth location (pitch) to the S.I. through NIST is established by use of reference gear-geometry artifacts calibrated by the Oak Ridge Metrology Center (ORMC) located at the Department of Energy's Y-12 National Security Complex and operated by BWXT Y-12. The ORMC establishes its gear metrology uncertainties in partnership with NIST in Gaithersburg, MD. NIST refers inquiries concerning calibration services for gear geometry artifacts to ORMC, stating in the process that measurement uncertainties for such calibrations will be identical for ORMC and NIST. ORMC is accredited by the National Voluntary Laboratory Accreditation Program (NVLAP), an ILAC accredited body, for the specific scope of accreditation under Lab Code 105000-0.

Traceability of other Lab measurements to the S.I. through NIST is established by use of instruments, gage pins, gage blocks, master rings & plugs, gauging systems, and assorted arbors and fixtures having current calibration documents from laboratories accredited by A2LA or by an A2LA recognized accrediting organization. In some cases, these calibrations may be carried out by the Lab, under A2LA accredited calibration procedures.

A2LA ACCREDITATION

The Gleason - M&M Calibration Lab is accredited by the American Association for Laboratory Accreditation (A2LA), an ILAC accredited organization, under Certificate Number 2054.01. This indicates that Lab operations, including U_{95} measurement uncertainty estimation methods and the resulting uncertainty values, have been assessed and found to comply with the requirements of ISO/IEC 17025:1999(E) and A2LA-specified requirements for Calibration Laboratories.

Lab measurement uncertainties accredited by A2LA are applicable within the scope of standard work limits listed in *SCOPE OF ACCREDITATION TO ISO/IEC 17025-1999 for the GLEASON - M&M PRECISION SYSTEMS CALIBRATION LABORATORY, Certificate Number: 2054.01* and summarized in this document under "SCOPE OF WORK". Revised measurement uncertainty estimations may be made for applications that are beyond these scope limitations. A2LA accreditation may apply to these estimations as well, depending on the given circumstances. The Lab may also carry out measurements beyond the scope of A2LA accreditation. Reported results of such measurements will be identified accordingly in the Measurement Report.

ENVIRONMENTAL CONDITIONS

The Lab is a temperature-controlled environment. Operations are prohibited if the ambient temperature exceeds ± 3° F (± 1.7° C) from standard temperature of 68° F (20° C). Test pieces are soaked in the Cal Lab environment for a minimum of 12 hours before measurement. When measuring involute or helix reference artifacts, observations of test piece temperatures are made and

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results are mathematically compensated for observed temperature deviations from 20° C (68° F) following methods outlined in *ISO/TR 10064-5*. Test piece measurements are prohibited if their temperature exceeds ± 1.5° C (± 2.7° F) from standard temperature of 20° C (68° F).

The Lab works diligently to maintain a high level of cleanliness to minimize the effects of particulate contamination on measurement results.

ELEMENTAL TEST RESULT ANALYSIS METHODS

In the absence of agreements to the contrary, documented in the purchase order and acknowledged by Gleason - M&M, the Lab provides a default analysis of test results based upon established practices of the Lab and the American gear industry. Other optional analysis methods may be agreed to. This may involve use of alternative analysis methods described in gear accuracy standards such as AGMA or ISO, which usually require additional Customer-supplied information for proper implementation. Custom analysis according to Customer-defined methods may also be available. Custom analysis requires availability of appropriate analysis software and additional Customer-supplied information. Compliance Service requires Customer-specified analysis methods and other information.

Datum Axis and Mounting

Measurement of gear involute, helix, and pitch parameters are made relative to a datum axis, which is defined by specification of reference features. The actual mounting configuration is at the discretion of the metrologist or application engineer.

The datum axis of a test piece may be defined by integral centers. Often this is the case with reference artifacts. Such test pieces are mounted and tested between instrument centers.

A bore may be specified as the reference feature that defines the datum axis. Such test pieces may be mounted upon a test arbor, which is subsequently mounted between instrument centers.

Test pieces may alternatively be mounted in the free state upon the instrument table then centered and tilted to optimize conformance to the specified test piece reference features with the reference axis of the instrument.

In some cases, standard Gleason - M&M software modules may be used to mathematically adjust test results according to specified reference features, which are not precisely mounted in conformance with the reference axis of the instrument.

Reference Face

When possible, a reference face is selected. Unless otherwise noted in the calibration report documents, the reference face for an external gear with an integral shaft and centers is the face adjacent the longer shaft feature. Unless otherwise noted in the calibration report documents, the reference face for an external gear with a bore or for an internal gear is the face with the preponderance of imprinted information. Implementation of reference face selection is at the discretion of the metrologist, application engineer, or Lab Technical Manager.

Flank Naming Convention

The tooth flank to the left, when viewing the reference face of the test piece, with the tip of a selected tooth above its root, *is* the right flank and the tooth flank to the right will be the left flank.

Tooth Numbering Convention

Teeth are numbered in a counterclockwise direction when viewing the reference face of the test piece.

Location of Tests

Involute and pitch testing is carried out at mid face width and helix and pitch testing is carried out at the pitch diameter. For center-relieved gears, involute and pitch testing is carried out at mid face width of each section.

Direction of Measurement

Involute, helix, and pitch tests are carried out with the measurement probe oriented to deflect tangent to the base diameter, within the transverse plane.

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Direction of Deviation Reporting

Involute test values are reported tangent to the base diameter, within the transverse plane. Helix test values are reported tangent to the base diameter, inclined to the transverse plane at the base helix angle. Pitch test values are reported tangent to the measurement diameter, within the transverse plane.

Helix and Involute Trace Data Filtering

Involute and helix test traces are filtered by the standard Gleason - M&M program option High Response, which produces only minimal smoothing of trace data.

Helix and Involute Trace Data Density

Involute and helix test traces consist of a minimum of 200 samples each.

Master Gears, Plugs and Rings: Involute and Helix Analysis, Total Deviation

Measurements of involute and helix are made according to classic generative methods. The Lab's standard analysis of involute and helix measurements is carried out using Gleason - M&M DIN Type analysis software. This method is based upon comparison of actual measurement traces to an unmodified involute of the specified base circle or to an unmodified helix with the specified lead. The parameter reported for these test pieces is Total Deviation. A straight line with zero slope (angle) deviation, which is analogous to the specified (unmodified) involute or helix, serves as the reference for observation of Total Deviation.

The Total Profile deviation value, F_f, is the distance between two non-sloping reference straight lines, which enclose the actual involute test trace, within the analysis region.

The Total Helix deviation value, F_β, is the distance between two non-sloping reference straight lines, which enclose the actual helix test trace, within the analysis region.

These methods represent standard practices commonly found within numerous national, international, and company-proprietary gear and spline accuracy standards.

Reference Artifacts: Involute and Helix Analysis, Slope Deviation

The Gleason - M&M Lab also uses DIN Type analysis software when measuring involute and helix reference artifacts. However, the reported parameter is Slope (Angle) Deviation, by best-fit line method. A best-fit straight line (linear regression within the analysis region) serves as a reference for observation of Slope Deviation.

The Involute Slope Deviation, $f_{H\alpha}$, is the slope or rise of the best-fit line, within the specified analysis region. This Slope Deviation value has positive polarity when the regression line shows an increase in material toward the tooth tip, and visa versa. Positive Slope Deviation polarity is analogous with a negative deviation of the pressure angle and a positive deviation of the base diameter.

The Helix Slope Deviation, $f_{H\beta}$, is the slope or rise of the best-fit line, within the specified analysis region. This Slope Deviation value has positive polarity when the regression line shows an increase in material toward the end of the given helix trace, and visa versa. The relationship between associated helix angle deviation and lead deviation values is therefore dependent upon the flank and the hand of the helix being measured.

These methods represent standard practices commonly found within numerous national, international, and company-proprietary gear and spline accuracy standards.

Center-Relieved Master Gears: Involute and Helix Analysis, Form and Slope Deviation

The Gleason - M&M Lab also uses DIN Type analysis software when measuring center-relieved master gears. However, the reported parameters are Form Deviation (for each section) and Slope (Angle) Deviation (overall), by construction line method. A best-fit straight line (linear regression within each analysis region) serves as a reference for observation of Form Deviation. A line constructed between points on each test trace at the limits of the overall helix analysis region serves as a reference for observation of Slope (Angle) Deviation, by construction line method. The total combined effect of deviations within both sections of each center-relieved tooth flank is not observed.

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The Total Profile deviation value, F_f, is the distance between two non-sloping reference straight lines, which enclose the actual involute test trace, within the analysis region.

The Helix Form deviation value, $f_{\beta f}$, is the distance between two sloping reference straight lines, which enclose the actual helix test trace, within each analysis region. Slope of these reference lines is determined by the corresponding best-fit straight line. The Helix Slope Deviation, $f_{H\beta}$, , by construction line method, is the slope or rise of the construction line, within the specified overall helix analysis region. This Slope Deviation value has positive polarity when the regression line shows an increase in material toward the end of the given helix trace, and visa versa. The relationship between associated helix angle deviation and lead deviation values is therefore dependent upon the flank and the hand of the helix being measured.

These methods represent standard practices commonly found within numerous national, international, and company-proprietary gear and spline accuracy standards.

Plus/Minus Lead and Taper Replica Setting Master Gears: Helix Analysis, Total and Slope Deviation

The Gleason - M&M Lab also uses DIN Type analysis software when measuring plus/minus lead and taper replica setting master gears that are often used with double-flank composite testers having gimbal instrumentation. Helix parameters reported include Average Helix (Lead) Slope Deviation (for plus/minus lead masters) and Summed Average Helix (Lead) Slope Deviations (for taper masters). Some users prefer to enter these values when setting their composite testers, rather than the specified design deviations of the master gears. Total Deviation is also reported for plus/minus lead masters and for taper masters.

Helix Analysis Region

The default analysis of helix test traces sets the analysis region to the central 80% of the specified face width. For center-relieved gears, default analysis sets the Form Helix Deviation analysis region to the central 80% of the specified face width of each section and the Slope (Angle) Deviation to the central 80% of the specified overall face width.

Involute Analysis Region

Involute analysis requires specification of an involute profile analysis region, including Start of Involute Analysis and End of Involute Analysis locations. Additionally, a Start of Involute Test location, somewhat lower on the profile than the Start of Involute Analysis, should be specified. Gleason - M&M's standard analysis determines these locations as follows:

1) Customer specified values for Start of Involute Analysis, End of Involute Analysis, and Start of Involute Test locations are applied when provided. Customer specified locations are adjusted when found to be below the base diameter or inaccessible with available probe tips.

2) When the Customer specifies a Form Diameter, Start of Active Profile (SAP), or equivalent value, it is used as the Start of Analysis location. Unless specified to the contrary, the default End of Analysis location is calculated at 95% of the roll distance from the Start of Analysis to the specified OD. The Start of Involute Test location is calculated at 5% (below the Start of Analysis location) of the roll distance from the Start of Analysis to the specified OD. Start of Involute Test and Start of Analysis locations are additionally evaluated to avoid diameters smaller than the base diameter and for possible interference of the measurement probe tip with the root diameter and adjusted if necessary.

3) In the absence of a specified Form Diameter, Start of Active Profile (SAP), or equivalent value, a calculation is made to determine if the subject gear is undercut. If it is not undercut, a Lowest Point of Contact is calculated for the subject gear, presuming a rack mate, this rack having been shifted according to a comparison of the specified OD of the gear to the standard proportion OD. This Lowest Point of Contact is used as the Start of Analysis location. The End of Analysis location is calculated at 95% of the roll distance from the Start of Analysis to the specified OD. The Start of Involute Test location is calculated at 5% (below the Start of Analysis location) of the roll distance from the Start of Analysis to the specified OD. Start of Involute Test and Start of Analysis locations are additionally evaluated to avoid diameters smaller than the base diameter and for possible interference of the measurement probe tip with the root diameter and adjusted if necessary.

4) If the calculation shows that the subject gear is undercut, the Start of Analysis location is set at 10% of the roll length from the base diameter to the specified OD. The End of Analysis location is calculated at 95% of the roll distance from the Start of Analysis to the specified OD. The Start of Involute Test location is calculated at 5% (below the Start of Analysis location) of the roll distance from the Start of Analysis to the specified OD. Start of Involute Test and Start of Analysis locations are additionally evaluated to avoid diameters smaller than the base diameter and for possible interference of the measurement probe tip with the root diameter and adjusted if necessary.

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5) When testing involute splines, locations for Start of Involute Analysis and End of Involute Analysis are calculated according to ANSI/SAE B92.2M-1980, Metric Module Involute Splines and ANSI/SAE B92.1-1996, Involute Splines and Inspection. These calculated locations are adjusted when found to be inaccessible with available probe tips.

6) Involute profile analysis regions of reference artifacts are set per case, based upon the design, existing calibration documents, and intended usage of the artifact.

In cases where base circle diameter, undercut, or root interference considerations require adjustment of Start of Involute Test or Start of Analysis values, the End of Analysis value may also be adjusted accordingly at the discretion of the metrologist, application engineer, or Lab Technical Manager.

Pitch Analysis

All measurements of pitch (tooth location) are made according to the classic single-probe index method. The Lab's standard analysis of pitch is carried out using Gleason - M&M DIN Type analysis software. This involves comparison of actual locations of individual tooth flanks relative to ideal equally spaced locations, at the reference angle of 360° / *z*. Three tooth location parameters are included in this default method, Total Cumulative Pitch, Single Pitch, and Runout.

The Total Cumulative Pitch parameter is the maximum algebraic difference between the position deviation values of any two tooth flanks of the test piece, relative to their ideal positions determined by summation of the appropriate number of reference angles.

The Single Pitch parameter is the maximum deviation of any adjacent pair of tooth flanks from their ideal relative positions as determined by the reference angle.

The Runout parameter is the maximum algebraic difference between the radial positions of a sphere placed into every tooth space. In practice, this observation is not physically carried out on the test piece. Standard Gleason - M&M algorithms in the DIN Type analysis software calculate Runout values from single-probe index measurements.

These methods represent standard practices commonly found within numerous national, international, and company-proprietary gear and spline accuracy standards.