GEAR FUNDAMENTALS

Gear Inspection and Measurement

Robert Moderow,
ITW, Illinois Tools, Lincolnwood, IL

The purpose of gear inspection is to:

- Assure required accuracy and quality,
- Lower overall cost of manufacture by controlling rejects and scrap,
- Control machines and machining practices and maintain produced accuracy as machines and tools wear,
- Determine heat treat distortions to make necessary corrections.

Basic Gear Inspection Terms

Runout (Radial) - The total variation of the radial distance of a gear's teeth from its center (or bore). Runout errors contribute to gear noise, binding, and additional stress in mating gears.

Runout (Sectional) - A condition of radial runount where much of the error occurs in a few teeth and is not evenly distributed over the entire gear. This is a more severe error than evenly distributed runout.

Runout (Axial) - Also called wobble or face runout. The total variation of a gear's teeth along its axis, measured from a reference plane perpendicular to its axis. While in itself not detrimental, it is almost always accompanied by lead variation, which causes excessive stress, noise, and possible binding in mating gears.

Lead - The axial advance of a screw thread (or gear tooth) in one turn (revolution, 360°).

Lead Error - The difference between the theoretical lead trace and the actual lead trace. Usually measured from one end of the tooth to the other, normal to the theoretical lead trace. Contributes to end-of-tooth contact with the mating gear, causing possible noise, surface crushing, binding, and early failure.

Lead Average - The average of the lead error of the gears teeth. Usually based on four lead traces taken around the gear at 90° intervals.

Lead Variation - The condition in a gear where some teeth vary in lead, plus and minus, from the average lead.

Total Lead Variation - The total amount of lead variation, plus to minus. Usually based on four lead traces taken around the gear at 90° intervals.

Plus Lead, Minus Lead - Plus lead is minus helix angle. Minus lead is plus helix angle. (See Fig. 3.)

Involute (Profile) - The curved shape of the gear teeth, usually from the S.A.P. or T.I.F. to the end of the tooth.

Involute (Profile) Error - The difference between the theoretical profile and the measured profile. Can cause noise, stresses, and early failure in mating gears.

Involute (Profile) Average - The average of the profile error the gear's teeth. Usually of four profile traces taken around the gear at 90° intervals.

Involute (Profile) Variation - The total amount of profile variation, plus to minus. Usually of four profile traces taken around the gear at 90° intervals.

Total Involute (Profile) Variation - The total amount of profile variation, plus to minus. Usually of four profile traces taken around the gear at 90° intervals.

Plus Involute, Minus Involute - Plus involute is plus material at tip of gear. Minus involute is minus material at tip of gear. (See Fig. 4.)

Spacing - The measured distance between corresponding points on adjacent gear teeth.

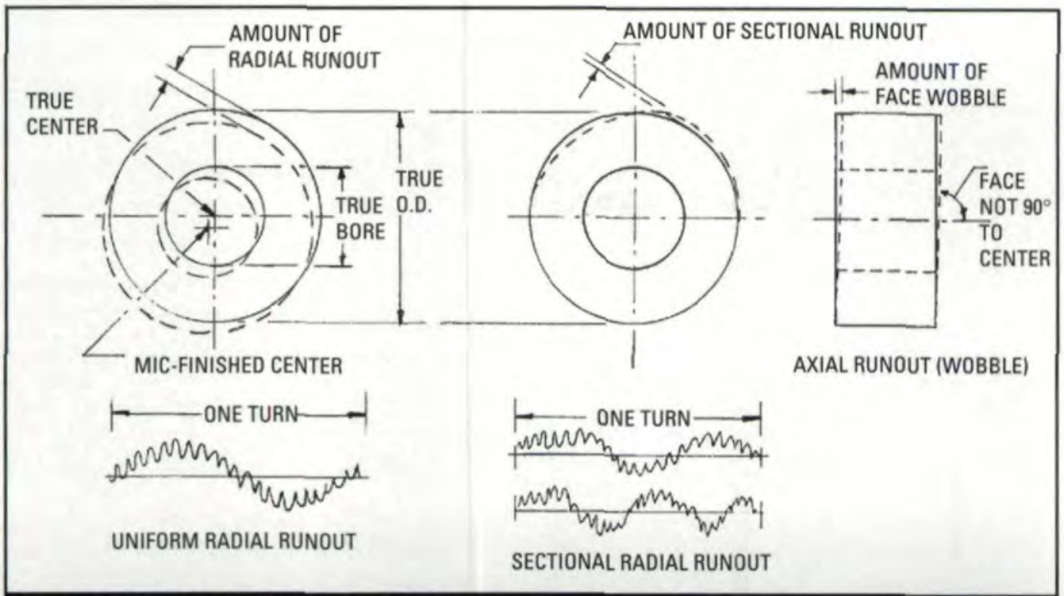

Fig. 1 - Uniform, radial, and axial runout.

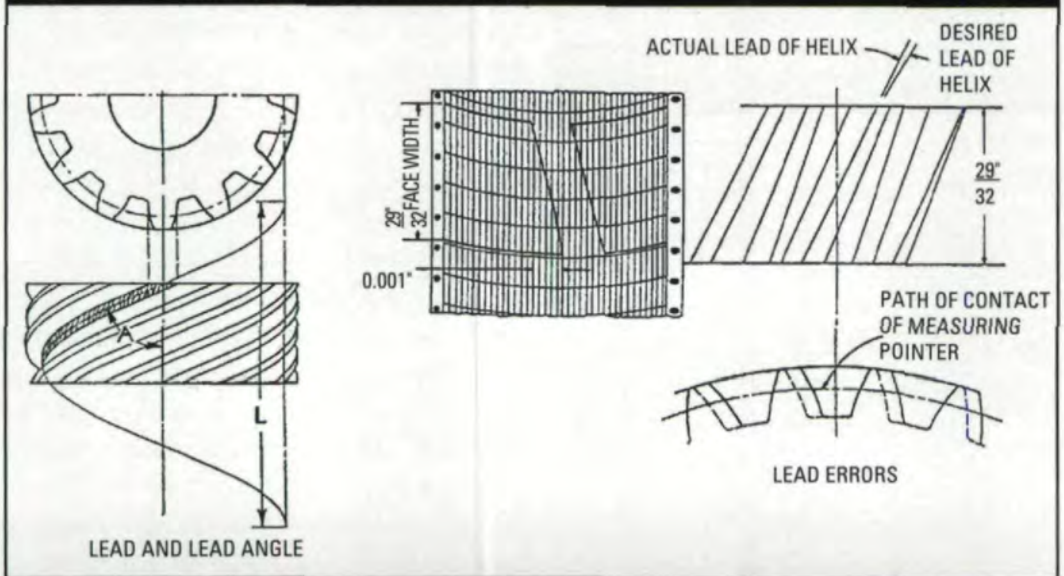

Fig. 2 - Types of lead errors.

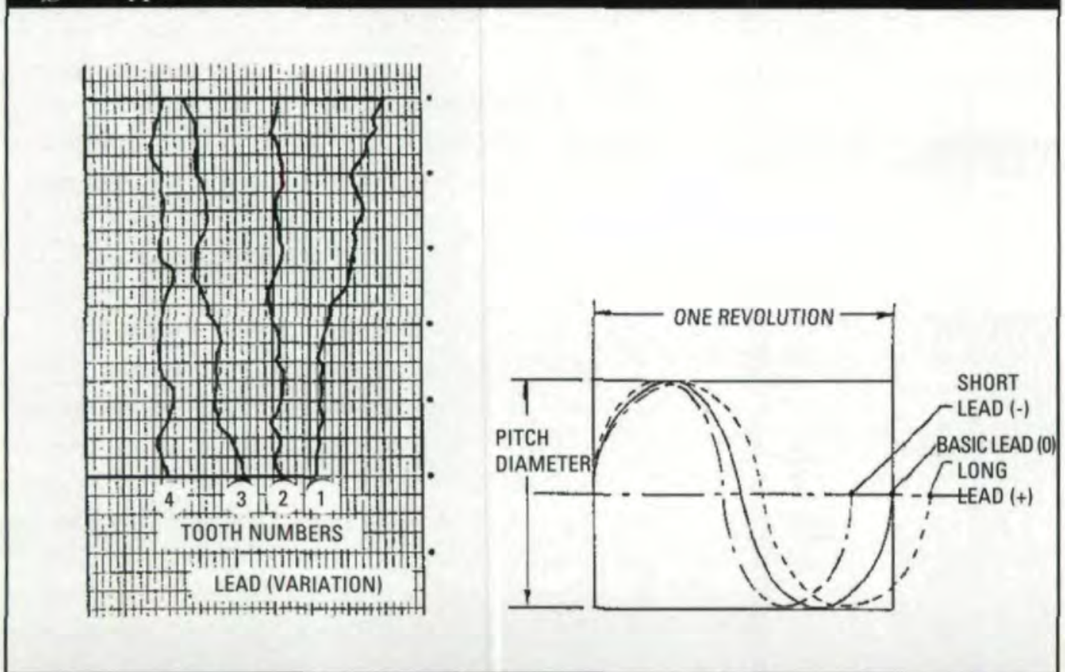

Fig. 3 - Charting lead variation caused by face runout - wobble.

Robert Moderow

was the training manager at ITW, Illinois Tools prior to his retirement earlier this year. He has over 35 years experience in gearing and is the author of numerous books and articles on gearing subjects.

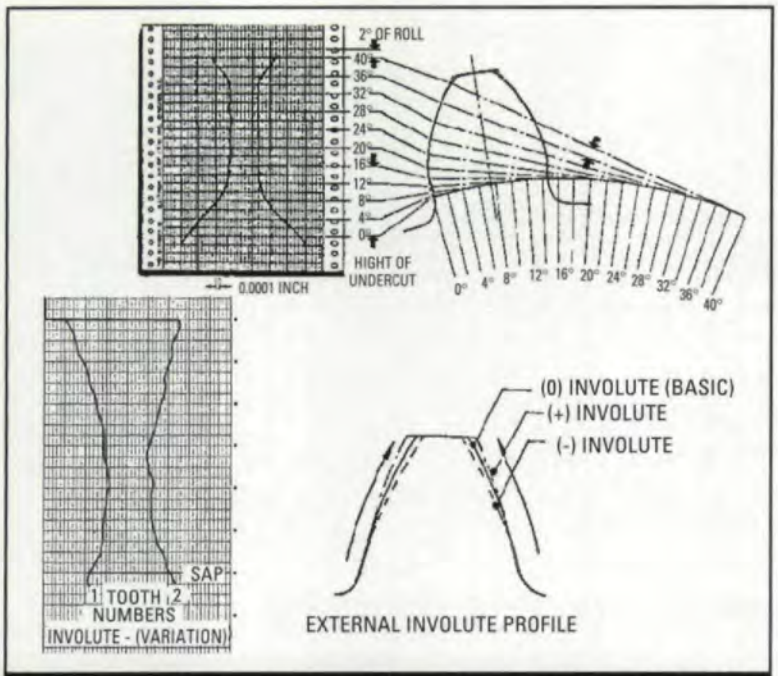

Fig. 4 - Charting involute variation on consecutive teeth; 2-THD hob cutting even number of teeth.

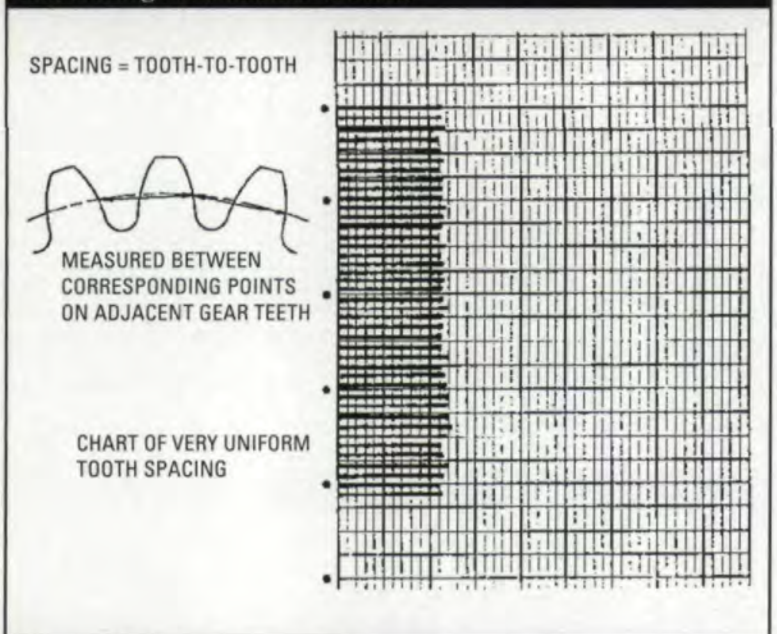

Fig. 5 - Tooth-to-tooth spacing.

Fig. 6 - Angular position of teeth.

Spacing Variation (Tooth to Tooth) - The difference between any two adjacent measurements of spacing. Can contribute to noise, stress, and early failure.

Pitch - The theoretical distance between corresponding points on adjacent teeth.

Pitch Variation (Error) - The difference between the theoretical pitch and the measured spacing.

Index - The theoretical angular position of teeth about an axis.

Index Variation (Error) - The displacement of any tooth from its theoretical position relative to a datum tooth.

Angular Velocity Error (Variable Velocity) - A tooth positioning error in a gear which was cut with runout. Subsequent operations (shaving, rolling) are unable to remove this runout, as teeth are not diametrically opposite, through the correct center. These subsequent operations tend to mask this runout, making this error difficult to find. It can be detected with a specially designed "high P. A." master gear if the gear is helical. It can also be detected with equipment that can check index error or with a "single flank" type gear roller. This type of error causes the driven gear of a gear set to speed up and slow down in one revolution, causing noise. In a planetary set, this error may cause a binding condition or will alternately carry load. This shifting load deflects the sun gear, causing noise and early failure. In an indexing gear set, this error will cause the indexed gear (driven) to vary from true position.

Nick - Actually a "rolling interference," which causes noise with the mating gear. May be a bright, shiny "nick." May be a burr left by a machining operation or a slight "plus material" condition left from a handling nick or burr, which has been "peened over" and barely noticeable.

Gear Inspection Methods

In *functional gear inspection* the gear is inspected by meshing with a known quality (master) gear. It is an attempt to inspect a gear as it is used. (See Fig. 8.)

In the *dual flank (tight mesh)* method the work gear is mounted on a fixture that allows it to rotate only. The master gear is mounted on a fixture that is free to vary the center distance with the work gear. The master gear's teeth are forced into the work gear's teeth (no backlash -

tight mesh) by pressure. An indicator senses the variations in center distance as the two gears are rolled together by hand or under power. A recorded chart can be obtained. (See Fig. 9.) *Total composite error* is the total variation of the center distance in one turn (360°) of the work gear. *Tooth-to-tooth composite error* is the variation of the center distance when the work gear is rotated through an angle of 360/N degrees, where N is the number of teeth in the work gear. (See Fig. 9.)

Terms Associated With the Dual Flank Method

Hand Roller - A dual flank gear roller where the gears are rotated by hand (no power). Usually just an indicator, rather than recording equipment is used.

Gear Charter - Similar to a hand roller, but having charting equipment and the power to drive one gear.

Red Liner - Same as a gear charter, but made by Fellows Corp.

Red Line Chart - The chart that comes from a "red liner." Also any chart showing the composite or rolling action of two gears.

Runout, nicks, and burrs can all be evaluated by this method. Functional tooth thickness can be determined by measuring the center distance between the work and the master. Involute, lead, spacing, fillet interperence, and other errors affect the tooth-to-tooth composite reading, but generally cannot be determined directly.

In the *single flank (fixed center distance) method*, the master gear and work gear are mounted on fixed center distance with backlash. (See Fig. 10.) The master gear drives the work gear. The relative angular rotation of the master and the work are compared and charted. This method can find the same errors as the dual flank method and can also detect angular velocity errors.

Analytical Gear Inspection

Analytical gear inspection is used for checking the individual elements of a gear - runout, lead, involute, tooth spacing, tooth thickness, etc.

Runout can be checked with a master gear (See previous paragraphs on functional gear inspection). It can also be checked by indicating over a ball or pin in a tooth space, progressing to the next tooth space. (See Fig. 11.) Some instruments, a tooth space comparator, for example, will inspect runout by plunging a ball into the

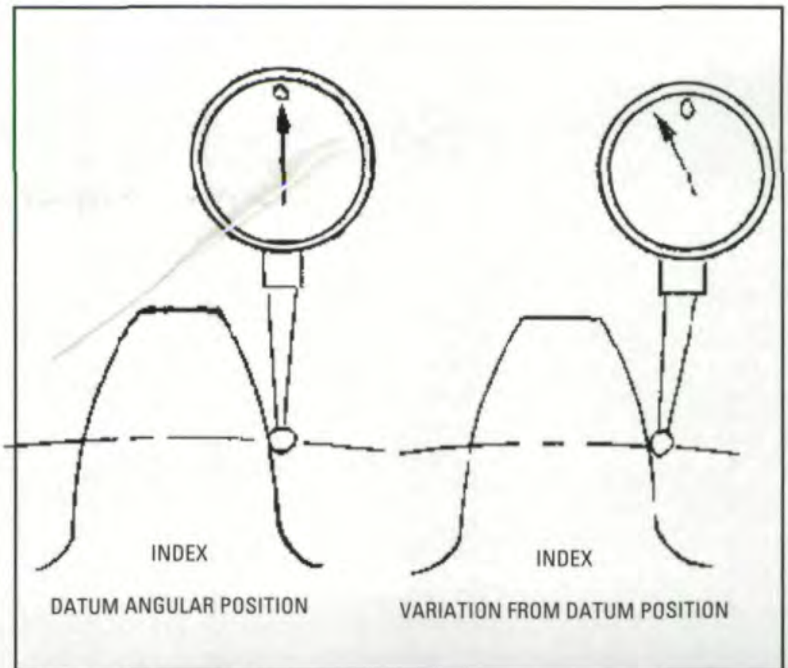

Fig. 7 - Pitch variation.

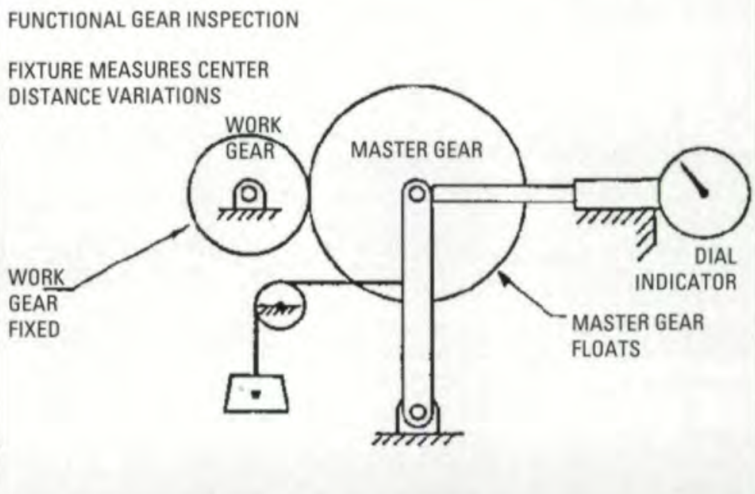

Fig. 8 - Schematic of dual flank rolling fixture.

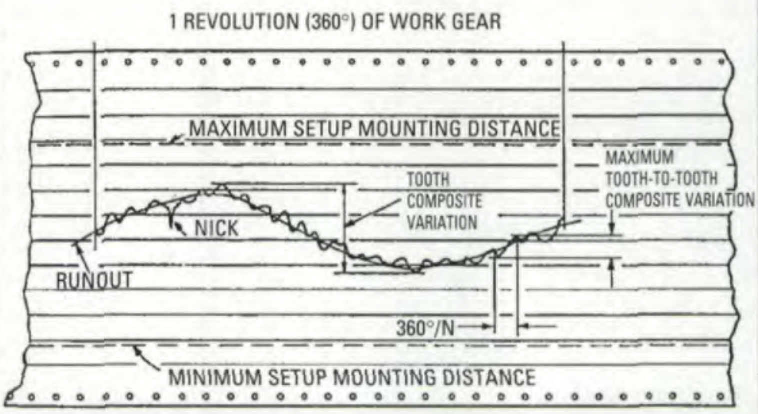

Fig. 9 - Chart of typical gear tooth errors - work gear rolled with master gear in dual flank fixture.

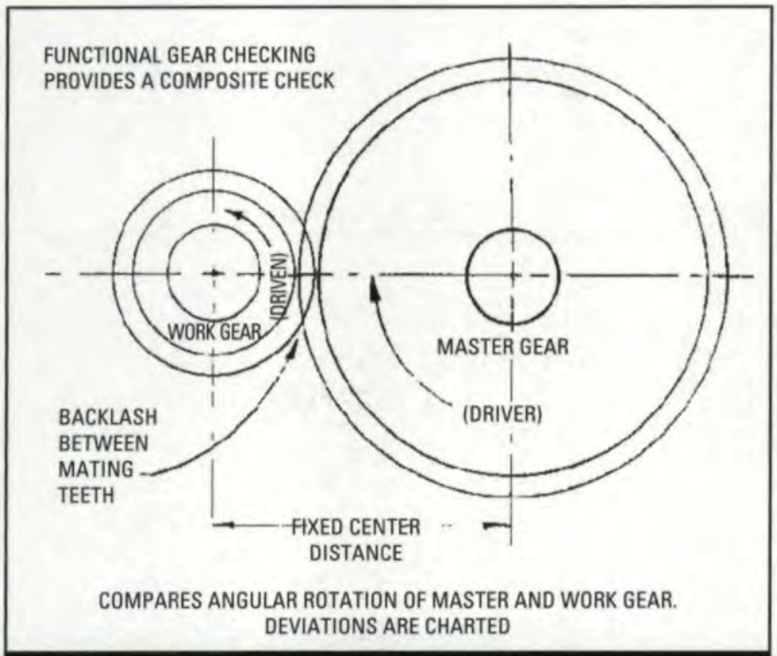

Fig. 10 - Schematic of single flank gear roller.

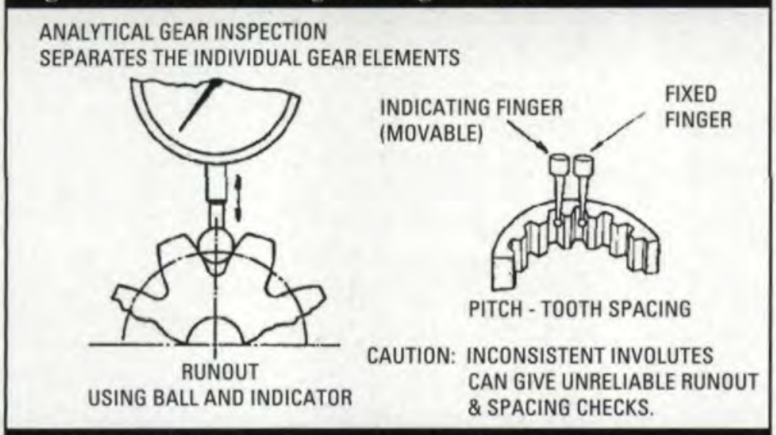

Fig. 11 - Analytical gear inspection systems.

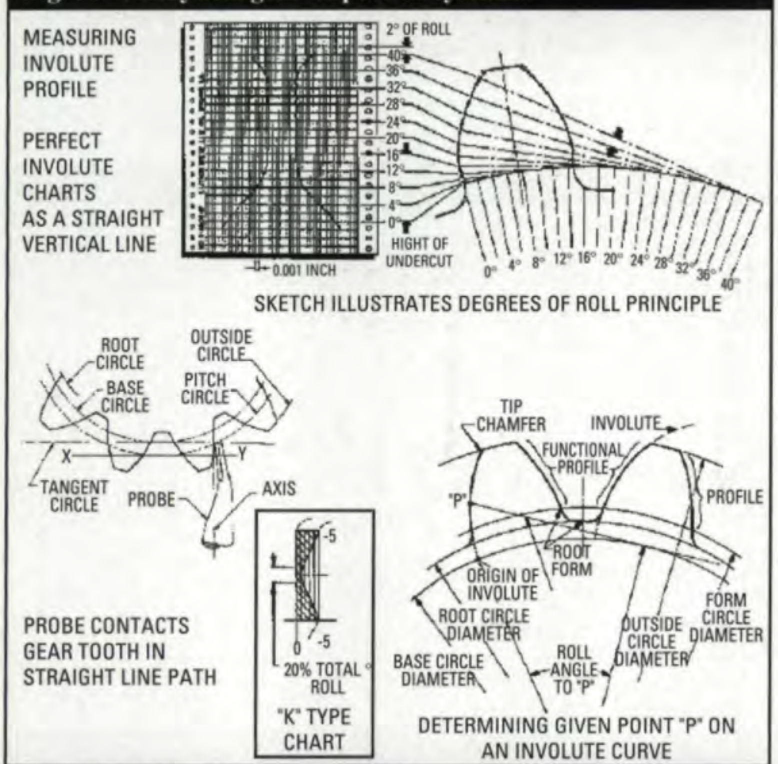

Fig. 12 - Measuring involute profile.

tooth spaces and also provide a chart.

Pitch (tooth spacing) can be check using a fixed finger and a movable (indicating) finger, measuring the distance from one tooth to another, progressing to the next pair of teeth. A tooth space comparator can do this automatically and can provide a chart.

Index can be checked by a coordinate measuring instrument with a single probe which is programmed to rotate the gear in increments of 360°/N (Number of teeth) and take readings on each tooth. This measures the true position of the gear teeth relative to the theoretical position.

Involute (profile) measuring instruments generate an involute curve. This is accomplished mechanically by rotating the work gear and moving the probe (which contacts the tooth surface) in a straight line path. It is also accomplished by coordinate measuring instruments programmed to move the probe and rotate the work gear in timed relationship. The instrument then detects any deviations from a true involute curve. A true involute will be charted as a straight line. (See Fig. 12.)

To determine a point (P) on an involute curve (tooth), we must convert a given diameter to involute measuring instrument movements. Since the instrument rotates the gear, we use degrees of rotations, (degrees of roll) to determine a given point (P). Also, the probe or contact finger moves in a straight line path so some instruments use this motion to determine a given point (P). This is call the *length of line of action* to point (P).

The chart paper on which the gear tooth involute trace is recorded is fed out of the recorder relative to either of the above two motions. When a gear's involute tolerance calls for zero to minus at the tip and zero to minus at the S.A.P., the resulting tolerance band resembes a "K"; hence, the term "K chart." Plastic overlays are often used to determine if a given involute chart is in or out of tolerance.

Lead checking instruments generate a lead path. This is accomplished mechanically by rotating the work gear and moving it along its axis in a timed relationship past a stationary indicating probe. This is also accomplished by coordinate measuring instruments programmed to move the probe and rotate the work in a timed relationship. The instrument then detects any deviations from this true lead path. (See Fig. 13.)

The chart paper on which the gear tooth lead trace is recorded is fed out of the recorder relative to the face width of the gear. To determine if a given lead chart is within a given tolerance band, plastic overlays are often used. They are especially helpful when the gear has crown, taper, etc.

A gear's tooth thickness can be checked in many ways. The most common method is to measure over balls or pins positioned in diametrically opposite tooth spaces on *external gears*. Internal *gears* are measure between balls or pins. Balls are usually used for helical gears. (See Fig. 14.)

Tooth thickness can also be measured by determining the center distance when in tight mesh (no backlash) with a master gear. Tooth thickness determined by a master gear is usually called "functional tooth thickness," as it will include other variables, such as lead, involute, spacing, and runout errors.

All of the analytical and functional inspection measurement (lead, involute, spacing, tooth thickness, runout, composite error, etc.) can now be analyzed by computers. It is no longer necessary for an inspector to judge if the part is in tolerance or not, as the computer will judge. Data storage is also accomplished so that the history of a given part can be stored for years and recalled at moment's notice.■

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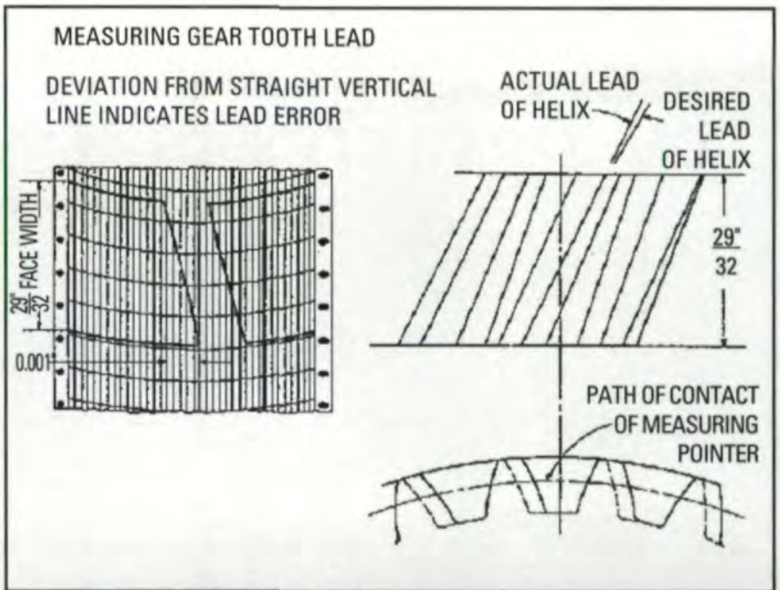

Fig. 13 - Measuring gear tooth lead.

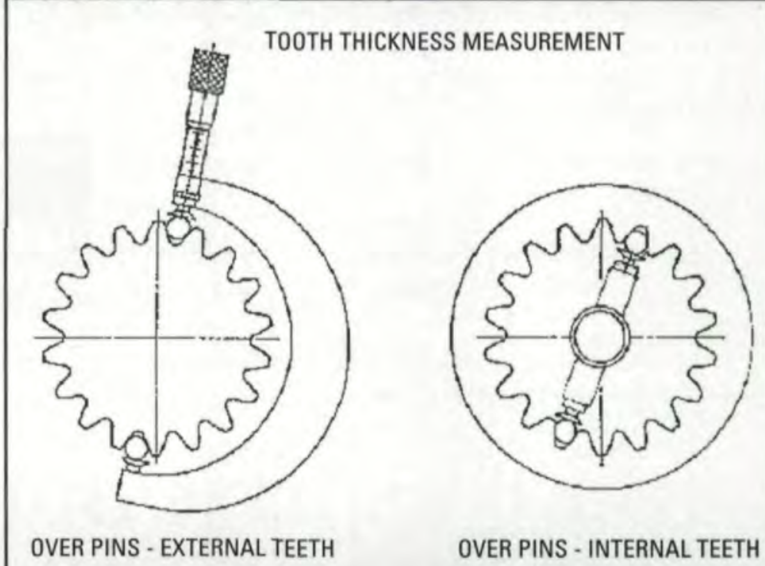

Fig. 14 - Tooth thickness measurement.