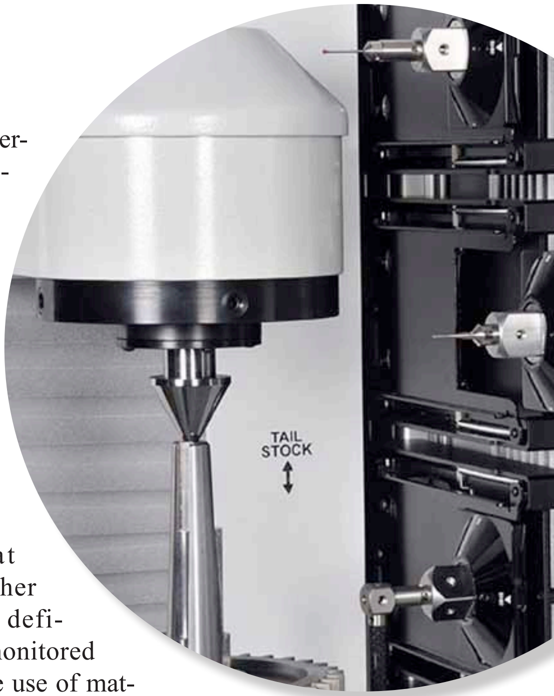
GEAR QUALITY INSPECTION:
How Good Is YoUrs?



How well you conduct your inspections can be the difference-maker for securing high-value contracts from your customers.

And as with most other segments of the gear industry, inspection continues striving to attain "exact science" status. With that thought in mind, following is a look at the state of gear inspection and what rigorous inspection practices deliver—*quality*.

A Brief Introduction

"Today's inspection process must include many methods to determine the overall functionality of a part or assembly," says Kim Gradolf, regional sales manager for Comtorgage Corp. "Simple go/no-go-type gages can be effectively used to verify functional aspects of a part, but other characteristics must be physically measured with dedicated, variable gaging at the machine to insure dimensional acceptability. A computer-based analytical check of a part using a CMM or dedicated machine—such as a gear checker—will usually confirm that the manufacturing process is maintained and the part will function properly in the assembly.

"Visual inspection using optical comparators, cameras, borescopes, etc., may reveal imperfections or flaws that might go unnoticed, and may be unacceptable.

"The high level of manufacturing that is capable today requires many different methods of inspection which must be utilized as a complete process for proper verification of part operation."

And what type of gear poses the greatest challenges regarding its manufacture and inspection?

"Every manufacturer will have issues, given a broad enough customer base," says Dennis Traynor, sales manager for Gleason Metrology Systems Corporation in Rochester, New York. "All gears have challenges—whether fine pitch; large wind energy size-gears with very tight tolerances (and which can deform easily with material handling); or spiral bevel gears with extremely tight tolerances, densely populated flank form grid sizes and supporting multiple manufacturing designs—all are tough applications with no easy answers.

"Although there are many sources of failure/rejection, I would say the quality of the gear blank drives a lot of the quality outcome," Traynor continues. "For instance, if the center bore location is out, the gear is destined to encounter runout (a potential for noise) and probably tooth thickness issues as well—just one example. I believe the bigger issue today is modified profiles and understanding how those profile changes contribute to gear strength/weakness, noise transmission, contact pattern changes and shifts—overall gearbox performance. Low-speed devices, for instance, typically do not have noise issues; however with the move to electric vehicles and gear motors replacing combustion engines—and running at significantly higher speed—noise is definitely a highly monitored issue. Through the use of mating gear contact pattern analysis, these transmission errors can be evaluated."

Step One: Check the Process

One of the most important steps in ensuring part quality is verifying the reliability of the measurement process itself, as in, for example, methods used for testing/verifying the manufacturing process's ability to meet the dimensional tolerance, especially if meeting that requirement is critical to part performance.

"The process is a gage repeatability and reproduceability study," says Louis Todd, president of California-based QC Solutions. "The (GR&R) is the amount of measurement variation introduced by a measurement system, which consists of the measuring instrument itself and the individuals using the instrument."

"A gage R&R study is a critical step in manufacturing Six Sigma projects," Todd says, "and it quantifies three things:

"Repeatability—variation from the measurement instrument

"Reproducibility—variation from the individuals using the instrument

"Overall gage R&R, which is the combined effect of (1) and (2) above

Another way to ensure that quality is being maintained is to use multiple types of checks and different machines and/or gages so that you're not reliant on just one system."

"Whether it is a gear or a spline we are manufacturing, we check the parts analytically for the involute profile, lead, adjacent tooth index variation and accumulated index variation with runout," says Fred Young, owner and

> "Large gears are usually the most challenging (for inspection)."
>
> — ***Dennis Traynor,*** *sales manager*
> *Gleason Metrology Systems Corporation*

operator of Forest City Gear in Roscoe, Illinois. "This is supplemented with measurement over or between wires to determine the tooth thickness or space width. The rule of thumb is to have inspection equipment capable of measuring to 10 percent of the individual tolerance allowed. Further, it is important to incorporate any variables in the manufacturing processes such as production on different machines by different operators or tooling and fixturing. Optimal in this case is to run the job on a variety of machines with different operators and tooling to determine all variables. You have to assume some givens, such as same material, hardness and blank qualities."

Photo courtesy of Gleason

Tighter Tolerances Cost More

With the ability of today's equipment to measure more accurately, there is sometimes an inclination to "enhance" an already tight tolerance without regard to the costs to achieve the new tolerance or its effect—or not—on the part performance? We're talking "tolerance creep."

"We always attempt to cut parts as accurately as possible to keep the CPK high and to distinguish our capabilities from those of our peers," says Young. "At the same time, many customers are not terribly sophisticated in gear/spline design and may assign tolerancing that is way too loose or, conversely, that tightens things down excessively, driving the price out of sight."

QC's Todd agrees. "With today's ability to design complex shapes and tighter tolerances in CAD software without the understanding of the ability to manufacture and measure to features, every time a tighter tolerance is applied, the cost to produce and inspect goes up."

"In many cases, just because the equipment or process is capable of holding very close tolerances, it is not always necessary or wise to reduce a tolerance just because it can be done," says Gradolf. "Reducing the tolerance of certain characteristics may result in a need to adjust tolerances of related dimensions of the part."

Gradolf explains: "For example, on an internal spline there is a relationship between the minor diameter, major diameter and the measurement between pins. Dimensional tolerances should be relative to each other. If not, this may cause poor fit, premature wear, poor lubrication and premature failure—just as too 'loose' of a tolerance. And, as mentioned, the additional costs involved to achieve a closer tolerance may not be justifiable. This would include more costly methods of inspection and more sophisticated measuring equipment."

The Importance of Setup

"With most of today's automation in high production manufacturing plants, precautions are in place to eliminate common sources (and) forces (of) contamination/workpiece misalignment," Traynor says. "Still—if the setup is misaligned, there is little hope of a quality gear being produced. On the inspection machine, pictures, graphics, audio and text are used to eliminate the chance for human error."

In addition, he adds, "Both inspection and production need to use quality workholding devices to support the best possible outcome," says Traynor.

On-Board Inspection

CNC onboard charting is another method used for inspection—but there are tradeoffs.

"It is popular to utilize charting equipment on newer gear grinding equipment, but generally, more credence and acceptance is given to checking the gear off the equipment that produced it," Young says. "For example, you usually have a well-defined interval of calibration for gear inspection equipment. It is much harder to keep current with the inspection aboard the cutting equipment. Also, the independent equipment can verify to datum surfaces such as bearing journals or bearing surfaces perpendicular to bores. We also encounter a whole host of parts that require alignments between different sets of gear teeth of some feature external to a tooth or space. Most often, the onboard inspection feature is designed to measure the involute and/or lead without having to remove a part to an independent checker due to size, weight or convenience.

"Perhaps an even more important consideration is to know what the charting you get means and whether the evaluation makes sense. There are a lot of gear companies who are willing to do outside inspection, and this may be a better option. If one does choose to go the in-house inspection route I would strongly recommend you send your inspector(s) to a qualified gear school to learn about gear measuring instruments. There is considerable variation in the experience/expertise of the setup/trainers for this type of gear inspection."

CMMs

And what of the pros and cons in using general purpose CMMs for gear inspection?"Using CMMs for gear inspection is excellent for those who only have a few gears or splines, while the vast majority of their work is positional relationship and sizing for non-gear work," Young says. "The software to check gears can be expensive, as can developing the appropriate probe to use. Is the CMM 3-axis or 4-axis? Are there standard 'artifacts' to verify the accuracy of involute, lead and spacing?

"The multi-sensing CMM systems today provide more data than in the past," Todd says. "Full 3-D scans of the actual part, compared to the CAD nominal or a scanned gear that is put into service and then compared to its actual manufactured specifications, are useful. Visual images can be stored for later recall. Surface finish is still a measurement that is not available on a multi-sensing system."

Gleason's Traynor also points out that "CMM's are typically much slower and much less efficient than dedicated gear inspection machines (GMMs). Typically, this is not their forte; they are best designed for prismatic part inspections." (*Ed.'s Note: See sidebar "Multifunctional Measurement" on page 33.*)

The Latest Technology

"I would hope we all recognize that charters that operate by printing lines on graph paper, with .0002" per-box requiring you to count the number of boxes traversed on the graph paper, is not nearly as informative as utilization of new analytical equipment that gives you a printout of all the individual parameters—sometimes with average values or graphics defining modified involutes (K-charts) or leads," Young says. "One gains much more information to control noise, longevity and wear."

"With the shift to global manufacturing it is imperative that inspection equipment be upgraded to compete with world-class manufacturers who would love to snag some of your customers. I find great reluctance on the part of many to upgrade their inspection capabilities, as they are not convinced it helps get parts out the back door. We use two different brands of analytical checkers so we can measure them against each other. You also made a good point (earlier) about the accuracy of the old plotters, which can be further defined by the cutoffs of the filters in the software of the newer, computerized gear measuring instruments."

100% Inspection

In today's quality-is-king manufacturing environment, is 100 percent inspection becoming the norm?

"This is industry-independent," Traynor says. "Automotive transmissions use composite methods (double-flank rolling) to support identification of defects. They don't tell you specifically what is in error, other than that some problem exists and that elemental analysis should be reverted to for proper diagnostics. Therefore only a smaller sampling of this type of gear passes over an analytical device, usually for process development, improvement and periodic sampling to assure maintained quality levels.

"Whereas with wind energy, every gear is inspected on an 'independent-of-process' inspection machine due to the quality level requirements of the gears, the performance levels the geartrain must support in longevity and durability, and of

> "With today's ability to design complex shapes and tighter tolerances… every time a tighter tolerance is applied, the cost to produce and inspect goes up."
>
> — ***Louis Todd,*** *president, QC-Solutions*

power transmission. Due to the stringent requirements of all gearboxes in use today, the demand for quality is at an all-time high; whether it's in mining, wind, chemical processing, marine, construction or power transmission, expected service life of these powertrains must meet design requirements and be absolutely reliable. Also, if there are geometric deviations, with the cost of the workpiece blanks being high, identification of the deviations is required."

Big Gears

Very large-diameter gear applications are proliferating, including the gears for wind turbines that Traynor alludes to. As it happens, they are also a BIG pain in the inspection.

"Large gears are usually the most challenging," Traynor allows. "Requirements for workholding, material handling and safety are also issues. The workholding needs to be efficient in order to support workpiece alignment and fine movement. Experience shows us that there is usually no universal device" for pain-free big-gear inspection.

"Large gears—especially internal ring (yaw) gears tend to 'potato-chip' or deform from being moved on 3- or 4-point slings, as well as on conventional spider-arm tooling for workholding. Typically, if the gear is mounted on less than four (slings)—preferably six supporting positions for leveling—it will have deformation quickly—by sagging—thus affecting measurement accuracy. This is to say nothing of trying to center this type of a ring; we have devised tooling to minimize distortion to the ring body."

"Our inspection machines—especially the larger-section 1,500 mm capacity and up—are 5-axis; all 4-linear axes can position to sub-micron levels, and the rotary axis is down to sub-arc second capability, (which is) extremely important to measuring gears of up to three-meter diameter that have tolerances higher than most Swiss watches. The geometry, timing and location tolerances on these parts are extremely critical when the end goal is a 25-year service life of a gearbox some 200 feet in the air. No one wants to bear those service costs, so the final OK has got to be absolute on quality."

"It is popular to utilize charting equipment on newer gear grinding equipment, but generally, more credence and acceptance is given to checking the gear off the equipment that produced it."

– ***Fred Young,*** *president*
Forest City Gear

What's Next

"(The) introduction of other devices to be supported on the inspection device—for instance, surface roughness analysis, Barkhausen noise detection, crack detection—are some of the more frequent test requests," Traynor says. "Non-contact inspection for speed is always on our radar, (but) industrially available sensors do not support current system configurations and require manipulation of the gear for line-of-site measurement."

For more information:

Comtorgage Corporation
P.O. Box 1217
Slatersville, RI 02876–0896
Phone: (401) 765–0900
Fax: (401) 765–2846
comtorgage.com

Forest City Gear
11715 Main Street
Roscoe, IL 61073
Phone: (815) 623–2168
Toll free: (866) 623–2168
Fax: (815) 623–6620
forestcitygear.com

Gleason Metrology Systems Corporation
Dennis Traynor, Sales Manager
300 Progress Rd.
Dayton, Ohio 45449
Phone (Direct): (937) 384–8950
Cell: (937) 626–7352
Fax: (937) 859–4452 Fax
dtraynor@gleason.com

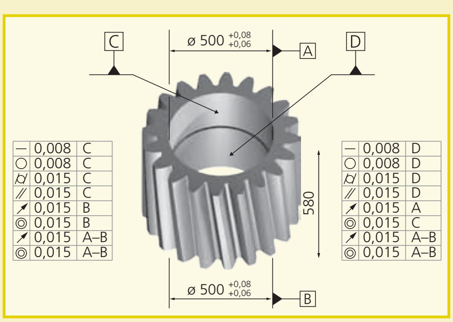
Quality Control Solutions, Inc.
43339 Business Park Drive, Ste. 101
Temecula, CA 92590
Phone: (951) 676–1616
Fax: (951) 676–8970
sales@qc-solutions.com

MULTIFUNCTIONAL MEASUREMENT

Klingelnberg's P 150 W tackles demanding wind turbine gear measurement with advanced gear inspection, form measurement and 3-D CMM features

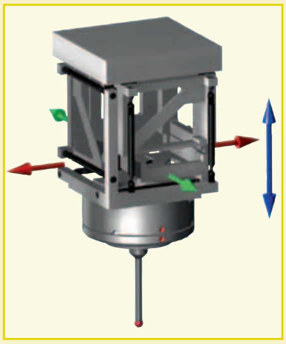
Manufacturers of wind turbine gearboxes continually strive for higher power density in smaller spaces. This means that gear components often have to do double-duty, with internal bores and faces often acting as load-bearing surfaces. Instead of using separate bearings to support the rotating motion, complex bearing geometries are being ground directly into the geared parts. Klingelnberg's P 150 W, based on the familiar P-series machines, was designed with these demanding components in mind.

A typical planet gear from a wind turbine transmission is shown in Figure 1. It includes tolerances for dimension, form and position, in addition to the normal gear tooth measurement requirements. By combining in one machine the ability to measure both gear and bearing features—such as roundness, concentricity and parallelism—the P 150 W allows for significant reduction in measurement cycle times.



The P 150 W also includes these key features:

- ***Vertically aligned boom***. Unlike the familiar P series of machines, the P 150 W uses a vertically aligned boom that enables measurement of internal gears and bearing surfaces with short probe rods.
- ***Unique parallel 3-D kinematics.*** Klingelnberg's 3-D measurement system combines the 3 axes of movement into one nested package; i.e., the mass moved is identical in all directions, ensuring the machine's applicability for both gear inspection and high-resolution form measurement tasks. This is a patented system that Klingelnberg says allows for more precise movement than a traditional CMM's kinematics.



- ***High-precision rotational bearing.*** Klingelnberg's rotational bearings have a static strength of 20 tons and a concentricity precision of less than 0.5 micrometers. This allows for highly precise circular measurements—a benefit both for measuring gear teeth as well as precision, internal bearing surfaces.

For more information:

Klingelnberg GmbH
Peterstrasse 45
D-42499 Hueckeswagen
Germany
Phone: +(49) 2192-81 0
Fax: +(49) 2192-81 200
info@klingelnberg.com
www.klingelnberg.com

Liebherr Gear Technology Inc.
1465 Woodland Drive
Saline, MI 48176-1259
Phone: (734) 429-7225
info.lgt@liebherr.com
www.klingelnberg.com