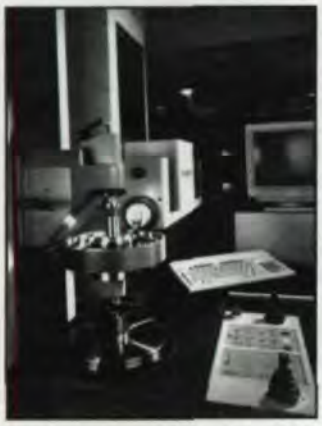
Analytical Gear Inspection: *The Shape of Things to Come*

It used to be that gear manufacturers wanting to perform analytical gear inspection required at least three machines to do so: The lead measuring instrument, the tooth space comparator and the involute checking instrument. In the beginning, these machines were mechanically driven. Over the years, the manufacturers of analytical gear inspection equipment have combined these functions—and a host of others.

In addition to basic generative gear testing, today's analytical gear checker often comes with the ability to check other types of parts, including rotors, threads, splines, cams and gear cutting tools; the ability to test forms such as roundness or straightness; the ability to measure all types of gears, including spiral bevel gears and worms; and the ability perform limited 3D coordinate measuring.



Class 14 Ground Gear for a high speed compressor being inspected at Nixon Gear, Syracuse, NY.

The ability of these machines to measure a wide variety of parts has been of great value to the Waukesha Engine Division of Dresser Equipment Group, Waukesha, WI, according to lab inspector/programmer Matt Banski, who uses an M&M Model 3000 Gear Analyzer to inspect more than 300 different parts, including spur & helical gears, worms, worm wheels, straight bevel gears, gear blanks and other parts for their line of internal combustion engines.

Measuring Bevel Gears

Certain kinds of gears, particularly bevel gears, cannot be reasonably measured using traditional generative gear testing, says Ed Lawson, director of metrology for M&M. This has required gear inspection equipment manufacturers to greatly modify the way their machines work, both mechanically and through their software.

Lawson sees analytical gear measurement technologies as being on a spectrum, with traditional generative gear testing at one end, and coordinate measuring on the other. In order to accommodate the measurement of worm gears, bevel gears and other parts, the best of today's dedicated gear machines, he says, are somewhere in the middle.

Traditionally, bevel gears have been tested functionally, rather than analytically, by applying marking compound

WHAT IS ANALYTICAL GEAR INSPECTION?

The term gear inspection covers many different types of gages, instruments and machines, and what exactly gear inspection is depends on who you ask. Related terms, such as gear testing, gear checking and gear analysis only add to the confusion. But gear inspection can roughly be divided into two broad categories: functional and analytical.

Functional inspection tells the gear manufacturer whether a gear will work in a given application. In other words, will it function as required? Generally, this type of inspection is performed by roll testing a gear in mesh with a master gear, or in the case of a bevel gear, with its mating pinion.

Roll testers come in many varieties, from the simple, hand turned mechanical instrument to the very sophisticated, high speed, automatic version with computer controls, printouts and recording. They come from a large number of manufacturers, including Gleason, Klingelnberg, ITW Heartland, Siemens-Moore Products, Mahr Federal, David Brown, Fellows, M&M Precision Systems, Parker Industries and many others. These machines are used to measure and detect nicks, runout, and center distance variation including short term (tooth to tooth composite) and long term (total composite) parameters. Also, when used in conjunction with a properly designed and certified master gear, absolute center distance values can be provided that relate very well with effective tooth thickness.

Functional inspection is, by its nature, a composite measurement. You may have a gear that performs well, but only by accident. For example, errors in pressure angle and pitch may work to cancel each other out. But just because the end result is a functional gear, that doesn't mean you have your manufacturing processes under control.

Analytical gear inspection, also referred to as elemental gear inspection, is used to inspect individual elements of the gear's geometry, such as lead, profile, pitch and accumulated pitch. The key advantage of analytical gear inspection is that it allows the user to quickly and easily identify elements of the gear that measure out of tolerance—the key information needed to control the manufacturing process.

For example, analytical gear inspection can reveal the presence of hob mounting errors, cutting tool wear, heat treat distortion patterns, and many other problems.

Analytical gear inspection can be performed on stand-alone machines dedicated to specific measurements such as lead, profile or tooth space. However, today's CNC generative gear inspection machines generally combine these functions with many other measurements and calculations. Such machines are available from M&M Precision, Klingelnberg, David Brown, Roto-Technology and Mahr-Federal, among others.

ANALYTICAL INSPECTION IN THE FIELD

User: Jerry Moxley, Quality Engineer/Gear Lab Manager
Company: Dana Spicer Off-Highway Products Division
Product: Planetary Axles, Single Reduction Axles, Power Shift Transmissions, Electronic Controls, Torque Converters, Brakes and Specialty Suspensions.
Types of parts inspected: parallel axis gears, splines and spiral bevel gearing
Equipment: M&M 3525 with 3-D probe, approximately 1 year old; M&M 3040, approximately 5 years old; M&M 2025, approximately 11 years old.
How analytical gear inspection is used:
The machines are located in the gear lab. They're used for accepting/rejecting parts, part development, process control and quality proving.

User: Mike Ocasio, Quality Technician
Company: Nixon Gear, Syracuse, NY
Product: Precision ground gears.
Types of parts inspected: Internal and external gears, splined shafts.
Equipment: Höfler ZME 402 CNC Gear Measuring Center, 7 years old; Fellows 12H Lead & 12M Involute manual gear inspection units, approximately 35 years old.
How analytical gear inspection is used:
"Our Höfler is kept in a climate-controlled lab. It is used daily by both quality assurance and the machine operators. We use it for first piece accept/reject, part development and quality proving."

User: Richard Hayes, Quality Engineer
Company: Sumitomo Machinery Corp. of America, Chesapeake, VA
Product: Cycloidal speed reducers and gear motors.
Types of parts inspected: Cycloidal discs, planetary gears, helical gears, spur gears, shafts, and limited bevel gears.
Equipment: M&M Model 3000 Gear Analyzer, approximately 7 years old.
How analytical gear inspection is used:
"It is primarily used for final inspection of sampled parts from our manufacturing process or receiving inspection of parts manufactured by outside suppliers. In some cases, it's used to verify first-piece setup for machining process control and evaluation of gear components from returned defective units."

User: Geoffrey T. Grill, Gear Engineer
Company: Meritor Automotive, Oshkosh, WI
Product: Heavy vehicle axles for mining, logging and heavy construction equipment.
Types of parts inspected: sun gears, planetary gears, ring gears and splines.
Equipment: M&M 2000-4, 14 years old.
How analytical gear inspection is used:
Accept/reject product, either on first-piece setups or random sample of finished product.

User: Matt Banski, Lab Inspector/Programmer
Company: Waukesha Engine Division of Dresser Equipment Group
Product: Internal combustion engines for gas and air compression, prime and standby power generation, pump, chiller, blower, and other industrial applications.
Types of parts inspected: Inch and metric spur gears, helical gears, worms, worm wheels, bevel gears, gear blanks, shafts and non-gear parts inspected for runout, etc.
Equipment: M&M Model 3000 Gear Analyzer, approximately 2 1/2 years old.
How analytical gear inspection is used:
In-process inspection, final inspection, prove-out, part development and quality control.

User: Ricky L. Shinkle, Senior Engineering Lab Technician
Company: Delco-Remy America
Product: Gear Reduction Starters
Types of parts inspected: Plastic internal gears, armature sun gears, planetary gears, pinions, engine ring gears, motor drive shaft splines and clutch cam surfaces.
Equipment: M&M Model 2025, approximately 17 years old.
How analytical gear inspection is used:
Accept/reject parts, part development and process control.

User: Paul Bojanowski, gear quality control, and Dan Wolosian, quality process consultant
Company: Visteon Automotive Systems, Sterling, MI
Product: Rear axles and front axles for cars and light trucks.
Types of parts inspected: Ring and pinion gears of several sizes and ratios, rear axle differential and side gears, transmission gears, and NASCAR racing gears.
Equipment: Klingelnberg PNCs, approximately 2 years old; Gleason, Ono Sokki and Oerlikon single-flank testers, all approximately 5 years old; and Zeiss CMMs, approximately 5 years old.
How analytical gear inspection is used:
To establish process capability, perform Design of Experiment (DOE), monitor continuous improvement activities, and containment of reject material. The inspection equipment is also used to validate machine summaries and tool settings.

to pinion-gear pairs and running them together on a dedicated bevel gear testing machine. Roll testing machines don't incorporate the analytical approach, so they are used primarily on the shop floor to prove gear sets. An experienced operator listens for noise problems and nicks, checks for runout and views the tooth contact patterns. The operator would then have to make a judgment, comparing the new set with gear sets known to work well together.

Of course, today's functional bevel gear testers computerize much of this process, and they are often used in the lab as well. For example, the Gleason Phoenix HCT tester incorporates digital tooth contact imaging, structure-borne noise analysis and computerized high-speed, single flank testing.

But no matter how sophisticated they get, roll testing machines cannot reproduce the geometry of a spiral bevel gear. Some form of coordinate measuring is required, and machines such as the Phoenix tester, when used in the lab, are often used in conjunction with other machines. At one time, that required a coordinate measuring machine, but today's dedicated gear inspection machines can be equipped with CMM functions.

For example, the Klingelnberg series of analytical gear inspection equipment incorporates this kind of technology. Their P26 model, introduced at EMO 99, is a compact measuring machine for workpieces up to 260 mm in diameter. According to Klingelnberg marketing specialist Andreas Montag, "The tester is suitable for all measuring tasks in the gear technology and guarantees short measuring times

with a high measuring accuracy." This includes all forms of spiral bevel gears manufactured by any of the major cutting processes.

The M&M machines also come with CMM-like capabilities. With the right software and probe, they can look at the gear tooth surface, compare it to either a theoretical or actually measured good gear, and mathematically recommend changes to the surface. The machines employ a sophisticated "virtual cutting" process simulation, which lets the operator see the effects of machine tool settings without having to cut another gear.

A relatively new machine on the market is the Primar, from Mahr Corporation. According to Mahr's marketing manager, Bruce Cowley, this machine is actually three machines in one. It combines the functions of a form tester for measuring roundness, straightness and other forms with those of a generative gear tester and a dedicated CMM. With the addition of a special software module, the Primar also has the ability to measure spiral bevel gears in 3D, Cowley says.

Advanced Computer Integration

Because of their ability to isolate the process parameters that cause parts to be out of tolerance, analytical gear inspection machines can be ideally suited for implementing a statistical process control program. All of the machines mentioned in this article come with computerized reporting and recording of inspection results. Software modules are available that allow for advanced statistical reporting.

In fact, the M&M and Klingelnberg machines can be used to generate corrective machine settings to directly control the manufacturing process. However, "a direct control of the manufacturing via statistical values is presently used only in a few companies," says Montag.

Versatility

Another advantage to analytical gear inspection systems is that they can be outfitted with the software to inspect gear cutting tools, including hobs, shaper cutters and broaches.

"The accuracy of gear cutting tools plays an important factor in producing quality gears," says Montag. "Klingelnberg has developed, in collaboration with important tool manufacturers and users, software modules for measuring hobs, shaping cutters and shaving cutters to monitor their quality and trace back problems caused by the geometry to the cutting tool."

M&M, Mahr and other manufacturers offer similar modules. M&M's software also includes measurement of broaching tools and racks, according to their product literature.

Today's analytical gear inspection machines are also called upon to measure tooth modifications such as crowning and tip relief. "Most of the gears which are used today are optimized," says Montag. "The flanks of the gears will be executed with clearly defined corrections, such as crowning, tip relief, root relief, etc. These clearly defined characteristics can only be manufactured and secured in connection with a suitable gear measuring machine." In today's competitive environment, it's important for the gear manufacturer to be able to prove these char-

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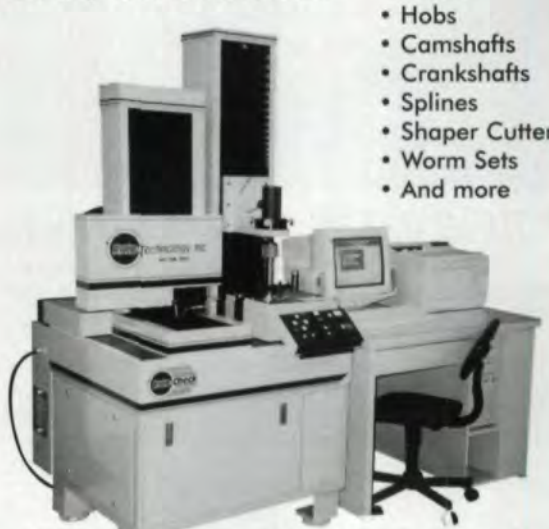

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acteristics to his customers, Montag says.

Inspection machines can also be outfitted with special analysis modules. For example, the M&M machines can perform inspections to pinpoint the effects of heat treat distortion. By measuring the part before and after heat treating, the manufacturer is better able to determine the ideal pre-hardening geometry.

Other machines may come with unique features. Mahr's Primar machine comes with a tilting table, which allows the machine to inspect parts based on their datum axes. In other words, the Primar can inspect gears as they will be mounted in their final application, rather than between centers, as most gear inspection is performed, says Cowley. The Primar performs two reference scans of the part prior to the inspection routine, adjusts the table to physically align the part, then performs the inspection. "Other machines on the market can do mathematical corrections, but cannot physically align the part," Cowley says.

Pushing Inspection to its Limits

Among the biggest challenges facing inspection equipment of all kinds today are the tighter and tighter tolerances demanded by manufacturing processes. "The increasing quality demands have led to the situation that in mass production, often tolerances smaller than 10 micrometers have to be secured," says Montag. "The old rule that the measuring uncertainty of a measuring system should be 10% of the tolerance to be checked cannot be kept. Today, measuring uncertainties of 20–30% are realistic."

While all the machine manufacturers are working to obtain ever-smaller uncertainties in their equipment, measurement accuracies are poorly understood by the end users, says Lawson, who adds that this understanding is increasingly important at a time when many manufacturing companies have either implemented or are planning to implement ISO 9000 or similar quality programs.

According to Lawson, most measuring machines, including CNC systems, aren't commonly being evaluated for accuracy. Instead, they're being evaluated for repeatability. Most companies employ a gage repeatability and reproducibility (GR&R) procedure, wherein some number of production parts are measured several different times by different operators, Lawson says. This allows them to statistically determine the repeatability of the measuring process. However, this observes only the consistency of the measurement, Lawson says, not the accuracy.

According to clause 4.11.1 of ISO 9001, "The supplier shall establish and maintain documented procedures to control, calibrate, and maintain inspection, measuring and test equipment (including test software) used by the supplier to demonstrate the conformance of product to the specified requirements. Inspection, measuring and test equipment shall be used in a manner which ensures that the measurement uncertainty is known and is consistent with the required measurement capability."

Further, Lawson reports that ISO Technical Committee 213 is developing new standards, which require manufacturers to subtract the measurement uncertainty from their manufacturing tolerances. This is logical, Lawson says, because our knowledge of a part's actual dimensions is limited by the uncertainty of the associated measurement process.

As has been the case with ISO 9000, implementation of this concept could be a stressful experience, Lawson says. However, ISO is becoming a powerful entity and many manufacturers are having to change their practices as customers begin to demand proof of quality at these levels. Today's inspection machines are powerful pieces of equipment, but if they're not calibrated, maintained, and used correctly, the validity of the measurement results will be adversely affected.

Today's dedicated gear inspection machine is a complex, multi-functional piece of equipment that can do work once requiring several machines, using sophisticated, on-board computer technology to record, transport and manipulate data in ways that were never before possible. ○

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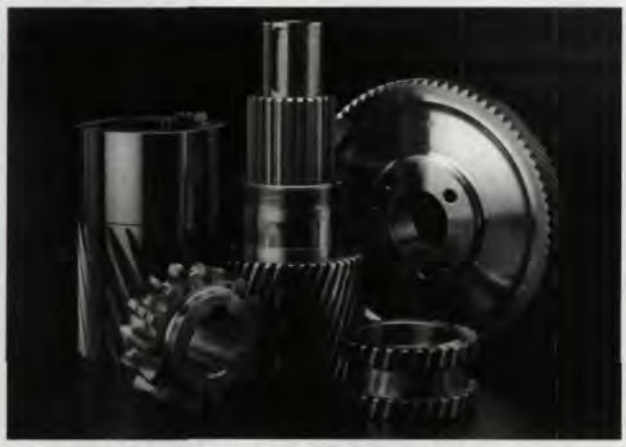

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