A Hippocratic Oath for the Big-Gear Industry: Do No Destructive Testing

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It is often said: "If it ain't broke, don't fix it."

And, in paraphrase of that old bromide regarding very LARGE gears—if it ain't tested, don't use it.

A too-clever-by-half way to introduce an article on non-destructive testing, perhaps, but you get the point—when outsize gear applications are in play—from bridges to boats to buses—two considerations are paramount: safety and do-re-mi. Which, by the way, makes perfect sense. After all, in most cases, the bigger the gear, the bigger the cost to make it. And as for personal safety—who in his right mind wants to step up and try to put a price on *that*?

So let us stipulate that big gears require very hands-on, meticulous, in-process procedures. But watch those hands!—a light touch is in fact required for these brawny beasts.

Non-destructive testing—NDT—has existed, in one form or another, since the mid-nineteenth century. Witness: 1854, Hartford, Connecticut—a boiler at the Fales & Gay Gray Car Works explodes, killing 21 people and seriously injuring 50. Within a decade, that state passes a law requiring annual inspection (in this case visual inspection) of boilers.

Jump ahead another 40 years or so and we find one Wilhelm Conrad Roentgen discovering X-ray technology. And, in his first published paper on the subject (1895), what does Herr Roentgen propose for the new technology's first application?—flaw detection. Not human flaws mind you—such as, for example,

A very pricey investment such as the behemoth ring gear seen here requires ASNT-certified testing (courtesy Rexnord Gear Group).

broken bones or cancerous tumors; rather—for identifying crack initiation in very heavy—and costly—steel railroad parts. Truly, "the squeaky wheel gets the grease" every time.

Make one more leap—to the 20th century—and we find that "Non-destructive testing, either by sound waves or magnetic fields, goes back to the late 1990s with the issuance of the first edition of American Society for Testing and Materials (ASTM) A609 for ultrasonic inspection and E709 for wet magnetic particle inspections," says Frank Uherek, principal engineer Rexnord Gear Group in Milwaukee, WI.

Ironically enough, however, we find that "Many of today's latest technical innovations come from the medical industry," says Israel Vasquez, an independent quality systems and NDT Level 3 consultant for more than 20 years, and principal owner of NDT specialists Vastek Consulting. In this instance he is speaking for Chicago-based Overton Gear, a longtime client. "The use of NDT on parts, components and materials is very much related to the procedures used by today's medical practitioners.

"The basic principles behind NDT are to examine materials, components and/or parts for characteristics (that are) detrimental to their use (i.e., defects), by methods that will not induce physical (and costly) changes (damage) to the item being inspected. When we have a medical examination, it is a form of nondestructive examination. After all, the objective (find physical imperfections), principles (do no harm to the patient), and examination methods are comparable.

"The NDT community uses radiographic inspection (and now computer and digital radiography), and the medical industry has radiology, computer-aided tomography (CAT scan) and digital radiology. We have magnetic particle inspection, and the medical industry has magnetic resonance. We have ultrasonic inspection (UT), and they have ultrascan, etc."

What types of big-gear applications require the most testing, you ask?

"The amount of testing required is a function of the economic risk of failure of the part in service and the level of experience of the supplier of the machined blank," says Uherek. "Manufacturing processes with a high level of control requires less testing than unique, one-off products."

"The primary purpose for the use of NDT is safety," says Vasquez. "Which is why the aerospace (military and commercial) and nuclear industries require the most NDT. Just about every structural or engine component of an aircraft, missile or ship undergoes some form of NDT, at the raw material source (for inherent imperfections), the machining company (for manufacturing induced defects), and during the life of the vehicle (for service induced defects). Nuclear facilities undergo initial inspections during installation, and periodic inspections for obvious reasons."

And while N.K. Chinnusamy, president of Roscoe, Illinois-based Excel Gear, Inc. agrees that such testing is typically performed on "Parts that are used in critical applications which require reliability," he adds that "(the gear) will have to pass inspection for hardness, burns, cracks, UT or X-ray testing for inclusions, porosity or discontinuity."

OK—better to be safe than sorry rules the day—thank God. But to what degree is NDT obligatory? Is the need for it typically customer- or, say, government-driven?

It's negotiable.

"The amount of required inspections is always subject to contract discussions between the buyer and seller," Uherek says. "AGMA 6014 for large gears requires NDT for Grade-2 materials only. Grade-1 material, having lower power capacities, does not have this requirement.

"Only if an organization has overall design control over the product can they omit NDT altogether," says Vasquez. "Even so, (that) would not be prudent, and (not testing) is very risky. NDT is a 'special process' that—by definition—is an activity conducted on a component, part or material that cannot be measured, monitored or verified until after the resulting product has been used or delivered. The purpose of NDT is to examine materials, components, and/or parts for defects by methods which will not induce physical changes to the item being inspected, and in most cases is a requirement specified in a manufacturing specification, drawing, or contract by the buyer or end user.

"Some pro-active companies choose to conduct NDT not only during 'final' inspection (100 percent) but also as an 'in-process' inspection on a sampling basis to monitor manufacturing operations. There are too many recorded cases where NDT was conducted incorrectly for which discrepant product had to be returned to the manufacturer or had to be discarded. Imagine if NDT hadn't been conducted at all."

Adds Chinnusamy, "Customers can waive any NDT requirement if they deem it is not required for that particular job. But manufacturers cannot skip NDT requirements without customer approval, which will be cause for rejection."

When working large, NDT benefits from economies of scale carrying the day, i.e.—portable testing equipment. One can now bring Mohammed to the mountain, so to speak.

"In most cases the equipment is portable so that the testing equipment can be brought to the part," says Uherek. "At Rexnord, we use a mixture of in-house equipment and selected third-party inspection houses that come on site to perform the inspection. Sending parts out is typically only required for radiographic (X-ray) inspections."

"NDT can be conducted in-house, by either the product manufacturer's personnel or by contracted personnel," says Vasquez. "In the first case, the manufacturer will have to have the appropriate equipment, materials and trained personnel. If contracted personnel are utilized, they will bring the necessary equipment/materials with them. Or, as an alternate, the product can be sent to an independent NDT laboratory for inspection."Speaking of "trained personnel," what skills are needed for conducting NDT?

"One needs to be certified by the American Society for Nondestructive Testing (ASNT)—SNT–TC-1A—and take periodic tests to maintain certification," Uherek says.

Adds Vasquez, "Typically, the employer's program will require three levels of qualification and subsequent certification. A Level I may be the person(s) conducting the pre-cleaning, processing and post-cleaning of the product. The Level II may conduct the same functions—including the actual inspection (acceptance/rejection) of the product. A Level III is the person responsible for the employer's certification program, NDT training, audits, NDT procedure writing and approval of NDT-related documents. All three levels require documented, formal (classroom) training, on-the-job (OJT) training for experience, visual acuity examinations, and qualification examinations consisting of general (method), specific and practical examinations in order for one to be certified."

And, says Chinnusamy, "Personnel should be trained to certify any NDT process; Level I or II certification is required to certify any NDT."

Indeed, if NDT is conducted by the manufacturer, Vasquez says that "Employees will have to have the proper NDT training and be qualified and certified by the employer. Contracted personnel are also required to have the same (credentials), except they are certified by their employers. NDT-knowledgeable auditors may be from the end-user's (the buyer) organization, or from a third-party agency—such as A2LA, Nadcap, L-A-B, etc.—and contracted by the manufacturer or the buyer for registration or accreditation purposes."

When a gear maker—or buyer—hears buzz (buzz kill, in some cases) words like "registration," "accreditation "or "standards"—global considerations come into play. Such as, to what extent is NDT being conducted internationally? Are corners being cut in some places? ASNT standards adhered to?

Uherek points out: "The basic NDT method and criteria are ASTM standards. They are referenced in both AGMA and ISO gear rating standards, and so have worldwide acceptance in their use."

Concurring, Vasquez states that "I would say that (NDT) is relatively consistent. Where the proper NDT equipment and certified personnel are available, most facilities are conducting NDT as prescribed. In the aerospace and nuclear industries, all NDT facilities are continually audited to ensure that the organizations are meeting the specified requirements and are not cutting corners."

NDT Testing Methods

Ultrasonic testing. Most ultrasonic testing concentrates on the interior of the component. The most common method is to use a transducer to send ultrasonic vibrations through the test object. The transducer converts electrical signals—sent from an oscilloscope—into ultrasonic vibrations. Interior defects show up in the sound waves reflected back to the transducer. The transducer converts the sound energy back to an electrical signal for display on the oscilloscope. Examining a weld or component can be quick and economical, but the skill of the inspector, coupled with the expense of his training and equipment, can be limiting factors.

Eddy current testing. Eddy current testing uses an alternating magnetic field to induce small electric currents in the component being examined. These currents are affected by surface or slightly sub-surface abnormalities in the components. Defect indications appear on the instrument CRT. Eddy current testing is limited to conductive materials. Care must be taken to avoid false indications due to part geometry or permeability variations (ferromagnetic materials).

Magnetic particle examination. The magnetic particle examination technique detects surface and sub-surface indications. While providing a magnetizing force over a test area of the component, the inspector sprays a suspension of colorized iron fillings—either dry or wet fluorescent—within the magnetized area. The iron fillings align themselves along the artificial magnetic field created by any defects. The process is simple to use and some methods do not require extensive training.

Liquid penetrant testing. Penetrants detect surface flaws by permeating cracks or pores. A small amount of penetrant is applied to a test area. Alter a specified dwell time has elapsed, the penetrant is removed from the surface. A blotter-like developer is applied over the test surface. The developer draws any excess penetrant from the defects. The penetrant is either a color that contrasts strongly against the component background or it is fluorescent. Although simple to use, penetrants can miss defects if the surface is not adequately cleaned or the flaw is obstructed with smeared metal.

Radiographic testing. Radiography employs X-rays or gamma rays to penetrate the test object. It displays a permanent picture of the test object's interior on radiographic film. Radiographic limitations include the need for adequate component geometry, strict security of the test area and time to develop and interpret the test film. Radiographic examiners require extensive training.

ACRONYM Soup De-Coded

Following are "translations" of the various acronyms used in the NDT story.

ASNT American Society for Non-Destructive Testing

A2LA American Association for Laboratory Accreditation

Grade-2 Material Low-to-medium carbon steel, as rated by ISO, SAE and ASTM

MPI Magnetic particle inspection

NDT, Level III Level III NDT technicians are capable of establishing techniques and procedures; interpreting codes, standards, and specifications; and designating the particular nondestructive testing methods, techniques and procedures to be used. They must also have knowledge of materials, fabrication and product technology. Level III technicians are responsible for training and examining Level I and Level II's. Usually Level III technicians are in administration, supervision or management positions, or are owners of a testing laboratory. Some Level III technicians also become consultants.

SNT TC 1A A personnel qualification and certification in NDT (2011) that provides guidelines for employers to establish in-house certification programs for the qualification and certification of non-destructive testing personnel. Since 1966, employers have used this industry-valued document as the general framework for their NDT certification programs.

Nadcap Nadcap is the leading, worldwide cooperative program of major companies designed to manage a cost- effective consensus approach to special processes and products and provide continual improvement within the aerospace industry.

UT Ultrasonic inspection

(Editors' Note: Those with a particular interest in NDT will want to be sure to check out two of this issue's three Technical Articles on pgs. 58 and 66.)

Taking a somewhat dimmer view, Chinnusamy offers an emphatic "No; it (compliance) depends upon the manufacturer. If the manufacturer can get by with cutting corners, they may try to do it."

Expanding on his previous comment regarding "certified personnel," Vasquez references the dilemma that gear makers everywhere are grappling with: "The biggest problem worldwide—including the U.S.—is in finding qualified personnel, especially at the Level III rank."

Indeed, consider alloys for a moment; their use in big gears requires, at minimum, conversant knowledge of metallurgy—especially for the most critical applications. And keep in mind: these are real—and real expensive—gears being tested, not oops—throw-away-and- let's-try-another-one prototypes.

Speaking of challenges, our contributors were asked which big-gear applications—bridges, rail, mining, etc.—present the most challenges?

For Vasquez it is "A gear which has been assembled and cannot be disassembled prior to inspection is the biggest challenge. When conducting the inspection, most NDT methods or techniques require access to all surfaces requiring inspection. Surface finish (or cleanliness) also has an impact on NDT feasibility."

"Chinnasumay cites the customer's requirement. "Large gears are normally loaded heavily and tooth breakage will be the main concern in some applications. Even small gears for aerospace and military applications will require more stringent inspection than some large gears. Not all heat treating companies are qualified to heat treat gears for aerospace and military."

And then there is the "size matters" challenge inherent with NDT; just thinking of the logistics involved gives one a headache.

For example, says Uherek, "Larger gears take more time to test due to surface area that needs to be examined. In-shop examinations allow for the area to be tested to be presented at a comfortable work height and in proper lighting to conduct the test."

"(It depends) on which NDT method is required or specified," Vasquez explains. "Conventional NDT equipment cannot be used for the larger gears in most cases. These gears may have to be lifted when 100 percent inspections of all surfaces are required, and they cannot be accommodated on magnetic particle inspection benches or fit in penetrant inspection tanks, dryers or inspection booths. When ultrasonic inspection is required, both sides may have to be accessible; therefore lifting equipment has to be available, and there is a much larger area which may require scanning."

Chinnusamy agrees that size-wise, NDT is no picnic. "Yes, because of size itself. To check for burns the gear must be dipped into nitric acid solution. MPI inspection has to be done one section at time, which is time consuming; and there are chances for error. Inspecting sizes and quality of large gears is very difficult.

As for working with those "black science" alloys, "There are limitations in each NDT method," Vasquez admits. "(And this) is why the appropriate NDT method or technique has to be selected by knowledgeable personnel—in most cases, a Level III. Austenitic steels cannot be magnetic particle-inspected since they are essentially non-magnetic. Porous metals cannot be inspected by the liquid penetrant method, since they entrap the penetrant and may interfere with the interpretation process. Some metals may be too dense for X-ray equipment with limited penetrating ability."

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