Selecting a Nondestructive Testing Method: Visual Inspection

A refresher is offered on the principles and capabilities of visual inspection, the most common NDE method

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This article is the second installment in a series dedicated to the subject of nondestructive examination published in the AMMTIAC Quarterly. *The* AMMTIAC Quarterly *is published by the Advanced Materials, Manufacturing, and Testing Information Analysis Center (AMMTIAC), which is a U.S. Department of Defense-sponsored Information Analysis Center.*

Visual inspection is by far the most common nondestructive examination (NDE) technique (Ref. 1). When attempting to determine the soundness of any part or specimen for its intended application, visual inspection is normally the first step in the examination process. Generally, almost any specimen can be visually examined to determine the accuracy of its fabrication. For example, visual inspection can be used to determine whether the part was fabricated to the correct size, whether the part is complete, or whether all of the parts have been appropriately incorporated into the device (Ref. 2).

While direct visual inspection is the most common nondestructive examination technique (Fig. 1), many other NDE methods require visual intervention to interpret images obtained while carrying out the examination. For instance, penetrant inspection using visible red or fluorescent dye relies on the inspector's ability to visually identify surface indications. Magnetic particle inspection falls into the same category of visible and fluorescent inspection techniques, and radiography relies on the interpreter's visual judgment of the radiographic image, which is either on film or on a video monitor. The remainder of this article provides a summary of the visual testing method, which at the minimum requires visual contact with the portion of the specimen that is being inspected.

In arriving at a definition of visual inspection, it has been noted in the literature that experience in visual inspection and discussion with experienced visual inspectors revealed that this NDE method includes more than use of the eye, but also includes other sensory and cognitive processes used by inspectors (Ref. 3). Thus, there is now an expanded definition of visual inspection in the literature:

"Visual inspection is the process of examination and evaluation of systems and components by use of human sensory systems aided only by mechanical enhancements to sensory input such as magnifiers, dental picks, stethoscopes, and the like. The inspection process may be done using such behaviors as looking, listening, feeling, smelling, shaking, and twisting. It includes a cognitive component wherein observations are correlated with knowledge of structure and with descriptions and diagrams from service literature (Ref. 3)."

Fig. 1 — Visual inspection of a torpedo tube aboard a Navy attack submarine. (Photo courtesy of the Department of Defense; photo taken by JO3 Corwin Colbert, USN.)

Fig. 2 — An inspector at Tinker Air Force base gets a magnified view of an engine's high-pressure turbine area with a new digital fiber-optic borescope. (Photo courtesy of U.S. Air Force; photo taken by Margo Wright.)

Physical Principles

The human eye is one of mankind's most fascinating tools. It has greater precision and accuracy than many of the most

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Fig. 3 — Part of a routine bridge visual inspection (Ref. 6).

Fig. 4 — Part of an in-depth bridge visual inspection using a man-lift (Ref. 6).

Fig. 5 — Visual inspection experiment inside a Boeing 737. (Photo courtesy of the Federal Aviation Administration.)

sophisticated cameras. It has unique focusing capabilities and has the ability to work in conjunction with the human brain so that it can be trained to find specific details or characteristics in a part or test piece. It has the ability to differentiate and distinguish between colors and hues as well. The human eye is capable of assessing many visual characteristics and identifying various types of discontinuities[1]. The eye can perform accurate inspections to detect size, shape, color, depth, brightness, contrast, and texture. Visual testing is essentially used to detect any visible discontinuities, and in many cases, visual testing may locate portions of a specimen that should be inspected further by other NDE techniques.

Many inspection factors have been standardized so that categorizing them as major and minor characteristics has become common (Ref. 4). Surface finish verification of machined parts has even been developed, and classification can be performed by visual comparison to manufactured finish standards. In the fabrication industry, weld size, contour, length, and inspection for surface discontinuities are routinely specified. Many companies have mandated the need for qualified and certified visual weld inspection. This is the case particularly in the power industry, which requires documentation of training and qualification of the inspector. Forgings and castings are normally inspected for surface indications such as laps, seams, and other various surface conditions.

Inspection Requirements

Requirements for visual inspection typically pertain to the vision of the inspector; the amount of light falling on the specimen, which can be measured with a light meter; and whether the area being inspected is in any way obstructed from view. In many cases, each of these requirements is detailed in a regulatory code or other inspection criteria (Ref. 2).

Mechanical and/or optical aids may be necessary to perform visual testing. Because visual inspection is so frequently used, several companies now manufacture gauges to assist visual inspection examinations. Mechanical aids include measuring rules and tapes; calipers and micrometers; squares and angle-measuring devices; thread, pitch and thickness gauges; level gauges; and plumb lines. Welding fabrication uses fillet gauges to determine the width of the weld fillet, undercut gauges, angle gauges, skew fillet weld gauges, pit gauges, contour gauges, and a host of other specialty items to ensure product quality.

At times, direct observation is impossible and remote viewing is necessary, which requires the use of optical aids. Optical aids for visual testing range from simple mirrors or magnifying glasses to sophisticated devices, such as closed-circuit television and coupled fiber-optic scopes. The following list includes most optical aids currently in use (Ref. 2):

- Mirrors (especially small, angled mirrors)
- Magnifying glasses, eye loupes, multilens magnifiers, measuring magnifiers
- Microscopes (optical and electron)
- Optical flats (for surface flatness measurement)
- Borescopes and fiber-optic borescopes
- Optical comparators
- Photographic records
- Closed-circuit television (CCTV) systems (alone and coupled to borescopes/microscopes)
- Machine vision systems
- Positioning and transport systems (often used with CCTV systems)
- Image enhancement (computer analysis and enhancement)

Before any mechanical or optical aids are used, the specimen should be well illuminated and have a clean surface. After the eyeball examination, mechanical aids help to improve the precision of an inspector's vision. As specifications and tolerances become closer, calipers and micrometers become necessary. The variety of gauges available help to determine thread sizes, gap thicknesses, angles between parts, hole depths, and weld features.

As it becomes necessary to see smaller and smaller discontinuities, the human eyes require optical aids that enable inspectors to see these tiny discontinuities. However, the increased magnification limits the area that can be seen at one time, and also increases the amount of time it will take to look at the entire specimen. Mirrors let the inspector see around corners or past obstructions. Combined with lenses and placed in rigid tubes, borescopes enable the inspector to see inside specimens such as jet engines, nuclear piping and fuel bundles, and complex machinery. When the rigid borescope cannot reach the desired area, flexible bundles of optical fibers often are able to access the area. Figure 2 shows visual inspection using a fiber-optic borescope. Some of the flexible borescopes have devices that permit the observation end of the scope to be moved around by a control at the eyepiece end. Some are also connected to CCTV systems so that a large picture may be examined and the inspection recorded on videotape or digitally. When the video systems are combined with computers, the images can be improved that may allow details not observable in the original to be seen.

Practical Considerations

Visual inspection is applicable to most surfaces, but is most effective where the surfaces have been cleaned prior to examination, for example, any scale or loose paint should be removed by wire brushing, etc. Vision testing of an inspector often

1. In general, as described in the literature of the American Society for Nondestructive Testing, inspectors determine the presence or absence of indications of "discontinuities." Whether or not a discontinuity is a defect is based upon the design criteria, and is generally not up to the inspector.

Visual Inspection Summary

Discontinuity types (e.g., what types can the method detect)	• Cracks • Holes • Corrosion • Blisters • Impact damage • i.e., most discontinuities that are surface breaking or result in a deformation at the surface
Size of discontinuities	• Approximately 0.25 in. and larger
Size of system that can be inspected	• Any, i.e., large (e.g., aircraft skin), medium (e.g., structural support), small (e.g., electrical circuitry)
Field portable method?	• Yes
Inspection restrictions	• Surface areas only Some internal and inaccessible areas can't be inspected visually.
Inspector training (level and/or availability, e.g., who provides training)	• Recommended Commercial training schools available
Equipment	• None Optical aids optional except where internal surfaces require borescopes or small television cameras, etc.
Certification required	• Depends on application Certification available through the American Welding Society and the American Society for Nondestructive Testing (ASNT)
Relative cost of inspection (i.e., compared to other methods)	• Low • Equipment cost can range from nothing to a modest price, but this method can be labor intensive

requires eye examinations with standard vision acuity cards such as Jaeger, Snellen, and color charts. Vision testing of inspectors has been in use for about 40 years. Although many changes in NDE methods have taken place over the years and new technologies have been developed, vision testing has changed little over time. Also, little has been done to standardize vision tests used in the industrial sector. For those seeking certification in the area of visual testing, the *ASNT Level III Study Guide and Supplement on Visual and Optical Testing* provides a useful reference (Ref. 5).

Studies on Visual Inspection

Bridge Inspection

Two major studies of visual inspection that have been carried out in recent years provide a great deal of insight into the reliability of visual inspection. Since visual inspection is the predominant NDE technique used for bridge inspection, the Federal Highway Administration (FHWA) Nondestructive Evaluation Validation Center (NDEVC) conducted a comprehensive study to examine the reliability of the visual inspection method for highway bridges (Ref. 6). Performance trials were conducted using 49 state bridge inspectors to provide overall measures of the accuracy and reliability of routine and in-depth inspections. One of the objectives was to study the influence of several key factors in order to provide a qualitative measure of their influence on the reliability of routine and in-depth inspections. Figures 3 and 4 show routine and in-depth inspections at a Safety Testing and Research (STAR) facility.

Among the findings is that vision testing of inspectors is almost nonexistent, with only two state respondents indicating that their inspectors had their vision tested. From the routine inspections it was found that the inspections were completed with significant variability in the results. This variability was most prominent in the assignment of condition ratings, but was also present in examination documentation. From the in-depth inspection tasks it was observed that in-depth inspections were unlikely to correctly identify many types of specific discontinuities for which this inspection is frequently prescribed. As an example, only 3.9% of weld inspections correctly identified the presence of crack indications.

As a result of this study, it was recommended that the accuracy and reliability of both routine and in-depth inspections could be improved through increased training of inspectors in the types of discontinuities that should be identified and the methods that would frequently allow identification to be possible. Also, additional research is needed to determine whether ensuring minimum vision standards through vision testing programs (with corrective lenses, if necessary) would benefit bridge inspection. Additional details are fully documented in the two-volume final report (Ref. 6).

Inspecting Aging Aircraft

In the second comprehensive study of visual inspection, experiments were performed at the Federal Aviation Administration's (FAA's) Aging Aircraft Nondestructive Inspection Validation Center (AANC) to provide a benchmark measure of the capability for visual inspection performed under conditions that are realistically similar to those usually found in major airline maintenance facilities (Ref. 3). More than 80% of inspections on large transport category aircraft are visual inspections. Small transport and general aviation aircraft rely on visual inspection techniques even more heavily than do large transport aircraft. Visual inspection, then, is the first line of defense for safety-related failures on aircraft and provides the least expensive and quickest method for assessing the condition of an aircraft and its parts (Ref. 3). Therefore, accurate and proficient visual inspection is crucial to the continued safe operation of the air fleet and it is important that its reliability should be high and well-characterized. The experiments at the AANC were conducted on a Boeing 737 aircraft test bed, as well as on a sample library of well-characterized flaws in aircraft components or simulated components. Figure 5 shows visual inspection inside an aircraft.

Results showed substantial inspector-to-inspector variation. For example, on a specific task of looking for cracks from beneath rivet heads, the 90% probability (percentage of cracks expected to be detected) of detection crack length for eleven inspectors ranged from 0.16 to 0.36 in., with the 90% probability of detection crack length for a twelfth inspector being 0.91 in. Also noted was a high variability from one inspection task to another as performed by the same inspector. Results of these experiments have paved the way for other organizations to better understand the intricacies of visual inspection in developing laboratory and field visual inspection protocol.

Conclusions

Despite advances in other NDE technologies, visual inspection will likely remain the first inspection method used in many field applications. As new mechanical and optical aids become available, the reliability of visual inspection will increase to more acceptable levels. It is expected that additional visual inspection standards will be developed to provide guidance in applying visual inspection for nondestructive testing. Visual inspection will continue to be an important NDE inspection approach that will often identify areas of structures or components where more advanced NDE methods need to be applied.❖

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