# Digital Radiography

## 1 Introduction

X-ray radiography is useful for non-destructive inspections of the interior of objects. This technique can reveal internal components of assemblies and defects in materials for examination and assessment. Features are exposed based on differences in transmitted intensity of an x-ray beam through variations in thickness and material.

## 2 Scope

This document applies to personnel using the associated instrument(s)/equipment in the following disciplines/categories of testing: firearms/toolmarks examinations and general physical and chemical analysis in support of metallurgy or anthropology examinations. Radiography is a powerful imaging technique that can be applied to a wide variety of objects and assemblies. Because of this versatility, the conditions associated with imaging a particular object are optimized during the operation of the radiograph. The following procedure outlines only the basic steps to acquire a digital radiograph (2-dimensional) with the Faxitron CS-100AC and NSI X5000 radiography systems and a computed tomography (CT) scan (3-dimensional) with the NSI X5000 system. Additional information and options for computed tomography are available from the extensive software manual which accompanies the NSI X5000 system. Under no circumstances should either x-ray system ever be independently operated by untrained personnel.

## 3 Principle

Digital radiography utilizes the same operating principles as traditional film radiography. An object of interest is exposed to an intense source of x-rays. These are absorbed by the components comprising the object to a degree which depends on the atomic weight and thickness of the components. An electronic detector behind the object measures the spatial distribution of the transmitted x-rays and produces an electronic image whose brightness and contrast depend on the point-to-point variation of the x-ray intensity. This electronic image can then be used to make inferences regarding the internal structure of the object without opening it.

CT uses a series of acquired x-ray images to generate a virtual 3-D representation of the x-ray transparency variations throughout the object. Visualization software allows this 3-D volume to be examined from any angle and at any depth from the object's surface.

The Faxitron CS-100AC uses a micro-focus x-ray source with fixed spot size for high-resolution 2-D imaging. The distances of the source and detector from the sample are adjustable, allowing optimization of field of view (FOV), focus and magnification. The maximum voltage of the x-ray tube is 90kV. Typically, this system can successfully image fine components within thin metal casings.

The NSI X5000 system provides capacity for both 2-D and 3-D x-ray imaging using either of two x-ray sources: a 225 kV micro-focus x-ray tube or a 450kV x-ray tube. The distances of the sample and the detector from the source are adjustable, allowing optimization of FOV, focus and magnification. The detector and source height are also adjustable. Automated positioning software allows acquisition of mosaic images of large specimens in 2-D. Combined with automated sample rotation, helical image acquisition can be used for 3-D CT scans of large specimens.

## 4 Specimens

Specimen size is limited by the x-ray system chamber size and the weight capacity of the sample platform. The material of construction is only important insofar as it affects the ability of the x-ray beam to penetrate the object. If the object construction is excessively thick-walled, a satisfactory image may not be obtained. See also 13 Limitations in this document.

The CS-100AC accommodates samples up to 18” x 24” x 8 ½” height on a moveable stage and has a 90kV maximum x-ray energy with a very small focal spot (10 microns or less.)

The NSI X5000 can accommodate larger samples, up to 200 lbs. Stage, detector and source(s) are all moveable to allow an area of interest in a large part to be imaged. The 225 kV microfocus tube has focal spot <6 µm at 320W and the 450 kV tube has a focal spot ~0.4 mm at 700W.

## 5 Equipment/Materials/Reagents

a. Digital x-ray radiography system (Faxitron CS-100AC, NSI X5000, or similar): Each unit consists of a lead-lined chamber, x-ray tube(s), power supply and controller, sample positioning table, a digital x-ray detection panel and a computer workstation. The NSI X5000 has an additional computer to construct 3-D CT images

b. X-ray filters (optional) – typically copper or aluminum sheets, but other materials may be used at the operator's discretion. Optimum sheet thickness depends on imaging conditions.

c. Tools for supporting specimen(s) on the sample table – these may include modeling clay, clamps, Styrofoam blocks, sandbags or other assorted objects as needed. Beeswax is a useful low atomic number mounting medium

d. For CT:
    i. anti-vibration mat to place under specimen
    ii. alignment reference standard

## 6 Standards and Controls

Although standards and controls are not required for basic operation and subsequent examination of 2-D digital radiographs, thickness and curvature standards of similar atomic number to the materials being examined can provide useful comparisons during analysis.

The NSI X5000 detector requires gain adjustment to remove background electronic noise and improve the appearance of the acquired digital radiograph. Failure to adjust can result in electronic artifacts appearing in the image. Gains are adjusted with respect to the conditions at which the object will be imaged, so changing the imaging conditions may require readjustment of the gains in order to ensure optimal image quality. The NSI X5000 software also accommodates removal of dead pixels from the image. The pixel clamping routine should be run daily when the instrument is in use.

Computed tomography requires alignment using reference materials that are provided by the manufacturer and exclusive to the particular software used to generate the 3-D reconstruction.

## 7 Sampling

If accommodated by the x-ray system, an entire object or region of interest can be imaged. For CT scans, limiting the image acquisition to a minimum region of interest can significantly reduce acquisition/computation time, allowing possible improvement in resolution (smaller increments between acquired images) or throughput. If the sampling plan will be used to make an inference about the population, then the plan will be based on a statistically valid approach. Any sampling plan and corresponding procedure used will be recorded in case notes.

## 8 Procedure

**8.1** Warm up the x-ray tube.

**8.2** Power down the x-ray tube in order to place or exchange samples in the chamber.

**8.3** When inserting the sample(s), consider imaging orientation. For symmetrical objects, angle the planes of symmetry in the beam path (source-to-detector) in order to provide more information than parallel or perpendicular alignment.

**8.4** Close the x-ray sample chamber in order to energize the x-ray tube.

**8.5** Adjust voltage and current (amperage) to obtain a satisfactory image (see 9 Instrumental Conditions).

**8.6** Adjust FOV, magnification, focus, distance to source and/or detector, power and other parameters to obtain the optimal image for the application. See 10 Decision Criteria for further information.

**8.7** A .tif file format is recommended for image file saving to retain the most digital information.

**8.8** Power off the system components when the imaging session is complete.

**8.9** Record usage in instrument log book.

## 9 Instrumental Conditions

The instrumental operating conditions are determined by the examiner in reference to the on-screen image. In general, increasing the current will increase the image brightness, and increasing the x-ray source voltage will increase the radiation penetration through the object. The voltage should be increased if the object appears opaque. Filtering the primary radiation source decreases the average x-ray wavelength reaching the sample and increases beam penetration through the sample. Filtering can be used in conjunction with voltage increases to improve object penetration. In general, any combination of operating parameters which produces a useful image is acceptable.

## 10 Decision Criteria

An x-ray radiograph is considered acceptable when the details of interest are visible in the image. This result is typically self-evident and is at the discretion of the operator. Interpretation of x-ray images is largely a matter of experience and training. X-ray scattering effects must be considered when interpreting the shapes of edges and corners and as a source of artifacts within the detected image. Atomic number and consequent x-ray absorption must also be considered when comparing relative thickness of the separate parts of multi-component and/or multi-material assemblies. Appropriate interpretation may require additional background investigation, including radiography and/or disassembly of exemplar components for comparison.

## 11 Calculations

Not applicable.

## 12 Measurement Uncertainty

Not applicable.

## 13 Limitations

An x-ray source is limited to a maximum operating voltage depending on the instrument in use. Thick metal sections may not permit sufficient flux of x-rays for useful imaging. The exact thickness limit will be a function of the object's geometry and its materials of construction. For example, according to published references, steel up to 40 mm thick can be satisfactorily examined with 300 kV x-rays.

Light items such as plastic and paper may not be visible due to poor x-ray absorption if they are inside a high atomic number material such as steel. However, it is usually possible to image plastics, tape, and other low atomic number materials if they are not otherwise shielded by higher atomic number materials.

## 14 Safety

a. Wear an x-ray film badge or dosimeter when operating instruments that generate x-rays. The instruments have protective enclosures and internal safety interlocks to prevent inadvertent x-ray radiation exposure. Never bypass or disable safety interlocks on instruments.

b. Wear personal protective gear and use engineering controls that are appropriate for the task being performed (e.g., safety glasses when cutting and chemical fume hood when etching). Electrical or mechanical hazards may require special precautions (e.g., grounding to prevent electric shock or wearing a face guard to prevent impact from flying debris.) Review instrument SOPs and pertinent material Safety Data Sheets (SDS) prior to conducting examinations. If additional guidance is required, contact the Laboratory Health and Safety Group.

c. For the NSI X5000, never close a person inside the chamber. The door is mechanically driven and may not open in case of power loss.

## 15 References

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Cartz, L., *Nondestructive Testing, Radiography, Ultrasonics, Liquid Penetrant, Magnetic Particle, Eddy Current*, ASM International 1995

Halmshaw, R., *Industrial Radiology, Theory and Practice*, 2nd ed., Chapman & Hall 1995

*Chemistry Unit Quality Assurance and Operations Manual*, Federal Bureau of Investigation, Laboratory Division, latest revision

*FBI Laboratory Operations Manual*, Federal Bureau of Investigation, Laboratory Division, latest revision

*FBI Laboratory Quality Assurance Manual*, Federal Bureau of Investigation, Laboratory Division, latest revision

| Rev. # | Issue Date | History |
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| 0 | 06/21/2006 | New document that replaces a previous document also entitled *Digital Radiography* |
| 1 | 03/02/2018 | Renumbered Metallurgy Standard Operating Procedure (SOP) Manual documents. This document was formerly Metal 9 and is now designated Metal 303. Updated sections 1, 2 and 3 for clarity. Added personnel to section 2. Made minor editorial corrections throughout document. Updated section 4 to include maximum specimen sizes. Removed obsolete equipment from section 5. Incorporated section 7 into section 6 and renumbered subsequent sections. Added sampling statement in section 7. Redacted parts of section 8 specific to a particular instrument and revised. Updated safety requirements in section 14. Deleted obsolete reference in section 15 and added additional references. |

**Approval** Redacted - Signatures on File

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