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INTRODUCTION

Real-time radiography (RTR), or real-time radioscopy, is a nondestructive test (NDT) method whereby an image is produced electronically rather than on film so that very little lag time occurs between the item being exposed to radiation and the resulting image. In most instances, the electronic image that is viewed, results from the radiation passing through the object being inspected and interacting with a screen of material that fluoresces or gives off light when the interaction occurs. The fluorescent elements of the screen form the image much as the grains of silver form the image in film radiography. The image formed is a "positive image" since brighter areas on the image indicate where higher levels of transmitted radiation reached the screen. This image is the opposite of the negative image produced in film radiography. In other words, with RTR, the lighter, brighter areas represent thinner sections or less dense sections of the test object.

Real-time radiography is a well-established method of NDT having applications in automotive, aerospace, pressure vessel, electronic, and munition industries, among others. The use of RTR is increasing due to a reduction in the cost of the equipment and resolution of issues such as the protecting and storing digital images. Since RTR is being used increasingly more, these educational materials were developed by the North Central Collaboration for NDT Education (NCCE) to introduce RTR to NDT technician students. NCCE is a collaborative effort between Northeast Iowa Community College (Peosta, IA) Cowley County Community College (Arkansas City, KS), Southeast Community College (Milford, NE), Ridgewater Community College (Hutchinson, MN) and Iowa State University (Ames, IA). Partial funding for this effort was provided by the National Science Foundation.

An outline of the topics covered by this course is as follows:

1. Differences between film/filmless radiography
2. Equipment
3. Process control tests
4. Defect analysis and applications
5. Specifications
6. Procedure development

DIFFERENCES BETWEEN REAL-TIME RADIOGRAPHY AND FILM RADIOGRAPHY

There are a number of differences between film radiograph and real-time radiograph. The four most significant differences are the speed at which an inspection can be accomplished, quality of the image, the equipment used and its related cost and, the method of image analysis and storage. In this section, some of the most important differences are discussed.

INSPECTION SPEED

One advantage of RTR is inspection speed. With film radiography, film is placed behind the area of interest and exposed to radiation for a certain length of time. Exposure time can range from seconds to several minutes. A snapshot or a still image, i.e., the way the area looked at a certain point in time is the result. The film must be developed before viewing, a requirement that involves additional time. With RTR, the image is available almost simultaneously as the radiation passes through the part. Lag time is less than one second and, for all practical purposes, not really a consideration. This feature allows for greatly increased inspection speed. For example, lengths of a welded joint a few feet long can be inspected in less than a minute.

With sample positioning equipment, the part can be moved, e.g., rotated or tilted, so that the inspection area can be shifted and an entire part inspected in seconds. In film radiography, a single panoramic shot can be used to obtain complete coverage (a shot for which film is wrapped around the object); this can require radioactive isotope usage, and there is still the time required for the exposure plus the time to develop and dry the film before viewing. Nonetheless, the region(s) of interest (ROIs) can be viewed and reviewed much more quickly for RTR than for film radiography.

IMAGE RESOLUTION

System resolution depends on a number of factors that include X-ray source focal-spot size, magnification, and imaging system performance. Imaging system performance depends mainly on the quality of the image intensifier, camera, frame grabber board, monitor or other components used. In general, RTR systems are not able to resolve as small of a defect as can be resolved using film radiography. This is primarily due to limitation of the image intensifier, which will be discussed in more detail later. However, with the use of image processing program the performance of RTR systems can be improved. Further, since magnification is easily accomplished with RTR systems equipped with sample positioning systems resolution can be significantly improved especially when minifocus or microfocus x-ray tubes are used. Table 1 provides a comparison the performance between film radiography and various RTR systems.

	Film Radiograph	Conventional RTR	RTR with Image Processing	Microfocus RTR with Image Processing
Resolution	0.1 to 0.06 mm (0.004 to 0.002 inch)	0.5 to 0.25 mm (0.02 to 0.01 inch)	0.5 to 0.25 mm (0.02 to 0.01 inch)	Up to 0.05 mm (0.002 inch)
Contrast Sensitivity	1 to 2 percent	3 to 4 percent	0.5 to 1 percent	0.5 to 1 percent
Speed	5 to 15 mins/image	Real time	1 to 30 sec/image	1 to 30 sec/image

Table 1. Performance comparison between film and various RTR system configurations.

When magnification is used in an RTR system, the geometric unsharpness of the inspection set-up needs to be taken into consideration. The size of the X-ray tube focal-spot and the magnification factors, namely the source-to-specimen and specimen-to-detector distances, are used to calculate the geometric unsharpness of the inspection setup.
Geometric unsharpness (Ug) is determined as follows:

$$Ug \; ? \; f \; ? \frac{b}{a}$$

where f = X-ray generator focal-spot size.

a = distance from x-ray source to front surface of material/object

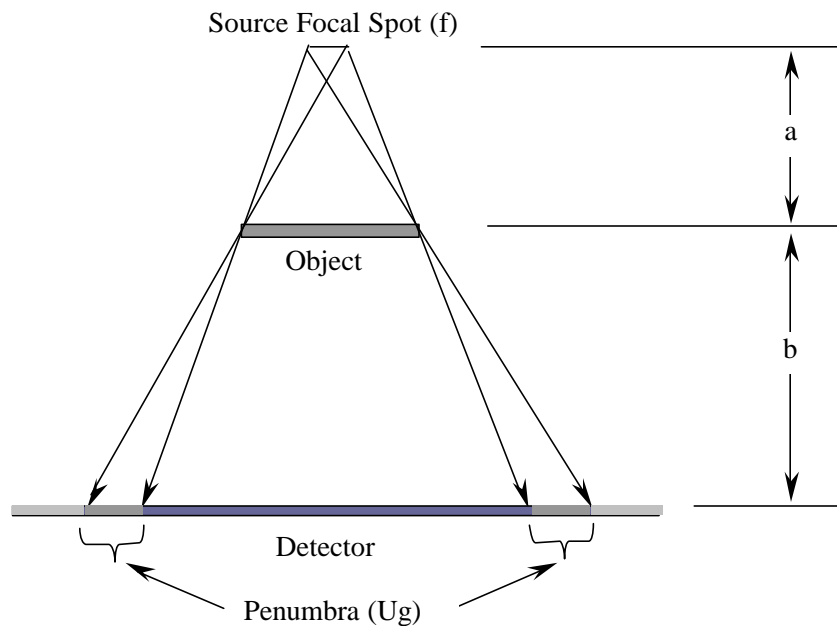b = distance from the material/object to the detector

Figure 1. Sketch showing geometric variables that affect the penumbra

To minimize the penumbra, the test specimen is usually placed as close as possible to the detector and the source is placed some distance from the sample. A greater the distance between the source and the object will reduce geometric unsharpness. However, the intensity of the source decreases as the distance increases. Therefore, the source should be placed only as far away as necessary to control the penumbra. If the test object is placed in direct contact with the detector (like is often done in film radiograph) the following formula can be used that takes into account the material thickness instead of the object-to-detector distance. This formula is

$$Ug \; ? \; f \; ? \; \frac{t}{d}$$

where f = X-ray generator focal spot size

t = the thickness of the material

d = distance from x-ray source to front surface of material/object

The allowable amount of unsharpness is controlled by specification being followed. In general, the allowable amount is 1/100 of the material thickness up to a maximum of 0.040 inch.

IMAGE MAGNIFICATION

Sometimes the distance between test specimen and image detector is increased to obtain magnification in the image. Magnification is especially useful when parts being inspected and their details are very small. The farther the test specimen is from the image detector, the greater the magnification achieved. The amount of magnification can be calculated using the following formula.

$$M \,?\, \frac{a\,?\,b}{a}$$

where M = magnification

a = distance from the source to the object

b = distance from the object to the detector
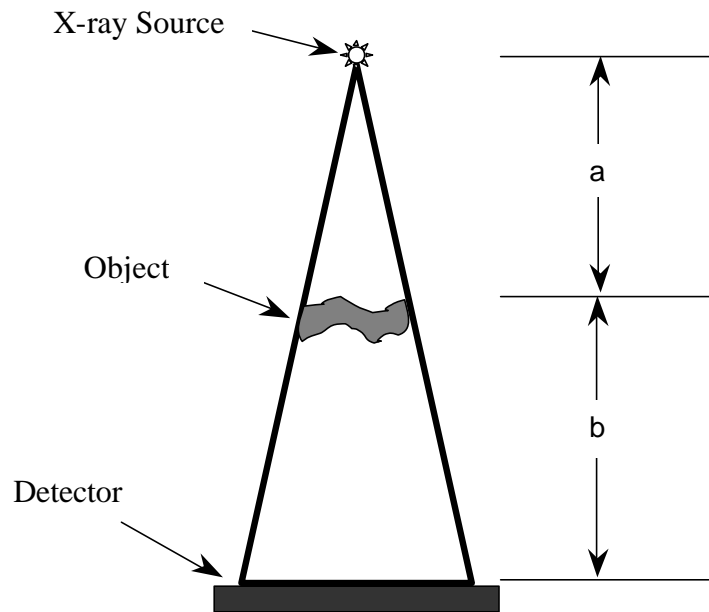
Figure 2. Sketch showing geometric variables that affect magnification.

In RTR, focal-spot sizes as small as 10 microns are used to allow for magnification of the image and yet keep the penumbra to a minimum. One micron or *micrometer* (my-króh-mee-tuhr) equals one-millionth of a meter (0.000001 meter, or .001 mm, or .00003937 inches, or 1/25,400 inch). If a newspaper sheet is .003 inches thick, it is approximately 76 microns thick. One disadvantage of magnification is that the field of view is decreased. When the viewable area

becomes smaller, this generally increases the inspection time. Refer to the applications booklet for a worksheet involving magnification problems.

More information on metric/English conversion may be found in the Appendix I. Penumbra work problems are provided in Appendix II.

IMAGE ENHANCEMENT

Image enhancement technology, such as a television camera, can be used for film radiography. This is a two-step process: getting the image on film, and enhancing it. Recent developments in which film is digitized result in obtaining more information from a single film. This, too, is at least a two-step process involving increased RTR. Image enhancement features in software can be used to improve the quality and therefore the usefulness of the image obtained. Image enhancement signifies that the original image is modified so that previously undetected information can be seen. In RTR, the enhancement is performed after viewing the image on the monitor. Much less time is spent producing the enhanced image than in film radiography. This is done usually to show low-contrast areas relating to cracks, boundaries, voids, inclusions, or part orientations. Low-contrast sensitivity and resolution are poorer in RTR than in film radiography.

REAL-TIME RADIOGRAPHY SYSTEM COSTS

Because an RTR system requires a number of system components, it generally costs more than a film radiography set-up. The RTR systems aregennerally self-contained. In other words, the parts come into one area, are X-rayed, imaged, and dispositioned all in the same area.

In film radiography, the part or source of radiation is brought to an area that may or may not be shielded. If not shielded, then precautions must be taken to protect personnel against radiation hazard. This may mean loss of production time if personnel must leave the area. The part is X-rayed with the use of film and the film is developed a darkroom where manual or automatic processing can take place. Real-time radiography usually takes place in a cabinet designed to

keep exposure to radiation within regulations and so the operator and others can work in proximity to the unit. This eliminates the loss of production time. Also, since there is no darkroom needed to develop film, RTR save floor space. With RTR, there are no hazardous film developing chemicals to dispose of.

Depending on what is to be inspected and the resolution needed, RTR systems consist of various components. Cost depends on how elaborate the system is and can run from approximately $50,000 to more than $200,000. Some microfocus X-ray tubes can cost more than $100,000 apiece. To learn the exact cost of systems or components, the manufacturer must be contacted.

EQUIPMENT

Real-time radiography systems are available in a number of configurations and sizes ranging from tabletop models to units that fill a large room. A typical system is shown in figure 3. The main components of a real-time radiograph system are shown in Figure 4.
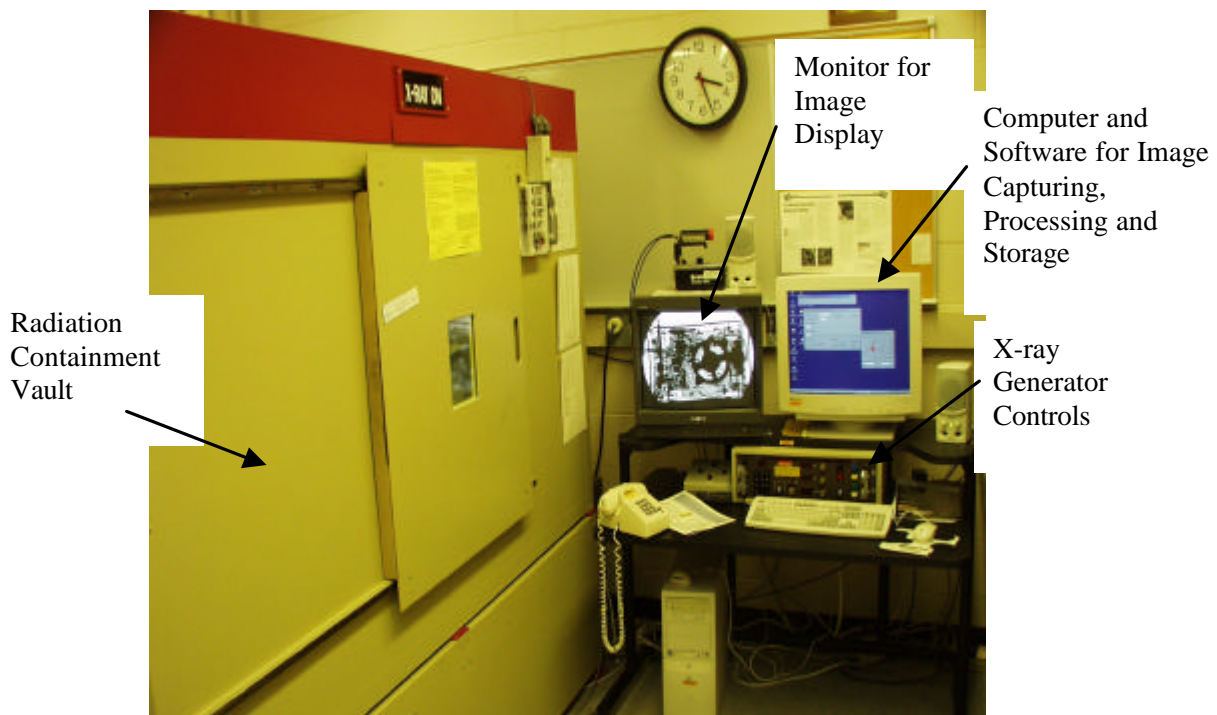

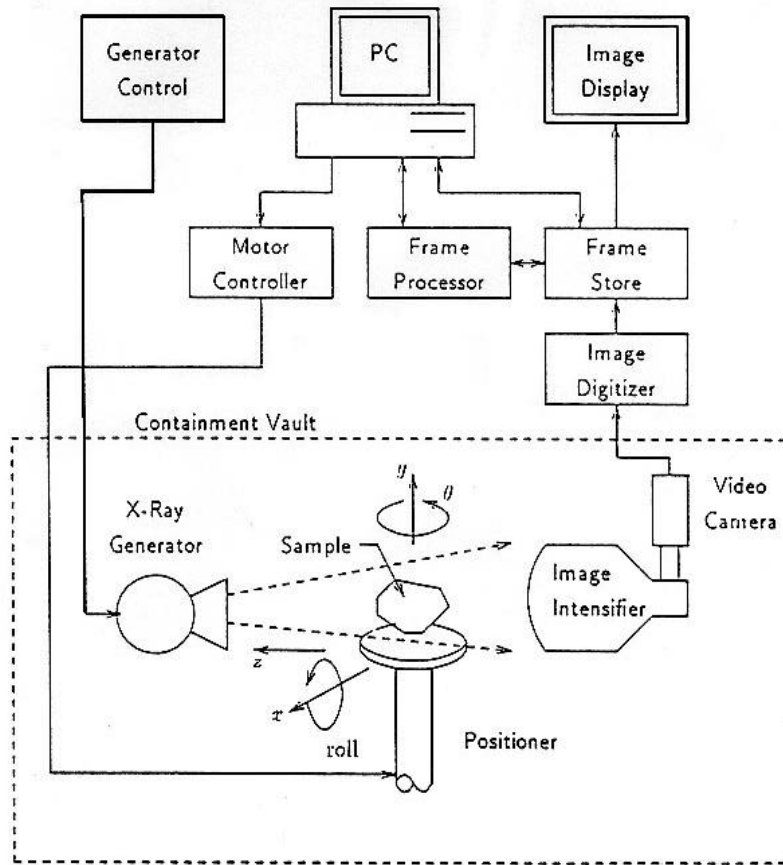Figure 3. Photograph of an example real-time radiograph system.

Figure 4. Schematic showing the various components of a real-time system.

The usual source of radiation for RTR systems is the X-ray generator. The main reason that an X-ray generator is used is because image intensifiers are relatively inefficient at converting radiation to light, and thus more flux is required than an isotope can offer. Additionally, X-ray energy and current must be adjustable to permit the correct exposure. (Time cannot be adjusted in this instance because the image is being viewed in real-time.) With radioactive isotope sources there is also the disadvantage that few wavelengths of different energies exist, and therefore the beam tends to be monochromatic compared with the beam from an X-ray machine. As discussed previously, the resolution in RTR systems is generally less than with film radiography. A way to improve resolution is to use a smaller focal-spot to reduce the penumbra. This will be discussed in more detail later.

Smaller spot sizes are especially advantageous in instances where magnification of object or region of the object is necessary. Magnification involves the use of minifocus and microfocus X-ray tubes. One common way to differentiate between conventional, minifocus, and microfocus is to say that conventional units have focal-spots greater than 200 microns; minifocus units have focal-spots

ranging from 50 microns to 200 microns (.050 mm to .2 mm); and microfocus have focal-spots smaller than 50 microns. As indicated, the cost of some microfocus tubes can exceed $100,000. Although this component must be selected carefully, it will enable the best resolution possible. Some manufacturers combine two filaments of different sizes to make a dual-focus tube. This usually involves a conventional and a minifocus spot-size and adds flexibility to the system.

An important point to keep in mind is that the milli amperage used in mini- and microfocus units is smaller than that used in conventional tubes. Amperage determines the intensity of X-rays. Such small focal-spots cannot withstand a great deal of heat. An X-ray generation feature offsetting the lower current levels is that mini- and micro-units usually are constant potential. This means that voltage is delivered at a very constant level, with very little ripple. In a conventional X-ray tube, voltages differ and the maximum X-ray output occurs when voltage peaks. Output tends, therefore, to vary with time. Because constant potential systems are essentially always at maximum output, the X-ray output over a given period of time is greater than that of a conventional tube at the same settings. The final result being that the output of constant potential units can be greater than the conventional X-ray tube.)

Figure 5. Photograph of a conventional x-ray tube used in a RTR system.

CONVERTER DEVICE

In RTR, as in conventional radiography, X-rays passing through the part are used to produce an image. For the transmitted energy to be useful, it must be converted to an energy form that the system components can utilize to produce the image. Usually, radiation is converted to light energy (visible light), and this light is converted to an electronic signal (a video signal).

The image intensifier commonly used as a converter device, contains a fluorescent material such as cesium iodide. On the input screen, the visible light is much too dim to produce a usable image. There, photons are converted to electrons, accelerated, and reconverted to light on the output screen. Light amplification typically is in the range of 30/10,000 light amplification factors. This factor arises, in part, from two causes: (1) electron amplification as the electrons are accelerated by a high voltage, 25-30 kv between the cathode and anode, and (2) electron focusing on a small output screen approximately 10 times smaller than the input screen. See Figure 6 and 7 for an illustration and picture of typical image intensifier. Figure 8 shows a picture of output phosphor screen that is imaged by the CCD camera.
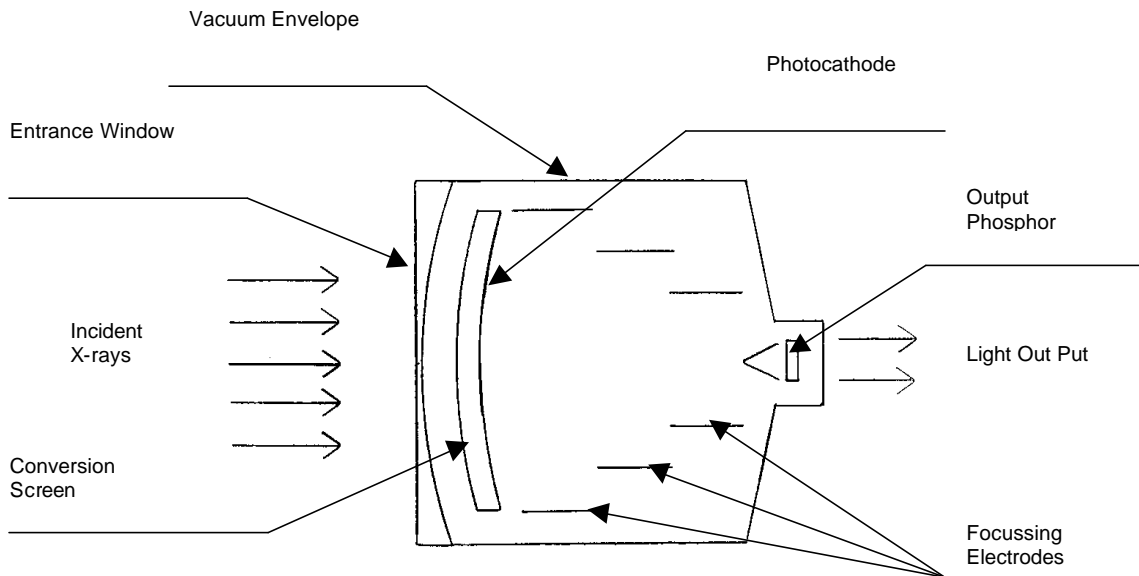
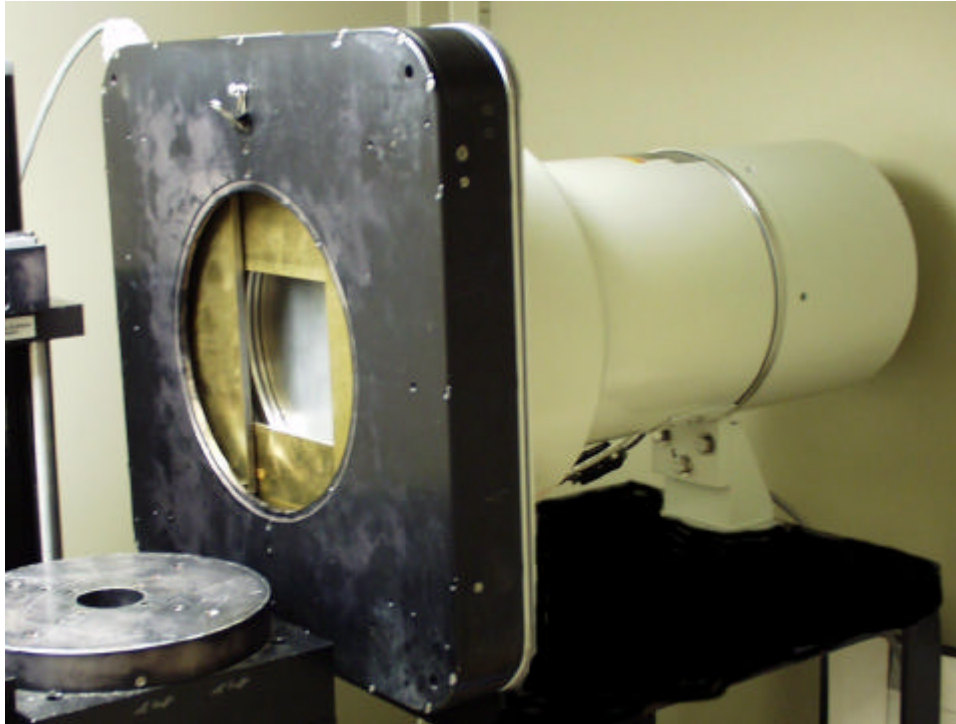Figure 6. Illustration of operation of a real-time image intensifier.

Figure 7. Picture of a real-time image intensifier with adjustable lead collimator on the front.
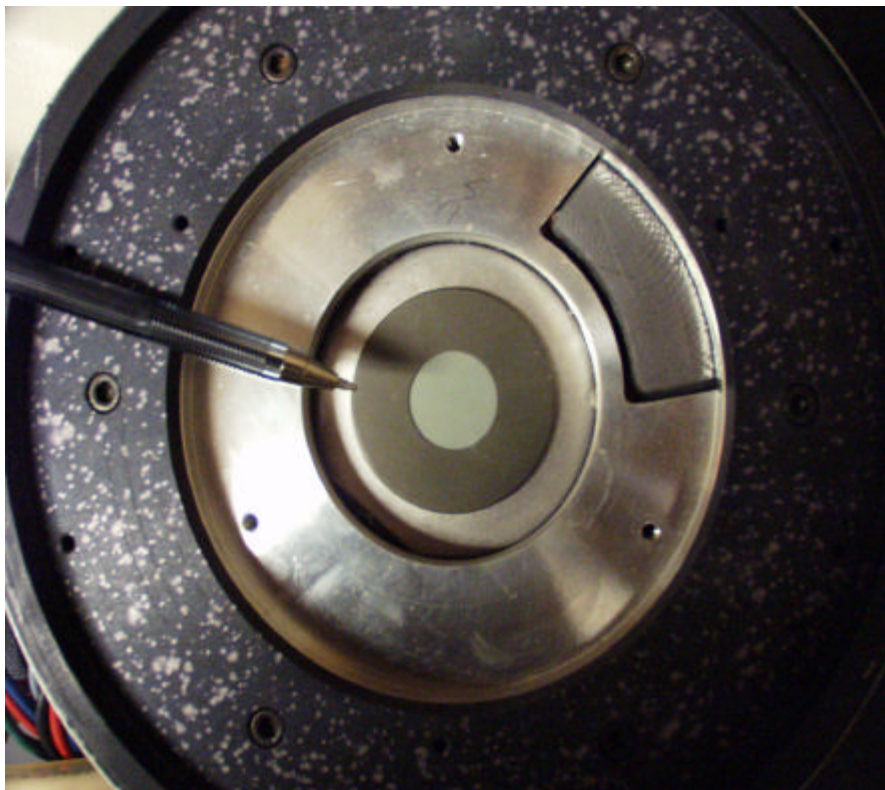

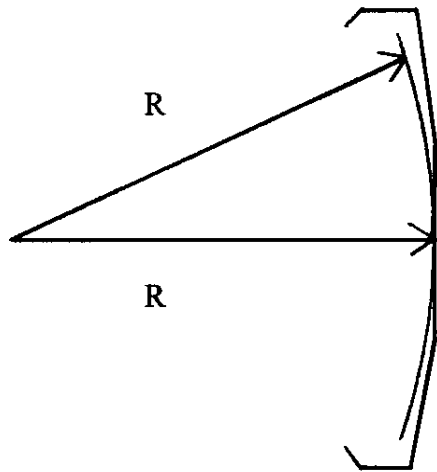Figure 8. Photograph of the output screen from an image intensifier.

Figure 9. Illustration showing
how the points of focus for
length R differ at the center and
at the top or bottom of the CRT.
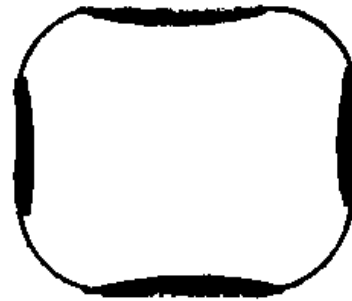
Figure 10. Illistration showing a
pincushion-shaped raster, which
makes the image appear warped at the
edges.

The advantage of using the image intensifier for RTR is that it has good light output. The

disadvantage is that it introduces several image artifacts. One of these artifacts is called pin

cushioning. Pin cushioning results from the fact that the distance for the point of focus at the

center of the CRT is different from that at the top or bottom of the CRT due to its curved shape.

(See figure 9.) The difference in distance results in an image that is slightly distorted at the

edges as illustrated in figure 10.

Other image artifacts include nonuniform pixel response and phosphor blooming. Nonuniform

pixel response is a condition where the gray level of the pixels at the edge differs from the gray

level at the center of the image. Phosphor blooming is a condition where the x-rays striking the

conversion screen cause the phosphor particle to glow so brightly that the light spreads from one

pixel to adjacent pixels and causes interference with its light output, or blurring.

CAMERA

After conversion of radiation to visible light, the light image must be changed to a video signal

so that an image can be produced for viewing on a monitor. In most instances, a closed-circuit

TV camera (CCTV) is used. The cameras can be very small are typically housed in an enclosure

on the back of the image intensifier. Several camera types are available, and each type has unique capabilities. One camera feature is the *dynamic range*, or the range of light levels that it can resolve. A high dynamic range is needed if part thicknesses differ and bright and dark areas must be imaged at the same time. Some cameras have very high dynamic ranges and would be especially suitable for RTR. Another feature of cameras is the type of transducer changing light energy to electrical energy. Some cameras have pickup tubes while others have solid-state electronics.

Charged couple device (CCD) cameras are very popular in RTR systems and have solid-state electronics consisting of a very small semiconductor chip. The chip is made up of discrete elements (*pixels*), which receive light and create a voltage and a current directly corresponding to the amount of light received. This same technology is used in home video camcorders and digital cameras. See figure 11 for an example of a CCD camera. The image is not recorded on film by means of grains of silver; rather, the voltage produced creates an RS170 signal either to produce an image on a monitor or to record the image on a VCR tape, CD or other means.

If the CCD camera is not used, another type of pickup device (a transducer) is used to convert the visible to an electronic signal. This usually involves a vacuum tube containing a light-

Figure 11. Picture showing one of the many commercially available CCD cameras that can be used for RTR. A lens would be attached to the right side of the camera and focused on the image intensifier output screen. The signal from the camera is then fed to a monitor for viewing.

sensitive material allowing the conversion of light to an electronic signal. Some common devices using this system are the image isocon, videcon, newvicon, and plumbicon videcon. These systems give better resolution than the CCD camera but usually have a lower dynamic range (1/m), which means that the range of light levels able to be shown is smaller. Vacuum tube devices usually have longer lag times, which can cause blurring if the part is to be inspected on the fly, or while moving.

Whichever transducer the camera uses, the RS170 signal produced creates the image on a monitor in the same way an image is produced on a TV screen. The CRT tube emits an electron beam controlled by two electromagnetic fields. One field causes the beam to move horizontally on the screen; the other to move vertically. The TV image or frame is made up of 525 lines (625 lines in Europe), and a new frame is generated every $1/30^{th}$ of a second. The 525 lines are scanned rapidly with every other line (odd lines first, then even lines) being scanned and interlaced with the adjacent line. Each new frame starts in the upper left-hand corner. Vertical resolution (visible details lying horizontal) is limited by the space between lines. In summary, the RS170 signal creates the image by means of an electromagnetic field moving the beam across the screen horizontally and then vertically to make another line. After 525 lines are created, a new frame is produced. Thirty frames per second is the standard that fools our eyes into believing we are looking at a steady picture. If fewer frames per second are produced, the eye may detect flicker in the image.

The monitor image is produced by an analog signal, and its increase or decrease is analogous to the value it represents. Therefore, the signal is or can be constantly differing in intensity. Examples of analog information are the column of mercury in a thermometer, or a car's speedometer when a needle in front of a scale of numbers indicates speed. For more information on digital and analog information, refer to the appendix of this book.

The image on the monitor produced by the analog RS170 signal can be used without enhancement. Equipment needed in this case consists of X-ray source, image intensifier, camera, and monitor. If the combination of components yield the spatial resolution and sensitivity needed, then the system is adequate.

FRAME GRABBER

During inspection in which spatial resolution and contrast are critical, analog information alone may be inadequate, and computer enhancement is required. Digital image processing, which is possible through desktop computers with the necessary internal components, is a solution. As indicated, the RS170 signal is an analog signal that must be converted to a digital signal before a computer's digital imaging processor can work with it. This is referred to as an A to D converter, or an analog to digital converter. There are also *D to A converters*, or digital to analog converters. Digital codes are based on the binary number system having 2 as the base number raised to various powers, e.g., $2^0 = \underline{1}$ $2^1 = 2$, $2^2 = 4$, $2^3 = 8$, $2^4 = 16$, $2^5 = 32$, $2^6 = 64$, $2^7 = 128$, $2^8 = 256$, etc. Digital electronic devices differ from analog devices because analog values change continuously in regard to what is being represented. Digital devices change in discreet increments rather than continuously. The digital signal has two modes: it is either *on* or *off*. These are discrete values. Modern computers are digital because the signals have better quality and can transmit and store more information than analog systems can.

By use of an A to D converter, the RS170 signal can be *digitized* or changed to a digital value. Digital image processors are designed to work with 525 lines, 30 frames-per-second TV images. The computer hardware used to convert the signal is referred to as a *frame grabber,* which converts the signal as it is creating the frames. This converter also starts with the upper left-hand corner of the image. With an eight-bit converter, A to D conversion will take place and resolve the gray scales into 256 levels ($2^8 = 256$), a value of 0 being black and a value of 255 being white. The digitization process takes place line by line until all 525 lines are complete. The number of pixels for 525 lines is in many instances 640 horizontally and 480 vertically. The analog signal consists of gray scales: no color is involved and none produced as a result of digitization. Benefits of this process are that (1) some electronic noise detracting from the quality of the image is eliminated, (2) when the gray scale is resolved by 256 levels, more information can be obtained from the image than otherwise and (3) edge detail is improved, and so is spatial resolution. Pixel size influences resolution because each pixel represents the smallest bit of information available, i.e., an image made up of small pixels will show greater

resolution than an image made up of large pixels. More information on A to D conversion can be found in Appendix III

FRAME AVERAGING

In TV images, snow or electronic noise detracts from the picture; in RTR, this random noise can also be present. If the CCD camera is subject to heat, the noise level will rise, detracting from the image. Some CCD cameras are kept at a lower temperature by a special cooling unit. The digital image processor can eliminate electronic noise by a process called *frame averaging* which is a mathematical process. The image represented by a set of numbers, i.e., is made up of shades of gray, where 0=black and 255=white. Each pixel is, in effect, given a value between zero and 255. True image information stays the same from one frame to the next. If numerical values are averaged from one frame to the next, the bogus value plus the negative effects of random noise are diminished. The data in the tables below illustrate the effect of frame averaging.

55	55	12
55	55	55
55	30	30
55	30	68

Pixel Values of 1st Frame

55	55	55
55	83	55
55	30	30
103	30	30

Pixel Values of 2nd Frame

55	55	34
55	70	55
55	30	30
79	30	49

Pixel Values of Averaged

If frame averaging is used, the image is improved; and the more frames averaged, the better the results for noise decreases with the square root of the number of frames averaged. That is, if 16 frames are averaged, noise reduction would be a factor of 4. There is a limit: averaging takes time, namely, 1/30 of a second for each frame averaged. After a certain number of frames are averaged, it is difficult to see any advantage in increasing the number of frames, and inspection slows.

There are three types of averaging used: integration averaging, averaging, and recursive averaging. Integration averaging requires a still image. Recursive averaging has the advantage

that it can be performed on the fly. Number of frames that can be averaged is usually 32 or fewer; with integration and averaging, greater numbers of frames can be dealt with.

IMAGE QUALITY AND PROCESSING TECHNIQUES

Real-time radiography is generally less sensitive than film radiography. A number of factors contribute to this difference. These factors include (1) the difference in size between the silver halide grains of film and the cesium iodide needles of the RTR scintillation screen, (2) the phosphor bloom of the fluorescent screen, (3) the random pixel noise inherent in image intensifiers, and (4) the pin-cushion image distortion also inherent in these systems.

Real-time radiography systems using an image intensifier tube have poorer resolution (2-4 line pairs per millimeter) [LP/mm] than film (10-20 LP/mm) does. Phosphor bloom, especially in the output conversion phosphor, is the principle cause of diminished resolution.

Image Processing Techniques

As has just been established, a number of factors can adversely affect RTR image quality. With the use of image enhancement techniques, the difference in sensitivity between film and RTR can be decreased. A number of image processing techniques, in addition to enhancement techniques, can be applied to improve the data usefulness. Techniques include convolution edge detection, mathematics, filters, trend removal, and image analysis. The various image enhancements and image processing techniques will be introduced in this section. Computer software programs are available, including some or all of the following programs:

Enhancement programs make information more visible.
- ?? Histogram equalization-Redistributes the intensities of the image of the entire range of possible intensities (usually 256 gray-scale levels).
- ?? Unsharp masking-Subtracts smoothed image from the original image to emphasize intensity changes.

Convolution programs are 3-by-3 masks operating on pixel neighborhoods.

- ?? Highpass filter-Emphasizes regions with rapid intensity changes.
- ?? Lowpass filter-Smoothes images, blurs regions with rapid changes.

Math processes programs perform a variety of functions.

- ?? Add images-Adds two images together, pixel-by-pixel.
- ?? Subtract images-Subtracts second image from first image, pixel by pixel.
- ?? Exponential or logarithm-Raises e to power of pixel intensity or takes log of pixel intensity. Nonlinearly accentuates or diminishes intensity variation over the image.
- ?? Scaler add, subtract, multiply, or divide-Applies the same constant values as specified by the user to all pixels, one at a time. Scales pixel intensities uniformly or nonuniformly.
- ?? Dilation-Morphological operation expanding bright regions of image.
- ?? Erosion-Morphological operation shrinking bright regions of image.

Noise filters decrease noise by diminishing statistical deviations.

- ?? Adaptive smoothing filter-Sets pixel intensity to a value somewhere between original value and mean value corrected by degree of noisiness. Good for decreasing statistical, especially single-dependent noise.
- ?? Median filter-Sets pixel intensity equal to median intensity of pixels in neighborhood. An excellent filter for eliminating intensity spikes.
- ?? Sigma filter-Sets pixel intensity equal to mean of intensities in neighborhood within two of the mean. Good filter for signal-independent noise.

Trend removal programs remove intensity trends varying slowly over the image.

- ?? Row-column fit-Fits image intensity along a row or column by a polynomial and subtract fit from data. Chooses row or column according to direction that has the least abrupt changes.

Edge detection programs sharpen intensity-transition regions.

- ?? First difference-Subtracts intensities of adjacent pixels. Emphasizes noise as well as desired changes.
- ?? Sobel operator-3-by-3 mask weighs inner pixels twice as heavily as corner values. Calculates intensity differences.
- ?? Morphological edge detection-Finds the difference between dilated (expanded) and eroded (shrunken) version of image.

Image analysis programs extract information from an image.

?? Gray-scale mapping-Alters mapping of intensity of pixels in file to intensity displayed on a computer screen.

?? Slice-Plots intensity versus position for horizontal, vertical, or arbitrary direction. Lists intensity versus pixel location from any point along the slice.

?? Image extraction-Extracts a portion or all of an image and creates a new image with the selected area.

?? Images statistics-Calculates the maximum, minimum, average, standard deviation, variance, median, and mean-square intensities of the image data.

COMPUTER INTERFACE

Many RTR systems are interfaced with computers for image manipulation and enhancement. The X-ray generator also can be interfaced with the computer via an RS232C serial data port. This means that all RTR controls are at the fingertips of the keyboard operator. This type of connector allows for serial communication between computers and peripheral equipment. The RS232C standard is set by the Electronics Industry Association (EIA) and controls the voltages and timing, among other things. The connector itself may be a DB25 connector (Figure 12) or a DB9 connector (Figure 13). This same connector is used to connect ultrasonic and eddy current machines to computers.
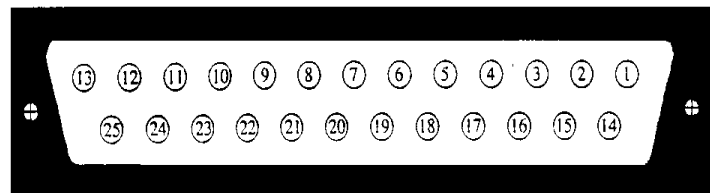

Figure 12. DB25 connector.
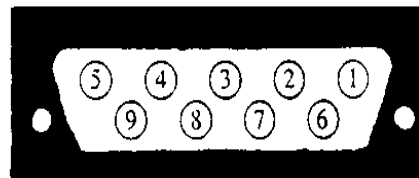
Figure 13. DB9 connector.

SAMPLE POSITIONING SYSTEM

Part-handling equipment such as manipulators can make it possible to move, rotate, or tilt the item being inspected. In some instances, a conveyer satisfactorily moves parts through the X-ray cabinet for inspection. Five axis manipulators are available for maximum part manipulation. Stepper motors allow for very close control of the movement of the part. When a manipulator is selected, the maximum weight of the inspection item must be considered. Fixtures such as a chuck may be necessary to hold the part. In automatic inspection systems, the manipulator must be capable of being programmed to sequence properly so that all inspection points are covered. Devices used for fixtures must be materials not contributing to scatter radiation. A sample positioning system is shown in figure 14.
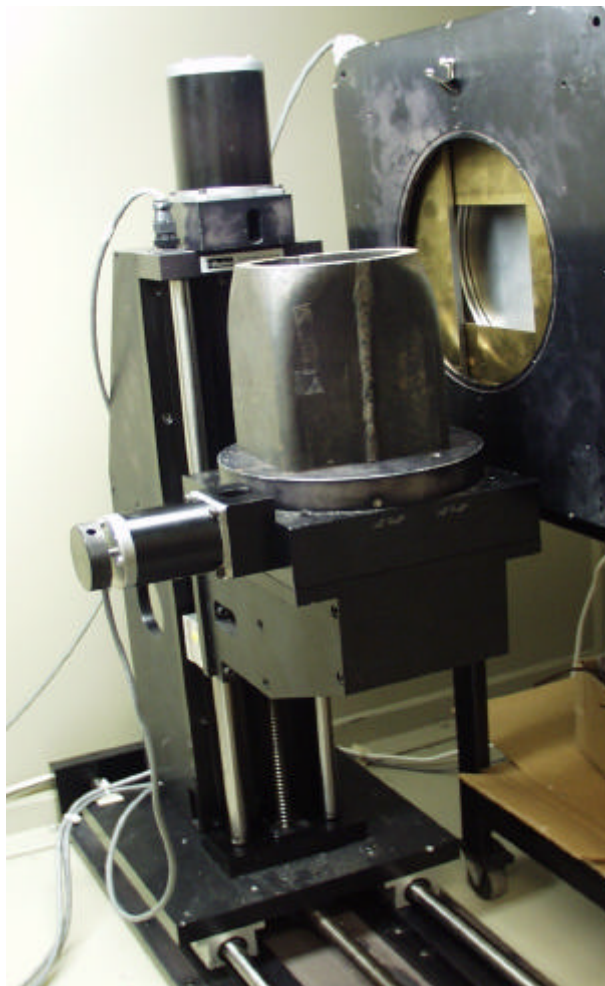
Figure 14. Photograph of a stepper motor controlled sample-positioning system with three degrees of movement.

COLLIMATORS AND SHUTTERS

Shutters and masks can help limit the radiation beam as it is directed toward the part, thereby decreasing scatter radiation by narrowing and decreasing beams to a specific location. Shutters are usually mounted on the front of the image intensifier and help keep radiation not passing through the part from impinging on image intensifier screen and causing phosphor blooming. Figure 15 shows examples of collimators and shutters.

Figure 15. Photographs of a beam collimator mounted on the x-ray tube on the left and shutters mounted to the front of an image intensifier on the right.

DATA STORAGE

Once an image has been produced, it may be necessary to make a copy for comparison purposes or for future reference. Digital techniques, while offering the best in image quality, must use still images and so consume large amounts of memory. VCR tapes can record movement, but quality is diminished. Here, as with other aspects of RTR, compromise is necessary. Optical discs have high-capacity storage capabilities.

ENVIRONMENT OF THE RTR SYSTEM

The environment of the RTR equipment contributes to overall RTR performance and end results. The control room should be dimly lit for viewing the monitor, and air conditioning can help keep the camera and related equipment at a controlled temperature.

PROCESS CONTROL TESTS

Whether equipment has the capacity to detect and show critical discontinuities is an important consideration in RTR. The *American Society for Testing Materials* (ASTM) E1255 indicates that the system shall be checked each day, a log maintained and a system requalification required when image quality is diminished. Equipment is usually much more sophisticated than that used for film radiography, and it must be ascertained that equipment is performing as it should. *ASTM E1411* is a standard practice that can be used initially to qualify and later to requalify a system by determining how it performs in a static mode-this means that the test object and the radiation beam are stationary. Many different equipment configurations and arrangements are possible with RTR, and *ASTM E1411*, addresses the elements of an RTR system operating together, rather than evaluating them individually. The procedure's intent is to obtain benchmark performance data at certain settings and a standardized test part. Because inspection of actual parts involves different variables, results differ. Operations differ in their ability to obtain optimum results from the system. Also, as a system ages, its performance diminishes because various materials degrade, and the cesium iodide input screen is particularly prone to fading in

the image intensifier. Obtaining an image of quality indicator when the system is new (a so-called *golden image*) is important because this image can be used for later comparison.

Measuring the focal spot of the X-ray tube can be done in accordance with *ASTM E1165*. The caveat is that this procedure may not produce useful results when the nominal focal spot is smaller than 0.3 mm (300 microns); with minifocus and microfocus X-ray tubes, this procedure is not recommended, for geometric unsharpness greatly influences image quality. *ASTM E1161* indicates that the film must be sufficiently fine-grained to resolve discontinuities down to 0.025 mm (25 microns), or .001 inches. When RTR is evaluated for use in locating small discontinuities, it is necessary to determine whether image magnification is necessary. If magnification is used, the potential for geometric unsharpness increases greatly unless extremely small focal spots (microfocus X-ray tubes) are used. To determine X-ray tube resolution, the LP gauge is used, with values expressed in a certain number of LP/mm. Another test device, made by Victoreen and consisting of a grid pattern also can be used. As indicated in *ASTM E1255* section 6.24, spatial resolution and contrast sensitivity can be checked with LP test pattern and step, respectively. The step wedge needs to be made from the same material as a test part and in various thicknesses. (Refer to *ASTM E1255* section 6.24.)

IMAGE QUALITY INDICATORS

Image quality indicators are used in RTR for the same reasons they are in film radiography to measure the performance of technique and equipment. (As with film radiography, contrast changes (seeing small thickness changes) and definition in film radiography or spatial resolution in RTR is being able to see small anomalies.) Image quality indicators (IQI) such as plaque type and wire type pentameters can be used, but the orientation to the X-ray beam is critical. IQIs original use was to indicate quality with a still image, not with a moving image as with RTR.

A line pair gauge is a device used in many radioscopic inspections (See Figure 16). This device indicates how many line pairs can be discerned in a width of one millimeter (.03937 inches). The resolving capability of an RTR system often is referred to as a certain number of LP, meaning LP/mm. Typical ranges are 2-5 LP/mm for conventional RTR systems and up to 20
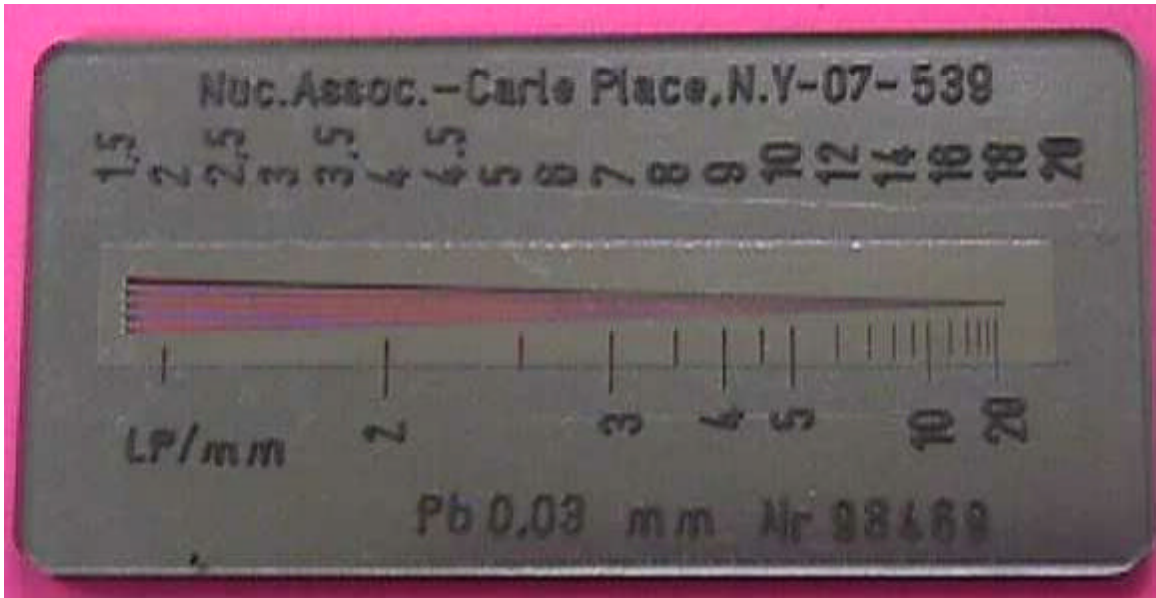
Figure 16. Photograph of a line pair resolution gauge.

LP/mm for microfocus RTR systems. Ten LP/mm indicates a space of .003937 inches (1 mm divided by 10). The line pair gauge is made of lead or gold and situated on a plastic base providing a good contrast. The lines at one end of the gauge are spaced widely and converge at the opposite end. When the separation of the lines no longer is visible, the perpendicular line closest to it is noted. Starting at the end of the gauge with the wide spaces, perpendicular lines are counted until no separation can be seen, and this number of lines is noted as well. With the gauge being used for this example, there are 18 perpendicular lines on one side and 18 corresponding numbers on the top opposite side. Matching the number with its line indicates the LP/mm. For instance, if the separation of lines cannot be seen beyond the mark between that labeled 3 and that labeled 4, this is 3 ½ LP/mm. If the limit of separation of the lines is one mark below the last mark where they converge or the 17th mark, this corresponds to 18 LP/mm because the 17th number down the scale is 18. In some instances, a part with an actual defect can be used as a check to see if the equipment is performing at a minimum level.

Another device made by Victoreen appears in Figure 17. This is a wire mesh LP gauge which is used to verify the resolution achievable by the system. This gauge reads in LP/in and can be placed directly on the image intensifier.

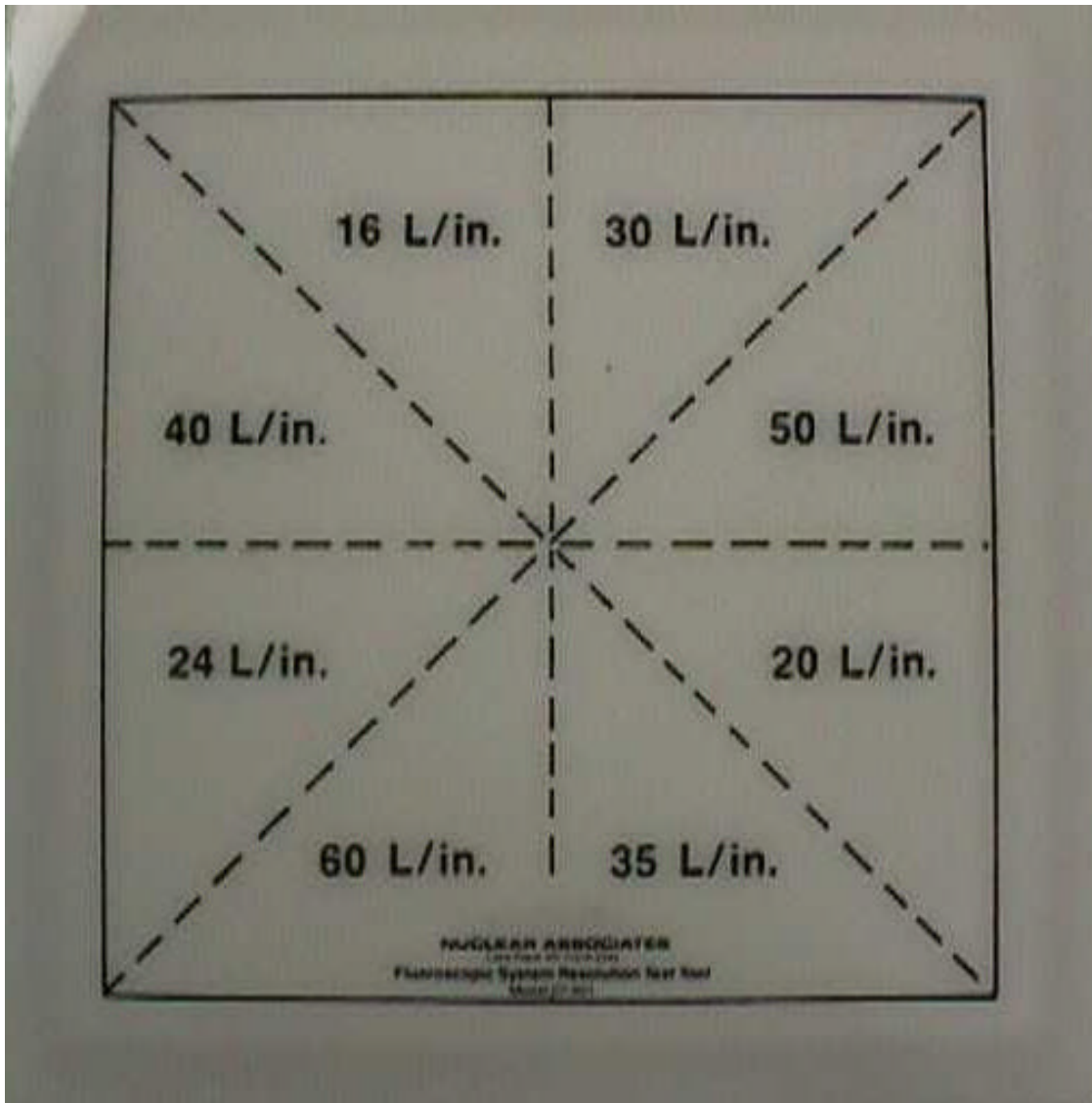Figure 17. Photograph of line pair gauge made by Victoreen.

In summary, several different image quality indicators can be used, the most common being the LP gauge for spatial resolution and the step wedge for contrast sensitivity. Calibration blocks or actual test pieces with known discontinuities also are used. Some test procedures require a check of the image before and after each inspection shift.

DEFECT ANALYSIS AND APPLICATIONS

In some systems, the constant interaction of a trained operator is required to determine whether the status is acceptable or rejectable. More sophisticated systems use automatic defect recognition (ADR) or artificial intelligence software that determines the status, without the constant need for an operator. Complexity depends on the use of the system, which might determine part presence or absence, placement, position, density variations, or size variations. For example, in certain instances, defective conditions are known and ADR algorithms, or step-by-step procedures for solving problems, are written. If the ground pin of an airbag initiator is being inspected for proper diameter and location, the ADR can be written to look where the ground pin should be. If it is not in the correct position, the ADR rejects it. This method allows for the examination of specific regions of interest (ROI), permitting faster inspection and decreasing the amount of image storage space.

More complex analysis ma y involve the program's algorithm to determine whether, in a certain ROI, there are any deviations such as discontinuities, pores, cracks, or inclusions. The RTR system may be tasked with automatic inspection (without operator interaction), making various required checks and proper archival records all at a relatively high rate of speed. Figures 18 through 22 show some of the different objects that are inspected with RTR systems but almost any component could be inspected use RTR.

Figure 18. Hot stage turbine blade.

Figure 19. Capacitor.

Figure 20. Aluminum connecting rod.

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Figure 21. Air bag inflator.

Figure 22. Electrical breaker.

SPECIFICATIONS

The use of RTR for industrial purposes is the result of the NDT industry's "latching on" to what the medical profession has been doing with real time in previous years. As a result, there are fewer specifications for RTR than for the NDT test methods, which have been established for a longer period.

At present, specifications are being put together by industry users in various settings. These are written for in-house use and for such organizations as the ASTM. (Refer to the applications booklet for worksheet exercises related to the ASTM.)

The following is a list of RTR specifications listed in the *1996 Annual Book of ASTM Standards*, Section 3 Volume 03.03, "Nondestructive Testing". Note the definitions for "*standard practice*", *standard test method*, and *standard guide*.

An ASTM *standard practice* is a definitive procedure for performing one or more specific operations or functions and does not produce a test result.

A *standard test method* is a definitive test procedure producing a result.

A *standard guide* is a series of options or instructions recommending no specific course of action.

E747   A standard practice for controlling the quality of radiographic examination using wire image quality indicators.

E801   A standard practice for controlling the quality of radiological examination of electronic devices.

E100   A standard guide for radioscopy.

E1025   A standard practice for hole-type image quality indicators.

E1255   A standard practice for radioscopy.

E1411   A standard practice for qualifying radioscopic systems.

E1416 A standard test method for radioscopic examination of weldments.

E1441 A standard guide for computer tomography (CT) imaging.

E1453 A standard guide for storage of media containing analog or digital radioscopic data.

E1475 A standard guide for data fields for computerized transfer of digital radiological test data.

E1647 A standard practice for determining contrast sensitivity in radioscopy.

E1734 A standard practice for radioscopic examination of castings.

Other standards applying to RTR involve the American National Standard that establishes requirements for the design and operation of installations using gamma and X-rays for nonmedical uses. The objective is to protect personnel from overexposure to radiation. The Code of Federal Regulations or the rules of the applicable state department of health provide other safety RTR equipment rules/regulations relating to radiation.

PROCEDURE DEVELOPMENT

Developing procedures for RTR involves several of the same concerns as that for NDT. As has been stated before, certain industries are required to use RTR and others do so voluntarily. As a result, the procedures used differ: some are very formal and specific; others may not be formal. One example of a specific required procedure is discussed at the end of this section.

Discussions of these areas of procedure development follow next:

1. determining the inspection requirement and accept/reject criteria

2. defining part parameters

3. determining parameters for each area of interest

4. determining which quality control indicators, if any, to use

5. determining archival record needs

6. determining whether parameters meet specification requirements

7. defining personnel qualifications

8. verifying system resolution

9. determining fixtures, masking, shutters, etc.

10. determining defining equipment requirements

1.   Determining the inspection requirements and accept/reject criteria. What discontinuities must be detected? Cracks, voids, misalignment, or presence or absence of components? Welds may evidence discontinuities such as incomplete penetration, nonfusion, or slag inclusion. Rolled plates may evidence lamination; bars may evidence stringers or seams. Castings may evidence porosity, blowholes, or shrinkage. Forgings may evidence bursts, laps, cold shuts, etc. What inherent discontinuities exist? Does RTR afford the best probability of detection (POD) for this part of material? Determining inspection requirements may involve testing and experimentation to find critical areas if the product or material application is new. Previous industry and acceptance standards must be considered.

2.   Defining part parameters. What are the thickness and geometric considerations? What type of material is involved? Is 100% inspection required, or will a sampling suffice? Does the part lend itself to inspection on the fly? If image processing is to be done, then the part may have to be stopped. Here, also, testing will probably have to be done to determine parameters. In instances such as checking food products for contaminants, either the product can be penetrated and the system will show enough contrast between the contaminant and the product, or it cannot be done. Comparing RTR images with film images may be helpful.

3.   Determining parameters for each area of interest. Does energy level and the MA need to be varied for different ROIs? Which source-to-object and object-to-imaging detector distance needs to be used? Must it be varied during the inspection? A scan plan must be defined: How is the part to be moved? Tilted? Turned on its axis? What speed can be used which retaining and detection capability? Testing and experimentation is needed, and comparison to existing film-based imaging can be utilized if RTR has not previously been used on the part/material.

4.   Determining which indicators, if any, to use. Film-based penetrameters are options, as are, wire gauges, line pair gauges, and, in the case of food-product tests, a sphere of carbon and stainless steel down to .5 mm measured through the product. If wire

penetrameters are used, decisions must be made as to what diameter of wire to use. A distinction must be made between gauges used to set up and to establish the image quality of the system and those used to check the radiographic image quality of production pieces/materials.

5. Determining archival record needs. Several possibilities are available. The traditional film radiograph is considered to have a long archival life. In most instances, however, the archival life of RTR is even longer. There are instances when due to the subjectivity of the interpretations process, a need may arise to review an image. Analog recording involves the use of a videotape recorder. This method is fairly inexpensive and the recorded images have a long life. The videotape referred to in the application booklet was recorded this way. Hard-copy video recordings can be made on thermally sensitive paper with modest quality and a limited shelf life. Digital recording will produce an archival image of the same quality as the original image because it is stored as a numerical pixel array. Two methods of recording are magnetic and optical. Magnetic media include magnetic floppy and hard disc and magnetic tape. Optical media include the laser optical disc and the laser holograph. Attention must be paid to protecting recorded images that they are not written over. Digital image recording is suited best to single frames onto a few frames of motion because a great deal of space is required for each video frame.

6. Determining whether parameters meet specification requirements. What specs are involved? As RTR gains wider acceptance and use, more and more specifications will emerge regarding the process. Customer's needs must be considered. These can involve a variety of material from the traditional metals, to composites, to U.S. Department of Agriculture standards for food inspection.

7. Defining personnel qualifications. Because RTR is required at times, and optional at others, personnel qualifications also differ. Requirements may be those of the American Society for Nondestructive Testing (ASNT), or a written practice recognized by the ASME. Personnel may be required to have Level II or III qualifications in radiography, with minimal additional training in operating, imaging, and interpreting the system. Other sources of specifications may include the American Welding Society (AWS), American Petroleum Institute (API), National Aeronautics and Space Administration

(NASA), the Department of Defense (DOD), and the Federal Aviation Administration (FAA).

8. <u>Verifying system resolution.</u> Addressing issues of checking the system itself and checking to see if the resolution of an actual production piece with known defect(s) may be used, *ASTM E1255* can be referred to for guidance. These resolution checks usually are conducted at least at the beginning and at the end of each shift. It must be determined whether the test is to be conducted in the static mode or on the fly.

9. <u>Determining fixtures, masking, shutters, etc.</u> Such determinations depend on the specific part and material and can be determined best by means of testing and experimenting. Surfaces must meet application specifications. With RTR, as with film radiography, weld ripples may need to be conditioned so that they do not mask or become confused with the images of other discontinuities. The area or the section examined must be identified and be traceable back to the part at a later date, if need be.

10. <u>Determining defining equipment requirements.</u> The necessary components to produce final image requirements is critical here. Application of RTR involves a wide variety of parts/materials. Equipment is relatively expensive and, to keep costs down, only the components necessary to produce the required image should be required. If magnification of images is not necessary, microfocus X-ray tubes probably are not either. If a new system is being considered, the decision needs careful consideration because a compromise between minimum system capability and cost must be achieved.

SPECIFICATIONS

ASTM E1255 section 5.2 indicates that the purchaser and the supplier of radioscopic examination systems must agree mutually upon a written procedure with the applicable requirements. Other recommendations are as follows:

1. Equipment qualifications (system features that must be qualified to ensure adequate performance).

2. Test-object scan plan: Test-object orientations, motions, and speed of manipulation necessary to ensure that the examination will be thorough.

3.   Radioscopic parameter (focal-spot size, source-to-object distance, object-to-image plane distance, etc.).

4.   Image processing parameter (electronic noise reduction, contrast enhancement).

5.   Image display parameters (brightness, contrast focus, and image linearity).

6.   Accept/reject criteria (expected discontinuity types and rejection levels).

7.   Performance evaluation (qualification tests to ensure system capabilities).

8.   Image archiving requirements (for preserving and recalling the image at a later date).

9.   Minimum operator qualification.

PROCEDURE DEVELOPMENT/ASME CODE

When work is being done to the American Society for Mechanical Engineers (ASME) code, there are procedure requirements in Article 2 (a mandatory appendix). These are for use in examination of ferrous and nonferrous weldments. Section II-221 lists specific areas that must be addressed in a written procedure; they are as follows:

1. Material and thickness range
2. Equipment qualification
3. Test-object scan plan
4. Radioscopic parameters
5. Image processing parameters
6. Image display parameters
7. Image archiving

Sections of *ASTM E1255* are referenced with the procedure requirements. Some requirements are addressed as follows: examination data <u>shall</u> be recorded and stored on videotape, magnetic disc, or optical disc.

A calibration block must be made of the same material type and product form as the test object. The block may be an actual test object or fabricated to simulate the test object with known discontinuities.

An LP test pattern shall be used to evaluate system resolution. A step wedge must be used to evaluate system contrast sensitivity. This wedge must be made of the same material as the test object and have steps representing 100%, 99%, 98%, and 97% of the thickest and the thinnest sections to be inspected. The system must be calibrated in the status mode (no motion between object and image detector) to satisfying LP test pattern resolution, step wedge contrast sensitivity, and calibration test block detection requirements.

System performance parameters must be determined initially and monitored on a regular basis with the system in operation to ensure consistent results. (Image intensifiers do degrade.) Here, once again, the LP test pattern, step wedge, and calibration block must be used; and the golden image can be compared with images produced over time.

The calibration block must be placed in the same position and manipulated through the same range and speed of motion as the actual test object. This will be a check on the system performance in the dynamic mode.

The system must have, at a minimum, the following features:
> a.   Radiation source
> b.   Manipulation system
> c.   Detection system
> d.   Information processing system
> e.   Image display system
> f.   Archiving system for records

Minimum information regarding radioscopic techniques must accompany test data. These must include at least operator identification and system performance test data. The manufacturer must interpret test data for acceptability before giving them to the inspector (an individual who checks for code compliance, independently of the manufacturer.

Appendix IV contains a set of questions that should be answered about RTR specifications.

APPENDIX I

METRIC CONVERSION

All units of length in the metric system are derived from the meter. Although not a commonly used unit of measure in engineering, the meter is included here to show place value. Prefixes to the basic unit denote unit length. For example, the prefix *cent-* signifies one-hundredth; therefore, one centimeter is one one-hundredth of a meter.

kilo=1,000   1 kilometer (km) = 1,000 meters (m)

hecto=100   1 hectometer (hm) = 100 m

Deca = 10   1 decameter (dam) = 10 m

                             1 meter (m) = 1 m

deci = 0.1   1 decimeter (dm) = 0.1 m

centi = 0.01   1 centimeter (cm) = 0.01 m

milli = 0.001   1 millimeter (mm) = 0.001 m

micro = 0.000001   1 micrometer (micron) = 0.000001 m

Conversion between units of length in the metric system involves moving the decimal point to the right or to the left. Listing the units in order from largest to smallest will indicate how many places to move the decimal point and in which direction.

?? To convert 4,200 cm to m, write the metric units in order, from largest to smallest.

<u>km</u> hm <u>dam</u> m <u>dm</u> <u>cm</u> <u>mm</u> __ __ <u>micron</u>

Because centimeters are two places to the right of meters, converting cm to m requires moving two decimal positions left; therefore, 4,200 cm = 42.00 m.

?? To convert 5.0 microns to mm, list the metric units in order, from largest to smallest.

<u>km</u> hm <u>dam</u> m <u>dm</u> <u>cm</u> <u>mm</u> __ __ <u>micron</u>

Because microns are three positions to the right of millimeters, converting micron to mm requires moving the decimal point three places left; therefore, 5.0 microns = .005 mm.

Measures of Length

10 millimeters (mm) = 1 centimeter (cm)

10 centimeters = 1 decimeter (dm)

10 decimeters = 1 meter (m)

1,000 meters = 1 kilometer (km)

Metric and English Conversion Table Linear Measure

1 kilometer = 0.6214 mile	1 mile = 1.609 kilometers
1 meter = 39.37 inches	1 yard = 0.9144 meter
3.2808 feet	1 foot = 0.3048 meter
1.0936 yards	1 foot = 304.8 millimeters
1 centimeter = 0.3937 inch	1 inch = 2.54 centimeters
1 millimeter = 0.03937	1 inch = 25.4 millimeters
1 micron = 0.00003937 inch	

To convert from mm to inches; divide the millimeters by 25.4.

Example: $\dfrac{550}{25.4}$ mm = 21.6535 in.

Or multiply by .03937; 550 mm x .003937 = 21.6535 in.
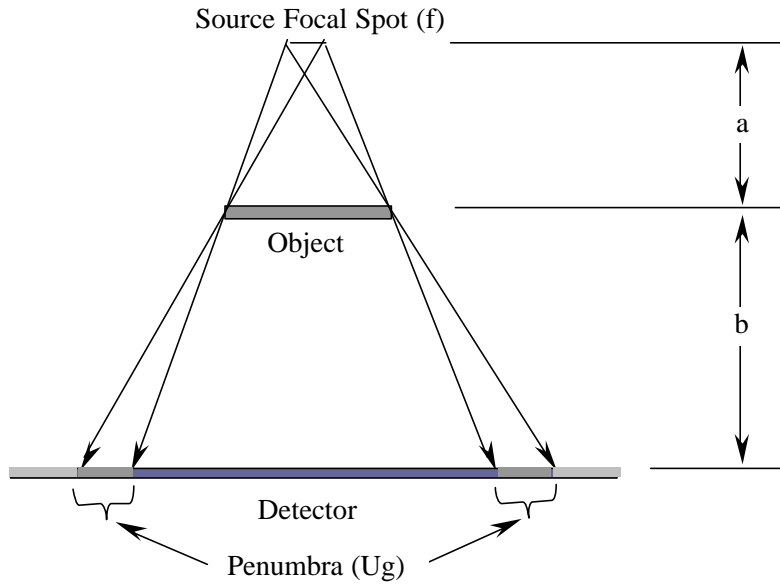

To convert from in. to mm, multiply the in. by 25.4.

Example: .750 x 25.4 = 19.05 mm.

Or divide by .03937:

Example: .750 in. divided by .03937 = 19.05 mm.

APPENDIX II

GEOMETRIC UNSHARPNESS WORK PROBLEMS

Source Focal Spot (f)

a

Object

b

Detector

Penumbra (Ug)

$$Ug \; ? \; f \; ? \; \frac{b}{a}$$

Given these parameters, give your answers in inches.

1.	f = 1.5 mm A = 20 in. b = 8 in. ug = ___ in.	2.	f = 4.5 mm A = 20 in. b = 8 in. ug = ___ in.	3.	f = .8 mm A = 40 in. b = 20 in. ug = ___ in.	4.	f = 1.8 mm A = 40 in. b = 20 in. ug = ___ in.
5.	f = 80 microns A = 3 in. b = 27 in. ug = ___ in.	6.	f = 1.5 mm A = 3 in. b = 27 in. ug = ___ in.	7.	f = 4.5 mm A = 3 in. b = 27 in. ug = ___ in.	8.	f = 10 microns A = 3 in. b = 27 in. ug = ___ in.
9.	f = 50 microns A = 47 in. b = .200 in. ug = ___ in.	10.	f = 50 microns A = 3 in. b = 47 in. ug = ___ in.	11.	f = 5 microns A = 47 in. b = .2 in. ug = ___ in.	12.	f = 5 microns A = .2 in. b = 47 in. ug = ___ in.

APPENDIX III

CONVERSION OF ANALOG AND DIGITAL INFORMATION

Today, the term *digital* is a word we hear frequently because digital circuits are becoming so widely used in computation, robotics, medical science and technology, communication, transportation, etc. Digital electronics developed from the principle that the circuitry of a transistor could be designed and fabricated easily to have an output of one or two voltage levels, based on its input voltage.

A *transistor* is a semiconductor used in circuits that acts as a high-speed switch or to provide amplification. Transistors have taken the place of vacuum tubes.

The two voltage levels are usually 5 volts (high) and 0 volts (low); the levels can be represented by 1 and 0. The binary numbering system (base-2 numbering system) is one of the numbering systems used in digital electronics. A digital value is represented by a combination of on and off voltage levels written as a string of 1s and 0s.

When applying technology, we are constantly dealing with quantities that must be measured, monitored, recorded, or manipulated. These values must be able to be represented efficiently and accurately. Two ways of representing these values are analog and digital.

In *analog* representation, a quantity is represented as on a voltage meter movement or current; the representation is proportional to the value of the quantity. One example is a column of mercury in a thermometer. The height of the mercury represents the temperature, and its height changes as the temperature rises or falls. Another example is an audio microphone, in which sound waves from the voice alter as they impinge on the microphone; these variations cause output voltage to vary proportionally. The important point to remember about analog representation is that the output represented can have a continuous range of values, i.e., the temperature in a room can have **any** value ranging from say 60? F to 85? F, and the height of the mercury would respond accordingly.

Digital, on the other hand, utilizes circuitry whereby quantities are represented not proportionally, but by symbols called digits. An example is the digital watch, which displays the time in the form of decimal digits. Even though the time of the day is changing continuously, the digital watch changes in steps or increments of a minute, or second, or hour. Put another way, an analog value is continuous, but a digital value is discrete; because of this difference, when reading a digital value there is no uncertainty but the value of an analog quantity depends on how the person reads it and the value may be different from that which the next person reads.

Consider the following examples and indicate whether they are analog or digital:

a. ten-position switch
b. water flowing out of a meter
c. temperature of a room
d. grains of sand on a beach
e. speedometer on an automobile

Answers: A. digital, B. analog, C. analog, D. digital (the number of grains is a discrete value), E. analog if it's the needle type, and digital if it's the numerical readout type. Digital systems are usually electronic, but they can be mechanical, pneumatic, or magnetic. Examples are digital computers and the telephone system, the world's largest digital system.

ADVANTAGES OF DIGITAL TECHNIQUES

1.   They are easier to design because switching circuits are used.
2.   Storage of information is easy because switching circuits can latch onto information and hold as long as needed.
3.   If more accuracy and precision is necessary, there is more of both, because additional switching circuits simply need to be added.
4.   More complex programming can be done.
5.   Circuits are not affected as much by noise or fluctuation in voltage.
6.   Integrated circuit chips have a higher degree of integration.

Digital quantification of values does have some limitations. Values in the real world, e.g., temperature, position, pressure, velocity, and flow rate, are mainly analog. We may digitally express these quantities by saying the temperature is 80?, but we are simply making a digital estimation of an inherently analogical quantity.

To represent accurately a complicated musical signal such as a digital string, several samples of the analog signal must be taken. The analog signal is produced when sound waves hit the microphone. The waves make a diaphragm move back and forth in proportion to the sound pressure received. This diaphragm (a conductor) moving back and forth in a magnetic field creates a voltage. Notice that the voltage trace in Figure 10 is constantly changing in value. The first point taken is at 2 volts; this converts to the binary number 0000 0010. (See figure 1.)
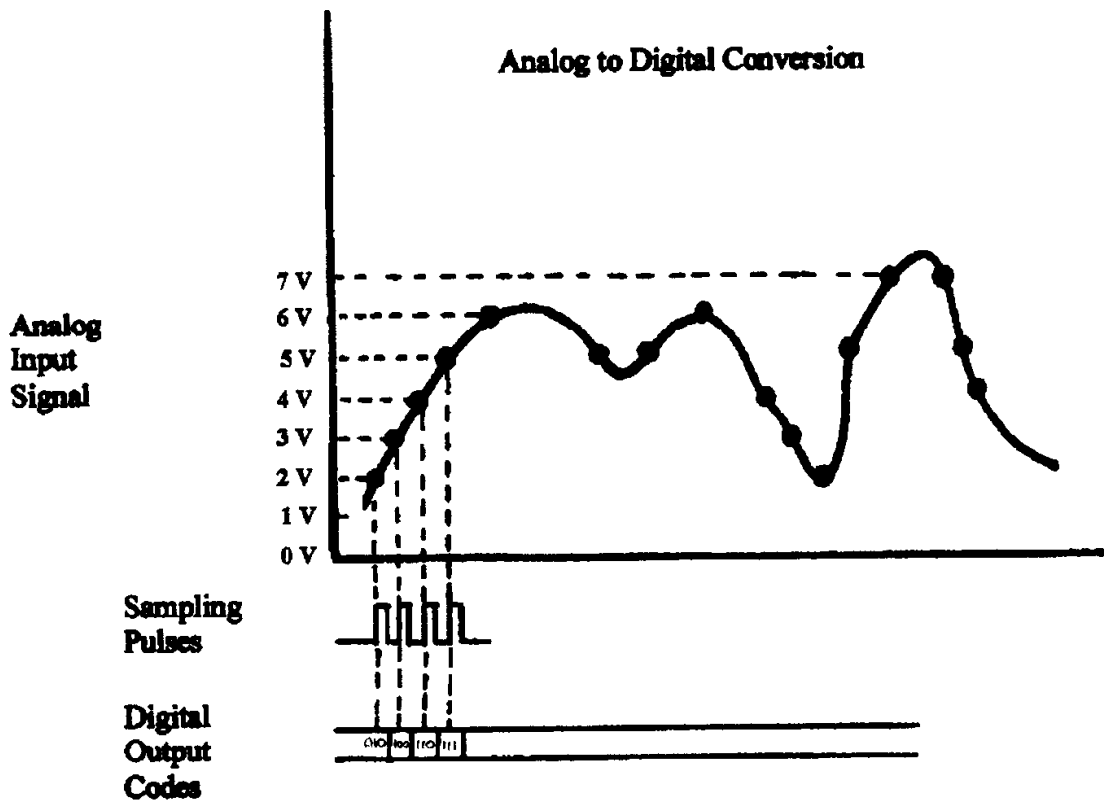

Figure 1. Graphical representation of the analog to digital conversion process.

Next, more and more points are taken as samples. To play back the music, this process is reversed. The more samples taken, the more exact the reproduction of the original conversion can be. Extra steps are involved, but when imperfections are introduced into a digital signal, variation in the digital level does not change the "on" to the "off" level. The human ear picks up this variation in an analog level, however. So "digitizing" can eliminate certain unwanted signals. Because it can help electronic noise, this characteristic of digital electronics is beneficial in RTR. Moreover, the number of steps (resolution) that the analog signal can be divided into is determined by converter's bit number. If you were converting an analog signal ranging from 0 – 16 volts and you had a 2-bit converter, the number of steps would be $2^2 = 4$, or four steps. Each value of analog voltage sampled, therefore, would be digitized and given one of four voltage values. This would not be very accurate or useful. If you used an 8-bit converter, however, the resolution in 2^8=256, and now each step will equal 16/256 or 0.0625 volt (1/16 volt). This would provide much greater accuracy. Many converters currently used in RTR systems are 8 bit. Range of grays, which provides contrast, to be at 256 different values, where 0 equals black and 255 equals white. In RTR, use of A-to-D and D-to-A converters common because of the advantages of each, but they do take time and add complexity and some expense to the system.

APPENDIX IV

ASTM STANDARDS AND RTR

Refer to the annual book of ASTM standards, Vol. 03.03, to answer the following questions.

1.   How does *ASTM E801* differ from *ASTM E1161*?

2.   Per *ASTM E801* and *ASTM E1161*, list four anomalies that RTR might indicate are present in an electronics device.

3.   Per *ASTM E1161*, if permanent records are required for nonfilm techniques, what are three methods of providing them?

4.   How thick, in inches, must the lead be for a lead-topped table, per *ASTM E1161*?

5.   Regarding part identification, per *ASTM E801*, what must each image header for each part image include?

6. Per *ASTM E801*, what is the deciding factor regarding permitting use of nonfilm technique, i.e., RTR?

7. Per *ASTM E1255*, regarding equipment and procedure, what will the <u>minimum</u> system configuration include?

8. List three advantages from section 6 of *ASTM E1255* regarding the use of X-ray sources instead of radioisotopic source.

For questions 9 – 11, See *ASTM E1255*, "Performance Measurement."

9. What is the best way to determine system performance?

10. Who determines what performance measurement methods are used?

11.   How would you determine the frequency of the performance measurement procedure?

12.   Per *ASTM E1255*, section 6.24 discusses the calibrated LP gauge and the step wedge.

      A.   What does the LP test pattern evaluate?

      B.   What does the step wedge evaluate?

13.   Per *ASTM E1255*, section 6.25, list five of the considerations you will take into account regarding the environment that the RTR will be performed in.

14.   How does *ASTM E1255* address operator qualifications?

15.   Regarding records and reports, what section of *ASTM E1255* will you refer to to determine the necessary information for an archival examination record?

16. Per *ASTM E1255*, section 6 – 1.4 – 3 addresses digital imaging. What is one precaution to keep in mind when inspecting on the fly (dynamically)?

17. *ASTM E1411* can be used to qualify and to requalify a system for a certain application for which inspection is done on the fly.

        True _____   False _____

18. Does *ASTM* E1411 provide methods with which to evaluate individual components of the RTR system, or the total system?

19. Per *ASTM E1416*, where can you go for help selecting radiation source?

20. Per *ASTM E1416*, what is the maximum geometric unsharpness allowed for a weld 1.75" thick?

21. Per *ASTM E1416* regarding geometric unsharpness, will a source-to-detector distance of 28" be acceptable for a weld 2.5" thick when an X-ray tube with a 300-micron focal spot is used?

Yes _____   No _____

If no, what will the actual ug factor be?

22. Per *ASTM E1416*, what factors will you consider when determining the examination speed for dynamic examination?

23. Per *ASTM E1734*, what are three methods of decreasing scattered radiation?

24. Per *ASTM E1734*, system performance can be tracked using an LP test pattern and step wedge. What energy and intensity levels must be used in evaluation?

25. Per *ASTM E1734*, what surface preparation is allowed castings?