

The contrast sensitivity in computed tomographic images is inherently high because each reconstructed volume element is composed of backprojected rays from many orientations about the object. Equation 34 shows an estimate of the signal-to-noise ratio (SNR) in a voxel element as a function of various computed tomographic system characteristics for a reconstruction of cylindrical object:¹⁹

$$(34) \text{ SNR} = 0.665 \mu w^{1.5} \sqrt{\frac{vnt}{\Delta p}} \exp(-2\pi R)$$

In this equation, μ is the linear attenuation coefficient, w is the X-ray beam width, v is the number of views, n is the photon intensity rate at the detector, t is the integration time of the detectors, Δp is the ray spacing and R is the radius of the object. The contrast ratio will be given by:

$$(35) \text{ Contrast ratio} = \frac{6}{\text{SNR} \times \sqrt{Z}}$$

where Z is the number of pixels over which the contrast is observed. Table 2 shows an example of calculations based on Eqs. 34 and 35. Computed tomographic systems often provide contrast sensitivity measurements in the range of 0.1 to 1.0 percent. What the equations show is that the signal-to-noise ratio improves with increases in computed tomographic system characteristics of X-ray beam width, number of views, X-ray beam intensity and integration time. The signal-to-noise ratio will also be improved by decreasing the ray spacing and object diameter. These computed tomographic system characteristics reflect the tradeoffs in optimizing a computed tomographic system. Fast scan times, fine resolution, high contrast sensitivity and

large object size are mutually exclusive, requiring compromise in system design.

Because of the high signal-to-noise ratio in any voxel, computed tomography can detect features below the resolution limit of the image. For features that are larger than a single voxel the contrast sensitivity improves by the square root of the number of pixels making up the feature. For a feature smaller than a pixel, the apparent density is averaged over the image voxel and therefore the signal for that image voxel is reduced. This is called a partial volume effect. Although the signal is reduced by the partial volume effect, the feature may still be detected. This is a significant point about the application of computed tomography because very often relatively large image voxels (compared to very fine discontinuities) may be used — the very small features are still detected but not necessarily resolved.

TABLE 2. Computed tomography contrast ratio calculation.

Parameter	Symbol	Quantification
Object diameter	D	150 mm (6.0 in.)
Attenuation coefficient	μ	0.24 cm ⁻¹
Beam width	w	0.08 mm (0.003 in.)
Number of views	v	588
Photon rate	n	10 ⁸ s ⁻¹
Integration time	t	10 ms
Ray spacing	Δp	2 mm (0.08 in.)
Signal to noise ratio	SNR	324
Number of pixels	Z	9
Contrast ratio	CR	0.0062 = 0.62 percent

If the sensor is not in intimate contact with the part, the error will be increased because the proportional ratio is based on the discontinuity height above the sensor plane.

Double Marker Approximate Formula

When the sensor cannot be placed in intimate contact with the object or when the image of the discontinuity is not present on a double exposed radiograph, the double marker approximate technique should be used (see Fig. 17c).

If both markers are thin, neglect their thickness and assume that they represent the top and bottom of the test piece. By measuring the parallax or image shift of each marker, as well as that of the discontinuity, the relative position of the discontinuity between the two surfaces of the test object can be obtained by linear interpolation, using Eqs. 5 to 9.

$$(5) \quad B_1 - B_3 \cong \Delta B_d$$

$$(6) \quad B_2 - B_3 \cong \Delta B_s$$

$$(7) \quad \frac{\Delta B_d}{\Delta B_s} \cong \frac{B_1 - B_3}{B_2 - B_3}$$

$$(8) \quad \frac{H_s}{H} \cong \frac{\Delta B_d}{\Delta B_s}$$

$$(9) \quad H_s \cong H \times \frac{\Delta B_d}{\Delta B_s}$$

where H_s is the height of the discontinuity above the sensor side marker and H is the distance between the source side marker and the sensor side marker.

Listed in Table 2 are the various parallax formulas, the triangulation measurement requirements and the general areas of application for the double-marker, single-marker and rigid formula parallax techniques.

Effects of Discontinuity Geometry on Parallax Accuracy

The effect of discontinuity geometry on the accuracy of parallax calculations is common to all three of these techniques. Calculations typically indicate the center line dimension of the discontinuity above the sensor plane. However, in those cases where the geometry of the discontinuity is not cylindrical or rectilinear, its shape can influence the accuracy and detectability of discontinuities. If the general shape of the discontinuity can be determined by viewing a standard radiograph, proper allowances can be made.

Figure 18 shows three cases where the approximate, average displacement of the discontinuity on the sensor plane can be calculated by using Eq. 10.

$$(10) \quad \text{Parallax shift} = \frac{L \times R}{2}$$

where R and L are indication widths caused by sources 1 and 2 respectively.

If the discontinuity geometry is similar to one of those in Fig. 19, averaging the

TABLE 2. Triangulation measurement requirements.

Formula	Flaw and Marker Shifts (B)	Distance from Source to Sensor (T)	Source Shift (A)	Sensor Separation (K)	Application Notes
Rigid formula	yes	yes	yes	yes	for relatively short distances from source to sensor or where marker placement is difficult where part thickness is unknown or difficult to measure
Approximate formula: source side marker	yes	no	no	yes	also requires that part thickness D_2 plus sensor separation K be known for relatively long distances for situations where sensor side marker placement is difficult
Approximate formula: source side and sensor side markers	yes	no	no	no	also requires that part thickness H be known most accurate approximate formula best for long distances from source to sensor simplifies data retrieval