Standard Test Method for Minimum Detectable Temperature Difference for Thermal Imaging Systems[1]

This standard is issued under the fixed designation E 1311; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the minimum detectable temperature difference (MDTD) capability of a compound observer-thermal imaging system as a function of the angle subtended by the target.

1.2 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 1316 Terminology for Nondestructive Examinations[2]

3. Terminology

3.1 *Definitions:*

3.1.1 *differential blackbody*—an apparatus for establishing two parallel isothermal planar zones of different temperatures, and with effective emissivities of 1.0.

3.1.2 *field of view (FOV)*—the shape and angular dimensions of the cone or the pyramid that define the object space imaged by the system; for example, rectangular, 4-deg wide by 3-deg high.

3.1.2.1 *Discussion*—The size of the field of view is customarily expressed in units of degrees.

3.1.3 See also Terminology E 1316.

4. Summary of Test Method

4.1 A standard circular target is used in conjunction with a differential blackbody that can establish one blackbody isothermal temperature for the target and another blackbody isothermal temperature for the background by which the target is framed. The target, at an undisclosed orientation, is imaged onto the monochrome video monitor of a thermal imaging system whence the image may be viewed by an observer. The temperature difference between the target and the background, initially zero, is increased incrementally until the observer, in a limited duration, can just distinguish the target. This critical temperature difference is the MDTD.

NOTE 1—Observers must have good eyesight and be familiar with viewing thermal imagery.

4.2 The temperature distributions of each target and its background are measured remotely at the critical temperature difference that defines the MDTD.

4.3 The background temperature and the angular subtense for each target are specified together with the measured value of MDTD. The (fixed) field of view included by the background is also specified.

4.4 The probability of detection is specified together with the reported value of MDTD.

5. Significance and Use

5.1 This test method gives a measure of a thermal imaging system's effectiveness for detecting a small spot within a large background. Thus, it relates to the detection of small material defects such as voids, pits, cracks, inclusions, and occlusions.

5.2 MDTD values provide estimates of detection capability that may be used to compare one system with another. (Lower MDTD values indicate better detection capability.)

NOTE 2—Test values obtained under idealized laboratory conditions may or may not correlate directly with service performance.

6. Apparatus

6.1 The apparatus consists of the following:

6.1.1 *Target Plates*, containing single or multiple circular targets of area(s) not greater than 5 % of the combined areas of target and background (that is, FOV area), and with the distance from the center of the target to the center of the FOV equal to one third of the height or the diameter of the FOV. See Fig. 1.

NOTE 3—A target plate may be fabricated by cutting one or more circular apertures in a metal plate of high thermal conductivity, such as aluminum, and coating with black paint of emissivity greater than 0.95. In this case an aperture would constitute a target, and the coated metal surrounding the target and within the field of view of the thermal imaging system would constitute the target's background.

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[1] This test method is under the jurisdiction of ASTM Committee E-7 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.10 on Emerging NDT Methods.

Current edition approved Oct. 27, 1989. Published January 1990.

[2] *Annual Book of ASTM Standards*, Vol 03.03.

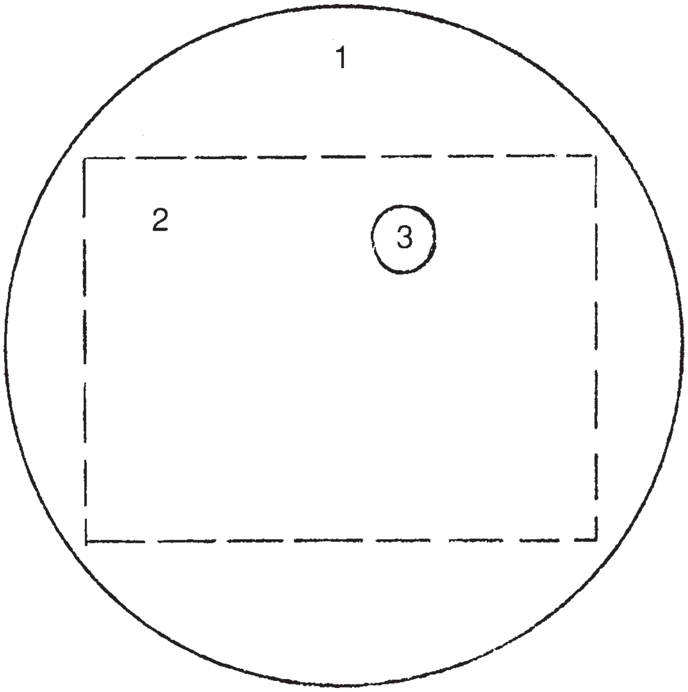

FIG. 1 Schematic Showing 1. Target Plate; 2. FOV; and 3. Target

6.1.2 *Facility*, for mounting target plates and varying the orientation of any given target through 360°.

6.1.3 *Differential Blackbody*, controllable to within 0.1°C and stable over the test period to within 0.1°C.

6.1.4 *Infrared Spot Radiometer*, calibrated with the aid of a blackbody source to an uncertainty not exceeding 0.1°C.

7. Procedure

7.1 Mount a target plate and orient the target in correspondence with some integral hour marking on an imaginary clock. Do not divulge the orientation to the observer.

NOTE 4—Only one observer at a time is to be present during the testing.

7.2 Optimally focus the thermal imaging system directly on the target or on an optical projection of the target.

7.3 Adjust the thermal imaging system for quasi-linear operation.

7.4 Adjust the monochrome video monitor controls so that the presence of noise is barely perceivable by the observer.

7.5 Make the display luminance and the laboratory ambient luminance mutually suitable for visual acuity and viewing comfort.

7.6 Advise the observer that a visible spot will eventually appear in the monitor's display. Instruct him to signal when he can perceive the spot and to cite its orientation relative to the 12 h of a clock; for example, 1 o'clock, 2 o'clock, 3 o'clock, etc. Refrain from further conversation during the test that could conceivably influence or bias the observer.

7.7 Set ΔT (the temperature of the target minus the nominal temperature of the background) equal to zero.

7.8 Increase ΔT in positive increments not exceeding 0.1°C every 60 s or until the observer signals. If the identification is incorrect, continue as before.

NOTE 5—To increase ΔT it is customary to fix the background temperature and raise the target temperature.

7.9 If the observer correctly identifies the orientation of the spot, record the diameter of the target, the diameter or the height and width of the FOV, and the observation distance normal to the target plate.

7.10 Measure the temperature distribution of the target and the target background with an infrared spot radiometer replacing the thermal imaging system. The target shall be measured in at least three locations, uniformly spaced. The background shall be measured at two zones: (1) adjacent to the target (that is, zone 1); (2) beyond zone 1 (that is, zone 2). The measurements in each zone shall be uniformly distributed, with the number of zone 2 measurements equal to twice that of zone 1 (except for the special case of 7.12).

7.11 Calculate the mean temperature, T, of the target. Calculate the weighted average, T_B, of the target background, in accordance with 8.3. Provisionally, $\Delta T = T - T_B$ is the MDTD. Record ΔT and T_B.

7.12 If the target size and the field of view of the spot radiometer are comparable, make double the number of zone 2 measurements, in pairs consisting of two adjacent locations. Compare adjacent temperature readings; the difference between any two adjacent readings must be less than the MDTD. Otherwise the MDTD test results are unacceptable for this particular target size.

NOTE 6—This criterion is intended to guard against spurious spots, that is, false targets.

7.13 Replace the target with another of different size. Randomly orient it in accordance with 7.1 and repeat the test (7.2 through 7.12).

7.14 Repeat step 7.13 one or more times.

7.15 Repeat the entire test (7.1 through 7.14) with a different observer.

7.16 Repeat step 7.15 one or more times.

8. Calculations

8.1 Calculate the angular subtenses for rectangular FOVs as follows:

$$\begin{aligned} \theta_w &= \tan^{-1}(W/R)\,[\text{deg}],\text{ or} \\ &= 10^3 W/R\,[\text{mrad}]; \\ \theta_h &= \tan^{-1}(H/R)\,[\text{deg}],\text{ or} \\ &= 10^3\, H/R\,[\text{mrad}], \end{aligned} \tag{1}$$

where:

W = width of FOV,
R = observation distance normal to centerpoint of FOV,
H = height of FOV,
$R >> W$, and
$R >> H$.

NOTE 7—θ_w may be referred to as the horizontal field of view, and denoted HFOV; θ_h may be referred to as the vertical field of view, and denoted VFOV.

8.2 Calculate the angular subtenses for circular FOVs and targets as follows:

$$\theta = \tan^{-1}(D/R)\,[\text{deg}],\text{or} \tag{2}$$

$$= 10^3\, D/R\ [\text{mrad}],$$

where:
D = diameter of circular FOV or target, as appropriate,
R = observation distance normal to centerpoint of FOV or of target, as appropriate, and

$R >> D$.

8.3 Calculate the weighted average, T_B, of the target background as follows:

$$T_B = \frac{6\sum^{m} x_i + \sum^{n} y_j}{6m + n} \tag{3}$$

where:
x_i = temperature measurement in zone 1, i = 1, 2, ... m,
y_j = temperature measurement in zone 2, j = 1, 2, ... n,
m = number of zone 1 temperature measurements,
n = number of zone 2 temperature measurements,
$\sum^{m} x_i$ = sum of all zone 1 temperature measurements, and
$\sum^{n} y_j$ = sum of all zone 2 temperature measurements.

NOTE 8—Seventy-five percent of T_B is weighted in the vicinity of the target.

8.4 Calculate the probability of detection as shown by the following illustration:

8.4.1 For a given target size, the MDTD results obtained with three different observers are 0.5°C, 0.6°C, 1.0°C. The observer who detected 0.5°C would also be capable of detecting 0.6°C and 1.0°C. Similarly the observer who detected 0.6°C would also be capable of detecting 1.0°C. Hence, the respective probabilities of detection are: for 0.5°C, ⅓ = 33 %; for 0.6°C, ⅔ = 67 %; for 1.0°C, 3⁄3 = 100 %.

9. Report

9.1 Report the following information:

9.1.1 Target angular subtense,

9.1.2 Observation distance to target,

9.1.3 FOV,

9.1.4 MDTD,

9.1.5 (Weighted) background temperature, and

9.1.6 Probability of detection.

9.2 MDTD values should relate to a probability of detection of at least 50 %.

9.3 When comparing different systems, different targets, or different angular subtenses, only a single probability of detection should be used throughout.

NOTE 9—A plot of MDTD versus target angular subtense is a convenient form for reporting the data for a given system or a given target.

10. Precision and Bias

10.1 *Precision*—Insufficient data are available upon which to formulate a precision statement. Notwithstanding, owing to the partially subjective nature of the test, repeatability and reproducibility are apt to be poor and MDTD differences less than 0.2°C are considered to be insignificant.

10.2 *Bias*—The procedure set forth in this test method for measuring the minimum detectable temperature difference for thermal imaging systems has no bias because the minimum detectable temperature difference can be defined only in terms of a test method.

11. Keywords

11.1 infrared imaging systems; minimum detectable temperature difference; nondestructive testing; thermal imaging systems; thermography; infrared