Standard Test Methods for
Flexivity of Thermostat Metals[1]

1. Scope

1.1 These test methods cover the determination of flexivity (a measure of thermal deflection rate or deflection temperature characteristics) of thermostat metals.

1.1.1 *Test Method A*—Tested in the form of flat strip 0.015 in. (0.38 mm) or over in thickness.

1.1.2 *Test Method B*—Tested in the form of spiral coils less than 0.012 in. in thickness.

1.2 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to become familiar with all hazards including those identified in the appropriate Material Safety Data Sheet (MSDS) for this product/material as provided by the manufacturer, to establish appropriate safety and health practices, and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

B389 Test Method for Thermal Deflection Rate of Spiral and Helical Coils of Thermostat Metal

3. Terminology

3.1 *Definitions:*

3.1.1 *thermostat metal, n*—a composite material in the form of sheet or strip comprising two or more metallic layers of differing coefficients of thermal expansion, such that the radius of curvature of the composite changes with temperature change.

3.1.2 *flexivity (F), n*—the change of curvature of the longitudinal center line of the specimen per unit temperature change for unit thickness, given by the following equation:

$$F = t \frac{(1/R_2) - (1/R_1)}{T_2 - T_1} \qquad (1)$$

To determine the flexivity between any two temperatures, T_1 and T_2, it is necessary to measure the curvature $1/R_1$ and $1/R_2$ at temperature T_1 and T_2, respectively. To find the curvature at either temperature (Fig. 1 and Fig. 2), measure the distance D. The curvature is given by the following equation:

$$1/R = 8D/(Q^2 + 4Dt + 4D^2) \qquad (2)$$

where:
R = radius of curvature of the longitudinal center line of the specimen, in. (mm),
t = thickness of test specimen, in. (mm),
Q = distance between support points, in. (mm), and
D = for point support (simply supported beam), = perpendicular distance between the longitudinal center lines of the lower surface of the specimen midway between the point supports and the straight line joining the support points, in. (mm).

4. Significance and Use

4.1 These test methods are used for determining response to temperature change or flexivity of thermostat metal. The flexivity is calculated from the temperatures, dimensions of specimen, and the relative movement of the specimen. The simple beam method (Method A) is the method for certification. Any use of the spiral coil method (Method B) is to be mutually agreed upon between the user and supplier.

TEST METHOD A—FLAT STRIPS

5. Apparatus

5.1 *Specimen Carrier,* provided with two conical supports for locating the specimen. The test length (that is, the distance between the point of contact of the specimen with one support and the point of contact of the specimen with the other support) shall be known to within ±0.005 in. (0.13 mm), and the line of plane passing through the points of contact shall be horizontal. The specimen carrier and supports shall hold the specimen without constraint so that the curvature, due to its deflection,
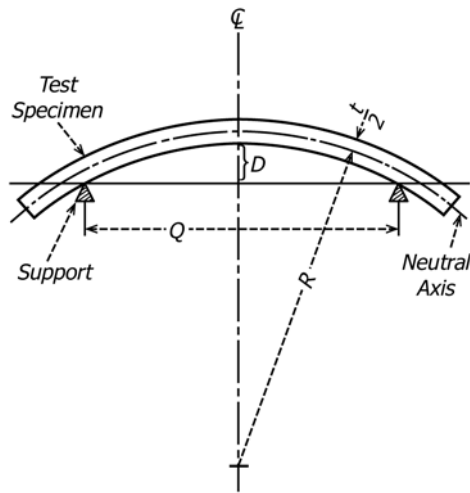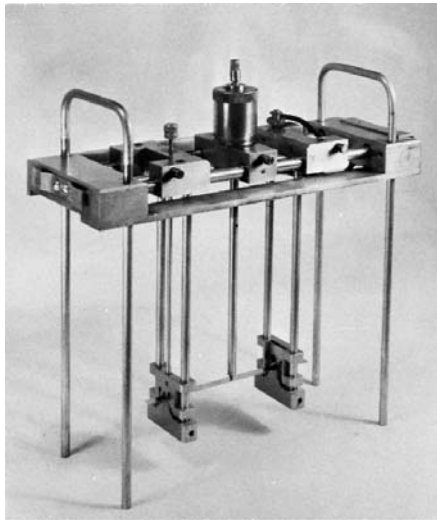
FIG. 1 Test for Flexivity of Thermostat Metals

FIG. 2 Typical Apparatus Design

the points of support and along the vertical line intersecting the line joining the points of support. Such means may comprise a transmission rod disposed with its axis vertical and terminating in a point or knife-edge, which shall engage the specimen midway between the points of contact with the supports.

5.5.1 The transmission rod shall be mounted in such a manner that it is free to move in the direction of its axis. The rod shall bear at its free end an index suitable for microscopical observation, or else an electrical contact with which a micrometer will permit the changes of the deflection of specimen to be accurately observed. Alternatively, the deflection of the midpoint of the specimen may be directly observed by optical means whose line of sight is horizontal and passes through the vertical line through the midpoint of the specimen. A micrometer screw with extended spindle making direct contact with the specimen may be used. In this case, electrical means shall be provided that will indicate contact without significant disturbance of the specimen. The measurement of the position of the midpoint of the test specimen shall be of such accuracy that the individual positions at the test temperatures shall be known to within ±0.0002 in. (0.005 mm).

5.5.2 If a transmission rod is used, it and any attached parts shall be of such weight or so counterweighted that they will not cause a deflection greater than 1 % of the maximum to be produced by the action of the thermostat metal alone. When free, the thermostat metal assumed very nearly a circular curvature. Concentrated loading at the center of the specimen will cause the curvature to be other than circular and may cause significant errors in the evaluation of flexivity. The location of the line passing through the points of contact between specimen and supports shall be known, with reference to the scale of the micrometer, to within ±0.002 in. (0.05 mm).

5.6 All metallic components of the flexivity apparatus should be made of very low coefficient of thermal expansion components. The recommended material is Invar.[3]

6. Test Specimens

6.1 The test specimen shall be in the form of a strip that displays no apparent initial irregularity of curvature.

6.2 The maximum thickness shall not be greater than the minimum thickness by more than 1 % of the latter.

6.3 The width shall be related to the thickness in accordance with Fig. 3. Preferred widths are to be used whenever possible. The maximum width shall not exceed the minimum width by more than 2 % of the latter.

6.4 The length shall be such as to allow a distance between supports that bears the relation to the thickness in accordance with Table 1 and to allow a distance beyond the supports not less than the width.

6.5 The thickness of the specimen shall be determined within ±0.0001 in. (0.002 mm) by means of a screw micrometer or an equivalent method.

6.5.1 For specimens less than 0.050 in. (1.27 mm) in thickness, special precautions are necessary, such as the use of

will follow a vertical plane passing through the line joining the points of contact between specimen and supports. Suitable means shall be used to ensure test length.

5.2 *Micrometer*—traveling microscope, or equivalent device, so connected to the specimen carrier that expansion during heating of the carrier or connecting parts will not cause appreciable displacement of the measuring device with respect to the supports.

5.3 *Bath*—A stirred liquid bath or uniformly heated enclosure in which the specimen carrier, together with adjustable electric heating source is placed. The specimen needs to be maintained at the desired temperatures, with a variation in temperature throughout the gage length of the specimen not to exceed 0.5 % of the temperature range used in the test.

5.4 *Temperature Measuring Apparatus,* of such accuracy that the individual temperatures shall be known to within ±0.5°F (0.3°C).

5.5 *Deflection Index*—Means shall be provided for measuring the deflection of the specimen at a point midway between

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[3] Invar is a registered trademark of CRS Holding, a subsidiary of Carpenter Technologies.
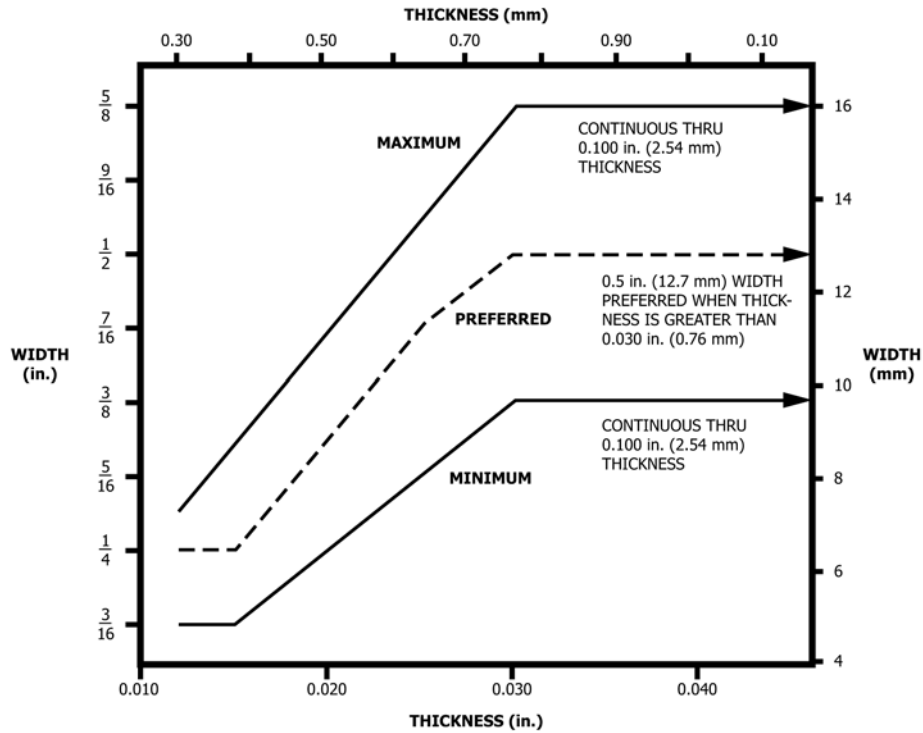
FIG. 3 Width of Test Specimen

TABLE 1 Gage Length of Test Specimen (Test Method A)

Specimen Thickness		Gage Length	
in.	mm	in.	mm
0.015 to 0.0199, incl	0.38 to 0.509, incl	2½ ± ½	63.5 ± 12.7
0.020 to 0.0249, incl	0.51 to 0.639, incl	3 ± ½	76.2 ± 12.7
0.025 to 0.0299, incl	0.64 to 0.759, incl	3½ ± ½	88.9 ± 12.7
0.030 to 0.0349, incl	0.76 to 0.889, incl	4 ± ½	101.6 ± 12.7
0.035 to 0.0449, incl	0.89 to 1.139, incl	4½ ± ½	114.3 ± 12.7
0.045 to 0.100, incl	1.14 to 2.54, incl	5 ± ½	127.0 ± 12.7

a micrometer reading directly to 0.0001 in. (0.002 mm). Suitable optical methods may also be used.

6.5.2 The average thickness may be calculated from measurements of length, average width, weight, and density. When the density is unknown, it may be determined by weighing a sample of at least 10 g first in air and then in water. The density in grams per cubic centimetre is equivalent to the weight in air divided by the loss of weight due to submergence in water. The temperature of the water shall be approximately the same as that of the balance room to avoid errors due to convection currents. For the accuracy required, no corrections are necessary for the temperature of the water or for the buoyancy of the air. However, care shall be exercised to remove all air bubbles from the sample when weighing it in water and to avoid the presence of grease or other films on the surface of the water. To this end it is recommended that after a preliminary cleaning to remove obvious dirt, the sample be attached to a fine wire to be used later in suspending it while weighing and thoroughly rinsed, first in ether, then alcohol and finally water, before immersing in the water to be used for weighing.

7. Preparation of Test Specimen

7.1 After being roughly cut or sheared from the sample, finish the test specimen to size by careful machining or filing. Remove the amount of material extending a distance not less than twice the thickness along each edge of the specimen, to eliminate material damaged by preliminary shaping. Slit edges with a minimum of burr may also be used.

7.2 When the specimen has been finished to size, make any necessary reference marks (by such means as a sharp drill, scribing tool, or milling cutter). Determine and record the relative locations of the reference marks. Do not use center punches or similar means because of the distortion produced.

7.3 It is recommended that the grain run along the length of the specimen.

8. Procedure

8.1 *Stabilization*—After all preparatory work has been completed, subject the test specimen to a stabilizing heat treatment to relieve internal stresses. This treatment may consist of heating the specimen, while free to bend, for a prescribed time and temperature. The details of the stabilizing procedure will depend upon the characteristics of the thermostat metal being tested and shall be as mutually agreed upon between the manufacturer and the purchaser.

8.2 *Test Routine*—Mount the specimen on the support on the specimen table. With the transmission rod in place take a zero reading at room temperature. Apply slight mechanical pressure and then remove the rod at a point near the center of the specimen. If appreciable zero shift is apparent with repeated applications of pressure, determine the cause and correct before proceeding with the test.

8.3 When satisfactory initial conditions have been established, make observations of deflection and temperature at low temperature and record the results.

8.4 Adjust the temperature of the specimen to the high value desired. Measure and record the temperature of the specimen at points on or near the center and ends after sufficient time for stabilization.

8.5 Measure and record the deflection.

8.6 Remeasure and record the temperature measurements as described in 6.4. If significant discrepancies of temperature or its distribution are found, correct them and again measure and record the deflection.

8.7 After having secured satisfactory temperature measurements and corresponding deflection data, establish the next chosen temperature and follow the preceding routine over the agreed upon range of temperatures.

8.8 In all cases, make a final set of measurements at or near room temperature to determine whether or not there has been permanent distortion or any mechanical incident that would prevent determination of flexivity within the desired limits of accuracy. If such is evident, repeat the test under one of the following conditions as agreed upon by the manufacturer and the purchaser.

8.8.1 Test the same specimen over the same temperature range and over a different temperature range.

8.8.2 Test another specimen over the same temperature range and over a different temperature range.

9. Calculation

9.1 For the calculation, see 3.1.2, Eq 1 and Eq 2.

10. Report

10.1 The report shall include the following:

10.1.1 Type of thermostat metal,

10.1.2 Dimensions of specimen,

10.1.3 Temperature and type of stabilizing heat treatment,

10.1.4 Temperature range of test, and

10.1.5 Flexivity.

11. Precision and Bias

11.1 Cumulative errors in the measurement of active length, temperature, thickness, and deflection positions can produce discrepancies between flexivity determinations on the same test specimen. Table 2 and Table 3 tabulate cumulative errors using a statistical approach for various sample sizes, flexivities, and temperature differences as percent at one standard deviation. Bias was not detected in round-robin measurements.

TABLE 2 Cumulative Errors in Flexivity Determination of Flat Strips (Test Method A)

NOTE 1—Interpolate for values not given in Table 2.

Flexivity	t		Q		One Standard Deviation Error in Flexivity, ± %		
in./in.°F (mm/mm°C)	in.	(mm)	in.	(mm)	ΔT = 100°F (55.5°C)	ΔT = 200°F (111.0°C)	ΔT = 300°F (166.5°C)
High flexivity samples typically							
21 × 10⁻⁶ (37.8 × 10⁻⁶)	0.100	(2.54)	5	(127.0)	0.82	0.44	0.32
	0.090	(2.29)	5	(127.0)	0.80	0.43	0.32
	0.080	(2.03)	5	(127.0)	0.79	0.43	0.32
	0.070	(1.78)	5	(127.0)	0.78	0.43	0.32
	0.060	(1.52)	5	(127.0)	0.78	0.43	0.34
	0.050	(1.27)	5	(127.0)	0.77	0.44	0.35
	0.040	(1.02)	4½	(114.3)	0.79	0.47	0.38
	0.030	(0.76)	4	(101.6)	0.82	0.52	0.45
	0.020	(0.51)	3	(76.2)	0.92	0.66	0.61
	0.015	(0.38)	2½	(63.5)	1.04	0.81	0.77
	0.012	(0.30)	2	(50.8)	1.18	0.98	0.94
Medium flexivity samples typically							
15 × 10⁻⁶ (27 × 10⁻⁶)	0.100	(2.54)	5	(127.0)	1.01	0.52	0.37
	0.090	(2.29)	5	(127.0)	0.96	0.50	0.36
	0.080	(2.03)	5	(127.0)	0.92	0.49	0.36
	0.070	(1.78)	5	(127.0)	0.88	0.47	0.35
	0.060	(1.52)	5	(127.0)	0.85	0.47	0.36
	0.050	(1.27)	5	(127.0)	0.83	0.46	0.36
	0.040	(1.02)	4½	(114.3)	0.84	0.49	0.40
	0.030	(0.76)	4	(101.6)	0.87	0.54	0.46
	0.020	(0.51)	3	(76.2)	0.98	0.68	0.62
	0.015	(0.38)	2½	(63.5)	1.10	0.83	0.77
	0.012	(0.30)	2	(50.8)	1.26	1.00	0.95
Low flexivity samples typically							
7 × 10⁻⁶ (12.6 × 10⁻⁶)	0.100	(2.54)	5	(127.0)	1.48	0.76	0.52
	0.090	(2.29)	5	(127.0)	1.37	0.70	0.49
	0.080	(2.03)	5	(127.0)	1.27	0.65	0.46
	0.070	(1.78)	5	(127.0)	1.17	0.61	0.43
	0.060	(1.52)	5	(127.0)	1.07	0.57	0.42
	0.050	(1.27)	5	(127.0)	0.99	0.54	0.40
	0.040	(1.02)	4½	(114.3)	1.00	0.56	0.43
	0.030	(0.76)	4	(101.6)	1.00	0.60	0.49
	0.020	(0.51)	3	(76.2)	1.15	0.75	0.65
	0.015	(0.38)	2½	(63.5)	1.28	0.89	0.80
	0.012	(0.30)	2	(50.8)	1.50	1.09	0.99

TABLE 3 Cumulative Errors in Flexivity Determination (Test Method B)

NOTE 1—Interpolate for values not given in Table 4.

Flexivity		t		Q		One Standard Deviation Error in Flexivity, ± %		
in./in.°F (mm/mm°C)	in.	(mm)	in.	(mm)	ΔT = 100°F (55.5°C)	ΔT = 200°F (111.0°C)	ΔT = 300°F (166.5°C)	
High flexivity samples typically								
21×10^{-6} (37.8×10^{-6})	0.0119	(0.302)	12	(305)	1.13	0.93	0.89	
	0.010	(0.254)	12	(305)	1.25	1.07	1.04	
	0.008	(0.203)	10	(254)	1.46	1.31	1.28	
	0.006	(0.152)	10	(254)	1.82	1.71	1.69	
	0.005	(0.127)	10	(254)	2.13	2.04	2.02	
	0.004	(0.102)	8	(203)	2.61	2.54	2.52	
Medium flexivity samples typically								
15×10^{-6} (27×10^{-6})	0.0119	(0.302)	12	(305)	1.18	0.94	0.89	
	0.010	(0.254)	12	(305)	1.28	1.08	1.04	
	0.008	(0.203)	10	(254)	1.40	1.32	1.29	
	0.006	(0.152)	10	(254)	1.84	1.71	1.69	
	0.005	(0.127)	10	(254)	2.14	2.04	2.02	
	0.004	(0.102)	8	(203)	2.62	2.54	2.52	
Low flexivity samples typically								
7×10^{-6} (12.6×10^{-6})	0.0119	(0.302)	12	(305)	1.35	1.00	0.92	
	0.010	(0.254)	12	(305)	1.39	1.12	1.06	
	0.008	(0.203)	10	(254)	1.57	1.35	1.30	
	0.006	(0.152)	10	(254)	1.87	1.73	1.70	
	0.005	(0.127)	10	(254)	2.16	2.04	2.02	
	0.004	(0.102)	8	(203)	2.64	2.54	2.52	

TEST METHOD B—SPIRAL COILS

12. Apparatus

12.1 This test method shall be conducted in accordance with Test Method B389.

13. Test Specimens

13.1 The test specimen shall be in the form of a spiral coil which displays no apparent irregularities. Wind the coil with the low expanding side outside, and inside diameter of ⁹⁄₃₂ in. (7.1 mm), an inside tab length of ³⁄₁₆ in. (4.8 mm), an outside radius of ¹²⁄₃₂ in. (11.9 mm), and no outer tab.

13.2 The maximum thickness shall not be greater than the minimum thickness by more than 1 % of the latter.

13.3 The thickness of the specimen shall be determined within ±0.0001 in. (0.002 mm) by means of a screw micrometer or equivalent method.

13.4 The active length, that portion of the coil which is free to deflect when subjected to a change in temperature, and does not include that portion of the coil which is used for mounting shall be known to within ±¹⁄₆₄ in. (0.4 mm).

13.5 The width and active length shall be related to the thickness in accordance with Table 4.

13.6 The required width shall be produced by slitting and the edges shall have a minimum of burrs.

14. Procedure

14.1 Conduct this test method in accordance with Test Method B389.

TABLE 4 Width and Length of Test Specimen (Test Method B)

Specimen Thickness		Width		Active Length	
in.	mm	in.	mm	in.	mm
0.004	0.102	⁷⁄₆₄	2.8	8	203
0.005	0.127	¹⁄₈	3.2	10	254
0.006	0.152	¹⁄₈	3.2	10	254
0.007	0.178	⁹⁄₆₄	3.6	10	254
0.008	0.203	⁹⁄₆₄	3.6	10	254
0.009	0.229	⁵⁄₃₂	4.0	10	254
0.010	0.254	³⁄₁₆	4.8	12	305
0.011	0.280	³⁄₁₆	4.8	12	305
0.0119	0.302	³⁄₁₆	4.8	12	305

15. Calculation

15.1 The flexivity shall be determined in accordance with the following equation.

$$F = 0.0154 \, Dt/L \qquad (3)$$

where:
F = flexivity, in./in.°F (mm/mm°C),
D = thermal deflection rate of test specimen, angular degree/°F, (angular degree/°C),
t = thickness of test specimen, in. (mm), and
L = active length of test specimen, in. (mm).

16. Report

16.1 See Section 10.

17. Precision and Bias

17.1 See Section 11.

18. Keywords

18.1 coefficient of thermal expansion; flexivity; micrometer; temperature; thermostat metal

APPENDIXES

(Nonmandatory Information)

X1. SAMPLE CALCULATION FOR FLEXIVITY (FLAT STRIPS, TEST METHOD A)

X1.1 *Test Information:*

Dimensions of Specimen:
  Thickness, 0.0202 in. (0.513 mm)
  Width, 0.345 in. (8.76 mm)
  Total length, 4.25 in. (108 mm)
  Length between point supports, 300 in. (76 mm)
Test Data:
  Temperature:
  T_1 = 98.2°F (36.8°C)
  T_2 = 202.8°F ((94.9°C)
Distance:
  D_1 = 0.0322 in. (0.818 mm)
  D_2 = 0.0546 in. (1.387 mm)

X1.2 *Calculations:*

From Eq 1 and Eq 2:

$$F = \frac{8t}{T_2 - T_1} \times \left[\frac{D_2}{(Q^2 + 4D_2 t + 4D_2{}^2)} - \frac{D_1}{(Q^2 + 4D_1 t + 4D_1{}^2)} \right] \tag{X1.1}$$

For measurements in inches and degrees Fahrenheit, combine as follows:

$$F = \frac{8(0.0202)}{202.8 - 98.2}$$
$$\times \left(\frac{0.0546}{3.00^2 + 4(0.0546)(0.0202) + 4(0.0546)^2} - \frac{0.0322}{3.00^2 + 4(-0.0322)(0.0202) + 4(-0.0322)^2} \right) \tag{X1.2}$$

For measurements in millimetres and degrees Celsius:

$$F = \frac{8(0.513)}{94.9 - 36.8} \times \left(\frac{1.387}{(76.0)^2 + 4(1.387)(0.513) + 4(1.387)^2} - \frac{0.818}{(76.0)^2 + 4(-0.818)(0.513) + 4(-0.818)^2} \right) \tag{X1.3}$$

$$F = 0.00002693/°C$$

X2. SAMPLE CALCULATION FOR FLEXIVITY (SPIRAL COIL, TEST METHOD B)

X2.1 *Test Information:*

Dimensions of Specimen:
  Thickness, 0.0109 in. (0.277 mm)
  Width, 0.1875 in. (4.76 mm)
  Total length, 12.1875 in. (309.6 mm)
  Active length, 12.00 in. (304.8 mm)

Test Data:
  Temperature:
  T_1 = 51.2°F (10.7°C)
  T_2 = 199.8°F (93.2°C)

Angular Position:
  A_1 = 12.50°
  A_2 = 171.25°

X2.2 *Calculations:*

$$D = (A_2 - A_1)/(T_2 - T_1) \tag{X2.1}$$

where:
D = thermal deflection rate
D = (171.25 − 12.50)/(199.8 − 51.2) = 1.0683 angular deg/°F, when measurements are in degrees Fahrenheit
D = (171.25 − 12.50)/(93.2 − 10.7) = 1.924 angular deg/°C, when measurements are in degrees Celsius
F = 0.0154 Dt/L
   = 0.0154(1.0683)(0.0109)/12
F = 0.00001494/°F, when measurements are in inches and degrees Fahrenheit
F = 0.0154 Dt/L
   = 0.0154(1.924)(0.277)/304.8
F = 0.00002692/°C when measurements are in millimetres and degrees Celsius