Thermostatic Bimetal Designer's Guide

Engineered Materials Solutions
Wickeder Group

Contents

Conversion Tables

Fractions of an inch	Decimals of an inch	Millimeters
1/64	0.0156	0.397
1/32	0.0313	0.794
3/64	0.0469	1.191
1/16	0.0625	1.588
5/64	0.0781	1.984
3/32	0.0938	2.381
7/64	0.1094	2.778
1/8	0.1250	3.175
9/64	0.1406	3.572
5/32	0.1563	3.969
11/64	0.1719	4.366
15/64	0.2344	5.953
17/64	0.2656	6.747
21/64	0.3281	8.334
11/32	0.3438	8.731
25/64	0.3906	9.922
13/32	0.4063	10.319
27/64	0.4219	10.716
7/16	0.4375	11.113
29/64	0.4531	11.509
15/32	0.4688	11.906
31/64	0.4844	12.303
1/2	0.5000	12.700
33/64	0.5156	13.097
17/32	0.5313	13.494
35/64	0.5469	13.891
9/16	0.5625	14.288
37/64	0.5781	14.684
19/32	0.5938	15.081
39/64	0.6094	15.478
5/8	0.6250	15.875
41/64	0.6406	16.272
21/32	0.6563	16.669
43/64	0.6719	17.066
11/16	0.6875	17.463
45/64	0.7031	17.859
23/32	0.7188	18.256
47/64	0.7344	18.653
3/4	0.7500	19.050
49/64	0.7656	19.447
25/32	0.7813	19.844
51/64	0.7969	20.241
13/16	0.8125	20.638
53/64	0.8281	21.034
27/32	0.8438	21.431
55/64	0.8594	21.828
7/8	0.8750	22.225
57/64	0.8906	22.622
29/32	0.9063	23.019
59/64	0.9219	23.416
15/16	0.9375	23.813
61/64	0.9531	24.209
31/32	0.9688	24.606
63/64	0.9844	25.003
1	1.0000	25.400

WEIGHTS AND MEASURES CONVERSION FACTORS					
Change to			Change back		
From Length	to	Multiply by	From Length	to	Multiply by
mm	in	0.03937	in	mm	25.4
cm	in	0.3937	in	cm	2.54
cm	ft	0.03281	ft	cm	30.48
in	m	0.0254	m	in	39.37
Area			Area		
cir mils	sq in	0.0000007854	sq in	cir mils	1,273,240.
cir mils	sq mils	0.7854	sq mils	cir mils	1.2732
cir mils	sq mm	0.0005066	sq mm	cir mils	1,973.53
sq mm	sq in	0.00155	sq in	sq mm	645.16
sq mils	sq in	0.000001	sq in	sq mils	1,000,000.
sq cm	sq in	0.155	sq in	sq cm	6.4516
Volume			Volume		
cm^3	in^3	0.06102	in^3	cm^3	16.387
Specific Heat Capacity			Specific Heat Capacity		
J/g/°C	BTU/lbs/°F	0.239	BTU/lbs/°F	J/g/°C	4.184
Energy			Energy		
joules	gram calories	0.2388	gram calories	joules	4.186
gram calories	BTU	0.003968	BTU	gram calories	252.
joules	BTU	0.000947	BTU	joules	1,055.
Weights			Weights		
oz (troy)	grams	31.11	grams	oz (troy)	.03214
lbs (avdp)	grams	453.59	grams	lbs (avdp)	.002205
oz (troy)	lbs (avdp)	.0686	lbs (avdp)	oz (troy)	14.58
Density			Density		
g/cm^3	lbs/in^3	0.03613	lbs/in^3	g/cm^3	27.68
Electrical Resistivity			Electrical Resistivity		
ohms circ. mil/ft	ohms sq mil/ ft	0.7854	ohms sq mil/ ft	ohms circ. mil/ft	1.273
ohms circ. mil/ft	ohms m	0.001662	ohms m	ohms circ. mil/ft	601.68
Flexivity			Flexivity		
Flexivity	specific deflection	0.9540	specific deflection	Flexivity	1.048
Modulus of Elasticity			Modulus of Elasticity		
Msi	GPa	6.895	GPa	Msi	0.14504
lbs sq in	N/mm^2	0.006895	N/mm^2	lbs sq in	145.04

A History of Solutions

Engineered Materials Solutions, headquartered in Attleboro, MA (USA) with production sites in Hamburg, PA (USA) and Baoying (China) traces its origins back to 1916. We have been manufacturing Clad Materials since our founding company, General Plate Company, was established 100 years ago.

Today we are experts in metallurgically bonding dissimilar metals. At EMS, we produce a variety of “laminated” materials that can offer distinctive properties, where one material alone could not. As part of our specialty product portfolio, EMS produces Thermostatic Bimetal. We are the world’s largest producer of Thermostatic Bimetal, producing more types in strip and parts form, than any other manufacturer worldwide.

Because of its reliability, Thermostatic Bimetal is employed as an economical solution for temperature sensing and control applications in Automotive, Electrical, HVAC, Home Appliance, and a wide range of other industries.

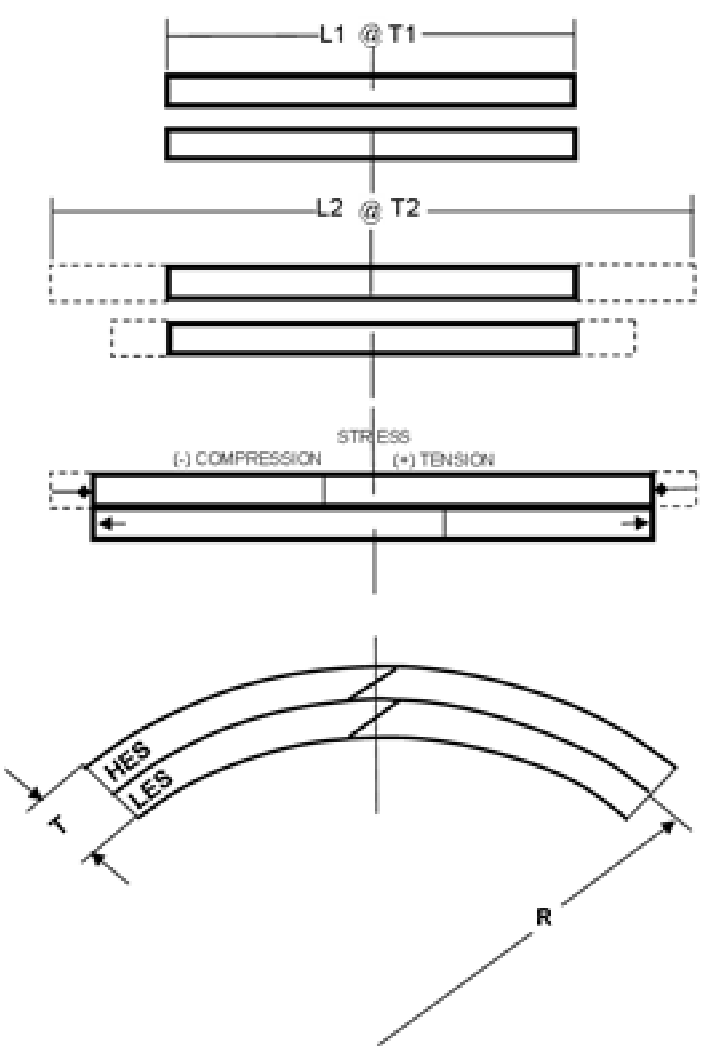
Production of these high performance metals and parts, understanding their innumerable applications and the customized processing parameters critical to their performance, has been at the heart of our business since its inception.

Open the Doors of Design to an Exciting New World of Possibilities

How Thermostatic Bimetal Works

Thermostatic Bimetal is a composite material, usually in the form of a strip or sheet, made up of two or more metallic layers having different coefficients of expansion. When permanently bonded together, these layers cause the material to change its curvature when subjected to a change in temperature. This change of curvature, or bending, in response to temperature change, (flexivity), is a fundamental property of all Thermostatic Bimetals.

If a Thermostatic Bimetal element is initially straight or has an initial uniform curvature, the resulting curvature for uniform temperature change is uniform; that is, a true arc of constant radius is produced.



1. Two metal strips of identical length (at a given temperature) having high and low coefficients of thermal expansion.

2. When the temperature rises, their relative lengths will change.

3. When the strips are bonded together, and the temperature is raised, the high expansion strip will be under compression and the low expansion strip will be under tension.

4. These forces produce a moment which causes the element to bend in a uniform arc.

Thermostatic Bimetal bending is directly proportional to the difference in the coefficient of expansion and the temperature change of the component strips, and inversely proportional to the thickness of the combined strips. The amount of bending is also affected by the ratio of the moduli of elasticity of the two strips and by their thickness ratio.

How It Is Made

A wide variety of alloys are used in the manufacture of Thermostatic Bimetals. The components are joined in a true metallurgical bond made by special techniques. The result is a permanent bond that in many instances exceeds the strength of the separate metals.

Truflex™ Thermostatic Bimetals are rolled to finish gauge on precision mills capable of holding very close tolerances. Intermediate annealing operations are performed in continuous strip annealing furnaces in reducing atmospheres. Pickling, cleaning, and brushing procedures also play an important part in the ultimate quality achieved.

Finishing operations include marking for identification of the material type and/or as identification of the high and low expansion side. The low expansion side is identified as a standard unless otherwise specified by the customer. Finally, the Thermostatic Bimetal is slit and flattened. A cold rolled surface is the standard finish. A uniform matte finish is available as is tension-leveled materials for special applications.

Following these finishing operations, the material undergoes a rigorous inspection to check its physical dimensions, flatness, hardness, electrical resistivity and flexivity.

The EMS Thermostatic Bimetal parts department is equipped with the finest standard and special equipment for producing a variety of parts and assemblies. Spiral and helix coils, flat blades, blanked and pierced members, U-shapes, and other intricate parts are made with exacting care to customers' specifications.

Sizes Available

Thickness: 0.003 to 0.125 inches

Width: 0.020 to 12 inches, in increments of 1/64 inch. As a general rule, the minimum width is three times the thickness.

Length: Strip is furnished in coils or flat cut lengths. Flat cut lengths are available up to 12 feet long. To minimize material waste, flat cut lengths should be ordered in multiples of the part lengths.

Hardness: Since Thermostatic Bimetals are composed of alloys which cannot normally be hardened by heat treating, hardness is developed by cold rolling. The elastic limit is also controlled by cold rolling reduction; a high elastic limit is associated with high hardness. Therefore, a high degree of hardness is desirable in a Thermostatic Bimetal element unless severe forming operations or sharp bends require softer material.

For any given thickness, Thermostatic Bimetal is produced to a standard value of hardness unless otherwise specified by the customer. Softer material can be supplied if the forming or bending operations are too severe for this standard hardness. Rolling and process annealing of all Thermostatic Bimetals are carefully controlled to maintain optimum grain size.

Most Thermostatic Bimetal is used in relatively thin gauge and, because the high and low expansion sides (and sometimes a third intermediate layer) are each only a part of the total cross section, hardness testing should be performed on machines such as Vickers, Tukon, and Knoop which have very light loads and shallow penetration. Even with these instruments, it is difficult to determine accurately the hardness of material having a thickness of only a few thousandths of an inch. Refer to ASTM standard test methods.

Standard Dimensional Tolerances

Strip Thickness					
Standard Total Variation*				Uniformity for Disc Grade**	
In Thickness	mm Thickness	In Tolerance	mm Tolerance	In Tolerance	mm Tolerance
Under 0.005"	Under 0.127	+/-.0003"	+/-.0076	+/- 0.0001”	+/-0.0025
0.005" to 0.0099"	0.127 to 0.253	+/-.00035"	+/-.0089	+/- 0.0001”	+/-0.0025
0.010" to 0.0149"	0.254 to 0.378	+/-.0004"	+/-.0102	+/- 0.00012”	+/-0.0030
0.015" to 0.0199"	0.381 to 0.505	+/-.0005"	+/-.0127	+/- 0.00015”	+/-0.0038
0.020" and over	0.508 and over	+/-2.5%	+/-2.5%	----	----

* The “Total Variation” represents overall gauge variation around specified thickness within a lot and lot-to-lot
**Uniformity is the gauge variation along the length at a fixed location across the width

Standard Dimensional Tolerances

Strip Width			
in Width	mm Width	in Tolerance	mm Tolerance
Up to 0.500"	Up to 12.70	+/-0.003"	+/-0.076
Over 0.5" to 1"	Over 12.70 to 25.4	+/-0.004"	+/-0.102
Over 1" to 3"	Over 25.4 to 76.2	+/-0.008"	+/-0.203
Over 3" to 6"	Over 76.2 to 152.4	+/-0.010"	+/-0.254
Over 6"	Over 152.4	+/-0.030"	+/-0.762

Strip Length

*Material will be supplied in coil form only or maximum 12 ft. cut-to-length

Edgewise camber - 9/32 in. max. in 3 feet (over 0.125" wide)

Edgewise camber is the deviation of a side edge from a straight line. It is measured by placing a 3 foot straight-edge on the concave edge and measuring the distance from the center of the 3 foot straightedge to the strip edge.

Edgewise Camber					
in Strip Width	ft Test Length	in Maximum Camber	mm Strip Width	m Test Length	mm Maximum Camber
Under 0.125"	1	0.03125"	Under 3.175 mm	0.254	0.8
0.125" and Over	3	0.28125"	3.175 mm and Over	1	8.5

Lengthwise flatness = 0.0005/thickness

Maximum in 3 inches at 75° F, where "t" is the thickness in inches. Lengthwise flatness, also known as linear curvature, is measured by using a 3 inch straightedge, laying it up against either the high expansion side or the low expansion side; whichever is concave, and measuring the distance from center of the straightedge to the Thermostatic Bimetal.

Linear Curvature

Inches Material Thickness	Maximum									
	0	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009
0.000"	---	0.500	0.250	0.167	0.125	0.100	0.830	0.720	0.630	0.560
0.010"	0.050	0.045	0.042	0.039	0.036	0.033	0.031	0.029	0.028	0.026
0.020"	0.025	0.024	0.023	0.022	0.021	0.020	0.019	0.018	0.017	0.017
0.030"	0.017	0.016	0.016	0.014	0.014	0.014	0.014	0.014	0.013	0.013
0.040"	0.013	0.012	0.012	0.012	0.011	0.011	0.011	0.011	0.010	0.010
0.050"	0.010	0.010	0.010	0.009	0.009	0.009	0.009	0.009	0.009	0.009
0.060"	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.007	0.007

* Linear curvature is measured in 3 inches @ 75F +/-2 F
* The values are FOR REFERENCE ONLY unless otherwise specified
* The direction of linear curvature shall be high expansion side (HES) concave unless otherwise specified

Cross Curvature

- Shall not exceed the value obtained according to the following relationship as measured at 75°F.
- Direction of cross curvature shall be high expansion side concave unless otherwise specified.

The maximum allowable cross curvature can be calculated using the following equation:

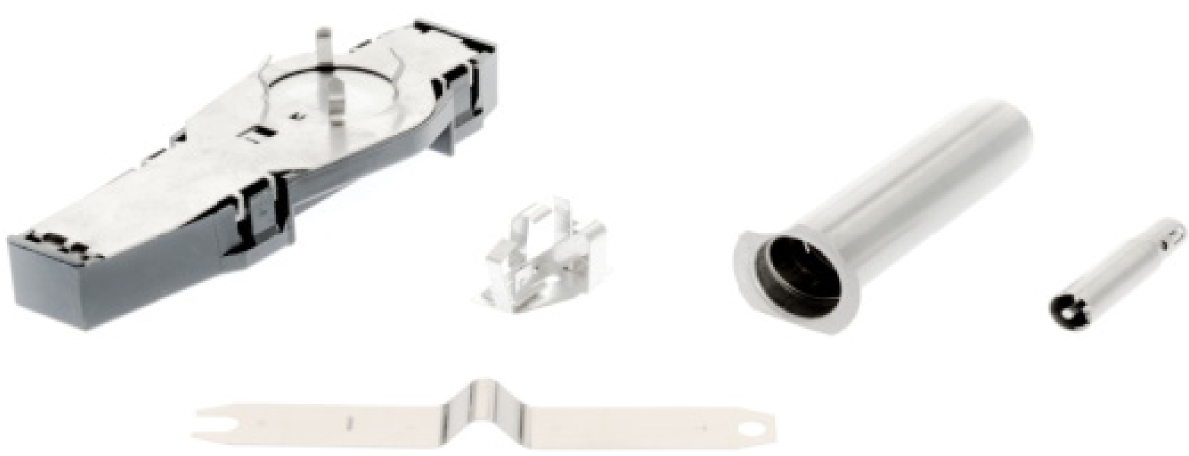
$$H = 0.10t + \frac{(0.00025\ W^2)}{t}$$

where H= chord height in inches
t = material thickness in inches
W = width of stock in inches

Metal Identification		
Type	**Thickness**	**Width**
Chemical Marking	All gauges	All widths
Mechanical Marking	0.012" and thicker	All widths
Engraving	0.040" and thicker	Less than 0.500"

* If not specified by the customer , the low expansion side (LES) is identified by chemical or mechanical marking with the word "Truflex" followed by the metal type designation

Alloy Composition				
High Expansion Alloys (HES)		**Interliners**	**Low Expansion Alloys (LES)**	
A	70 Cu, 30 Zn	Cu	10	36 Ni, Bal Fe
B	22 Ni, 3 Cr, Bal Fe	Fe	11	39 Ni, Bal Fe
C	19.4 Ni, 2.25 Cr, 0.5 C, Bal Fe	Ni	13	32 Ni, 15 Co, 1 Mo, Bal Fe
E	25 Ni, 8.5 Cr, Bal Fe		14	38 Ni, 7 Cr, Bal Fe
G	18 Ni, 11.5 Cr, Bal Fe		15	32 Ni, 1 Co, 1 Mo, Bal Fe
GB	19 Ni, 7 Cr, Bal Fe		20	40 Ni, Bal Fe
J	5 Sn, Bal Cu		30	42 Ni, Bal Fe
LA	20 Ni, 6 Mn, Bal Fe		40	45 Ni, Bal Fe
M	18 Cr, 8 Ni, Bal Fe		50	50 Ni, Bal Fe
N	Nickel		70	17 Cr, Bal Fe
P	72 Mn, 18 Cu, 10 Ni			



Standard Bimetal Materials

Material Type	HES	Center	LES	Material Type	HES	Center	LES
A1*	Alloy A	-	Alloy 10	LA20R10	Alloy LA	Cu	Alloy 10
B1	Alloy B	-	Alloy 10	LA35R10	Alloy LA	Cu	Alloy 10
B11	Alloy B	-	Alloy 11	LA50R10	Alloy LA	Cu	Alloy 10
B2	Alloy B	-	Alloy 20	LA70R10	Alloy LA	Cu	Alloy 10
B3	Alloy B	-	Alloy 30	LA90R10	Alloy LA	Cu	Alloy 10
B100R	Alloy B	Ni	Alloy 10	LA100R10	Alloy LA	Cu	Alloy 10
B125R	Alloy B	Ni	Alloy 10	LA115R10	Alloy LA	Cu	Alloy 10
B150R	Alloy B	Ni	Alloy 10	LA125R10	Alloy LA	C50500	Alloy 10
B175R	Alloy B	Ni	Alloy 10	LA125R	Alloy LA	Ni	Alloy 10
B200R	Alloy B	Ni	Alloy 10	LA150R	Alloy LA	Ni	Alloy 10
B250R	Alloy B	Ni	Alloy 10	LA180R	Alloy LA	Ni	Alloy 10
B300R	Alloy B	Ni	Alloy 10	LA210R	Alloy LA	Ni	Alloy 10
B350R	Alloy B	Ni	Alloy 10	LA300R	Alloy LA	Ni	Alloy 10
B400R	Alloy B	Ni	Alloy 10	LA330R	Alloy LA	Ni	Alloy 10
B100R30	Alloy B	Ni	Alloy 30	LA35R11	Alloy LA	Cu	Alloy 11
BP1	Alloy B	Alloy P	Alloy 10	LA55R20	Alloy LA	Cu	Alloy 20
BP10	Alloy B	Alloy P	Alloy 10	LA3	Alloy LA	-	Alloy 30
BP560R	Alloy B	Alloy P	Alloy 10	LA55R30	Alloy LA	Cu	Alloy 30
C1	Alloy C	-	Alloy 10	M7*	Alloy M	-	Alloy 70
C11	Alloy C	-	Alloy 11	N1*	Alloy N	-	Alloy 10
C3	Alloy C	-	Alloy 30	P30R	Alloy P	Cu	Alloy 10
E1	Alloy E	-	Alloy 10	P35R	Alloy P	Cu	Alloy 10
E3	Alloy E	-	Alloy 30	P50R	Alloy P	Cu	Alloy 10
E4	Alloy E	-	Alloy 40	P70R	Alloy P	Cu	Alloy 10
E5	Alloy E	-	Alloy 50	P90R	Alloy P	Cu	Alloy 10
E70R20	Alloy E	Cu	Alloy 20	P100R	Alloy P	Cu	Alloy 10
F20R	Alloy B	Cu	Alloy 10	P125R	Alloy P	Cu	Alloy 10
F25R	Alloy B	Cu	Alloy 10	P150R	Alloy P	B-Plate	Alloy 10
F30R	Alloy B	Cu	Alloy 10	P175R	Alloy P	C50500	Alloy 10
F35R	Alloy B	Cu	Alloy 10	P250R	Alloy P	C50500	Alloy 10
F40R	Alloy B	Cu	Alloy 10	P300R	Alloy P	Fe	Alloy 10
F50R	Alloy B	Cu	Alloy 10	P350R	Alloy P	Fe	Alloy 10
F60R	Alloy B	Cu	Alloy 10	P500R	Alloy P	Fe-Ni	Alloy 10
F70R	Alloy B	Cu	Alloy 10	P675R	Alloy P	-	Alloy 10
F90R	Alloy B	Cu	Alloy 10	P850R	Alloy P	-	Alloy 10
F100R	Alloy B	Cu	Alloy 10	P30RC	Alloy P/Cu	Cu	Alloy 10
F125R	Alloy B	Cu	Alloy 10	P3	Alloy P	-	Alloy 30
F55R20	Alloy B	Cu	Alloy 20	PJ*	Alloy P	-	Alloy J
G7*	Alloy G	-	Alloy 70	S363	B/SS305	-	SS301/10
GB2	Alloy GB	-	Alloy 20	SB175R	Alloy B	Fe	Alloy 10
GB5	Alloy GB	-	Alloy 50	SB250R	Alloy B	Fe	Alloy 10
GB14	Alloy GB	-	Alloy 14	SB300R	Alloy B	Fe	Alloy 10
J1*	Alloy J	-	Alloy 10	1513*	Alloy 15	-	Alloy 13
J7*	Alloy J	-	Alloy 70				
LA1	Alloy LA	-	Alloy 10				

*Limited Availability

Standard Test Methods

The standard test methods that follow have been established by committee B2.10 of the American Society for Testing and Materials (ASTM). Engineered Materials Solutions has collaborated in the extensive work undertaken to develop these test methods. Their use in Thermostatic Bimetals specifications will help prevent misunderstandings which might arise from the use of other methods.

Test no. Property tested

B63 Resistivity of metallically conducting resistance and contact materials.
B70 Change of resistance with temperature of metallic materials for electrical heating.
B106* Flexivity of Thermostatic Bimetals.
B223* Modulus of elasticity of Thermostatic Bimetals.
B362* Mechanical torque rate of spiral coils of Thermostatic Bimetal.
B388* Specification for Thermostatic Bimetal sheet and strip.
B389* Thermal deflection rate of spiral and helix coils of Thermostatic Bimetal.
B478* Cross curvature of Thermostatic Bimetals.
B753* Standard Specification for Thermostat Component Alloys
E92 Diamond pyramid hardness of metallic materials.

* These are specifically designed to test or list the particular properties of Thermostatic Bimetals.

When changes are made in all ASTM methods, a suffix is added to the basic test method number to indicate the latest revision. To avoid confusion, no suffixes have been listed above; however, in carrying out a test program, the latest revisions of test methods should be used.

If specifications and test procedures not covered by these ASTM methods are to be employed with Truflex™ Thermostatic Bimetals, consult EMS engineers. They will be glad to outline alternate methods. In this way, comparative test results can be obtained and misunderstandings can be avoided.

BASIC THEORY & FUNDAMENTAL CALCULATIONS

RADIUS OF CURVATURE

The following equation describes the flexing of a two-component Thermostatic Bimetal strip:

$$\frac{1}{\rho} = \frac{6(\alpha_2-\alpha_1)(T_1-T_0)(1+m)^2}{t\left[3(1+m)^2+(1+mn)\left(m^2+\frac{1}{mn}\right)\right]} \qquad (1)$$

where

α_1 and α_2	=	temperature coefficients of expansion (expansivities)
E_1 and E_2	=	moduli of elasticity
t_1 and t_2	=	thickness of components
t	=	thickness of strip
ρ	=	radius of curvature of strip
T_0 and T_1	=	temperatures
m	=	t_1/t_2
n	=	E_1/E_2

If the thicknesses of both materials are the same,
$t_1 = t_2$ therefore $m = 1$

then

$$\frac{1}{\rho} = \frac{24(\alpha_2-\alpha_1)(T_1-T_0)}{t\left(14+n+\frac{1}{n}\right)} \qquad (2)$$

Further, if the moduli of elasticity are the same,
$E_1 = E_2$ $n = 1$

then

$$\frac{1}{\rho} = \frac{3}{2}\frac{(\alpha_2-\alpha_1)(T_1-T_0)}{t} \qquad (3)$$

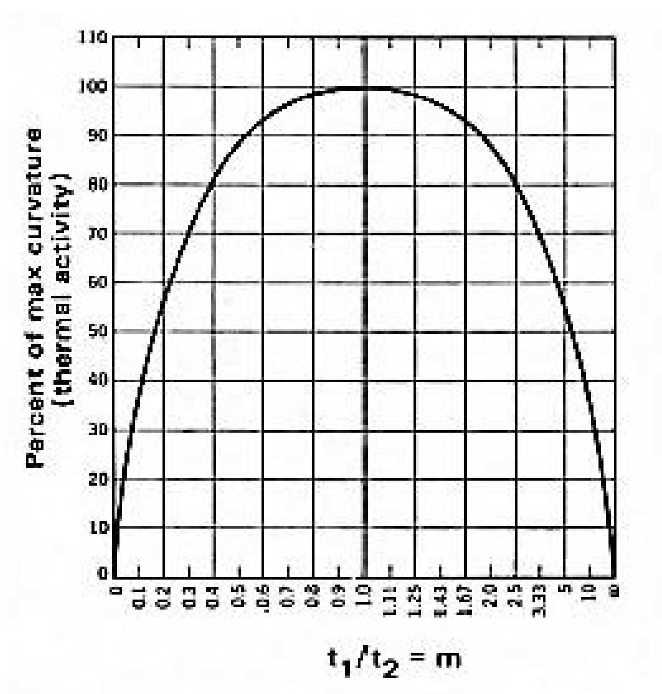
Note that the curvature is directly proportional to the difference in the expansivities and the temperature change, but inversely proportional to the strip thickness. The ratio of thicknesses affects the radius of curvature, with $t_1/t_2 = 1$ as the optimum when the moduli of elasticities are equal. The radius of curvature is also affected by the ratio of moduli of elasticity of the components.

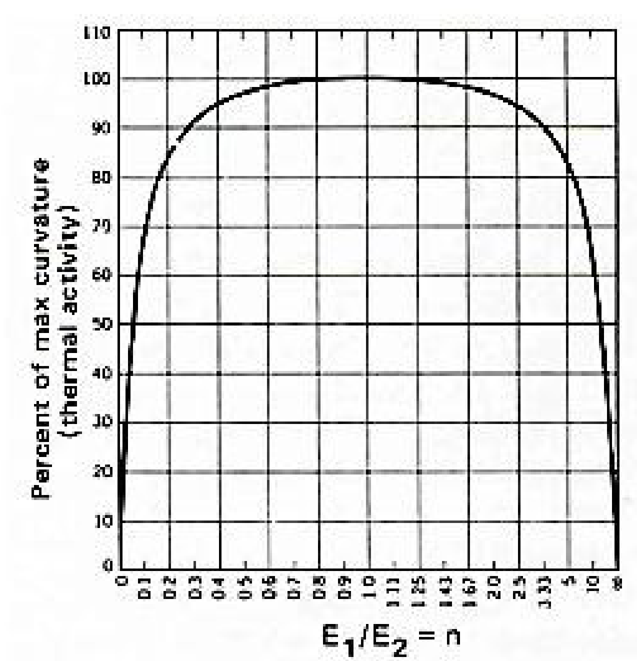
The graph shown illustrates the relationship between the
thickness ratio and the curvature of any two materials, with 100% representing the maximum attainable curvature.

Component thickness ratios can be varied in either direction without seriously affecting thermal activity in the region of maximum curvature. For example, a variation in the ration from 0.5 to 2.0 does not reduce the thermal activity below 88% of maximum obtainable curvature. (In actual practice the ratio is maintained much closer than in this example.

It would be coincidental if the modulus of elasticity were the same for both components. Assuming component thicknesses to be equal, the effect of unequal moduli is illustrated in the following graph.

Thermal activity is less sensitive to variations in the ratios of the moduli of elasticity than to the ratios of the component thicknesses in the region of maximum curvature. Using the same numbers as in the previous example, a change from 0.5 to 2.0 in the ratios of the moduli of elasticity causes only a 3% loss in thermal activity in any Thermostatic Bimetal. This loss of 3 percentage points is compensated for in practice by using a higher percent of the less stiff alloy compared to the stiffer alloy, permitting the Thermostatic Bimetal to attain 100% of maximum curvature and hence, maximum work.





FLEXIVITY AND THERMAL DEFLECTION

Flexivity (F) is the most important property of a Thermostatic Bimetal - it is defined as "the change of curvature of the longitudinal center line of the specimen per unit temperature change for unit thickness" and is given by the following formula, illustrated below:

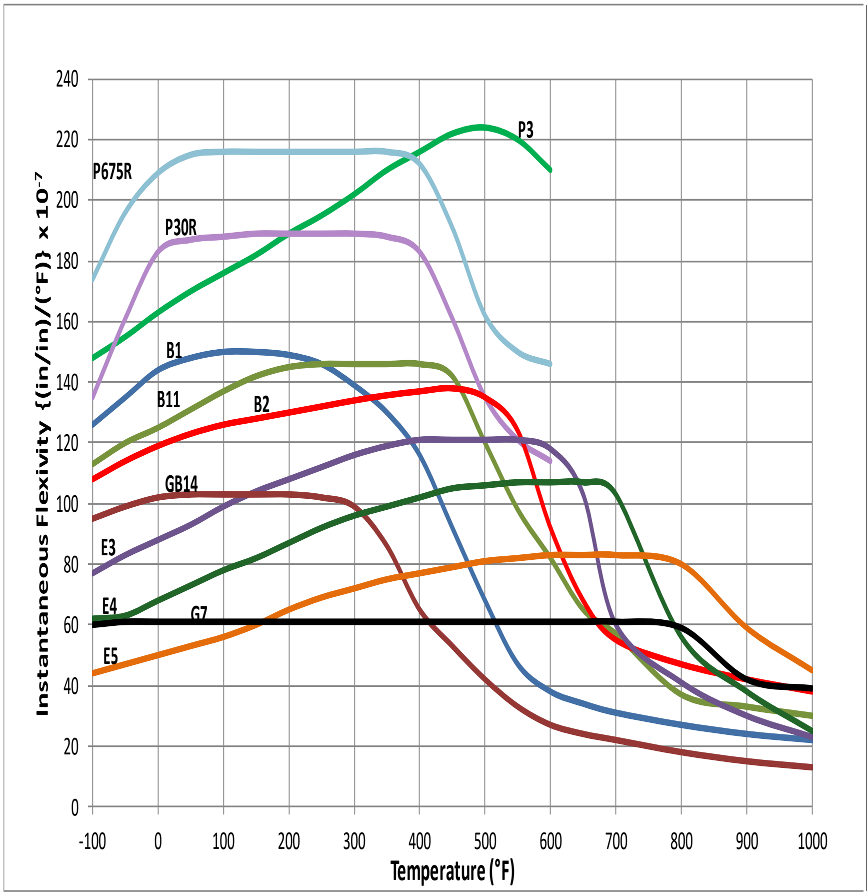
$$F = \frac{\left(\frac{1}{R_2} - \frac{1}{R_1}\right)t}{T_2 - T_1}$$

4

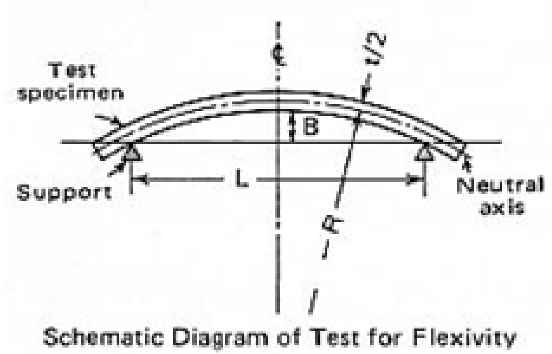
where for a simple beam,

$$\frac{1}{R} = \frac{8B}{L^2 + 4Bt + 4B^2}$$

INSTANTANEOUS FLEXIVITY OF DIFFERENT BIMETAL CLASSES



F	=	flexivity
R_2 and R_1	=	radii of curvature, in.
T_2 and T_1	=	temperature, °F
t	=	thickness, in.
B	=	movement, in.
L	=	distance between support points, in.



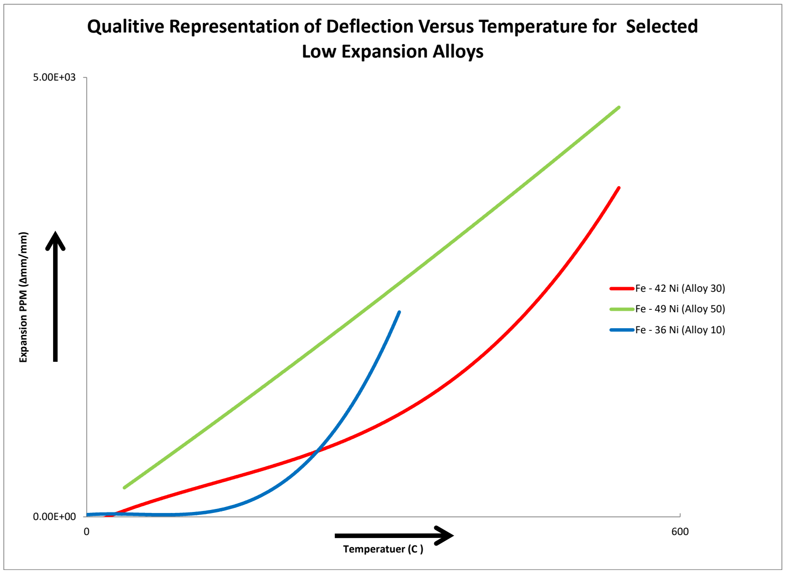
Schematic Diagram of Test for Flexivity

Units used in this guide are inches per inch per degree Fahrenheit. For the Thermostatic Bimetals listed in this publication, the flexivity over a 50°F to 200°F temperature range varies from .21 × 10^{-7} for Truflex 1513 to 215 × 10^{-7} for Truflex P675R which is the most active. While a few Thermostatic Bimetal types have a flexivity which is linear with temperature, most have a non-linear flexivity which is at its highest value over a limited temperature range.

The table of mechanical and physical properties (pp 24-26) gives the flexivity over a 50°F to 200°F temperature range, (Engineered Materials Solutions standard test range). In addition, the table on page 47 lists the instantaneous flexivities at twenty different temperatures from -100°F to +1000°F for all Thermostatic Bimetal types included in this publication. This table enables the determination of the average flexivity value over any required temperature range. Instantaneous Flexivity versus temperature is plotted above for different Bimetal classes.

THE EFFECT OF FLEXIVITY TEMPERATURE DEPENDENCE ON MATERIAL SELECTION

Most LES materials exhibit a phenomenon known as the "Invar Effect". The Invar Effect is the near zero thermal expansion that occurs in some materials. The Invar Effect occurs below the materials Curie temperature. The Curie temperature is a specific temperature for each material defined by the material's atomic structure at which the material changes magnetic permeability. Above the Curie temperature, a phase transformation occurs which changes the material's magnetic permeability from ferro-magnetic to para-magnetic. The changes in crystallographic orientation, energy, and entropy that occur as the Curie temperature is approached cause LES materials to lose their low expansion properties. Above the Curie temperature, LES materials have rates of thermal expansion similar to typical steel. Therefore, LES materials must remain ferromagnetic and be used below their Curie temperatures to maintain their low expansion characteristics. The commonly defined Curie temperature for standard Invar (Fe-36Ni) is 230°C. The schematic below illustrates thermal expansion versus temperature for some LES Alloys.



Qualitative Representation of Thermal Expansion vs. Temp for selected LES Materials

It is important to consider whether or not a stable instantaneous flexivity is required at higher temperatures. Thermostatic Bimetals with high temp LES layers with stable instantaneous flexivity to higher temperatures often have a lower overall flexivity over a specified temperature range when compared to other LES materials that are not rated to such high temperatures. Having the correct amount of flexivity over the temperature range of interest is important in many applications. EMS can assist customers with selecting materials with properties that best exhibit the behavior needed to effectively meet the requirements of an application.

Modulus of Elasticity in Bending

Modulus of elasticity in bending ($E_{bending}$) is a measure of the force required to bend a material within its elastic bending limit. The higher the modulus, the greater the force required. All formulas for mechanical force on any member in bending, (regardless of shape), include the modulus of elasticity (E). The modulus of elasticity for the eighty-nine types of Thermostatic Bimetal materials in this publication range from 17 Msi for Truflex PJ to 27.5 Msi for Truflex B100R.

While the modulus of elasticity changes somewhat with temperature, the variation in Thermostatic Bimetals is marginal and therefore only room temperature values are published. For most Thermostatic Bimetals, the modulus of elasticity is relatively constant with increasing temperature due the fact the low expansion side has an increasing modulus (due to Invar effect) while the high expansion side has a decreasing modulus.

The bending modulus of composite materials increases the complexity of calculations due to the fact that the effect of each of the component materials on the bulk material must be considered. This can be done by using mechanics of materials to find the modular ratio. (Philpot, 2011) The modulus of elasticity of a composite Thermostatic Bimetal may be calculated from the moduli of elasticity and the thicknesses of its components. The equation historically used to calculate the elastic modulus in bending of a two layer Thermostatic Bimetal material system is shown below. (Savolainen and Sears, 1969)

$$E_{bending} = \frac{4E_1\{(t_1 - c_1)^3 + c_1^3 + (E_2/E_1[(t_2 + t_1 - c_1)^3 - (t_1 - c_1)^3])\}}{t^3} \quad (5)$$

where

$$c_1 = \frac{E_1 t_1^2 + E_2 t_2 \,(2t_1 + t_2)}{2(E_1 t_1 + E_2 t_2)}$$

E_1	=	Elastic Modulus of Component 1
E_2	=	Elastic Modulus of Component 2
t_1	=	Thickness of Component 1
t_2	=	Thickness of Component 1
t	=	Thickness of the Bulk Thermostatic Bimetal

For Thermostatic Bimetals composed of three or more layers, the equations for modulus of elasticity become increasingly complex (Savolainen and Sears, 1969). Because of this complexity, and due to limited measurements of Elastic Modulus in bending, Moduli values in the tables of this designer's guide are approximated by measurements in uniaxial tension as well as the rule of mixtures under uniaxial tension. Due to the similar moduli and thickness ratios of Thermostatic Bimetal components for a bonded bimetal, a maximum difference of 10% was estimated between the modulus calculated in tension and the modulus calculated in bending.

THERMAL FORCE

If a Thermostatic Bimetal part is completely restrained when heated or cooled, it develops a force instead of deflecting. The force generated is equal to the mechanical force required to return the part to its original position from the bend it would have assumed due to temperature change if the part were allowed to move without restraint.

STRESS AS RELATED TO TEMPERATURE

Like so many other materials engineered for specific applications, Thermostatic Bimetals also have their limitations - one of the most important being allowable working stresses at different temperatures. Thermostatic Bimetals, like other metals, exhibit a decrease in material strength with an increase in temperature.

Stresses in Thermostatic Bimetal are difficult to analyze properly because the factors involved are quite complex (Savolainen and Sears, 1969). A finished Thermostatic Bimetal element has stresses in it which are caused by: thermal changes, mechanical loading, and the original effects of the strip manufacturing operations (cold rolling, slitting, and flattening.) The effects of thermal changes and mechanical loading are fairly simple to calculate, but the effects of strip manufacturing are largely indeterminate.

The "thermal" bending stress at the bond of a heated strip which is free to move is:

$$\sigma_{Thermal} = \tfrac{1}{2} E(\alpha_2 - \alpha_1)(T_1 - T_0) \quad (6)$$

With the low expansive component in tension and the high expansive component in compression. The outer fiber stresses for both components are one half the bond stresses, with the low expansive component in compression and the high expansive component in tension. Zero stresses occur one-sixth of the total thickness in from the outer surfaces.

Uniform heating and uniform restraining of the strip results in "mechanical" bending stress of:

$$\sigma_{Mechanical} = \tfrac{1}{2} E(\alpha_2 - \alpha_1)(T_1 - T_0) \quad (7)$$

With the low expansive component in tension and the high expansive component in compression. In this instance, the stress is uniform through-out the total thickness of the strip. These stresses are the same as the bond stresses of a freely deflecting strip. If a straight cantilever strip of Thermostatic Bimetal is heated with the free end restrained in its original position, the mechanical restraint and the stresses due to heating reach maximum at or near the point of clamping. The following equation gives the maximum stresses which are at the outer fibers (Savolainen and Sears, 1969):

$$\sigma = {}^{7}/_{8} E(\alpha_2 - \alpha_1)(T_1 - T_0) \quad (8)$$

However, the bond stresses remain the same as the bond stresses in either a freely deflecting or uniformly restrained strip. A straight cantilever strip with uniform cross-section is not efficient since it is worked at full capacity only at the clamped end. One approach to maximize work for a minimum volume of bimetal is to employ a tapered beam, as either a triangular element or a trapezoidal element, with the larger width at the clamped end (Sears, 1958).

Equations (6), (7), and (8), which are used to determine thermo-mechanical stresses, assume the internal stresses to be zero, and this is not necessarily the case. For these reasons, high safety factors must be used to figure allowable stresses after the simple thermal and mechanical stresses have been calculated. Elements should also be life tested.

For applications where there is no restraint of the Thermostatic Bimetal, the maximum temperature each material can withstand for brief periods is indicated in the table of properties on page 22. This figure will be lower if exposure time is long and the allowable amount of calibration change is very small. Therefore, it is best to make actual tests on samples before making a final production run.

For applications where the Thermostatic Bimetal is partially or completely re-strained from motion, it is preferable to have load decrease with an increase in temperature. If load must increase with temperature, it is best to keep the load under that which would be equivalent to approximately 100°F of restraint. In applications involving re-strained parts, it is advisable to make samples for testing before proceeding with production.

ELECTRICAL RESISTIVITY AND RESISTIVE HEATING

A variety of Thermostatic Bimetals covering a wide range of electrical resistivities are used in applications in which heat is generated by passing an electric current through the Thermostatic Bimetal. Different ratings can also be obtained by varying the thickness and width of one type of Thermostatic Bimetal.

The relation between resistivity and resistance in rectangular Thermostatic Bimetal elements is given by the following formula:

$$\rho = \frac{RA}{L} = \frac{Rwt}{L} \qquad (9)$$

where:

ρ	=	resistivity of Thermostatic Bimetal in (ohms mm^2/m or μohms-m)
R	=	resistance in ohms.
A	=	cross sectional area in mm^2.
w	=	width in mm.
t	=	thickness in mm.
L	=	length in meters.

Or in English units as:

$$\rho = \frac{12 \times 10^6 \, Rwt}{0.7854 \, L} \qquad (10)$$

where:

ρ	=	resistivity of Thermostatic Bimetal in (ohms circular mil per foot)
R	=	resistance in ohms.
w	=	width in inches.
t	=	thickness in inches.
L	=	length in inches.

Example: A strip of P850R Thermostatic Bimetal 0.030 inches by 0.500 inches by 15.6 inches long between points of electrical contact and having an electrical resistivity of 850 ohms per cmf is used. Find the resistance of the strip.

$$R = \frac{0.7854 \, L \, P}{12x10^6 \, w \, t} = \frac{(0.7854)(15.6)(850)}{(12x10^6)(0.500)(0.030)} = 0.0579\Omega$$

EMS has designed four series of controlled electrical resistivity Thermostatic Bimetals (FR's, BR's, LAR's, and PR's) to fill the need of circuit breaker manufacturers who have found it desirable to make a line of breakers using bimetal elements of the same physical size with varying current carrying abilities. This design incorporates a shunt layer of an appropriate electrically-conductive alloy between the high and low expansive components to control the resistivity.

The calculation for resistivity is relatively simple if the three components are considered as a parallel circuit:

$$\frac{t_1^f}{\rho_1} + \frac{t_2^f}{\rho_2} + \frac{t_3^f}{\rho_3} = \frac{1}{\rho} \qquad (11)$$

where

t_1^f , t_2^f , and t_3^f	=	Thickness fraction (versus total thickness of three) for components 1, 2, and 3
ρ_1 , ρ_2 and ρ_3	=	resistivity of the three components
ρ	=	resistivity of the bonded Thermostatic Bimetal

Through the use of Joule's First Law and the definition of Specific Heat Capacity, it is possible to derive an ideal temperature rise in a bimetal where convection and radiation heat losses are considered negligible.

From Joule's First Law, an electric current has a heating effect of:

$$Q = I^2 R\theta \qquad (12)$$

where

Q	=	heat in calories,
R	=	resistance in ohms,
I	=	current in amperes,
θ	=	time in seconds

The relationship between this Joule heating and the temperature rise is given by:

$$Q = c\, m\, (\Delta T)$$

where

c	=	specific heat capacity in J/(g °C),
m	=	mass in g,
ΔT	=	temperature rise in °C

Therefore, the temperature rise of a resistor (disregarding convection and radiation heat losses) is given by:

$$\Delta T = \frac{I^2 R\,\theta}{c\,m} \qquad (13)$$

Substituting for R using Equation (9), and assuming a rectangular cross section, formula 13 can be expressed as:

$$\Delta T = \frac{I^2 \rho\,\theta}{cd(wt)^2} \qquad (14)$$

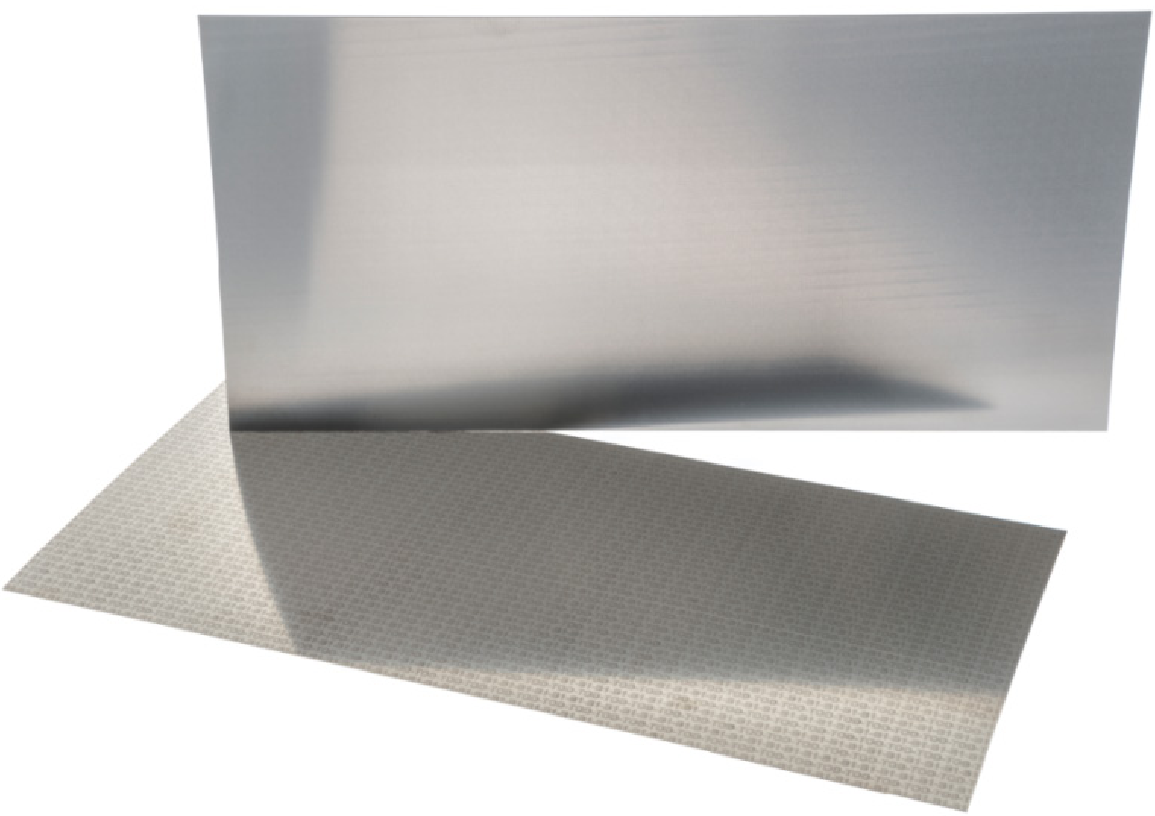
where

ΔT	=	temperature rise in °C
$\imath$	=	current in amperes
ρ	=	electrical resistivity in µohms-m
θ	=	time in sec
c	=	specific heat capacity in J/(g °C), estimated at 0.502 for all Bimetals.
d	=	density in g/cm^3, or mass divided by volume (wtL)
w	=	width in mm
t	=	total thickness in mm

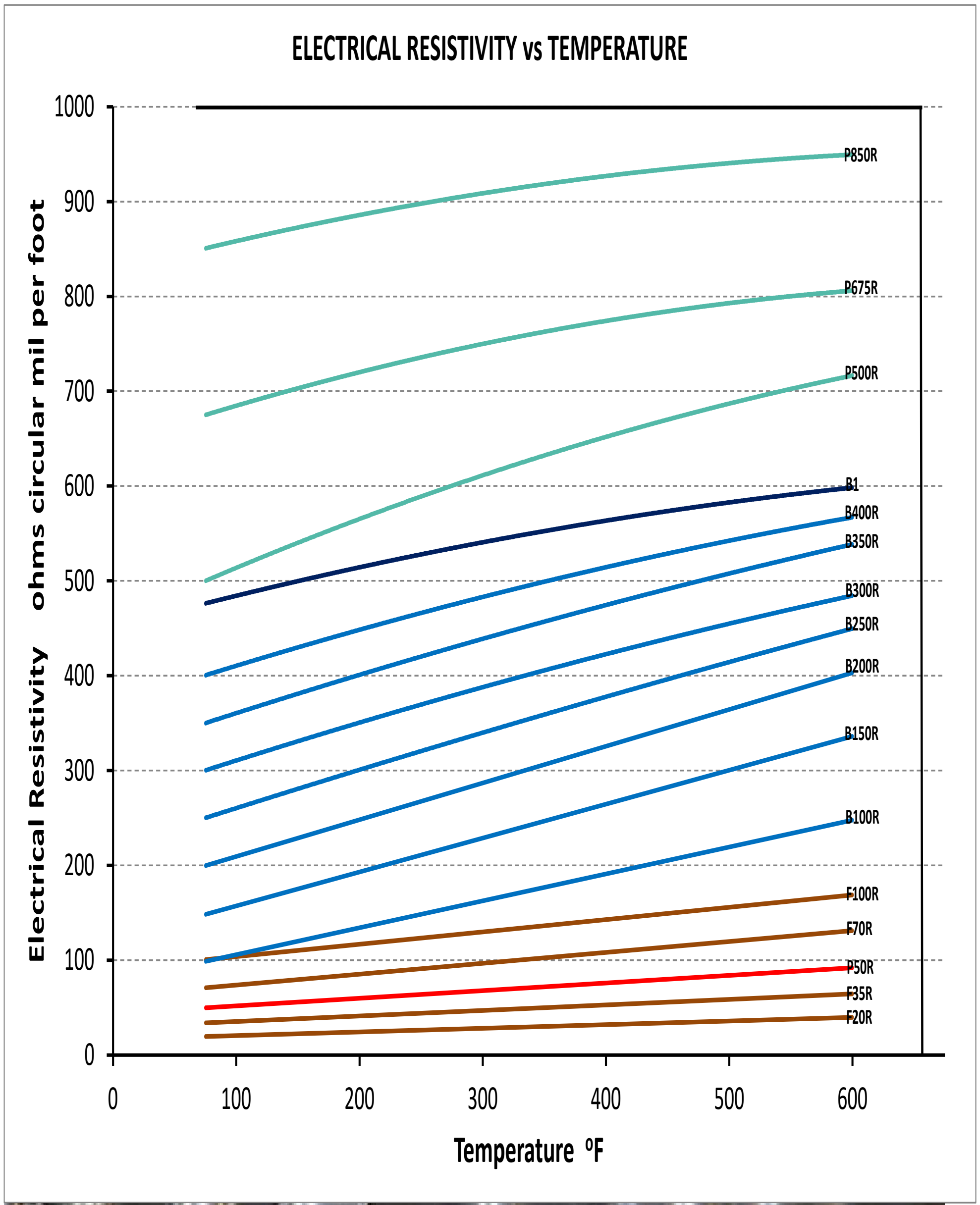
A similar equation can be derived in English units utilizing available conversion factors from these metric quantities.

Given the approximate nature of Equation (14), the most critical observation is that the heating effect is proportional to $\imath^2 \rho$ in which $\imath^2$ is analogous to the current rating of a breaker and ρ is analogous to the electrical resistivity of the Thermostatic Bimetal. Throughout a line of circuit breakers, $\imath^2 \rho$ must be fairly constant for uniform tripping time. Therefore, the series of Thermostatic Bimetals must vary in electrical resistivity as the square of the rating. The previous equation is useful in laying out a line of breakers since, after the type of material has been experimentally determined for one rating, the others can be approximately calculated for the same thickness and width of the breaker. Further, Equation (14) shows that temperature rise is inversely proportional to the squares of both the thickness and width.

Equation (14) will also assist in determining whether EMS resistive series materials available are sufficient for the range of current ratings within a designed line of breakers. If the range of resistive materials is not sufficient, thickness or width changes may be required.



ELECTRICAL RESISTIVITY vs TEMPERATURE



Truflex type	ohms circular mil per foot					
	75 °F	200 °F	300 °F	400 °F	500 °F	600 °F
A1	74	78	81			
B1	475	517	539	567	585	603
B2	424	479	515	547	577	601
B3	415	472	511	545	575	603
B11	452	519	563	598	626	647
BP1	650	700	720	740	755	760
B100R	100	130	155	180	215	250
B125R	125	158	186	215	248	283
B150R	150	193	227	263	300	338
B175R	175	215	250	290	330	370
B200R	200	249	286	325	363	405
B250R	250	301	340	378	414	450
B300R	300	351	388	423	454	485
B350R	350	401	439	475	507	539
B400R	400	450	482	514	543	567
C1	483	523	548	569	585	600
C3	415	474	514	550	581	609
C11	456	507	543	574	600	618
E1	500	537	561	583	603	618
E3	440	499	539	579	616	630
E4	406	469	512	557	597	622
E5	360	420	467	514	561	608
F20R	20	24	28	32	36	40
F25R	25	30	34	38	43	48
F30R	30	36	41	46	51	57
F35R	35	41	46	53	59	65
F40R	40	48	54	60	67	73
F50R	50	61	69	77	85	93
F60R	60	71	80	90	101	111
F70R	70	85	99	108	119	131
F90R	90	107	120	133	146	157
F100R	100	114	127	140	154	168
F125R	125	150	165	185	205	225
G7	440	469	490	510	530	551
GB14	511	539	560	579	596	611
J1	110	115	120	124	129	132
J7	106	110	114	118	122	125
M7	435	481	512	545	575	598
N1	95	125	149	177	208	244
P3	565	642	680	736	770	800
P30R	30	35	40	45	50	55
P35R	35	43	50	55	60	65
P40R	40	49	57	64	71	78
P50R	50	60	68	76	84	92
P60R	60	76	85	92	98	103
P70R	70	88	100	109	115	120
P90R	90	110	125	138	148	155
P100R	100	120	137	153	168	181
P125R	125	152	170	188	202	215
P150R	150	180	201	221	241	260
P175R	175	204	227	248	270	288
P200R	200	225	245	265	285	305
P250R	250	290	315	355	378	395
P300R	300	370	423	476	521	561
P350R	350	408	452	495	536	575
P400R	400	470	518	562	600	630
P450R	450	515	560	600	630	658
P500R	500	565	612	652	686	717
P550R	550	615	657	690	712	728
P600R	600	653	688	720	743	762
P675R	675	720	750	774	793	806
P850R	850	887	909	926	940	950
PJ	120	132	140	146	152	157
1513	395	447	484	519	549	575

STABILIZING HEAT TREATMENT

Because of residual stresses which build up in Thermostatic Bimetals during rolling, slitting, straightening, cutting and forming operations, parts made from Thermostatic Bimetal are commonly heat treated before assembly into a final product. Heat treating relieves or redistributes these stresses to maintain stability, accuracy and uniformity of operation of the part which otherwise will go out of calibration either when the temperature is increased or time has elapsed.

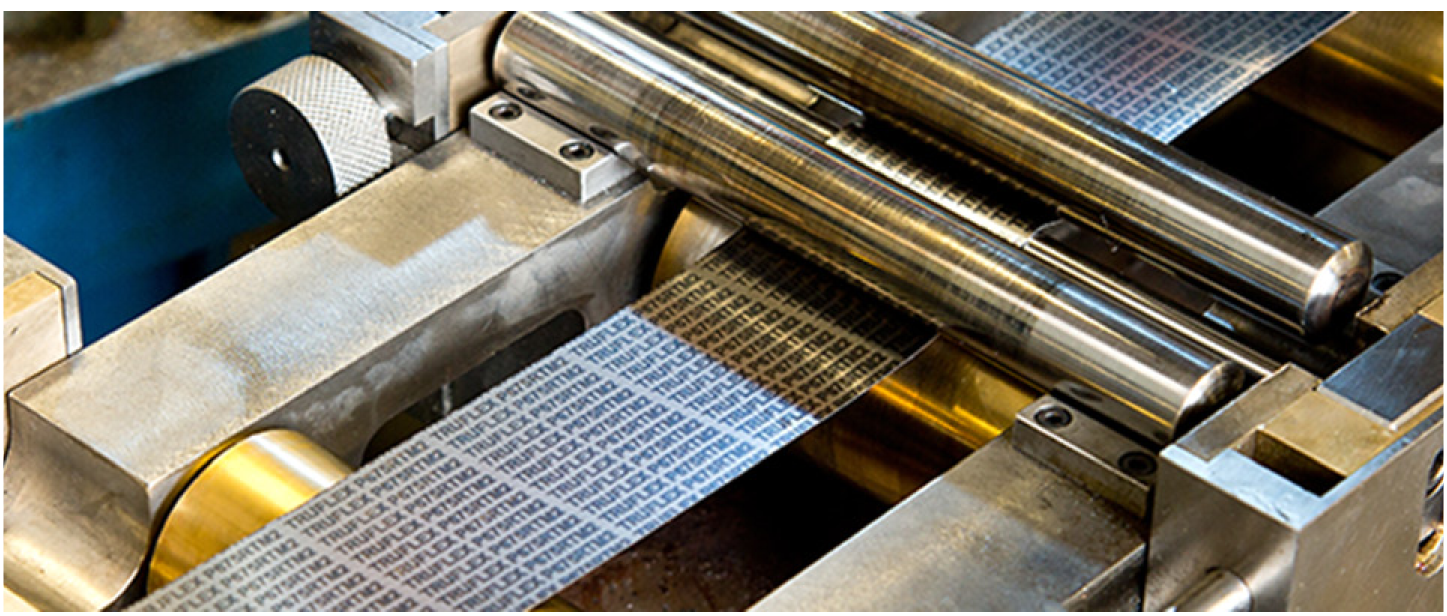
Heat treating is performed in either an air or inert atmosphere furnace. During the heat treating process, the parts must be free to deflect to ensure uniform heat treatment between parts within a lot. Heat treatment temperatures should be at least 50 °F above the maximum temperature encountered in operation or in processing after assembly. A minimum of 400°F for one hour is recommended for most Thermostatic Bimetals.

Since heat treating is not an annealing or normalizing process, it has only a minor effect on the physical properties of Thermostatic Bimetal. Recommended heat treatment will cause no change in hardness and only slight changes in temperature deflection rate and mechanical force rate. However, the change in shape which results from heat treatment should be considered when fabricating a part, so that compensation can be made for this change.

When heat treated, a formed part tends to revert to its original shape because some of the stresses caused in forming the part have been relieved. A blade which is flat prior to heat treatment will assume a curvature after heat treating with the high expansive side becoming concave. Strip material can be pre-curved (in a direction opposite to the curvature caused by heat treatment) by a roller flattener ahead of the press. The opposition of these two curvatures will result in the desired flatness or curvature of the finished blade.

Usually simple heat treating is all that is necessary for most parts and is satisfactory even if the parts are adjusted slightly after heat treatment. However, for cases where stability is critical, such as in room Thermostats, the parts or the whole assembly should be heat treated again after any mechanical adjustment. The best method is not to calibrate the part, but rather some other component of the device, such as the part on which the Thermostatic Bimetal is mounted.

In some cases, where the Thermostatic Bimetal parts must operate under restraint, strength may be materially increased by heat treating under similar restraint.



PHYSICAL AND MECHANICAL PROPERTIES (English)

Values are based on material 0.030 x ½ inch and will vary from those for other thickness to width variations

Truflex Type	ASTM Flexivity F x 10^{-7} 50° - 200° F temp range	Maximum sensitivity temperature range °F	Useful deflection temperature range °F	Recommended maximum temp °F	Modulus of elast. E, lbs/sq.in by 10^6	Resistivity at 75°F ohms cm/ft.	Density lb./cu.in.	ASTM type	Remarks
A1	150	0 to 300	-100 to 350	350	18.0	74	0.300	--	Brass / Invar
B1	150	0 to 300	-100 to 700	1000	25.0	475	0.295	TM1	
B11	141	150 to 450	-100 to 1000	1000	25.0	452	0.295	--	Best all purpose 150 to 450°F (65 to 232°C)
B2	133	100 to 550	-100 to 1000	1000	25.0	440	0.295	TM6	Best all purpose 100 to 550°F (38 tp 260°C)
B3	118	200 to 600	-100 to 1000	1000	25.0	415	0.296	TM30	Best all purpose 200 to 600°F (93 to 316°C)
B100R	106	0 to 300	-100 to 700	1000	27.5	100	0.308	TM9	Intermediate Resistivity, General Purpose 0 to 300°F (-20 to 150°C)
B125R	124	0 to 300	-100 to 700	1000	27.0	125	0.305	TM10	Intermediate Resistivity, General Purpose 0 to 300°F (-20 to 150°C)
B150R	134	0 to 300	-100 to 700	1000	26.5	150	0.303	TM11	Intermediate Resistivity, General Purpose 0 to 300°F (-20 to 150°C)
B175R	138	0 to 300	-100 to 700	1000	26.0	175	0.301	TM12	Intermediate Resistivity, General Purpose 0 to 300°F (-20 to 150°C)
B200R	141	0 to 300	-100 to 700	1000	26.0	200	0.300	TM13	Intermediate Resistivity, General Purpose 0 to 300°F (-20 to 150°C)
B250R	147	0 to 300	-100 to 700	1000	25.5	250	0.298	TM14	Intermediate Resistivity, General Purpose 0 to 300°F (-20 to 150°C)
B300R	149	0 to 300	-100 to 700	1000	25.5	300	0.297	TM15	Intermediate Resistivity, General Purpose 0 to 300°F (-20 to 150°C)
B350R	149	0 to 300	-100 to 700	1000	25.0	350	0.295	TM16	Intermediate Resistivity, General Purpose 0 to 300°F (-20 to 150°C)
B400R	150	0 to 300	-100 to 700	1000	25.0	400	0.295	TM14	Intermediate Resistivity, General Purpose 0 to 300°F (-20 to 150°C)
B100R30	90	200 to 550	-100 to 1000	1000	26.5	100	0.307	--	Intermediate Resistivity, Special Use 200 to 550°F (93 to 288°C)
BP1*	185	0 to 300	-100 to 500	800	20.0	650	0.278	--	Better Corrosion Resistance and Joining Compared to P675R
BP10	145	0 to 300	-100 to 500	800	19.5	675	0.275	--	Better Corrosion Resistance and Joining Compared to P675R
BP560R*	148	0 to 300	-100 to 500	800	21.5	560	0.285	--	Medium Flexivity. Higher Resistivity
C1	152	0 to 300	-100 to 700	1000	25.0	483	0.295	TM35	High strength, all purpose 0 to 300°F (-20 to 150°C)
C11*	141	150 to 450	-100 to 900	1000	25.0	456	0.295	TM19	High strength, all purpose 150 to 450°F (65 to 232°C)
C3	117	200 to 600	-100 to 800	1000	25.0	420	0.296	TM18	High strength, all purpose 200 to 600°F (93 to 316°C)
E1*	148	0 to 300	-100 to 700	1000	25.0	500	0.295	TM36	Good all purpose 0 to 300°F(-20 to 150°C) Higher Resistivity
E3	103	200 to 600	-100 to 1000	1000	25.0	440	0.295	TM3	Good all purpose 200° to 600°F (93° to 316°C)
E4	86	250 to 700	-100 to 1000	1000	25.0	400	0.296	TM4	Best all purpose 250° to 70°F (120° to 370°C)
E5	64	300 to 800	-100 to 1000	1000	25.5	350	0.297	TM5	Best all purpose 300° to 800°F (150° to 425°C)
E70R20	117	100 to 550	-100 to 700	700	23.0	70	0.298	-	Low Electrical Resistivity and Medium Flexivity
F20R	131	0 to 300	-100 to 500	700	20.0	20	0.309	TM24	Low Electrical Resistivity and Medium Flexivity
F25R	135	0 to 300	-100 to 500	700	22.0	25	0.307	-	Low Electrical Resistivity and Medium Flexivity
F30R	140	0 to 300	-100 to 500	700	23.0	30	0.305	TM25	Low Electrical Resistivity and Medium Flexivity
F35R	143	0 to 300	-100 to 500	700	23.5	35	0.303	--	Low Electrical Resistivity and Medium Flexivity
F40R	144	0 to 300	-100 to 500	700	24.0	40	0.302	--	Low Electrical Resistivity and Medium Flexivity
F50R	147	0 to 300	-100 to 500	700	24.0	50	0.300	TM26	Low Electrical Resistivity and Medium Flexivity
F60R	145	0 to 300	-100 to 500	700	24.5	60	0.300	--	Low Electrical Resistivity and Medium Flexivity

* FLEXIVITY TEST TEMPERATURE RANGE 100°F TO 300°F

**FLEXIVITY TEST TEMPERATURE RANGE 68°F TO 266°F

Truflex Type	ASTM Flexivity F x 10^{-7}	Maximum sensitivity temperature range °F	Useful deflection temperature range °F	Recommended maximum temp °F	Modulus of elast. E, lbs/ sq.in by 10^6	Resistivity at 75°F ohms cm/ ft.	Density lb./ cu.in.	ASTM type	Remarks
	50° - 200° F temp range								
F70R	147	0 to 300	-100 to 500	700	24.5	70	0.299	TM27	Low Electrical Resistivity and Medium Flexivity
F90R	148	0 to 300	-100 to 500	700	25.0	90	0.298	TM28	Low Electrical Resistivity and Medium Flexivity
F100R	149	0 to 300	-100 to 500	700	25.0	100	0.297	--	Intermediate Electrical Resistivity and Medium Flexivity
F125R	148	0 to 300	-100 to 500	700	25.0	125	0.297	--	Intermediate Electrical Resistivity and Medium Flexivity
F55R20	130	100 to 500	-100 to 700	700	22.0	54	0.300	--	Low Electrical Resistivity and Medium Flexivity
G7	61	0 to 800	-100 to 1000	1000	27.5	440	0.280	--	Linear flexivity 0-800°F
GB2	128	100 to 550	-100 to 1000	1000	26.0	445	0.295	--	General purpose 100° to 550°F (38° to 260°C). Good High Temperature Stability
GB5	75	300 to 800	-100 to 1000	1000	26.0	342	0.296	--	General purpose 300° to 800°F (150° to 425°C). Higher Flexivity than E5.
GB14	100	0 to 300	-100 to 1000	1000	26.0	511	0.294	--	Good corrosion resistance in aqueous environments
J1	134	0 to 300	-100 to 500	625	19.0	110	0.310	--	Low temperature only
J7	56	0 to 500	-100 to 500	625	22.0	106	0.300	--	Best corrosion resistance
LA1	158	0 to 300	-100 to 700	1000	25.0	475	0.292	TM29	Good all purpose 0-300°F
LA20R10*	140	0 to 300	-100 to 500	700	19.0	20	0.309	--	Low electrical resistivity with medium flexivity
LA35R10	150	0 to 300	-100 to 500	700	21.0	35	0.301	--	Low electrical resistivity with medium flexivity
LA50R10*	151	0 to 300	-100 to 500	700	22.5	50	0.298	--	Low electrical resistivity with medium flexivity
LA70R10*	153	0 to 300	-100 to 500	700	23.0	70	0.297	--	Low electrical resistivity with medium flexivity
LA90R10	159	0 to 300	-100 to 500	700	23.0	90	0.296	--	Low electrical resistivity with medium flexivity
LA100R10**	157	0 to 300	-100 to 500	700	23.0	102	0.294	--	Low electrical resistivity with medium flexivity
LA115R10**	159	0 to 300	-100 to 500	700	23.5	115	0.294	--	Intermediate electrical resistivity with medium flexivity
LA125R10*	140	0 to 300	-100 to 500	500	23.0	125	0.296	--	Intermediate electrical resistivity with medium flexivity
LA125R*	150	0 to 300	-100 to 700	1000	26.0	125	0.302	--	Intermediate electrical resistivity with medium flexivity
LA150R**	145	0 to 300	-100 to 700	1000	25.5	150	0.299	--	Intermediate electrical resistivity with medium flexivity
LA180R**	146	0 to 300	-100 to 700	1000	25.0	180	0.297	--	Intermediate electrical resistivity with medium flexivity
LA210R*	153	0 to 300	-100 to 700	1000	25.0	210	0.296	--	Intermediate electrical resistivity with medium flexivity
LA300R*	156	0 to 300	-100 to 700	1000	24.5	300	0.294	--	Intermediate electrical resistivity with medium flexivity
LA330R**	162	0 to 300	-100 to 700	1000	24.5	330	0.293	--	Intermediate electrical resistivity with medium flexivity
LA35R11	139	150 to 450	-100 to 650	700	23.0	36	0.301	--	Low electrical resistivity with medium flexivity
LA55R20	139	100 to 500	-100 to 700	700	22.0	54	0.297	--	Low electrical resistivity with medium flexivity
LA3**	125	200 to 600	-100 to 800	1000	24.0	417	0.292	--	Medium electrical resistivity with medium flexivity
LA55R30	120	200 to 550	-100 to 700	700	22.0	54	0.298	--	Low electrical resistivity with medium flexivity
M7	40	0 to 800	-100 to 1000	1000	27.5	435	0.290	--	High corrosion resistance
N1	102	0 to 300	-100 to 500	1000	26.0	95	0.310	TM22	Low resistivity and flexivity
P30R	189	0 to 400	-100 to 500	700	19.0	30	0.296	TM31	Low electrical resistivity with high flexivity
P35R	200	0 to 400	-100 to 500	700	19.0	35	0.291	--	Low electrical resistivity with high flexivity
P50R	208	0 to 400	-100 to 500	700	19.0	50	0.286	TM33	Low electrical resistivity with high flexivity
P70R	214	0 to 400	-100 to 500	700	19.0	70	0.283	TM34	Low Resistivity, High Flexivity, General use 0 to 400°F (-20 to 200°C)

* FLEXIVITY TEST TEMPERATURE RANGE 100°F TO 300°F

**FLEXIVITY TEST TEMPERATURE RANGE 68°F TO 266°F

Truflex Type	ASTM Flexivity F x 10^{-7} 50° - 200° F temp range	Maximum sensitivity temperature range °F	Useful deflection temperature range °F	Recommended maximum temp °F	Modulus of elast. E, lbs/sq.in by 10^6	Resistivity at 75°F ohms cm/ft.	Density lb./cu.in.	ASTM type	Remarks
P90R*	204	0 to 400	-100 to 500	700	19.0	90	0.281	--	Low Resistivity, High Flexivity, General Use 0 to 400°F (-20 to 200°C)
P100R	216	0 to 400	-100 to 500	700	19.0	100	0.282	--	Low Resistivity, High Flexivity, General Use 0 to 400°F (-20 to 200°C)
P125R*	209	0 to 400	-100 to 500	700	19.0	125	0.28	--	Intermediate Resistivity, High Flexivity, General Use 0 to 400°F (-20 to 200°C)
P150R	216	0 to 400	-100 to 500	800	19.0	150	0.279	TM32	Intermediate Resistivity, High Flexivity, General Use 0 to 400°F (-20 to 200°C)
P175R*	209	0 to 400	-100 to 500	500	19.0	175	0.278	--	Intermediate Resistivity, High Flexivity, General Use 0 to 400°F (-20 to 200°C)
P250R*	209	0 to 400	-100 to 500	500	19.0	250	0.279	--	Intermediate Resistivity, High Flexivity, General Use 0 to 400°F (-20 to 200°C)
P300R	208	0 to 400	-100 to 500	800	20.0	300	0.277	--	Intermediate Resistivity, High Flexivity, General Use 0 to 400°F (-20 to 200°C)
P350R	213	0 to 400	-100 to 500	800	20.0	350	0.276	--	Intermediate Resistivity, High Flexivity, General Use 0 to 400°F (-20 to 200°C)
P500R	202	0 to 400	-100 to 500	800	21.0	500	0.281	--	High Resistivity, High Flexivity General Use 0 to 400°F (-20 to 200°C)
P675R	217	0 to 400	-100 to 500	800	19.0	675	0.275	TM2	*** Most active material available
P850R	156	0 to 400	-100 to 500	800	19.5	850	0.267	TM8	Highest Resistivity
P30RC	188	0 to 400	-100 to 500	700	19.0	30	0.295	--	Low electrical resistivity with high flexivity. Copper outer layer for brazeability or weldability
P3	182	200 to 600	-100 to 600	800	19.0	565	0.276	TM23	Uniform flexivity increase with increasing temperature
PJ	75	0 to 600	-100 to 625	625	17.0	120	0.300	--	Non-magnetic-both sides
S363	115	0 to 300	-100 to 700	1000	25.0	475	0.292	--	Good corrosion resistance in aqueous environments
SB175R	125	0 to 300	-100 to 700	1000	26.0	175	0.291	--	Intermediate electrical resistivity with medium flexivity
SB250R	144	0 to 300	-100 to 700	1000	25.5	250	0.293	--	Intermediate electrical resistivity with medium flexivity
SB300R	146	0 to 300	-100 to 700	1000	25.0	300	0.294	--	Intermediate electrical resistivity with medium flexivity
1513	-21	500 to 800	225 to 1000	1000	23.0	395	0.290	--	Reverses motion direction at 225°F

* FLEXIVITY TEST TEMPERATURE RANGE 100°F TO 300°F

**FLEXIVITY TEST TEMPERATURE RANGE 68°F TO 266°F

PHYSICAL AND MECHANICAL PROPERTIES (Metric)

Values are based on material 0.76 x 12.7 mm and will vary from those for other thickness to width variations.

Truflex Type	Specific curvature 10^{-6} (temp range: 10°C to 93°C)	Maximum sensitivity temperature °C	Useful deflection temperature range °C	Recommended maximum temp °C[6]	Modulus of elasticity Gpa	Resistivity @ 24°C µ ohms-m	Density g/cm³	ASTM type
A1	27.00	-20 to 150	-70 to 180	180	124	0.123	8.30	--
B1	27.00	-20 to 150	-70 to 370	540	172	0.789	8.17	TM1
B1	25.40	70 to 230	-70 to 540	540	172	0.751	8.17	--
B2	23.90	-40 to 290	-70 to 540	540	172	0.731	8.17	TM6
B3	21.25	90 to 320	-70 to 540	540	172	0.690	8.18	TM30
B100R	19.10	-20 to 150	-70 to 370	540	179	0.166	8.53	TM9
B125R	22.30	-20 to 150	-70 to 370	540	186	0.208	8.44	TM10
B150R	24.10	-20 to 150	-70 to 370	540	183	0.249	8.38	TM11
B175R	24.80	-20 to 150	-70 to 370	540	179	0.291	8.33	TM12
B200R	25.40	-20 to 150	-70 to 370	540	179	0.332	8.30	TM13
B250R	26.50	-20 to 150	-70 to 370	540	176	0.416	8.25	TM14
B300R	26.80	-20 to 150	-70 to 370	540	176	0.499	8.22	TM15
B350R	26.80	-20 to 150	-70 to 370	540	172	0.582	8.17	TM16
B400R	27.00	-20 to 150	-70 to 370	540	172	0.665	8.17	TM14
B100R30	16.20	93 to 288	-73 to 538	540	183	0.166	8.5	--
BP1*	33.30	-20 to 150	-70 to 260	430	138	1.080	7.70	--
BP10	26.10	-20 to 150	-70 to 260	430	134	1.122	7.6	--
BP560R*	26.60	-20 to 150	-70 to 260	427	148	0.931	7.89	--
C1	27.40	-20 to 150	-70 to 350	540	172	0.803	8.17	TM35
C11*	25.40	66 to 232	-73 to 482	540	172	0.758	8.17	TM19
C3	21.10	90 to 320	-70 to 430	540	172	0.698	8.18	TM18
E1*	23.90	-20 to 150	-70 to 370	540	172	0.831	8.16	TM36
E3	18.50	90 to 320	-70 to 540	540	172	0.731	8.17	TM3
E4	15.50	120 to 370	-70 to 540	540	172	0.665	8.18	TM4
E5	11.50	150 to 430	-70 to 540	540	176	0.582	8.22	TM5
E70R20	21.00	38 to 288	-72 to 371	371	159	0.116	8.25	--
F20R	23.60	-20 to 150	-70 to 260	370	138	0.033	8.57	TM24
F25R	24.30	-20 to 150	-70 to 260	370	152	0.042	8.51	--
F30R	25.20	-20 to 150	-70 to 260	370	161	0.050	8.43	TM25
F35R	25.70	-20 to 150	-70 to 260	370	164	0.058	8.38	--
F40R	25.90	-20 to 150	-70 to 260	370	165	0.066	8.37	--
F50R	26.50	-20 to 150	-70 to 260	370	165	0.083	8.32	TM26

* FLEXIVITY TEST TEMPERATURE RANGE 38°C TO 150°C

**FLEXIVITY TEST TEMPERATURE RANGE 20°C TO 130°C

Truflex Type	Specific curvature 10^{-6} (temp range: 10°C to 93°C)	Maximum sensitivity temperature °C	Useful deflection temperature range °C	Recommended maximum temp $°C^{6}$	Modulus of elasticity Gpa	Resistivity @ 24°C µ ohms-m	Density g/cm^3	ASTM type
F60R	26.10	-20 to 150	-70 to 260	370	175	0.100	8.3	--
F70R	26.50	-20 to 150	-70 to 260	370	169	0.116	8.27	TM27
F90R	26.60	-20 to 150	-70 to 260	370	172	0.150	8.24	TM28
F100R	26.80	-20 to 150	-70 to 260	370	172	0.166	8.23	--
F125R	26.60	-20 to 150	-70 to 260	370	172	0.208	8.22	--
F55R20	23.40	38 to 288	-70 to 370	370	152	0.090	8.53	--
G7	10.94	-200 to 430	-70 to 540	540	190	0.731	7.75	
GB2	23.00	40 to 290	-70 to 540	540	179	0.740	8.17	--
GB5	13.50	150 to 430	-70 to 540	540	179	0.568	8.19	--
GB14	18.00	-20 to 150	-70 to 540	540	179	0.849	8.12	--
J1	24.14	-20 to 150	-70 to 260	330	131	0.183	8.58	
J7	10.00	-20 to 260	-70 to 260	540	152	0.176	8.3	
LA1	28.40	-20 to 150	-70 to 370	540	172	0.789	8.07	TM29
LA20R10*	25.20	-20 to 150	-70 to 260	370	131	0.033	8.55	--
LA35R10	27.00	-20 to 150	-70 to 260	370	145	0.058	8.34	--
LA50R10*	27.20	-20 to 150	-70 to 260	370	155	0.083	8.25	--
LA70R10*	27.50	-20 to 150	-70 to 260	370	158	0.116	8.22	--
LA90R10	28.60	-20 to 150	-70 to 260	370	159	0.150	8.19	--
LA100R10**	28.30	-20 to 150	-70 to 260	370	159	0.170	8.14	--
LA115R10**	28.60	-20 to 150	-70 to 260	370	162	0.191	8.14	--
LA125R10*	25.20	-20 to 150	-70 to 260	260	159	0.208	8.19	--
LA125R*	25.20	-20 to 150	-70 to 370	540	179	0.208	8.36	--
LA150R**	26.10	-20 to 150	-70 to 370	540	176	0.249	8.28	--
LA180R**	26.30	-20 to 150	-70 to 370	540	172	0.299	8.22	--
LA210R*	27.50	-20 to 150	-70 to 370	540	172	0.349	8.19	--
LA300R*	28.10	-20 to 150	-70 to 370	540	169	0.499	8.14	--
LA330R**	29.10	-20 to 150	-70 to 370	540	169	0.548	8.11	--
LA35R11	25.00	66 to 232	-73 to 340	370	159	0.060	8.34	--
LA55R20	25.00	38 to 288	-70 to 370	370	152	0.090	8.22	--
LA3**	22.50	95 to 315	-70 to 430	540	165	0.693	8.07	--
LA55R30	21.60	93 to 288	-70 to 370	370	152	0.090	8.25	--
M7	7.17	-20 to 800	-70 to 540	540	190	0.723	8.03	--
N1	18.29	-20 to 150	-70 to 260	430	1.79	0.158	8.58	TM22
P30R	34.00	-20 to 200	-70 to 260	370	131	0.050	8.19	TM31
P35R	36.00	-20 to 200	-70 to 260	370	131	0.058	8.05	--

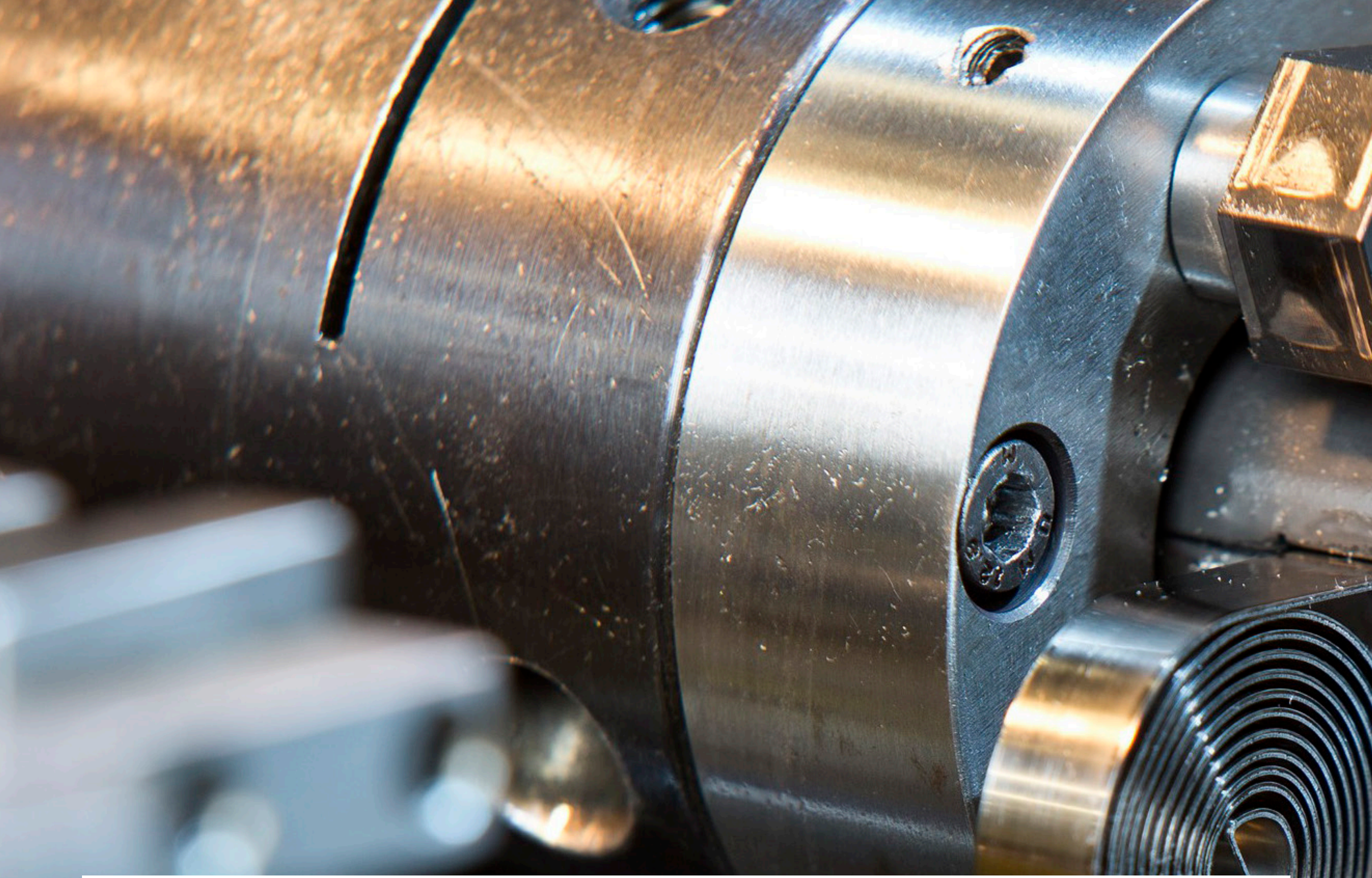
* FLEXIVITY TEST TEMPERATURE RANGE 38°C TO 150°C

**FLEXIVITY TEST TEMPERATURE RANGE 20°C TO 130°C

Truflex Type	Specific curvature 10^{-6} (temp range: 10°C to 93°C)	Maximum sensitivity temperature °C	Useful deflection temperature range °C	Recommended maximum temp $°C^{6}$	Modulus of elasticity Gpa	Resistivity @ 24°C µ ohms-m	Density g/cm^3	ASTM type
P50R	37.40	-20 to 200	-70 to 260	370	131	0.083	7.91	TM33
P70R	38.50	-20 to 200	-70 to 260	370	131	0.116	7.83	TM34
P90R*	36.70	-20 to 200	-70 to 260	370	131	0.150	7.78	--
P100R	38.90	-20 to 200	-70 to 260	370	131	0.166	7.81	--
P125R*	37.60	-20 to 200	-70 to 260	370	131	0.208	7.75	--
P150R	38.90	-20 to 200	-70 to 260	430	131	0.249	7.73	TM32
P175R*	37.60	-20 to 200	-70 to 260	260	131	0.291	7.70	--
P250R*	37.60	-20 to 200	-70 to 260	260	131	0.416	7.72	--
P300R	37.40	-20 to 200	-70 to 260	430	138	0.499	7.66	--
P350R	38.30	-20 to 200	-70 to 260	430	138	0.582	7.65	--
P500R	36.40	-20 to 200	-70 to 260	430	145	0.831	7.77	--
P675R	39.10	-20 to 200	-70 to 260	430	131	1.122	7.61	TM2
P850R	28.10	-20 to 200	-70 to 260	430	134	1.413	7.38	TM8
P30RC	33.80	-20 to 200	-70 to 260	370	131	0.050	8.17	--
P3	32.80	90 to 320	-70 to 320	430	131	0.939	7.64	TM23
PJ	13.58	-20 to 320	-70 to 360	330	117	0.199	8.3	
S363	20.70	-20 to 150	-70 to 370	540	172	0.789	8.08	--
SB175R	22.50	-20 to 150	75 to 370	540	179	0.291	8.06	--
SB250R	25.90	-20 to 150	-70 to 370	540	176	0.416	8.1	--
SB300R	26.30	-20 to 150	-70 to 370	540	172	0.499	8.12	--
1513	3.77	+260 to 430	-70 to 540	540	159	0.656	8.03	

* FLEXIVITY TEST TEMPERATURE RANGE 38°C TO 150°C

**FLEXIVITY TEST TEMPERATURE RANGE 20°C TO 130°C



DESIGN CONSIDERATIONS

THE KEY TO SUCCESS

The key to a successful design of thermostatic bimetal elements lies in selecting the ideal element shape, dimensions, and bimetal type for given application needs, while considering when necessary the bimetal's joinability and resistance to corrosion in service.

Design Information: To design a Thermostatic Bimetal element, the following will be required:

1. The temperature range of use.
2. The maximum temperature to which the element will be subjected.
3. Movement or force required, or combination of the two.
4. Space limitations.
5. Service conditions.

Standard Design Rule: It is recommended to use the Thermostatic Bimetal having the highest average flexivity over the working temperature range, since this will involve a minimum volume of active material. In some applications, the selection of the Thermostatic Bimetal must be tempered by special considerations:

1. Electrical resistivity.
2. Corrosion resistance.
3. Maximum temperature.
4. Thermal conductivity.
5. Temperature at which the device will actuate.

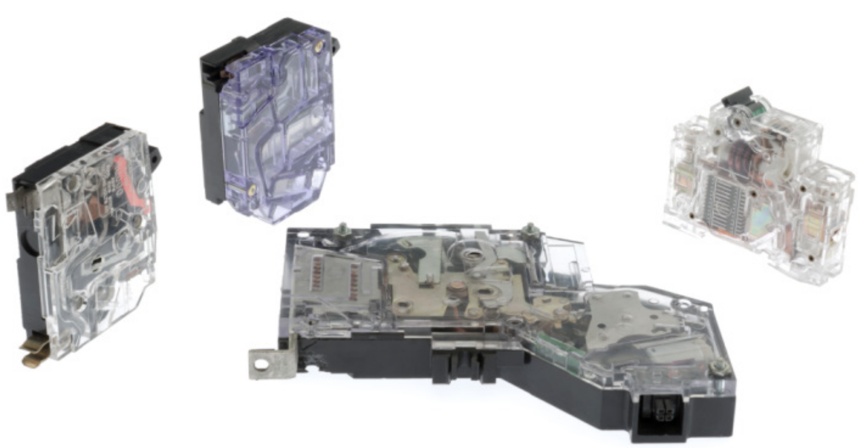
Mounting (Joinability):
Bimetal elements should be rigidly mounted to their supports in such a way that the inactive lengths are clearly defined and closely maintained. Mounting (installation) to prevent overstressing is another important design consideration. Attachment may be achieved by riveting, bolting, spot welding, soldering or brazing, depending on requirements. Materials have been developed with outer layers to meet the joining requirements for specific industries. For example, use of an outside copper layer, such as in P30RC Thermostatic Bimetal, aids in brazeability. Thermostatic Bimetals can also be plated with materials such as nickel to meet specific welding requirements.

Corrosion Considerations:
Corrosion resistance is an important consideration if the Thermostatic Bimetal may be exposed to caustic, basic, aqueous, or other environments. Also, when mounting Thermostatic Bimetal parts to other metallic parts, care should be taken to see that no galvanic action can occur which may cause corrosion to the bimetal during the life of the part. EMS's GB14 and S363 materials provide superior corrosion protection in water immersion environments when compared to standard bimetal types. For some improvement in service life, Thermostatic Bimetal strip or parts may be electro-less or electro-plated with silver, nickel, tin, cadmium, zinc or gold. Plating often has a negligible effect on the physical properties of thermal deflection and thermal or mechanical force.

Because of the high manganese content of the high expansion alloy, the P series thermostatic bimetals are highly susceptible to corrosion and stress corrosion cracking. Consequently, their use should be avoided when they may encounter prolonged exposure to high humidity, moisture or saline solutions.

Heat Source:
Close proximity between the thermostatic bimetal element and the heat source is desirable.

Adjustment / Calibration:
A means of adjusting the thermostatic bimetal element should be incorporated in the design to compensate for normal production tolerances on parts and to assure accurate performance. Provision for mechanical adjustment can be more economical than specifying close tolerances on the part itself. The means of adjustment should not affect the active length of the element and, preferably, should be on some component member of the assembly. Friction must be evaluated and its effect included in the design as an extra force requirement.



THE EMS ADVANTAGE

History:
EMS has a legacy for excellence and innovation that has provided customers with specialty clad metal solutions since the founding of the General Plate Company in 1916. In 1954 PT (Pressure Temperature) bonding, now the most common method of clad metal bonding, was invented. Over the years EMS has been at the forefront of innovation and development for Thermostatic Bimetal materials.

Facilities:
EMS maintains a global presence and provides worldwide customer support by operating three facilities in Attleboro Massachusetts, Hamburg Pennsylvania, and Baoying China. Each facility operates under the same core values that have driven EMS to excellence over the years. Product Variety: EMS currently manufactures 89 Thermostatic Bimetal systems for a wide range of applications. EMS is a world leader in the production of "disc" grade strip materials for snap action devices, as well as in the production of heavy gauge materials for thermal and electrical breakers, thermostatic blades, and thermostatic coils.

Capabilities:
EMS has developed an impressive range of capabilities at our worldwide facilities, including:

- Bonding mills with the capability to bond between thicknesses of 0.015" and 0.250", at widths ranging from 2.0" to 25.5", and with bond forces up to or exceeding 1000 tons.
- Rolling mills equipped with cluster configurations and automatic gauge control, capable of ensuring excellent shape and tight thickness tolerances.
- Continuous strip annealing.
- Various strip marking methods, including chemical, embossing, and engraving.
- Precision slitting.
- Unique flattening modes to meet customer's specific shape needs.
- Precision stamping operations.

Quality:
EMS has stringent quality standards and multiple inspections in place to ensure quality products to our customers. EMS tests flexivity, resistivity, and hardness of every lot of Thermostatic Bimetal according to ASTM testing procedures. EMS also employs visual inspections and non-destructive testing techniques to ensure surface quality and bond integrity. EMS certifies chemistry, hardness, flexivity, and resistivity as required by the customer, and maintains full lot traceability from raw stock through finished goods.

Technical Support:
EMS is technically adept in engineering the properties of Thermostatic Bimetals. EMS had developed robust and repeatable manufacturing process for making over 100 Thermostatic Bimetal material systems. EMS's team of technical experts can help assist customers in Thermostatic Bimetal material and property selection. EMS has product specialists and metallurgists that can assist in identifying customer issues that may be related to Thermostatic Bimetal. The appendix in this designers guide contains equations and examples for calculating thermal force, mechanical force and thermal deflection for a variety of commonly used Thermostatic Bimetal parts. While the provided equations are helpful in defining a design, it is often advisable to make and test samples before final design is set. EMS has the ability to provide sample material to customers if needed. Contact a product manager if a sample is required.

APPENDIX: USEFUL EQUATIONS FOR DESIGNERS

DESIGN CONFIGURATIONS

Performance:
The performance of a Thermostatic Bimetal element is based fundamentally on its ability to deflect and to do work when its temperature is changed.

Thermal deflection:
The basic free deflection is utilized without the development of any force. The thermal deflection equations will result in a ratio of thickness to length with an infinite variety of combinations. The final size is determined by factors other than the free deflection specification, such factors being rigidity, resistance to vibration, space limitations and practicality for production.

Thermal force:
The basic free deflection is completely prevented, and only force is developed. The thermal force equations will result in a ratio of width, thickness and length with an infinite variety of combinations. Aside from the thermal force specifications, the final size will be determined by the same factors as for free deflection, plus the factor of allowable stress.

Thermal deflection and force:
Part of the potential free deflection is prevented and transformed into force which the element develops in addition to a deflection. This is the most common application of thermostatic bimetal. By utilizing one half the available temperature change for developing thermal deflection and the other half for developing thermal force, a minimum volume of material is involved. However, due to dimensional, fabricating, assembly and allowable stress considerations, it may be advisable to deviate from this 50-50 optimum division. In so doing, there are an infinite number of variations which can be calculated; however, there are a few interesting limitations. If one-third of the total available temperature change is used for developing force, the formulas will arrive at the shortest element for a given width for these types: cantilever, simple beam, U-shape spiral or helix coil. If two-thirds of the total available temperature change is used for developing force, the thinnest element for a given width is obtained for cantilevers, simple beams and U-shapes. By using most of the available temperature change to produce force in spiral and helix coils, the strip can be made as thin as is practical; however, this necessitates increasing the length of the strip proportionally.

Change in slope:
Sometimes it is important to know the change in slope of the end or some other point of a thermostatic bimetal element. For an element free to move, this change is given by the thermal deflection formula for spiral and helix coils but it applies to any shape element.

Minimum volume of material:
Using the thermostatic bimetal with the highest flexivity in the working temperature range permits the use of a minimum volume of material for a given combination of deflection and force.

KEY TO SYMBOLS USED IN FORMULAS

- Thickness (t), Width (w), Length (L), Deflection (B), Outer Disc Diameter (D), Inner Disc Diameter (d), and Radius (r) in inches
- Angular Deflection (A) in degrees

- Modulus of Elasticity (E) in Psi
- Flexivity (F) in (in/in)/(°F)
- Force (P) in ounces
- Temperature Change (T_2-T_1) in °F

GENERAL LAWS GOVERNING THERMOSTATIC BIMETALS

DEFLECTION on temperature change varies:

For cantilever, Simple Beam, and U shape	For Spiral and Helix
Directly as temperature change	Directly as temperature change
Directly as length squared	Directly as length
Inversely as thickness	Inversely as thickness

FORCE exerted on temperature change varies:

For cantilever, Simple Beam, and U shape	For Spiral and Helix
Directly as temperature change	Directly as temperature change
Directly as width	Directly as width
Inversely as thickness squared	Inversely as thickness squared
Inversely as length	Inversely as radius

*Note: Only two properties of thermostatic bimetal, flexivity (F) and modulus of elasticity (E), are needed to solve any or all the formulas in this guide.

CANTILEVER STRIPS (English Units)

THERMAL DEFLECTION

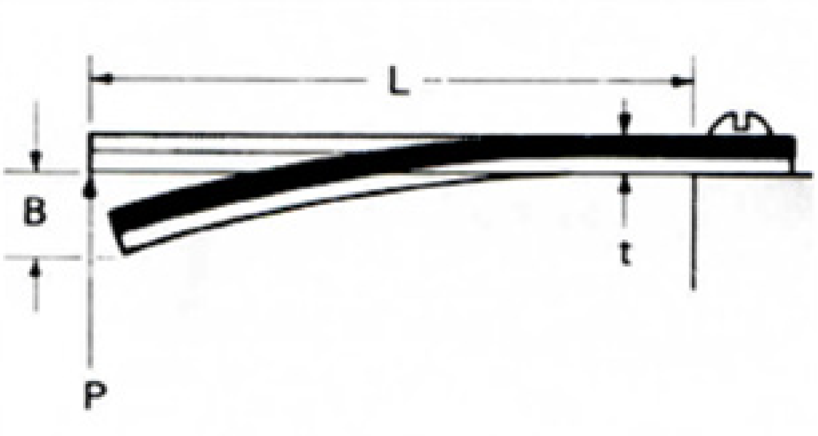
$$B = \frac{0.53F\,(T_2 - T_1)L^2}{t}$$

MECHANICAL FORCE

$$P = \frac{4EBwt^3}{L^3}$$

THERMAL FORCE

$$P = \frac{2.12EF\,(T_2 - T_1)wt^2}{L}$$



THERMAL DEFLECTION

A strip of B1 thermostatic bimetal having a 1.75" active length is to be used as a cantilever element. A deflection of 0.125" at the free end is to be produced by a temperature change from 80°F to 290°F. Find the thickness of the strip required. By averaging the flexivity values from 50°F to 200°F a flexivity of 150 x 10-[7](in/in)/°F is obtained.

$$B = \frac{0.53F\,(T_2 - T_1)L^2}{t} \rightarrow t = \frac{0.53F\,(T_2 - T_1)L^2}{B} \rightarrow t = \frac{0.53\,(150\,x\,10^{-7}\frac{(in/in)}{°F})(290°F - 80°F)(1.75in)^2}{0.125in} \rightarrow \boxed{t = 0.0409\ in}$$

MECHANICAL FORCE

Using a cantilever strip of B1 thermostatic bimetal 0.030" x 0.5" x 1.5" active length find its mechanical spring rate.

$$P = \frac{4EBwt^3}{L^3} \rightarrow \frac{P}{B} = \frac{4EBwt^3}{L^3} \rightarrow \frac{P}{B} = \frac{16\frac{ozs}{lbs}(25\ X\ 10^6(lbs/in^2))(0.5in)(0.030in)^3}{4(1.5in)^3} \rightarrow \boxed{\frac{P}{B} = 400\frac{oz}{in}}$$

COMBINATION OF THERMAL DEFLECTION AND THERMAL FORCE

A cantilever strip of P675R Thermostatic Bimetal 0.75" wide is to move 0 .267" and develop a force of 4.8 lbs at the free end when subjected to a temperature change from 75°F t o 315°F. Find the thickness and active length of strip required. By averaging the flexivity values from 100°F to 300°F a flexivity of 216×10^{-7} (in/in)/°F is obtained.

$$B = \frac{0.53F\,(T_2 - T_1)L^2}{t} \rightarrow t = \frac{0.53F\,(T_2 - T_1)L^2}{B} \rightarrow t = \frac{0.53\left(216\,x\,10^{-7}\frac{(in/in)}{°F}\right)(0.5^*)(315°F - 75°F)L^2}{0.267in} \rightarrow t = 0.00515L^2$$

Substitute the result from the thermal deflection equation into the thermal force equation

$$P = \frac{2.12EF\,(T_2 - T_1)wt^2}{L} \rightarrow (4.8lbs)\left(\frac{16\ oz}{lb}\right) = \frac{2.12\left(19.0x10^6\left(lbs/in^2\right)\right)\left(216\,x\,10^{-7}\frac{(in/in)}{°F}\right)(0.5^*)(315°F - 75°F)(0.75in)\left(0.00515L^2\right)^2}{L}$$

$$L^3 = \frac{(4.8lbs)\left(\frac{16\ oz}{lb}\right)}{2.12\left(19.0x10^6(lbs/in^2)\right)\left(216\,x\,10^{-7}\frac{\left(\frac{in}{in}\right)}{°F}\right)(0.5^*)(315°F - 75°F)(0.75in)(0.00515)^2} \rightarrow L^3 = 37.05in^3 \rightarrow \boxed{L = 3.33in}$$

Substitute the result for L to solve for t

$$t = 0.00515L^2 \rightarrow t = 0.00515(3.33in)^2 \rightarrow \boxed{t = 0.0571\ in}$$

*Note: For maximum effectiveness and minimum volume of thermostatic bimetal, one half the temperature changes should be used in computations to produce the deflection and the other half used to develop the force. This temperature distribution is used in the example above.

U SHAPE ELEMENTS (English Units)

THERMAL DEFLECTION

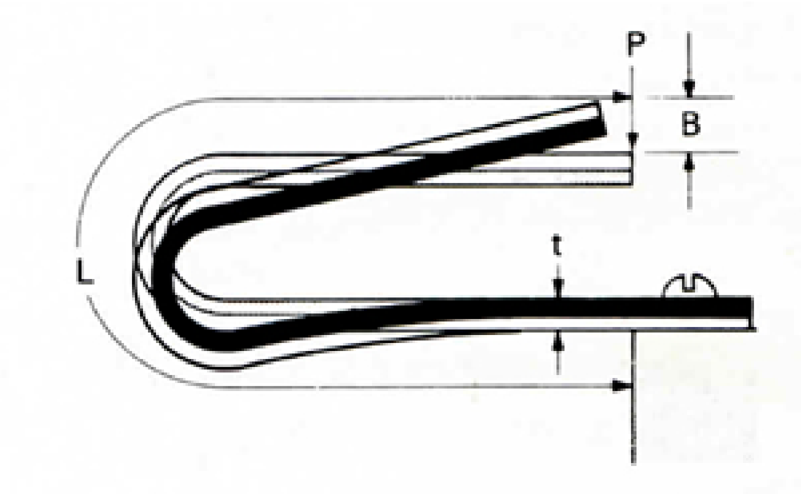
$$B = \frac{0.265F\,(T_2 - T_1)L^2}{t}$$

MECHANICAL FORCE

$$P = \frac{16E\,Bwt^3}{L^3}$$

THERMAL FORCE

$$P = \frac{4.24EF\,(T_2 - T_1)wt^2}{L}$$



THERMAL DEFLECTION

A U-shape element of P675R thermostatic bimetal 0.025" thick is available. A movement of 0.075" is to be produced at the free end by a temperature change from 50°F to 200"F. Find the active length of the strip required.

$$B = \frac{0.265F\,(T_2 - T_1)L^2}{t} \quad \rightarrow \quad L^2 = \frac{Bt}{0.265F(T_2 - T_1)}$$

From the table of mechanical and physical properties, the flexivity is $217\text{x}10^{-7}$ (in/in)/°F

$$L^2 = \frac{(0.075in)(0.025in)}{0.265\left(217\ x\ 10^{-7}\frac{(in/in)}{°F}\right)(200°F - 50°F)} \quad \rightarrow \quad L^2 = 2.17in^2 \quad \rightarrow \quad \boxed{L = 1.47\ in}$$

Note: Free deflection calculations are independent of width. Therefore, any width suitable for the application may be chosen.

MECHANICAL FORCE

A U-shape of P675R thermostatic bimetal 0.060" x 0.75" x 8" active length is available. Find the mechanical deflection at the free end due to the application of a load of 0.75 Lbs.

$$P = \frac{16EBwt^3}{L^3} \quad \rightarrow \quad B = \frac{PL^3}{16Ewt^3} \quad \rightarrow \quad B = \frac{(0.75\ lbs)\left(16\ \frac{oz}{lbs}\right)(8\ in)^3}{16(19.0\ x\ 10^6(lbs/in^2))(0.75\ in)(0.060\ in)^3} \quad \rightarrow \quad \boxed{B = 0.125\ in}$$

COMBINATION OF THERMAL DEFLECTION AND THERMAL FORCE

A space of about 1" length is available to accommodate a U- shape element with an active length of 1.6". A movement of 0.067" and a force of 5.5 ounces at the free end is to be produced by a temperature change from 50°F to 250°F. The material must withstand a temperature of 700°F. Find the type of material, its thickness and width.

(1) First choose a material. Materials should be chosen such that they can withstand the maximum service temperature.

Note: P675R being the most active in this temperature range would ordinarily be selected. The temperature limitation dictates the use of B1 with a flexivity of 149 x 10^{-7}(in/in)/°F, from 50 to 250°F.

$$B = \frac{2.65F\,(T_2-T_1)L^2}{t} \rightarrow t = \frac{0.265F\,(T_2-T_1)L^2}{B} \rightarrow t = \frac{0.265\left(149\,x\,10^{-7}\frac{(in/in)}{°F}\right)(0.5^{*})(250°F-50°F)(1.6\,in)^2}{(0.067\,in)} \rightarrow \boxed{t = 0.015\,in}$$

Substitute the thickness into the Thermal Force Equation

$$P = \frac{4.24EF\,(T_2-T_1)wt^2}{L} \rightarrow w = \frac{PL}{4.24EF(T_2-T_1)t^2} \rightarrow w = \frac{(5.5\,oz)(1.6\,in)}{4.24\,(25.0\,x\,10^6(lbs/in^2))\left(149\,x\,10^{-7}\frac{(in/in)}{°F}\right)(0.5^{*})(250°F-50°F)(0.015\,in)^2} \rightarrow \boxed{w = 0.248\,in}$$

*Note: for maximum effectiveness and minimum volume of thermostatic bimetal, one half of the temperature change should be used in computations to produce the deflection and the other half used to develop the force. This temperature distribution is used in the example above.

CREEP TYPE DISCS (English Units)

THERMAL DEFLECTION

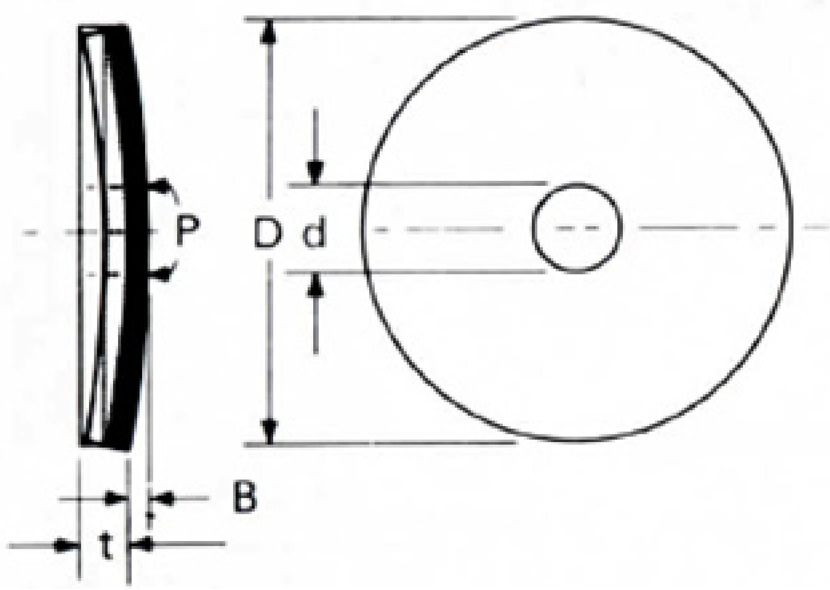
$$B = \frac{0.106F(T_2 - T_1)(D^2 - d^2)}{t}$$

MECHANICAL FORCE

$$P = \frac{64EBt^3}{(D^2 - d^2)}$$

THERMAL FORCE

$$P = 6.78EF\,(T_2 - T_1)t^2$$



THERMAL DEFLECTION

A solid disc of B1 thermostatic bimetal with a diameter of 1" is to deflect 0.0105" for a temperature change of 100°F. Find the thickness of the material.

$$B = \frac{0.106F\,(T_2 - T_1)(D^2 - d^2)}{t} \rightarrow \quad t = \frac{0.106F\,(\Delta T)(D^2 - d^2)}{B}$$

$$t = \frac{0.106\left(150\ x\ 10^{-7}\frac{(in/in)}{°F}\right)(100°F)\left((1\ in)^2 - (0in)^2\right)}{0.0105\ in} \rightarrow \boxed{t = 0.015\ in}$$

MECHANICAL FORCE

Find the mechanical force rate of the above disc if it has a 0.2" diameter hole in the center

$$P = \frac{64E\,Bt^3}{(D^2 - d^2)} \rightarrow \quad \frac{P}{B} = \frac{64Et^3}{(D^2 - d^2)} \rightarrow \quad \frac{P}{B} = \frac{4(16\frac{ozs}{lbs})\left(25.0\ x\ 10^6(lbs/in^2)\right)(0.015\ in)^3}{(1\ in)^2 - (0.2\ in)^2} \rightarrow \boxed{\frac{P}{B} = 5625\ oz/in}$$

COMBINATION OF THERMAL DEFLECTION AND THERMAL FORCE

A disc of P675R thermostatic bimetal is to produce a deflection of 0.007" and a force of 16 pounds when subjected to a temperature change from 200°F to 350°F. Find the thickness and diameter of the disk.

The average flexivity of P675R is 216 x 10^{-7}(in/in)/°F, between 200 and 350°F.

$$P = 6.78EF\,(T_2 - T_1)t^2 \rightarrow \quad t = \left(\frac{P}{6.78EF\,(T_2 - T_1)}\right)^{\frac{1}{2}}$$

$$t = \left(\frac{(16lbs)\left(16\frac{oz}{lbs}\right)}{6.78\left(19\ x\ 10^6\ (lbs/in^2)\right)\left(216\ x\ 10^{-7}\frac{(in/in)}{°F}\right)(0.5^*)(350°F - 200°F)}\right)^{\frac{1}{2}} \rightarrow \boxed{t = 0.034\ in}$$

$$B = \frac{0.106F\,(T_2 - T_1)(D^2 - d^2)}{t} \rightarrow \quad d^2 = 0 \quad \rightarrow \quad \therefore D = \left(\frac{Bt}{0.106F(T_2 - T_1)}\right)^{\frac{1}{2}}$$

$$D = \left(\frac{(0.007\ in)(0.034\ in)}{0.106\left(216\ x\ 10^{-7}\frac{(in/in)}{°F}\right)(0.5^*)(350°F - 200°F)}\right)^{\frac{1}{2}} \rightarrow \boxed{D = 1.20\ in}$$

*Note: for maximum effectiveness and minimum volume of thermostatic bimetal, one half of the temperature change should be used in computations to produce the deflection and the other half used to develop the force. This temperature distribution is used in the example above

SIMPLE BEAMS (English Units)

THERMAL DEFLECTION

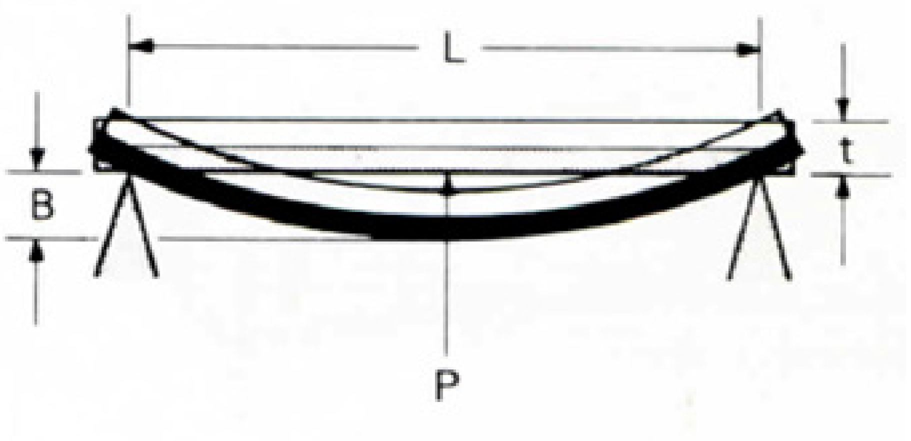
$$B = \frac{0.133F\ (T_2 - T_1)L^2}{t}$$

MECHANICAL FORCE

$$P = \frac{64EBwt^3}{L^3}$$

THERMAL FORCE

$$P = \frac{8.51EF\ (T_2 - T_1)wt^2}{L}$$



THERMAL DEFLECTION

A strip of P675R thermostatic bimetal 0.035″ thick is to be used as a simple beam. Supports 3″ apart are available for positioning the beam. A movement of 0.045″ is required at the center of the beam. Find the temperature change required.

$$B = \frac{0.133F\ (T_2 - T_1)L^2}{t} \quad \rightarrow \quad \Delta T = \frac{Bt}{0.133F\ L^2}$$

$$\Delta T = \frac{(0.045\ in)(0.035\ in)}{(0.133)\left(217\ x\ 10^{-7}\frac{(in/in)}{°F}\right)(3\ in)^2} \quad \rightarrow \quad \boxed{\Delta T = 60.6°F}$$

Note: Free deflection calculations are independent of width. Therefore, any width suitable for the application may be chosen.

MECHANICAL FORCE

A simple beam of E5 thermostatic bimetal 0.375″ wide by 1.5″ active length between two supports is available. A force of 4 ounces is to be supported at the center with a resultant deflection of 0.020″. Find the thickness of the strip required.

$$P = \frac{64EBwt^3}{L^3} \quad \rightarrow \quad t = \left(\frac{PL^3}{64EBw}\right)^{\frac{1}{3}}$$

$$t = \left(\frac{(4\ oz)\ (1.5\ in)^3}{4(16\frac{ozs}{lbs})(25.5\ x\ 10^6(lbs/in^2))(0.020\ in)(0.375\ in)}\right)^{\frac{1}{3}} \rightarrow \quad \boxed{t = 0.0103\ in}$$

COMBINATION OF THERMAL DEFLECTION AND THERMAL FORCE

A simple beam of E5 thermostatic bimetal 0.025” x 0.375” x 3.5” active length is subjected to a temperature change from 300°F to 800°F. Maximum work is required of the beam. Find the deflection and force obtainable. Flexivity of E5 is 79 x 10^{-7}(in/in)/°F, in range of 300 and 800°F.

$$B = \frac{0.133F\,(T_2 - T_1)L^2}{t}$$

$$B = \frac{0.133\left(79\ x\ 10^{-7}\frac{(in/in)}{°F}\right)(0.5^*)(800°F - 300°F)(3.5\ in)^2}{(0.025\ in)} \rightarrow \boxed{B = 0.128\ in}$$

$$P = \frac{8.51EF\,(T_2 - T_1)wt^2}{L} \rightarrow P = \frac{8.51\left(25.5x10^6\ (lbs/in^2)\right)\left(79x10^{-7}\frac{(in/in)}{°F}\right)(0.5^*)(800°F - 300°F)(0.375\ in)(0.025\ in)^2}{3.5\ in} \quad \boxed{P = 28.7\ oz}$$

*Note: for maximum effectiveness and minimum volume of thermostatic bimetal, one half of the temperature change should be used in computations to produce the deflection and the other half used to develop the force. This temperature distribution is used in the example above.

SPIRAL AND HELIX COILS (English Units)

THERMAL DEFLECTION

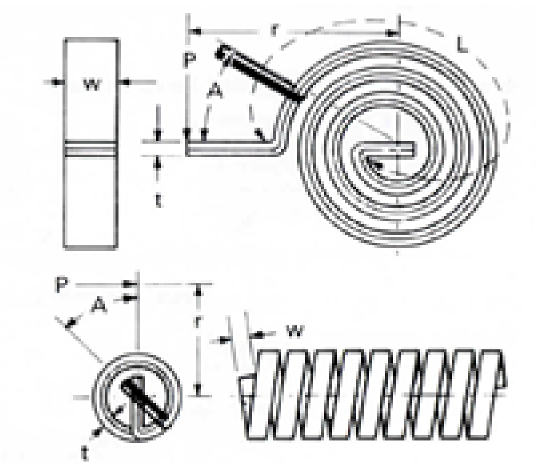
$$A = \frac{67F\,(T_2 - T_1)L^2}{t}$$

MECHANICAL FORCE

$$P = \frac{0.0232E\,Awt^3}{Lr}$$

THERMAL FORCE

$$P = \frac{1.55EF\,(T_2 - T_1)wt^2}{r}$$



THERMAL DEFLECTION

A spiral coil is to be used as a thermometer element. The dial has a 270° angle from 100°F to 700°F. Determine type of material and size.

E4 is the selected as it is the most active in this temperature range. The Average Flexivity of E4 is 98 x 10^{-7} (in/in)/°F.

$$A = \frac{67F\,(T_2 - T_1)L}{t} \rightarrow t = \frac{67F\,(T_2 - T_1)L}{A} \rightarrow t = \frac{67\left(98 \times 10^{-7} \frac{(in/in)}{°F}\right)(700°F - 100°F)L}{270°} \rightarrow t = 0.00146L$$

Note: There are an unlimited number of combinations of length and thickness per the formula that will satisfy the deflection requirements. The final size will be determined by space available, rigidity, suitability for production, etc. Assume space is available for a 6" active length.

$$t = 0.00146L \rightarrow t = 0.00146(6\ in) \rightarrow \boxed{t = 0.00875\ in}$$

Note: Free deflection calculations are independent of width. Therefore, any width suitable for the application may be chosen.

MECHANICAL FORCE

A spiral coil of B1 thermostatic bimetal 0.030" x 0.375" is available. The coil is to have a mechanical torque rate of 0.3 (in oz). Find the active length of the coil and the load at 0.75" radius.

$$P = \frac{0.0232EAwt^3}{Lr} \rightarrow L = \frac{0.0232E\ Awt^3}{Pr} \rightarrow L = \frac{16\frac{ozs}{lbs}0.0232\left(25 \times 10^6 (lbs/in^2)\right)(1°)(0.375\ in)(0.030\ in)^3}{(16)\ 0.3\ (oz\ in)} \rightarrow \boxed{L = 19.6\ in}$$

$$P = \frac{Pr}{r} \rightarrow P = \frac{0.3\ (oz\ in)}{0.75\ in} \rightarrow \boxed{P = 0.4\ oz\ at\ 0.75"\ radius}$$

COMBINATION OF THERMAL DEFLECTION AND THERMAL FORCE

A spiral coil of B1 thermostatic bimetal 0.3125" wide is to have a thermal deflection rate of 1.2 angular degrees per degree F and a mechanical torque rate of 0.049 ounce inches per angular degree of rotation. Find the thickness and active length of the coil strip required.

Note: Either the thermal deflection and mechanical force formulas, or the thermal deflection and thermal force formulas may be used. It is somewhat easier to use the latter two formulas since length is not a factor in the thermal force formula.

$$P = \frac{1.55EF\,(T_2 - T_1)wt^2}{r} \rightarrow t = \left(\frac{Pr}{1.55\ EF\ (\Delta T)w}\right)^{1/2} \rightarrow t = \left(\frac{\left(1.2\frac{°}{°F}\right)\left(0.049\left(\frac{oz\ in}{°}\right)\right)}{1.55\left(25.0x10^6\ (lbs/in^2)\right)\left(150 \times 10^{-7}\frac{(in/in)}{°F}\right)(1°F)(0.3125\ in)}\right)^{1/2} \rightarrow \boxed{t = 0.018\ in}$$

$$A = \frac{67F\,(T_2 - T_1)L}{t} \rightarrow L = \frac{At}{67F(\Delta T)} \rightarrow L = \frac{(1.2°)\ (0.018\ in)}{67\left(150 \times 10^{-7}\frac{(in/in)}{°F}\right)(1°F)} \rightarrow \boxed{L = 21.5\ in}$$

*Note: Although not involved in this example, for maximum effectiveness and minimum volume of thermostatic bimetal, one half of the temperature change should be used in computations to produce the deflection and the other half used to develop the torque

REVERSE ELEMENTS (English Units)

Additional Symbols for Reversed Elements Only:

T_a =	Thickness in inches of section a	d =	Length in inches of section d
T_b =	Thickness in inches of section b	R =	Mean radius in inches
a =	Length in inches of section a	F_a =	Flexivity of section a
b =	Length in inches of section b	F_b =	Flexivity of section b
c =	Length in inches of section c		

CANTILEVER ELEMENT

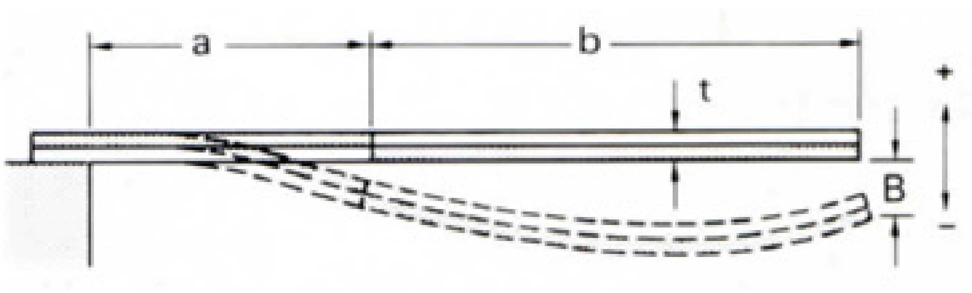
THERMAL DEFLECTION

$$B = \frac{0.53F\,(T_2 - T_1)}{t}(b^2 - 2\,ab - a^2)$$

when b>2.4a B = +

b=2.4a B = 0

b<2.4a B = -



A reverse welded cantilever element of B1 thermostatic bimetal is available with section a = 1" and section b = 2". Find the thickness required to give a deflection of -0.026" from 50°F to 150°F.

The average Flexivity of B1 is 150 x 10^{-7}(in/in)/°F.

$$B = \frac{0.53F\,(T_2 - T_1)}{t}(b^2 - 2\,ab - a^2) \rightarrow t = \frac{0.53F(T_2 - T_1)(b^2 - 2ab - a^2)}{B} \rightarrow t = \frac{0.53\left(150x10^{-7}\frac{(in/in)}{°F}\right)(150°F - 50°F)\left((2\,in)^2 - 2(1in)(2in) - (1\,in)^2\right)}{-0.026\,in}$$

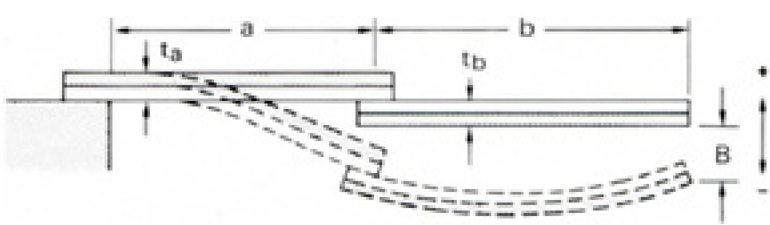
$$\boxed{t = 0.0306\,in}$$

CANTILEVER ELEMENT

A lap-welded element made of two different materials of different thicknesses and lengths

THERMAL DEFLECTION

$$B = 0.53(T_2 - T_1)\left[\frac{F_b\,b^2}{t_b} - \frac{F_a(a^2 + 2ab)}{t_a}\right]$$



A reverse lap-welded element is made of E4 and B2. The E4 is 0.040" x 1" (section a); the B2 is 0.020" x 0.5" (section b). Find the deflection through a temperature change from 100°F to 500°F

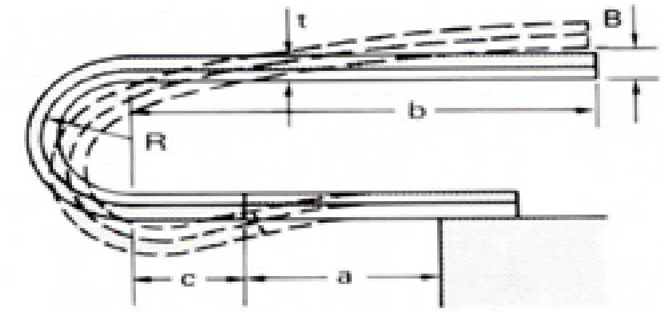
The average flexivity of E4 and B2 are 94 x 10^{-7}(in/in)/°F and 133 x 10^{-7}(in/in)/°F respectively.

$$B = 0.53(T_2 - T_1)\left[\frac{F_b b^2}{t_b} - \frac{F_a(a^2+2ab)}{t_a}\right] \rightarrow B = 0.53(500°F - 100°F)\left[\frac{\left(133x10^{-7}\frac{(in/in)}{°F}\right)(0.5\ in)^2}{0.020\ in} - \frac{\left(94x10^{-7}\frac{(in/in)}{°F}\right)\left((1\ in)^2+2(1\ in)(0.5\ in)\right)}{0.040in}\right]$$

$$\boxed{B = -0.064\ in}$$

U SHAPE ELEMENT

THERMAL DEFLECTION



$$B = \frac{0.53F(T_2-T_1)}{t}\left[(b^2 + 4R^2 + 2\pi\ Rb) - (c^2 - 2ac - a^2) + 2b(c-a)\right]$$

A strip of reversed welded P675R thermostatic bimetal is formed into a U-shape with the following dimensions: c = 0.5", b = 2", a = 1", R = 0.25". Find the thickness of material required to give a deflection of 0.15" from 50°F to 150°F.

$$B = \frac{0.53F(T_2-T_1)}{t}\left[(b^2 + 4R^2 + 2\pi\ Rb) - (c^2 - 2ac - a^2) + 2b(c-a)\right]$$

$$t = \frac{0.53F(T_2-T_1)}{B}\left[(b^2 + 4R^2 + 2\pi\ Rb) - (c^2 - 2ac - a^2) + 2b(c-a)\right]$$

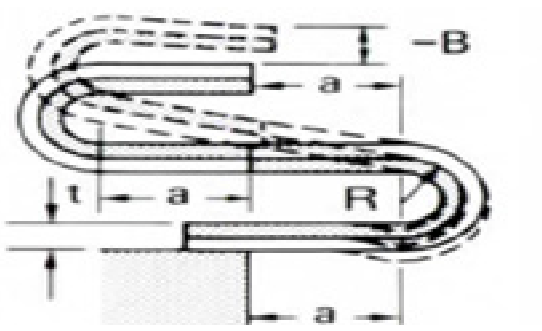
$$t = \frac{0.53F\left(217\ x\ 10^{-7}\frac{(in/in)}{°F}\right)(150°F-50°F))}{0.15\ in}\left[((2in)^2 + 4(0.25in)^2 + 2\pi(0.25in)(2in)) - ((0.5in)^2 - 2(1in)(0.5in) - (1in)^2) + 2(2in)(0.5in - 1in))\right]$$

$$\boxed{t = 0.055\ in}$$

TWO U SHAPE ELEMENTS

THERMAL DEFLECTION

$$B = \frac{2.12F(T_2 - T_1)}{t}\ (a^2 + \pi\ Ra + 2R^2)$$



A reverse welded thermostatic bimetal U-shape is made of 0.20″ thick B1 with 0.5″ radii and section a = 1″. Find the deflection from 50°F to 200°F. The flexivity of B1 is 150 x 10^{-7}(in/in)/°F.

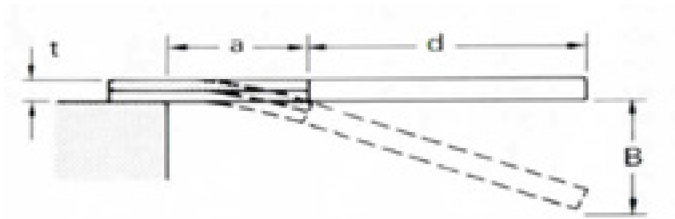
$$B = \frac{2.12F(T_2 - T_1)}{t} \left(a^2 + \pi\, Ra + 2R^2\right) \rightarrow B = \frac{2.12\left(150\ x\ 10^{-7}\frac{(in/in)}{°F}\right)(200°F - 50°F)}{0.020\ in}\left((1in)^2 + \pi(0.5in)(1in) + 2(0.5in)^2\right)$$

$$\boxed{B = 0.734\ in}$$

THERMOSTATIC BIMETAL & INACTIVE METAL CONTILEVER STRIP

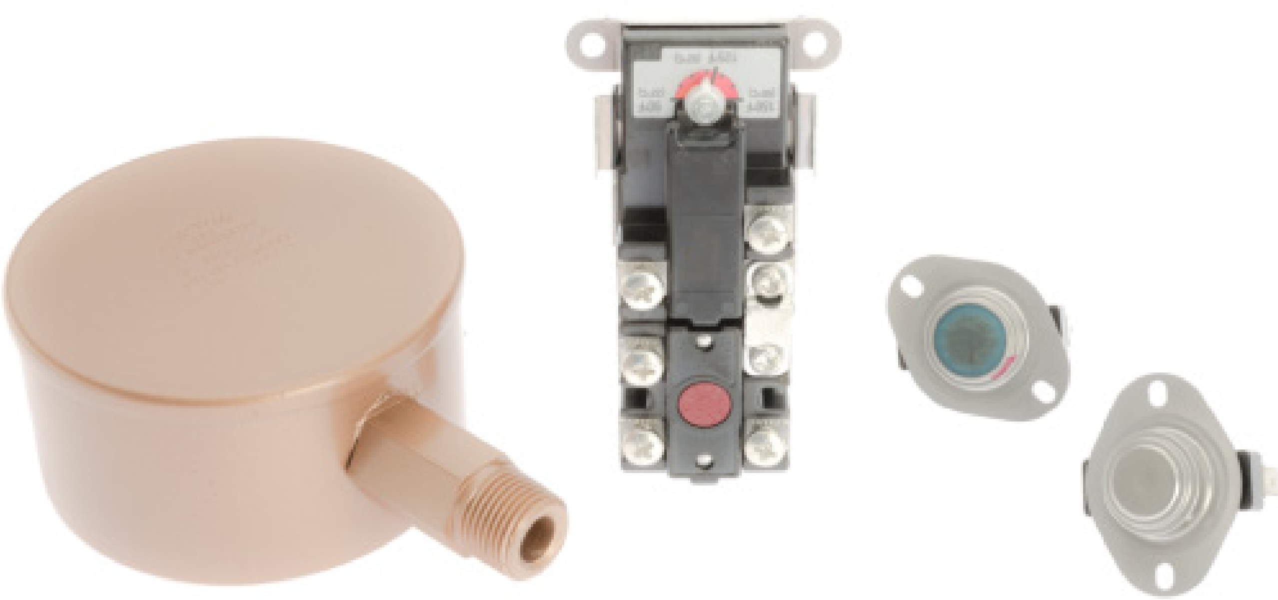
THERMAL DEFLECTION

$$B = \frac{0.53F\ (T_2 - T_1)(a^2 + 2ad)}{t}$$



A strip composed of 1″ of B1 thermostatic bimetal butt welded to 1-1/2″ of a thermally inactive material is to be used as a cantilever. Using 0.030″ thick material, find the deflection produced by changing the temperature from 50°F to 200°F. The flexivity of B1 between 50°F to 200°F range is 150 x 107(in/in)/°F.

$$B = \frac{0.53F\ (T_2 - T_1)(a^2 + 2ad)}{t} \rightarrow B = \frac{0.53\left(150\ x\ 10^{-7}\frac{(in/in)}{°F}\right)(200°F - 50°F)\left((1\ in)^2 + 2(1\ in)(1.5\ in)\right)}{0.030} \rightarrow \boxed{B = 0.159\ in}$$



USEFUL EQUATIONS FOR DESIGNERS *(Metric Units)*

Cantilever

THERMAL DEFLECTION: $B = \frac{f(T_2 - T_1)L^2}{t}$

MECHANICAL FORCE: $P = \frac{E\,B\,wt^3}{4L^3}$

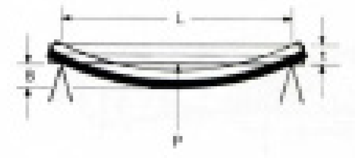
THERMAL FORCE: $P = \frac{Ef(T_2 - T_1)wt^2}{4L}$

Simple Beam

THERMAL DEFLECTION: $B = \frac{f(T_2 - T_1)L^2}{4t}$

MECHANICAL FORCE: $P = \frac{4E\,B\,wt^3}{L^3}$

THERMAL FORCE: $P = \frac{Ef(T_2 - T_1)wt^2}{L}$

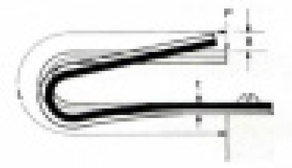


U-Shape

THERMAL DEFLECTION: $B = \frac{f(T_2 - T_1)L^2}{2t}$

MECHANICAL FORCE: $P = \frac{E\,B\,wt^3}{L^3}$

THERMAL FORCE: $P = \frac{Ef(T_2 - T_1)wt^2}{2L}$



Spiral Coil

THERMAL DEFLECTION: $A = \frac{f(T_2 - T_1)L \times 10^3}{8t}$

MECHANICAL FORCE: $P = \frac{E\,A\,wt^3}{690\,Lr}$

THERMAL FORCE: $P = \frac{Ef(T_2 - T_1)wt^2}{5.5r}$

Helix Coil

THERMAL DEFLECTION: $A = \frac{f(T_2 - T_1)L \times 10^3}{8t}$

MECHANICAL FORCE: $P = \frac{E\,A\,wt^3}{690\,Lr}$

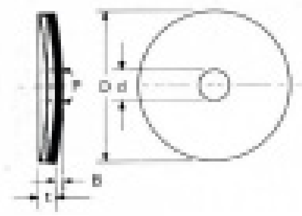
THERMAL FORCE: $P = \frac{Ef(T_2 - T_1)wt^2}{5.5r}$

Disc

THERMAL DEFLECTION: $B = \frac{f(T_2 - T_1)(D^2 - d^2)}{5t}$

MECHANICAL FORCE: $P = \frac{4E\,B\,t^3}{(D^2 - d^2)}$

THERMAL FORCE: $P = \frac{4\,Ef(T_2 - T_1)t^2}{5}$



KEY TO SYMBOLS USED IN FORMULAS

- t = Thickness in mm.
- w = Width in mm.
- L = Active length in mm.
- P = Force in Newtons
- B = Deflection in mm.
- E = Modulus of Elasticity in N/mm²
- f = Specific deflection in (mm/mm)/°C
- D = Diameter of disc in mm.
- A = Angular rotation for coils in degrees
- r = Radius in mm. at point load is applied.
- d = Diameter of hole in disc in mm.
- $(T_2 - T_1)$ = Temperature change in °C

INSTANTANEOUS FLEXIVITY VALUES, (F) (x 10^{-7} (in/in)/°F)

Truflex Type	-100	-50	0	50	100	150	200	250	300	350	400	450	500	550	600	650	700	800	900	1000	Mod. Of Elast. E x 10^6
A1	146	148	149	150	150	150	149	146	142	134											18.0
B1	126	135	144	150	150	150	150	146	139	130	116	92	68	47	38	35	31	28	24	22	25.0
B2	108	114	118	123	126	129	130	132	134	135	137	138	135	124	92	69	55	47	44	38	25.0
B3	87	96	105	112	119	121	125	127	131	132	133	133	135	135	129	107	80	51	47	40	25.0
B11	113	120	125	135	137	142	146	146	146	146	146	142	120	98	83	65	57	37	33	30	25.0
BN	35	38	44	44	45	47	48	47	47	43	38	36	33	30	29	23	15				28.5
BP1	150	168	189	185	185	185	186	186	186	185	183	165	139	129	126						20.0
B100R	102	110	112	113	113	114	114	113	106	100	86	65	42	32	25	22	17	16	16	16	26.0
B125R	113	123	128	129	130	129	128	126	125	119	99	77	56	46	32	28	25	23	19	17	26.0
B150R	118	126	135	136	137	138	136	135	130	121	105	76	53	42	37	31	26	19	17	16	26.0
B175R	122	129	141	142	142	143	142	141	135	125	109	78	54	45	38	31	28	21	18	16	25.5
B200R	124	134	143	143	144	145	145	140	134	126	112	81	50	40	31	30	26	25	22	18	25.5
B250R	130	140	142	147	147	147	147	144	139	125	112	82	67	53	44	38	30	28	25	22	25.5
B300R	132	142	145	149	149	150	149	146	141	128	112	83	67	53	44	38	30	28	25	22	25.0
B350R	135	140	147	149	150	150	148	144	140	129	111	81	64	48	33	31	29	25	23	21	25.0
B400R	135	140	147	149	150	150	148	144	140	129	111	81	64	48	33	31	29	25	23	21	25.0
C1	136	142	149	153	154	154	153	149	144	117	102	85	65	49	39	31	25	15	14	12	25.0
C3	99	107	113	119	121	124	126	129	132	137	138	140	146	148	148	131	116	62	26	15	25.0
C11	118	129	136	140	143	145	149	151	152	152	152	149	125	95	73	57	45	31	19	15	25.0
D560R	128	135	143	145	145	143	142	139	137	125	112	109	69	57	48	43	40	35	34	32	24.0
E1	125	129	136	138	139	138	135	134	133	118	100	73	54	39	33	26	25	22	19	17	25.0
E3	77	83	90	93	99	105	108	112	116	120	121	121	121	121	121	108	60	41	30	23	25.0
E4	62	63	69	75	78	82	85	92	96	98	101	104	107	107	107	107	107	56	38	25	25.5
E5	44	47	51	55	57	60	66	68	71	74	75	77	81	82	83	83	83	82	59	45	25.5
F15R	63	70	72	73	72	71	67	66	63	52	47	43	38	31	28	22	13				20.0
F20R	114	121	124	127	128	129	127	126	118	109	93	68	48	38	28	22	15				20.0
F25R	119	130	133	134	135	135	134	129	125	118	97	72	52	41	31	25	19				22.0
F30R	129	134	137	139	139	139	137	132	127	118	97	72	52	42	33	26	19				23.0
F35R	130	137	141	143	143	141	140	137	130	121	98	72	53	44	36	29	21				23.5
F40R	131	139	142	144	144	144	142	139	135	123	100	72	56	46	39	32	23				24.0
F50R	134	141	144	146	146	145	145	142	136	124	101	75	58	47	39	32	24				24.0
F60R	133	139	145	146	146	146	144	140	134	123	100	74	58	46	40	32	25				24.5
F70R	135	140	147	147	147	147	144	141	135	123	100	75	59	46	32	32	25				24.5
F90R	137	143	145	147	149	149	146	143	137	128	107	75	60	47	41	34	27				25.0
F100R	137	143	145	148	149	149	147	143	138	128	110	77	65	49	41	34	29				25.0
F125R	137	143	145	148	149	149	147	143	138	128	110	77	65	49	41	34	29				25.0
G1	124	130	137	138	139	139	138	135	132	120	99	75	60	37	30	30	24	15	9	5	25.0
G3	83	89	95	97	101	107	110	116	119	121	121	121	121	121	115	95	68	52	39	32	25.0
G7	60	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	45	39	27.5
GB14	95	99	102	103	104	103	102	101	100	86	64	57	45	37	27	24	22	18	15	13	26.0
J1	124	129	132	134	135	135	134	131	130	115	89	63	48	39	29						19.0
J7	54	56	56	56	56	56	56	56	56	56	56	56	56	56	56						22.0
M7	38	40	40	40	40	40	40	39	39	39	39	39	39	39	39	39	39	37	35	32	27.5
MB15	122	125	134	140	140	141	140	140	138	134	118	94	71	56	47	40	35	29	24	16	24.0
N1	86	94	99	102	103	103	102	101	97	87	67	43	26	20	14	8	6	0	-5	-8	26.0
P3	148	155	164	171	176	182	189	195	202	210	216	222	224	220	210						20.0
P30R	135	161	183	187	188	189	189	189	189	185	183	161	135	121	114						20.0
P35R	139	168	192	194	198	198	198	198	198	193	190	169	140	126	118						20.0
P40R	143	171	194	198	201	201	201	201	201	196	193	171	143	131	122						20.0
P50R	146	176	198	202	207	207	207	207	207	201	198	176	146	132	121						20.0
P60R	150	179	203	207	210	210	210	210	210	206	203	179	150	136	129						20.0
P70R	150	180	203	207	211	211	211	211	211	206	203	180	150	136	129						20.0
P90R	151	182	205	210	214	214	214	214	214	209	206	182	151	138	128						20.0
P100R	153	184	207	211	215	215	215	215	215	210	207	184	153	138	129						20.0
P125R	156	185	209	213	216	216	216	216	216	212	209	185	155	139	129						20.0
P150R	155	184	209	213	216	216	217	217	216	211	208	184	154	138	129						20.0
P175R	155	184	209	213	216	216	217	217	216	211	208	184	154	138	129						20.0
P200R	155	184	209	213	216	216	217	217	216	211	208	184	154	138	129						20.0
P250R	154	184	208	213	216	216	217	217	216	211	208	185	153	140	130						20.0
P300R	154	184	208	213	216	216	216	216	216	211	208	185	154	138	130						20.0
P350R	155	184	209	213	216	216	216	216	215	211	209	184	154	140	129						20.0
P400R	155	184	209	213	216	216	216	216	215	211	209	184	154	140	129						20.0
P450R	155	185	209	214	216	216	216	216	215	212	210	185	154	140	130						20.0
P500R	155	185	209	214	216	216	216	216	215	212	210	185	154	140	130						20.0
P550R	153	183	207	212	216	216	216	216	216	211	207	183	154	139	130						20.0
P600R	155	184	209	213	216	216	216	216	216	211	208	184	154	140	129						20.0
P675R	174	196	208	215	215	215	216	216	216	215	213	191	162	150	146						20.0
P850R	133	145	148	149	150	150	150	150	148	142	136	132	120	108	90						19.5
PJ	61	65	69	71	76	76	78	80	81	82	84	87	89	90	90						17.0
1513	-60	-54	-48	-38	-29	-18	-04	11	33	47	58	66	78	81	82	83	84	78	41	24	23.0

INSTANTANEOUS SPECIFIC DEFLECTION (f) (x 10^{-5} (mm/mm)/°C)

Truflex Type	-50°C	0°C	50°C	100°C	150°C	200°C	250°C	300°C	350°C	400°C	450°C	500°C
A1	1,41	1,43	1,43	1,41	1,35							
B1	1,20	1,37	1,43	1,43	1,33	1,11	0,65	0,36	0,30	0,27	0,25	0,22
B2	1,03	1,13	1,20	1,24	1,29	1,31	1,29	0,88	0,52	0,45	0,42	0,36
B3	0,91	1,02	1,14	1,18	1,24	1,26	1,27	1,25	0,96	0,62	0,47	0,43
B11	1,14	1,25	1,32	1,39	1,39	1,39	1,22	0,87	0,60	0,45	0,33	0,31
BN	0,36	0,42	0,44	0,46	0,45	0,37	0,32	0,29	0,20			
BP1	1,43	1,71	1,76	1,77	1,77	1,74	1,32	1,20				
B100R	0,97	1,07	1,08	1,09	1,01	0,82	0,40	0,24	0,16	0,15	0,15	0,15
B125R	1,09	1,22	1,24	1,22	1,19	0,94	0,53	0,31	0,24	0,22	0,18	0,16
B150R	1,13	1,29	1,31	1,30	1,24	1,00	0,51	0,35	0,25	0,18	0,16	0,15
B175R	1,16	1,35	1,35	1,35	1,29	1,04	0,52	0,36	0,27	0,20	0,17	0,15
B200R	1,18	1,36	1,37	1,38	1,29	1,07	0,48	0,30	0,25	0,24	0,21	0,17
B250R	1,24	1,35	1,40	1,40	1,33	1,07	0,64	0,42	0,33	0,28	0,26	0,23
B300R	1,26	1,38	1,42	1,42	1,35	1,07	0,64	0,42	0,33	0,28	0,26	0,23
B350R	1,29	1,40	1,43	1,41	1,34	1,06	0,61	0,31	0,29	0,26	0,23	0,21
B400R	1,29	1,40	1,43	1,41	1,34	1,06	0,61	1,31	0,29	0,26	0,23	0,21
C1	1,30	1,42	1,47	1,46	1,37	0,97	0,62	0,37	0,24	0,18	0,14	0,12
C3	0,95	1,08	1,16	1,20	1,26	1,32	1,39	1,41	1,11	0,58	0,25	0,21
C11	1,13	1,30	1,36	1,42	1,45	1,45	1,19	0,70	0,43	0,30	0,18	0,16
D560R	1,22	1,36	1,38	1,35	1,31	1,07	0,66	0,46	0,38	0,33	0,32	0,31
E1	1,19	1,30	1,33	1,29	1,27	0,95	0,52	0,31	0,24	0,21	0,18	0,16
E3	0,78	0,88	0,97	1,04	1,11	1,15	1,15	1,15	0,92	0,48	0,34	0,27
E4	0,60	0,70	0,76	0,83	0,92	0,96	1,01	1,02	1,02	0,76	0,45	0,31
E5	0,45	0,52	0,55	0,63	0,68	0,72	0,77	0,78	0,79	0,78	0,69	0,52
F15R	0,60	0,69	0,69	0,64	0,60	0,45	0,36	0,27	0,12			
F20R	1,09	1,18	1,22	1,21	1,13	0,89	0,46	0,32	0,19			
F25R	1,14	1,26	1,29	1,28	1,19	0,93	0,50	0,30	0,18			
F30R	1,23	1,31	1,33	1,31	1,21	0,93	0,50	0,31	0,18			
F35R	1,24	1,35	1,36	1,34	1,24	0,92	0,51	0,34	0,20			
F40R	1,25	1,35	1,37	1,35	1,29	0,95	0,53	0,37	0,22			
F50R	1,28	1,37	1,39	1,38	1,30	0,96	0,55	0,37	0,23			
F60R	1,27	1,38	1,39	1,37	1,28	0,95	0,55	0,38	0,24			
F70R	1,29	1,40	1,40	1,37	1,29	0,95	0,56	0,38	0,24			
F90R	1,31	1,38	1,42	1,39	1,31	1,02	0,57	0,38	0,26			
F100R	1,31	1,38	1,42	1,40	1,32	1,05	0,62	0,39	0,28			
F125R	1,31	1,76	1,81	1,82	1,82	1,79	1,36	1,23				
G1	1,26	1,32	1,33	1,31	1,26	0,97	0,62	0,41	0,27	0,18	0,11	0,08
G3	0,79	0,91	0,96	1,05	1,14	1,15	1,15	1,10	0,65	0,50	0,44	0,35
G7	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,52	0,41
GB14	0,91	0,97	0,99	0,97	0,95	0,61	0,43	0,26	0,21	0,17	0,14	0,12
J1	1,18	1,26	1,29	1,28	1,24	0,85	0,46	0,28				
J7	0,53	0,53	0,53	0,53	0,53	0,53	0,53	0,53	0,37	0,36	0,34	0,32
M7	0,38	0,38	0,38	0,38	0,37	0,37	0,37	0,37	0,37	0,31	0,26	0,20
MB18	1,16	1,28	1,34	1,34	1,33	1,13	0,76	0,50	0,07	0,03	-0,02	-0,06
N1	0,82	0,94	0,98	0,97	0,93	0,64	0,31	0,16				
P3	1,47	1,60	1,71	1,81	1,92	2,05	2,13	2,06				
P30R	1,29	1,75	1,79	1,80	1,80	1,76	1,29	1,09				
P35R	1,33	1,83	1,89	1,89	1,89	1,81	1,34	1,13				
P40R	1,36	1,85	1,92	1,92	1,92	1,84	1,36	1,16				
P50R	1,39	1,89	1,97	1,97	1,97	1,89	1,39	1,19				
P60R	1,43	1,94	2,00	2,00	2,00	1,94	1,43	1,23				
P70R	1,43	1,94	2,01	2,01	2,01	1,94	1,43	1,23				
P90R	1,44	1,96	2,04	2,04	2,04	1,97	1,44	1,22				
P100R	1,46	1,97	2,05	2,05	2,05	1,97	1,46	1,23				
P125R	1,49	1,99	2,06	2,06	2,06	1,99	1,48	1,23				
P150R	1,48	1,99	2,06	2,07	2,06	1,98	1,47	1,23				
P175R	1,48	1,99	2,06	2,07	2,06	1,98	1,47	1,23				
P200R	1,48	1,99	2,06	2,07	2,06	1,98	1,47	1,23				
P250R	1,47	1,98	2,06	2,07	2,06	1,98	1,46	1,24				
P300R	1,47	1,98	2,06	2,06	2,06	1,98	1,47	1,24				
P350R	1,48	1,99	2,06	2,06	2,05	1,99	1,47	1,23				
P400R	1,48	1,99	2,06	2,06	2,05	1,99	1,47	1,23				
P450R	1,48	1,99	2,06	2,06	2,05	2,00	1,47	1,24				
P500R	1,48	1,99	2,06	2,06	2,05	2,00	1,47	1,24				
P550R	1,46	1,97	2,06	2,06	2,06	1,97	1,47	1,24				
P600R	1,48	1,99	2,06	2,06	2,06	1,98	1,47	1,23				
P675R	1,66	1,98	2,06	2,06	2,06	2,03	1,55	1,39				
P850R	1,35	1,42	1,42	1,43	1,41	1,31	1,18	0,96				
PJ	0,61	0,67	0,72	0,74	0,71	0,80	0,84	0,86				
1513	-0,52	-0,42	0,23	0,00	0,32	0,54	0,70	0,77	0,79	0,77	0,59	0,34

Engineered Materials Solutions, LLC provides customer assistance in varied technical areas. Since EMS does not possess full access to data concerning all of the uses and applications of customers' products, responsibility is assumed by EMS neither for customer product design nor for any infringements of patents or rights of others which may result from EMS assistance.

References

(Savolainen and Sears,1969) -"Thermostat Metals", U. Savolainen and R. Sears; Composite Engineering Laminates, M.I.T. Press, 1969, pp. 212-226.

(Sears, 1958) -"Optimum Shapes for Thermostat Metal Cantilever Strips", R. Sears: Electrical Manufacturing, Vol. 62, No. 4, 1958, pp. 72-75,99.

(Philpot, 2011) -"Mechanics of Materials: An Integrated Learning System", T.A. Philpot: John Wiley & Sons, Inc., 2011, pp. 291-304.

www.emsclad.com

Engineered Materials Solutions
EMSA
39 Perry Avenue
Attleboro, MA 02703
Phone: +1 508 342 2100
Fax: +1 508 342 2125
E-mail: solutions@emsclad.com

Engineered Materials Solutions
EMSH
600 Valley Road
Hamburg, PA 19526
Phone: +1 610 562 3841
Fax: +610 562 5800
E-mail: solutions@emsclad.com

Engineered Materials Solutions
EMSC
Italian Industrial Park
Baoying, Jiangsu, 225800 PR China
Phone: +86 514 8891 6888
Fax: +86 514 8891 6889
E-mail: solutions@emsclad.com