SHIVALIK THERMOSTATIC BIMETAL

Handbook

Shivalik is certified according to

ISO/TS 16949

ISO 9000

ISO 14001

OHSAS 18001

Our quality assurance group has developed a well-defined, integrated system of checks and controls, starting from incoming raw materials upto the final inspection, so that you get a product that meets or exceeds standards accepted worldwide.

Our customer service has been extended by providing a complete choice, not only of strips, but also of ready-to-use components.

Our engineers, are at your service to provide advice and assistance in your design & applications.

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General Introduction to Thermostatic Bimetals

1 - Principle of Operation

A thermostatic bimetal consists of two or more layers of different alloys firmly bonded together. One layer consists of an alloy having a high coefficient of expansion while the other layer is one with a lower coefficient of expansion.

Consider two metal strips, A and B, with different coefficients of expansion say α and β where $\alpha > \beta$. When heated the strips expand to different lengths where L1 > L2

Fig. 1

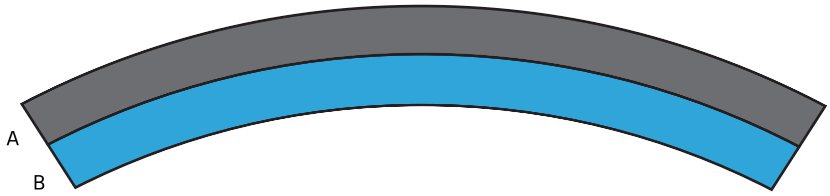


Fig. 2

If the two strips are firmly bonded together and the composite strip is now heated, strip B is pulled into tension by strip A which in turn is restrained by strip B and is under compression. These two forces produce a moment which causes the composite strip to bend into a uniform arc of a circle. This bending or change in curvature is dependent upon the difference between the two coefficients of expansion α and β, the moduli of elasticity, relative thickness and the change of temperature. The relationship of the above are dealt with in the following section.

2 - Definitions of Terms and Properties

2.1.1 Specific Thermal Curvature, Flexivity, Specific Thermal Deflection

These terms, used in different countries, are all a measure of the thermal activity of a bimetal. The variation of curvature of a bimetal was first calculated by Frenchman, Yvon Villarceau as:-

$$\frac{1}{R} - \frac{1}{R_0} = \frac{3}{2} \times \frac{\alpha - \beta}{t} \times \frac{T - T_0}{1 + \dfrac{(E_1 t_1^2 - E_2 t_2^2)^2}{4E_1 E_2 t_1 t_2 t^2}} \qquad (01)$$

Where R_0 is the curvature at initial temperature T_0

R is the curvature at final temperature T

α and β are the mean coefficients of expansion in the temperature range T_0 to T

E_1, E_2 are the moduli of Elasticity of the two components in the temp. range T_0 to T

t_1, t_2 are the respective thickness of the component metals ($t = t_1 + t_2$)

($T - T_0$) is the temperature differential ΔT.

Assuming $E_1 = E_2$ and $t_1 = t_2$ as is usually the case,* the above equation can be considerably simplified as follows :

$$\frac{1}{R} - \frac{1}{R_0} = \frac{3}{2} \times \frac{(\alpha - \beta)\ (\Delta T)}{t} \qquad (02)$$

Where $\frac{3}{2}\ (\alpha - \beta)$ is known as the **Villarceau Coefficient**, V.

In USA this constant is known as Flexivity, F.

from equation (2) , we have V or $F = \dfrac{\left(\dfrac{1}{R} - \dfrac{1}{R_0}\right) t}{\Delta T}$ (03)

Flexivity is defined as "the change of curvature of the longitudinal centre line of a bimetal specimen per unit temperature change for unit thickness". (ASTM B-106).

Since practically it is easier to measure deflection than measuring curvature, hence various 'constants' are derived and calculated by measuring deflection, mainly by beam or cantilever method, as follows.

2.1.2 Calculation of Flexivity, Specific Thermal Curvature and Specific Deflection by Simple Beam method

In USA Flexivity is measured by the simple beam method according to ASTM B-106. In Europe too this method is finding favour and the term "Specific thermal curvature" denoted by 'k' is also being used.

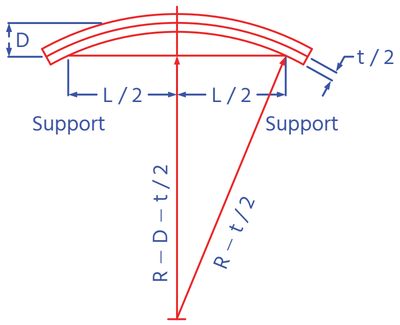


Fig. 3

* Infact for 95% of maximum activity, E1/E2 can be between 0.4 to 2.5 and t1/t2 between 0.7 to 1.4

For equation (3), if initial curvature is assumed to be zero, we have

$$V \text{ or } F = \frac{1}{R} \times \frac{1}{\Delta T} \qquad (04)$$

From Figure 3

$$\left[R - \frac{t}{2}\right]^2 = \left[R - \left(D + \frac{t}{2}\right)\right]^2 + \left[\frac{L}{2}\right]^2 \quad \text{or} \quad \frac{1}{R} = \frac{8\,D}{L^2 + 4D^2 + 4Dt} \qquad (05)$$

from equation (4) and (5), we have,

$$V \text{ or 'k' or } F = \boxed{\frac{8\,Dt}{\Delta T\,(L^2 + 4D^2 + 4Dt)}} \qquad (06)$$

ASTM B 106-1985
DIN 1715-1983 (revised)

In equation (6), if $D \leq 0.05L$, we can ignore D^2 and the product 4Dt, we then have

$$V \text{ or 'k' or } F = \frac{8\,Dt}{L^2\,\Delta T} \qquad (07)$$

If we substitute specific deflection $a \approx \frac{V}{2}$

$$\text{We have } a = \frac{4\,Dt}{L^2\,\Delta T} \qquad (08)$$

IS 8588 part I 1977

However, **specific thermal deflection**, 'a', is still used and measured by the cantilever method as per DIN 1715-1973 (see section 2.1.3)

2.1.3 Calculation of Specific Thermal Deflection by the Cantilever method

From Fig. 4

$$\left(R + \frac{t}{2}\right)^2 = \left(R + \frac{t}{2} - D\right)^2 + L^2 \quad \text{or} \quad \frac{1}{R} = \frac{2\,D}{L^2 + D^2 - Dt} \qquad (09)$$

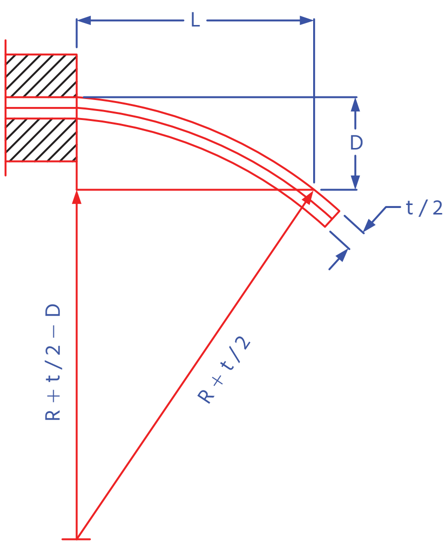


Fig. 4

From equation (4) and (9) we have

$$V = \frac{2\,Dt}{\Delta T\,(L^2 + D^2 - Dt)}$$

Substituting specific thermal deflection $a \approx \frac{V}{2}$

$$\text{We have } a = \frac{Dt}{\Delta T\,(L^2 + D^2 - Dt)}$$ DIN 1715-1973 (10)

Ignoring product Dt, and D being much less than L

$$\text{We obtain } a = \frac{Dt}{\Delta T \quad L^2}$$ JIS C2530-1975 (11)

The values of specific thermal deflection obtained by this method are material dependant and are 4% to 8% higher than by the simple beam method. The reason, while not yet clear, is assumed to be due to the difference in the distribution of stresses in a cantilever and a simple beam and that the operative length of the cantilever does not begin exactly at the outside edge of the clamp but is slightly greater. In Europe, the deflection of a straight strip clamped at one end, 1mm thick and 100mm long, for a temperature difference of 1 degree C within the linearity range is also frequently designated as specific thermal deflection. This value is four decimal exponents higher than the value given in the Table of Physical Properties.

2.2 Electrical Resistivity

ρ is the electrical resistance of a body per unit length and unit cross-sectional area.

$$\rho = \frac{A}{L} R$$ (12)

Where	ρ	=	resistivity (or volume resistivity)	$\Omega\ mm^2/m$
	A	=	cross sectional area	mm^2
	L	=	gauge length used to determine R	meters
and	R	=	measured resistance,	ohms

The resistance value is generally measured at 20°C. In the U.S.A. the reference temperature is generally 75°F.

2.3 Electrical Resistivity

Linearity Range: It denotes the temperature range in which the thermal deflection does not vary by more than ± 5 per cent from the deflection as calculated from the nominal value of specific deflection/flexivity. This value is given as a guideline only as the Bimetal can be used outside this range. In such cases refer to the instantaneous value of specific thermal deflection/Flexivity. Nominal value refers to value between 20–100°C temperature range.

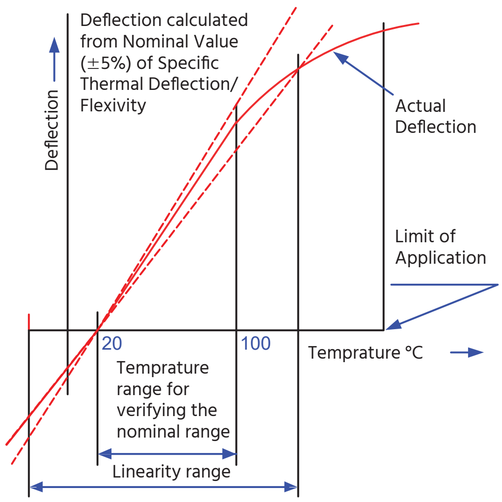


Fig. 5

2.4 Limits of application

Denotes the temperature upto which the thermostat metal does not become permanently set. The values given are recommended only and provide a sufficient safety margin.

2.5 Permissible Bending Stress

Denotes the mechanical stress which does not cause permanent deformation. Stresses in a Bimetal are a combination of 1) Mechanical, 2) Thermal, due to the great difference in the expansion coefficients of the components and 3) Induced, due to the manufacturing processes (rolling, slitting, levelling, flattening, blanking etc.).

The sum of these stresses should not exceed the maximum permissible stress, σ_{max} at the maximum temperature that the bimetal is to be used. While thermal and mechanical stresses can be determined, the stresses due to manufacturing processes remain largely indeterminate. Therefore, a wide safety margin has to be allowed.

2.6 Tensile Strength, Yield Strength and Hardness

These mechanical properties depend on the degree of cold rolling reduction. The hardness value ranges given in the Table of Properties are for the standard cold reduction of 20 to 35%.

2.7 Thermal Conductivity

This is an important property especially when the bimetal is subjected to rapid variations of temperature. This property governs the rate at which the entire element will reach a uniform temperature and is independent of how the heat is supplied. Generally the thermal conductivity increases as resistivity decreases. The values are listed in the Table of Properties.

2.8 Specific Heat

The specific heat capacity 'c,' is a value that may be required in heat calculations. This value scarcely changes from one bimetal type to the next and may be taken as 0.45 Ws/g°C.

Fig. 4

3 - Method of Manufacture

The Continuous Hot Atomic Bonding Process

There are two major types of bonding process in use today. Most of the industry uses a cold bonding process which requires a subsequent sintering operation to drive oxides and other impurities away from the metal interfaces to improve the bond.

Shivalik, on the other hand, uses cladding technology called "continuous hot bonding" which relies on more heat and less pressure than conventional methods.

Upto the point where the joining of metals takes place, the materials pass through a reducing atmosphere which removes oxides and other microscopic contaminants.

At the mating point, the materials are reduced in thickness under pressure at temperatures ranging from 70% to 80% of their liquidous temperature (ie. the temperature at which the atomic structure changes from solid to liquid). No subsequent sintering operations are required to improve bond strength. A strong bond is created by the sharing of electrons of the surface atoms of the component strips. In fact, the as-bonded material in many cases achieves a bond shear strength equal to that of its components.

The continuous hot bonding process used by Shivalik also results in long coils of material without welds and with excellent bond integrity. Prior to final processing, the coils weigh upto 60 kg per centimetre of width.

As for bond integrity, microscopic examination of materials clad by this process reveals a superior bond interface with no interfacial oxides or impurities evident. This is a quality often highly valued by users of thermostat metals.

Subsequent to bonding, the material is annealed and rolled on a precision cold rolling mill to finished thickness, under continuous automatic gauge measuring, correcting and recording equipment. The strip is then etched with a special acid to identify the low or high expansion side. Following this the material is stretcher roller levelled by a patented process to remove cross curvature, camber and coil-set. The strip is then precision slit and edge-conditioned to remove any burr. Quality checks are carried out at each stage of the process. The various tests carried out are listed in Section F.

Section B

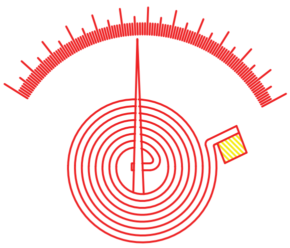
Applications

1 - Principle of Operation

Thermostatic Bimetals have a wide array of applications but these can be classified under the following broad headings

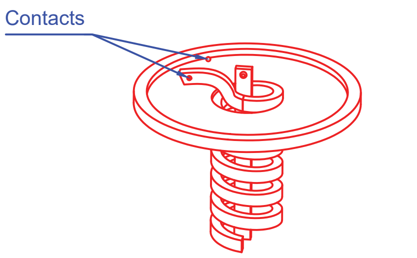
1. Temperature indication
2. Compensation (usually for ambient temperature)
3. Control of any parameter against temperature
4. Thermo-mechanical applications where heat is converted into mechanical energy

In our daily lives we activate bimetals regularly in one of its many fields of applications. Listed below is a selection of typical applications



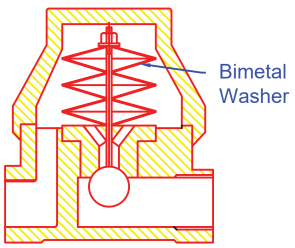
Thermometer

Fig. 6



Fire Detector

Fig. 7



Steam trap

Fig. 8

Industrial

- Circuit Breakers
- Time Delay relays
- Motor Protection
- Transformer protection
- Overload relays
- Air Dryers
- Steam Traps
- Electronic Furnaces
- Electronic Instruments
- Pressure Gauges
- Automatic Fuses
- Light Flashers
- Radiator Valves
- Temperature Indicators
- Damper Controls
- Energy Regulators
- Flame Fail devices
- Fire Alarm

Automotive

- Voltage Regulators
- Turn Indicators
- Volt Meters
- Oil Pressure-gauges
- Heaters
- Cigarette Lighters
- Exhaust Manifold Controls
- Circuit Breakers
- Oil cooling regulators
- Carburetor Chokes

Domestic Appliances

- Electric Irons
- Electric Ranges
- Refrigerators
- Tea Kettles
- Waffle Irons
- Washing Machines
- Heat Convectors
- Voltage Regulators
- Water Heaters
- Fluorescent Lamp Starters
- Percolators
- Baking Ovens

Aviation

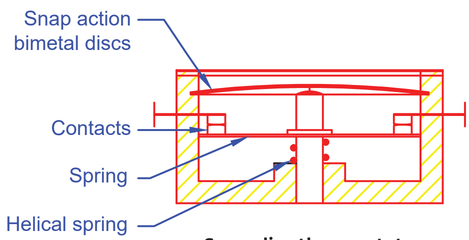
- Altimeters
- Circuit Breakers
- Instrument & wiring protection

Agriculture / Animal Husbandry

- Incubators
- Brooders
- Thermometers

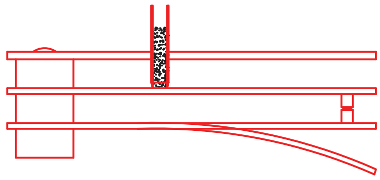
Medical

- Medical Sterilizers
- Dental Furnaces



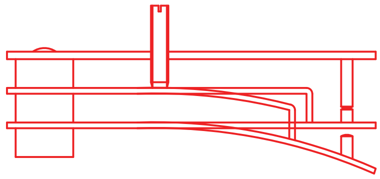
Snap disc thermostat

Fig. 9



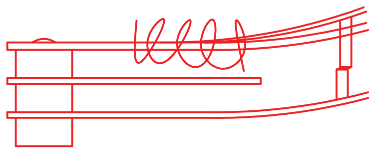
Adjustable thermostat

Fig. 10



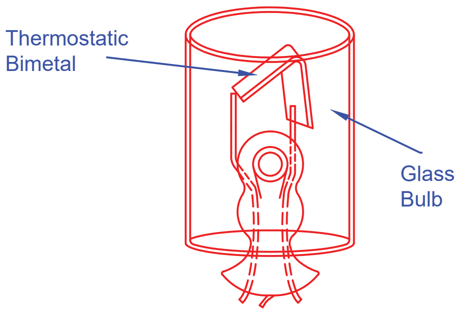
Indirectly adjustable thermostat

Fig. 11



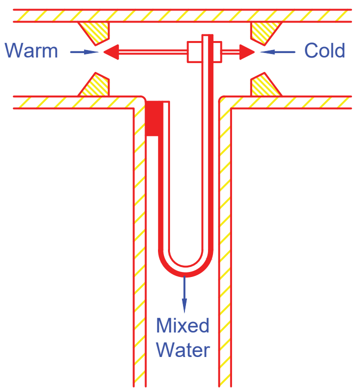
Ambient compensated thermostat

Fig. 12



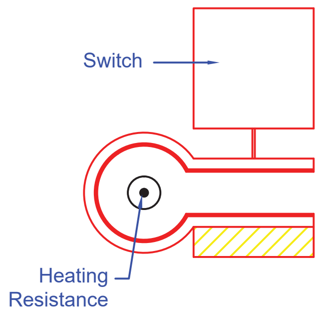
Fluorescent tube starter glow switch

Fig. 13



Hot water mixing valve

Fig. 14



Timer Switch

Fig. 15

Section C

Design

1 - Selection of Bimetal Types

The selection of the type of thermostatic bimetal will be based on the following factors. These and other properties are listed in Tables and Graphs in Section G

1. Thermal Activity
2. The Temperature-range in which linearity of deflection is required
3. Electrical Resistivity and Thermal Conductivity
4. Special factors such as high corrosion resistance or high strength
5. The Maximum Operating Temperature
6. Price

Depending upon the application, certain properties are more sought after than others. Shivalik's range of bimetals and trimetals covers a wide variety of types both of the DIN and ASTM standards. Broadly the classification is as follows

High activity and medium operating temperature types

206-1 206-2 223-1	The most extensively used general purpose bimetals. While 223-1(ASTM-TM-1) is most popular in the USA, Type 206-1 (DIN type 1577) is popular in Europe. Both these types are used for linearity ranges upto 200° C and useful deflection temperature range upto 350° C

Medium activity and high operating temperature types

206-3 206-4 223-3 206Cu9H 258-1	Due to higher nickel content of the low expansion side, these bimetals have a lower deflection rate at lower temperatures but a higher activity at higher temperatures and a wide linearity range.

Low activity and low resistivity types

223-N N-1	These types are widely used in automotive applications and high current circuit breakers.

Highest activity and highest resistivity types

721-112 721-140	Type 721-112 has the highest activity. Both types have high resistivities making them eminently suitable for low current applications. Type 721-112, because of its greatest deflection rate, is the second most widely used type of bimetal.

Medium activity, low resistivity trimetals (with copper shunt layer in middle)

206Cu6 206Cu9 206Cu11 206Cu15 206Cu17 206Cu19 223Cu3 223Cu4 223Cu5 223Cu6 223Cu7 223Cu8 223Cu11 223Cu15 223Cu16	Systematic variation of thickness of this shunt layer gives a series of bimetals suitable for circuit breakers with a wide variety of current ratings for the same size of breaker. The 206 series are more popular in Europe while the 223 series are widely used in the USA. Grades with same resistivity can be interchanged, provided the observed values of flexivity and resistivity lie within the tolerance limits

Precision Slitting Capability

Automated Stretch Levelling Line

Medium activity, medium and high series resistivity (with nickel shunt layer in the middle)

206Ni25 206Ni35 206Ni45 206Ni50 206Ni55 223Ni16 223Ni20 223Ni25 223Ni30 223Ni35 223Ni40 223Ni50 223Ni60	Companions in applications to the low resistivity series above. Grades with same resistivity can be interchanged provided the observed values of flexivity and resistivity lie within the tolerance limit.
197-7 258-1 258-3 258-5	(for high corrosion resistance application)

High activity, low and medium resistivity series

721cu3 721Cu5 721Cu8 721cu10 721Cu11 721Cu15 721Cu17 721Cu20 721Cu25 721Cu30 721Cu35 721Cu40 721S50 721S60 721S80	High activity, low and medium resistivity trimetals series for applications where factors such as the combination of high activity and low resistivity outweigh corrosion resistance and strength.

2 - Choosing Bimetal Shape and Size

Having chosen the type of bimetal for a particular application, the shape of the element has to be decided. The shapes most commonly used are

1. Cantilever strip
2. U-Shapes
3. Simple Beams
4. Discs
5. Spiral and helix coils
6. Snap elements

The selection of shape is based on factors such as

1. Deflection
2. Dead weight of the bimetal
3. Force required
4. Permissible bending stress
5. Space available
6. Minimum bimetal volume
7. External forces, such as friction, spring force etc.
8. Economy and accuracy of manufacture

Cantilevers and Simple Beams

These are the simplest and most common shapes used. Generally the thickness should not be less than 5% of the width and the width not larger than 20% of the length. This is to ensure that across width deflection has little effect on the functioning of the cantilever or simple beam.

The force can be multiplied by stacking of blades, though the deflection will remain the same as for a single blade.

U-Shape

In comparison with cantilevers and simple beams, U-Shapes double the force but halve the deflection. Their main use is in transforming temperature change to force such as in control valves or for operating switches.

Spiral and Helix Coils

These shapes provide large movements for small temperature changes in a small space. They also provide torque which can be used in applications such as temperature indication, ambient temperature compensation, opening and closing of valves, flaps, fuels, dampers etc

3 - Basic Design Formulae

Symbols used

D = Deflection in mm

A = Angular deflection in degrees

ΔT = Temperature change in degree C

w = Width in mm

σ_{max} = Maximum bending stress in N/mm2

t = Thickness in mm

L = Active length in mm, i.e. the length free to deflect

a = Specific thermal deflection in per degree C

E = Youngs modulus in N/mm2

F_m = Mechanical force in N, i.e. the force required to mechanically cause a deflection of D.

F_t = Thermal force in N, i.e. the force that would be developed if the bimetal is completely restrained.

3.1 Cantilever fixed at one end

$$D = \frac{a \Delta T L^2}{t} \quad (13)$$

$$F_m = \frac{E w t^3 D}{4 L^3} \quad (14)$$

$$F_t = \frac{E a t^2 w \Delta T}{4 L} \quad (15)$$

$$\sigma_{max} = \frac{6 F L}{t^2 w} \quad (16)$$

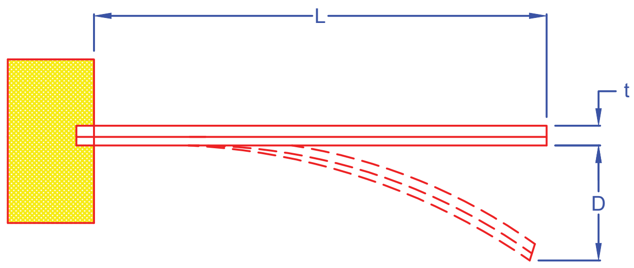


Fig. 17

3.2 Simple Beam Freely Supported

$$D = \frac{a \Delta T L^2}{4t} \quad (17)$$

$$F_m = \frac{4 E w t^3 D}{L^3} \quad (18)$$

$$F_t = \frac{E a t^2 w \Delta T}{L} \quad (19)$$

$$\sigma_{max} = \frac{3 F L}{2 t^2 w} \quad (20)$$

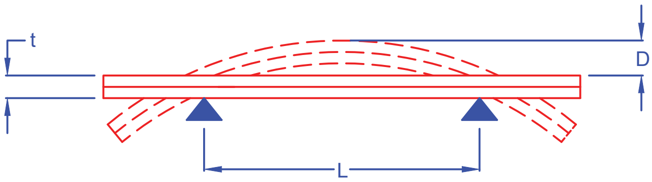


Fig. 18

3.3 U-Shape

Assuming radius of bend is small compared to length

$$D = \frac{a \Delta T L^2}{2t}$$ (21)

$$F_m = \frac{E w t^3 D}{L^3}$$ (22)

$$F_t = \frac{E a w t^2 \Delta T}{2L}$$ (23)

$$\sigma_{max} = \frac{3 F L}{t^2 w}$$ (24)

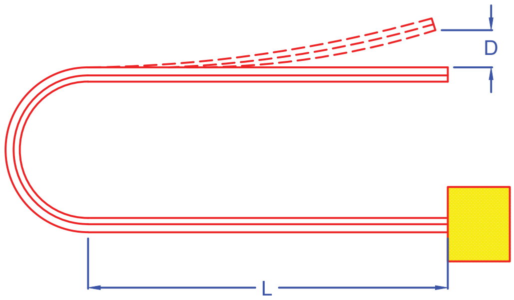


Fig. 19

3.4 Spirals and helix

$$A = \frac{360 a \Delta T L}{\pi t}$$ (25)

$$F_m = \frac{2\pi AE t^2 w}{360 \times 12 L r}$$ (26)

$$F_t = \frac{E a w t^2 \Delta T}{6 r}$$ (27)

$$\sigma_{max} = \frac{6 F r}{t^2 w}$$ (28)

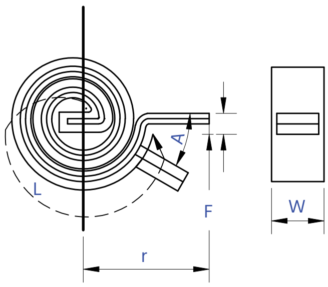


Fig. 20

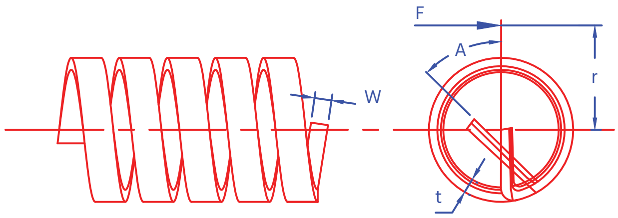


Fig. 21

3.5 Creep type discs

$$D = \frac{a \,\Delta T \,(x^2 - y^2)}{4t} \qquad (29)$$

$$F_m = \frac{4 E t^3 D}{x^2 - y^2} \qquad (30)$$

$$\sigma_{max} = \frac{3F}{2t^2} \qquad (31)$$

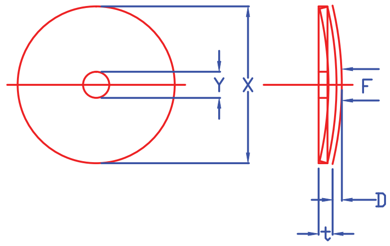


Fig. 21

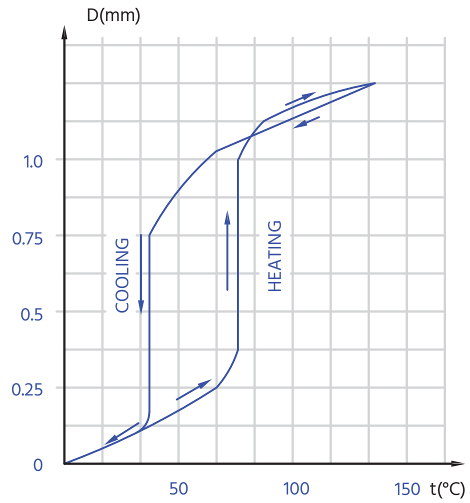
3.6 Snap Acting Discs

The snap acting thermostat metal disc is becoming increasingly popular as a cost effective protection of small motors and appliances.

A disc of thermostat metal is pretensioned by dishing or doming. With a rise in temperature, the thermal stresses produced due to the bimetal action reach a point where they equal the pretensioning stresses. At this point the disc snaps to the opposite concave. Upon cooling the reverse action takes place but at a lower temperature.

The upper and lower snapping temperatures depend upon the disc geometry. No exact mathematical formulas are possible to determine these temperatures but certain guidelines will help to establish the size and geometry of trial discs:

Formed and tested discs of standard diameter can be produced on our precision special purpose machines.



Deflection of Bimetal Stamped Into a Snap – Action Disc

- **A** The ratio between the diameter and thickness of the disc should be between 70 & 140.
- **B** The ratio of chord height to thickness should be between 1.8 and 3.0.
- **C** Increasing of doming will increase upper snap temperature but will not appreciably increase lower snap temperature.
- **D** The differential between upper snap temperature and lower snap temperature increases with higher operating temperature. This difference can be lowered with a spring, or manual reset in cases where lower snap temperature is below room temperature.
- **E** The thickness tolerance, besides cross curvature and coil set, have to be more rigorous in this case than for other applications. Since tighter tolerances usually involve extra cost, we suggest a discussion with our technical staff while finalizing these values.
- **F** The blanking operation has to be as precise as possible. The speed, stroke and dwell time of the punch should be constant.
- **G** The punching operations should be carried out at a constant temperature. The variation of room temperature during this operation will cause an equally-large difference in snap temperature.

4 - Optimum Bimetal Volume

In most applications of bimetals, a part of the temperature differential is used in overcoming force and the other part is used to produce movement. If the former is denoted by ΔT_F and the latter by ΔT_D, then using formula (13) and (14) for a cantilever element we have

$$D = \frac{a \, \Delta T_D L^2}{t}$$

$$F_t = \frac{E \, a \, t^2 W \, \Delta T_F}{4 L}$$

∴ Work done

$$W = F_t \times D = \frac{a \, \Delta T_D L^2}{t} \times \frac{E \, a \, t^2 w \, \Delta T_F}{4 L}$$

$$= \frac{E \, a^2 \, L \, w \, t \, \Delta T_D \times \Delta T_F}{4}$$

Substituting Volume, $v = L \, w \, t$, in the above equation we have,

$$W = \frac{E \, a^2 \, v \, \Delta T_D \times \Delta T_F}{4}$$

$$\text{or } V = \frac{4 W}{E \, a^2 \, \Delta T_D \times \Delta T_F}$$

Volume will be minimum when $\Delta T_D \times \Delta T_F$ is maximum,

$$\text{i.e. when } \Delta T_D = \Delta T_F = \frac{\Delta T \text{ (total)}}{2}$$

In other words, the minimum volume of bimetal is used when half the temperature differential is used to overcome force and the other half to cause deflection,

∴ The minimum volume for a cantilever,

$$V_{min} = \frac{16 W}{E \, a^2 \, \Delta T^2} \quad (32)$$

The minimum volume can be calculated in a similar fashion for other shapes.

5 - Direct Electric Heating

To raise the temperature of a thermostat metal by ΔT the heat required (Q) is,

$$Q = mc \ \Delta T \tag{33}$$

Where m = mass and c = specific heat capacity. When heated directly by a current I, the heat generated is,

$$Q = I^2 \ R\tau \tag{34}$$

when R is the resistance in ohms and τ is time is seconds

$$\therefore mc \ \Delta T = I^2 R\tau \tag{35}$$

Or

$$\Delta T = \frac{I^2 R\tau}{mc} \tag{36}$$

Since heat losses are not taken into account, this formula stands good for a time of a few seconds and a temperature not exceeding 100 degree C. For higher temperatures and longer time periods the temperature rise should be checked by experiment as the heat exchange can be due to a variety of factors which will be different from case to case.

The specific heat will also vary with temperature but for most bimetals it can be taken as 0.45 Ws/g degree C.

6 - Worked Examples of Calculation

Ex. 1. Free Deflection

A strip of bimetal type 223-1 having an active length of 30 mm is to be used as a cantilever element. A deflection of 1.5 mm at the free end is to be produced by a temperature change from 40° C to 120° C. Find the thickness of the strip.

From equation (13) and the table of values

$$t = \frac{a \ \Delta T \, L^2}{D} = \frac{14.3 \times 10^{-6} \times 80 \times (30)^2}{1.5} = 0.69\text{mm}$$

Ex. 2. Combination of Thermal Deflection and Force

A cantilever strip of bimetal type 721-112, 12 mm wide is to move 1.5 mm and develop a force of 5N at the free end when subjected to a temperature change from 40° C to 100° C Calculate the thickness and active length of the strip required.

From section C-4, for minimum volume using half the temperature differential for deflection and from Eq (13) and the table of values,

$$t = \frac{a \ \Delta T \, L^2}{D} = \frac{20.5 \times 10^{-6} \times ½ \, (100 - 40) \times L^2}{1.5}$$

or $t = 0.00041 \, L^2$

or $t^2 = 0.168 \times 10^{-6} \ L^4$

From equation (15) and using the other half of the temperature differential for thermal force, we have,

$$F_t = \frac{E \, a \, t^2 \, w \Delta \, T}{4 \, L} \tag{37}$$

$$L = \frac{14000 \times 20.5 \times 10^{-6} \times t^2 \times 12 \times ½ \ (100 - 40)}{4 \times 5} = 50.184 \, t^2$$

Substituting the value of t^2 from above we have,

$L^3 = 118611$ or $L = 49.1$ mm.

Substituting the value of L we obtain : t = 0.99 mm, Say 1.0 mm.

The maximum bending stress should be checked.

$$\sigma_{max} = \frac{6\,F\,L}{t^2\,w} = \frac{6 \times 5 \times 49.1}{1 \times 12} = 122.8\ N/mm^2$$

In this case the maximum stress is well within the allowable limits. Therefore trials can be based on a size of 49 mm length and 1 mm thickness.

Ex. 3. Free Deflection due to Direct Heating by Passage of Current

A strip of bimetal type 721-140, arranged as a cantilever, of active length 45 mm and width 5 mm, should deflect 2 mm when carrying current of 100A for 0.2 seconds. Find the thickness required and the temperature rise.

From equation (36)

$$\Delta T = \frac{I^2 R \tau}{mc} \qquad (36)$$

$$R = \rho \frac{L}{A} = \rho \frac{L}{t \times w}$$

$m = \gamma \times L \times w \times t$, where γ is density-gm/cm^3

$$\therefore\ \Delta T = \frac{I^2 \rho \tau}{\gamma\, t^2 \times w^2\, c}$$

From the table of values,

$$\Delta T = \frac{(100)^2 \times 1.4 \times 0.2}{7.5 \times t^2 \times 25 \times 0.45} = \frac{33.18}{t^2}$$

From equation (13)

$$D = \frac{a\,\Delta T\,L^2}{t} \quad \text{or} \quad t = \frac{14.4 \times 10^{-6} \times \Delta T \times (45)^2}{2}$$

$$t = 0.01458\ \Delta T$$

From the two equations,

$t^3 = 0.484$

$t = 0.79$ mm

$\therefore\ \Delta T = 53.2°C$

Ex. 4. Select bimetals of the same size as example 3 but able to carry 200A & 300A for the same conditions. Find also the temperature rise in each case.

Combining equation (13) and equation (36) from example 3 we have

$$I^2 = \frac{w^2\, t^3\, \gamma\, c\, D}{\rho\, L^2\ a\ \tau}$$

Since D, L. w, t, & τ remain unaltered, $I^2 \propto \dfrac{\gamma c}{\rho a}$

Since the density γ and specific heat c scarcely varies from one bimetal to another,

we can assume, $\dfrac{I_1^2}{I_2^2} = \dfrac{\rho_2 a_2}{\rho_1 a_1}$

Choosing a bimetal which has a similar specific deflection we can use the ratio ρ_2 / ρ_1 as a basis of initial selection.

Substituting the value for I_2 = 200A we have : $\left[\dfrac{100}{200}\right]^2 = \dfrac{\rho_2}{1.4}$

or ρ_2 = 0.35 Ω mm^2/m

We can therefore select type 206 Ni 35.

Similarly where $I_2 = 300A$

$\rho_2 = 0.16$

Therefore we can select type 223 Cu16 for trials. Note that for both the types of thermostat metals selected the specific deflection is within 5% of the nominal value for type 721-140.

The temperature rise for I = 200A using thermostat metal type 206 Ni 35 would be

$$\Delta T = \frac{(200)^2 \times 0.35 \times 0.2}{8.3 \times (0.79)^2 \times 25 \times 0.45} = 48°C$$

The temperature rise for I = 300A using thermostat metal type 223 Cu16 would be

$$\Delta T = \frac{(300)^2 \times 0.166 \times 0.2}{8.3 \times (0.79)^2 \times 25 \times 0.45} = 51.3°C$$

7 - Design Hints

The formulas and equations are at best approximate, as many assumptions are made, however, they provide a good basis for the design. Once the preliminary determinations of bimetal type, shape and size of an element have been made, with due regard to maximum safe stress at the operating temperature, the element should be tested under actual operating conditions.

If for example, the combination of mechanical and thermal stresses exceeds the elastic limit of the bimetal element, a permanent set occurs, resulting in a change of the calibration of the thermostatic device. If unfavourable conditions continue this change will continue to get worse. The designer must keep in mind, however, that other factors may also cause a thermostat to change calibration such as weak mounting of the element, excessive restraint of deflection, exceeding the heat treating temperature, relieving of mechanical stresses in other structural members, corrosion and contact wear.

The designer should also keep in mind the dimensional and mounting tolerances when designing a device, as these add up to the final tolerance on the device.

For example, consider a cantilever element of active length L, width w and thickness t, having a specific thermal deflection of 'a'. Using equation (1), the deflection per degree C is

$$D = \frac{aL^2}{t}$$

Therefore, the total error in the theoretical deflection will be given by $\delta D = \delta a + 2\delta l + dt$. The δa is controlled to within ±5% while δt, depending upon the gauge used, to ±2½%, although the material can be performance rolled to tighter tolerances at extra cost. The accuracy of the length of the element (δL) is, of course, more the responsibility of the manufacturer of the device. The inaccuracy of the length doubles the inaccuracy of deflection and may arise from two sources. 1) the blanking or cropping of the element and 2) the mounting of the element to give the correct active length (L in the above equation). Even if, in production runs, a tolerance ±1% on active length can be maintained, it adds to ±2% on the error of the theoretical deflection. In the case of force which is proprtional to the active length, width and square of thickness, a close watch on dimensions becomes even more important. Therefore, special care and precaution should be taken in designing the mounting of the element as active length is a very important parameter. There is little point in specifying very close thickness tolerances, usually at extra cost, unless these are justified by the accuracy maintained on the active length.

In the final device, if electrically heated, either directly or indirectly, the errors due to tolerances of the resistivity or the resistance tolerance of the heating element would also be added. It is because of this totalling up of tolerances that it becomes necessary to have some means of adjustable calibration.

Section D

Fabrication Thermostat Metal Parts

1 - Forming / Stamping / Cropping

While thermostat metals may be treated as stainless steels for the above operation, it will be advantageous to keep in mind the following points:

- Ensure no burr occurs in the stamped part. Use accurate cutting tools.
- Cutting should be initiated on the harder side, which is the high expansion side for all grades except the 721-series in which it is the low expansion side. This will avoid burr.
- Purchase thermostat metal in the final width of the component. This will reduce cutting and therefore, a chance of burr which, if large may cause longitudinal stiffening and adversely affect deflection.
- While thermostat metal strips are isotropic, it is advisable, for better shape accuracy, to have the length in the direction of rolling. Across-width lengths will reduce permissible bending stress by 10% and deflection by approx. 2%
- Preferably the bending axis should be perpendicular to rolling direction.
- Bend radii less than twice the strip thickness should be avoided. If this is absolutely necessary, a lower degree of cold rolling may be necessary. In that case consult SBCL.
- To calculate cutting pressure a shear strength of 600 N/mm2 can be assumed.
- Bimetal parts should preferably be fabricated, as far as possible, under uniform temperature conditions.
- During stress relieving (stablizing heat treatment) a slight deformation of the element can occur. This can be taken into account during fabrication. For example, in the case of curved discs, slight over bending may be necessary which will be reduced during the stablizing heat treatment. For other shapes such as cantilevers and beams, an adjusting device for calibration can take care of small deformations.

2 - Stablizing Heat Treatment (Stress Relieving, Ageing)

During the manufacturing process of a thermostat metal, many (See also hints on element design in section C-7) indeterminate stresses are induced during rolling, slitting, stretcher levelling, cutting and forming. These stresses, while within the elastic limit, are distributed unevenly in the bimetal. This produces instability in the bimetal component. Heat treatment relieves or re-distributes these stresses to maintain stability, accuracy and uniformity of operation of the part, which would otherwise go out of calibration either when the temperature is increased or time has elapsed. If a component is not heat-treated it would not return to zero during its first heating. This is because of only a partial relaxation of stresses. Of course, the hysteresis effect would gradually dwindle and finally disappear after a number of cycles under "natural ageing". Proper heat treatment eliminates the hysteresis and accelerates the stress relief so that the characteristics of the bimetal do not alter in any way after final assembly and calibration, provided the maximum working temperature is not exceeded. Usually simple heat-treatment as recommended, is sufficient for most applications however where stability is critical the whole assembly should be heat treated again after any mechanical adjustment, or two or three heat treatment cycles can be performed, with each subsequent treatment at a somewhat lower temperature than the first. Stablizing heat treatment should not be confused with normal heat treatment of steel such as annealing, normalizing etc., where the properties change considerably. The stablizing heat treatment cycle does not appreciably alter any of the properties of the thermostat metal, causing no change in hardness and only a slight change in temperature deflection rate and mechancial force rate. A slight change of shape results because some of the stresses caused in forming the part have been relieved. A blade, which is flat prior to heat treament, will assume a curvature after heat treatment with the high expansion side becoming concave. Strip material can be precurved by a roller flattener prior to the press so that the opposition of the two curvatures will cancel each other, resulting in a flat blade.

2.1 Procedure for Stabilizing Heat Treatment

The stablizing heat treatment of Thermostat metal components can be done in the trays of an electric or gas heated oven in which close temperature control is provided. The following points must be borne in mind during this treatment

- The components must be free to deflect. If restrained in any way say, even by the weight of other components, further stresses may be induced. Therefore, they should be spread out singly on the tray of the oven.
- The temperature, which should be carefully controlled, should be 50 degree C above the maximum temperature to be encountered in service or during calibration, subject to a minimum of 250 degree C.* The temperature should not exceed the maximum working temperature, however, if such high temperatures are likely to be encountered, then some drop in mechanical strength should be considered due to softening of the material. The components should be soaked at the final temperature for two hours.
- The temperature rise should be gradual. Cooling can be done in the furnace or in still air, a maximum heating or cooling speed of 20 degree C/min is recommended.
- The heat treatment can be performed in air. A thin oxide layer of a dark tarnish will be formed on the components. This is usually desirable as it improves emissivity, giving better heat exchange properties. However, if the oxide layer interferes with subsequent processes such as spot welding or plating then the heat treatment should be done in an inert atmosphere such as cracked ammonia ($N_2 + H_2$).
- For certain stressed parts such as snap elements or discs, the normal recommended temperatures may cause harmful deformation. In such cases it is recommended to snap the elements several times at the maximum operating temperature.
- If parts are to be stored after heat treatment apply anti-rust oil.

3 - Mounting/Fastening of Thermostat Metal Parts

The accuracy of deflection and zero point stablity of bimetal depends importantly upon the active length.** Therefore, the mounting of a thermostat metal element should be accurate and rigid. The following points may be observed

- Thermostat metal parts can be fastened either by rivetting, bolting, spot welding, resistance brazing, soldering or clamping. Do not use a torch or electric arc for welding.
- Degrease, abrade or otherwise mechanically clean mating surfaces. Acid pickling is not recommended especially for the 721-series. For spot welding, a welding projection on either of the mating parts will be of advantage.
- Since the range of bimetals have a wide variety of resistivities, the spot welding machine and shape of electrodes should be adjusted beforehand to suit the type of bimetal. For the 721-series of bimetal, the active side, which is a high manganese alloy may have a hard oxide layer. It is recommended that this series is spot welded on LE side only. If this is not possible then a higher density of current over a sharp point will help break through the oxide layer, especially for the high resistivity types such as 721-112 and 721-140.
- The bimetal element must be tightened across its whole width.
- Select the materials for the mating parts so that galvanic action is avoided. Corrosion at the mounting surface would lead to a loosening of the fastening and instability in the thermostat operation.

4 - Corrosion Resistance And Protection

Generally all thermostat metals are corrosion resistant in ordinary atmosphere. In atmospheres of high salinity and humidity the 721 series bimetals, because of the high manganese content of the active side, are liable to stress corrosion after prolonged exposure. For most bimetals (with the exception of 721 series) corrosion protection can be provided by electroplating with nickel, tin, cadmium, silver, zinc or gold. Silver plating may be useful to reduce contact resistance of direct electric heated bimetals.

Generally coatings of thickness 10-15µm are sufficient. Platings below 3% of thickness will not adversely effect thermal activity. Non-metallic coatings are not generally recommended as they choke the exchange of heat but for low temperatures (upto 100 degrees C) coatings of plastic or epoxy resins have been used successfully.

CNC Multislide Forming Machines

Section E

Forms of Supply & Tolerances

1 - Forms of Supply

From normal production we can supply bimetal strips in thickness ranging from 0.1mm to 2.0mm and width ranging from 1mm to 72mm. Thickness and width outside this range can be supplied by special arrangement.

Unless otherwise specified our thermostat metal is supplied in cold rolled state with 20 to 50% cold reduction.*

Thermostat metal may be supplied in continuous coil or cut lengths or shaped parts.

Thinner material is wound on a Cardboard core. For very thin and narrow material, for example, material for flourescent tube starters, the strip is wound on plastic bobbins.

The material is lightly coated with anti rust oil as a protection against corrosion in transit. If desired this may be degreased before use. Continuous Zinc/Tin plated strips can be provided at extra cost.

2 - Deflection Tolerances

The tolerances for the Flexivity, Specific Thermal Deflection are : ± 5%

3 - Resistivity Tolerance

The resistivity tolerances vary with the type of bimetal. Generally the larger the shunt layer and lower the resistivity, the higher the tolerance value. These values are listed in the Table of Values in Section G-2

4 - Thickness Tolerances

Thickness	Tolerance µ.m
$t \leq 0.15$	± 7
$0.15 < t \leq 0.25$	±10
$0.25 < t \leq 0.6$	± 15
$t > 0.6$	± 2½% of t

Disc Material

Thickness	Tolerance µ.m
$t \leq 0.2$	± 4
$0.2 < t \leq 0.40$	± 2% of t

Tighter tolerances can be provided by prior agreement.

*In special applications such as discs and snap acting elements or in applications involving severe bending radii, consult our Technical Staff for the appropriate hardening.

5 - Width Tolerances

Thickness in mm	Width Tolerance in mm	
	W ≤ 50mm	W > 50mm
t ≤ 0.2	± 0.1	± 0.15
t > 0.2	± 0.15	± 0.20

Tighter tolerances can be provided by prior agreement.

6 - Lengthwise Flatness (Coil Set)

The normal manufacturing process gives the bimetal a flatness & straightness which is normally fully satisfactory, however any special requirements can be agreed at the time of placing the order.

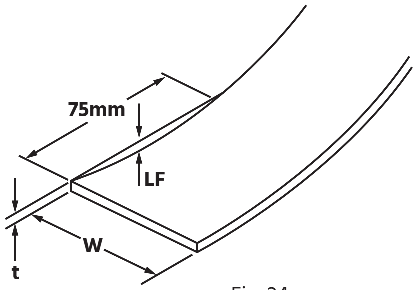


Fig. 24

7 - Edgewise Camber

Edgewise camber is less than 3mm in 1 metre, when measured by placing a 1 meter straight edge on the concave edge of the material and measuring from the centre of the straight edge to the strip edge.

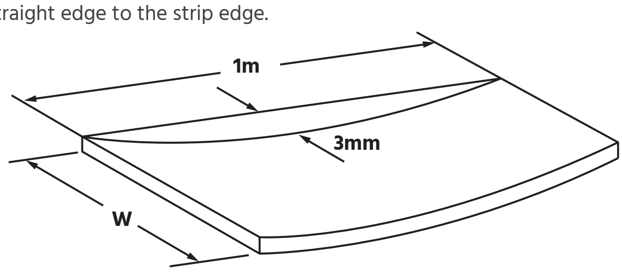


Fig. 25

8 - Cross Curvature (Transverse Straightness)

The normal manufacturing process gives the bimetal a flatness & straightness which is normally fully satisfactory, however any special requirements can be agreed at the time of placing the order.

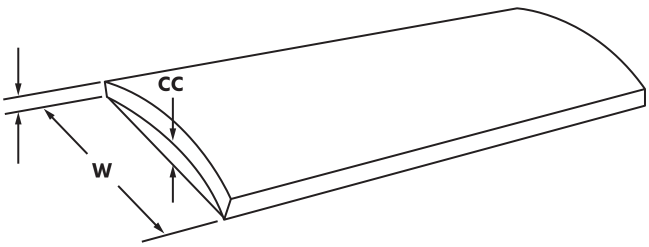


Fig. 26

9 - Standard Etch Patterns (Marking)

Unless otherwise specified the marking of the grade is etched on the Low Expansion Side with a special acid. For large enough quantities we can etch the customers own code at extra cost. However, the art work must be supplied well in advance. Marking of strip by Engraving can be provided on special request.

Section F

Testing of Thermostatic Bimetals

1 - Measuring Flexivity / Specific Thermal Curvature and Specific Thermal Deflection

All our bimetals are measured as per ASTM B 106 in the device shown in the picture below: The specimen strip is heat stabilized and placed accurately on the knife edges of the device. The device, which is constructed out of Invar to reduce errors due to expansion of its components, is then placed in a thermostatic oil bath in which the temperature is controlled to ± 0.1° C. The deflection is measured by means of a large least count micrometer when its transmission rod first makes contact with the deflected strip. To avoid errors due to contact pressure, an electrical circuit is incorporated wherein a multimeter indicates the point at which contact is made with the strip. The values of flexivity are then calculated as described in section A-2.1.2

Specific Thermal Deflection was measured earlier as per DIN 1715 (1963) but this has been replaced by DIN 1715 (1983) in which the value measured is Specific Thermal Curvature which corresponds to Flexivity. Conversion of Flexivity to Specific Thermal Curvature is done by multiplying the Flexivity value by 1.8.

Values given in our table for Specific Thermal Deflection are for reference only.

ASTM Flexivity Measuring Apparatus

2 - Measuring Electrical Resistivity

The resistance of the specimen is measured using a Kelvin Bridge. The specimen is held in screw down knife edge clamps to minimize contact resistance, since the material is hard. From the dimensions of the specimen and the measured resistance, the resistivity is calculated using equation (12).

3 - Measuring Hardness

The hardness value of the low expansion and high expansion components is measured as Vickers hardness. A microhardness testing apparatus is used with very low loads (less than 10 N) to avoid errors due to the influence of the component on the underside

4 - Measuring Shape

For coil set, camber, cross curvature Refer section E-6, E-7, E-8 respectively.

If alternate test methods are used, we suggest a consultation with our Engineers so that comparative test results can be obtained and misunderstandings can be avoided.

Shivalik Bimetal Types Technical Data

Type Designation and Composition

Shivalik's grades have been rationalised so as to indicate the type of element alloys used. The first three numbers of the grade indicate the high expansion alloy followed by a number which codifies the low expansion alloy.

For example on the high expansion side 223 stands for alloy containing 22% Ni, 3% Cr, balance Fe and

206 stands for an alloy containing 20% Ni, 6% Mn and balance Fe, while 721 indicates 72% Mn, 10% Ni,

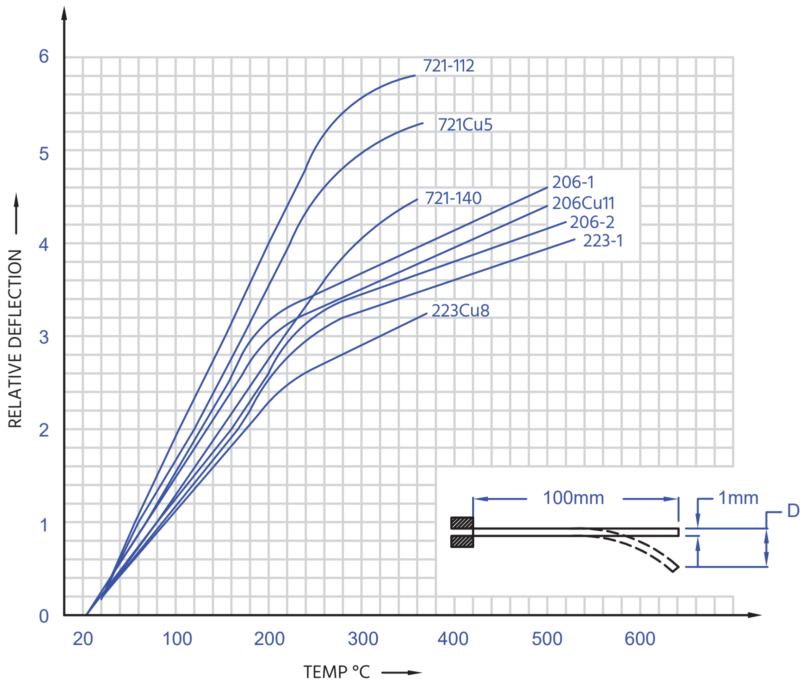
18% Cu, and N indicates pure Nickel.

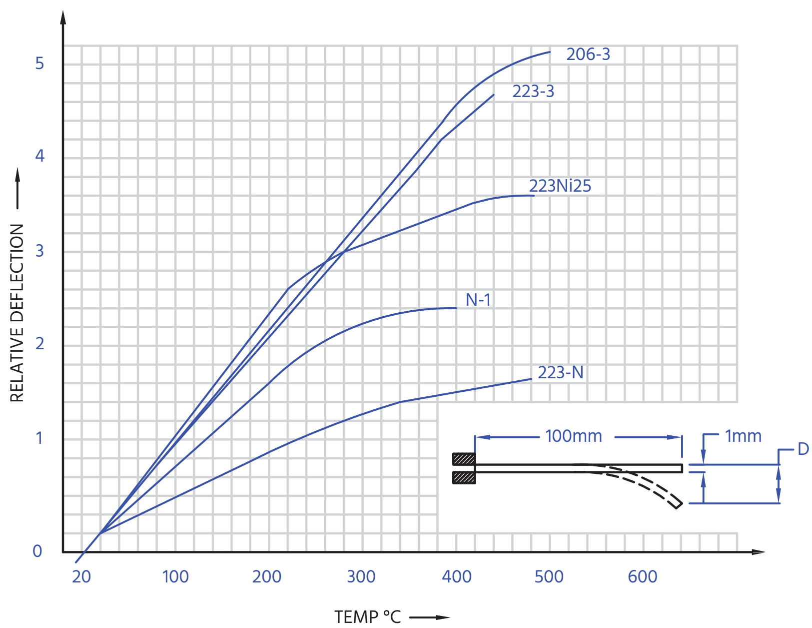
On the low expansion side 1 indicates Invar i.e. 36% Ni Bal.Fe, 2 stands for 38% Ni Bal.Fe and 3 for 42% Ni, Bal.Fe.

In the resistivity series, with the exception of 206 Cu 9H, which has 42% Ni, Bal Fe on the LE side, all resistivity types have Invar on the LE side. In these types material of shunt is indicated alongwith the resistivity values in μ Ω cm. For example 206 Cu 11 is a trimetal with 206 alloy on the active side, a Copper shunt layer in the middle and having a resistivity of 11 μ Ω cm. The low expansion side, common for the whole series, is Invar.

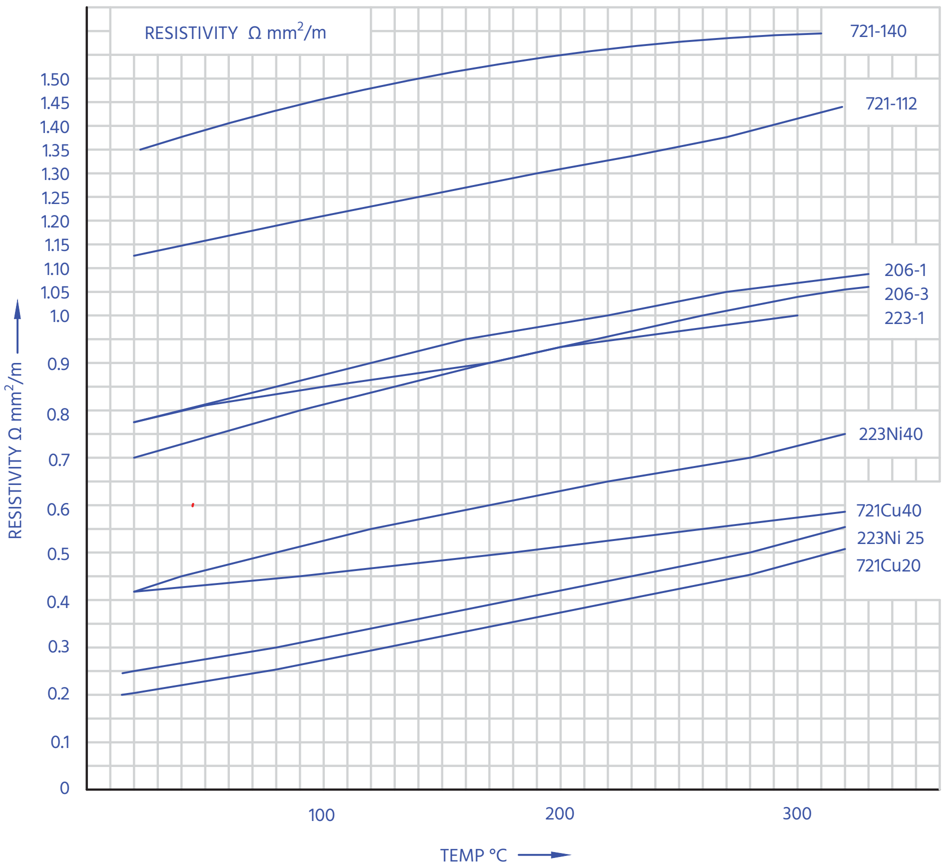
The graphs printed in this section are intended to demonstrate relative behaviour only. Extrapolated values may be in approximation.

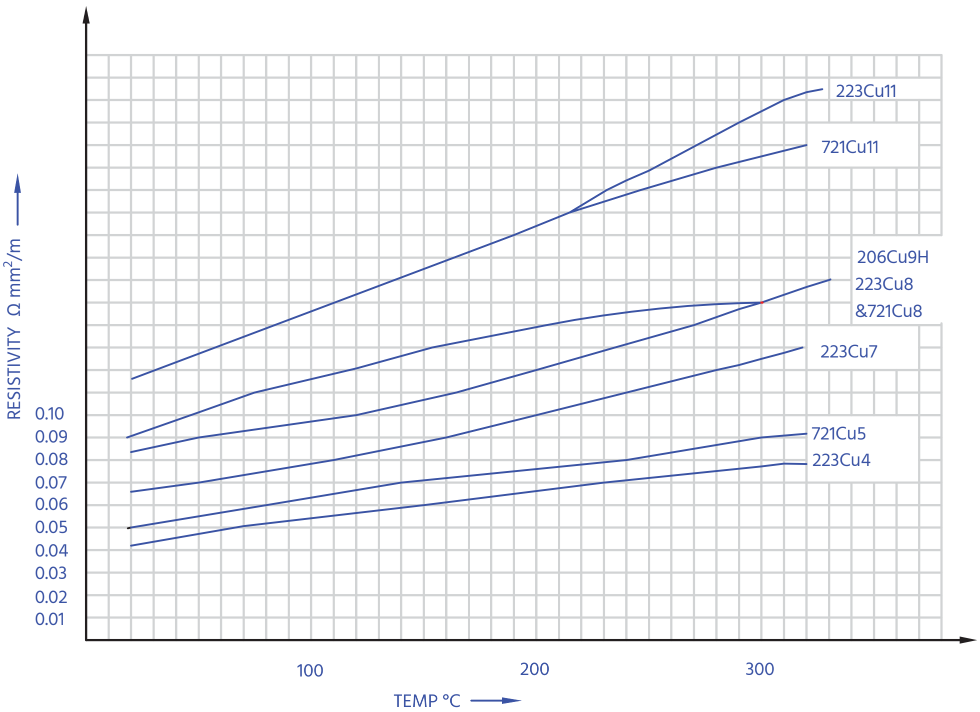
Deflection Vs Temperature





Resistivity Vs Temperature

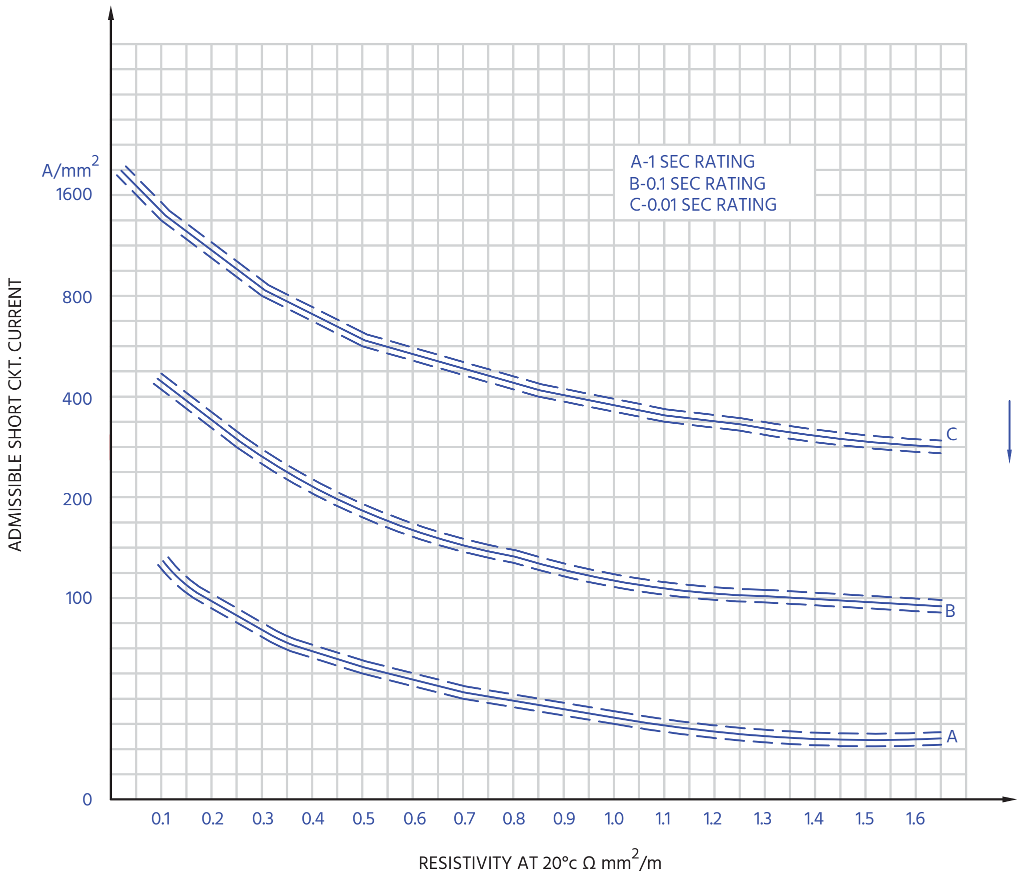




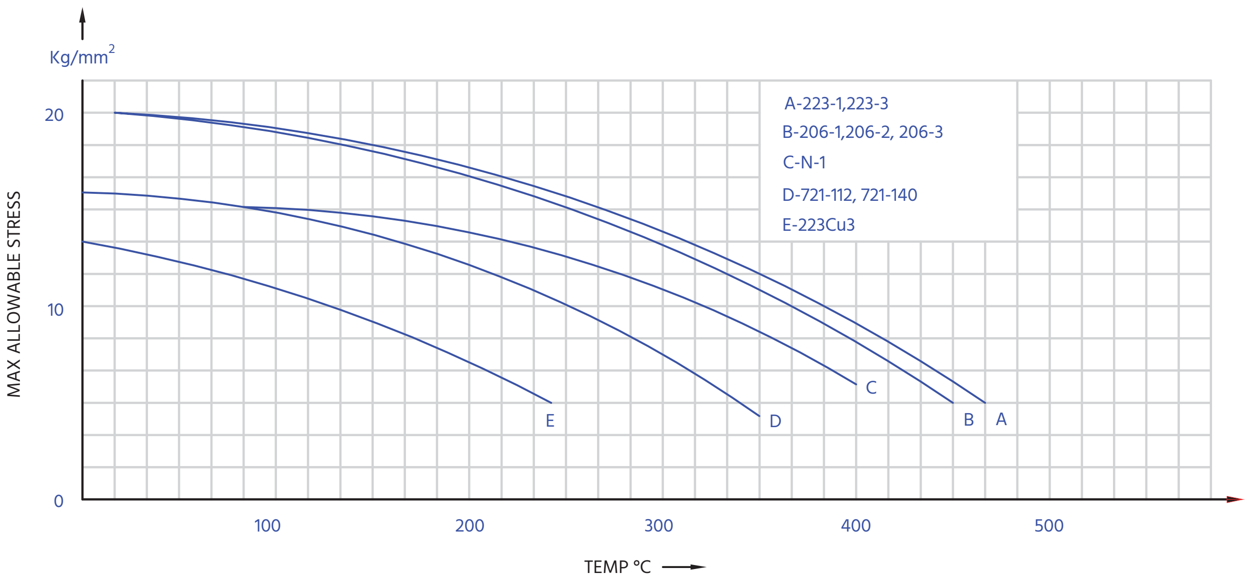
SHIVALIK BIMETAL CONTROLS LTD. SUMMARY OF STANDARD GRADES

Sr No.	TYPE SHIVALIK	'FLEXIVITY F (50 to 200°F)	FLEXIVITY TOLERANCE	SPECIFIC THERMAL CURVATURE 'k'**	RANGE OF LINEARITY**	Max Temp of usage**	RESISTIVITY AT 20°C ρ*	RESISTIVITY AT 75°F ρ*	RESISTIVITY TOLERANCE	Modulus of Elasticity 'E' **	DENSITY **	THERMAL CONDUCTIVITY 'K'**	RECOMENDED HEAT TREATMENT FOR 2 HRS	STANDARD HARDNESS RANGE: LE SIDE	STANDARD HARDNESS RANGE: HE SIDE	EQUIVALENT GRADES: ASTM	IMPHY	EMS	FPEC	DIN	AUERHAMMER	NEOMAX
		$X 10^{-6}$ /°F	± %	$X10^{-6}$ /°C	°C	°C	Ohm mm ^{2} /m	Ohm circmil/ft.	± %	KN /mm ^{2}	gm/cm ^{3}	W/cm °C	°C	VICKERS HARDNESS NO.(HV)								
1	206-1	15.80	5	28.44	-20 to 200	500	0.780	470	4	170	8.1	0.120	350	190-240	200-275.	TM29	AS	LA1	FPA206-78	TB1577A	TB155/78	(BL-2)
2	206-2	14.60	5	26.28	-20 to 300	500	0.770	465	4	170	8.1	0.120	350	190-240	200-275						TB150/74	
3	206-3	12.20	5	21.96	-20 to 380	500	0.700	420	4	170	8.1	0.125	350	190-240	200-275		BS	LA3	FPA206-70	TB1170A	TB 115/70	BH-2
4	206-4	9.90	5	17.82	-20 to 430	500	0.619	373	4	170	8.0		350	190-240	200-275							
5	206-S	6.30	5	11.34	-20 to 200	500	0.211	127	4	170	8.0		350	180-230	200-275							
6	223-1	15.00	5	27.00	-20 to 200	500	0.790	475	4	170	8.1	0.120	350	190-240	215-300	TM1	R80	B1	FPA223-80		TB 140/80	BL-5
7	223-1D	14.72	4	26.50	-20 to 200	500	0.790	475	4	170	8.1	0.120	350	200-240	240-300	TM1	R80	B1	FPA223-80		TB 140/80	BL-5
8	223-3	11.70	5	21.06	-20 to 320	500	0.690	415	4	170	8.1	0.130	350	190-240	215-300							
9	223-N	4.60	5	8.28	-20 to 200	500	0.158	95	6	200	8.6	0.420	350	190-240	215-300							
10	N-1	10.20	5	18.36	-20 to 150	450	0.158	95	6	170	8.6	0.420	350	190-240	190-240	TM22	R15/15B	N1	FPAN-16		TB 97/16	BL-3
11	258-1	13.90	5	25.02	-20 to 200	500	0.830	500	4	175	8.1		350	190-240	210-270			E1	FPA258-75			
12	258-3	10.40	5	18.72	+90 to 320	500	0.722	435	4	175	8.1		350	190-240	210-270	TM3		E3				
13	258-5	6.60	5	11.88	+150 to 430	500	0.614	370	5	175	8.1		350	190-240	210-270	TM5		E5	FPA258-60			
14	703-1	15.00	5	27.00	-20 to 150	175	0.123	74	15	130	8.3	1.980	150	190-240	150-180							
15	206Cu3	13.10	5	23.58	-20 to 200	400	0.033	20	10	140	8.6		250	190-240	200-275.						TB132/03	
16	206Cu6	14.80	5	26.64	-20 to 200	400	0.060	36	10	165	8.4	1.360	250	190-240	200-275			LA35R10	FPA206-06	TB1406	TB130/06	
17	206Cu9	15.40	5	27.72	-20 to 200	400	0.090	55	7	165	8.2		250	190-240	200-275							
18	206Cu9H	12.00	5	21.60	-20 to 380	450	0.090	55	10	170	8.2	0.160	350	190-240	200-275		BS9	LA55R30	FP206-9	TB1109	TB115/09	THC-9
19	206Cu9L	13.90	5	25.02	-20 to 200	400	0.090	55	10	165	8.2		250	190-240	200-275							
20	206Cu11	15.40	5	27.72	-20 to 200	400	0.110	66	7	165	8.2	0.650	250	190-240	200-275		AS11	LA70R10	FP206-11	TB1511	TB150/11	
21	206Cu15	15.60	5	28.08	-20 to 200	400	0.150	90	7	170	8.2	0.550	250	190-240	200-275				FP206-15		TB150/15	TRC-15K
22	206Cu17	15.60	5	28.08	-20 to 200	400	0.170	102	7	170	8.2	0.460	250	190-240	200-275				FP206-17		TB150/17	
23	206Cu19	15.60	5	28.08	-20 to 200	400	0.191	115	6	170	8.2	0.400	250	190-240	200-275						TB150/19	
24	206Ni25	14.50	5	26.10	-20 to 200	450	0.250	150	6	170	8.3	0.270	350	190-240	200-275		AS25		FP206-25	TB1425	TB140/25	TR-25
25	206Ni35	15.20	5	27.36	-20 to 200	450	0.352	210	5	170	8.3	0.220	350	190-240	200-275		AS35	LA200R10	FP206-35	TB1435	TB148/35	TR-35
26	206Ni45	15.60	5	28.08	-20 to 200	450	0.450	270	5	170	8.2	0.180	350	190-240	200-275						TB150/45	TR-45
27	206Ni50	15.40	5	27.72	-20 to 200	450	0.500	300	5	170	8.2	0.880	350	190-240	200-275						TB150/50	TR-50
28	206Ni55	15.70	5	28.26	-20 to 200	450	0.550	330	5	170	8.2	0.163	350	190-240	200-275		AS55		FP206-55	TB1555	TB150/55	TR-60
29	223Cu3	13.00	5	23.40	-20 to 150	350	0.033	20	10	140	8.6	2.240	250	190-240	80-120	TM24	R3	F20R	FPA982-3		TB121/03	
30	223Cu3 (3)	13.10	5	23.58	-20 to 200	400	0.033	20	10	140	8.6		250	190-240	200-275.						TB132/03	
31	223Cu4	13.50	5	24.30	-20 to 200	400	0.042	25	10	140	8.6		250	190-240	215-300		R4	F25R	FPA982-4		TB124/04	TRC-5
32	223Cu5	13.90	5	25.02	-20 to 150	350	0.050	30	10	160	8.5	1.601	250	190-240	215-300	TM25		F30R	FPA982-5		TB128/05	
33	223Cu5L	12.40	5	22.32	-20 to 250	400	0.050	30	10	160	8.5	1.601	250	190-240	215-300						TB115/05	
34	223Cu6	14.20	5	25.56	-20 to 150	350	0.058	35	10	160	8.4	1.360	250	190-240	215-300		R6	F35R	FPA982-6		TB131/06	
35	223Cu7	14.40	5	25.92	-20 to 150	350	0.070	42	10	165	8.3	1.422	250	190-240	215-300			F40R	FPA982-7		TB134/07	
36	223 Cu7L	13.20	5	23.76	-20 to 250	400	0.070	42	10	165	8.3	1.422	250	190-240	215-300						TB125/07	
37	223Cu8	14.60	5	26.28	-20 to 150	350	0.083	50	9	170	8.3	1.041	250	190-240	215-300	TM26	R8	F50R	FPA982-8		TB135/08	TRC-10
38	223 Cu8L	13.60	5	24.48	-20 to 250	400	0.083	50	9	170	8.3	1.041	250	190-240	215-300						TB128/08	
39	223 Cu10	15.00	5	27.00	-20 to 150	350	0.100	60	7	170	8.3		250	190-240	215-300			F60R			TB137/10	
40	223Cu11	14.70	5	26.46	-20 to 150	350	0.116	70	7	170	8.3	0.712	250	190-240	215-300	TM27	R11	F70R	FPA982-11		TB137/12	TRC-12
41	223 Cu11L	13.90	5	25.02	-20 to 250	400	0.116	70	7	170	8.3	0.712	250	190-240	215-300						TB131/12	
42	223Cu15	14.80	5	26.64	-20 to 150	350	0.150	90	7	170	8.3	0.540	250	190-240	215-300	TM28		F90R	FPA982-15		TB138/15	TRC-15
43	223Cu16	14.80	5	26.64	-20 to 150	350	0.166	100	7	170	8.3	0.140	250	190-240	215-300		R16	F100R			TB138/17	
44	223Cu17L	13.40	5	24.12	-20 to 250	400	0.166	100	7	170	8.3	0.140	250	190-240	215-300						TB125/17	
45	223Ni16	11.50	5	20.70	-20 to 150	500	0.166	100	7	180	8.3	0.412	350	190-240	215-300	TM9	R15-T	B100R	FPA223-17		TB100/17	
46	223Ni20	13.10	5	23.58	-20 to 150	500	0.208	125	6	180	8.3	0.341	350	190-240	215-300	TM10		B125R	FPA223-21		TB119/21	
47	223 Ni20L	12.60	5	22.68	-20 to 250	450	0.208	125	6	180	8.3	0.341	350	190-240	215-300						TB118/21	
48	223Ni25	13.70	5	24.66	-20 to 150	500	0.249	150	6	180	8.3	0.292	350	190-240	215-300	TM11	R25	B150R	FPA223-25		TB127/25	
49	223Ni30	14.10	5	25.38	-20 to 150	500	0.291	175	6	175	8.3	0.252	350	190-240	215-300	TM12		B175R	FPA223-30		TB130/29	
50	223Ni35	14.40	5	25.92	-20 to 150	500	0.332	200	5	175	8.3	0.212	350	190-240	215-300	TM13		B200R	FPA223-35		TB134/33	
51	223 Ni35L	13.80	5	24.84	-20 to 250	450	0.332	200	5	175	8.3	0.212	350	190-240	215-300						TB130/33	
52	223Ni40	14.70	5	26.46	-20 to 150	500	0.416	250	5	175	8.3	0.200	350	190-240	215-300	TM14	R40	B250R	FPA223-40		TB138/42	
53	223 Ni40L	13.90	5	25.02	-20 to 250	450	0.416	250	5	175	8.3	0.200	350	190-240	215-300						TB131/42	
54	223Ni50	14.90	5	26.82	-20 to 150	500	0.499	300	5	170	8.3	0.171	350	190-240	215-300	TM15		B300R	FPA223-50		TB139/50	
55	223Ni60	15.00	5	27.00	-20 to 150	500	0.582	350	5	170	8.1	0.162	350	190-240	215-300	TM16	R60	B350R	FPA223-60		TB140/58	
56	223-560	14.50	5	26.10	-20 to 150	350	0.929	560	5	170	8.6		350	190-240	215-300	TM7						
57	721-3	18.00	5	32.40	-20 to 200	350	0.938	565	5	170	7.8		260	190-240	185-235	TM23		P3	FPA721-95			
58	721-112	21.50	5	38.70	-20 to 200	350	1.122	675	5	140	7.8	0.061	260	190-240	185-235	TM2	108SP	P675R	FPA721-110	TB20110	TB 208/110	
59	721-140	15.90	5	28.62	-20 to 200	350	1.413	850	5	136	7.6	0.050	260	190-240	185-235	TM8	140SP	P850R	FPA721-140		TB140/140	BR-2
60	721 Cu3	17.56	5	31.61	-20 to 200	350	0.033	20	10	170	8.3		260	190-240	185-235						TB170/03	
61	721Cu5	18.50	5	33.30	-20 to 200	350	0.050	30	10	140	8.3	1.600	260	190-240	185-235	TM31	5SP	P30R	FP721-5	TB1805	TB180/05	BRC-6
62	721Cu8	19.80	5	35.64	-20 to 200	350	0.083	50	9	140	8.1	1.000	260	190-240	185-235		8SP	P50R	FP721-8	TB2008	TB185/08	BRC-8
63	721Cu8LE	21.10	4	38.00	-20 to 200	350	0.082	49	9	140	8.1	1.000	260	190-240	185-235							
64	721 Cu10	20.60	5	37.08	-20 to 200	350	0.100	60	8	140	8.0		260	190-240	185-235		10SP	P60R	FP721-10	TB2010	TB200/10	
65	721Cu11	20.50	5	36.90	-20 to 200	350	0.113	68	8	140	7.9	0.710	260	190-240	185-235		11SP	P70R	FP721-12	TB2011	TB200/11	
66	721Cu15	21.10	5	37.98	-20 to 200	350	0.150	90	7	140	7.9	0.541	260	190-240	185-235		15SP	P90R	FP721-15	TB2015	TB200/15	
67	721Cu17	21.10	5	37.98	-20 to 200	350	0.166	100	7	140	7.9	0.462	260	190-240	185-235			P100R	FP721-17		TB200/17	
68	721Cu20	21.20	5	38.16	-20 to 200	350	0.208	125	7	140	7.9	0.365	260	190-240	185-235		20SP	P125R	FP721-20	TB2020	TB200/20	BRC-22
69	721Cu25	21.20	5	38.16	-20 to 200	350	0.249	150	6	140	7.9	0.270	260	190-240	185-235				FP721-25	TB2025	TB200/25	
70	721Cu30	21.20	5	38.16	-20 to 200	350	0.291	175	6	140	7.9	0.250	260	190-240	185-235		30SP	P175R	FP721-30	TB2030	TB200/30	BRC-32
71	721Cu35	21.50	5	38.70	-20 to 200	350	0.332	200	6	140	7.9	0.210	260	190-240	185-235							
72	721Cu40	21.50	5	38.70	-20 to 200	350	0.416	250	6	140	7.9	0.190	260	190-240	185-235		40SP	P250R	FP721-40	TB2040	TB200/40	
73	721Cu40LE	21.39	4	38.50	-20 to 200	350	0.400	241	5	140	7.9	0.190	260	190-230	185-225							
74	721S50	21.50	5	38.70	-20 to 200	350	0.499	300	5	140	7.8	0.170	260	190-240	185-235					TB2050		
75	721S60	21.50	5	38.70	-20 to 200	350	0.582	350	5	140	7.8	0.162	260	190-240	185-235		60SP	P350R	FP721-60	TB2060	TB200/60	BRC-61
76	721S80	21.50	5	38.70	-20 to 200	350	0.831	500	5	140	7.8	0.110	260	190-240	185-235		80SP	P500R			TB200/80	BRC-83
77	197-7	9.90	5	17.80	0 to 200	450	0.850	510	4	190	8.1	0.120	350	200-250	215-300			GB-14				
FLEXIVITY CORRESPONDS TO THERMAL CURVATURE IN °C(MULTIPLYING FACTOR 1.8)						*VALUES ARE MEASURED AND CERTIFIED, **THESE VALUES ARE NOT MEASURED AND ARE PRESENTED TO AID DESIGNING AND SHALL NOT BE USED FOR REJECTION OR ACCEPTANCE PURPOSE															SBCL/TS/BM /001/10	

Resistivity Vs Admissible Short Circuit Current



Stress Vs Temperature



Enquiry for Thermostatic Bimetals

If you are using Thermostat metals in an existing product, the equivalent Shivalik grade can be obtained by writing to us the grade number presently being used by you.

For new applications and new product development we suggest that you involve us at an early stage. We would require answers to the following questions to deduce the size and type of bimetal for your application.

- What is the operating temperature range?
- What is the maximum temperature the bimetal may be subjected to?
- What is the deflection and force required?
- How is the bimetal element heated?
- If electrically heated what is the Voltage and Amperage?
- What is the available space for the element? Give a description and drawing.
- Type of movement required i.e. angular or linear?
- Is the bimetal element required to operate under corrosive conditions.

Section G

Components And Subassemblies

Shivalik can provide components of Bimetal EB Welded Material stamped inhouse on precision stamping presses.

The toolings are also developed inhouse. Shivalik supplies OEMs with millions of components every month conforming to their ever increasing quality requirements.

Statistical techniques are used to ensure quality on ppm levels.

Conversion Factors

Fractions of an inch	Decimals of an inch	Millimeters
1/64	0.0156	0.397
1/32	.0313	0.794
3/64	.0469	1.191
1/16	.0625	1.588
5/64	.0781	1.985
3/32	.0938	2.381
7/64	.1094	2.778
1/8	.1250	3.175
9/64	.1406	3.572
5/32	.1563	3.969
11/64	.1719	4.366
3/16	.1875	4.763
13/64	.2031	5.159
7/32	.2188	5.556
15/64	.2344	5.953
1/4	.2500	6.350
17/64	.2656	6.747
9/32	.2813	7.144
19/64	.2969	7.541
5/16	.3125	7.938
21/64	.3281	8.334
11/32	.3438	8.731
23/64	.3594	9.128
3/8	.3750	9.525
25/64	.3906	9.922
13/32	.4063	10.319
27/64	.4219	10.716
7/16	.4375	11.113
29/64	.4531	11.509
15/32	.4688	11.906
31/64	.4844	12.303
1/2	.5000	12.700
33/64	.5156	13.097
17/32	.5313	13.494
35/64	.5469	13.891
9/16	.5625	14.288
37/64	.5781	14.684
19/32	.5938	15.081
39/64	.6094	15.478
5/8	.6250	15.875
41/64	.6406	16.272
21/32	.6563	16.669
43/64	.6719	17.066
11/16	.6875	17.463
45/64	.7031	17.859
23/32	.7188	18.256
47/64	.7344	18.653
3/4	.7500	19.050
49/64	.7656	19.447
25/32	.7813	19.844
51/64	.7969	20.241
13/16	.8125	20.638
53/64	.8281	21.034
27/32	.8438	21.431
55/64	.8594	21.828
7/8	.8750	22.225
57/64	.8906	22.622
29/32	.9063	23.019
59/64	.9219	23.416
15/16	.9375	23.813
61/64	.9531	24.209
31/32	.9688	24.606
63/64	.9844	25.003
1	1.0000	25.400

To Change			To Change Back		
From	**to**	**Multiply by**	**From**	**to**	**Multiply by**
Length			**Length**		
mm	in	.03937	in	mm	25.4
cm	in	.3937	in	cm	2.54
cm	ft	.03281	ft	cm	30.48
in	m	.0254	m	in	39.37
Area			**Area**		
cir mils	sq in	..0000007854	sq in	cir mils	1,273,240
cir mils	sq mils	.7854	sq mils	cir mils	1.2732
cir mils	sq mm	.0005066	sq mm	cir mils	1,973.51
sq mm	sq in	.00155	sq in	sq mm	645.16
sq mils	sq in	.000001	sq in	sq mils	1,000,000
sq cm	sq in	.155	sq in	sq cm	6.4516
Volume			**Volume**		
cu cm	cu in	0.0610	cu in	cu cm	16.387
Weights			**Weights**		
grams	lbs	.002205	lbs	grams	453.59
Density			**Density**		
grams cu cm	lbs (avdp) cu in	.03613	lbs (avdp) cu in	grams cu cm	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 mm^2/m	0.001662	ohms mm^2/m	ohms circ mil/ft	601.68
Flexivity			**Flexivity**		
Flexivity	Specific deflection	0.9540	Specific deflection	Flexivity	.1.048
Flexivity	Sp. Thermal curvature	.5556	Sp. Thermal curvature	Flexivity	1.800
Modulus of Elasticity			**Modulus of Elasticity**		
lbs sq in	N/mm^2	0.006895	N/mm^2	lbs sq in	145.04
Kp/mm^2	N/mm^2	9.81	N/mm^2	Kp/mm^2	0.102
Temperature change			**Temperature change**		
F ° temp change	C ° temp change	0.5556	C ° temp change	F ° temp change	1.800

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