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 high coefficient of expansion while the other layer is with a lower coefficient of expansion.

Consider two metal strips A and B with different coefficient of expansion say a and ß where a > ß. When heated, the strips expand to different lengths where L1 > L2

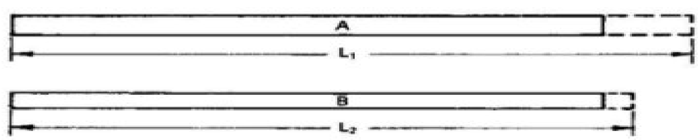

Fig. 1

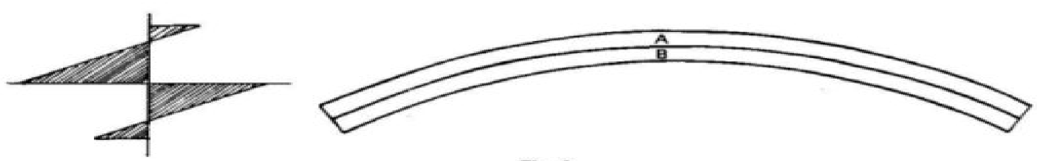

Fig. 2

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 a and ß, 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 Villaceau as :-

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

Where R_0 is the curvature at initial temperature T_0
R is the curvature at final temperature T
a and ß 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 ?T

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

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

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

In USA this constant is known as Flexivity, F.

$\therefore$ from equation (2), we have $V \text{ or } F = \dfrac{\left(\frac{1}{R} - \frac{1}{R_0}\right) t}{\Delta T}$ (3)

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 that 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 Flexivit, 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.

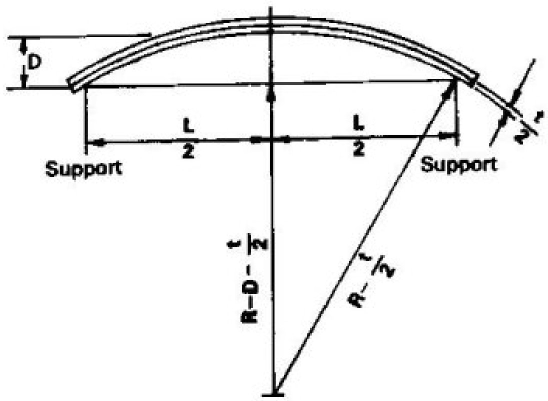

Fig. 3

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

$$V \text{ or } F = \frac{1}{R} \times \frac{t}{\Delta T} \quad (4)$$

From Figure 3

$$\left[R - \frac{t}{2}\right]^2 = \left[R - \left(D + \frac{t}{2}\right)\right]^2 + \left[\frac{L}{2}\right]^2 \quad \text{or} \quad \frac{1}{R} = \frac{8\,D}{L^2 + 4D^2 + 4Dt} \quad (5)$$

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

$$V \text{ or 'k' or } F = \boxed{\frac{8\,D\,t}{\Delta T\,(L^2 + 4D^2 + 4Dt)}} \quad (6)$$

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

$$V \text{ or 'k' or } F = \frac{8\,D\,t}{L^2\,\Delta T} \quad (7)$$

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

$$\text{We have } a = \frac{4\,D\,t}{L^2\,\Delta T} \quad (8)$$

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However, **specific thermal deflection**, ‘a’, is still used and measured by tge cantilever method as per DIN 1715-1973

2.1.3 Calculation of Specific Thermal Deflection by the Cantilever method

From Fig. 4 :-

$$\left(R + \frac{t}{2}\right)^2 = \left(R + \frac{t}{2} - D\right)^2 + L^2 \quad \text{or} \quad \frac{1}{R} = \frac{2D}{L^2 + D^2 - Dt} \qquad (9)$$

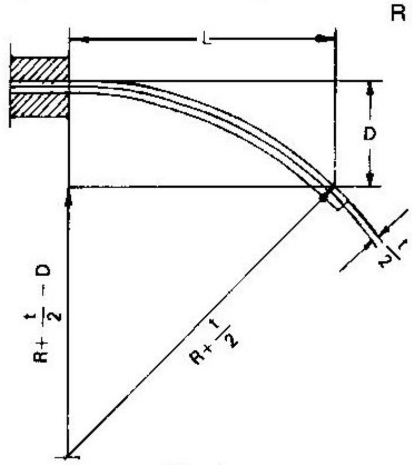

Fig. 4

From equation (4) and (9) we have

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

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

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

Ignoring product Dt, and D being much less than L

$$\text{We obtain } a = \frac{D\,t}{\Delta T\,L^2} \qquad \text{JIS C2530-1975} \qquad (11)$$

The values of **specific thermal deflection** obtained by this method are material dependent and are 4% to 8% higher than by simple beam method. The reason, while not yet clear, is assumed to be due to the distribution of stresses in a cantilever and a simple beam and 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. The value is for 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.

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

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 Linearity Range

It denotes the temperature range in which the thermal deflection does not vary by more than ±5% 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 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 temp range.

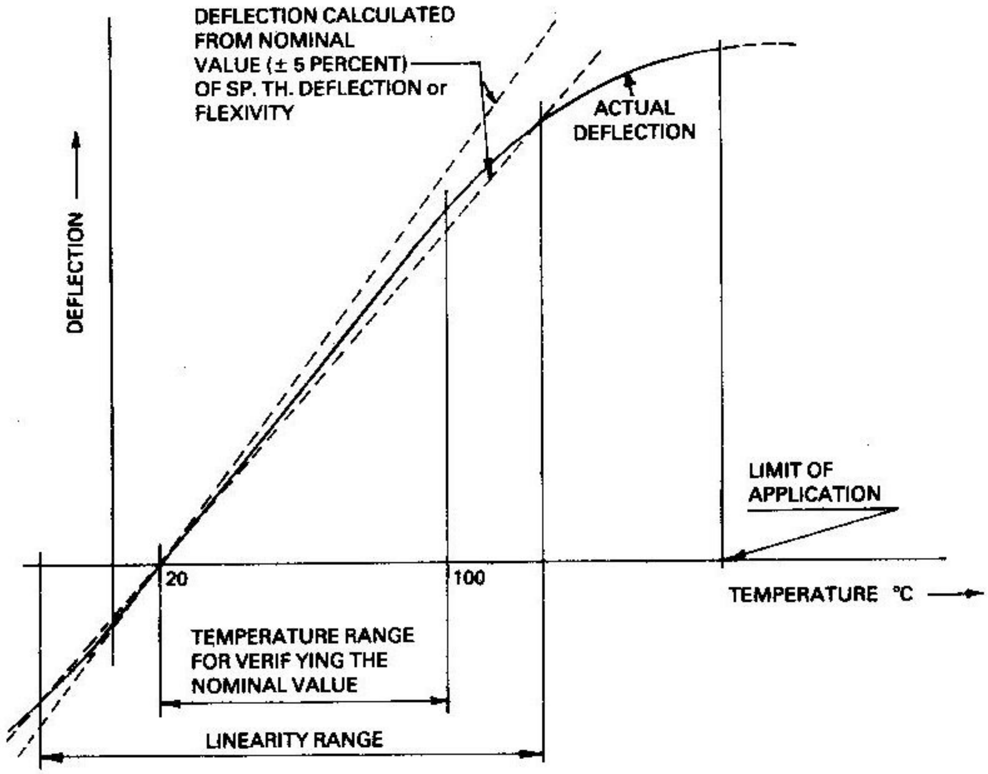

Fig. 5

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 process (rolling, slitting, leveling, flattening, blanking etc.)

The sum of these stresses should not exceed the maximum permissible stress s_{max} at the maximum temperature that the bimetal is to be used. While the 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 upon 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^{o}C.

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 temp. ranging from 70% to 80% of their liquidous temp. (ie. The temp 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/cm of width.

As for the bond integrity, microscopic examinations 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 leveled 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.