Kanthal
Thermostatic Bimetal Handbook

Kanthal Thermostatic Bimetal Handbook

Catalog 3-A-1-3 05-08-3000

Disclaimer: The information contained in this document is for illustrative purposes only. The data and examples are only general recommendations, and not a warranty or a guarantee that such data will function in individual/specific cases. The purchaser of a Kanthal product has the responsibility to control the applicability of Kanthal's products in a specific application before using them.

Kanthal – a Member of the Sandvik Group
The Sandvik Group is a global high technology enterprise with 47,000 employees and annual sales of approximately SEK 86 billion. Sandvik spends about 4 percent of its turnover on research and development. As a member of the Sandvik Group, Kanthal has full access to world-class competence within materials and process technology, as well as Sandvik's R&D-center in Sweden, which is one of the most distinguished in the world. Through Sandvik's global sales organization Kanthal is represented in 130 countries.

KANTHAL – Other Products

Wire, Strip and Ribbon. Resistance material.

Alloy	Max temp.
KANTHAL APM	1425°C
KANTHAL A-1	1400°C
KANTHAL A	1350°C
KANTHAL AE	1300°C
KANTHAL AF	1300°C
KANTHAL D	1300°C
ALKROTHAL®	1100°C
NIKROTHAL® 80	1200°C
NIKROTHAL 70	1250°C
NIKROTHAL 60	1150°C
NIKROTHAL 40	1100°C
KANTHAL 70	600°C
KANTHAL 52	600°C

Thermocouple Alloys

KANTHAL Super Heating Elements

Grade	Max temp.
KANTHAL Super 1700	1700°C
KANTHAL Super 1800	1800°C
KANTHAL Super 1900	1850°C
SUPERTHAL® Heating Modules	1650°C

System Products

Metallic heating elements
Heating elements of KANTHAL or NIKROTHAL for furnaces and other industrial applications.

TUBOTHAL®
Radiant tube heating element made in KANTHAL APM.

Tubes
Extruded radiant tubes for gas- or electrically heated furnaces.
Thermocouple protection tubes.

FIBROTHAL®
Ready-to-install heating modules

Silicon Carbide Products

Silit, Hot Rod, GLOBAR®, CRUSILITE®, Float heating elements for furnaces up to 1600°C.

Kanthal Machinery

Machines for manufacturing of tubular heating elements.

Foreword

We are pleased to present the sixth edition of KANTHAL Thermostatic Bimetal Handbook. This edition introduces new technical data with appropriate recommendations for use.

The handbook also contains new information from our research and development work, from the technical knowledge accumulated in co-operation with users, as well as from the experience gained in the manufacture of KANTHAL Thermostatic Bimetals.

For many years KANTHAL Thermostatic Bimetals have maintained their reputation for close tolerances and consistent high quality. From a metallurgical aspect, there is a close relationship between the components of KANTHAL Thermostatic Bimetals and our world-renowned electrical resistance alloys. The sophisticated production methods we employ right from the melt up to the finished strip or fabricated part ensure perfect function of the thermostatic element.

Our customer service department, in co-operation with our laboratories, is always available to provide advice and assistance. Samples can be quickly made available for trial and experimental purposes. We would be grateful to receive any information you may have regarding your experience in using KANTHAL Thermostatic Bimetals and of your requirements in respect of their properties.

Hallstahammar, Sweden, 2008
Kanthal AB

Introduction

Properties

Application

Miscellaneous

KANTHAL Thermostatic Bimetal and its Manufacture

1. Description of Thermostatic Bimetal and its Function

It is well known that different metals expand to different extents when heated. When the temperature is reduced, this expansion is reversed. Fig. 1 shows two strips of different metals before and after heating. The area enclosed by the dotted lines indicates the elongation after heating. Strip A should elongate more than strip B.

When the two metal strips are bonded together, the strip A is partly prevented from expanding by the strip B when heated. A considerable force is thereby developed which causes the bonded strips to bend as shown in Fig. 2. In absence of external forces the bimetal will take the shape of an arc. The deformation of the assembly is greater than the elongation of the individual strips. The bimetal will also bend in the direction of the width. This cross curvature reduces the length curvature and explains why the bimetal deflection also depends upon the bimetal width.

A bimetal is also called thermostatic bimetal, since its function results from the effect of heat. Instead of the metal strips mentioned above, different alloys can be chosen.

Fig. 1

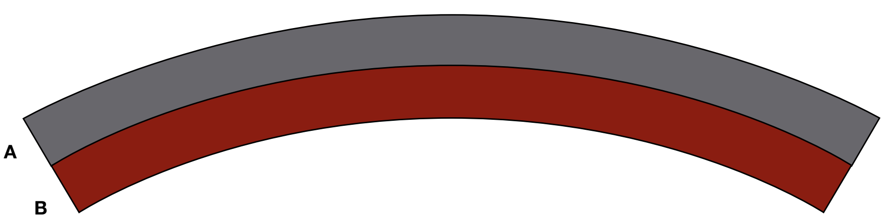


Fig. 2

Two alloys with greatly differing coefficients of thermal expansion are normally selected. Of the two metal layers which are permanently joined together, the side which develops the largest thermal expansion is known as the active component. It generally consists of an alloy containing nickel, iron, manganese or chrome in different amounts. The side with the lower degree of expansion is known as the passive component, for which Invar is often chosen, which is an iron-nickel alloy containing 36 % nickel. The relation of the thickness of the layers of the two components can vary for different grades. Within one bimetal type, however, the relationship is always the same.

Some bimetal types have a layer of nickel or copper between the two layers mentioned in order to reduce the electrical resistivity and to increase the thermal conductivity.

2. The Manufacture of Thermostatic Bimetals

The components of KANTHAL Thermostatic Bimetal are melted in high-frequency furnaces. Samples are taken from each melt for verification of chemical analysis and determining the resistivity and expansion properties. On the basis of these laboratory tests, the components are selected so that the finished bimetal products have uniform properties according to the quality specification.

The two components are bonded together by means of cold bonding. Special measures are taken to ensure that the joint is completely free from defects. The quality of the bonded joints is verified by microscopic and mechanical tests.

The bonded material is then rolled in different cold-rolling mills where the thickness is maintained within close tolerances. Between the various rolling processes, the bimetal strips are heat-treated in annealing furnaces in a controlled atmosphere. The sequence of annealing and rolling affects the properties of the bimetal.

During the final manufacturing process the cold-rolled strips are provided with the respective quality designation marks and the edges are slit and deburred. Marking is normally done on the active component, which is situated on the convex side of the heated thermostatic bimetal strip.

3. Quality Control

During manufacture the material is subjected to continuous control. The extensive and thorough final control includes a check of dimensions, surface finish, straightness and flatness. Laboratory tests include a check of hardness, resistivity and deflection.

Kanthal is certified according to EN ISO 9001–2000.

Basic Thermostatic Bimetal Data

1. General Formulae

A bimetal strip consisting of two components and subjected to heat alters its curvature according to the expression

$$\frac{1}{R_T} - \frac{1}{R_O} = \frac{6\,(\alpha_2 - \alpha_1)\,(1 + m)^2}{3\,(1 + m)^2 + (1 + m \cdot n)\,\left(m^2 + \frac{1}{m \cdot n}\right)} \cdot \frac{T - T_O}{s} \qquad [1]$$

where

R_T = Radius at temperature T

R_O = Radius at temperature T_O

$m = \frac{s_1}{s_2}$ where s_1 and s_2 are thicknesses of the component alloys

$n = \frac{E_1}{E_2}$ where E_1 and E_2 are moduli of elasticity of the component alloys

α_1 and α_2 = coefficients of linear thermal expansion of component alloy I and II respectively.

If the thicknesses of the component layers are the same, $s_1 = s_2$, we obtain m = 1, and if the moduli of elasticity are also the same we obtain n = 1. The expression [1] can then be simplified to

$$\frac{1}{R_T} - \frac{1}{R_O} = \frac{3\,(\alpha_2 - \alpha_1)}{2} \cdot \frac{T - T_O}{s} \qquad [2]$$

In USA the constant $\frac{3}{2}\,(\alpha_2 - \alpha_1)$ is known as flexivity, (see ASTM Designation B 106) in Europe as specific curvature k.

If $\frac{3\,(\alpha_2 - \alpha_1)}{2}$ in equation [2] is replaced by k, we obtain

$$k = \frac{\left(\frac{1}{R_T} - \frac{1}{R_O}\right) s}{T - T_O} \qquad [3]$$

Flexivity can be defined as "the change of curvature of a bimetal strip per unit temperature change times thickness" in the absence of external forces. In this context, it must be remembered that in USA the temperature is measured in °F. If the strip is flat to start with $R_O = \infty$, the formula [2] can be simplified to:

$$\frac{1}{R_T} = k\,\frac{T - T_O}{s} \qquad [4]$$

2. The Deflection of a Cantilever Strip

Figure 3 shows how the deflection is calculated at the free end of a cantilever strip.

From the figure we obtain

$$\left(R_T + \frac{s}{2}\right)^2 = \left(R_T + \frac{s}{2} - A\right)^2 + L^2$$

or

$$\frac{1}{R_T} = \frac{2A}{L^2 + A^2 - A \cdot s} \qquad [5]$$

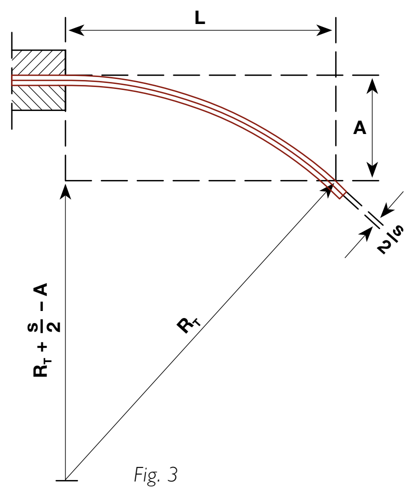


Fig. 3

From equations [4] and [5] we obtain

$$k = \frac{s}{T - T_O} \cdot \frac{2A}{L^2 + A^2 - A \cdot s} \qquad [6]$$

If we substitute $\mathbf{a} = \frac{k}{2}$ for k,

we obtain

$$\mathbf{a} = \frac{A \cdot s}{(T - T_O)(L^2 + A^2 - A \cdot s)} \qquad [7]$$

In Europe the constant **a** is called specific deflection (DIN 1715, page 126). Normally we can disregard the product A × s in the denominator. This means that we can use the following equation

$$\mathbf{a} = \frac{A \cdot s}{(T - T_O)(L^2 + A^2)} \qquad [8]$$

In most calculations A is smaller than 10 % of L. Therefore, A^2 can be disregarded in relation to L^2. Thus we obtain the simplified equation

$$\mathbf{a} = \frac{A \cdot s}{(T - T_O) L^2} \quad \text{or } A = \mathbf{a} \frac{(T - T_O) L^2}{s} \qquad [9]$$

The deflection of the cantilever strip is however affected by the external forces suppressing the cross curvature where the strip is fastened. This circumstance explains why **a** is not exactly equal to k/2.

3. Determination of Specific Curvature (Flexivity)

In USA the deflection is measured according to the ASTM standard (see ASTM Designation B 106). The new DIN 1715 standard is similar to the ASTM standard. Since bimetal components often elongate in a nonlinear way as a function of the temperature the specific curvature or flexivity depends upon the temperatures between which it has been measured. These are different in ASTM B 388 and in DIN 1715.

The thermostatic bimetal strip is supported at its two ends and the deflection, A, is measured in the middle.

From Figure 4 we obtain

$$\left(R_T - \frac{s}{2}\right)^2 = \left(R_T - A - \frac{s}{2}\right)^2 + \left(\frac{L}{2}\right)^2$$

or

$$\frac{1}{R_T} = \frac{8\,A}{L^2 + 4\,A^2 - 4\,A \cdot s} \qquad [10]$$

From equations [4] and [10] we obtain

$$k = \frac{s}{T - T_O} \cdot \frac{8\,A}{L^2 + 4\,A^2 - 4\,A \cdot s} \qquad [11]$$

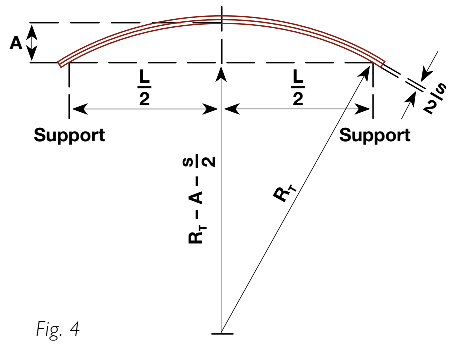


Fig. 4

Again, we can normally disregard the product 4 A s in the denominator, and so we obtain

$$k = \frac{8\,A\,s}{(T - T_O)\,(L^2 + 4\,A^2)} \qquad [12]$$

If A is less than 5 % of L, we can also disregard $4\,A^2$

$$k = \frac{8\,A\,s}{(T - T_O)\,L^2} \qquad [13]$$

4. Temperature Range for Linear Deflection

The opening angle of a bimetal coil made of a bimetal strip having the length L is **a**= L/R when the bending radius R is constant all along the strip. The angular deflection of such a coil when heated can by utilizing formula [2] be calculated:

$$\alpha = \alpha_T - \alpha_O = L(1/R_T - 1/R_O) = k(T - T_O)\,L/s \qquad [14]$$

Such a coil can be heated to different temperatures and the deflection measured and plotted on a graph.

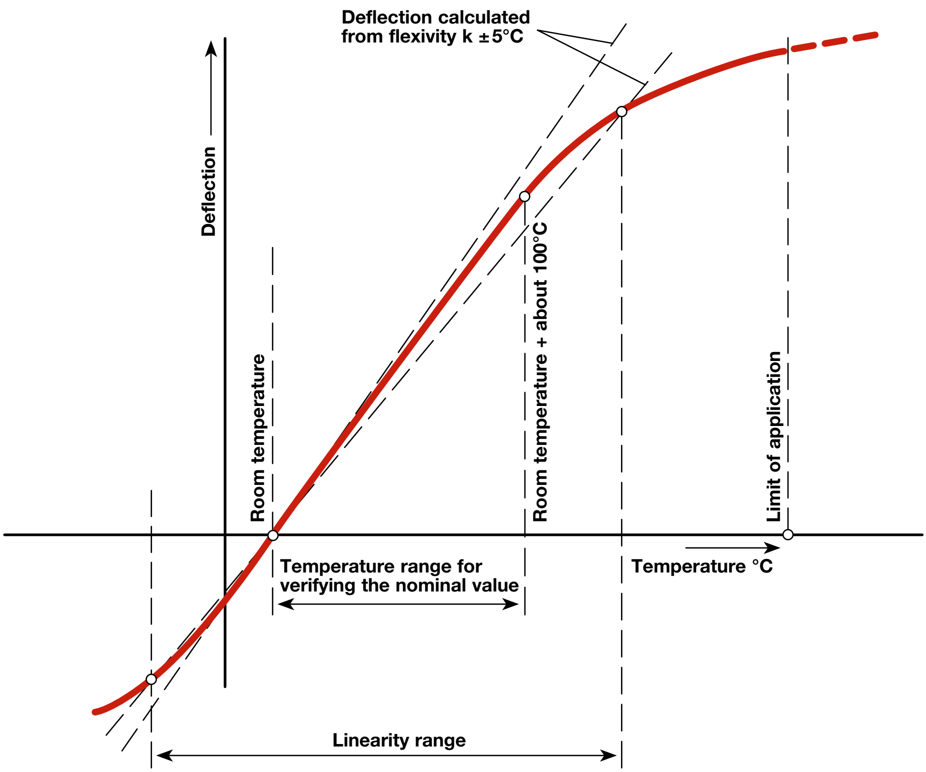


Fig. 5

An example of a deflection graph is shown in Fig. 5. The graph shows that only within a certain range is the deflection linear with the temperature. The linearity range is the temperature range in which the thermal deflection does not deviate more than ± 5 % from the deflection which is calculated from the nominal value of the flexivity. In many cases it is not necessary to limit the application within the linearity range. Consequently, as the graph shows, the normal range of application frequently extends beyond the linearity range.

5. Measuring the Deflection

KANTHAL Thermostatic Bimetals are always measured in the DIN measuring device, provided no other instructions are given by the customer. The test strips are heated in a silicon oil bath, the temperature of the oil being kept uniform by thermostatic control. Since the length, L, appears as a squared value in all formulae, the active length of the test strip is subjected to accurate control measurement. If the deflection, A, is large in relation to the length, L, the specific curvature must be calculated according to equation [11].

The measurement is normally carried out in the temperature range prescribed by DIN 1715. Prior to the measurement, the test strips are stress-relieved by means of a stabilizing heat treatment process (page 124). If the bimetal is thinner than 0.25 mm (0.01 in), the angular rotation of a standard spiral coil is measured. From this value the flexivity can be calculated by using the spiral coil formula [14] (ASTM Designation B 389). These standard spiral coils have an active strip length of 150 mm (5.91 in) and are coiled on a mandrel with a diameter of 4 mm (0.16 in).

6. Type Designations

In designating KANTHAL Thermostatic Bimetals we generally use the nominal value of the specific deflection as a whole number. Thus, for example KANTHAL 155 has a specific deflection of $15.6 \times 10^{-6}\,°C^{-1}$ and KANTHAL 60 a specific deflection of $6.0 \times 10^{-6}\,°C^{-1}$.

For designating the resistance series the letter R is added and followed by a whole number, indicating the electrical resistivity of the type concerned. For example: KANTHAL 140R140 has a specific deflection of $14.0 \times 10^{-6}\,°C^{-1}$ and an electrical resistivity of $1.40\ \Omega \times mm^2 \times m^{-1}$, while KANTHAL 145R10 has a specific deflection of $15.0 \times 10^{-6}\,°C^{-1}$ and an electrical resistivity of $0.11\ \Omega \times mm^2 \times m^{-1}$.

KANTHAL Thermostatic Bimetal Types

1. Summary of Our Standard Types

Thermostatic bimetal type	DIN designation added	Specific deflection	Specific curvature	Linearity range	Max operating temperature	Resistivity [Ω mm² m⁻¹] at temperature °C						Thermal conductivity	Modulus of elasticity	Standard hardness [H_v]		Density
		[10^{-6} K^{-1}]	10^{-6} K^{-1}]	[°C]	[°C]	0	20	100	200	300	400	[Wm^{-1} °C^{-1}]	10^3 N mm^{-2}]	low exp. side	high exp. side	[g cm^{-3}]
230		22.7	43.0	-20 – +230	330	1.04	1.05	1.15	1.22	1.28		6	135	210	220	7.8
200	TB20110	20.8	39.0	-20 – +200	330	1.09	1.10	1.20	1.27	1.33		6	135	210	220	7.8
155	TB1577A	15.6	28.5	-20 – +250	450	0.77	0.78	0.86	0.94	1.00	1.07	13	170	210	260	8.1
145		14.8	27.7	-20 – +250	450	0.78	0.79	0.85	0.93	0.99	1.06	12	170	210	260	8.1
135		13.9	25.9	-20 – +200	450	0.78	0.79	0.85	0.93	0.99	1.06	12	170	210	260	8.1
130		13.2	24.8	-20 – +325	450	0.72	0.74	0.82	0.89	0.95	1.02	12	170	210	260	8.1
115	TB1170	11.7	22.0	-20 – +380	450	0.68	0.70	0.78	0.86	0.93	0.99	13	170	210	260	8.1
100	TB0965	10.0	18.6	-20 – +425	450	0.62	0.65	0.75	0.86	0.94	1.00	15	175	210	260	8.2
94S		9.5	17.8	0 – +200	450	0.84	0.85	0.90	0.95			12	190	210	250	8.1
60		6.0	11.3	-20 – +450	450	0.19	0.21	0.28	0.37	0.47	0.59	44	190	230	260	8.0
50HT		5.0	9.4	-20 – +500	550	0.635	0.66	0.72	0.78	0.83		20	200	240	340	7.8
Resistance range																
140R140		14.0	26.1	-20 – +200	330	1.38	1.40	1.43	1.48	1.52		4	130	210	240	7.4
200R10		20.0	39.0	-20 – +200	330	0.09	0.10	0.15	0.17	0.19		72	130	210	240	7.90
180R05		18.0	33.8	-20 – +200	350	0.045	0.050	0.070	0.085	0.100		170	130	210	240	8.20
155R55	TB1555	15.0	28.2	-20 – +200	450	0.52	0.55	0.65	0.75	0.84	0.91	16	170	210	260	8.15
145R50		14.9	27.7	-20 – +200	450	0.48	0.50	0.59	0.70	0.79	0.86	16	170	210	260	8.15
145R45		14.9	27.7	-20 – +200	450	0.44	0.45	0.55	0.67	0.79		16	170	210	260	8.20
145R35	TB1435	14.8	27.4	-20 – +200	450	0.33	0.35	0.45	0.56	0.68	0.78	22	170	210	260	8.25
135R25	TB1425	14.0	26.1	-20 – +200	450	0.23	0.25	0.33	0.44	0.55	0.65	28	170	210	260	8.3
145R19		14.9	27.9	-20 – +200	400*	0.18	0.19	0.23	0.27	0.31		39	170	210	260	8.2
145R17		14.9	27.9	-20 – +200	400*	0.16	0.17	0.20	0.24	0.28		43	170	210	260	8.2
145R15		14.9	27.7	-20 – +200	400*	0.14	0.15	0.18	0.22	0.25		48	170	210	260	8.2
145R10	TB1511	15.0	27.8	-20 – +200	400*	0.107	0.11	0.14	0.16	0.19		70	165	210	260	8.3
135R05		14.2	26.6	-20 – +200	275*	0.057	0.060	0.078	0.096	0.122		114	165	210	260	8.4
130R03		13.2	24.5	-20 – +200	275	0.031	0.033	0.038	0.042	0.047		224	145	210	260	8.65
Bimetal with extra broad linearity range and good thermal conductivity																
127R09		13.4	25.0	-20 – +325	400*	0.085	0.090	0.11	0.12	3.21	0.16	88	170	210	260	8.2
115R09	TB1109	11.5	21.6	-20 – +380	400*	0.085	0.090	0.11	0.13	3.36	0.17	88	165	210	260	8.2

*In the case of direct heating by an electric current flowing through the bimetal, the max temperature should not exceed 275°C

Thermostatic bimetal type DIN designation added		Flexivity	Linearity range	Max operating temperature	Resistivity [Ω per cir. mil ft,] at temperature °F						Thermal conductivity	Modulus of elasticity	Standard [hardness H_v]		Density
		[10^{-6} °F^{-1}]	[°F]	[°F]	32	68	210	390	570	750	[BTU/h/ft² /°F/in]	[10^6 lb/in²]	low	high	[lb/in³]
230		23.9	0 – 450	625	624	630	690	732	768		42	19.2	210	200	0.281
200	TM2	21.7	0 – 395	625	654	660	720	762	798		42	19.2	210	220	0.281
155		15.8	0 – 480	840	462	468	516	564	600	642	91	24.2	210	260	0.292
145		15.4	0 – 480	840	469	475	512	560	596	638	84	24.2	210	240	0.292
135	TM1	14.4	0 – 395	840	469	475	512	560	596	638	84	24.2	210	240	0.292
130		13.8	0 – 620	840	432	444	492	534	560	594	84	24.2	210	240	0.292
115		12.2	0 – 720	840	409	420	469	517	560	596	91	24.8	210	240	0.292
100		10.3	0 – 800	840	372	390	450	516	564	600	105	24.8	210	240	0.296
94S	TM24	9.9	32 – 395	840	504	510	540	570			84	27.0	210	250	0.292
60		6.3	0 – 840	840	114	127	169	223	283	354	307	27.0	140	240	0.289
50HT		5.2	0 – 930	1020	381	390	432	468	498		130	28.4	240	340	0.281
Resistance range															
140R140	TM8	14.5	0 – 395	625	830	843	860	890	915		28	18.5	210	250	0.267
200R10		21.7	0 – 395	625	54	60	90	102	114		504	18.5	210	200	0.285
180R05		18.8	0 – 395	625	27	30	42	51	60		1185	18.5	210	200	0.296
155R55		15.7	0 – 395	840	312	330	390	450	504	536	112	24.2	210	240	0.294
145R50		15.4	0 – 395	840	288	200	354	420	474	516	111	24.2	210	240	0.294
145R45		15.4	0 – 395	840	264	270	330	402	474	468	111	24.2	210	260	0.296
145R35		15.2	0 – 395	840	198	210	270	336	408	390	153	24.2	210	240	0.298
135R25		14.5	0 – 395	840	138	150	198	264	330		195	24.2	210	240	0.300
145R19		15.5	0 – 395	750*	108	114	138	162	186		272	24.2	210	240	0.296
145R17		15.5	0 – 395	750*	96	102	120	144	168		300	24.2	210	240	0.296
145R15		15.4	0 – 395	750*	84	90	108	132	150		334	24.2	210	240	0.296
145R10		15.4	0 – 395	750*	64	66	84	96	114		487	23.5	210	240	0.300
135R05		14.8	0 – 395	730*	34	36	47	58	73		795	23.4	210	240	0.303
130R03		13.6	0 – 395	530	19	20	23	25	28		1560	20.6	210	240	0.312
Bimetal with extra broad linearity range and good thermal conductivity															
127R09		13.9	0 – 620	750*	51	54	66	72	84	96	615	24.2	210	260	0.296
115R09	TB1109	12.0	0 – 720	750*	51	54	66	78	90	102	615	23.5	210	260	0.296

*In the case of direct heating by an electric current flowing through the bimetal, the max temperature should not exceed 530°F

2. Mechanical Properties

2.1 Tensile Strength, Yield Point and Hardness

KANTHAL Thermostatic Bimetals have normally a tensile strength of 600 to 800 N × mm^{-2}, and a yield point of between 400 and 500 N × mm^{-2}. Tensile strength, yield point and hardness depend on the degree of cold rolling reduction.

The hardness values of the table on page 17–18 are approximate values for the standard reduction. KANTHAL Thermostatic bimetals can also be supplied with a higher degree of hardness, which means considerably improved elasticity properties (see also page 107). It must be recognized, however, that if the hardness is increased, a decreased maximum operating temperature should be taken into account. As a standard for slow moving bimetal parts the cold rolling reduction is 20–30 % depending on type. Disc type material for snap action applications is normally supplied with higher levels of cold rolling reductions.

KANTHAL Thermostatic Bimetals can also be supplied in a softer state in cases where the requirements for ductility are particularly high. However, due to the softer state the bending load capacity is reduced. The cold rolling reduction must be at least 7 %.

For measuring the Vickers hardness, the following loads are recommended:

Thickness [mm]	Thickness (in)	Load N
0.08–0.19	(0.003–0.007)	2.5
0.20–0.29	(0.008–0.011)	5.0
0.30–0.39	(0.012–0.015)	10.0
0.40–0.49	(0.016–0.019)	20.0
0.50–0.69	(0.020–0.027)	30.0
0.70–0.99	(0.028–0.039)	50.0
1.00–2.50	(0.040–0.099)	100.0

2.2 Modulus of Elasticity

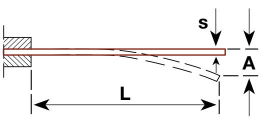
The values indicated for the modulus of elasticity have been measured at room temperature in accordance with DIN 50151. It is difficult to judge to what extent this property changes with temperature. The stiffness at increased temperature is influenced not only by the Modulus of elasticity but also by deformations of the thermostatic bimetal part, which can appear for instance as cross curvature, page 80.

In order not to complicate the calculation of bimetal elements, we refrain from considering the Modulus of elasticity as a temperature dependent material constant. When making calculations, the value of Modulus of elasticity at room temperature can also be used for temperatures within the normal range

3. Specific Deflection and Instantaneous Specific Deflection

The nominal value of the specific deflection is defined in DIN 1715 and corresponds to the specific deflection between T_O = 20°C (68°F) and T = 130°C (265°F). This nominal value of the specific deflection, which we denominate merely as specific deflection, is valid only for calculations within the linearity range of the considered or used type of thermostatic bimetal.

For calculation of the deflection of thermostatic bimetal parts, which should operate within a certain temperature range and partly or completely outside the linearity range, the instantaneous specific deflection is used. The instantaneous specific deflection, whose dependence on the temperature is shown in the form of graphs on the following pages, derives from differentiation of the deflection as a function of the temperature.



Deflection A as a function of the temperature measured on a cantilever bimetal strip in size 100 × 10 × 1 mm (3.94 × 0.39 × 0.039 in)

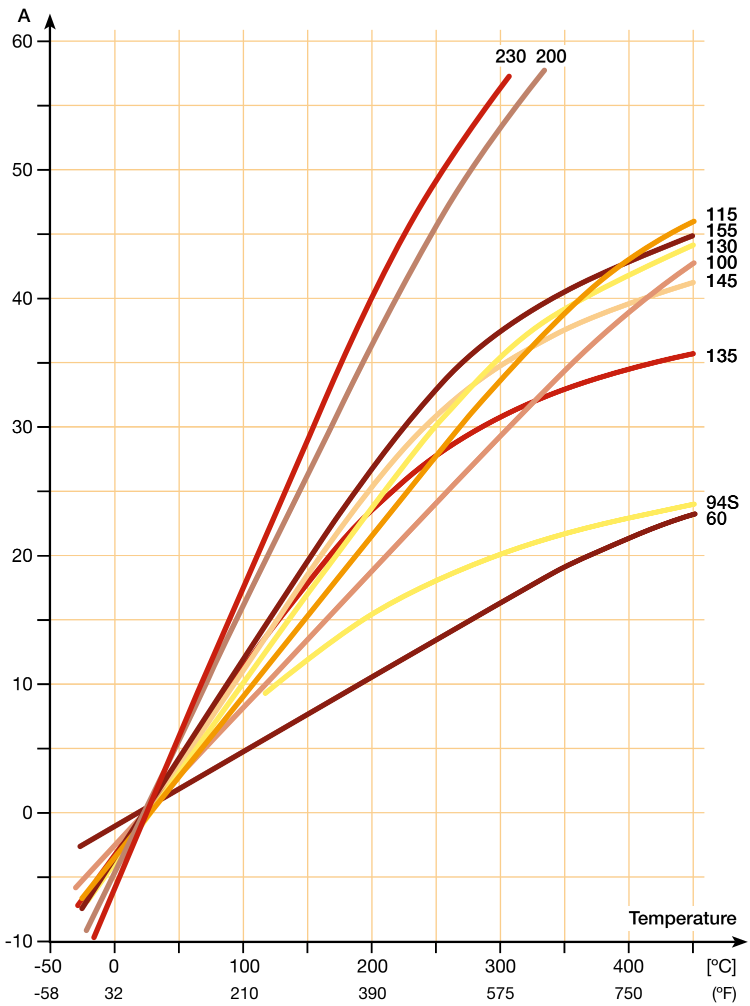


Fig. 6 Deflection graphs for KANTHAL Thermostatic Bimetal types. As regards the R-types, see data sheets on pages 46–77

Thus the actual values are valid only at the corresponding temperature. For narrow temperature ranges it is possible to use the mean value of the instantaneous specific deflection of the temperature range.

Examples:

1. KANTHAL 200 has an instantaneous specific deflection, $\mathbf{a}_d$ at 175°C (350°F) of 21.3×10^{-6} °C^{-1}.

2. KANTHAL 155 has in the temperature range 175 to 250°C (350 – 480°F) a specific deflection $\mathbf{a} = \mathbf{a}_d$ (275°C (530°F)) = 8.5×10^{-6} °C^{-1} (average value).

3. KANTHAL 115 has in the temperature range 175 to 250°C (350 – 480°F) a specific deflection $\mathbf{a} = \mathbf{a}_d$ (175 – 250°C (350 – 480°F)) = 12.8×10^{-6} °C^{-1}. The nominal value of the specific deflection is 11.7×10^{-6} °C^{-1} related to the linearity range 0 to 380°C (32 – 715°F). The value $\mathbf{a}_d = 12.8 \times 10^{-6}$ C^{-1} refers to the temperature range 175 to 250°C (350 – 480°F), because here the deflection approaches the upper limit of the tolerance range of the linearity.

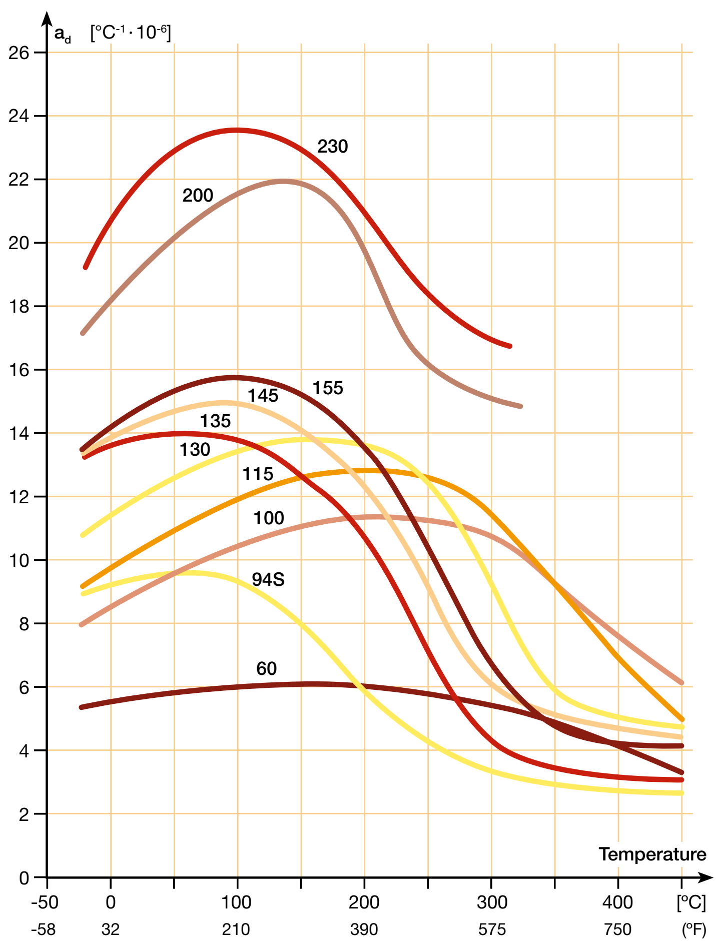


Fig. 7 Graphs of instantaneous specific deflection for KANTHAL Thermostatic Bimetal types. As regards the R-types, see data sheets on pages 46–77

Bimetal applications in domestic appliances

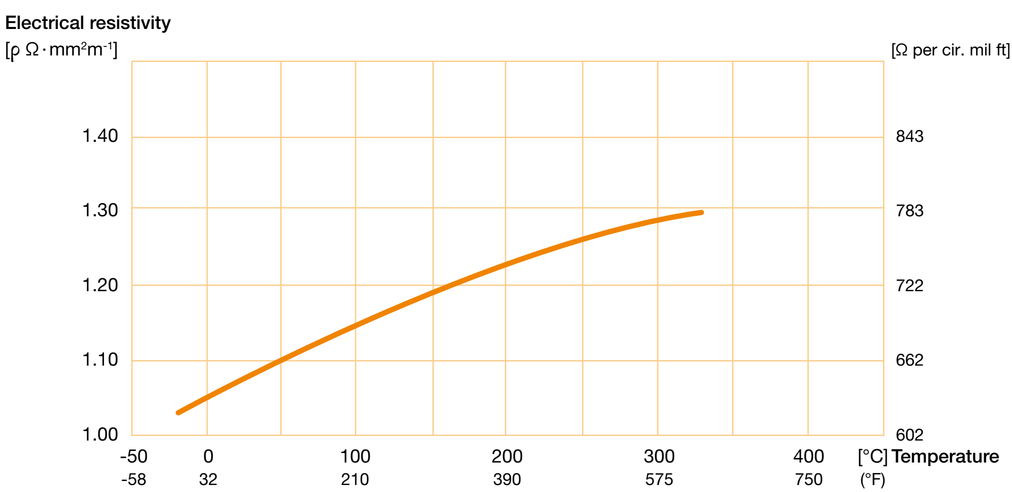
Various bimetal operated switches and controls

Bimetal can be shaped in many different ways

4. Tehnical Data and Temperature Dependant Properties

KANTHAL 230

Component .... 36 Ni/NiMn-steel
Specific deflection .... **a** = 22.7 × 10^{-6} K^{-1}
Specific curvature .... k = 43.0 × 10^{-6} K^{-1}; Tolerance ± 4 %
Flexivity .... F = 23.9 × 10^{-6} F^{-1}; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F) ...... ρ = 1.05 Ω × mm^2 × m^{-1}; Tolerance ± 6 %
(= 630 Ω per cir. mil ft)
Temperature range .... Normal -20 to +250°C; (0 to 480°F) Maximum 330°C (625°F)
Linearity range .... -20 to +230°C (0 to 450°F)
Modulus of elasticity at 20°C (68°F) .... E = 135 × 10^3 N × mm^{-2} (= 19.2 × 10^6 lb/in^2)
Standard hardness, Vickers
Low expansion side .... H_v = 210
High expansion side .... H_v = 220
Thermal conductivity .... λ = 6 W × m^{-1} × $°C^{-1}$ = 0.015 cal × cm^{-1} × s^{-1} × $°C^{-1}$
(= 42 BTU/h/ft^2/°F/in)
Specific heat .... c = 0.46 J × g^{-1} × $°C^{-1}$ = 0.11 cal × g^{-1} × $°C^{-1}$
(= 0.11 BTU/lb/°F)
Density .... γ = 7.8 g × cm^{-3} (= 0.281 lb/in^3)
Heat treatment (guiding value) .... Ageing 2 hours at 260°C (660°F), see also page 124
Weldability .... See page 125
Marking on the high expansion side ... 230R105 230R105 230R105 230R105 230R105
30R105 230R105 230R105 230R105 230R105
OR105 230R105 230R10 230R10 230R105

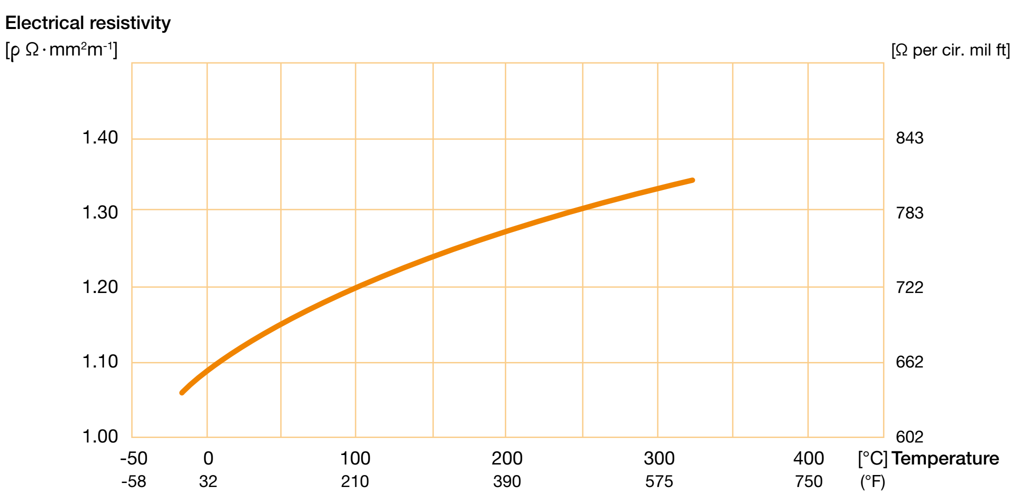


See also table on page 17 and 18

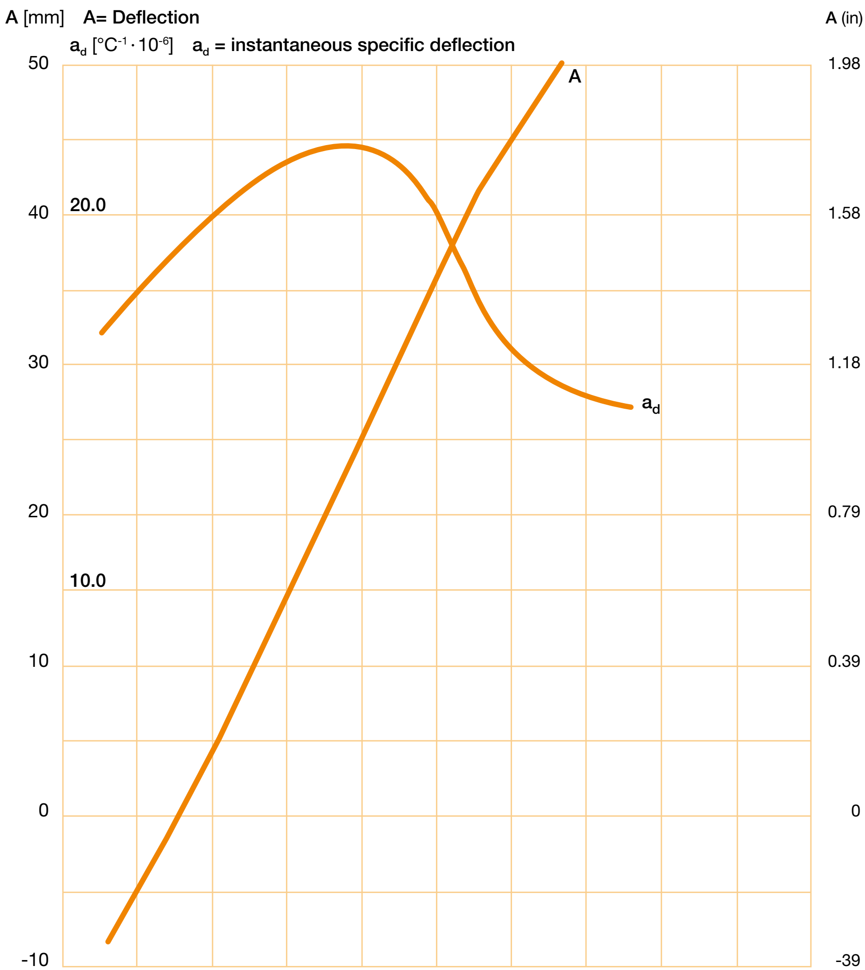

A [mm]
A= Deflection
a_d [°C^{-1} · 10^{-6}]
a_d = instantaneous specific deflection
A (in)
60
50
40
30
20
10
0
-10
2.37
1.98
1.58
1.18
0.79
0.39
0
-39
20.0
10.0
A
a_d
See section 3, page 20
Permissible bending stress
[σ N · mm^{-2}]
[σ lb/sp in · 10^{-4}]
250
200
150
100
50
3.56
2.85
2.12
1.42
0.71
-50
0
100
200
300
400
[°C] Temperature
-58
32
210
390
575
750
(°F)

KANTHAL 200 TB20110

Components .... 36 Ni/MnNiCu
Specific deflection .... **a** = 20.8 × 10^{-6} K^{-1}
Specific curvature .... k = 39.0 × 10^{-6} K^{-1}; Tolerance ± 4 %
Flexivity .... F = 21.7 × 10^{-6} F^{-1}; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F) ...... ρ = 1.10 Ω × mm^2 × m^{-1}; Tolerance KANTHAL 200 ± 6 %
(= 660 Ω per cir. mil ft)
Temperature range .... Normal -20 to +250°C; (0 to 480°F) Maximum 330°C (625°F)
Linearity range .... -20 to +200°C (0 to 395°F)
Modulus of elasticity at 20°C (68°F) .... E = 135 × 10^3 N × mm^{-2} (= 19.2 × 10^6 lb/sq.in)
Standard hardness, Vickers
Low expansion side .... H_v = 210 ± 20
High expansion side .... H_v = 220 ± 20
Thermal conductivity .... λ = 6 W × m^{-1} × $°C^{-1}$ = 0.015 cal × cm^{-1} × s^{-1} × $°C^{-1}$
(= 42 BTU/h/sq.ft/°F/in)
Specific heat .... c = 0.46 J × g^{-1} × $°C^{-1}$ = 0.11 cal × g^{-1} × $°C^{-1}$
(= 0.11 BTU/lb/°F)
Density .... γ = 7.8 g × cm^{-3} (= 0.281 lb/cu.in)
Heat treatment (guiding value) .... Ageing 2 hours at 260°C (500°F) see also page 124
Weldability .... See page 125
Marking on the high expansion side 210TB20110 210TB2010 210TB20110 210TB20110 210TB20110
10TB20110 210TB20110 210TB20110 210TB20110 210TB20110
0TB20110 210TB20110 210TB20110 210TB20110 210TB20110

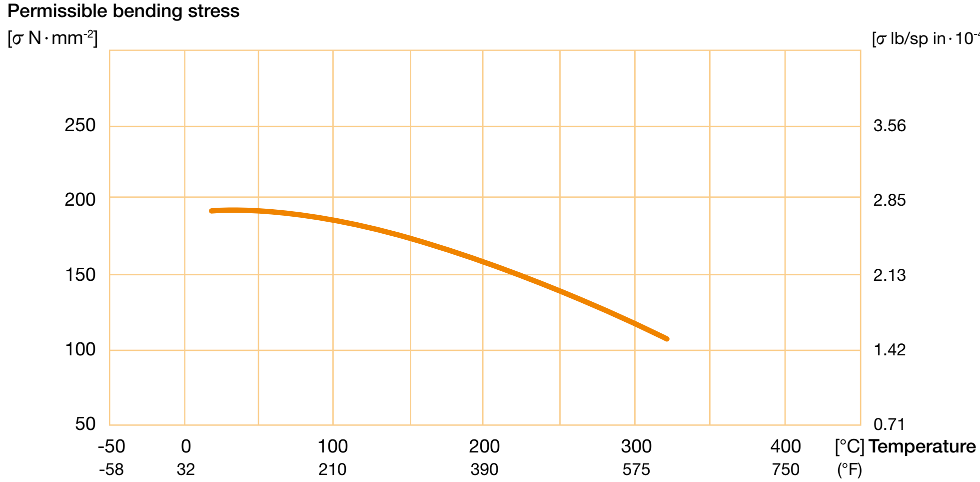


See also table on page 17 and 18



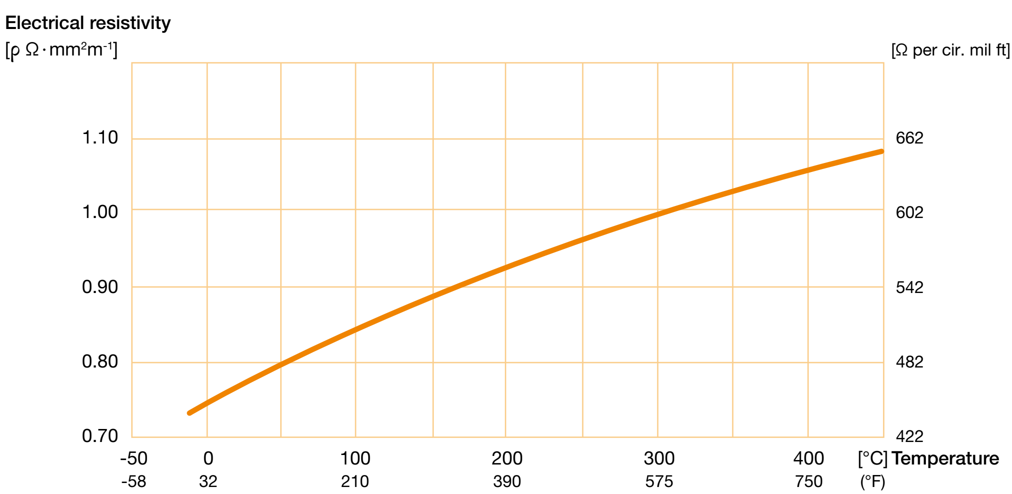
See section 3, page 20

Permissible bending stress

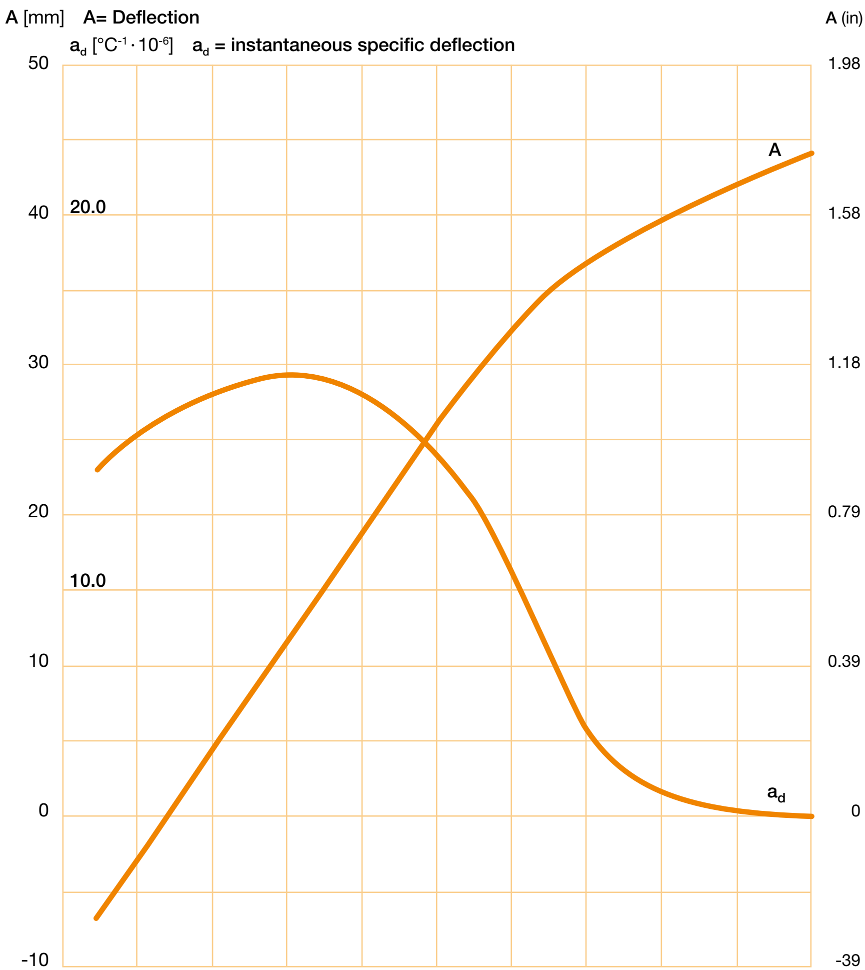


KANTHAL 155 TB1577A

Components	36 Ni/NiMn-steel
Specific deflection	**a** = 15.6×10^{-6} K^{-1}
Specific curvature	k = 28.5×10^{-6} K^{-1}; Tolerance ± 4 %
Flexivity	F = 15.8×10^{-6} F^{-1}; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F)	ρ = 0.78 Ω × mm^2 × m^{-1}; Tolerance ± 4 % (= 465 Ω per cir. mil ft)
Temperature range	Normal -20 to +350°C; (0 to 660°F) Maximum 450°C (840°F)
Linearity range	-20 to +250°C (0 to 480°F)
Modulus of elasticity at 20°C (68°F)	E = 170 × 10^3 N × mm^{-2} (= 24.2 × 10^6 lb/sq.in)
Standard hardness, Vickers	
Low expansion side	H_v = 210
High expansion side	H_v = 260
Thermal conductivity	λ = 13 W × m^{-1} × $°C^{-1}$ = 0.031 cal × cm^{-1} × s^{-1} × $°C^{-1}$ (= 84 BTU/h/sq.ft/°F/in)
Specific heat	c = 0.46 J × g^{-1} × $°C^{-1}$ = 0.11 cal × g^{-1} × $°C^{-1}$ (= 0.11 BTU/lb/°F)
Density	γ = 8.1 g × cm^{-3} (=0.292 lb/cu.in)
Heat treatment (guiding value)	Ageing 2 hours at 350°C (660°F), see also page 124
Weldability	Good on both sides
Marking on the high expansion side	155TB1577 155TB1577 155TB1577 155TB157 155TB1577 155 55TB1577 155TB1577 155TB1577 155TB1577 155TB1577 155 5TB1577 155TB1577 155TB1577 155TB1577 155TB1577 155

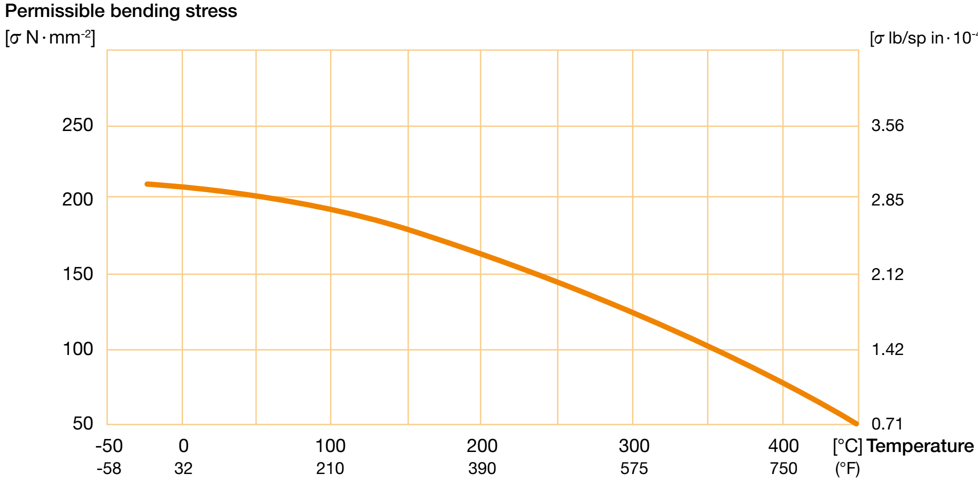


See also table on page 17 and 18



See section 3, page 20

Permissible bending stress



KANTHAL 145

Components .... 36 Ni/NiMn-steel

Specific deflection .... **a** = $14.8 \times 10^{-6}\,K^{-1}$

Specific curvature .... k = $27.7 \times 10^{-6}\,K^{-1}$; Tolerance ± 4 %

Flexivity .... F = $15.4 \times 10^{-6}\,F^{-1}$; Tolerance ± 4 %

Electrical resistivity at 20°C (68°F) ...... $\rho = 0.79\,\Omega \times mm^2 \times m^{-1}$; Tolerance ± 4 %
(= 475 Ω per cir. mil ft)

Temperature range .... Normal -20 to +350°C; (0 to 660°F) Maximum 450°C (840°F)

Linearity range .... -20 to +250°C (0 to 480°F)

Modulus of elasticity at 20°C (68°F) ... E = $170 \times 10^3\,N \times mm^{-2}$ (= 24.2×10^6 lb/sq.in)

Standard hardness, Vickers

Low expansion side .... $H_v = 210$

High expansion side .... $H_v = 260$

Thermal conductivity .... $\lambda = 12\,W \times m^{-1} \times °C^{-1} = 0.029\,cal \times cm^{-1} \times s_{-1} \times °C^{-1}$
(= 84 BTU/h/sq.ft/°F/in)

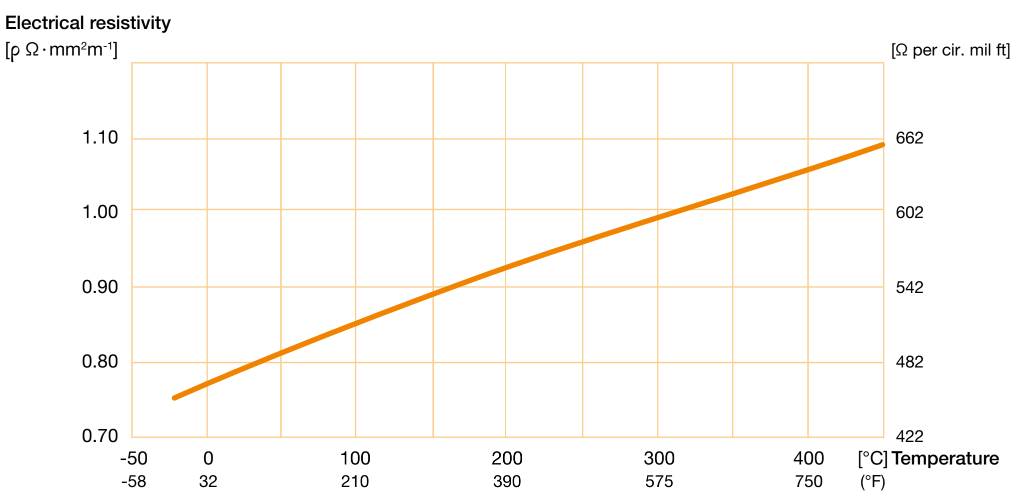
Specific heat .... $c = 0.46\,J \times g^{-1} \times °C^{-1} = 0.11\,cal \times g^{-1} \times °C^{-1}$
(= 0.11 BTU/lb/°F)

Density .... $\gamma = 8.1\,g \times cm^{-3}$ (= 0.292 lb/cu.in)

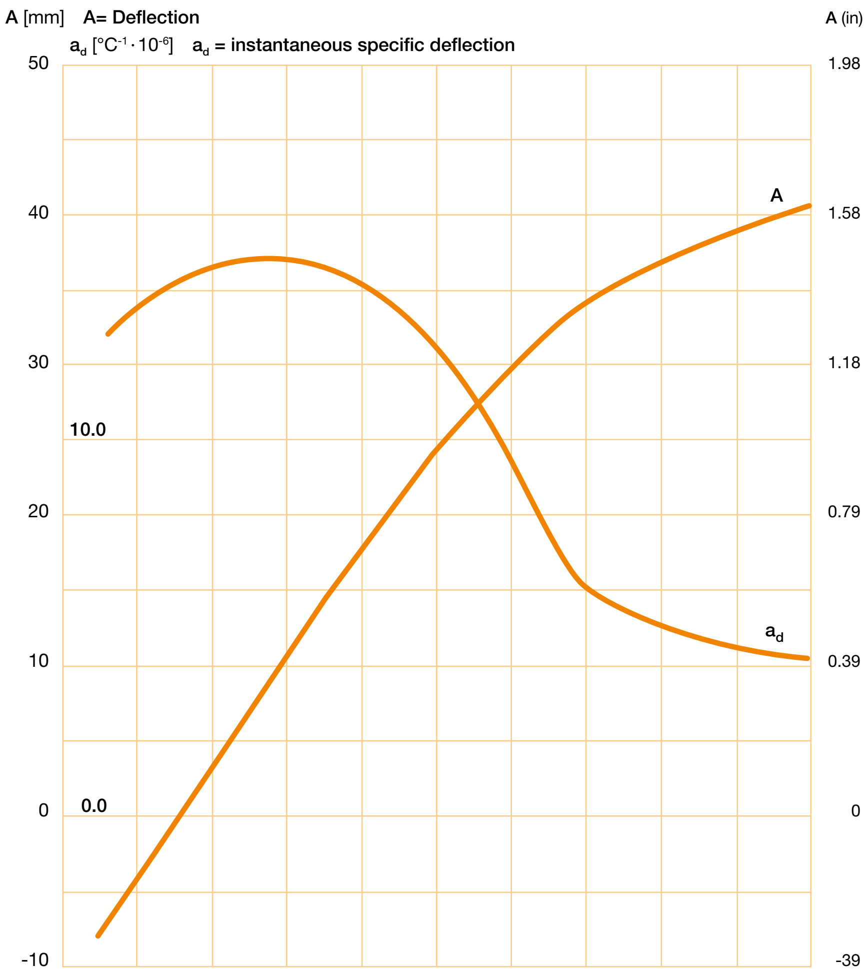
Heat treatment (guiding value) .... Ageing 2 hours at 350°C (660°F) see also page 124

Weldability .... Good on both sides

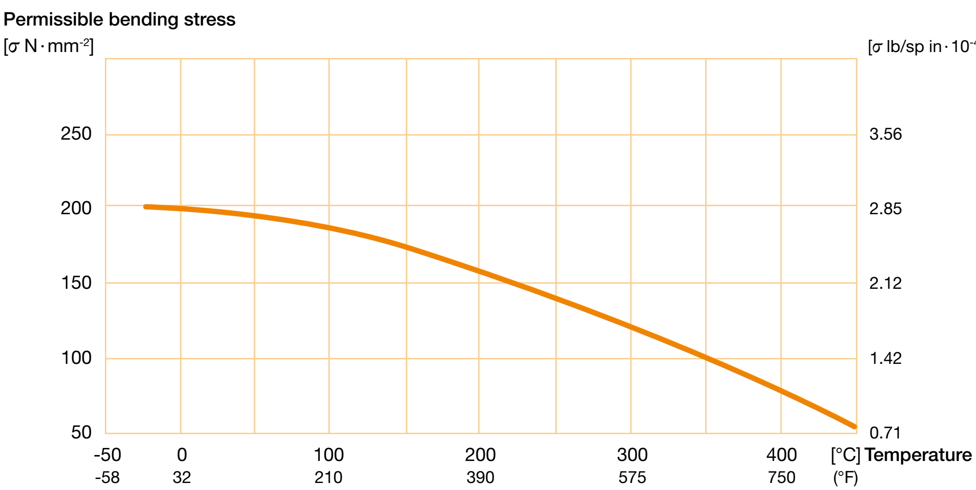
Marking on the high expansion side 145TB1477 145TB1477 145TB1477 145TB1477 145TB1477 145
45TB1477 145TB1477 145TB1477 145TB1477 145TB1477 145
5TB1477 145TB1477 145TB1477 145TB1477 145TB1477 145



See also table on page 17 and 18



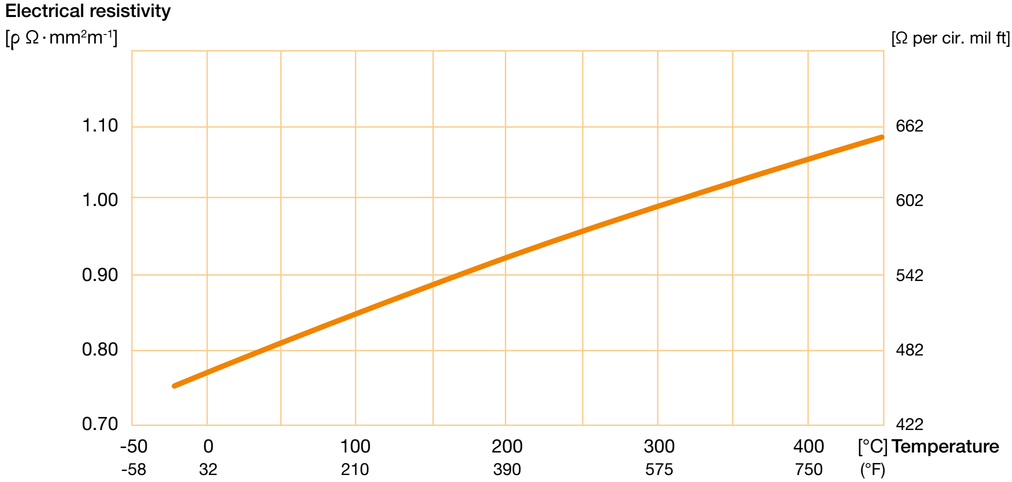
See section 3, page 20



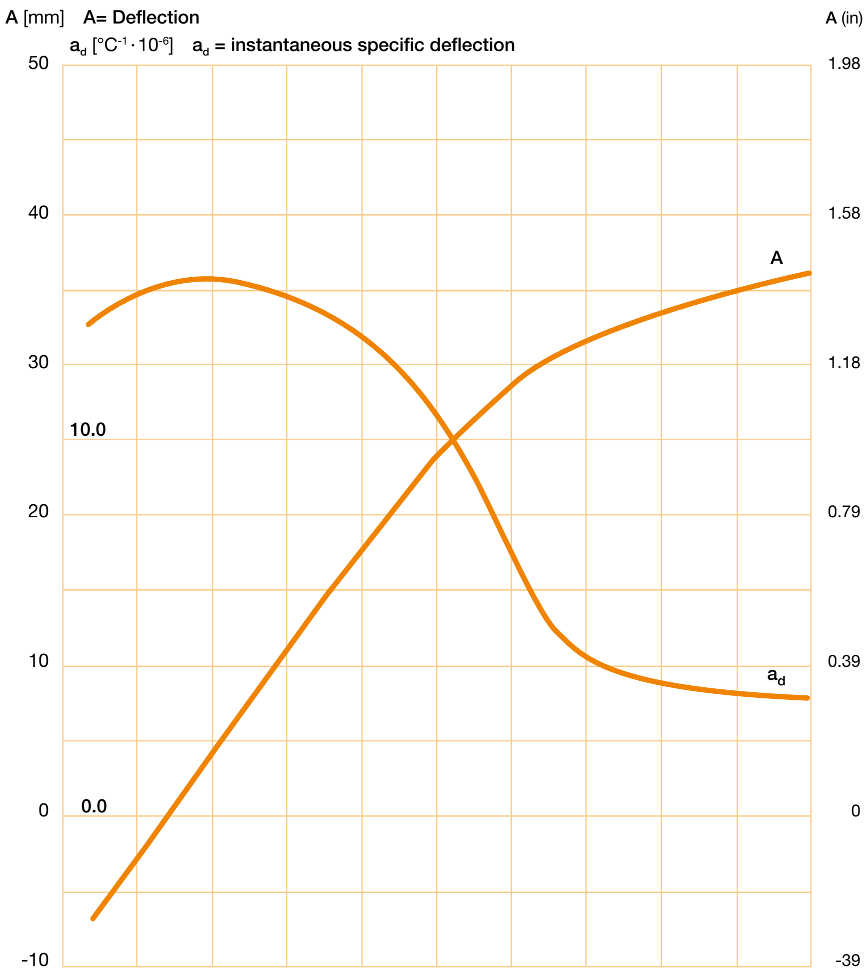
KANTHAL 135

Components .... 36 Ni/NiMn-steel
Specific deflection .... **a** = 13.9 × 10^{-6} K^{-1}
Specific curvature .... k = 25.9 × 10^{-6} K^{-1}; Tolerance ± 4 %
Flexivity .... F = 14.4 × 10^{-6} F^{-1}; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F) ...... ρ = 0.79 Ω × mm^2 × m^{-1}; Tolerance ± 4 %
(= 475 Ω per cir. mil ft)
Temperature range .... Normal -20 to +300°C; (0 to 570°F) Maximum 450°C (840°F)
Linearity range .... -20 to +200°C (0 to 395°F)
Modulus of elasticity at 20°C (68°F) ... E = 170 × 10^3 N × mm^{-2} (= 24.2 × 10^6 lb/sq.in)
Standard hardness, Vickers
Low expansion side .... H_v = 210
High expansion side .... H_v = 260
Thermal conductivity .... λ = 12 W × m^{-1} × $°C^{-1}$ = 0.029 cal × cm^{-1} × s^{-1} × $°C^{-1}$
(= 84 BTU/h/sq.ft/°F/in)
Specific heat .... c = 0.46 J × g^{-1} × $°C^{-1}$ = 0.11 cal × g^{-1} × $°C^{-1}$
(= 0.11 BTU/lb/°F)
Density .... γ = 8.1 g × cm^{-3} (= 0.292 lb/cu.in)
Heat treatment (guiding value) .... Ageing 2 hours at 350°C (660°F) see also page 124
Weldability .... Good on both sides
Marking on the high expansion side ... 135TB1477 135TB1477 135TB1477 135TB1477 135TB147 135
35TB147 135TB1477 135TB1477 135TB1477 135TB1477 135
5TB1477 135TB1477 135TB1477 135TB1477 135TB1477 135

Electrical resistivity

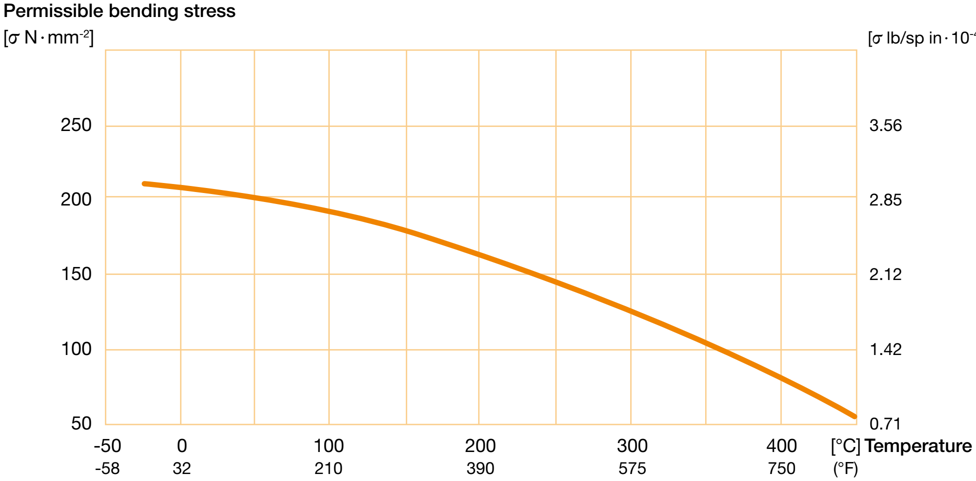


See also table on page 17 and 18



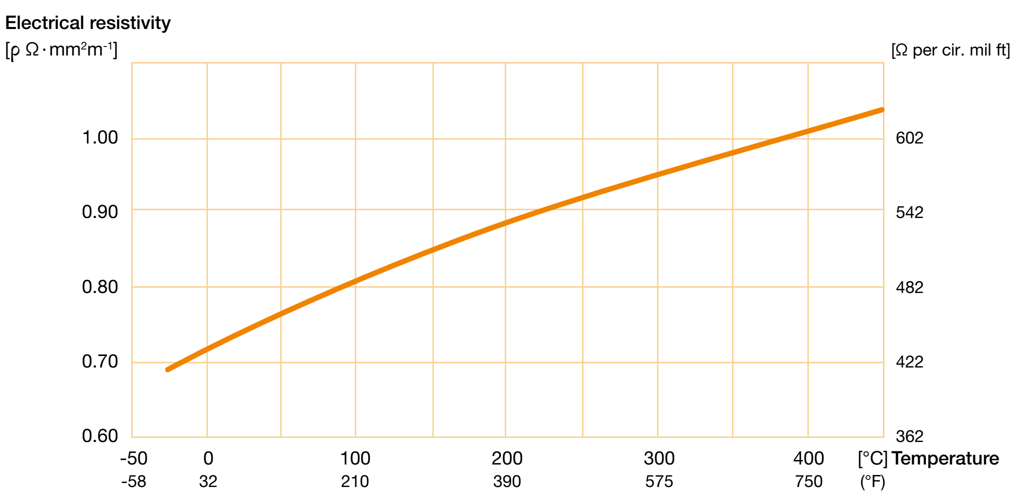
See section 3, page 20

Permissible bending stress

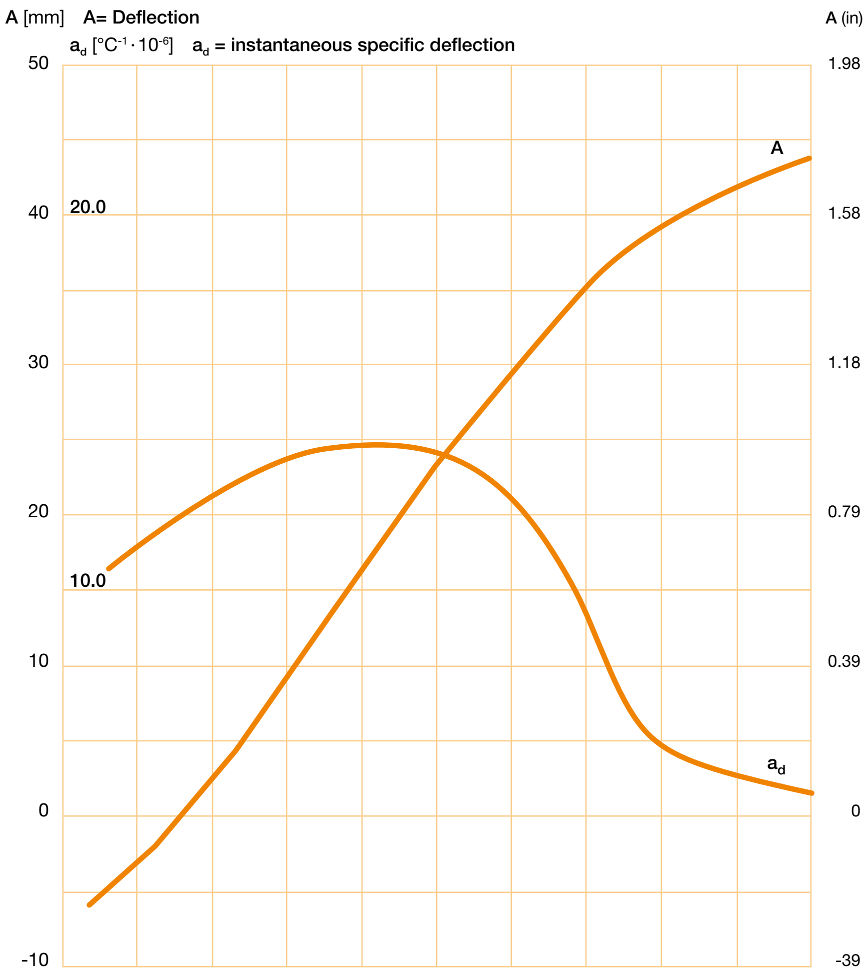


KANTHAL 130

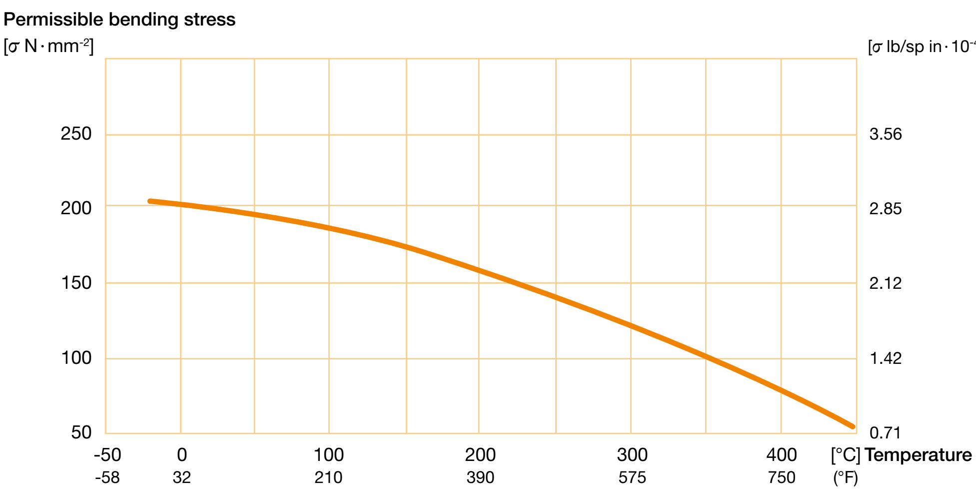
Components	40 Ni/NiMn-steel
Specific deflection	**a** = 13.2×10^{-6} K^{-1}
Specific curvature	k = 24.8×10^{-6} K^{-1}; Tolerance ± 4 %
Flexivity	F = 13.8×10^{-6} F^{-1}; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F)	ρ = 0.74 Ω × mm^2 × m^{-1}; Tolerance ± 4 % (= 444 Ω per cir. mil ft)
Temperature range	Normal -20 to +425°C; (0 to 800°F) Maximum 450°C (840°F)
Linearity range	-20 to +325°C (0 to 620°F)
Modulus of elasticity at 20°C (68°F)	E = 170×10^3 N × mm^{-2} (= 24.2×10^6 lb/sq.in)
Standard hardness, Vickers	
Low expansion side	$H_v = 210$
High expansion side	$H_v = 260$
Thermal conductivity	λ = 12 W × m^{-1} × $°C^{-1}$ = 0.029 cal × cm^{-1} × s^{-1} × $°C^{-1}$ (= 84 BTU/h/sq.ft/°F/in)
Specific heat	c = 0.46 J × g^{-1} × $°C^{-1}$ = 0.11 cal · g^{-1} · $°C^{-1}$ (= 0.11 BTU/lb/°F)
Density	γ = 8.1 g × cm^{-3} (= 0.292 lb/cu.in)
Heat treatment (guiding value)	Ageing 2 hours at 350°C (660°F) see also page 124
Weldability	Good on both sides
Marking on the high expansion side	130TB1374 130TB1374 130TB1374 130TB1374 130TB1374 130 30TB1374 130TB1374 130TB1374 130TB1374 130TB1374 130 0TB1374 130TB1374 130TB1374 130TB1374 130TB1374 130



See also table on page 17 and 18

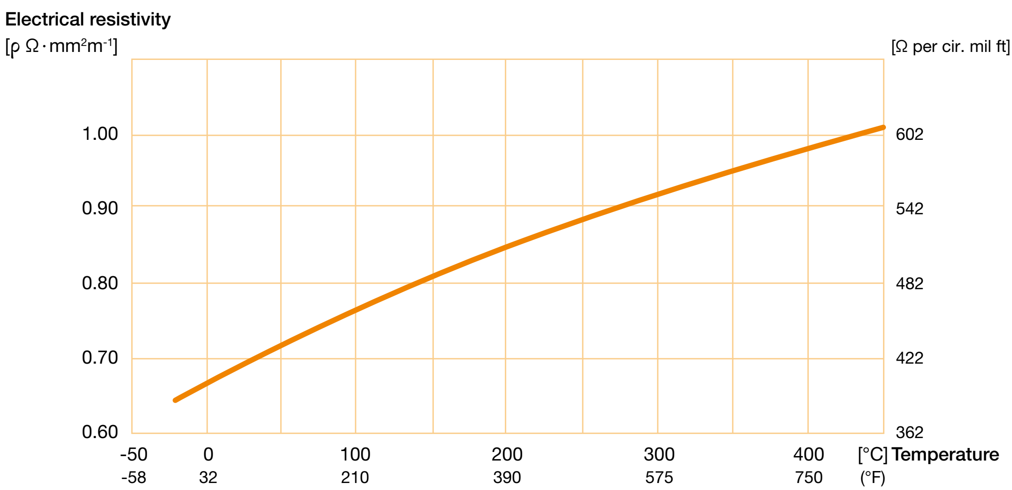


See section 3, page 20

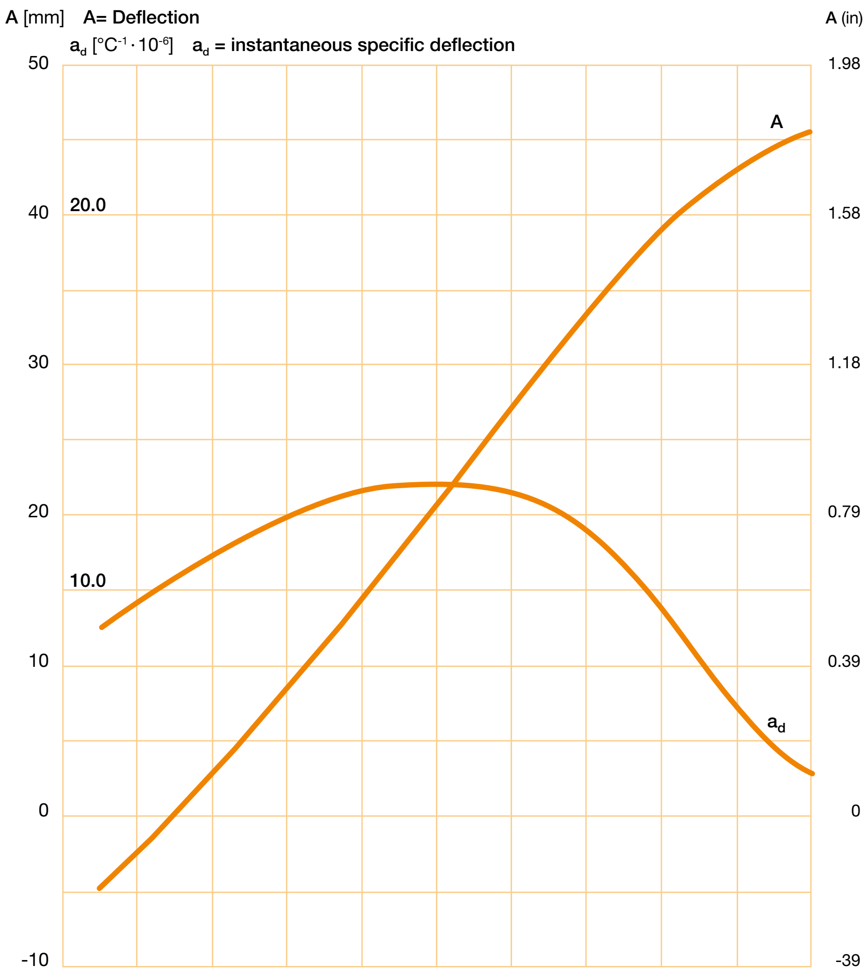


KANTHAL 115 TB1170

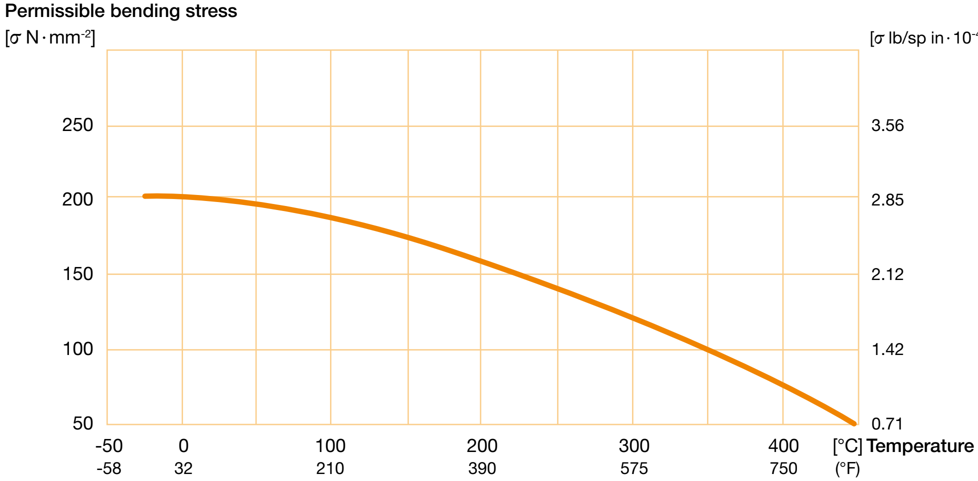
Components .... 42 Ni/NiMn-steel
Specific deflection .... **a** = $11.7 \times 10^{-6}\,K^{-1}$
Specific curvature .... k = $22.0 \times 10^{-6}\,K^{-1}$; Tolerance ± 4 %
Flexivity .... F = $12.2 \times 10^{-6}\,F^{-1}$; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F) ...... ρ = $0.70\,\Omega \times mm^2 \times m^{-1}$; Tolerance ± 4 %
(= 420 Ω per cir. mil ft)
Temperature range .... Normal -20 to +450°C; (0 to 840°F) Maximum 450°C (840°F)
Linearity range .... -20 to +380°C (0 to 720°F)
Modulus of elasticity at 20°C (68°F) .... E = $170 \times 10^3\,N \times mm^{-2}$ (= 24.8×10^6 lb./sq.in)
Standard hardness, Vickers
Low expansion side .... $H_v = 210$
High expansion side .... $H_v = 260$
Thermal conductivity .... λ = $13\,W \times m^{-1} \times °C^{-1} = 0.031\,cal \times cm^{-1} \times s^{-1} \times °C^{-1}$
(= 91 BTU/h/sq.ft/°F/in)
Specific heat .... c = $0.46\,J \times g^{-1} \times °C^{-1} = 0.11\,cal \times g^{-1} \times °C^{-1}$
(= 0.11 BTU/lb/°F)
Density .... γ = $8.1\,g \times cm^{-3}$ (= 0.292 lb/cu.in)
Heat treatment (guiding value) .... Ageing 2 hours at 350°C (660°F) see also page 124
Weldability .... Good on both sides
Marking on the high expansion side 115TB1170 115TB1170 115TB1170 115TB1170 115TB1170 115
15TB117 115TB1170 115TB1170 115TB1170 115TB1170 115
5TB1170 115TB1170 115TB1170 115TB1170 115TB1170 115



See also table on page 17 and 18



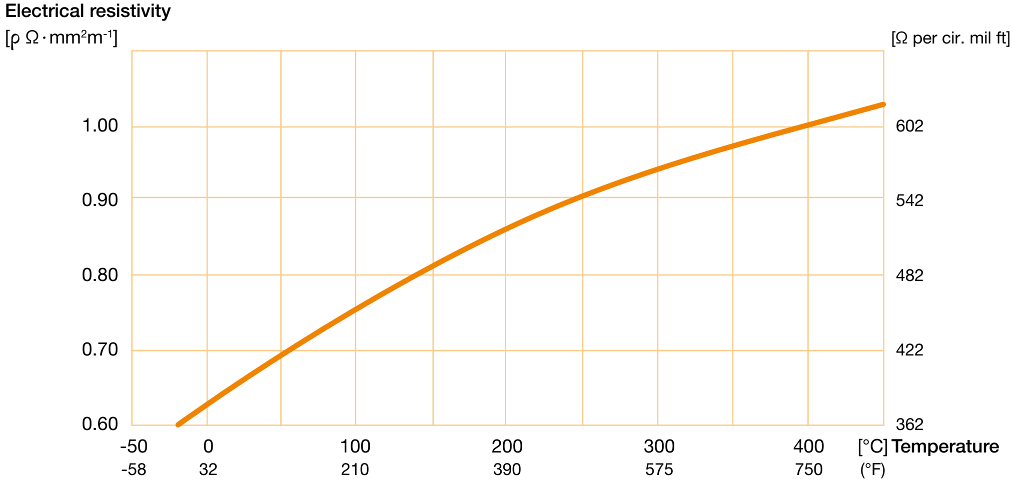
See section 3, page 20



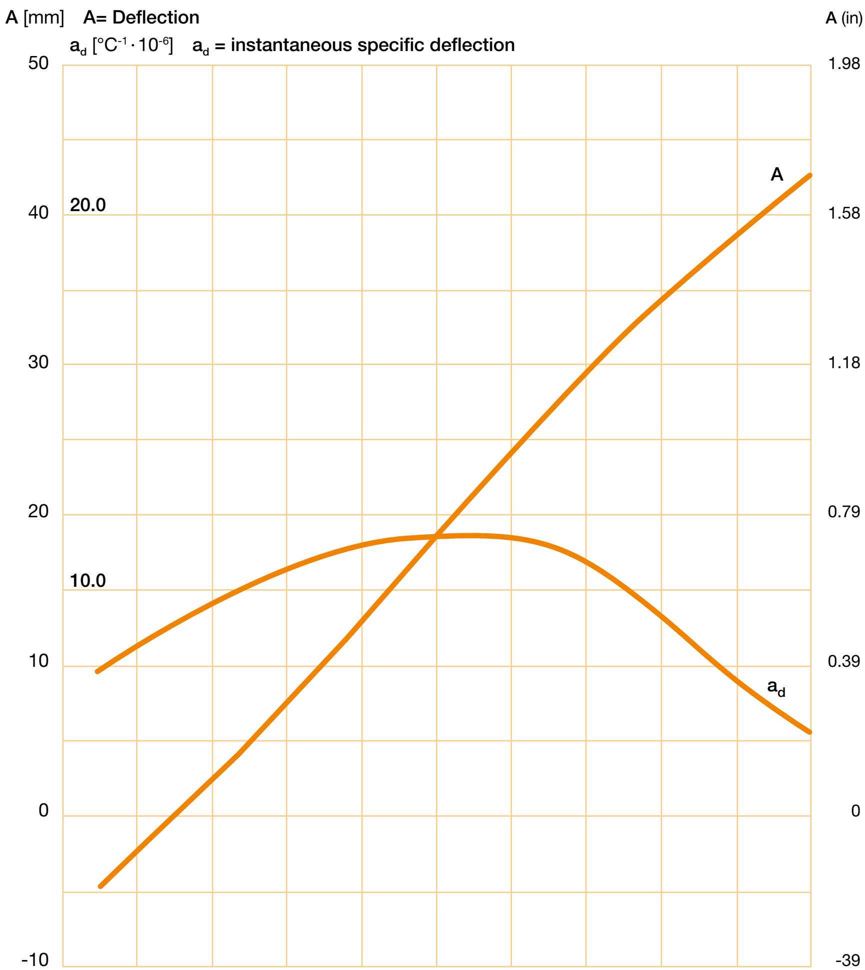
KANTHAL 100 TB0965

Components	46 Ni/NiMn-steel
Specific deflection	**a** $= 10.0 \times 10^{-6}\,K^{-1}$
Specific curvature	$k = 18.6 \times 10^{-6}\,K^{-1}$; Tolerance ± 4 %
Flexivity	$F = 10.3 \times 10^{-6}\,F^{-1}$; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F)	$\rho = 0.65\,\Omega \times mm^2 \times m^{-1}$; Tolerance ± 4 % (= 398 Ω per cir. mil ft)
Temperature range	Normal -20 to +425°C; (0 to 840°F) Maximum 450°C (840°F)
Linearity range	-20 to +425°C (0 to 800°F)
Modulus of elasticity at 20°C (68°F)	$E = 175 \times 10^3\,N \times mm^{-2}$ (= 24.8×10^6 lb/sq.in)
Standard hardness, Vickers	
Low expansion side	$H_v = 210$
High expansion side	$H_v = 260$
Thermal conductivity	$\lambda = 15\,W \times m^{-1} \times °C^{-1} = 0.035\,cal \times cm^{-1} \times s^{-1} \times °C^{-1}$ (= 98 BTU/h/sq.ft/°F/in)
Specific heat	$c = 0.46\,J \times g^{-1} \times °C^{-1} = 0.11\,cal \times g^{-1} \times °C^{-1}$ (= 0.11 BTU/lb/°F)
Density	$\gamma = 8.2\,g \times cm^{-3}$ (= 0.296 lb/cu.in)
Heat treatment (guiding value)	Ageing 2 hours at 350°C (660°F) see also page 124
Weldability	Good on both sides
Marking on the high expansion side	100TB0965 100TB0965 100TB0965 100TB0965 100TB0965 100 00TB096 100TB0965 100TB0965 100TB0965 100TB0965 100 0TB0965 100TB0965 100TB0965 100TB0965 100TB0965 100

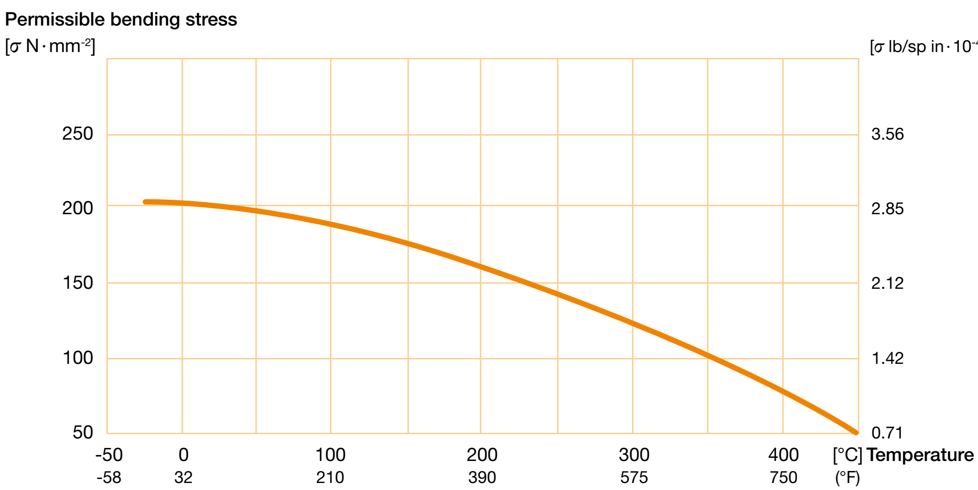
Electrical resistivity



See also table on page 17 and 18

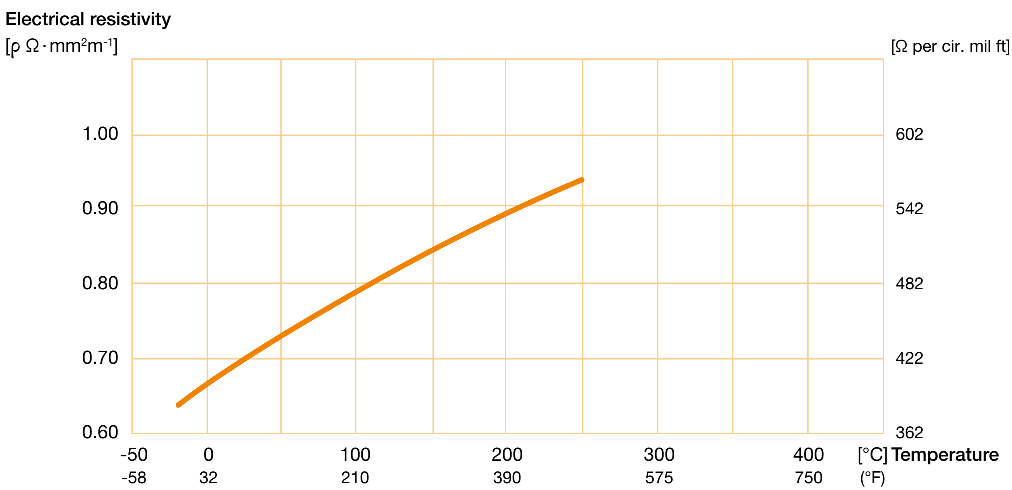


See section 3, page 20

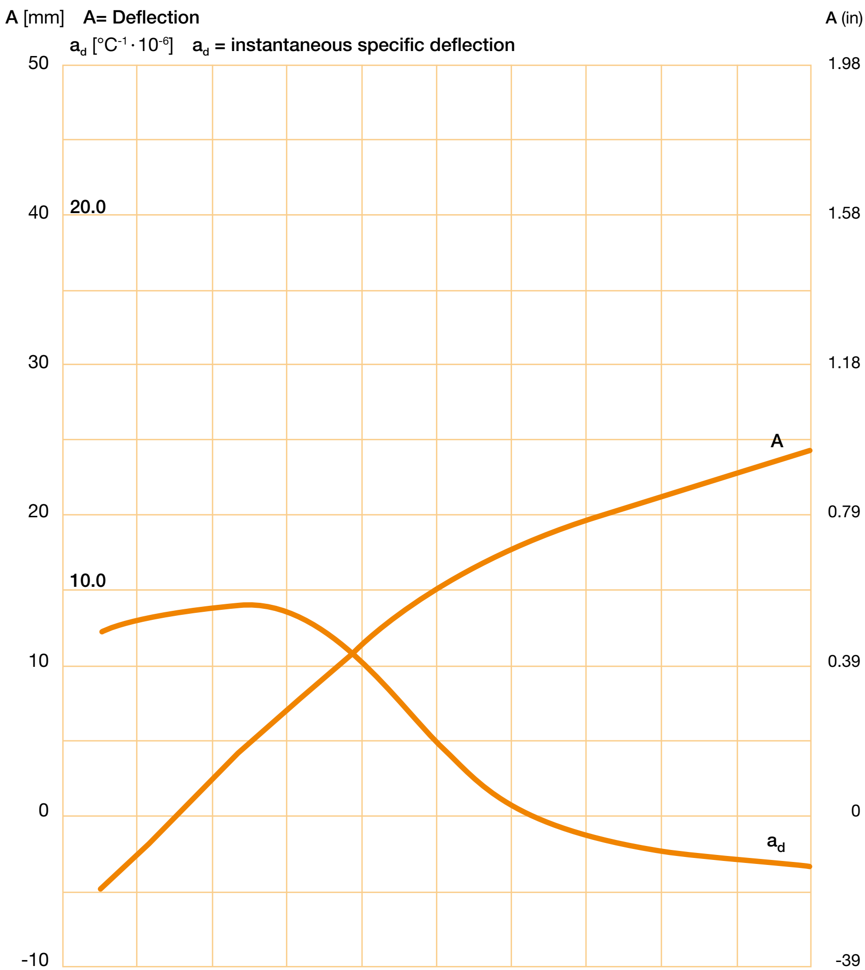


KANTHAL 94S

Components	38/7 NiCr-steel/19/7 NiCr-steel
Specific deflection	**a** = $9.5 \times 10^{-6} K^{-1}$
Specific curvature	k = $17.8 \times 10^{-6} K^{-1}$; Tolerance ± 4 %
Flexivity	F = $9.9 \times 10^{-6} F^{-1}$; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F)	ρ = 0.85 Ω × $mm^2 \times m^{-1}$; Tolerance ± 4 % (= 510 Ω per cir. mil ft)
Temperature range	Normal -20 to +375°C; (0 to 710°F) Maximum 450°C (840°F)
Linearity range	0 to +200°C (32 to 395°F)
Modulus of elasticity at 20°C (68°F)	E = 190×10^3 N × mm^{-2} (= 27.0×10^6 lb/sq.in)
Standard hardness, Vickers	
Low expansion side	H_v = 210
High expansion side	H_v = 250
Thermal conductivity	λ = 12 W × $m^{-1} \times °C^{-1}$ = 0.029 cal × $cm^{-1} \times s^{-1} \times °C^{-1}$ (= 84 BTU/h/sq.ft/°F/in)
Specific heat	c = 0.46 J × $g^{-1} \times °C^{-1}$ = 0.11 cal × $g^{-1} \times °C^{-1}$ (= 0.11 BTU/lb/°F)
Density	γ = 8.1 g × cm^{-3} (= 0.292 lb/cu.in)
Heat treatment (guiding value)	Ageing 2 hours at 350°C (660°F) see also page 124
Weldability	Good on both sides
Marking on the high expansion side	94STB985 94STB985 94STB985 94STB98 94STB985 94STB985 4STB985 94STB985 94STB985 94STB985 94STB985 94STB985 STB985 94STB985 94STB985 94STB985 94STB985 94STB985

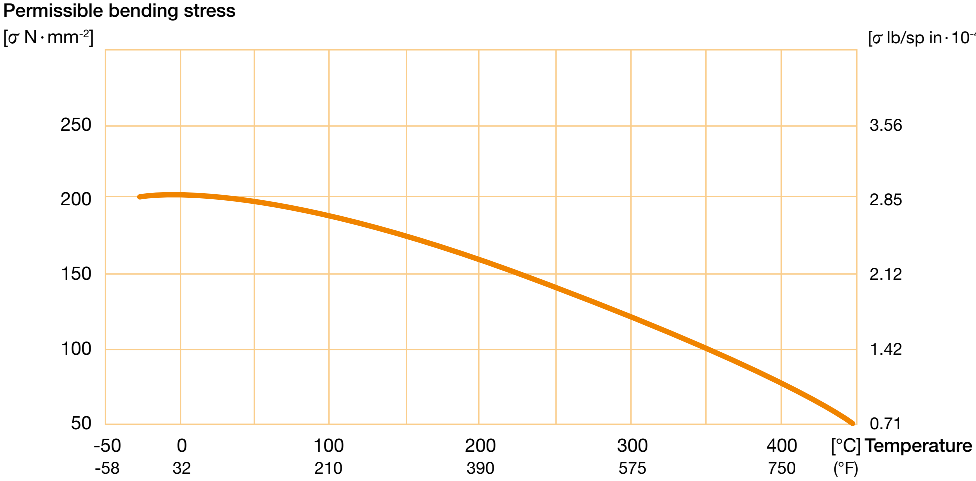


See also table on page 17 and 18



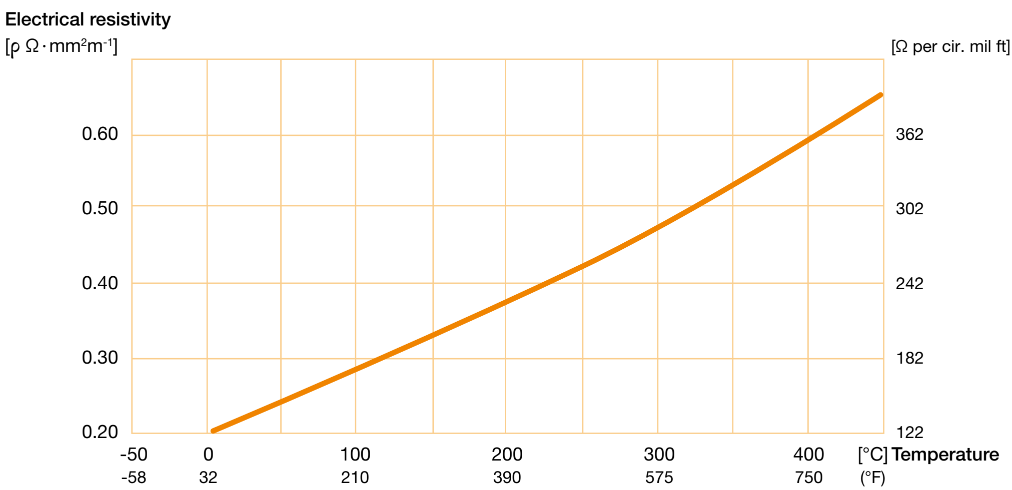
See section 3, page 20

Permissible bending stress

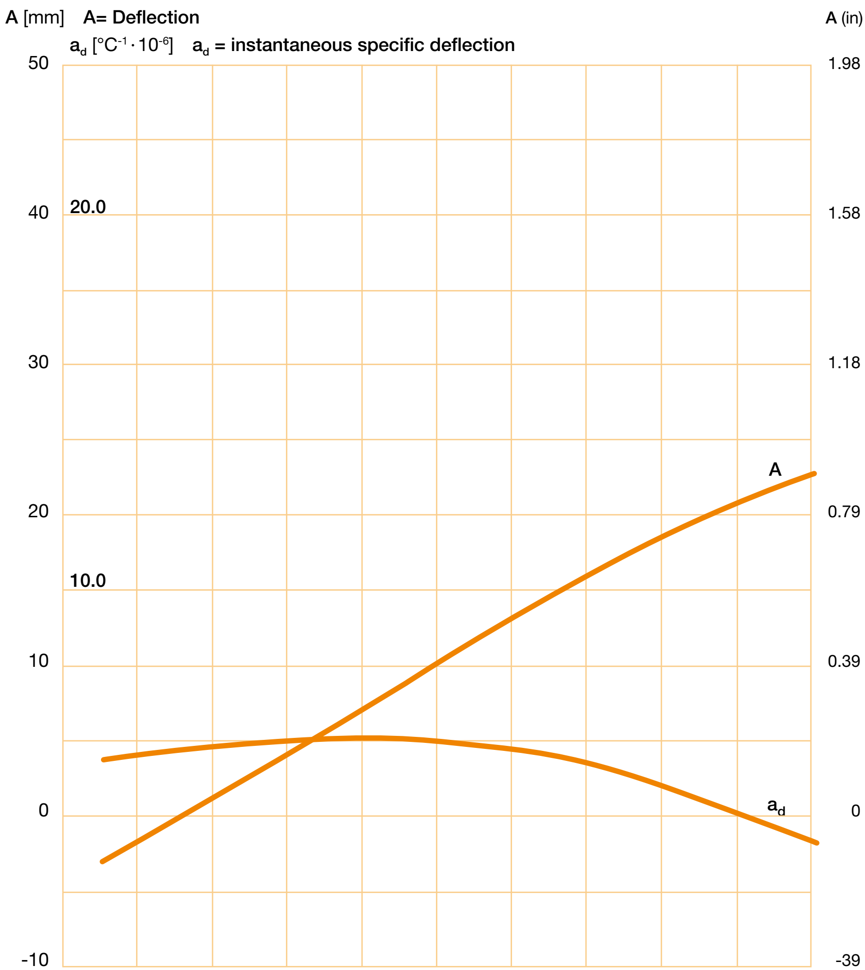


KANTHAL 60

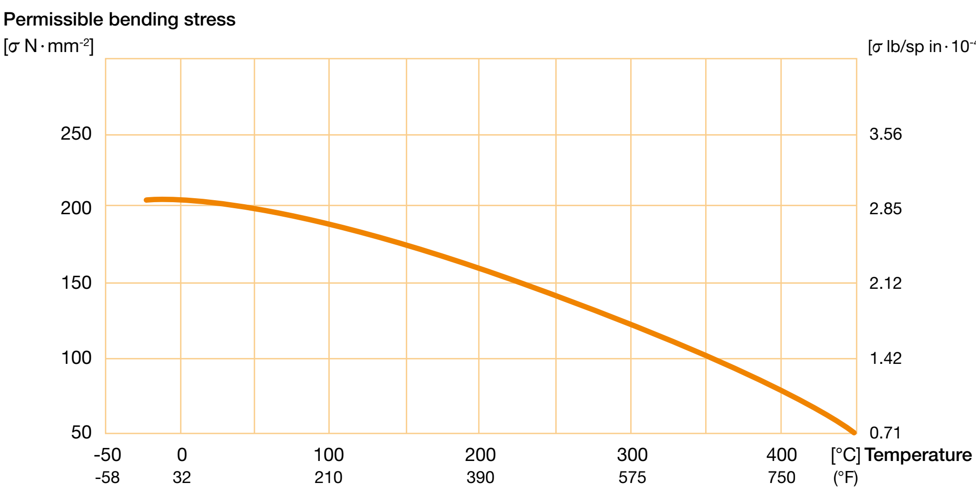
Components	Fe/NiMn-steel
Specific deflection	**a** = 6.0×10^{-6} K^{-1}
Specific curvature	k = 11.3×10^{-6} K^{-1}; Tolerance ± 4 %
Flexivity	F = 6.3×10^{-6} F^{-1}; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F)	ρ = 0.21 Ω × mm^2 × m^{-1}; Tolerance ± 4 % (= 127 Ω per cir. mil ft)
Temperature range	Normal -20 to +450°C; (0 to 840°F) Maximum 450°C (840°F)
Linearity range	-20 to + 450°C (0 to 840°F)
Modulus of elasticity at 20°C (68°F)	E = 190 × 10^3 N × mm^{-2} (= 27.0 × 10^6 lb/sq.in)
Standard hardness, Vickers	
Low expansion side	H_v = 230
High expansion side	H_v = 260
Thermal conductivity	λ = 44 W × m^{-1} × $°C^{-1}$ = 0.105 cal × cm^{-1} × s^{-1} × $°C^{-1}$ (= 307 BTU/h/sq.ft/°F/in)
Specific heat	c = 0.46 J × g^{-1} × $°C^{-1}$ = 0.11 cal × g^{-1} × $°C^{-1}$ (= 0.11 BTU/lb/°F)
Density	γ = 8.0 g × cm^{-3} (= 0.292 lb/cu.in)
Heat treatment (guiding value)	Ageing 2 hours at 350°C (660°F) see also page 124
Weldability	Good on both sides
Marking on the high expansion side	60TB621 60TB621 60TB621 60TB621 60TB621 60TB621 60 0TB621 60TB621 60TB621 60TB621 60TB621 60TB621 60 TB621 60TB621 60TB621 60TB621 60TB621 60TB621 60



See also table on page 17 and 18

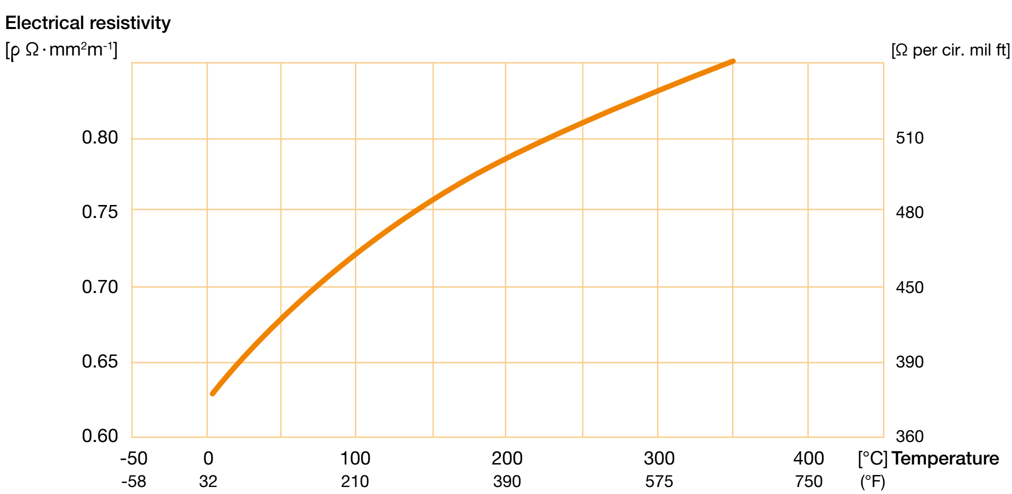


See section 3, page 20

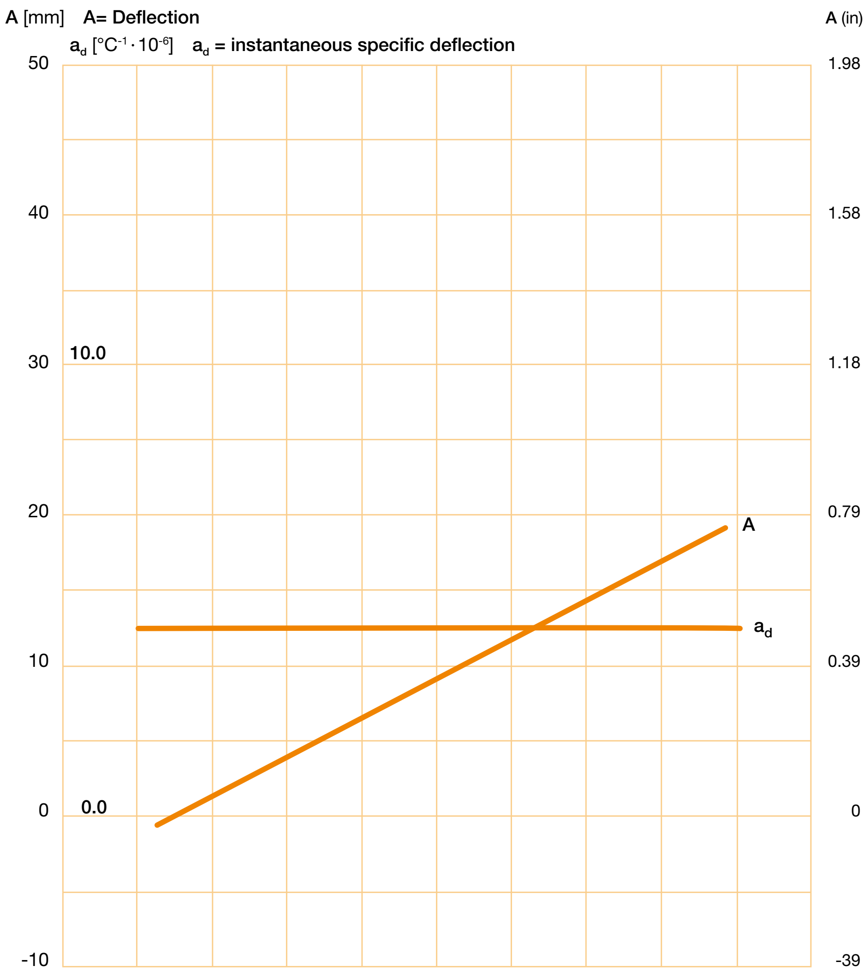


KANTHAL 50HT

Components	2320/2333-steel
Specific deflection	**a** = 5.0×10^{-6} K^{-1}; Tolerance ± 4 %
Specific curvature	k = 9.4×10^{-6} K^{-1}; Tolerance ± 4 %
Flexivity	F = 5.2×10^{-6} F^{-1}; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F)	ρ = 0.65 Ω × mm^2 × m^{-1}; Tolerance ± 4 % (= 390 Ω per cir. mil ft)
Temperature range	Normal -20 to +500°C; (0 to 930°F) Maximum 550°C (1020°F)
Linearity range	-20 to +500°C (0 to 930°F)
Modulus of elasticity at 20°C (68°F)	E = 200 × 10^3 N × mm^{-2} (= 28.4 × 10^6 lb/sq.in)
Standard hardness, Vickers	
Low expansion side	H_v = 240 ± 20
High expansion side	H_v = 340 ± 20
Thermal conductivity	λ = 20 W/m°C = 0.047 cal/cms°C (= 130 BTU/h/sq.ft/°F/in)
Specific heat	c = 0.46 J/g°C = 0.11 cal/g°C (= 0.11 BTU/lb/°F)
Density	γ = 7.8 g × cm^{-3} (= 0.281 lb/cu.in)
Heat treatment (guiding value)	Ageing 2 hours at 400°C (750°F) see also page 124
Weldability	Good on both sides
Marking on the high expansion side	Color marking at the ends

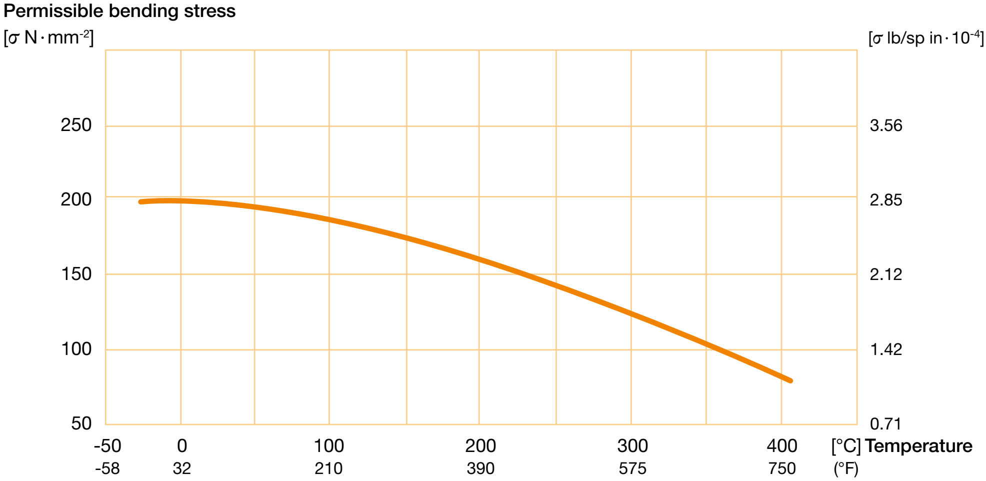


See also table on page 17 and 18



See section 3, page 20

Permissible bending stress



KANTHAL 140R140

Components .... 36 Ni/MnNiCu

Specific deflection .... **a** = 14.0 × 10^{-6} K^{-1}; Tolerance ± 4 %

Specific curvature .... k = 26.1 × 10^{-6} K^{-1}; Tolerance ± 4 %

Flexivity .... F = 14.5 × 10^{-6} F^{-1}; Tolerance ± 4 %

Electrical resistivity at 20°C (68°F) ...... ρ = 1.40 Ω × mm^2 × m^{-1}; Tolerance ± 5 %
(= 843 Ω per cir. mil ft)

Temperature range .... Normal -20 to +250°C; (0 to 480°F) Maximum 330°C (625°F)

Linearity range .... -20 to +200°C (0 to 395°F)

Modulus of elasticity at 20°C (68°F) ... E = 130 × 10^3 N × mm^{-2} (= 18.5 × 10^6 lb/sq.in)

Standard hardness, Vickers

- Low expansion side .... H_v = 210
- High expansion side .... H_v = 240

Thermal conductivity .... λ = 4 W/m°C = 0.009 cal/cms°°
(= 28 BTU/h/sq.ft/°F/in)

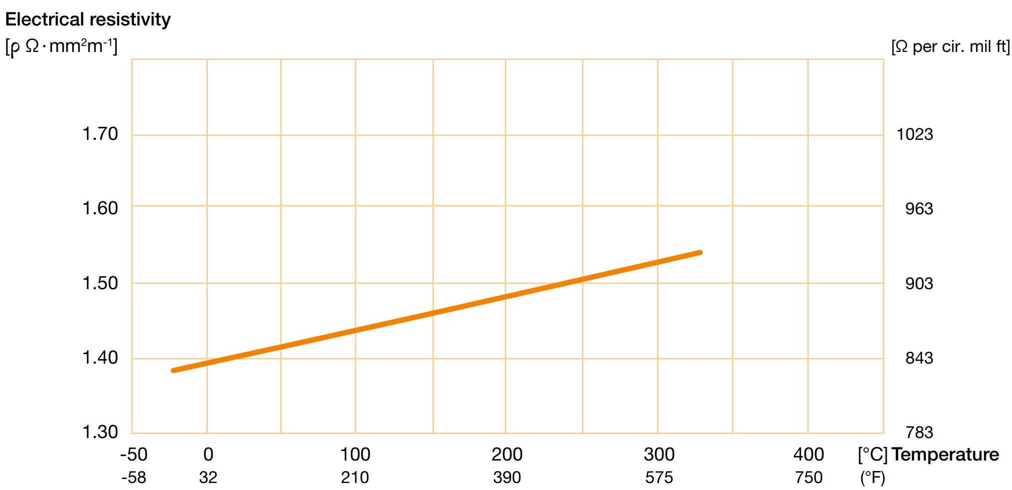
Specific heat .... c = 0.46 J/g°C = 0.11 cal/g°C
(= 0.11 BTU/lb/°F)

Density .... γ = 7.4 g × cm^{-3} (= 0.267 lb/cu.in)

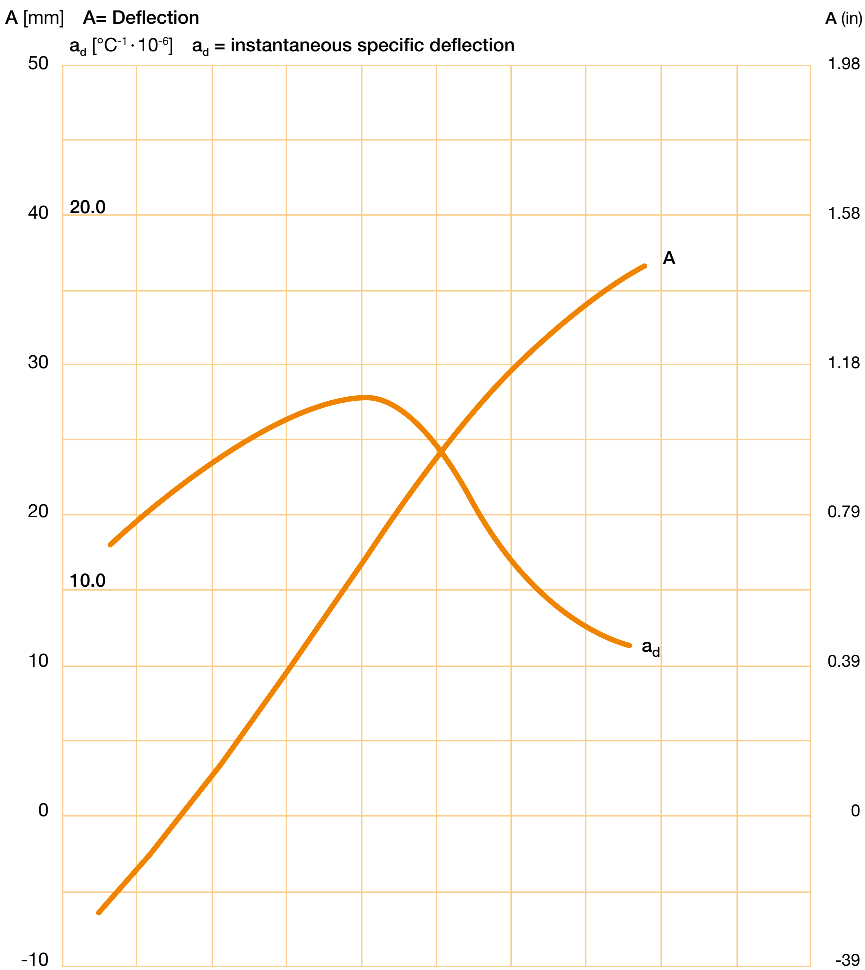
Heat treatment (guiding value) .... Ageing 2 hours at 260°C (500°F) see also page 124

Weldability .... See page 125

Marking on the high expansion side ... 140R140TB14140 140R140TB14140 140R140TB14140 140R140
40R140TB14140 140R140TB14140 140R140TB14140 140R140
0R140TB14140 140R140TB14140 140R140TB14140 140R140

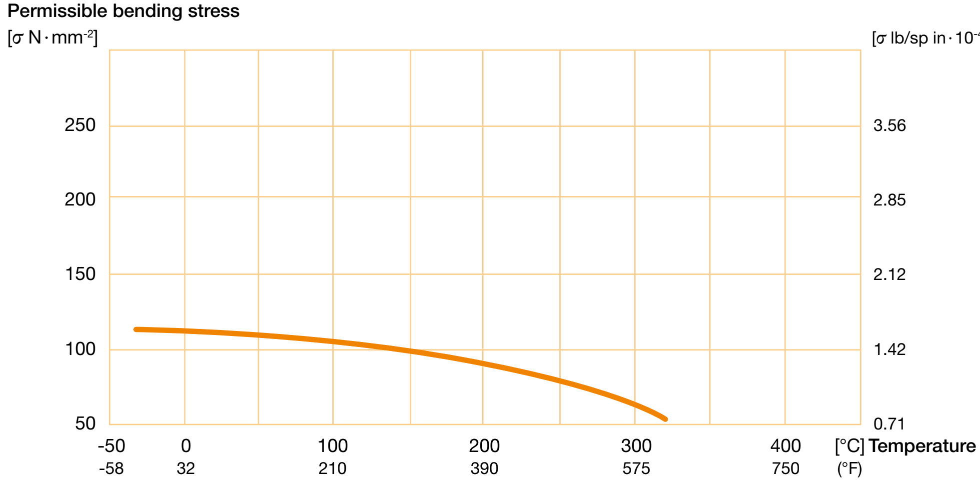


See also table on page 17 and 18



See section 3, page 20

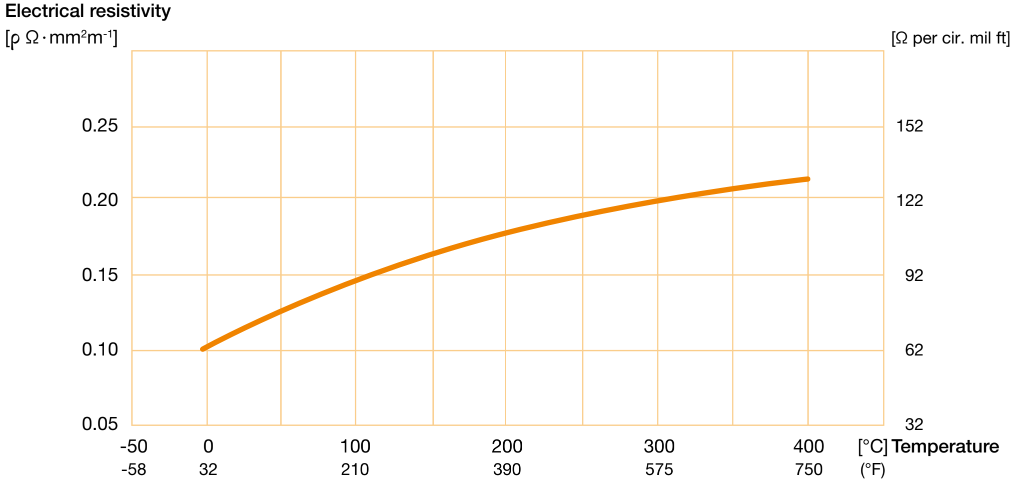
Permissible bending stress



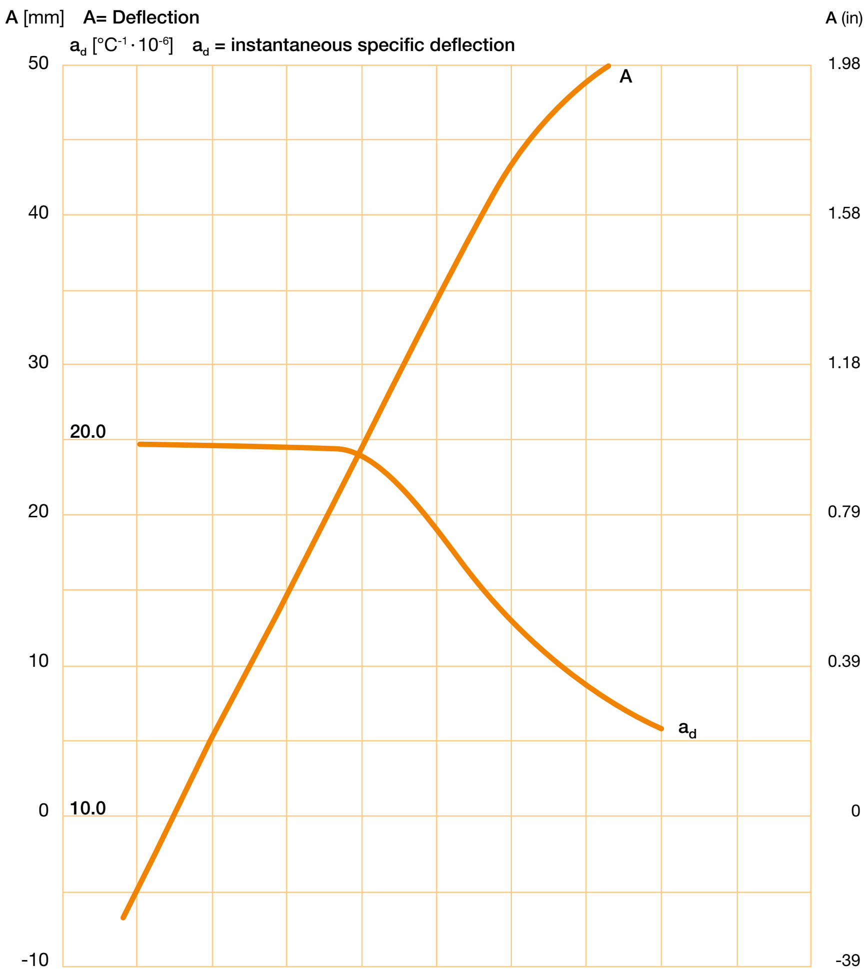
KANTHAL 200R10 TB2010

Components	36 Ni/Cu/MnNiCu
Specific deflection	**a** = 20.0 × 10^{-6} K^{-1}; Tolerance ± 4 %
Specific curvature	k = 39.0 × 10^{-6} K^{-1}; Tolerance ± 4 %
Flexivity	F = 21.7 × 10^{-6} F^{-1}; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F)	ρ = 0.10 Ω × mm^2 × m^{-1}; Tolerance ± 4 % (= 60 Ω per cir. mil ft)
Temperature range	Normal -20 to +250°C; (0 to 480°F) Maximum 330°C (625°F)
Linearity range	-20 to 200°C° (0 to 395°F)
Modulus of elasticity at 20°C (68°F)	E = 130 × 10^3 N × mm^{-2} (= 18.5 × 10^6 lb/sq.in)
Standard hardness, Vickers	
Low expansion side	H_v = 210 ± 20
High expansion side	H_v = 240 ± 20
Thermal conductivity	λ = 72 W/m°C = 0.172 cal/cms°C (= 504 BTU/h/sq.ft/°F/in)
Specific heat	c = 0.46 J/g°C = 0.11 cal/g°C (= 0.11 BTU/lb/°F)
Density	γ = 7.9 g × cm^{-3} (= 0.285 lb/cu.in)
Heat treatment (guiding value)	Ageing 2 hours at 250°C (480°F) see also page 124
Weldability	See page 125
Marking on the high expansion side	200R10TB2010

Electrical resistivity

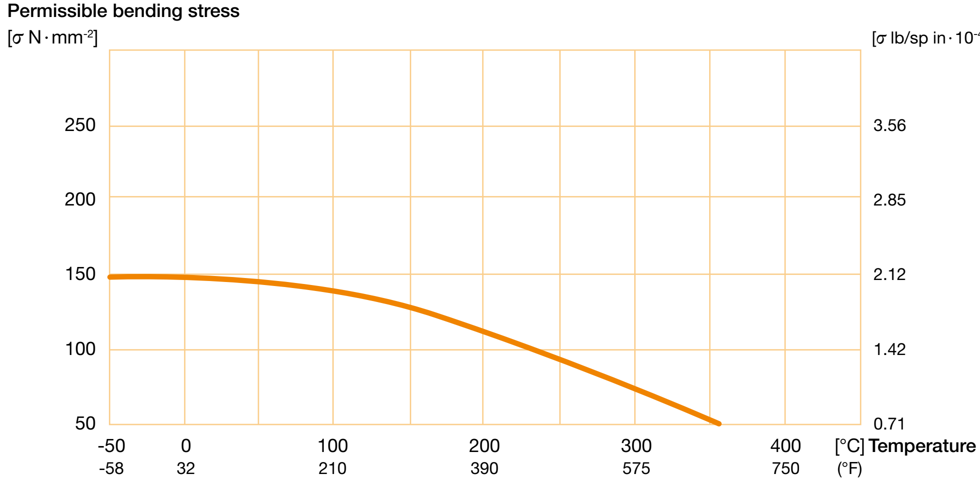


See also table on page 17 and 18



See section 3, page 20

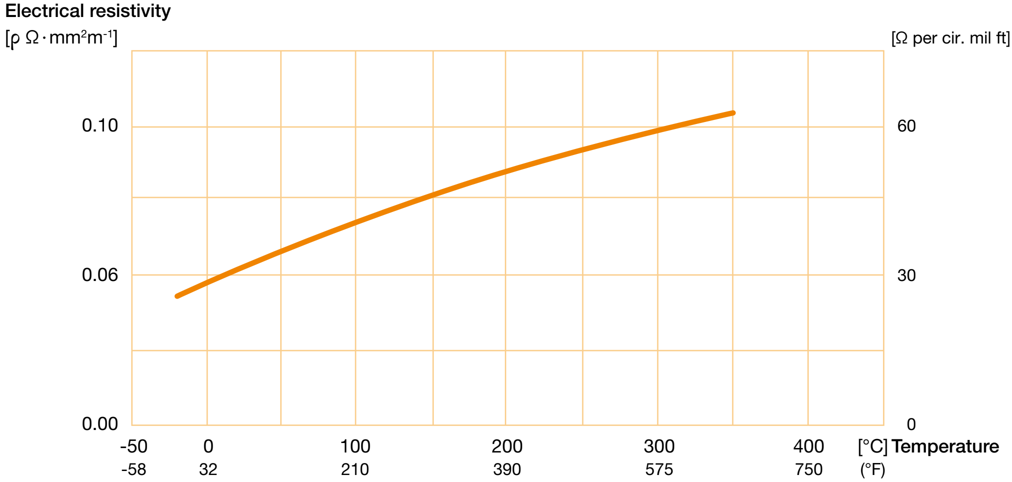
Permissible bending stress



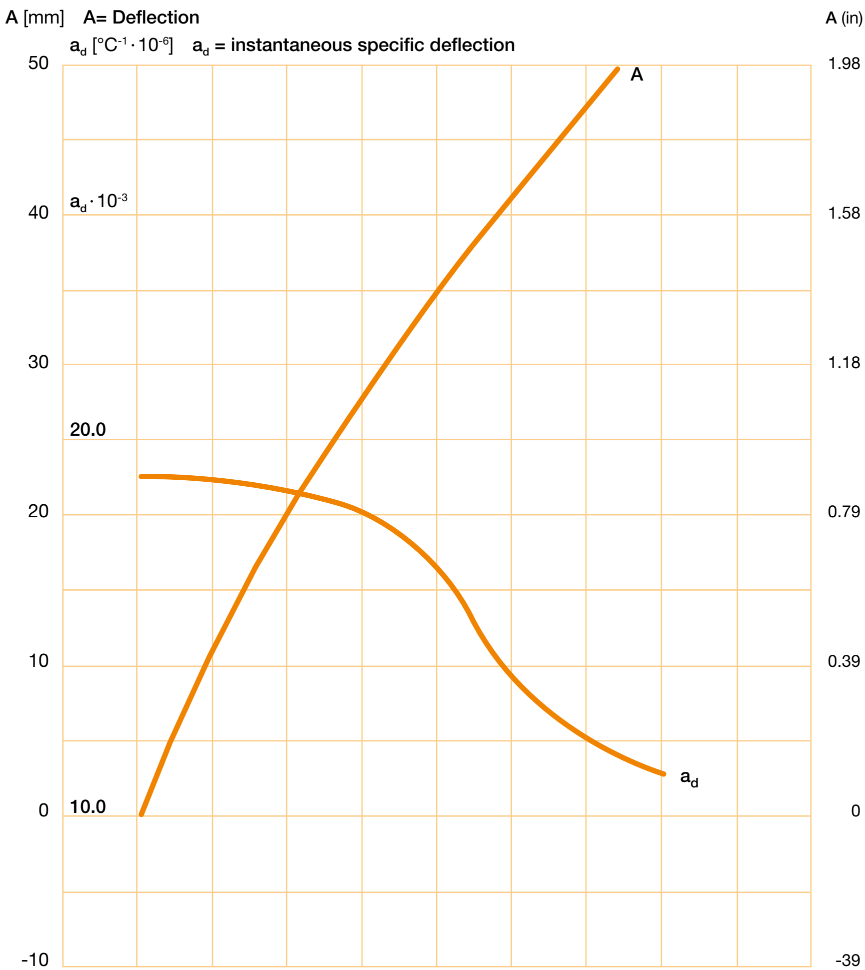
KANTHAL 180R05

Components .... 36 Ni/Cu/MnNiCu-steel
Specific deflection .... **a** = 18×10^{-6} K^{-1}; Tolerance ± 4 %
Specific curvature .... k = 33.8×10^{-6} K^{-1}; Tolerance ± 4 %
Flexivity .... F = 18.8×10^{-6} F^{-1}; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F) ...... ρ = 0.05 Ω × mm^2 × m^{-1}; Tolerance ± 4 %
(= 30 Ω per cir. mil ft)
Temperature range .... Normal -20 to +200°C; (0 to 395°F) Maximum 350°C (660°F)
Linearity range .... -20 to +200°C (0 to 395°F).
Modulus of elasticity at 20°C (68°F) .... E = 130×10^3 N × mm^{-2} (= 18.5×10^6 lb/sq.in)
Standard hardness, Vickers
Low expansion side .... H_v = 210 ± 20
High expansion side .... H_v = 240 ± 20
Thermal conductivity .... λ = 170 W/m°C = 0.40 cal/cms°C
(= 1185 BTU/h/sq.ft/°F/in)
Specific heat .... c = 0.46 J/g°C = 0.11 cal/g°C
(= 0.11 BTU/lb/°F)
Density .... γ = 8.2 g × cm^{-3} (= 0.296 lb/cu.in)
Heat treatment (guiding value) .... Ageing 2 hours at 250°C (480°F) see also page 124
Weldability .... See page 125
Marking on the high expansion side ... 180R05TB1805

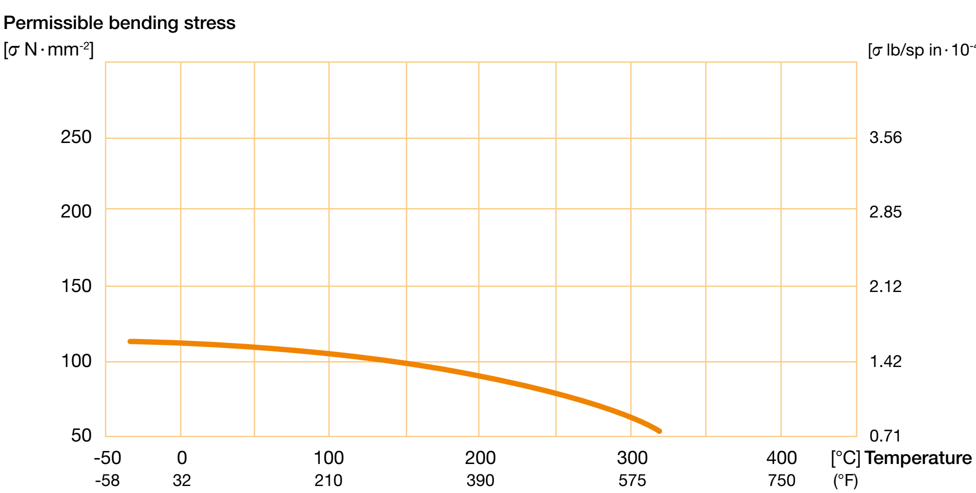
Electrical resistivity



See also table on page 17 and 18

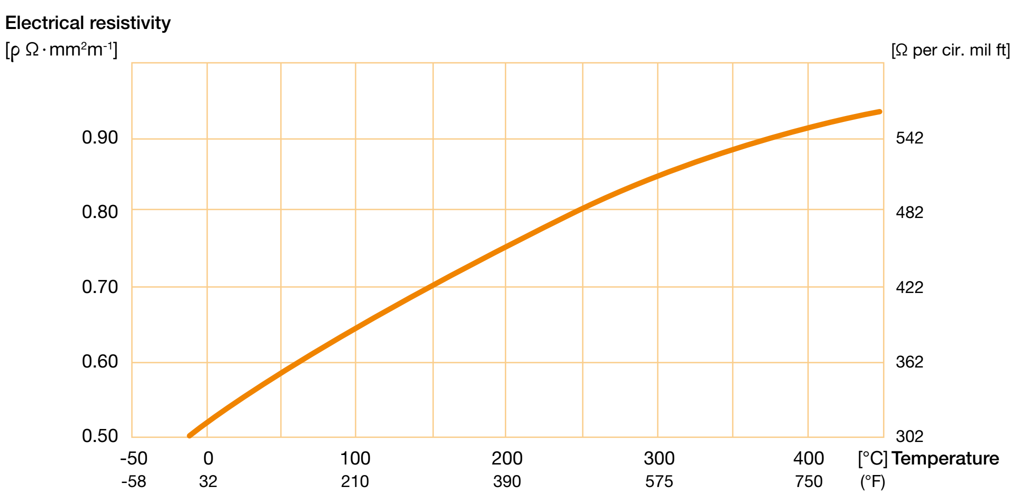


See section 3, page 20

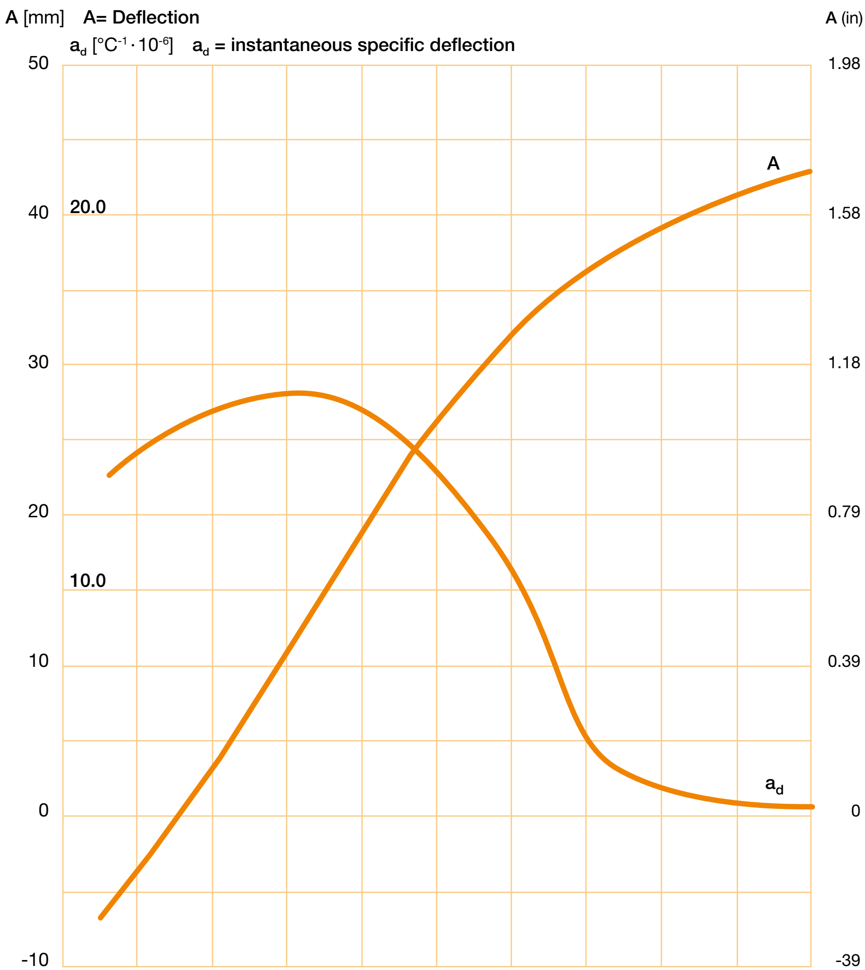


KANTHAL 155R55 TB1555

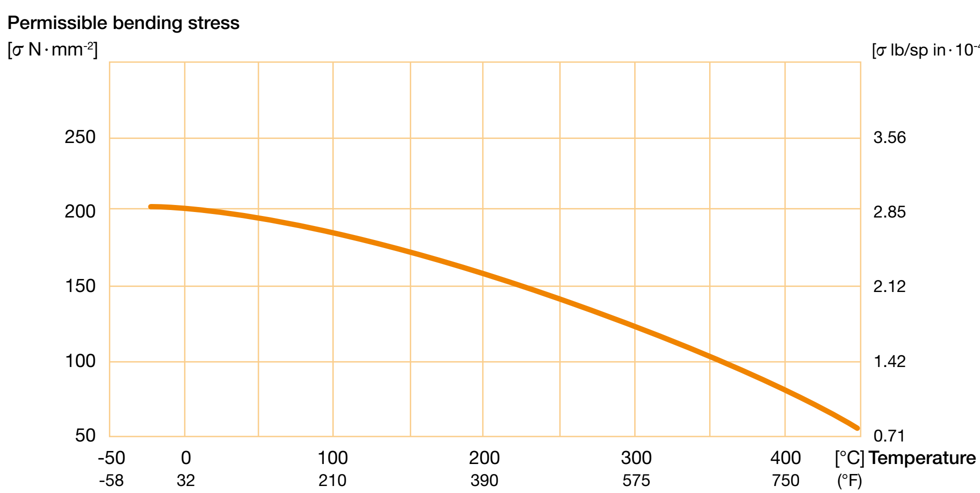
Components	Same as 155 with intermediate Ni-layer
Specific deflection	**a** = 15.0 × 10^{-6} K^{-1}; Tolerance ± 4 %
Specific curvature	k = 28.2 × 10^{-6} K^{-1}; Tolerance ± 4 %
Flexivity	F = 15.7 × 10^{-6} F^{-1}; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F)	ρ = 0.55 Ω × mm^2 × m^{-1}; Tolerance ± 5 % (= 330 Ω per cir. mil ft)
Temperature range	Normal -20 to +350°C; (0 to 660°F) Maximum 450°C (840°F)
Linearity range	-20 to +200°C (0 to 395°F)
Modulus of elasticity at 20° (68°F)	E = 170 × 10^3 N × mm^{-2} (= 24.2 × 10^6 lb/sq.in)
Standard hardness, Vickers	
Low expansion side	H_v = 210
High expansion side	H_v = 260
Thermal conductivity	λ = 16 W/m°C = 0.038 cal/cms°C (= 112 BTU/h/sq.ft/°F/in)
Specific heat	c = 0.46 J/g°C = 0.11 cal/g°C (= 0.11 BTU/lb/°F)
Density	γ = 8.15 g × cm^{-3} (= 0.294 lb/cu.in)
Heat treatment (guiding value)	Ageing 2 hours at 350°C (660°F) see also page 124
Weldability	Good on both sides
Marking on the high expansion side	155R55TB1555 155R55TB1555 155R55TB1555 155R55TB1555 55R55TB1555 155R55TB1555 155R55TB1555 155R55TB1555 5R55TB1555 155R55TB1555 155R55TB1555 155R55TB1555



See also table on page 17 and 18

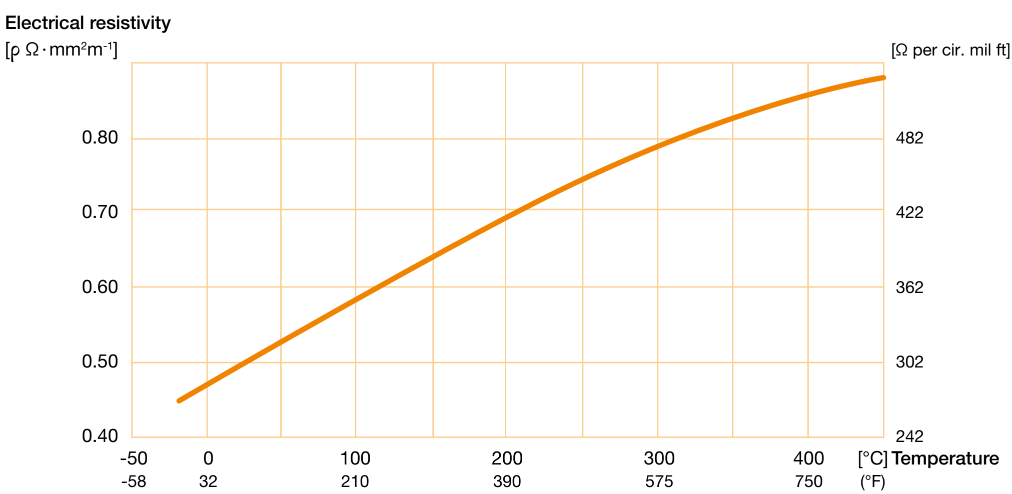


See section 3, page 20

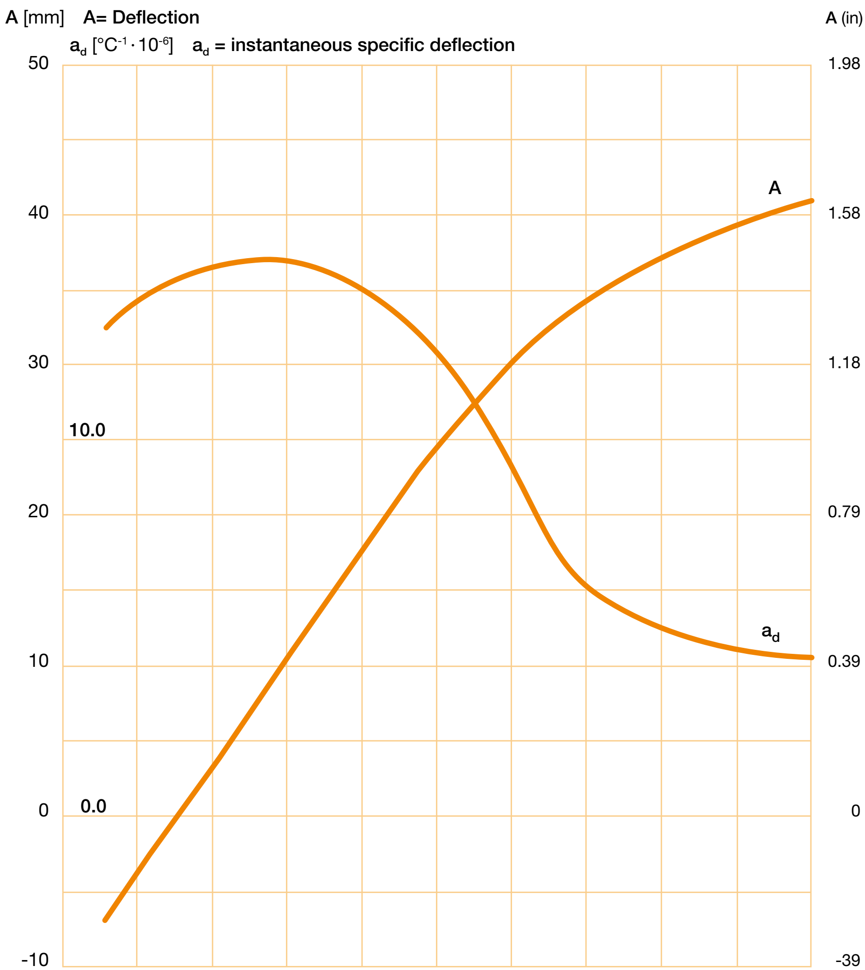


KANTHAL 145R50

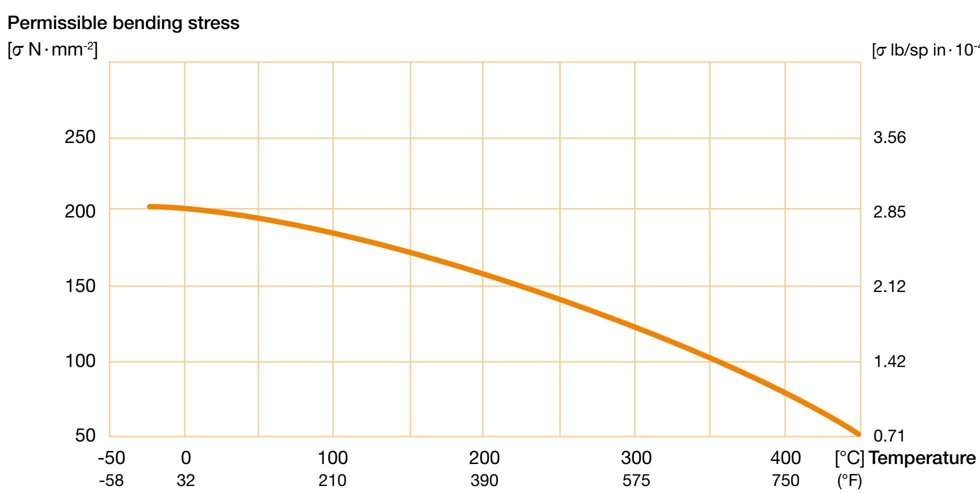
Components	Same as 145 with intermediate Ni-layer
Specific deflection	**a** = 14.9 × 10^{-6} K^{-1}; Tolerance ± 4 %
Specific curvature	k = 27.7 × 10^{-6} K^{-1}; Tolerance ± 4 %
Flexivity	F = 15.4 × 10^{-6} F^{-1}; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F)	ρ = 0.50 Ω × mm^2 × m^{-1}; Tolerance ± 5 % (= 300 Ω per cir. mil ft)
Temperature range	Normal -20 to +350°C; (0 to 660°F) Maximum 450°C (840°F)
Linearity range	-20 to +200°C (0 to 395°F)
Modulus of elasticity at 20°C (68°F)	E = 170 × 10^3 N × mm^{-2} (= 24.2 × 10^6 lb/sq.in)
Standard hardness, Vickers	
Low expansion side	H_v = 210
High expansion side	H_v = 260
Thermal conductivity	λ = 16 W × m^{-1} × $°C^{-1}$ = 0.038 cal × cm^{-1} × s^{-1} × $°C^{-1}$ (= 111 BTU/h/sq.ft/°F/in)
Specific heat	c = 0.46 J × g^{-1} × $°C^{-1}$ = 0.11 cal × g^{-1} × $°C^{-1}$ (= 0.11 BTU/lb/°F)
Density	γ = 8.15 g × cm^{-3} (= 0.294 lb/cu.in)
Heat treatment (guiding value)	Ageing 2 hours at 350°C (660°F) see also page 124
Weldability	Good on both sides
Marking on the high expansion side	145R50TB1450 145R50TB1450 145R50TB1450 145R50TB1450 45R50TB1450 145R50TB1450 145R50TB1450 145R50TB1450 5R50TB1450 145R50TB1450 145R50TB1450 145R50TB1450



See also table on page 17 and 18

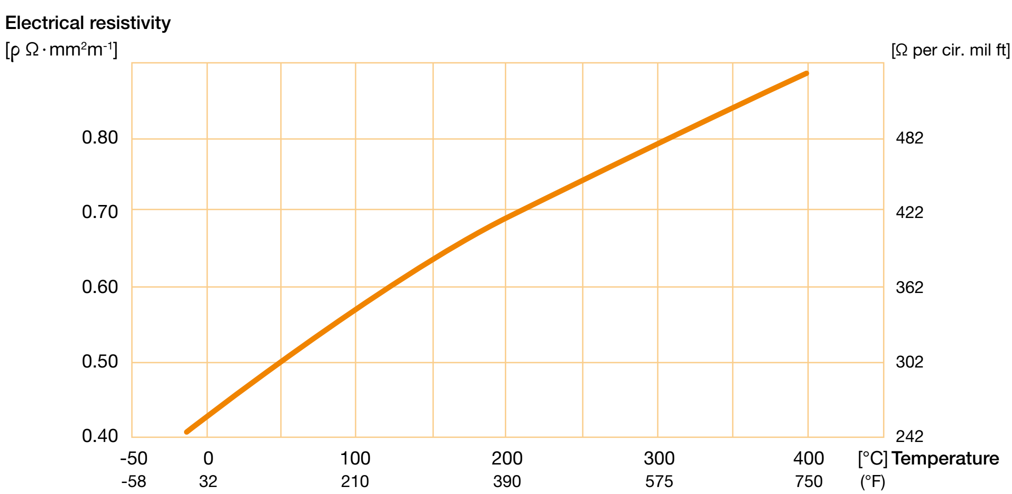


See section 3, page 20

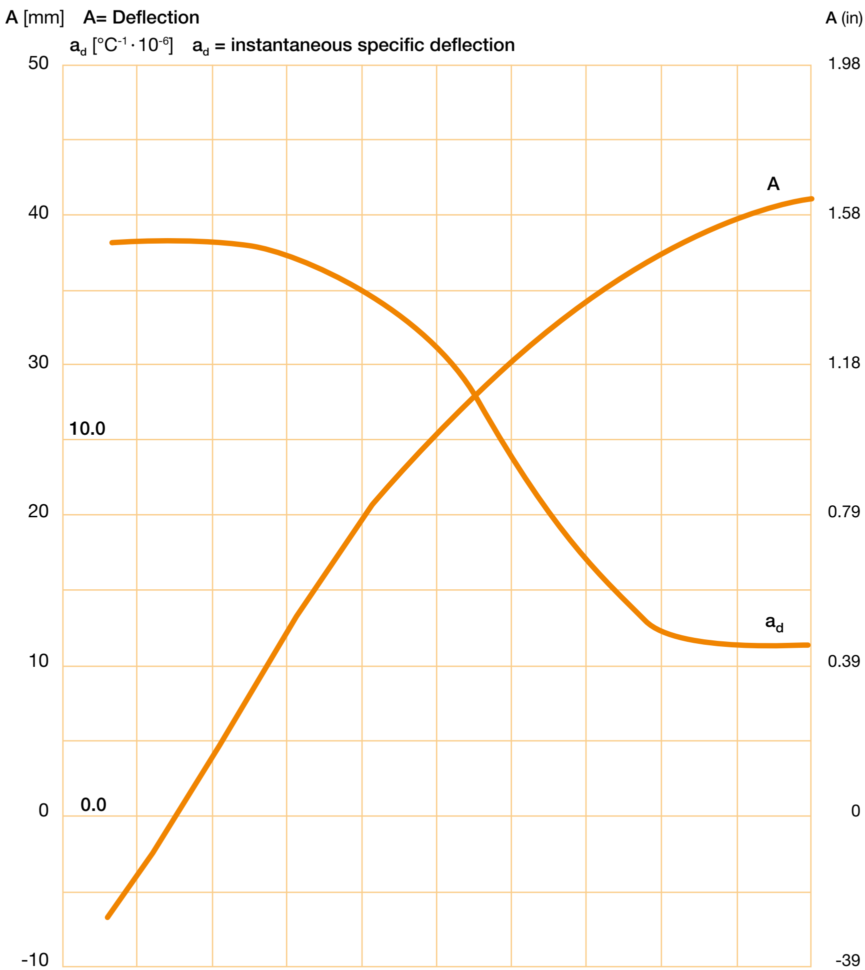


KANTHAL 145R45 TB1445

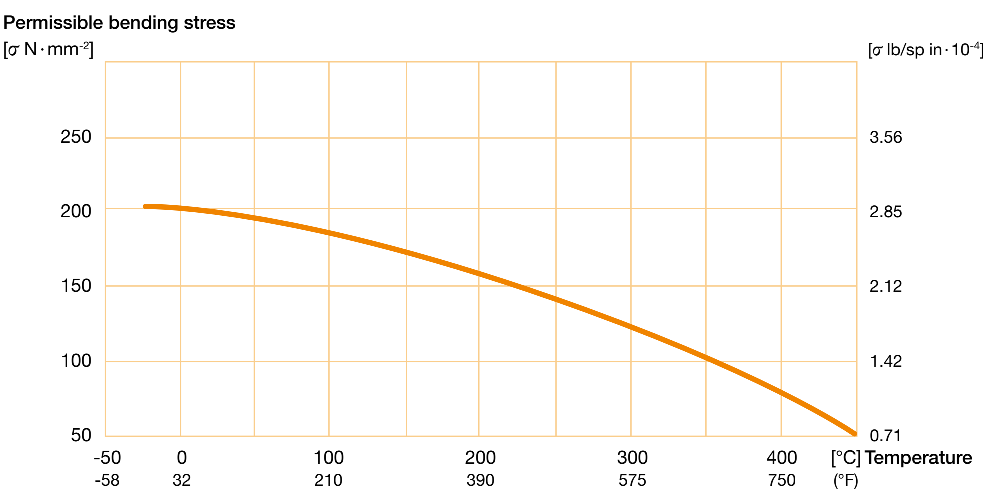
Components .... 36 Ni/Ni/NiMn-steel
Specific deflection .... **a** = 14.9 × 10^{-6} K^{-1}; Tolerance ± 4 %
Specific curvature .... k = 27.7 × 10^{-6} K^{-1}; Tolerance ± 4 %
Flexivity .... F = 15.4 × 10^{-6} F^{-1}; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F) ...... ρ = 0.45 Ω × mm^2 × m^{-1}; Tolerance ± 4 %
(= 270 Ω per cir. mil ft)
Temperature range .... Normal -20 to +350°C; (0 to 660°F) Maximum 450°C (840°F)
Linearity range .... -20 to 200°C (0 to 395°F)
Modulus of elasticity at 20°C (68°F) ... E = 170 × 10^3 N × mm^{-2} (= 24.2 × 10^6 lb/sq.in)
Standard hardness, Vickers
Low expansion side .... H_v = 210 ± 20
High expansion side .... H_v = 260 ± 20
Thermal conductivity .... λ = 16 W/m°C = 0.038 cal/cms°C
(= 111 BTU/h/sq.ft/°F/in)
Specific heat .... c = 0.46 J/g°C = 0,11 cal/g°C
(= 0.11 BTU/lb/°F)
Density .... γ = 8.2 g × cm^{-3} (= 0.296 lb/cu.in)
Heat treatment (guiding value) .... Ageing 2 hours at 350°C (660°F) see also page 124
Weldability .... Good on both sides
Marking on the high expansion side ... 145R45TB1445



See also table on page 17 and 18

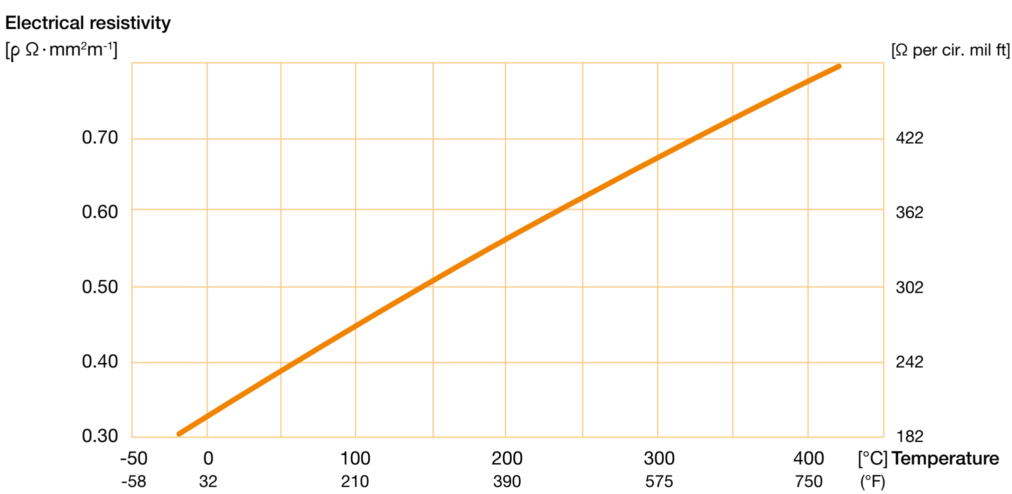


See section 3, page 20

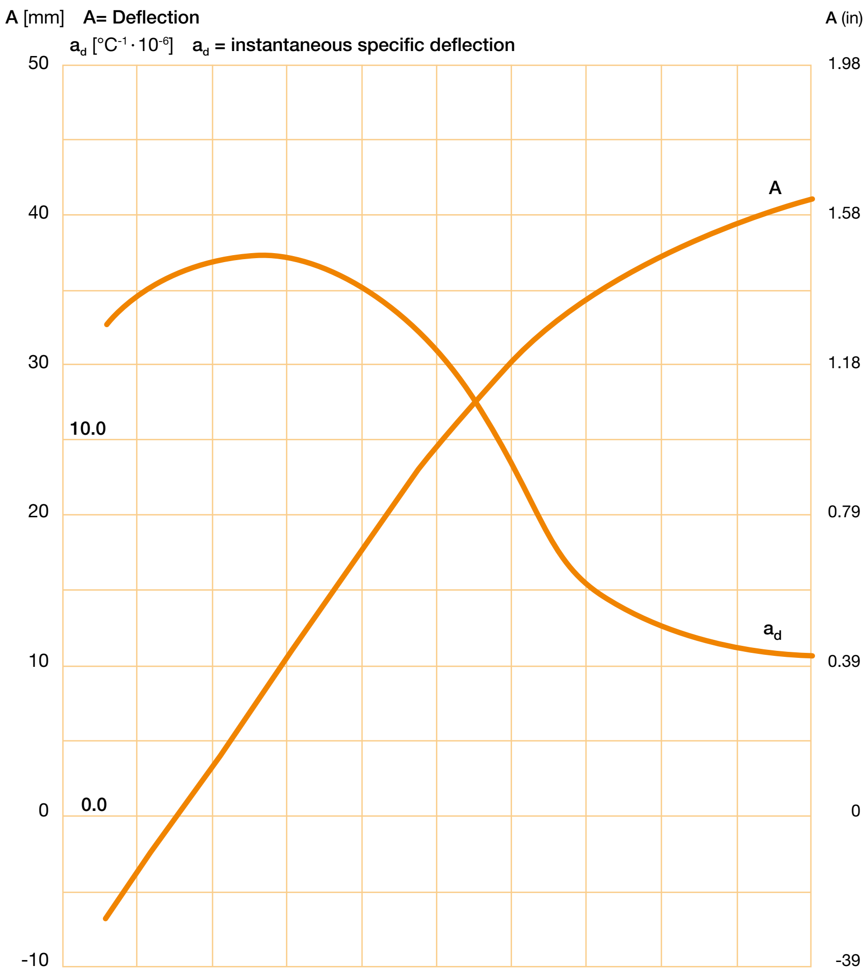


KANTHAL 145R35 TB1435

Components	Same as 145 with intermediate Ni-layer
Specific deflection	**a** = 14.8×10^{-6} K^{-1}; Tolerance ± 4 %
Specific curvature	k = 27.4×10^{-6} K^{-1}; Tolerance ± 4 %
Flexivity	F = 15.2×10^{-6} F^{-1}; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F)	ρ = 0.35 Ω × mm^2 × m^{-1}; Tolerance ± 5 % (= 210 Ω per cir. mil ft)
Temperature range	Normal -20 to +350°C; (0 to 660°F) Maximum 450°C (842°F)
Linearity range	-20 to +200°C (0 to 395°F)
Modulus of elasticity at 20°C (68°F)	E = 170 × 10^3 N × mm^{-2} (= 24.2 × 10^6 lb/sq.in)
Standard hardness, Vickers	
Low expansion side	H_v = 210
High expansion side	H_v = 260
Thermal conductivity	λ = 22 W × m^{-1} × $°C^{-1}$ = 0.053 cal × cm^{-1} × s^{-1} × $°C^{-1}$ (= 153 BTU/h/sq.ft/°F/in)
Specific heat	c = 0.46 J × g^{-1} × $°C^{-1}$ = 0.11 cal × g^{-1} × $°C^{-1}$ (= 0.11 BTU/lb/°F)
Density	γ = 8.25 g × cm^{-3} (= 0.298 lb/cu.in)
Heat treatment (guiding value)	Ageing 2 hours at 350°C (660°F) see also page 124
Weldability	Good on both sides
Marking on the high expansion side	145R35TB1435 145R35TB1435 145R35TB1435 145R35TB1435 45R35TB1435 145R35TB1435 145R35TB1435 145R35TB1435 5R35TB1435 145R35TB1435 145R35TB1435 145R35TB1435

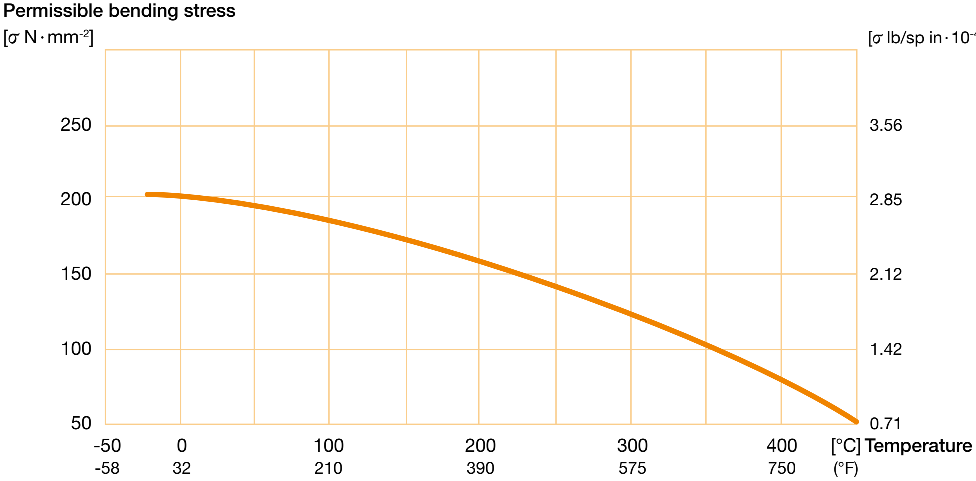


See also table on page 17 and 18



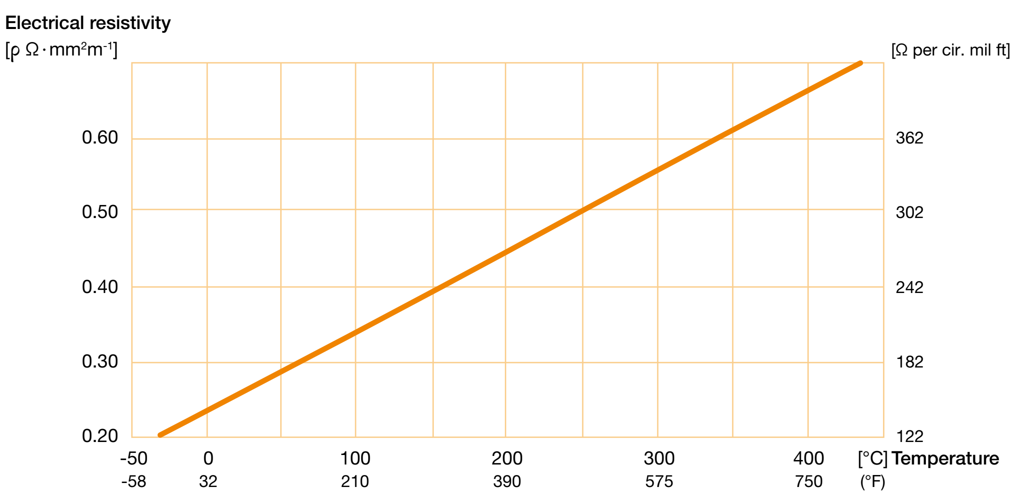
See section 3, page 20

Permissible bending stress

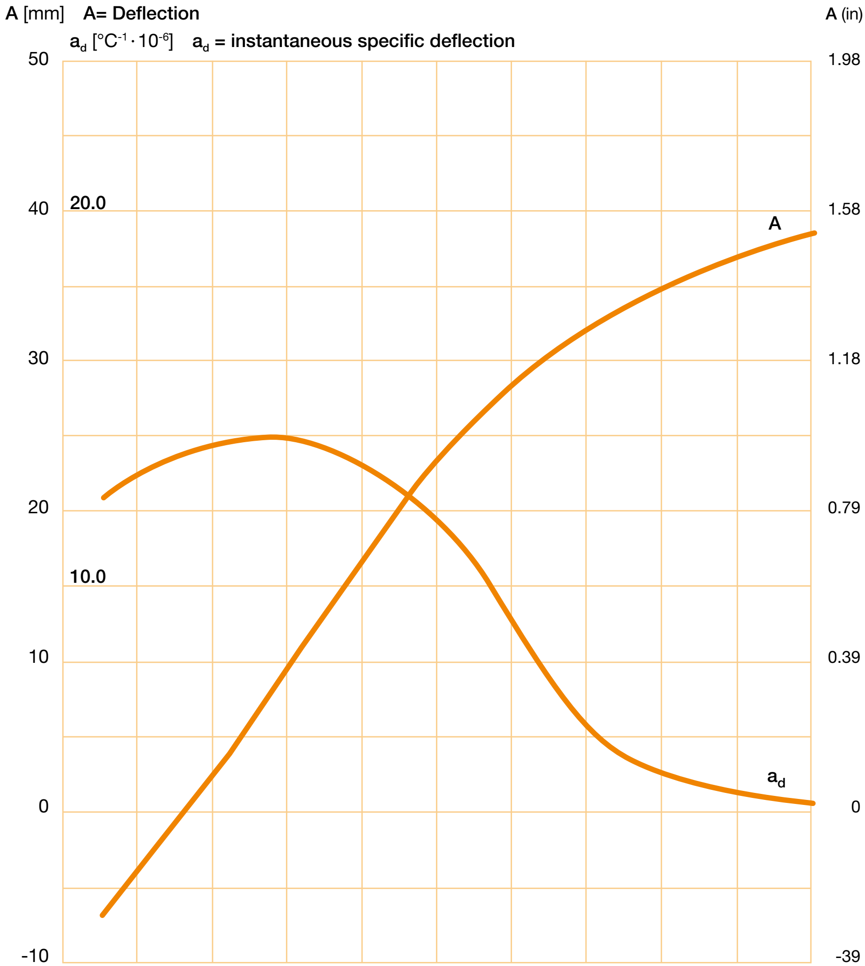


KANTHAL 135R25 TB1425

Components	Same as 145 with intermediate Ni-layer
Specific deflection	**a** = 14.0 × 10^{-6} K^{-1}; Tolerance ± 4 %
Specific curvature	k = 26.1 × 10^{-6} K^{-1}; Tolerance ± 4 %
Flexivity	F = 14.5 × 10^{-6} F^{-1}; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F)	ρ = 0.25 Ω × mm^2 × m^{-1}; Tolerance ± 5 % (= 150 Ω per cir. mil ft)
Temperature range	Normal -20 to +350°C; (0 to 660°F) Maximum 450°C (842°F)
Linearity range	-20 to +200°C (0 to 395°F)
Modulus of elasticity at 20°C (68°F)	E = 170 × 10^3 N × mm^{-2} (= 24.2 × 10^6 lb/sq.in)
Standard hardness, Vickers	
Low expansion side	H_v = 210
High expansion side	H_v = 260
Thermal conductivity	λ = 28 W × m^{-1} × $°C^{-1}$ = 0.067 cal × cm^{-1} × s^{-1} × $°C^{-1}$ (= 195 BTU/h/sq.f/°F/in)
Specific heat	c = 0.44 J × g^{-1} × °C = 0.11 cal × g^{-1} × °C (= 0.11 BTU/lb/°F)
Density	γ = 8.3 g × cm^{-3} (= 0.300 lb/cu.in)
Heat treatment (guiding value)	Ageing 2 hours at 350°C (660°F) see also page 124
Weldability	Good on both sides
Marking on the high expansion side	135R25TB1425 135R25TB1425 135R25TB1425 135R25TB1425 35R25TB1425 135R25TB1425 135R25TB1425 135R25TB1425 5R25TB1425 135R25TB1425 135R25TB1425 135R25TB1425

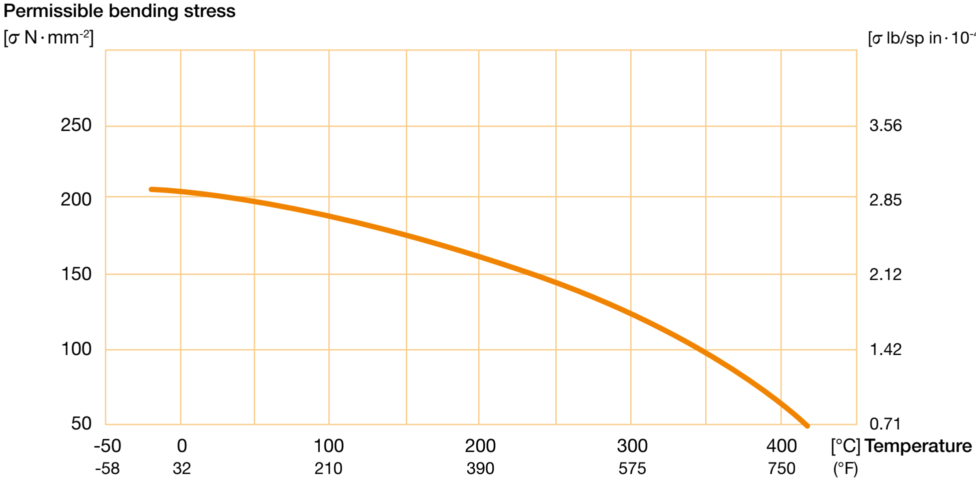


See also table on page 17 and 18



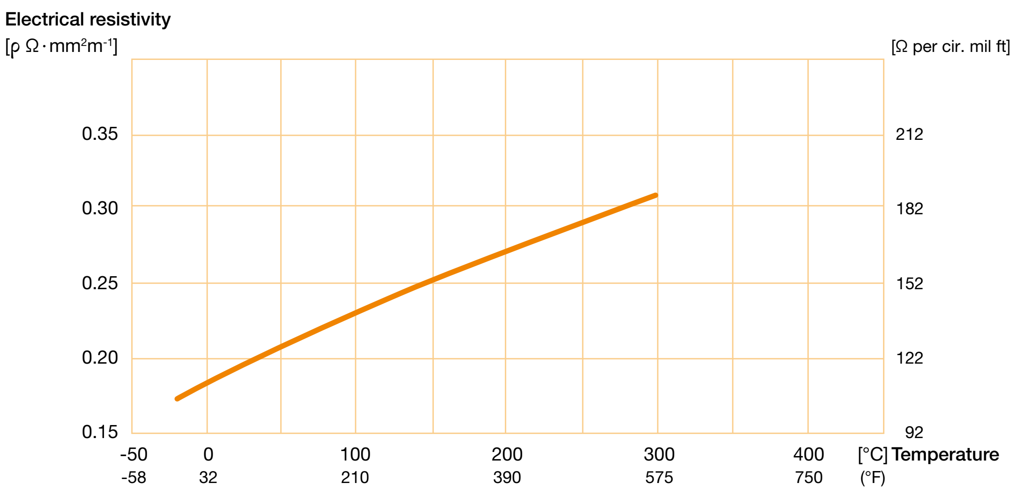
See section 3, page 20

Permissible bending stress

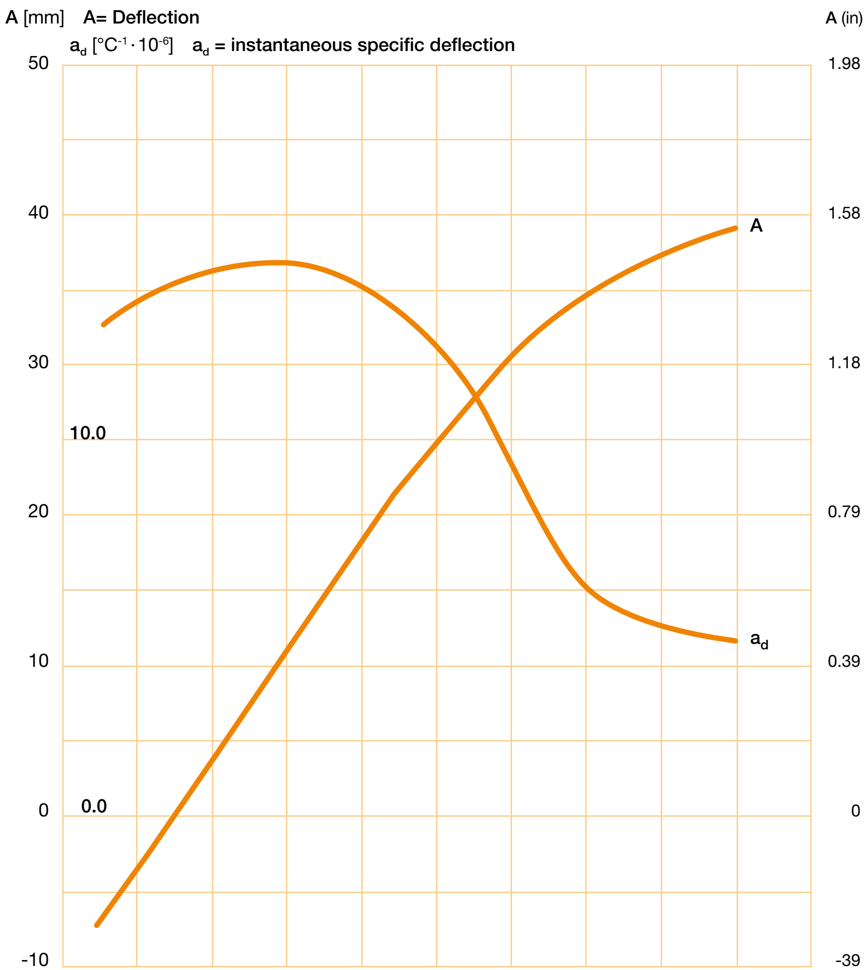


KANTHAL 145R19

Components	Same as 145 with intermediate Ni-layer
Specific deflection	**a** = $14.9 \times 10^{-6} K^{-1}$; Tolerance ± 4 %
Specific curvature	k = $27.9 \times 10^{-6} K^{-1}$; Tolerance ± 4 %
Flexivity	F = $15.5 \times 10^{-6} F^{-1}$; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F)	ρ = 0.19 Ω × mm2 × m^{-1}; Tolerance see page 79 (= 114 Ω per cir. mil ft)
Temperature range	Normal -20 to +250°C; (0 to 480°F) Maximum 400°C (750°F)
if directly electrically heated	Maximum 275°C (530°F)
Linearity range	-20 to +200°C (0 to 395°F)
Modulus of elasticity at 20°C (68°F)	E = $170 \times 10^3 N \times mm^{-2}$ (= 24.2×10^6 lb/sq.in)
Standard hardness, Vickers	
Low expansion side	$H_v = 210$
High expansion side	$H_v = 260$
Thermal conductivity	λ = $39 W \times m^{-1} \times °C^{-1} = 0.067 cal \times cm^{-1} \times s^{-1} \times °C^{-1}$ (= 272 BTU/h/sq.ft/°F/in)
Specific heat	c = $0.46 J \times g^{-1} \times °C^{-1} = 0.11 cal \times g^{-1} \times °C^{-1}$ (= 0.11 BTU/lb/°F)
Density	γ = $8.2 g \times cm^{-3}$ (= 0.296 lb/cu.in)
Heat treatment (guiding value)	Ageing 2 hours at 260°C (500°F) see also page 124
Weldability	Good on both sides
Marking on the high expansion side	145R19TB1419 145R19TB1419 145R19TB1419 145R19TB1419 45R19TB1419 145R19TB1419 145R19TB1419 145R19TB1419 5R19TB1419 145R19TB1419 145R19TB1419 145R19TB1419

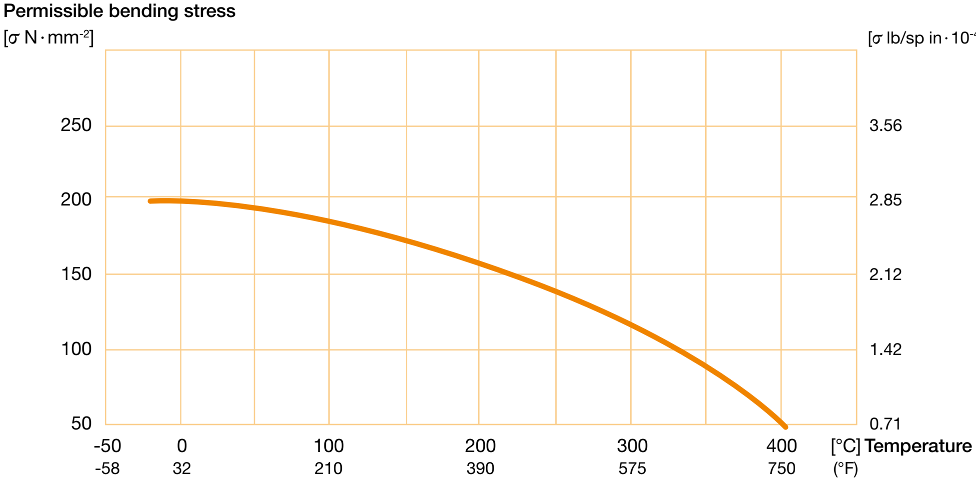


See also table on page 17 and 18



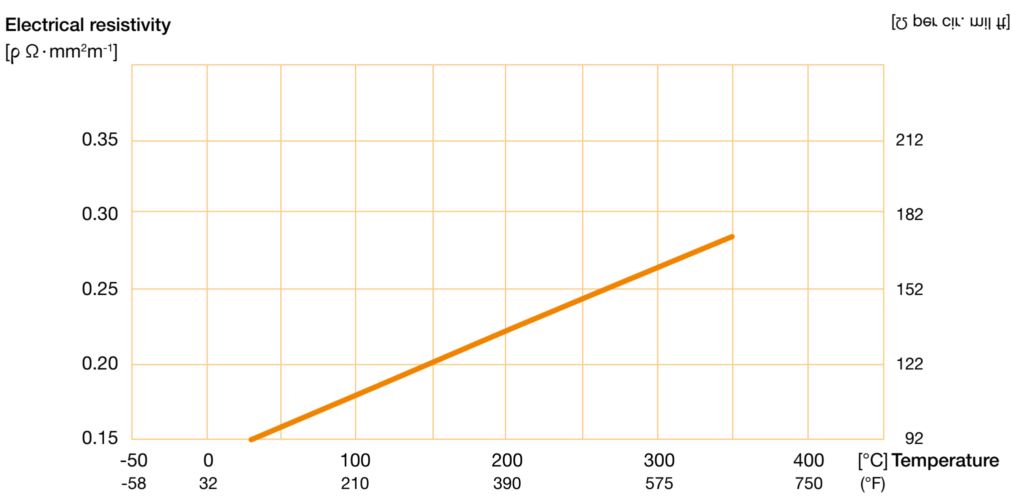
See section 3, page 20

Permissible bending stress

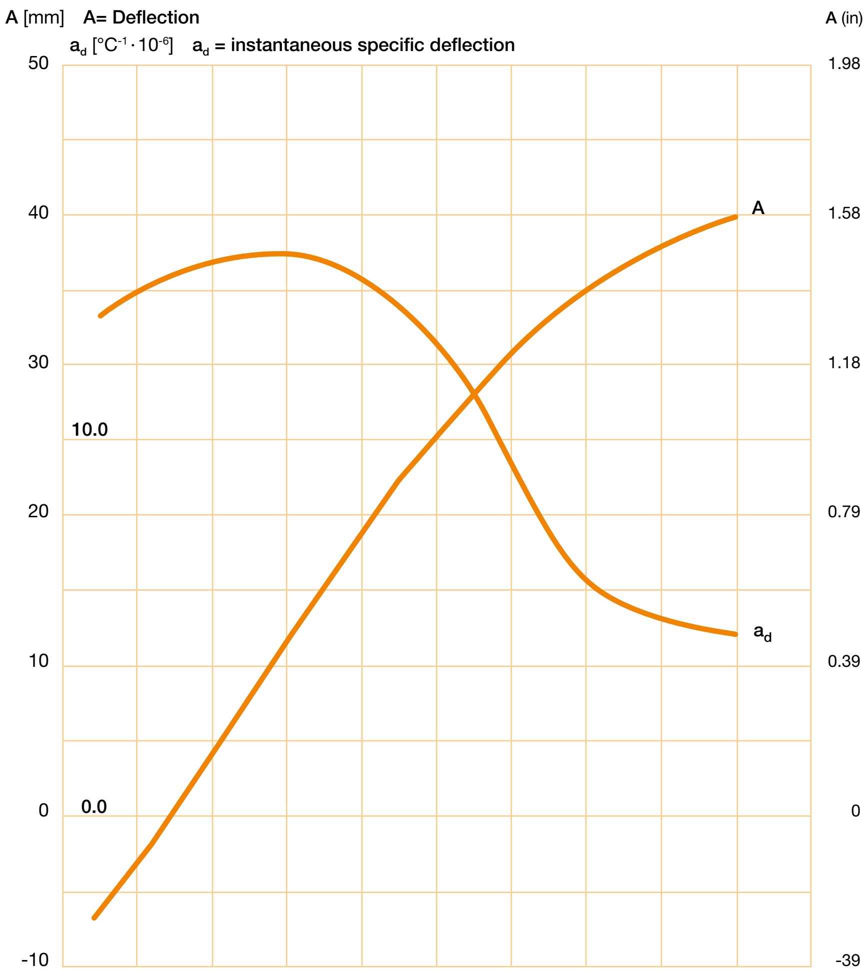


KANTHAL 145R17

Components	Same as 145 with intermediate Ni-layer
Specific deflection	**a** = 14.9 × 10^{-6} K^{-1}; Tolerance ± 4 %
Specific curvature	k = 27.9 × 10^{-6} K^{-1}; Tolerance ± 4 %
Flexivity	F = 15.5 × 10^{-6} F^{-1}; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F)	ρ = 0.17 Ω × mm^2 × m^{-1}; Tolerance see page 79 (= 102 Ω per cir. mil ft)
Temperature range	Normal -20 to +250°C; (0 to 480°F) Maximum 400°C (750°F)
if directly electrically heated	Maximum 275°C (530°F)
Linearity range	-20 to +200°C (0 to 395°F)
Modulus of elasticity at 20°C (68°F)	E = 170 × 10^3 N × mm-2 (= 24.2 × 10^6 lb/sq.in)
Standard hardness, Vickers	
Low expansion side	H_v = 210
High expansion side	H_v = 260
Thermal conductivity	λ = 43 W × m^{-1} × $°C^{-1}$ = 0.067 cal × cm^{-1} × s^{-1} × $°C^{-1}$ (= 300 BTU/h/sq.ft/°F/in)
Specific heat	c = 0.46 J × g^{-1} × $°C^{-1}$ = 0.11 cal × g^{-1} × $°C^{-1}$ (= 0.11 BTU/lb/°F)
Density	γ = 8.2 g × cm^{-3} (= 0.296 lb/cu.in)
Heat treatment (guiding value)	Ageing 2 hours at 260°C (500°F) see also page 124
Weldability	Good on both sides
Marking on the high expansion side	145R17TB1417 145R17TB1417 145R17TB1417 145R17TB1417 45R17TB1417 145R17TB1417 145R17TB1417 145R17TB1417 5R17TB1417 145R17TB1417 145R17TB1417 145R17TB1417

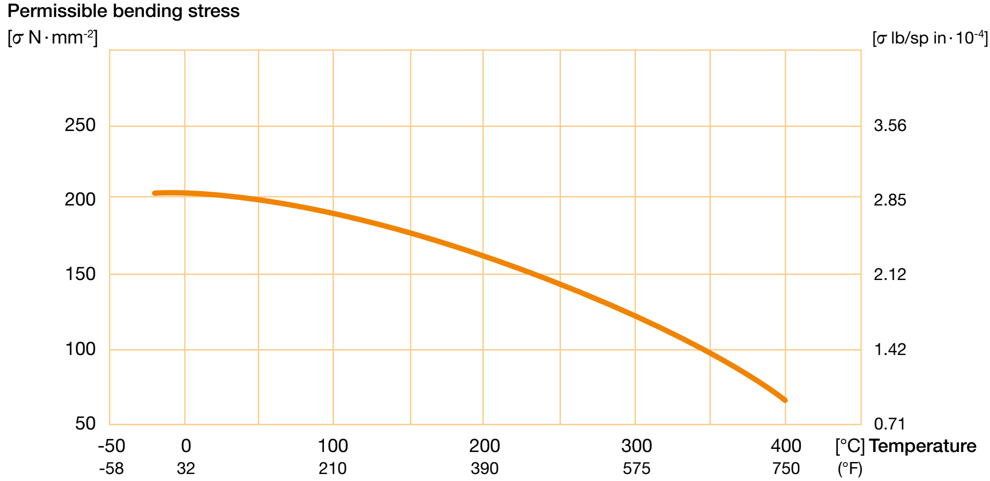


See also table on page 17 and 18



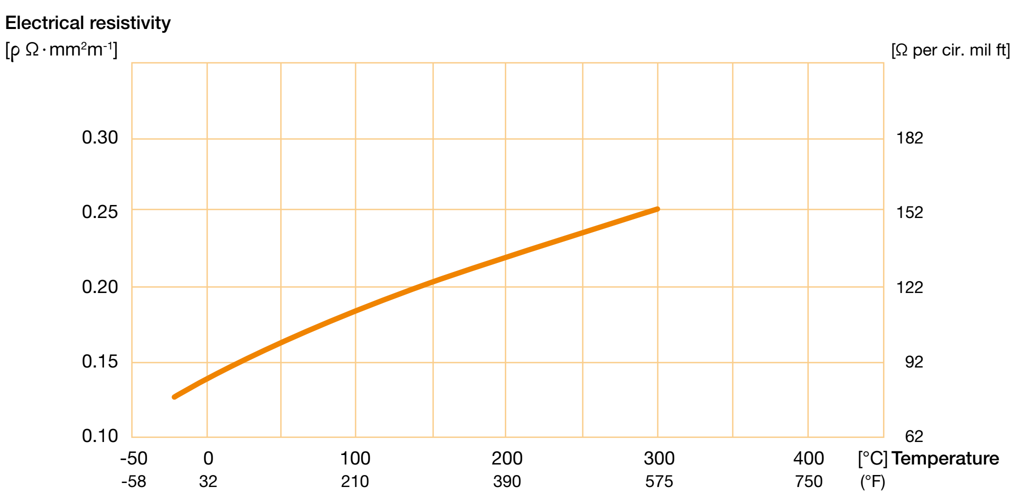
See section 3, page 20

Permissible bending stress

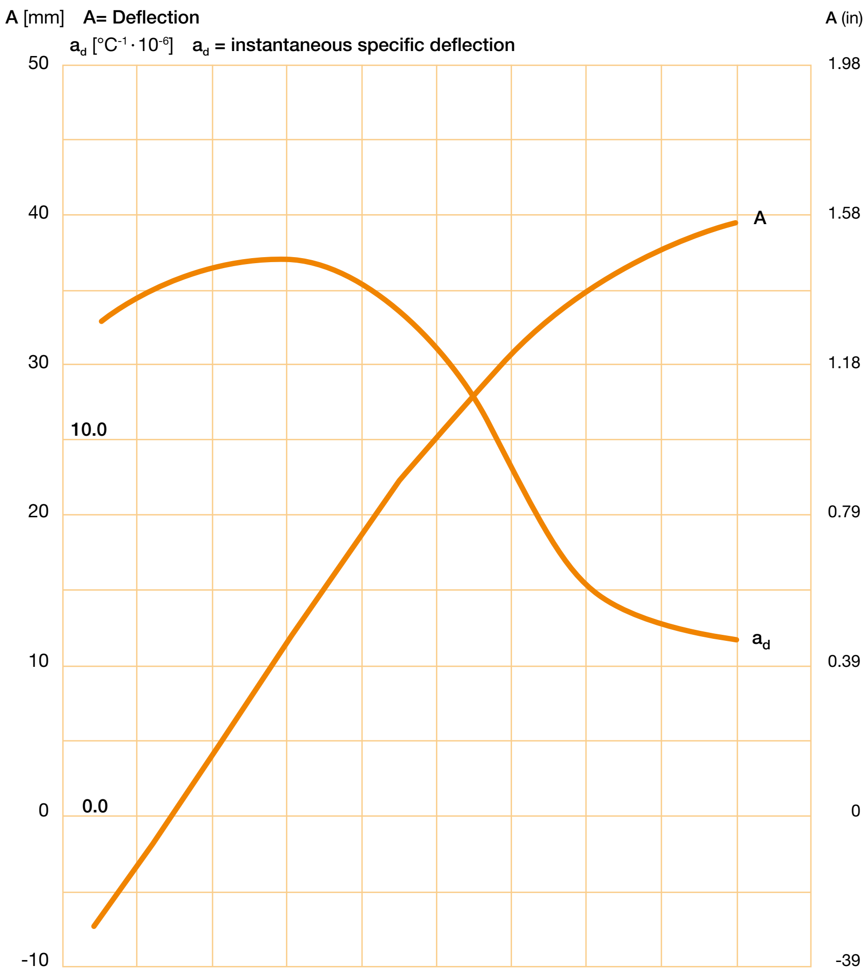


KANTHAL 145R15

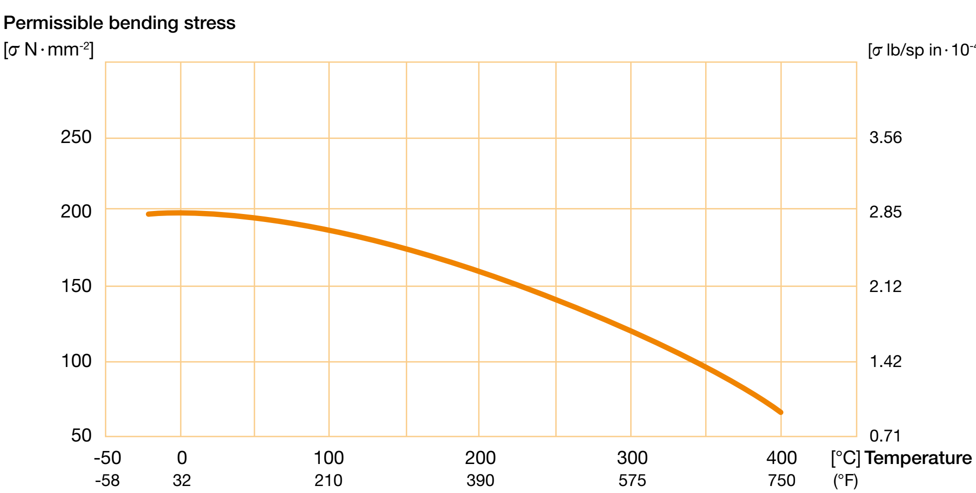
Components	Same as 145 with intermediate Ni-layer
Specific deflection	**a** = 14.9 × 10^{-6} K^{-1}; Tolerance ± 4 %
Specific curvature	k = 27.7 × 10^{-6} K^{-1}; Tolerance ± 4 %
Flexivity	F = 15.4 × 10^{-6} F^{-1}; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F)	ρ = 0.15 Ω × mm^2 × m^{-1}; Tolerance see page 79 (= 90 Ω per cir. mil ft)
Temperature range	Normal -20 to +250°C; (0 to 480°F) Maximum 400°C (750°F)
if directly electrically heated	Maximum 275°C (530°F)
Linearity range	-20 to +200°C (0 to 395°F)
Modulus of elasticity at 20°C (68°F)	E = 170 × 10^3 N × mm^{-2} (= 24.2 × 10^6 lb/sq.in)
Standard hardness, Vickers	
Low expansion side	H_v = 210
High expansion side	H_v = 260
Thermal conductivity	λ = 48 W × m^{-1} × $°C^{-1}$ = 0.067 cal × cm^{-1} × s^{-1} × $°C^{-1}$ (= 334 BTU/h/sq.ft/°F/in)
Specific heat	c = 0.46 J × g^{-1} × $°C^{-1}$ = 0.11 cal × g^{-1} × $°C^{-1}$ (= 0.11 BTU/lb/°F)
Density	γ = 8.2 g × cm^{-3} (= 0.296 lb/cu.in)
Heat treatment (guiding value)	Ageing 2 hours at 260°C (500°F) see also page 124
Weldability	Good on both sides
Marking on the high expansion side	145R15TB1415 145R15TB1415 145R15TB1415 145R15TB1415 45R15TB1415 145R15TB1415 145R15TB1415 145R15TB1415 5R15TB1415 145R15TB1415 145R15TB1415 145R15TB1415



See also table on page 17 and 18

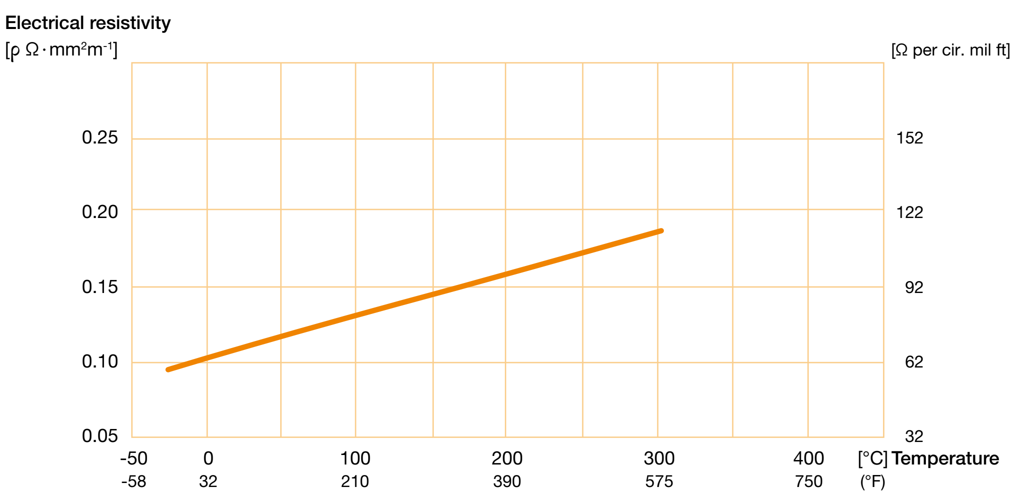


See section 3, page 20

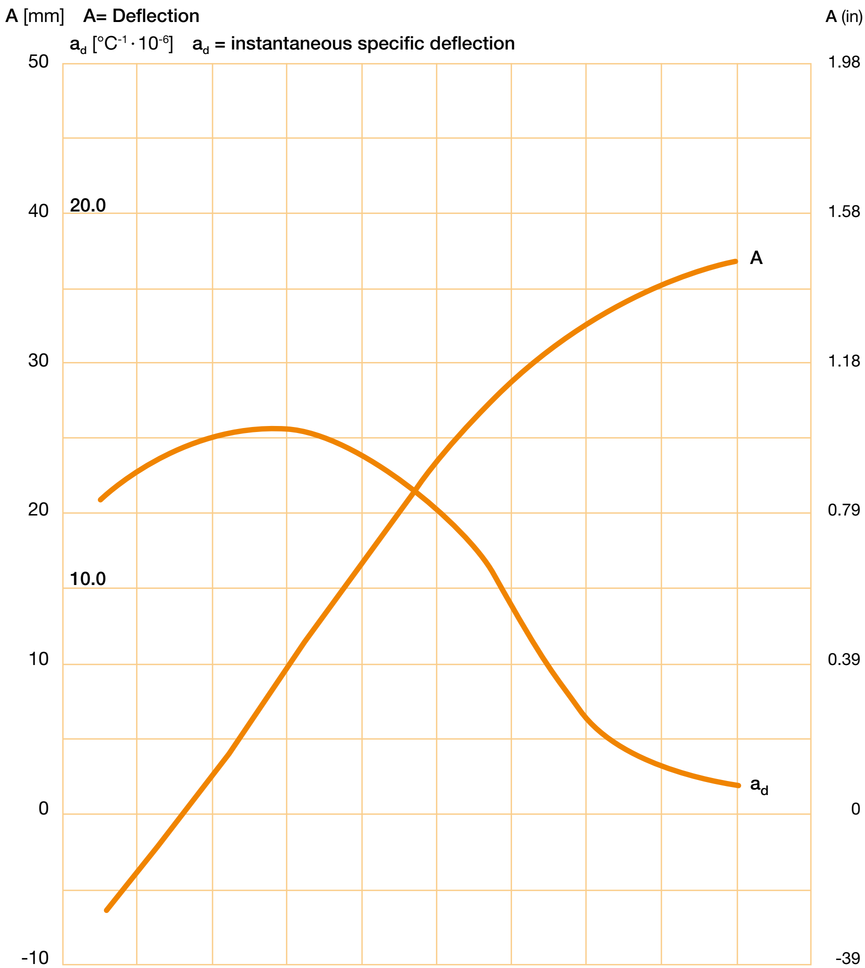


KANTHAL 145R10 TB1511

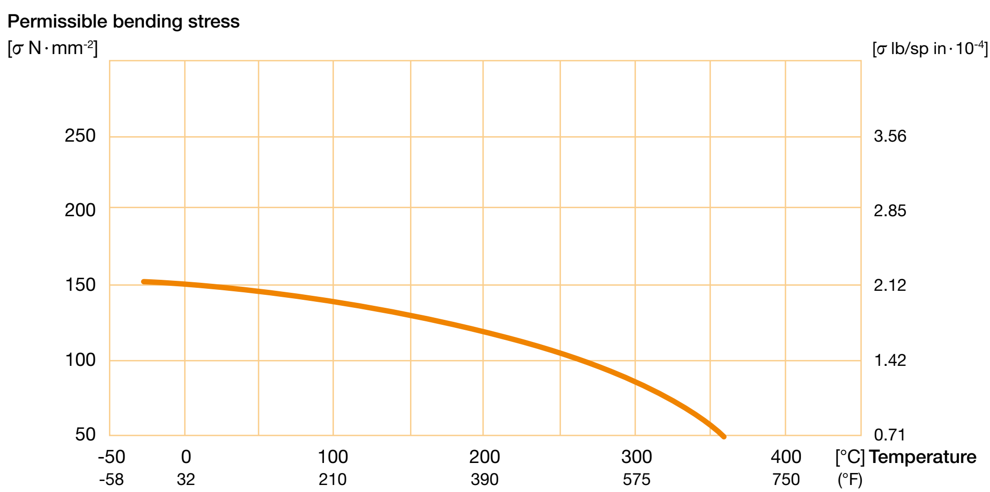
Components	Same as 145 with intermediate Cu-layer
Specific deflection	**a** = 15.0 × 10^{-6} K^{-1}; Tolerance ± 4 %
Specific curvature	k = 27.8 × 10^{-6} K^{-1}; Tolerance ± 4 %
Flexivity	F = 15.4 × 10^{-6} F^{-1}; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F)	ρ = 0.11 Ω × mm^2 × m^{-1}; Tolerance see page 79 (= 66 Ω per cir. mil ft)
Temperature range	Normal -20 to +250°C; (0 to 480°F) Maximum 400°C (750°F)
if directly electrically heated	Maximum 275°C (530°F)
Linearity range	-20 to +200°C (0 to 395°F)
Modulus of elasticity at 20°C (68°F)	E = 165 × 10^3 N × mm^{-2} (= 23.5 × 10^6 lb/sq.in)
Standard hardness, Vickers	
Low expansion side	H_v = 210
High expansion side	H_v = 260
Thermal conductivity	λ = 70 W × m^{-1} × $°C^{-1}$ = 0.167 cal × cm^{-1} × s^{-1} × $°C^{-1}$ (= 487 BTU/h/sq.ft/°F/in)
Specific heat	c = 0.44 J × g^{-1} × $°C^{-1}$ = 0.11 cal × g^{-1} × $°C^{-1}$ (= 0.11 BTU/lb/°F)
Density	γ = 8.3 g × cm^{-3} (= 0.300 lb/cu.in)
Heat treatment (guiding value)	Ageing 2 hours at 260°C (500°F) see also page 124
Weldability	Good on both sides
Marking on the high expansion side	145R10TB1511 145R10TB1511 145R10TB1511 145R10TB1511 45R10TB1511 145R10TB1511 145R10TB1511 145R10TB1511 5R10TB1511 145R10TB1511 145R10TB1511 145R10TB1511



See also table on page 17 and 18



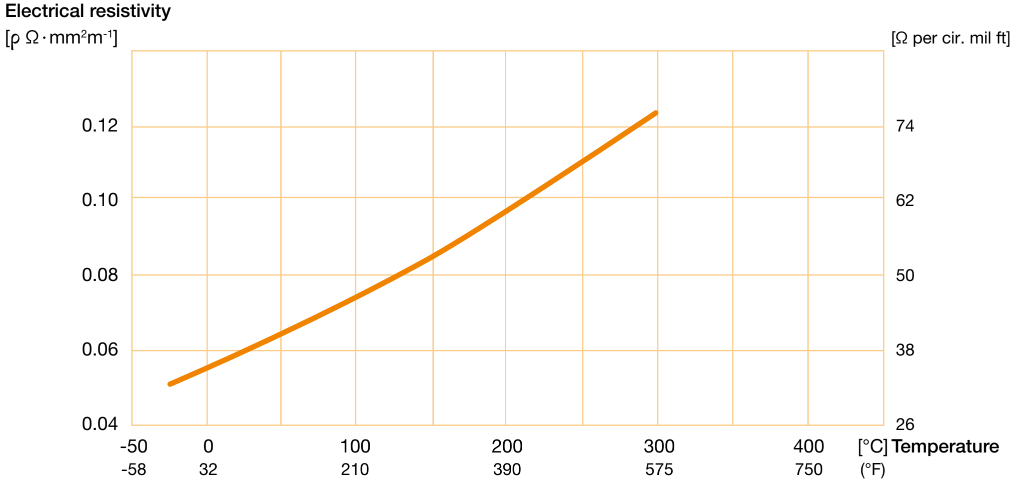
See section 3, page 20



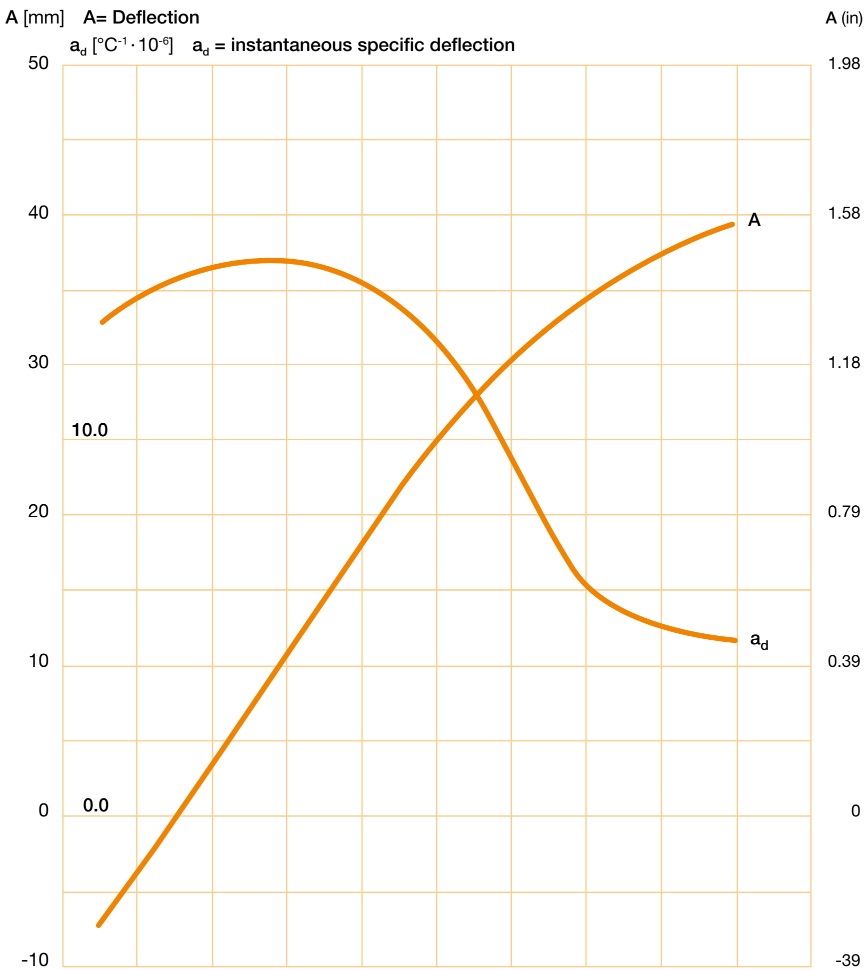
KANTHAL 135R05

Components .... Same as 145 with intermediate Cu-layer
Specific deflection .... **a** = 14.2×10^{-6} K^{-1}; Tolerance ± 4 %
Specific curvature .... k = 26.6×10^{-6} K^{-1}; Tolerance ± 4 %
Flexivity .... F = 14.8×10^{-6} F^{-1}; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F) .... ρ = 0.06 Ω × mm^2 × m-1; Tolerance see page 79
(= 36 Ω per cir. mil ft)
Temperature range .... Normal -20 to +250°C; (0 to 480°F) Maximum 400°C (750°F)
if directly electrically heated .... Maximum 275°C (530°F)
Linearity range .... -20 to +200°C (0 to 395°F)
Modulus of elasticity at 20°C (68°F) .... E = 165 × 10^3 N × mm^{-2} (= 23.4 × 10^6 lb/sq.in)
Standard hardness, Vickers
Low expansion side .... H_v = 210
High expansion side .... H_v = 260
Thermal conductivity .... λ = 114 W × m^{-1} × $°C^{-1}$ = 0.272 cal × cm^{-1} × s^{-1} × $°C^{-1}$
(= 795 BTU/h/sq.ft/°F/in)
Specific heat .... c = 0.46 J × g^{-1} × $°C^{-1}$ = 0.11 cal × g^{-1} × $°C^{-1}$
(= 0.11 BTU/lb/°F)
Density .... γ = 8.4 g × cm^{-3} (= 0.303 lb/cu.in)
Heat treatment (guiding value) .... Ageing 2 hours at 260°C (500°F) see also page 124
Weldability .... Good on both sides
Marking on the high expansion side 135R05TB1406 135R05TB1406 135R05TB1406 135R05TB140
35R05TB1406 135R05TB1406 135R05TB1406 135R05TB1406
5R05TB1406 135R05TB1406 135R05TB1406 135R05TB1406

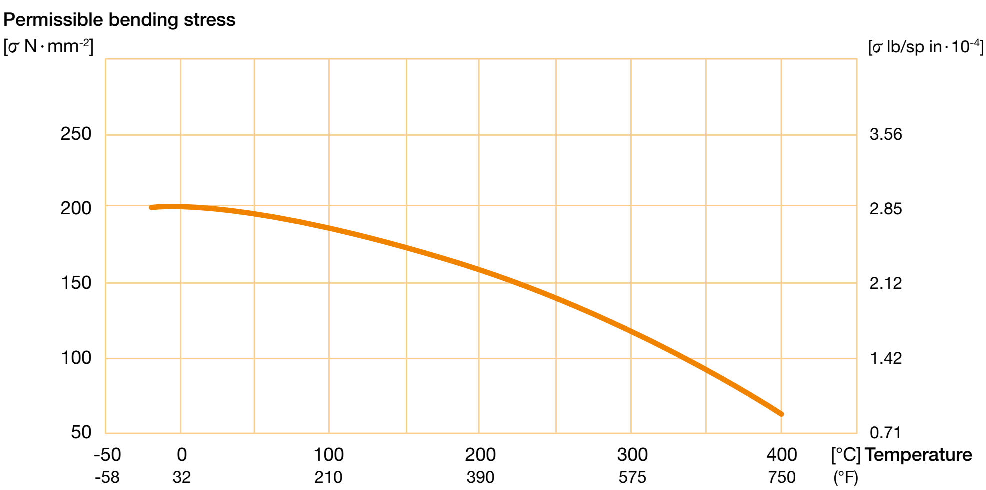
Electrical resistivity



See also table on page 17 and 18

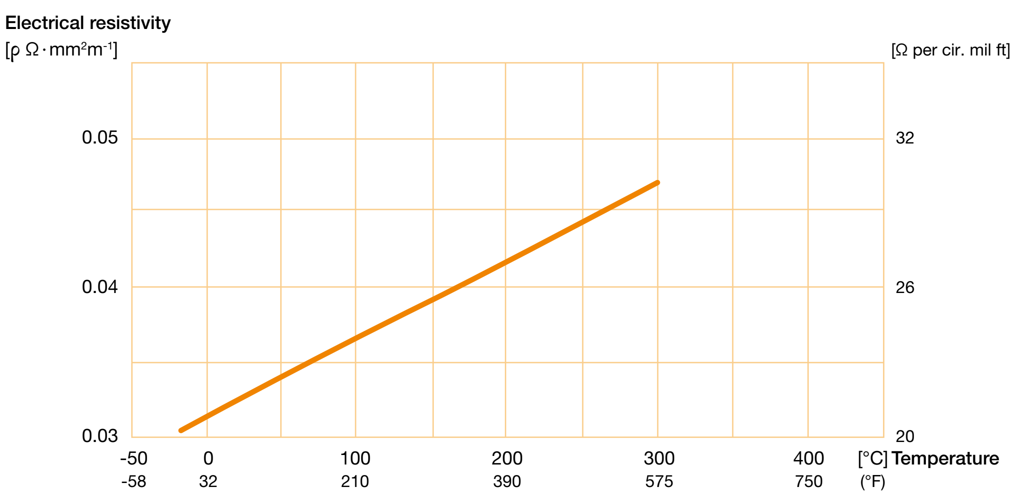


See section 3, page 20

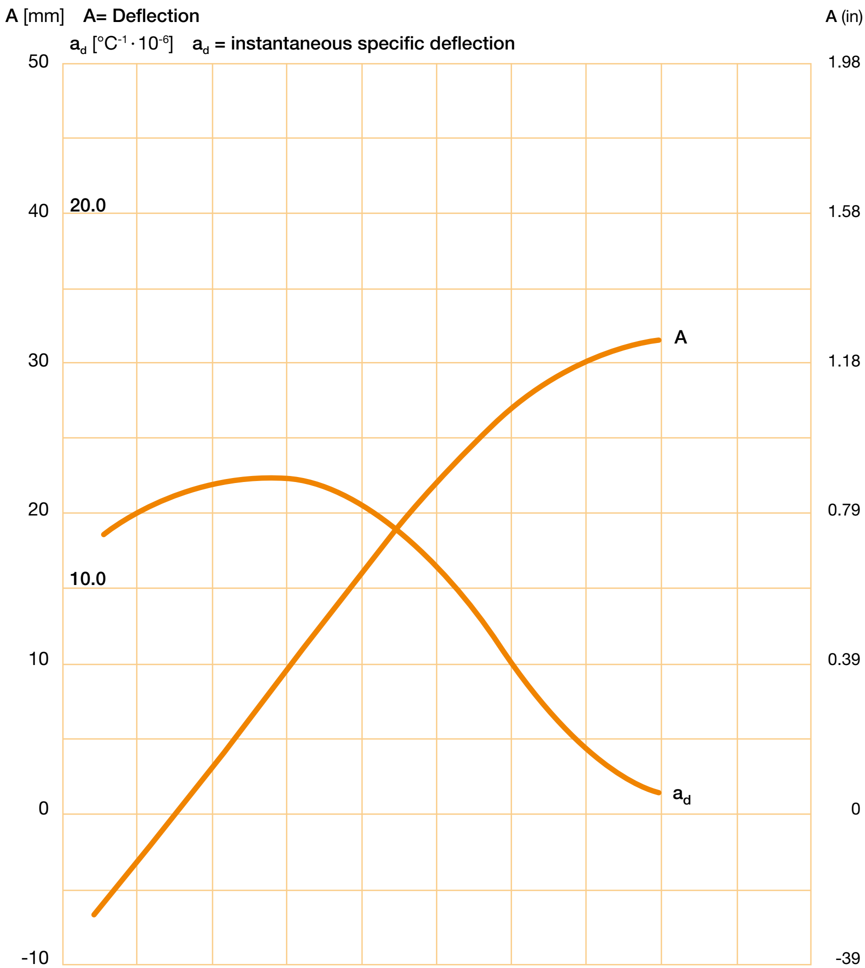


KANTHAL 130R03

Components	Same as 145 with intermediate Cu-layer
Specific deflection	**a** = $13.2 \times 10^{-6}\,K^{-1}$; Tolerance ± 4 %
Specific curvature	k = $24.5 \times 10^{-6}\,K^{-1}$; Tolerance ± 4 %
Flexivity	F = $13.6 \times 10^{-6}\,F^{-1}$; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F)	$\rho = 0.033\,\Omega \times mm^2 \times m^{-1}$; Tolerance see page 79 (= 20 Ω per cir. mil ft)
Temperature range	Normal -20 to +250°C; (0 to 480°F) Maximum 275°C (530°F)
Linearity range	-20 to +200°C (0 to 395°F)
Modulus of elasticity at 20°C (68°F)	E = $145 \times 10^3\,N \times mm^{-2}$ (= 20.6×10^6 lb/sq.in)
Standard hardness, Vickers	
Low expansion side	$H_v = 210$
High expansion side	$H_v = 260$
Thermal conductivity	$\lambda = 224\,W \times m^{-1} \times °C^{-1} = 0.535\,cal \times cm^{-1} \times s^{-1} \times °C^{-1}$ (= 1560 BTU/h/sq.ft/°F/in)
Specific heat	$c = 0.46\,J \times g^{-1} \times °C^{-1} = 0.11\,cal \times g^{-1} \times °C^{-1}$ (= 0.11 BTU/lb/°F)
Density	$\gamma = 8.65\,g \times cm^{-3}$ (= 0.312 lb/cu.in)
Heat treatment (guiding value)	Ageing 2 hours at 260°C (500°F) see also page 124
Weldability	Good on both sides
Marking on the high expansion side	130R03TB1303 130R03TB1303 130R03TB1303 130R03TB1303 30R03TB1303 130R03TB1303 130R03TB1303 130R03TB1303 0R03TB1303 130R03TB1303 130R03TB1303 130R03TB1303

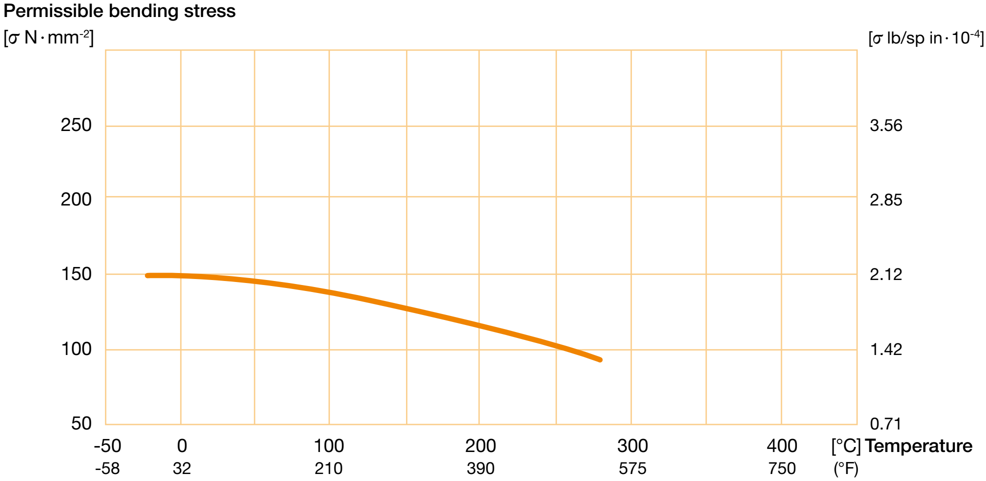


See also table on page 17 and 18



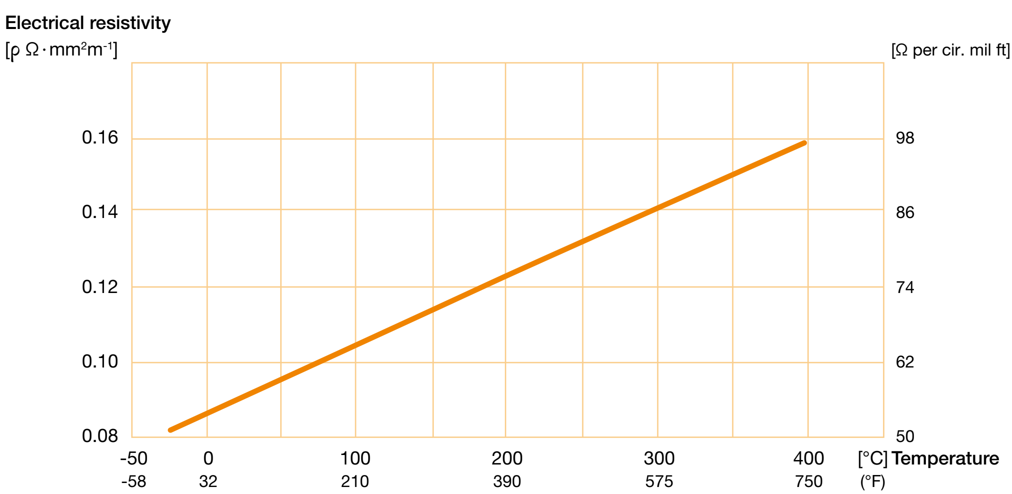
See section 3, page 20

Permissible bending stress

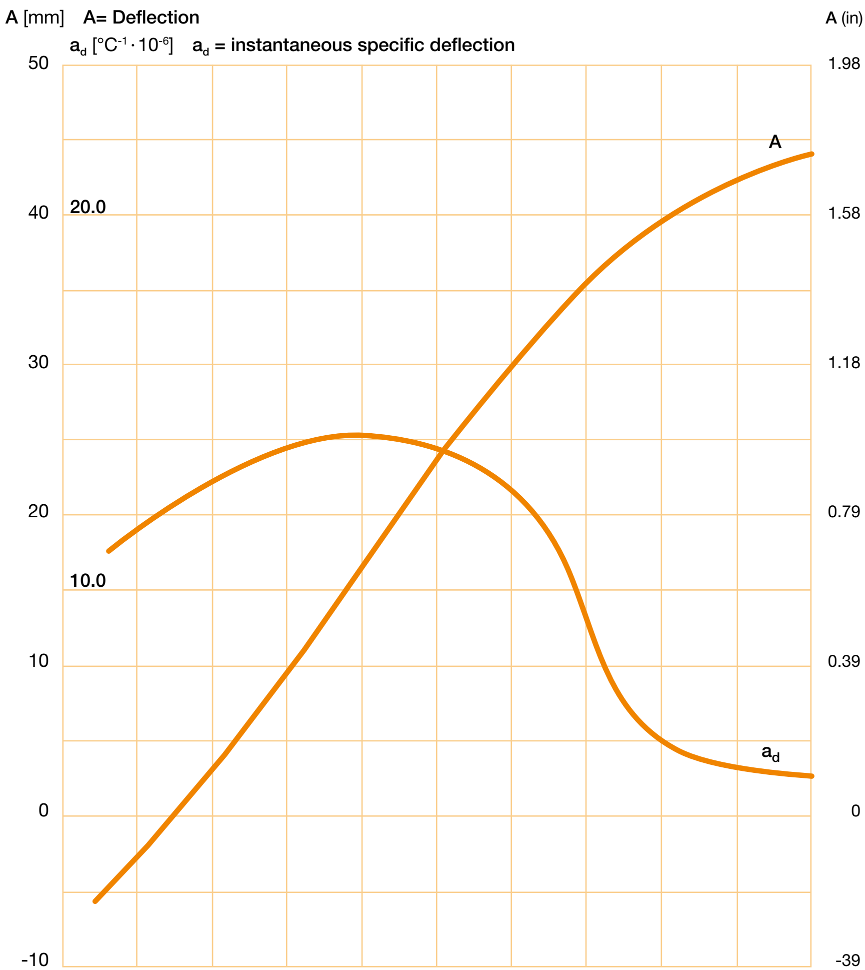


KANTHAL 127R09

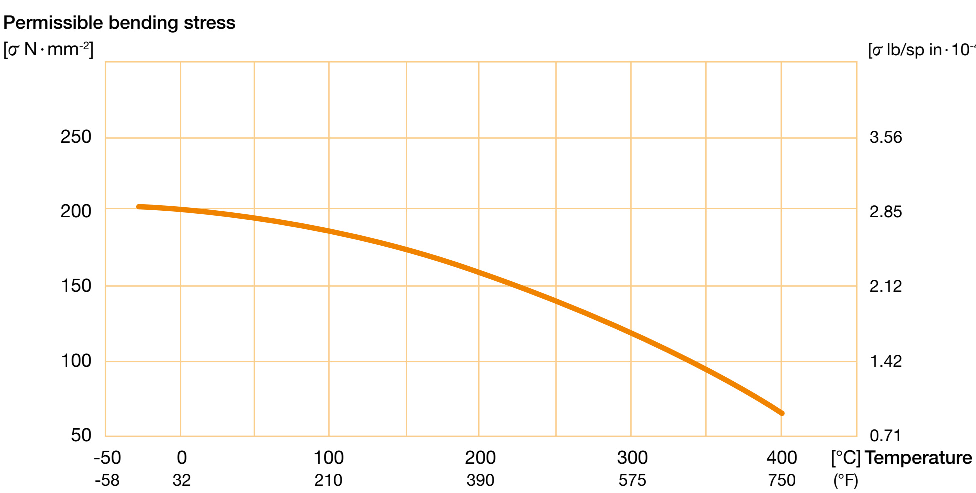
Components	Same as 145 with intermediate Cu-layer
Specific deflection	**a** = 13.4 × 10^{-6} K^{-1}; Tolerance ± 4 %
Specific curvature	k = 25.0 × 10^{-6} K^{-1}; Tolerance ± 4 %
Flexivity	F = 13.9 × 10^{-6} F^{-1}; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F)	ρ = 0.09 Ω × mm^2 × m^{-1}; Tolerance see page 79 (= 54 Ω per cir. mil ft)
Temperature range	Normal -20 to +350°C; (0 to 660°F) Maximum 400°C (750°F)
if directly electrically heated	Maximum +275°C (530°F)
Linearity range	-20 to +325°C (0 to 620°F)
Modulus of elasticity at 20°C (68°F)	E = 170 × 10^3 N × mm^{-2} (= 24.2 × 10^6 lb/sq.in)
Standard hardness, Vickers	
Low expansion side	H_v = 210
High expansion side	H_v = 260
Thermal conductivity	λ = 88 W × m^{-1} × $°C^{-1}$ = 0.210 cal × cm^{-1} × s^{-1} × $°C^{-1}$ (= 538 BTU/h/sq.ft/F°/in)
Specific heat	c = 0.46 J × g^{-1} × $°C^{-1}$ = 0.11 cal × g^{-1} × $°C^{-1}$ (= 0.11 BTU/lb/F°)
Density	γ = 8.2 g × cm^{-3} (= 0.296 lb/cu.in)
Heat treatment (guiding value)	Ageing 2 hours at 260°C (500°F) see also page 124
Weldability	Good on both sides
Marking on the high expansion side	127R09TB1309 127R09TB1309 127R09TB1309 127R09TB1309 27R09TB1309 127R09TB1309 127R09TB1309 127R09TB1309 7R09TB1309 127R09TB1309 127R09TB1309 127R09TB1309



See also table on page 17 and 18

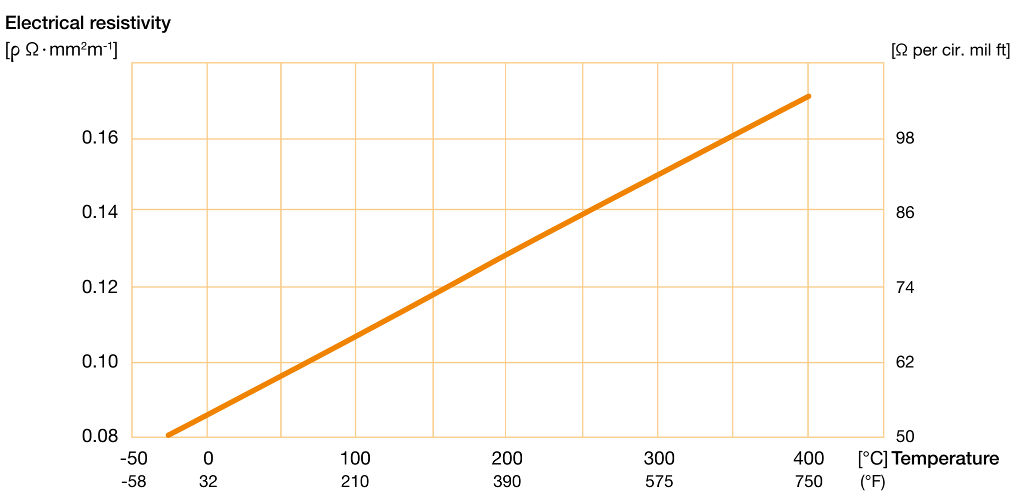


See section 3, page 20

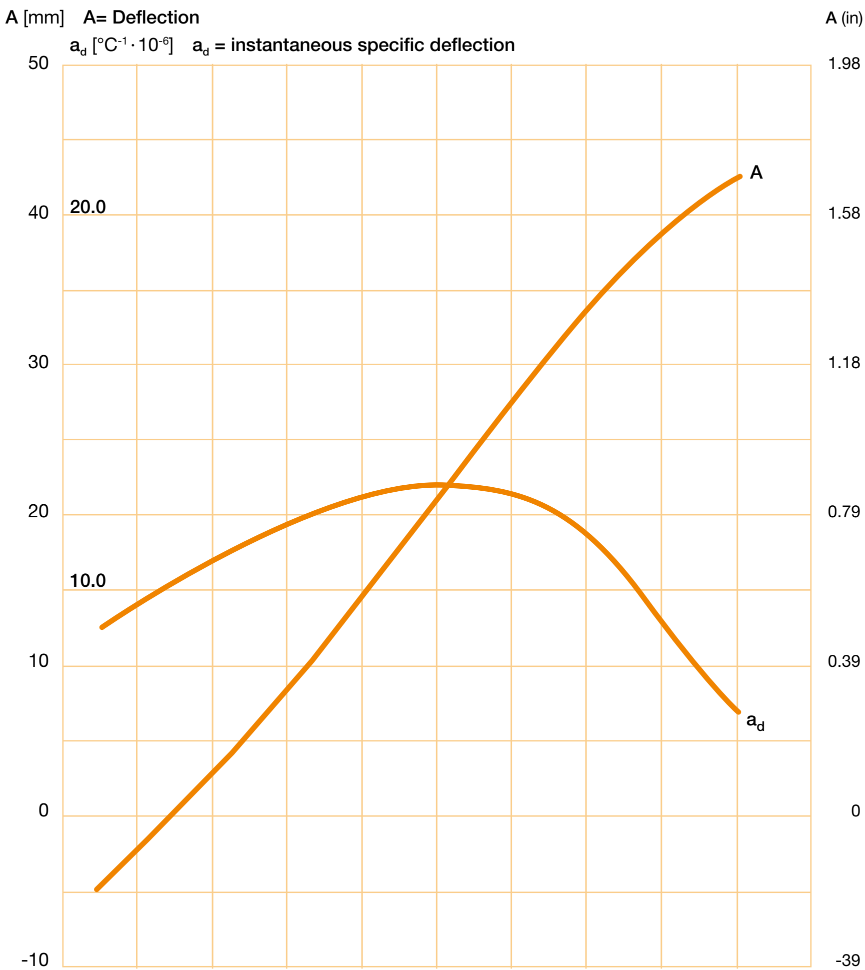


KANTHAL 115R09 TB1109

Components	Same as 115 with intermediate Cu-layer
Specific deflection	**a** = 11.5×10^{-6} K^{-1}; Tolerance ± 4 %
Specific curvature	k = 21.6×10^{-6} K^{-1}; Tolerance ± 4 %
Flexivity	F = 12.0×10^{-6} F^{-1}; Tolerance ± 4 %
Electrical resistivity at 20°C (68°F)	ρ = 0.09 Ω × mm^2 × m^{-1}; Tolerance see page 79 (= 54 Ω per cir. mil ft)
Temperature range	Normal -20 to +350°C; (0 to 660°F) Maximum 400°C (750°F)
if directly electrically heated	Maximum 275°C (530°F)
Linearity range	-20 to +380°C (0 to 720°F)
Modulus of elasticity at 20°C (68°F)	E = 165×10^3 N × mm^{-2} (= 23.5×10^6 lb/sq.in)
Standard hardness, Vickers	
Low expansion side	H_v = 210
High expansion side	H_v = 260
Thermal conductivity	λ = 88 W × m^{-1} × $°C^{-1}$ = 0.210 cal × cm^{-1} × s^{-1} × $°C^{-1}$ (= 615 BTU/h/sq.ft/°F/in)
Specific heat	c = 0.46 J × g^{-1} × $°C^{-1}$ = 0.11 cal × g^{-1} × $°C^{-1}$ (= 0.11 BTU/lb/°F)
Density	γ = 8.2 g × cm^{-3} (= 0.296 lb/cu.in)
Heat treatment (guiding value)	Ageing 2 hours at 260°C (500°F) see also page 124
Weldability	Good on both sides
Marking on the high expansion side	115R09TB1109 115R09TB1109 115R09TB1109 115R09TB1109 15R09TB1109 115R09TB1109 115R09TB1109 115R09TB1109 5R09TB1109 115R09TB1109 115R09TB1109 115R09TB1109

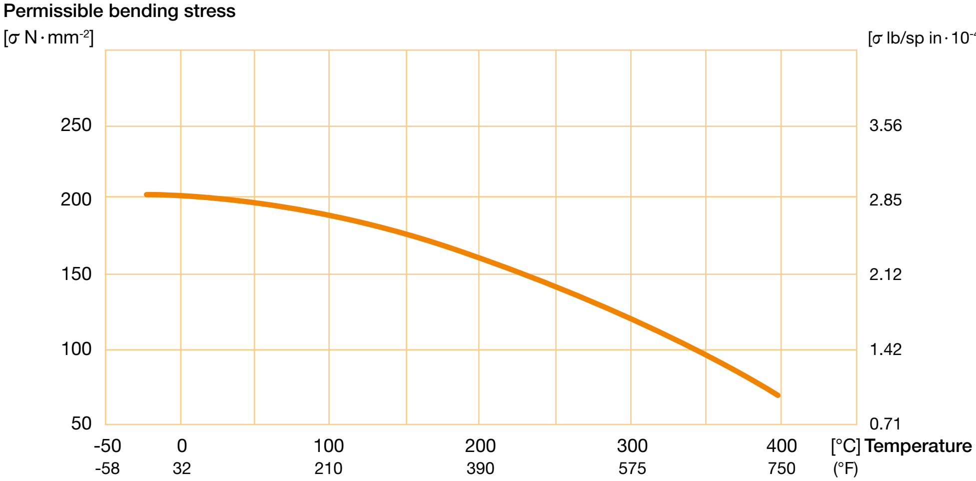


See also table on page 17 and 18



See section 3, page 20

Permissible bending stress



Tolerances and Delivery Dimensions

1. Tolerances on Specific Curvature

The specific curvature of KANTHAL Thermostatic Bimetal is measured in accordance with the DIN method. We maintain a tolerance of ± 4 % on the values measured as per DIN 1715.

2. Tolerances on Resistivity

The specific electrical resistance as per the table on page 17 and 18 is kept to the following tolerances. (These tolerances are important only in the case of direct passage of electrical current through the thermostatic bimetal part.)

Thermostatic bimetal types	Tolerance on resistivity for different strip thicknesses [mm] (in)	
	≥ 0.5 (0.02)	< 0.5 (0.02)
155, 145, 135, 130, 115, 100, 60, 200	± 4 %	± 4 %
145R45, 140R140, 155R55, 145R50, 145R35, 135R25, 94S, 50HT	± 5 %	± 5 %
145R19, 145R17, 145R156, 145R10, 135R05, 140R10	± 6 %	± 7 %
127R09, 115R09	± 6 %	± 7 %
230	± 6 %	± 6 %
130R03, 180R05, 200R10	±10 %	±12 %

3. Tolerances on Thickness, Width and Length

Our standard dimensional tolerances are satisfactory for the manufacture of most bimetal parts. In certain cases, however, closer tolerances may be necessary. We can, after special agreement, maintain closer tolerances at extra cost. The range of tolerance can, if required, be placed on the plus or minus side of the nominal value. If no special instructions are given by the customer, we maintain the following tolerances.

Thickness Tolerances

Strip thicknesses	0.10 mm – (0.20 mm) = ± 0.007 mm	(0.004 in – (0.008 in) = ± 0.0003 in)
	0.20 mm – (0.40 mm) = ± 0.010 mm	(0.008 in – (0.016 in) = ± 0.0004 in)
	0.40 mm – (2.50 mm) = ± 2.5 %	(0.016 in – (0.100 in) = ± 2.5 %)

Disc Type Material

Thickness s [mm] (in)	Tolerances	
	Standard	Special
s ≤ 0.20 (0.008)	± 4 µm	± 2 µm
0.20 (0.008) ≤ s ≤ 0.40 (0.016)	± 2 % of s	± 1 % of s

Width Tolerances

Thickness [mm] (in)	Width [mm] (in)				
	1.0–(4) (0.04–0.16)	4–(20) (0.16–0.79)	20–(40) (0.79–1.57)	40–(80) (1.57–3.15)	80–(180) (3.15–7.09)
0.1–(0.4) **(0.004–0.016)**	+0.10/-0 (+0.004/-0)	±0.05 (±0.002)	±0.05 (±0.002)	±0.07 (±0.003)	±0.12 (±0.005)
0.4–(0.8) **(0.016–0.031**	+0.14/-0 (0.006/-0)	±0.07 (±0.003)	±0.07 (±0.003)	±0.10 (±0.004)	±0.17 (±0.007)
0.8–(1.6) **(0.031–0.063)**		±0.10 (±0.004)	±0.12 (±0.005)	±0.15 (±0.006)	±0.20 (±0.008)
1.6–(2.5) **(0.063–0.098)**		±0.13 (±0.005)	±0.15 (±0.006)	±0.18 (±0.007)	±0.23 (±0.009)

Disc Type Material

Thickness s [mm] (in)	Width tolerances [mm] (in)
s ≤ 0.20 (0.008)	± 0.07 (0.003)
0.20 (0.008) ≤ s ≤ 0.40 (0.016)	± 0.10 (0.004)

Length Tolerances for Cut Lengths

Up to 300 mm (0.98 ft) = ±1 mm (0.04 in)
From 300 mm (0.98 ft) to 1000 mm (3.28 ft) = ± 1.5 mm (0.06 in)
From 1000 mm (3.28 ft) to 2000 mm (6.56 ft) = ± 2 mm (0.08 in)
From 2000 mm (6.56 ft) to 4000 mm (13.12 ft) = ± 5 mm (0.20 in)

4. Flatness and Straightness

The normal manufacturing process gives the bimetal a shape which is normally completely satisfactory. By means of special flattening and straightening operations we can fulfill particularly exacting demands in these respects.

To clearly define flatness and straightness a special terminology is normally used which is visualized in the illustrations below.

Coil set

Crosswise curvature

Edgewise curvature

Twisted

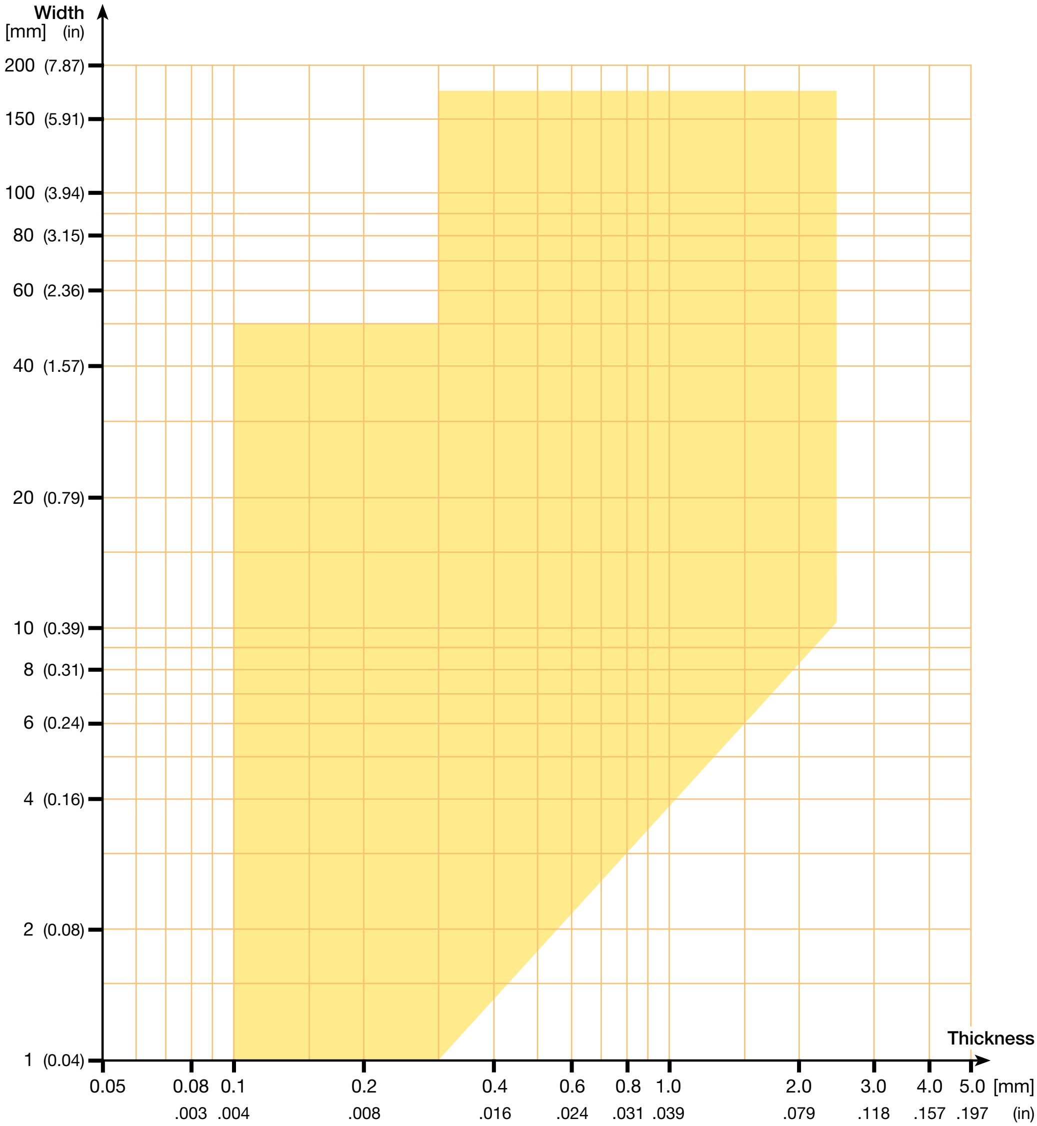


Fig. 8

5. Sizes Available

KANTHAL Thermostatic Bimetal strips are supplied, as shown in Fig. 8, in thicknesses from 0.10 to 2.5 mm (0.004 – 0.098 in) and in widths from 1.0 to 170 mm (0.039 – 6.69 n). Regarding some thermostatic bimetal types of the resistance series, the thickness is restricted to the range 0.10 to 1.65 mm (0.004 – 0.065 in) and the width to maximum 65 mm (2.56 in).

Reel	Tare		Dimensions D		l		d		d_1		d_2		s		L		Nominal net weight	
No	g	(lbs)	mm	(in)	mm	(in)	mm	(in)	mm	(in)	mm	(in)	mm	(in)	mm	(in)	kg	(lbs)
DIN 125	200	(0.44)	125	(4.92)	100	(3.94)	80	(3.15)	16	(0.63)	24	(0.95)	12.5	(0.49)	125	(4.92)	2.5	(5.51)

Material in reel is shock resistant polystyrene

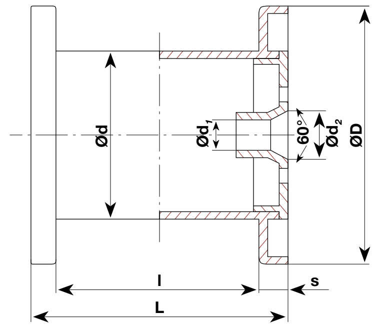


Fig. 9 Plastic reel as per DIN EN ISO 7090

6. Supply Details

KANTHAL Thermostatic Bimetals are available in the following forms:

- Coils with a weight of 1.4 – 1.7 kg/mm (75 – 90 lb/in) of width. The inner diameter of the coil normally amounts to about 400 mm (15.7 in).
- Flat cut lengths in strips of up to 4 meters (13 ft) with thicknesses exceeding 0.5 mm (0.02 in).
- Thin and narrow bimetal strips (thicknesses below 0.5 mm (0.02 in) and widths below 4 mm (0.16 in) are normally supplied on reels as per DIN 46399.

KANTHAL Thermostatic Bimetals are also supplied as parts fabricated by means of stamping, bending or coiling to customers' drawings or samples. The fabricated parts are heat treated without controlled atmosphere, if no other instructions are given in customers' specification (see also section 2, page 124).

7. Identification Marking

KANTHAL Thermostatic Bimetals are usually etched on the high expansion side. The etching includes the type designation (see section 6, page 14) and the standard designation as per DIN 1715, or a designation derived from it. The standard etching is shown on the individual data sheets in "KANTHAL Thermostatic Bimetal Types" section 4, pages 24 – 77.

On special request the etched identification can be applied to the low expansion side. In such cases the type designation is followed by the character "LE".

In some cases, where etching is unsuitable, for instance on corrosion resistant types, the identification marking is applied by means of a printing ink. In other cases, where the stabilizing heat treatment is performed at such a high temperature that the etched or printed marking becomes hardly legible, or where a galvanic protective coating is used, KANTHAL Thermostatic Bimetal strips with thicknesses of more than about 0.5 mm (0.02 in) can be identified by means of a stamped marking.

8. Packing

KANTHAL Thermostatic Bimetals supplied in flat cut lengths or coils are wrapped in plastic- or wax-treated crepe paper depending on transport needs and are subsequently carefully packed.


& Weldings

Applications with Drawings

As previously mentioned, the function of a thermostatic bimetal strip is caused by an alteration in temperature. Therefore, the bimetal is used in most cases for transformation of a temperature change into movement and/or force. Electrical energy can also be used for release of the function in cases where the thermostatic bimetal is electrically heated. Conversely, a movement and a force can be converted into an electrical effect, for instance in a liquid level gauge.

This means that there is a wide range of use for thermostatic bimetal within the fields of measuring, regulating and safety techniques. Since bimetal is a simple and reliable element, technical development continuously opens new possibilities for utilizing its function. Some important applications for thermostatic bimetal are as follows:

Temperature Indication
as thermometers for air, steam or liquids (see Fig. 18).

Indication of other characteristics, for example, indication of electrical current (see Fig. 34), voltage or power, indication of gas or oil pressure, level of fluid or velocity of flow and quantity of circulating gas.

Control
as in thermostats in heating, cooling, cooking and baking appliances, for control of room temperature in living-rooms and industrial plants (Fig. 25 and 26), for stepless control of electrical power (Fig. 32), for the control of cooling water circulation or ventilation, as guide plates and valve control of circulating air, gases and exhaust gases (Fig. 15 and 19), for temperature control in water mixing valves (Fig. 17), steam traps and liquid outlets (Fig. 16 and 20), for use in current and voltage regulators (Fig. 33), in brightness regulators for twilight switches etc.

Time Limiting and Control
as in cigar lighters (Fig. 12), fluorescent lamp starters and staircase lighting switches.

Safety Function
as overload protection of electric motors (Fig. 11), transformers and wiring (Fig. 10), overheating protection in the windings of electric machines and transformers, in gas safety pilot elements (Fig. 14), as thermal cut-outs against non-permittable heating in devices and in fire alarms.

Temperature compensation in measuring devices and control units, as for compensation of fluctuating room temperature (Fig. 32 to 34).

The Thermostatic Bimetal can be Heated in Different Ways:
Heat transmission by conduction, where the bimetals is in direct contact with the source of heat or the medium to be controlled (Fig. 21).

Heat transmission by radiation or convection (Fig. 14 and 15).

Heat developed by passage of electric current, where the bimetal itself serves as resistance and thus as the source of heat (Fig. 10, 30 and 34).

Indirect electric heating by means of a heating element made of KANTHAL wire, ribbon or strip (Fig. 11, 32 and 33).

The function of bimetal can be utilized to produce a force, a movement or a combination of both. By using stacks of bimetal strips (Fig. 13 and 31) a relatively great force is obtained by a large movement. Parts of heating elements or shunts can be inserted between the bimetal layers. Disadvantages are friction between adjacent layers and risk of corrosion.

By energy accumulation in spring or magnetic systems, rapid switching action can be obtained, thereby ensuring make and break contact without flutter or disturbance (Fig. 21 to 28). A thermostatic bimetal which acts as a direct switching device has a slow action unless it is specially shaped (Fig. 23 and 24).

Fig. 10 *Miniature circuit breaker*

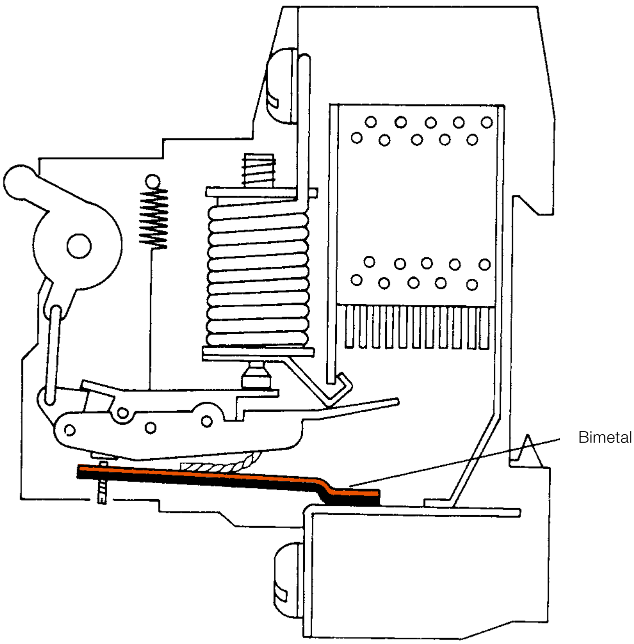


Fig. 11 *Overload motor protector*

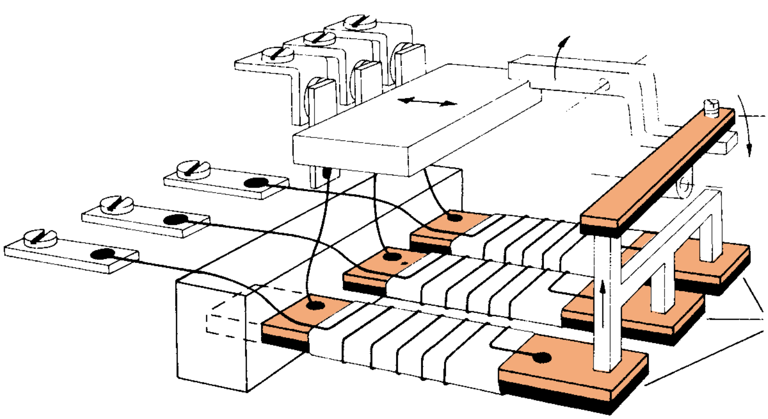


Fig. 12 Cigar lighter

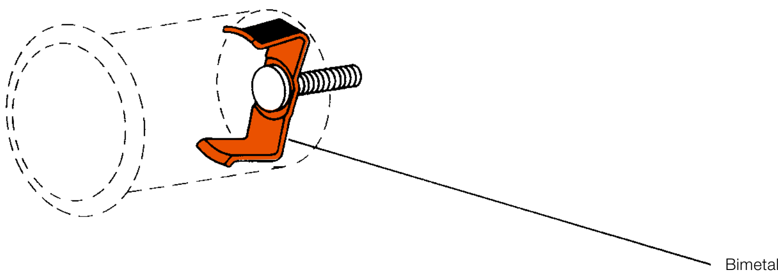


Fig. 13 Stacks of bimetal strips arranged to produce increasing force with increasing temperature

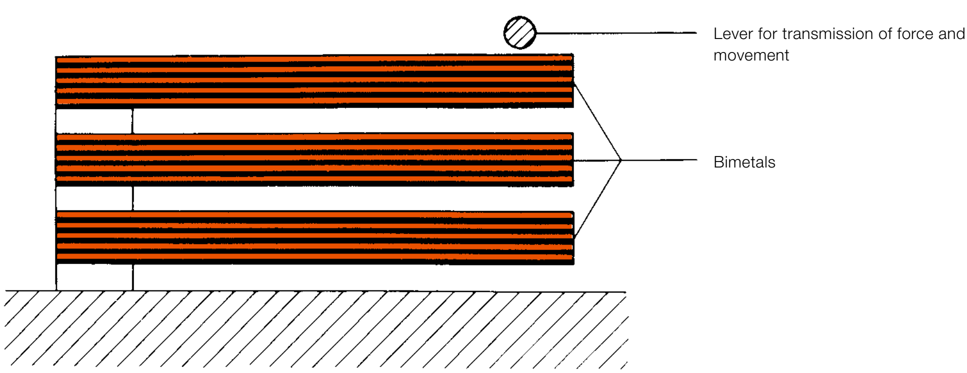


Fig. 14 Gas safety pilot element

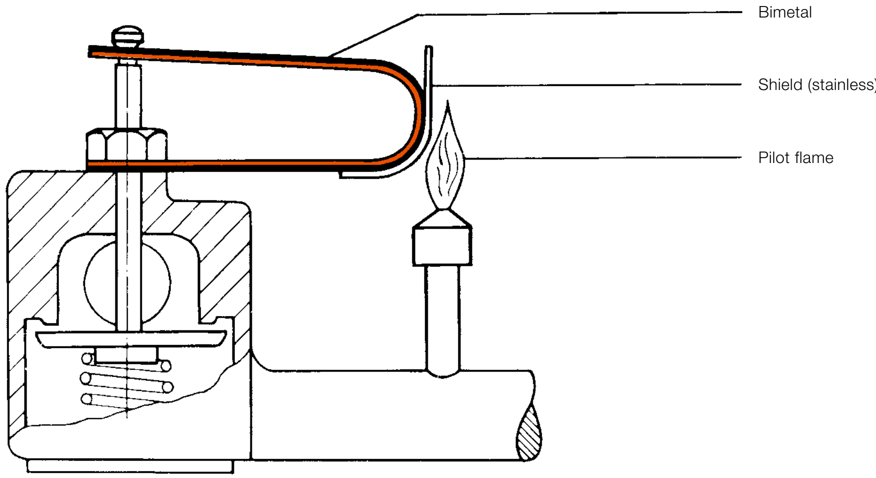


Fig. 15 Temperature responding regulation of cross section

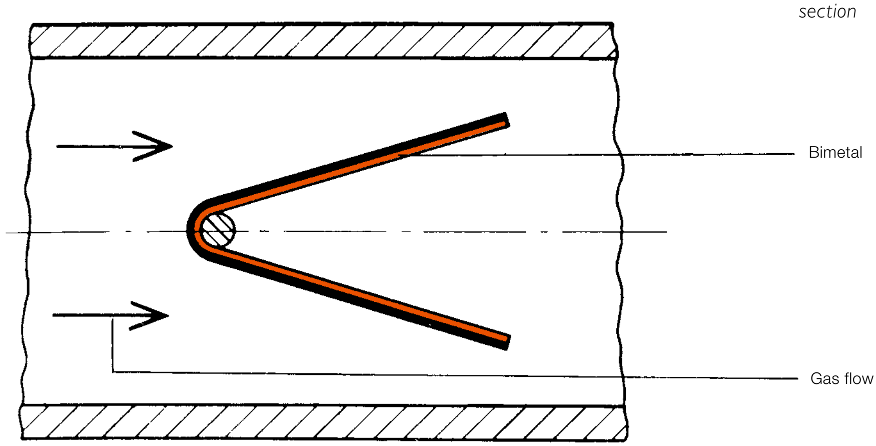


Fig. 16 Steam trap

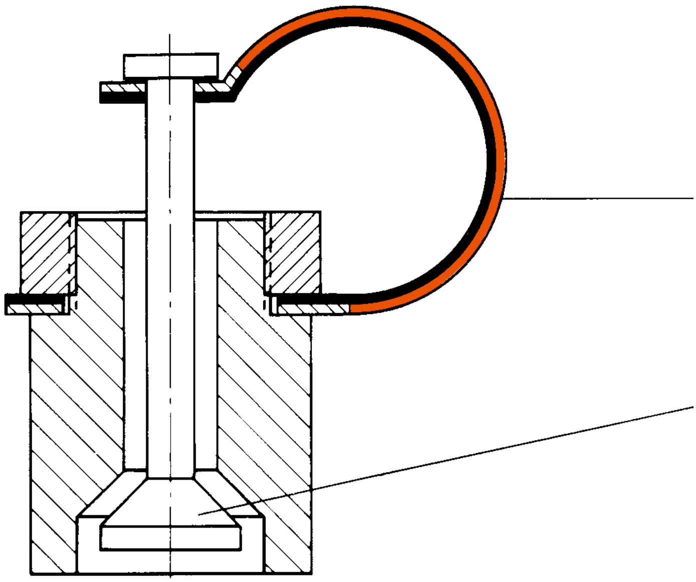


Fig. 17 Thermostatic water mixing

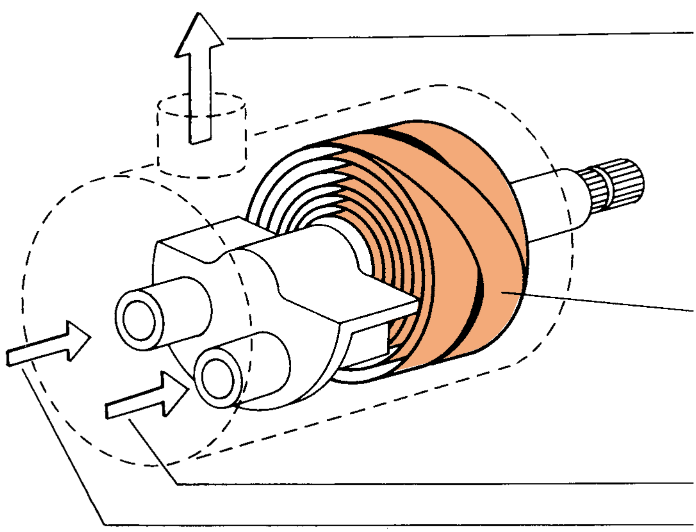


Fig. 18 Thermometers with bimetal

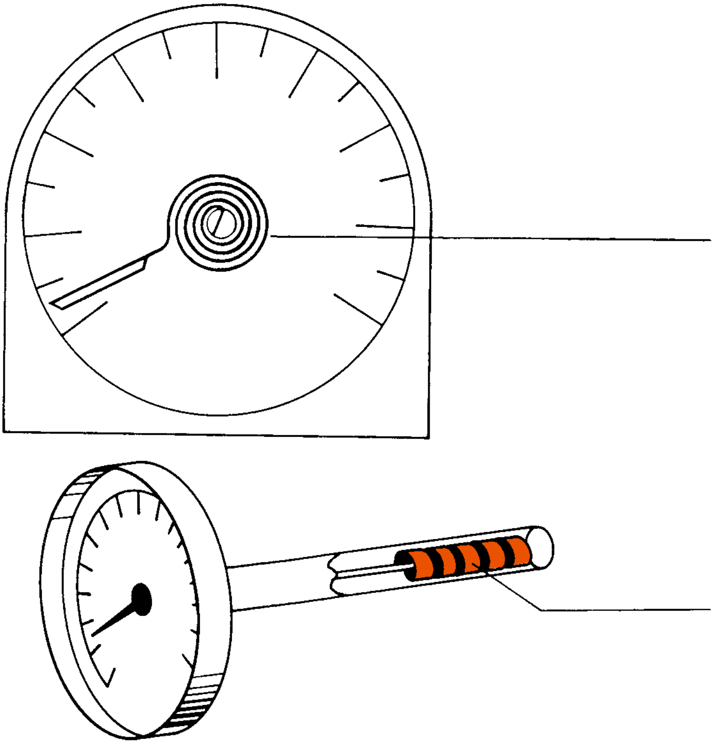


Fig. 19 Regulation of hot air in storage heaters by means of a thermostatic bimetal coil

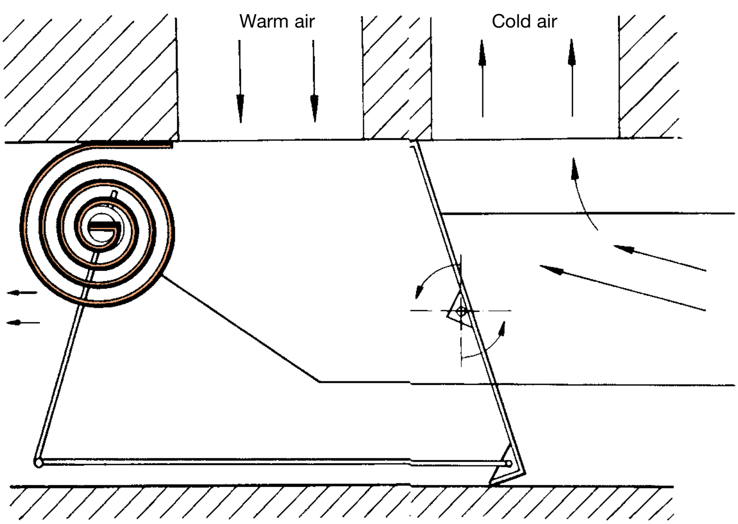


Fig. 20 Steam trap with thermostatic bimetal

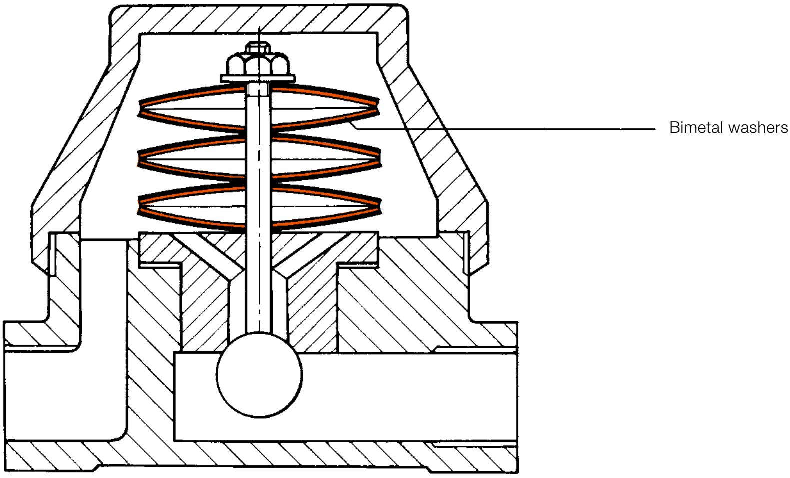


Fig. 21 Adjustable thermostat with snap action and small temperature differential

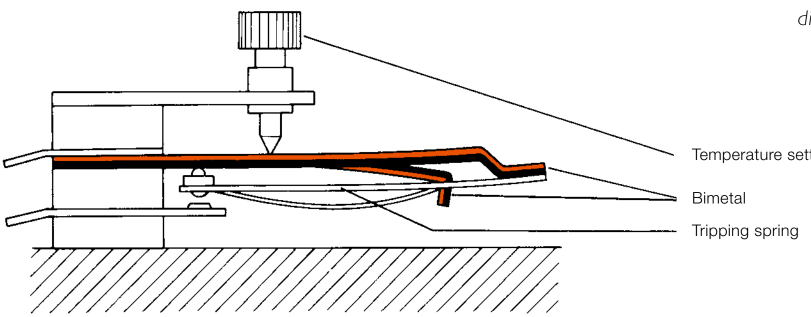


Fig. 22 Adjustable thermostat with snap action

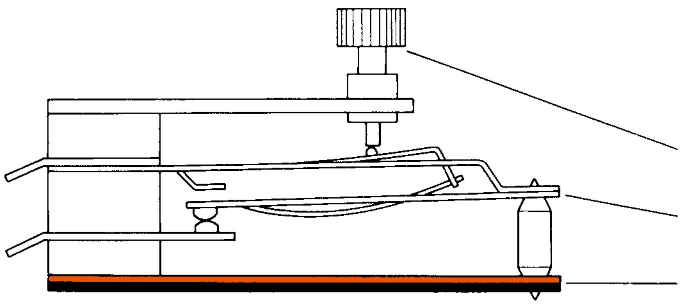
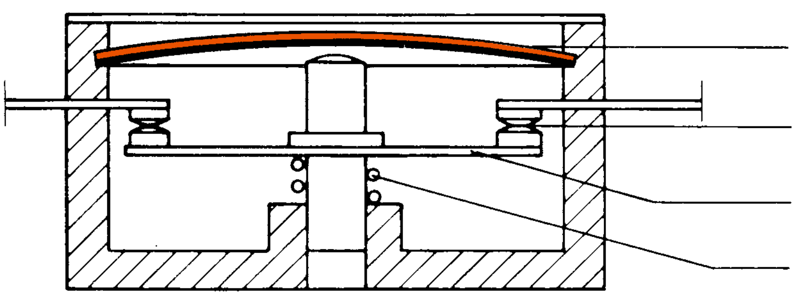


Fig. 23 Thermostat with snap acting bimetal disc for rapid contact breaking



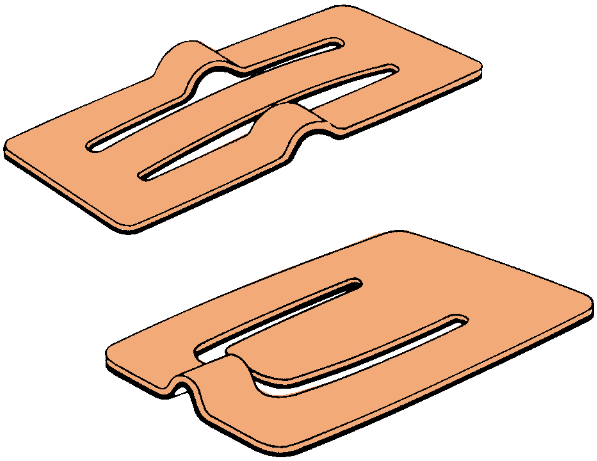


Fig. 24 Two snap action bimetal elements

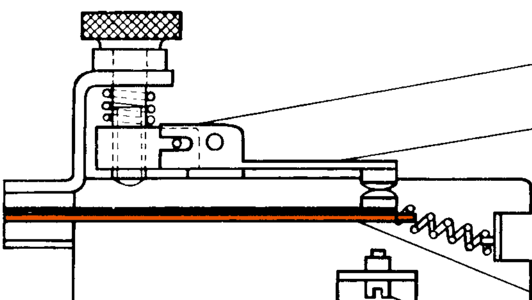


Fig. 25 Thermostat with snap action

Fig. 26 Thermostat with snap action

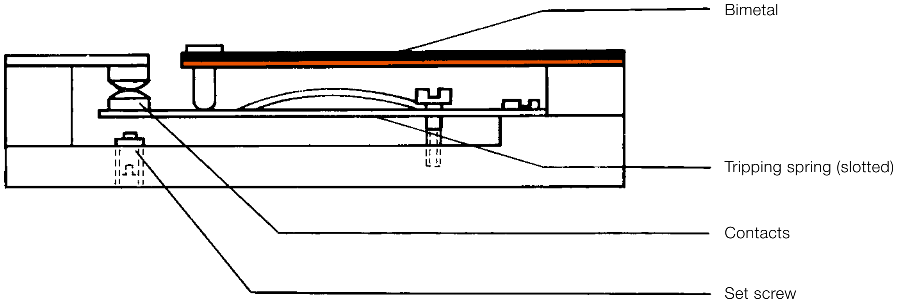


Fig. 27 Snap action by means of a permanent magnet

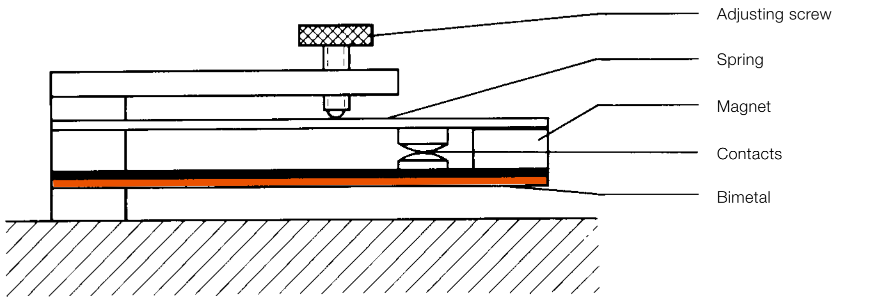


Fig. 28 Thermal cut-out with snap action to be manually reset

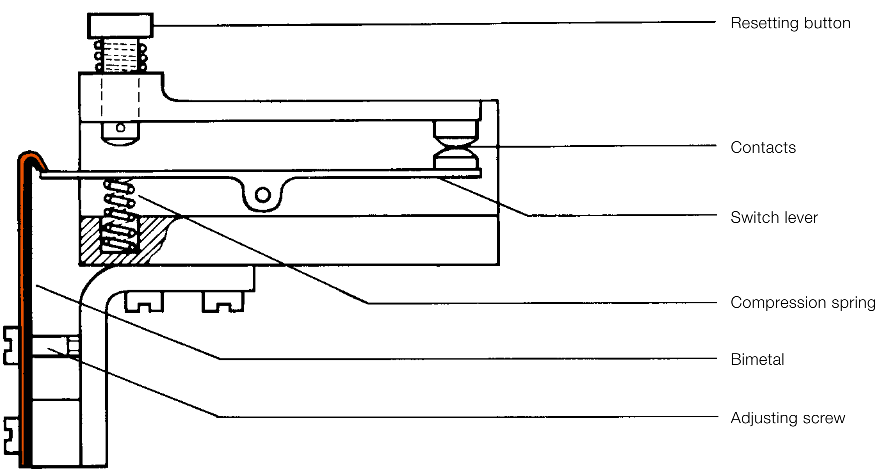


Fig. 29 Heating by means of passing current

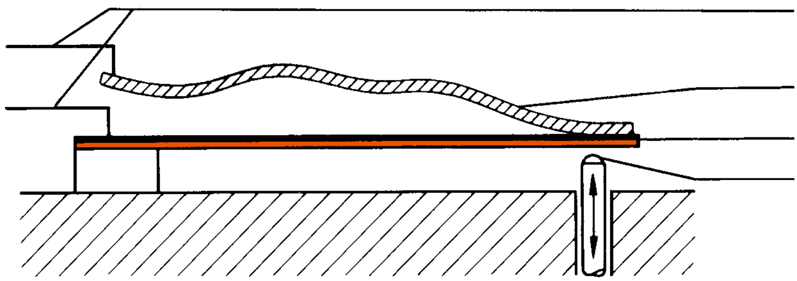


Fig. 30 Hairpin-shaped bimetal for amperages 5–10 A with one-sided current

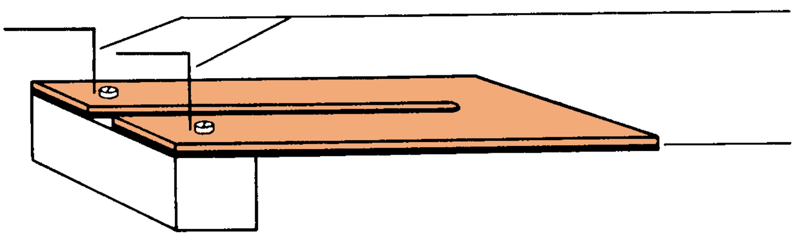


Fig. 31 Stacks of bimetal elements for amperages less than 5 A (the elements are connected in series)

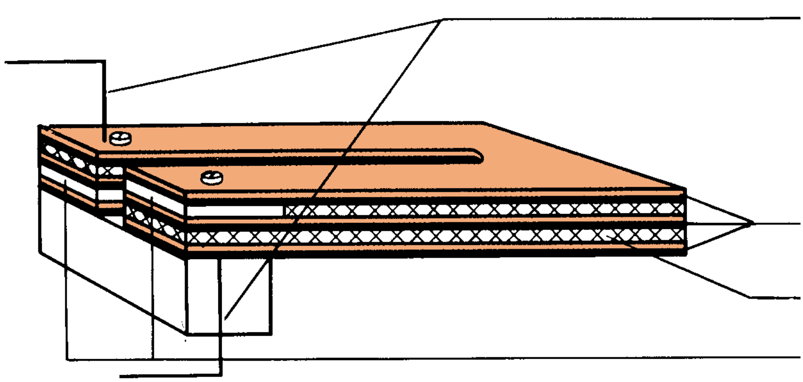


Fig. 32 Power controller with ambient temperature

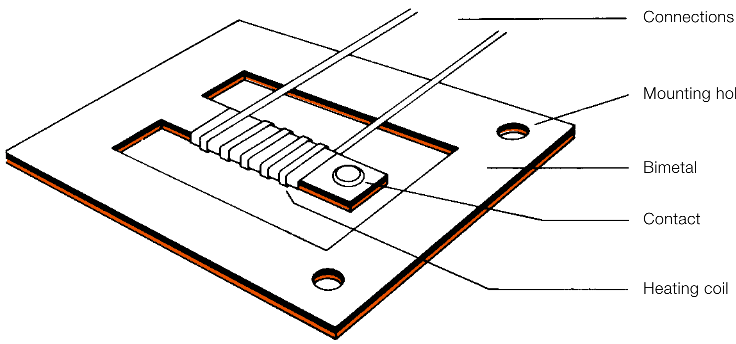


Fig. 33 Current and voltage regulators

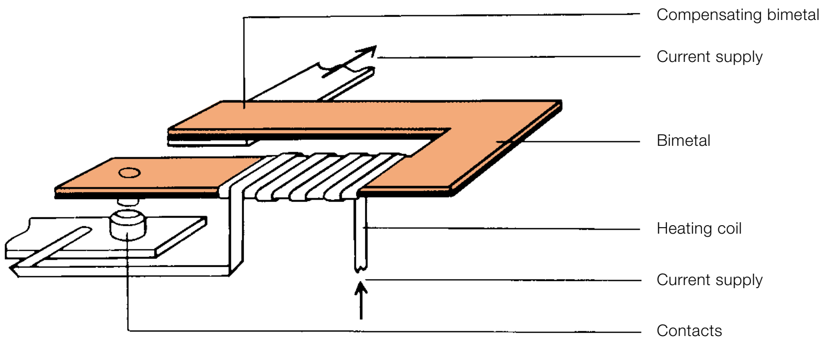
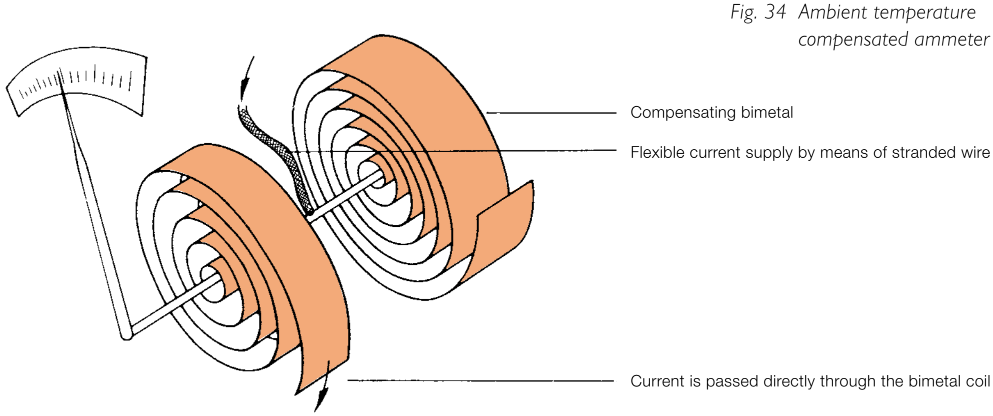


Fig. 34 Ambient temperature compensated ammeter



Choice of Suitable Bimetal Type

The most important properties of KANTHAL Thermostatic Bimetals are shown by tables and graphs on pages 24 – 77. When choosing a bimetal type for a particular application the following factors should be considered:

- Temperature of operation and deflection
- Mechanical stress
- Electrical resistivity and thermal conductivity
- Corrosion resistance
- Machineability

1. Temperature of Operation and Deflection

As shown in section 1, page 100, the bimetal volume required for a desired performance decreases with increasing specific deflection. It should be recognized that the specific deflection changes with temperature (see pages 20 and 21). Normally, the greater the specific deflection of a bimetal type, the smaller is its linearity range and the lower its highest permissible temperature.

KANTHAL 230 and 200 are thermally the most active bimetal types. They are principally used in cases where large deflection is required by a moderate temperature change of a small active length. These bimetal types do not withstand high mechanical strain and should not be heated to a temperature much higher than 250°C (480°F). In the temperature range up to 350°C (660°F) KANTHAL 155 and 135 are normally adequate, although their specific deflection is somewhat lower. If the service temperature is higher than about 350°C (660°F), and at the same time a large linearity range is required, KANTHAL 115, 100 and 60 can be recommended.

KANTHAL 115 is often used in thermostats for heating appliances operating at high temperatures. This bimetal type has also been found suitable for use in gas safety pilot elements and thermometers for wide temperature ranges. The normal maximum operating temperature is about 450°C (840°F), although KANTHAL 115 has been operating successfully at temperatures 100°C (180°F) higher. KANTHAL 100 has the same range of application as KANTHAL 115. It has, however, a temperature range for linear deflection up to 425°C (800°F) and is therefore particularly suitable for high temperature thermometers and other bimetal devices where a good linearity at high temperature is required. KANTHAL 60 has a linear deflection up to 450°C (840°F). The specific deflection is, however, relatively low.

2. Mechanical Stress

The bimetal is often in a state of mechanical stress by the action of an external force. When a thermostatic bimetal element is overstressed, a permanent deformation occurs. Different types of KANTHAL Thermostatic Bimetals differ with regard to maximum permissible bending stress and its dependence on temperature. The same applies to modulus of elasticity. The maximum permissible bending stress as a function of the temperature is indicated in section 4, pages 24 –77.

In many thermostats operating as temperature limiters the thermostatic bimetal strip is under restraint by an adjusting screw in such a way that the contacts do not open until a temperature has been reached and thus a force developed, which corresponds to the restraint. If this type of thermostat is exposed to very low temperatures a permanent deformation of the bimetal may occur.

Such thermostats can only be adjusted to a certain maximum temperature, as otherwise the permissible bending stress of the thermostatic bimetal at low temperatures would be exceeded due to the restraint. For these types of thermostats the temperature is

$$T - T_O = \frac{2}{3} \cdot \frac{\sigma}{\mathbf{a} \cdot E} \qquad [15]$$

Thermostats for higher temperatures should be designed so that the thermostatic bimetal element is without stress at ambient temperature.

The influence of hardness on the maximum permissible bending stress, as well as the maximum permissible increase of temperature in cases where the thermostatic bimetal is completely restrained from motion, are described in "Calculation of Bimetal Elements", page 100.

3. Electrical Resistivity and Thermal Conductivity

The values of electrical resistivity and thermal conductivity of KANTHAL Thermostatic Bimetals are indicated in section 4, pages 24 –77. A thermostatic bimetal with high electrical resistivity always has a low thermal conductivity. Conversely, if the electrical resistivity is low, the thermal conductivity is always high.

When the bimetal is heated, mainly by conduction in its length direction, a high thermal conductivity causes a rapid reaction.

Bimetal parts which are heated indirectly by a heating coil should preferably have a low thermal conductivity, as otherwise great losses occur due to conduction. This would result in unnecessary heating of the fixing point and require a higher powered heating coil.

The bimetal part is often included in the electric circuit. If in such a case any heating due to the electric current is undesirable, the type of bimetal used should have a low electrical resistivity. It is often necessary to produce the heating of the bimetal by the passage of an electric current. The current is normally fixed, and thus the internal resistance of the bimetal can be calculated in relation to this amperage. The higher the passing current, the smaller should be the electrical resistivity of the bimetal.

In switch manufacture there are many regulating and control applications. We have therefore developed an extensive resistance series. A summary of these thermostatic bimetal types, which have electrical resistivities between 1.40 and 0.033 $\Omega \times mm^2 \times m^{-1}$, is found on page 17 and 18. this means that by varying the resistivity of the thermostatic bimetal, different amperages can be controlled using bimetal parts with unchanged dimensions. See also equation 27 on page 107.

Due to their high resistivity, KANTHAL 200 and KANTHAL 140R140 are suitable for direct electric heating, particularly in the range of low amperages where a large thermal deflection is desirable. In many cases the low thermal conductivity of these bimetal types is also advantageous.

KANTHAL 155R55, 145R50, 145R35 and 135R25 have deflection properties similar to those of KANTHAL 155, 145 and 135. Due to an intermediate layer of nickel a reduced electrical resistivity is obtained. These bimetal types are therefore specially suitable for direct heating as part of an electric circuit. KANTHAL 145R19, 145R17, 145R15, 145R10, 135R05 and 130R03 with an insert of copper have a low electrical resistivity and a relatively high thermal deflection. They are therefore used preferably directly heated in thermal releasers in the high amperage range.

KANTHAL 127R09 and 115R09, as well as the resistance series types with a low electrical resistivity provided by copper inserts, are, due to their high thermal conductivity, also used for thermostats controlling limited temperature ranges where quick response is needed. The high conductivity of these bimetal types means that both overheating and cooling are limited when used for thermostatic control in such applications as flat irons, etc.

4. Corrosion Resistance and Protection

The corrosion resistance of most KANTHAL Thermostatic Bimetals is considerably better than that of iron. The bimetals can often operate without particular protection. For special purposes we recommend KANTHAL 94S. this type has a high corrosion resistance due to the fact that both components consist of NiCr steels. KANTHAL 94S is suitable for use in water and steam.

The condition of the surface of the bimetal is of great importance where the bimetal is subject to corrosion attacks. In such cases the identification marking is often applied by means of a printing ink instead of etching. Electrolytic polishing of fabricated bimetal parts presents an advantageous improvement of the corrosion resistance.

KANTHAL Thermostatic Bimetals do not normally oxidize in dry air at operating temperature. Direct contact with open flame should be avoided, for example, in gas safety pilot elements. In such applications it is advisable to spot-weld a chromium steel plate on the bimetal close to the point of contact with the flame.

In conditions of severest corrosion, for example in humid atmospheres, the surface of the non-stainless types should be protected. When the temperature of operation is relatively low, this can be done by means of a plastic covering. At higher temperatures the only solution is plating of the surface.

For operation in humid atmospheres we recommend galvanizing. In water copper plating is preferable. The thermal deflection is normally not affected by the surface treatment, and only in the case of thicker layers can a diminution occur.

Chromium plating and nickel plating result in a hard surface and are to be preferred, in the case of high operating temperatures. It should be noted, however, that the true protection provided by nickel plating is often doubtful, as the nickel coating is porous and can easily be damaged.

5. Machineability

Viewpoints regarding processing can also be of importance for the choice of bimetal type, welding being an example. Differences between the various bimetal types as regards punching, bending and threading can generally be overcome by changing the degree of cold-rolling since this affects the hardness. See also section "Fabricating Thermostatic Bimetal Parts", page 123.

Calculation of Bimetal Elements

When calculating thermostatic bimetal elements the following factors should be considered:

- Movement desired
- External forces
- Permissible bending stress
- Dead weight of the bimetal element
- Optimum bimetal volume
- Method of manufacture
- Space available

1. Optimum Bimetal Volume

When a cantilever strip is subjected to a change of temperature T_O to T and a change of force F_O to F, the total deflection is equal to the deflection caused by the change of temperature less the deflection resulting from the force (corresponding to example c, <page 111):

$$A = \frac{\mathbf{a}\,(T - T_O)\,L^2}{s} \cdot \frac{4\,(F - F_O)\,L^3}{b\,s^3\,E} \qquad [16]$$

(The principle symbols used are listed on page 127.)

It is assumed that the force counteracts the movement and that it is applied to the free end of the strip. In cases where the force acts in the direction of the movement, the total deflection represents the sum of the two components.

This equation can also be expressed as follows:

$$T - T_O = (T - T_O)\,T_A + (T - T_O)\,T_F = \frac{A\,s}{\mathbf{a}\,L^2} \cdot \frac{4\,(F - F_O)\,L^3}{\mathbf{a}\,E\,b\,s^2} \qquad [16a]$$

It is conceivable that the change of temperature $T–T_O$ is divided into two components, the first one corresponding to the movement and the second one to the change of force.

$$(T - T_O)\,T_A = \frac{A\,s}{\mathbf{a}\,L^2} \qquad [17]$$

$$(T - T_O)\,T_F = \frac{4\,(F - F_O)\,L^3}{\mathbf{a}\,E\,b\,s^2} \qquad [18]$$

$$T_F + T_A = 1 \qquad [19]$$

It can easily be proved mathematically that the minimum bimetal volume is obtained when $T_F = T_A = 0.5$, or

$$V_{min} = \frac{16\,(F - F_O)\,A}{E\,\mathbf{a}^2\,(T - T_O)^2} \qquad [20]$$

These equations are valid only for bimetal strips clamped at one end. In section "Calculation of Bimetal Elements" (page 100) corresponding equations for other shapes of bimetal part are indicated. For all these shapes the following equation is valid:

$$\frac{V}{V_{min}} = \frac{1}{4\,T_F\,T_A} \qquad [21]$$

This equation is graphically illustrated in the figure below.

When the forces F and F_O correspond to the stresses s and s_O, the following equation generally applies.

$$\frac{\sigma - \sigma_O}{a\,K\,E} = T_F\,(T - T_O) \qquad [22]$$

K is constant with the value 1 for a spiral or helical coil, 1.2 for a disc and 1.5 for a straight strip. The change of stress is thus proportional to T_F.

If frictional forces occur in a bimetal construction, it should be noted that such forces change sign when the direction of movement is changed. For example, if at first the temperature increases, a movement corresponding to a subsequent cooling will begin only after a certain decrease of the temperature. This temperature change without motion, which can be of great importance in regulating processes, increases with increasing T_F.

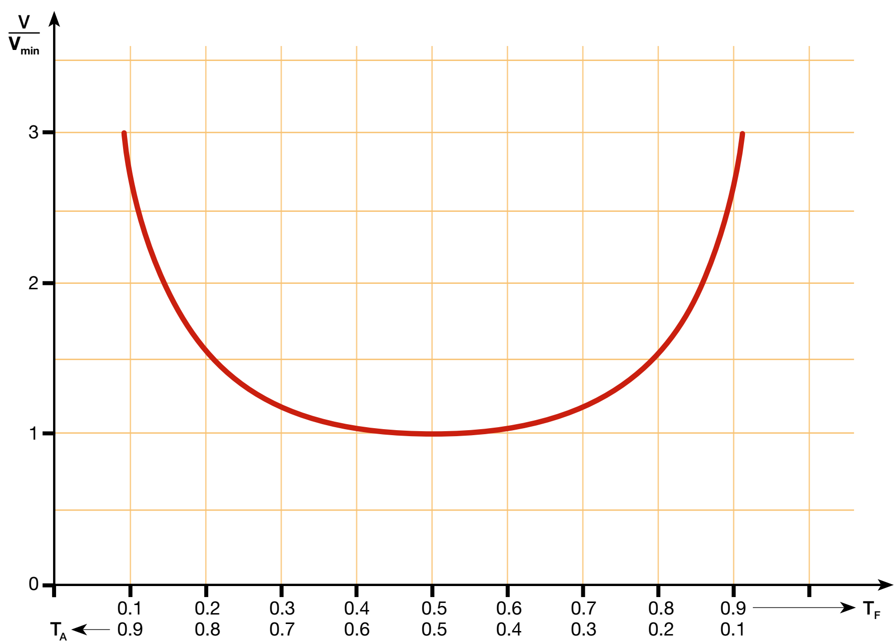


Fig. 35 T_F *= Component of the temperature change which corresponds to the force developed*
T_A *= Component of the temperature change which corresponds to the movement*

In certain cases, particularly with spiral coils, the dead weight of the bimetal element can cause a disturbing deflection. When the bimetal element is subjected to a change of the external force as well as a change of temperature, it should be noted that the disturbing influence of the dead weight increases with increasing T_F.

Thus, the mechanical stress in the bimetal, the temperature change without motion and the disturbance due to the dead weight increase with increasing T_F. For that reason a T_F smaller than 0.5 is often chosen, although T_F = 0,5 results in minimum bimetal volume.

2. Checking the Bending Load

When designing bimetal elements, it should always be checked that the material is not too heavily restrained. The following equation is used for determining the maximum bending stress of straight strips clamped at one end:

$$\sigma = \frac{6\,F\,L}{b\,s^2} \qquad [23]$$

The calculation for other bimetal elements can be derived from this equation. The maximum permissible bending stress at varying temperatures is shown graphically for our bimetal types on pages 24 to 77.

It can also happen that the thermostatic bimetal is restrained from motion only at increased temperatures. In order to prevent permanent deformation, the increase of the temperature at restrained motion should not exceed the values shown in the curves on Figures 38 and 39. The first graph is valid for spirals and helices and the second one for straight strips. The values of the abscissa correspond to the temperature from which the free deflection is restrained. From the ordinate the values of the permissible temperature increase from restraint of free deflection can be obtained. By utilizing these values it can be guaranteed that an un-allowably high bending stress, which could cause permanent set, does not occur.

Examples: In its entire operating temperature range KANTHAL 200 should be restrained from motion at a temperature charge of only about 30°C (84°F) when used as a straight strip and about 40°C (105°F) when used as a spiral or helix.

A straight strip of KANTHAL 94S can be restrained from motion within a temperature range of 20°C (68°F) to 90°C (195°F) and a coil or helix within a range of 20°C (68°F) to 120°C (250°F). With a straight strip the permissible temperature range from a limit temperature of 200°C (390°F) increases to 95°C (205°F) for a strip and to 135°C (275°F) for a coil or helix. (See also example 8 in section 6.2, page 122 and section 2, page 97.)

If the values for permissible bending stress indicated in graphs and tables are exceeded, the use of a harder bimetal with a higher degree of cold-rolling can be considered. The relationship between the degree of cold-rolling and the permissible bending stress is shown in Fig. 38. It should be borne in mind, however, that the ductility of the thermostatic bimetal deteriorates if the hardness is increased.

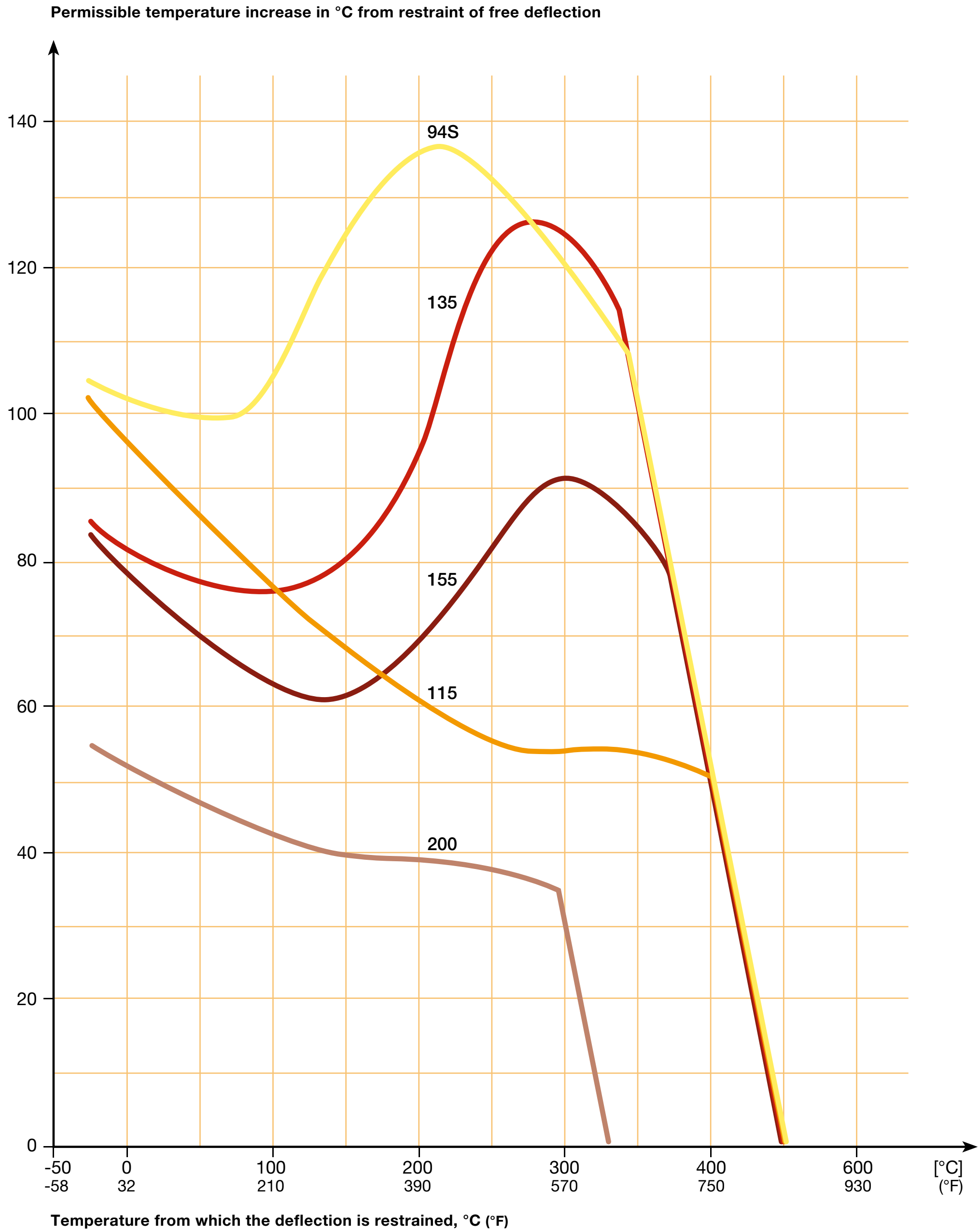


Fig. 36 Thermostatic bimetal spiral and helical coils. Permissible temperature increase in °C (°F) from restraint of free deflection.

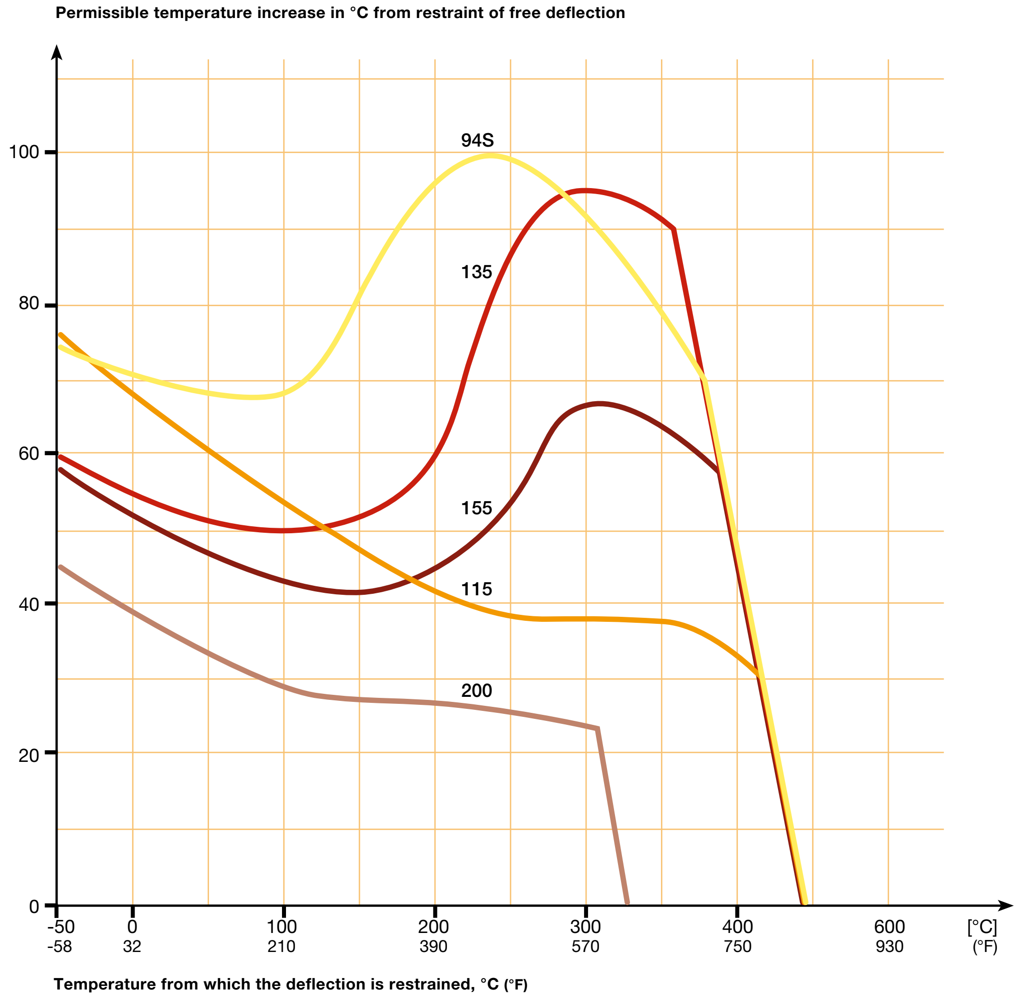


Fig. 37 Straight strip of thermostatic bimetal. Permissible temperature increase in °C (°F) from restraint of free deflection.

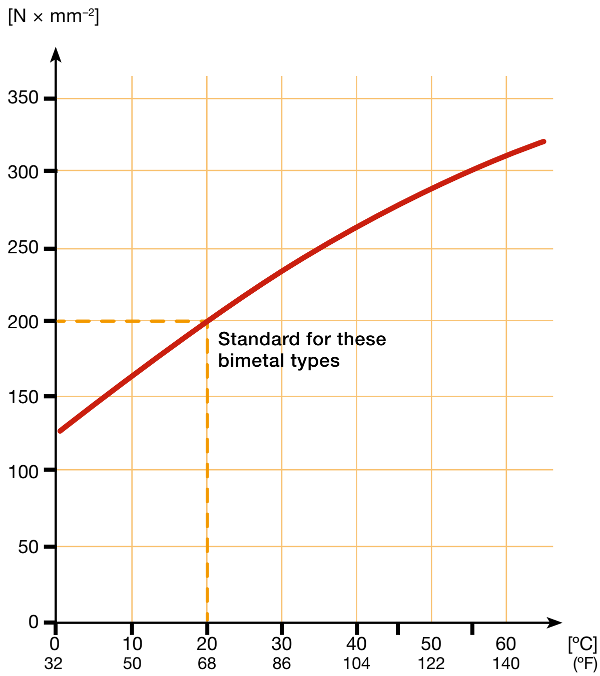


Fig. 38 KANTHAL 155 and 145. Permissible bending stress in N × mm^{-2} at 20°C (68°F) in relation to degree of cold-rolling.

3. Direct Heating by Electric Current

The increase of temperature in a thermostatic bimetal heated by an electric current can be calculated in the same way as for an ordinary electrical conductor.

$$T - T_O = \frac{I^2 R t}{m c} = \frac{\varrho i^2}{c \gamma} t \qquad [24]$$

(The meaning of the formula symbols is explained on page 127.)

The above formula applies only when the exchange of heat between the bimetal and its surroundings can be disregarded. This means that the heating time should be very short, as occurs for example during short circuiting.

Fig. 39 shows the increases of temperature in a thermostatic bimetal strip subjected to one or more current impulses of short duration. It is assumed that the heating time is short. The entire amount of heat developed is stored in the bimetal strip. This means that no heat exchange takes place with the surroundings. The development of heat can occur as a result of one or more impulses of current. In the diagram the temperature increase of the bimetal is therefore plotted as a function of the expression which follows from [24]:

$$C = \int_O^t i^2 \ dt = \int_O^T \frac{c\gamma}{\varrho} \ dT \qquad [25]$$

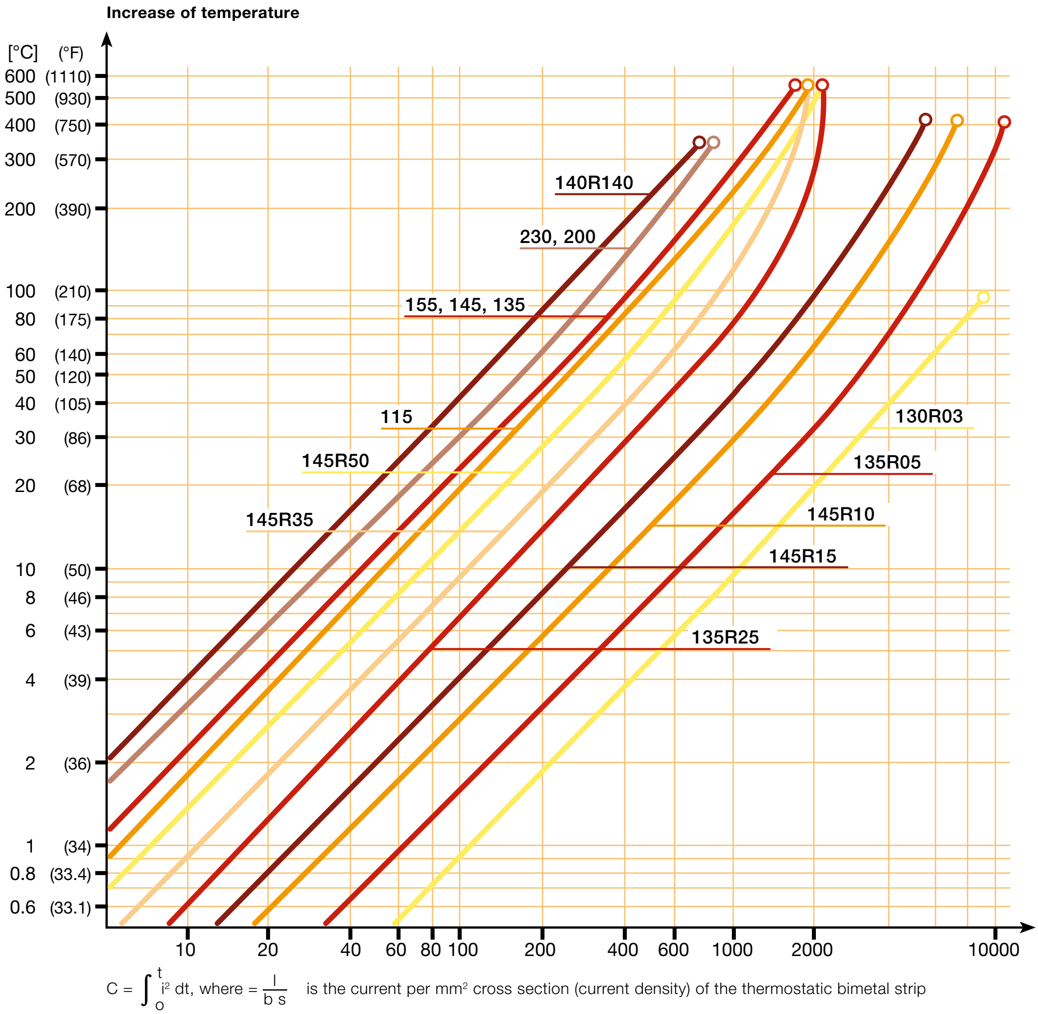


Fig. 39 The increase of temperature in a thermostatic bimetal strip as a function of the electric current passed through it by current impulses of short duration.

and is illustrated in Fig. 39, i is the current per mm² cross section (current density) of the thermostatic bimetal and t is the total time in seconds. The curves are plotted only to the maximum permissible temperature of the different bimetal types. It can be established from the diagram that, for example, the maximum temperature increase of KANTHAL 155 is obtained for the value

$$C = \int_{o}^{t} i^2 \, dt = 1700 \text{ A}^2 \cdot \text{s} \cdot \text{mm}^{-4}$$

A current density of 41 A per mm² cross section of the bimetal strip can thus be permitted for one second or 130 A for 0.1 seconds or 410 A for a duration of 0.01 seconds.

In steady state the temperature of the bimetal is influenced by the heat exchange with the surroundings. This heat exchange is due to factors which are difficult to calculate, and which can vary from one case to another.

The thickness of bimetals heated directly by electric current is generally 0.6 to 1.2 mm (0.024 – 0.047 in) and the width 4 to 12 mm (0.16 – 0.47 in). A careful calculation taking the heat conduction in the length direction of the bimetal into consideration indicates that the maximum temperature and the deflection at steady state depend on dimensions, type and current intensity as per the equations 26 and 27:

$$(T - T_O)_{max} \sim \frac{\varrho^{1+K} L^{2K}}{b^2 s^{1+K}} I^2 \quad 0 < K < 0.5 \qquad [26]$$

$$A \sim \frac{a \varrho^{1+K} L^{2+2K}}{b^2 s^{1+K}} I^2 \qquad [27]$$

For K = 0, neglecting heat transfer in the bimetal length direction we obtain:

$$(T - T_O)_{max} \sim \frac{\varrho I^2}{b^2 s^{1+K}} \qquad [26a]$$

$$A \sim \frac{a \varrho I^2}{b^2 s^2} L^2 \qquad [27a]$$

The constant K is nearly 0 for a high resistivity and nearly 0.5 for a low one.

In order to obtain satisfactory heating and consequently adequate deflection at amperages below 10 A, the bimetal strip can be slit longitudinally in the middle. In this way an increased electrical resistance is achieved (Fig. 30). For amperages below 5 A the use of stacks of bimetal strips may be advisable. The individual strips are insulated from each other. They are connected electrically in series, and the current flows through them one after the other (Fig. 31). In such stacks the friction of the individual strips against each other should be considered.

4. Indirect Heating by Means of an Electric Heating Element

For amperages below about 5 A heating of the thermostatic bimetal is usually performed by electric heating elements. A resistance wire can be wound on a heat resisting insulating material (glass tissue, mica, ceramics) directly surrounding the bimetal, or it can be placed near to the bimetal part. It is also possible to locate such heaters between several stacked bimetal elements with insulating intermediate layers.

Wires, ribbons or strips of resistance alloys are used for this application. KANTHAL resistance alloys, due to their high resistivity, provide the possibility of applying a high ohmic value in the limited space available, or they offer the choice of a larger heat emitting cross section. As the melting point of KANTHAL electric resistance alloys is higher than that of low ohmic materials, they also offer a higher resistance to short circuiting. Another advantage is their low temperature coefficient of resistivity, i.e. the small difference between cold and hot resistance. For the same purpose we also supply our NIKROTHAL alloys. Some alloy types are also available in the form of insulating oxidized wire, so that the heating element can be closely wound if necessary.

We can supply KANTHAL and NIKROTHAL ribbon in certain sizes with very close electrical resistance tolerances per unit length, (±1–2 %). This is of particular advantage for the indirect heating of bimetal release relays, mainly because the close tolerances considerably reduce time-taking and expensive adjusting work. When manufacturing the heaters, these close tolerances mean that uniform lengths of resistance ribbon can be used. The adaptation of the resistance coil, which was previously necessary due to variations in the resistance, is no longer necessary. For more detailed information, please ask for the KANTHAL Handbook, which gives full particulars of the properties of these resistance alloys. We shall also be pleased to supply samples of our resistance materials to your specification in the sizes required for your experiments.

The rating of the heating element depends on the required temperature, the dimensions of the bimetal element, and the conditions of heat emission. Normally a power of 1 to 100 W is needed. When amperage and power are known, the resistance value can easily be calculated. If the ratio of resistance value to the area of bimetal provided with a resistance coil is 0.001 et 1 $\Omega \times cm^{-2}$, tape or strip is normally used. If this ratio is 1 to 10.000 $\Omega \times cm^{-2}$, the use of wire is preferred.

In motor protectors the heating element is often subjected to short-circuit loads. The heating conductor should in such a case not melt. In order to prevent this, C as per equation [25] calculated for the resistance material should not exceed the value corresponding to the melting point of the electric heating alloy, i.e. it must stay below 4.900 to 5.800 $A^2 \times s \times mm^{-4}$. The values for KANTHAL alloys of FeCrAl are somewhat higher than those of NIKROTHAL alloys consisting of NiCr and NiCrFe. When the heating element is energized directly from the mains a high resistance is required and a resistor of nonmetallic material such as carbon or PTC material may be considered.

5. Calculating Formulae

(The principle symbols used are listed on page 127.)

5.1 Cantilever Strip

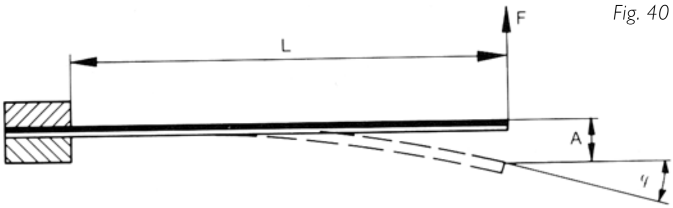


Fig. 40

Maximum bending stress: $\sigma = \frac{6\,F\,L}{b\,s^2}$ [23]

a) Change of temperature (force constant):

Deflection $A = \frac{\mathbf{a}\,(T - T_O)\,L^2}{s}$ [9]

Angle at free end of strip in relation to the original direction:

$\varphi = \frac{2\,\mathbf{a}\,(T - T_O)\,L}{s} \cdot \frac{360}{2\,\pi}$ [28]

Bimetal volume $V = \frac{6\,A\,F}{\mathbf{a}\,\sigma\,(T - T_O)}$ [28a]

b) Change of force (temperature constant):

Deflection $A = \frac{4\,(F - F_O)\,L^3}{b\,s^3\,E}$ [29]

c) Change of temperature and force (see also section 1, page 100):

Deflection $A = \frac{\mathbf{a}\,(T - T_O)\,L^2}{s} - \frac{4\,(F - F_O)\,L^3}{b\,s^3\,E}$ [16]

or

$T - T_O = (T - T_O)\,T_A + (T - T_O)\,T_F = \frac{A\,s}{\mathbf{a}\,L^2} + \frac{4\,(F - F_O)\,L}{b\,s^2\,E\,\mathbf{a}}$ [16a]

Minimum bimetal volume $V_{min.} = \dfrac{16\,(F - F_O)\,A}{E\,\mathbf{a}^2\,(T - T_O)^2}$ for $T_A = T_F = 0.5$ [20]

d) Temperature change when the motion is restrained:

Change of force $F - F_O = \dfrac{\mathbf{a}\,E(T - T_O)\,B\,s^2}{4\,L}$ [30]

5.2 Simple Beam

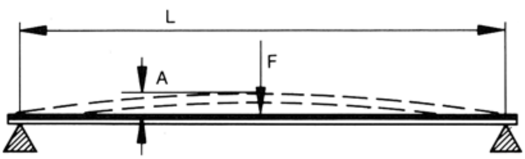


Fig. 41

Maximum bending stress $\sigma = \dfrac{3}{2} \cdot \dfrac{F\,L}{b\,s^2}$ [31]

a) Change of temperature (force constant):

Deflection $A = \dfrac{\mathbf{a}\,(T - T_O)\,L^2}{4\,s}$ [14]

b) Change of force (temperature constant):

Deflection $A = \dfrac{(F - F_O)\,L^3}{4\,b\,s^3\,E}$ [32]

c) Change of temperature and force:

Deflection $A = \dfrac{\mathbf{a}\,(T - T_O)\,L^2}{4\,s} - \dfrac{(F - F_O)\,L^3}{4\,b\,s^3\,E}$ [33]

or

$T - T_O = (T - T_O)\,T_A + (T - T_O)\,T_F = \dfrac{4\,A\,s}{\mathbf{a}\,L^2} + \dfrac{(F - F_O)\,L}{E\,\mathbf{a}\,b\,s^2}$ [33a]

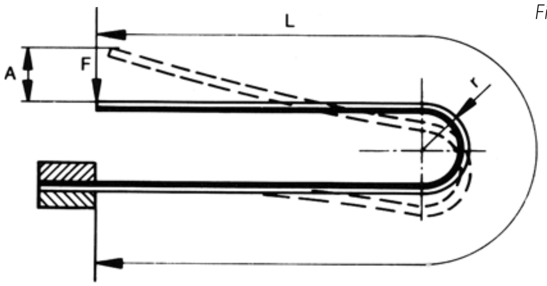
Minimum bimetal volume $V_{min.} = \dfrac{16\,(F - F_O)\,A}{E\,\mathbf{a}^2\,(T - T_O)^2}$ for $T_A = T_F = 0.5$ [34]

d) Temperature change when the motion is restrained:

Change of force $F - F_O = \dfrac{\mathbf{a}\,(T - T_O)\,E\,B\,s^2}{L}$ [35]

5.3 U-Shape

Fig. 42



Maximum bending stress $\sigma = \dfrac{3\,F\,L}{b\,s^2}$ [36]

a) Change of temperature (force constant):

Deflection $A = \dfrac{\mathbf{a}\,(T - T_O)\,L^2}{2\,s}$ [37]

b) Change of force (temperature constant):

Deflection $A = \dfrac{(F - F_O)\,L^3}{E\,b\,s^3}$ [38]

c) Change of temperature and force:

Deflection $A = \dfrac{\mathbf{a}\,(T - T_O)\,L^2}{2\,s} - \dfrac{(F - F_O)\,L^3}{E\,b\,s^3}$ [39]

or

$T - T_O = (T - T_O)\,T_A + (T - T_O)\,T_F = \dfrac{2\,A\,s}{\mathbf{a}\,L^2} + \dfrac{2\,(F - F_O)\,L}{\mathbf{a}\,E\,b\,s^2}$ [39a]

Minimum bimetal volume $V_{min.} = \dfrac{16\,(F - F_O)\,A}{E\,\mathbf{a}^2\,(T - T_O)^2}$ for $T_A = T_F = 0.5$ [40]

d) Temperature change when the motion is restrained:

Change of force $F-F_O = \frac{\mathbf{a}\,(T-T_O)\,E\,B\,s^2}{2\,L}$ [41]

The formulae 26 to 41 apply when the legs are equally long and r is small compared with L.

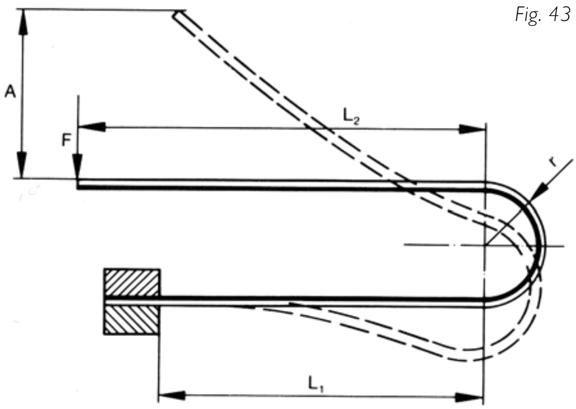


Fig. 43

$A = \frac{\mathbf{a}\,(T-T_O)}{s}\,(L_2^2 - L_1^2 + 2\,L_1L_2 + 4\,r^2 + 2\,\pi\,r\,L_2)$ [42]

This formula should always be used for a change of temperature when L_1 and L_2 are not equally long and when r is large compared with L.

5.4 Spiral and Helical Coils

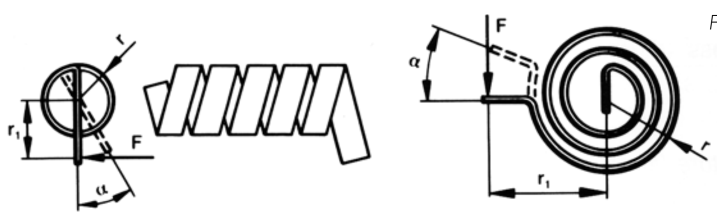


Fig. 44

Maximum bending stress $\sigma = \frac{6\,F\,R_1}{b\,s^2}$ [43]

a) Change of temperature (force constant):

Angular rotation $\alpha = \frac{2\,\mathbf{a}\,(T-T_O)\,L}{s} \cdot \frac{360}{2\,\pi}$ [44]

b) Change of force (temperature constant):

Angular rotation $\alpha = \frac{2\,(F - F_O)\,L\,r_1}{b\,s^3\,E} \cdot \frac{360}{2\,\pi}$ [45]

c) Change of temperature and force:

Angular rotation $\alpha = \left(\frac{2\,\mathbf{a}\,(T - T_O)\,L}{s} - \frac{12\,(F - F_O)\,L\,r_1}{b\,s^3\,E}\right) \frac{360}{2\,\pi}$ [46]

or

$T - T_O = (T - T_O)\,T_A + (T - T_O)\,T_F = \frac{\alpha\,s}{2\,\mathbf{a}\,L} \cdot \frac{2\,\pi}{360} + \frac{6\,(F - F_O)\,r_1}{b\,s^2\,E\,\mathbf{a}}$ [46a]

Minimum bimetal volume $V_{min.} = \frac{12\,(F - F_O)\,r_1\,\alpha}{E\,\mathbf{a}\,(T - T_O)^2} \cdot \frac{2\,\pi}{360}$ for $T_A = T_F = 0.5$ [47]

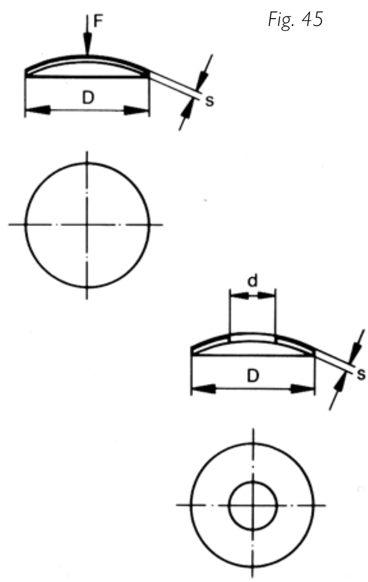
d) Temperature change when the motion is restrained:

Change of torque $(F{-}F_O)\,r_1 = \frac{1}{6}\,\mathbf{a}\,(T{-}T_O)\,E\,b\,s^2$ [48]

In order to avoid the disturbing influence of the dead weight of the bimetal element a value of L/s < 2500 is normally chosen.

5.5.1 Disc, Slow Mowing

Fig. 45



Maximum bending stress $\sigma = \frac{3}{2} \cdot \frac{F}{s^2}$ [49]

a) Change of temperature (force constant):

Deflection $A = \frac{\mathbf{a}\,D^2\,(T{-}T_O)}{5\,s}$ [50]

b) Change of force (temperature constant):

Deflection $A = \frac{(F{-}F_O)\,D^2}{4\,E\,s^3}$ [51]

c) Change of temperature and force:

Deflection $$A = \frac{\mathbf{a}\, D^2\, (T - T_O)}{5\, s} - \frac{(F - F_O)\, D^2}{4\, E\, s^3}$$ [52]

or

$$T - T_O = (T - T_O)\, T_A + (T - T_O)\, T_F = \frac{5\, s\, A}{\mathbf{a}\, D^2} + \frac{5}{4} \cdot \frac{(F - F_O)}{\mathbf{a}\, E\, s^2}$$ [52a]

Minimum bimetal volume $$V_{min.} = \frac{25}{4}\pi \cdot \frac{(F - F_O)A}{\mathbf{a}^2\, (T - T_O)^2\, E} \quad \text{for} \quad T_A = T_F = 0.5$$ [53]

d) Temperature change when the motion is restrained:

Change of force $$(F - F_O) = \frac{4}{5}\, \mathbf{a}\, E\, (T - T_O)\, s^2$$ [54]

The value D/s normally between 20 and 60.

5.5.2 Disc, Snap Action

In order to estimate the upper and lower re-set temperature of a snap action disc, the following formulas may be applied: (Wittrick)

(1) $$T_u = \frac{1}{\mathbf{a}} \left(\frac{s}{D}\right)^2 \cdot f_u + T_r$$

(2) $$T_l = \frac{1}{\mathbf{a}} \left(\frac{s}{D}\right)^2 \cdot f_l + T_r$$

These formulas are valid provided E1 = E1, s1 = s2, that Poisson's constant = 0.3 and that the discs have a perfect spherical form and no mechanical stress at T_r (room temperature).

Example: KANTHAL 155, d = 25 mm, Ao = 0.6 mm, s = 0.25 mm and T_r = 25 C.

Ao/s = 2.4 gives T_u = 10 ^ 6/15 · (0.25/25) ^ 2 · 14.4 + 25 = 117°C
T_l = 10 ^ 6/15.6 · (0.25/25) ^ 2 · 10.0 + 25 = 93°C

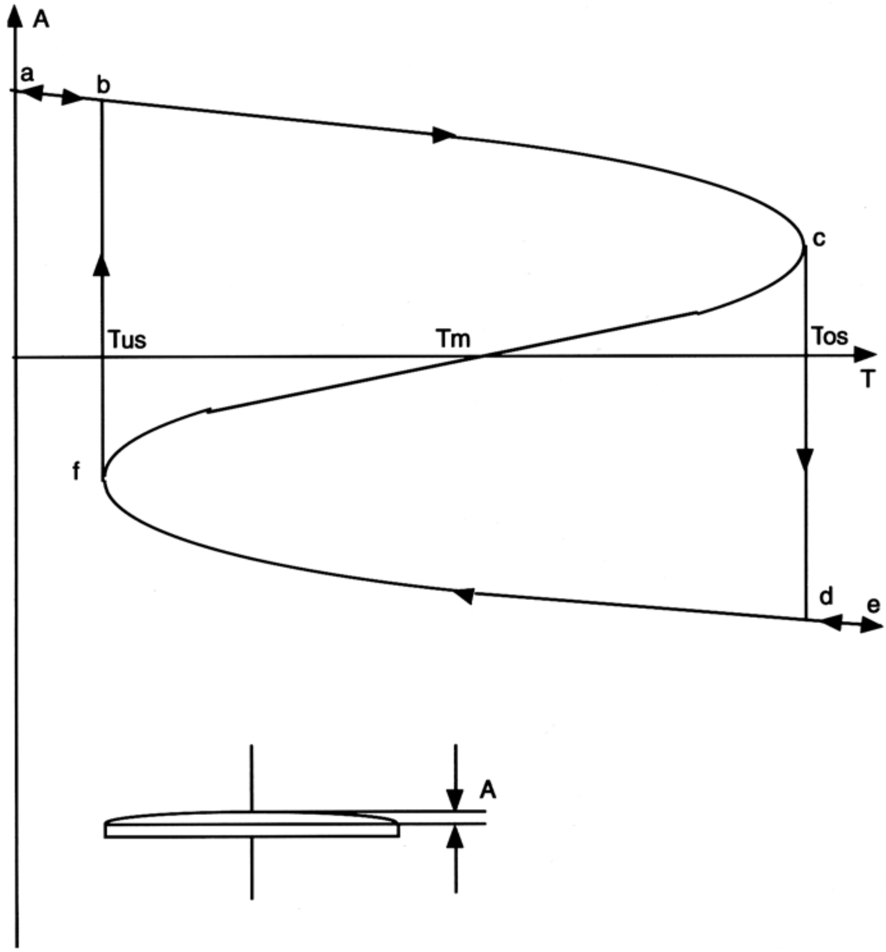


Fig. 46

$$T_u = \frac{1}{\mathbf{a}}\left(\frac{s}{D}\right)^2 \cdot f_u + T_r$$

$$T_l = \frac{1}{\mathbf{a}}\left(\frac{s}{D}\right)^2 \cdot f_l + T_r$$

$$T_m = \frac{1}{\mathbf{a}}\left(\frac{s}{D}\right)^2 \cdot f_m + T_r = \frac{5.2}{\mathbf{a}}\left(\frac{s}{D}\right)^2 \frac{A}{s} + T_r$$

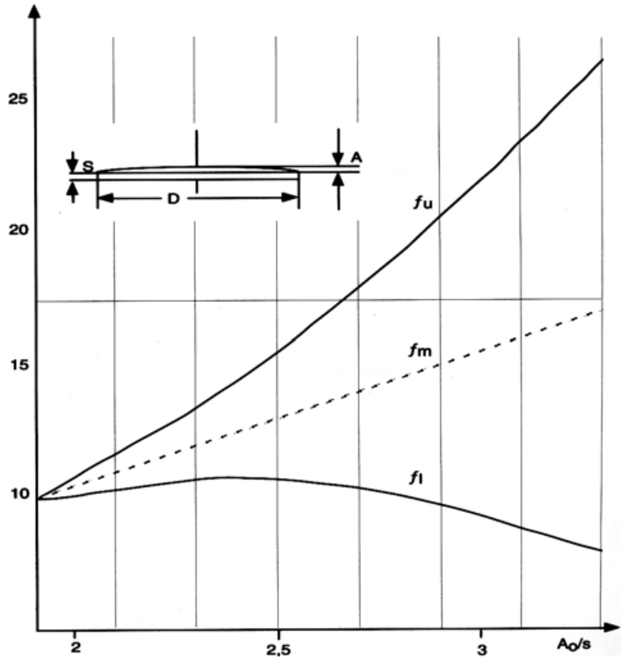


Fig. 47

5.6 Washer

The formulae for discs are also valid for washers, if $D^2 - d^2$ is substituted for D^2.

5.7 Reverse Lap-Welded Bimetal

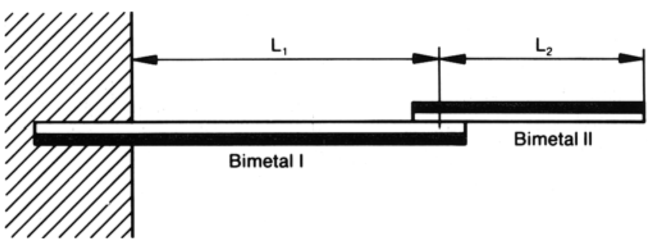


Fig. 48

L_1; s_1; $\mathbf{a_1}$ (active length, thickness and specific deflection of bimetal I)

L_2; s_2; $\mathbf{a_2}$ (active length, thickness and specific deflection of bimetal II)

$$A = (T - T_O)\left[\frac{\mathbf{a}_2 L_2^2}{s_2} - \frac{\mathbf{a}_1 (L_1^2 + 2 L_1 L_2)}{s_1}\right] \qquad [55]$$

Si $s_1 = s_2 = s$ and $\mathbf{a}_1 = \mathbf{a}_2 = \mathbf{a}$ we get:

$$A = \frac{\mathbf{a}_2 (T - T_O)}{s}(L_2^2 - 2L_1 L_2 - L_1^2) \qquad [56]$$

5.8 Accuracy of the Formulae

All the formulae mentioned in chapter 5 should be regarded as approximate. They can be used for assessing the dimensions and type of bimetal element. The final shape can normally only be established after thorough testing. Where particularly exacting demands are placed on the constancy of the zero point position, the bending load should be kept as low as possible.

As regards the formula for deflection of a straight strip due to change of temperature, it should be recognized that the specific deflection in the formulae [9] and [14] depends to some extent on the dimensions of the bimetal strip.

It should also be mentioned that the formulae for discs are somewhat inaccurate. One reason is that the influence of initial centre rise on the deflection has not been taken into consideration.

6. Examples of Calculation

6.1 Cantilever

Example 1. Free movement (Calculation of Bimetal Elements, case 5.1a)

A straight strip of KANTHAL 155 with an active length of L = 45 mm is clamped at one end. The deflection at the free end should be A = 3 mm at a temperature increase from 30°C to 150°C. Calculate the strip thickness s.

Using the deflection formula [9] page 11:

$$A = \frac{\mathbf{a}_2 (T - T_O) L_2}{s}$$

we obtain

$$s = \frac{15.6 \cdot 10^{-6} \cdot 120 \cdot 45^2}{3} = 1.26 \text{ mm}$$

Example 2. Restrained motion (Calculation of Bimetal Elements, case 5.1d)

A straight strip of KANTHAL 145, s = 1.0 mm; b = 12 mm; L = 50 mm, is subjected to a temperature alteration from 60 to 95°C, i.e. of 35°C. Calculate the force necessary to restrain the motion and the maximum bending stress occurring.

The formula for change of force is [30] page 110:

$$F - F_O = \frac{\mathbf{a}\, E\, (T - T_O)\, b\, s^2}{4\, L} = \frac{14.8 \cdot 10^{-6} \cdot 170000 \cdot 35 \cdot 12 \cdot 1^2}{4 \cdot 50} = 5.28 \text{ N}$$

The maximum bending stress occurring is (23):

$$\sigma = \frac{6\, F\, L}{b\, s^2} = \frac{6 \cdot 5.28 \cdot 50}{12 \cdot 1^2} = 132 \text{ N} \cdot \text{mm}^{-2}$$

Example 3. Development of force and movement (Calculation of Bimetal Elements, case 5.1c)

Calculate the thickness and the width of a strip of KANTHAL 155 with a length L = 50 mm which is to develop a force F = 1 N against a deflection A = 4 mm resulting from a rise in temperature from 20°C to 120°C.

In order to obtain a minimum bimetal volume, half the temperature alteration should be utilized in force and the other half for movement.

From the formula [17] and [18] page 100 we obtain

$$(T - T_O)\,0.5 = \frac{A\,s}{\mathbf{a}\,L^2} = \frac{4\,(F - F_O)\,L}{b\,s^2\,E\,\mathbf{a}}$$

i.e.

$$s = \frac{\mathbf{a}\,(T - T_O)\,L^2\,T_A}{A} = \frac{15.6 \cdot 10^{-6} \cdot 100 \cdot 50^2 \cdot 0.5}{4} = 0.5\text{ mm}$$

and

$$b = \frac{4\,(F - F_O)\,L}{E\,\mathbf{a}\,s^2\,(T - T_O)\,T_F} = \frac{4 \cdot 1 \cdot 50}{170000 \cdot 15.6 \cdot 10^{-6} \cdot 0.52 \cdot 100 \cdot 0.5} = 6\text{ mm}$$

The volume is $V = 150\text{ mm}^3$ and the maximum bending stress occurring is

$$\sigma = \frac{6\,F\,L}{b\,s^2} = \frac{6 \cdot 1 \cdot 50}{6 \cdot 0.5^2} = 200\text{ N} \cdot \text{mm}^{-2}$$

If instead ⅓ and ⅔ respectively of the temperature increase are used for development of force, the following values are obtained:

Proportion of $T\text{-}T_0$ for force, T_F	Thickness s [mm]	Width b [mm]	Bending stress s [N · mm⁻²]	Volume V [mm³]
1/3 (33°C)	0.65	5.35	132.6	174
2/3 (66°C)	0.325	10.7	265.4	174

In order to avoid obtaining too high a stress, a strip with the dimensions 5.35 × 0.65 mm is chosen. The volume will only be insignificantly larger than that of the optimum strip s = 0,5 mm and b = 6 mm.

Example 4. Direct heating by the passage of electric current (see also section 3, page 105)

A straight bimetal strip KANTHAL 145 is stamped into U-shape and heated with a current of I = 100 A. The length of the legs is 50 mm and the width b = 2.5 mm. The deflection of the strip should be A = 3 mm after current has been passed through for a time of t = 0.1 seconds. The active length of the strip is L = 50 mm. Calculate the thickness and the temperature rise. For KANTHAL 145, $\rho = 0.79\ \Omega \times mm^2 \times m^{-1}$.

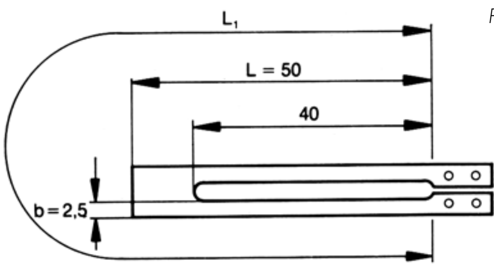


Fig. 49

Formulae on page 105

$$T - T_O = \frac{R\, I^2\, t}{m\, c} \quad \text{(Section 3, page 105)} \qquad [24]$$

$$A = \frac{\mathbf{a}\,(T - T_O)\, L^2}{s} \qquad [9]$$

$$R = \varrho \frac{L_1}{b\, s}$$

$$m = \gamma\, b\, s\, L_1$$

i.e.

$$A = \frac{\mathbf{a}\, \varrho\, I^2\, t\, L^2}{\gamma\, b^2\, s^3\, c}$$

$$T - T_O = \frac{\varrho\, I^2\, t}{\gamma\, b^2\, s^2\, c}$$

$$s^3 = \frac{14.8 \cdot 10^{-6} \cdot 0.79 \cdot 10^4 \cdot 0.1 \cdot 50^2}{8.1 \cdot 2.5^2 \cdot 0.46 \cdot 3} = 0.42\ mm^3$$

s = 0.75 mm strip thickness

$$T - T_O = \frac{0.79 \cdot 10^{-3} \cdot 10^4 \cdot 0.1}{8.1 \cdot 10^{-3} \cdot 2.5^2 \cdot 0.75^2 \cdot 0.46} = 60.3°C \text{ temperature rise}$$

Example 5. Comparing different bimetal types directly heated by electric current.

A straight bimetal strip KANTHAL 145 is directly heated for a time of t = 0.2 seconds by a current of I = 200 A. The deflection should amount to A = 3 mm. The width of the strip is b = 5 mm and the active length is L = 50 mm. Calculate the thickness and the temperature rise $T - T_O$.

By using the formulae in example 4, we obtain

$$s^3 = \frac{14.8 \cdot 10^{-6} \cdot 0.79 \cdot 200^2 \cdot 0.2 \cdot 50^2}{8.1 \cdot 5^2 \cdot 0.46 \cdot 3} = 0.84 \text{ mm}^3$$

s = 0.95 mm strip thickness

$$T - T_O = \frac{0.79 \cdot 10^{-3} \cdot 200^2 \cdot 0.2}{8.1 \cdot 10^{-3} \cdot 5^2 \cdot 0.95^2 \cdot 0.46} = 75.2°C$$

What current would KANTHAL 200 have to carry assuming the same conditions? Referring to the formulae in example 4, we obtain

$$I^2 = \frac{b^2 s^3 \gamma c A}{\varrho L^2 \mathbf{a} t} \quad \text{constant}$$

Since A, L, b, s and t remain unaltered, the formula can be rewritten as follows

$$I^2 = \frac{\gamma c}{\varrho \mathbf{a}}$$

The relationstrip between the current for two different bimetals is

$$\frac{I_1}{I_2} = \sqrt{\frac{\varrho_2 \mathbf{a}_2 \gamma_1 c_1}{\varrho_1 \mathbf{a}_1 \gamma_2 c_2}}$$

Placing in the data for KANTHAL 145 and 200, we obtain

$$I_1 = 200 \sqrt{\frac{14.8 \cdot 0.79 \cdot 7.8 \cdot 0.46}{20.8 \cdot 1.10 \cdot 8.1 \cdot 0.46}}$$

I_1 = 140A

The temperature rise of KANTHAL 200R is

$$T - T_O = 75.2 \cdot \frac{14.8}{20.8} = 53.5°C$$

6.2 Spiral and Helical Coils

Example 6. Free movement (Calculation of Bimetal Elements, case 5.4a)

A spiral coil of KANTHAL 155 strip, 2 × 0.1 mm, should have an angular movement of about 2.25 degrees per °C in the temperature range of 0 to 100°C. Calculate the active length of the bimetal strip (see page 112).

$$\alpha = \frac{360\,\mathbf{a}\,(T - T_O)\,L}{\pi\, s} \qquad [44]$$

$$2.25 = \frac{360 \cdot 15.6 \cdot 10^{-6} \cdot L}{3.14 \cdot 0.1}$$

L = 126 mm

Example 7. Development of force and movement (Calculation of Bimetal Elements, case 5.4c)

A spiral coil should have an angular movement of 0.8 degrees per °C and should develop a torque of 2 mm × N per °C. The coil is to operate in water between 20 and 100°C. Calculate the dimensions of the coil.

Since the coil has to operate in hot water, KANTHAL 94S is recommended. It is assumed that half the temperature increase is used to produce force and the other half to produce angular movement. In this way a bimetal strip with minimum volume is obtained.

The following formulae apply for spiral coils (see page 113).

$$\alpha = \frac{\mathbf{a}\,(T - T_O)\,L\,360}{\pi\, s}\,T_A \qquad [44]$$

$$F\,r_1 = \frac{\mathbf{a}\,(T - T_O)\,E\,b\,s^2}{6}\,T_F \qquad [46a]$$

$T_A = T_F = 0.5$

$$2 = \frac{9.5 \cdot 10^{-6} \cdot 190000 \cdot b\,s^2}{6}\,0.5 \qquad [46a]$$

$b\,s^2 = 13.3\ mm^3$

s = 1.0 mm is chosen

Thus we obtain b = 13.3 mm

$$0.8 = \frac{9.5 \cdot 10^{-6} \cdot L \cdot 0.5}{3.14 \cdot 1.0} \cdot 0.5 \qquad [44]$$

L = 1470 mm

Checking the bending stress $\sigma = \frac{6\,F\,r_1}{b\,s^2}$ [43]

Maximum torque developed = 2 × 80 = 160 mm × N

$$\sigma = \frac{6 \cdot 160}{13.3} = 72.2 \ \mathrm{N \cdot mm^{-2}}$$

According to the diagram on page 41, the bending stress is thus sufficiently below the maximum permissible limit.

Example 8. Partially restrained motion (Calculation of Bimetal Elements, case 5.4a and d)

A helical bimetal coil of 1 × 10 mm KANTHAL 115 strip with an active length L = 280 mm is subjected to a temperature increase from 20 to 300°C. After an angular rotation of 90°C without external counter-force, the further angular motion is to be restrained. At what temperature does the restraint of angular motion occur? Check whether the rise in temperature when the motion is restrained will result in a permanent deformation.

The angular motion becomes restrained at the rise in temperature

$$T - T_O = \frac{\alpha\, s}{2\, \mathbf{a}\, L} \; \frac{2\,\pi}{360} = \frac{90 \cdot 1 \cdot 2 \cdot 3.14}{2 \cdot 11.7 \cdot 10^{-6} \cdot 280 \cdot 360} = 240°\mathrm{C} \qquad [44]$$

At heating from 260 to 300°C the angular motion is restrained. From equation [48] we obtain the torque developed

$$F\, r_1 = \frac{1}{6}\, \mathbf{a}\, (T - T_O)\, E\, b\, s^2$$

The bending stress occurring is [43]

$$\sigma = \frac{6\, F\, r_1}{b\, s^2}\, \mathbf{a}\, (T - T_O)\, E \qquad [57]$$

(See also formula [15] on page 98.)

It should be checked whether the bending stress resulting is smaller than the maximum permissible bending stress. This can immediately be established from Fig. 36 on page 103. It is evident from the diagram that at a temperature of 260°C KANTHAL 115 can withstand a temperature increase of 55°C. In this case there is no risk of permanent deformation of the bimetal coil.

Fabricating Thermostatic Bimetal Parts

1. Stamping, Cutting, Bending and Coiling Bimetal Strip

a) Stamping and Cutting

A thermostatic bimetal is made up of two different alloys, which also differ with regard to hardness. In order to obtain an appropriate function of the fabricated bimetal part care should be taken to ensure that there is no burr left from stamping and cutting operations. This means that stamping and cutting tools must be very accurate and the clearance should be the smallest possible. The bimetal strip must be fed in so that the cutting tool is first applied to the harder component.

When calculating the cutting pressure a shearing strength of 600 N × mm^{-2} can be assumed.

It is an advantage to cut the bimetal element longitudinally from the strip. However, for economical reasons bimetal strips are often stamped across the direction of rolling. In such a case a decrease in deflection of 1 to 2 % must be considered. Moreover, the maximum permissible bending stress must be reduced to 90 % of the values indicated in the graphs in "KANTHAL Thermostatic Bimetal Types" section 4, pages 24 –77.

b) Bending

Sharp bends should be avoided as far as possible since this may cause cracks to develop in the outer layer. No general rules can be given as to how bending should be carried out, since several factors influence. In this context, the degree of cold-rolling or hardness is of important significance. The harder a bimetal strip is, the better are the elastic properties. At the same time it is also considerably more brittle. Bending across the direction of rolling offers less difficulty than bending along the direction of rolling. The stress of bimetal strips differs according to the shape of the bending. A bimetal strip with normal degree of cold-rolling should not be bent across the direction of rolling with a radius less than the strip thickness. If the bending is done along the rolling direction the bending radius should not be less than 1.5–2 times the strip thickness.

c) Coiling

When manufacturing spiral and helical coils for thermometers and other applications the normal resilience properties of the bimetal type chosen should be considered. Spiral coils of strips with small cross sectional area can be coiled without the use of inserts provided that the strip has the correct degree of hardness (cold-rolling). When using strips of heavier sizes it is recommended to employ an insert during coiling in order to obtain a uniform pitch.

Coils with a small distance between the turns should preferably be wound with the active component on the inside. In such a case the coil operates on opening and there is no risk of contact between adjacent turns. Such a contact would restrain the angular deflection and should be avoided. If coils which operate on closing have a sufficient pitch this problem does not occur.

It can generally be said that bimetal parts should preferably be fabricated and assembled in as constant and uniform temperature conditions as possible. A temperature of about 20°C is recommended. When assembling devices with bimetal elements under varying temperature conditions and especially when the bimetal parts are sensitive, subsequent adjustment to a uniform zero point position is necessary. The ambient temperature during manufacture of the device should always be considered when such adjustments are made.

2. Stress-Relieving (Ageing)

During the manufacture of bimetal parts, certain stresses occur which affect their function. For this reason, a stress-relieving operation is recommended. This is especially important when the shape of a bent bimetal part is complicated. A proper heat treatment process (ageing) will not change the physical properties, the strength or the hardness of the bimetal element. Such a process will assist in maintaining a uniform function and will not result in any alteration of the initial values. One stress-relieving treatment followed by slow cooling is generally sufficient. The temperature should be at least 50°C above the maximum temperature of operation. However, the maximum operating temperature values as tabulated on page 17 and 18 should not be exceeded. Even at these temperatures a certain amount of softening takes place, which can effect the resilience of hard-rolled bimetals.

The duration of the stress-relieving treatment should amount to two to three hours. The lower the temperature of stress-relieving, the longer the duration of the treatment should be.

Ageing is seldom performed at temperatures below 200°C, as the duration of treatment would be too long.

During the stress-relieving treatment a deformation of the bimetal element can occur. This deformation, which is especially apparent as far as bent parts are concerned, can usually be taken into account during the manufacture of the bimetal part.

To meet high demands for accuracy of function and retention of shape of the bimetal element, multiple ageing in 2 to 3 stages is advantageous.

The heat treatment temperature during the second and third ageing stages should be somewhat lower than during the first one.

A protective atmosphere is not necessary for this stress-relieving treatment, although it is recommended if the bimetal part is to be welded, brazed or surface-treated after heat treatment. If stress-relieving is carried out in normal atmospheric air, a dark surface will be formed which causes a higher emissivity, thereby improving the heat exchange with the surroundings.

The ageing is generally performed in electrically heated convection furnaces provided with accurate temperature regulation equipment.

If the demands for retention of shape after ageing are particularly high and the temperature of heat treatment is moderate, the ageing of bimetal parts can be done in oil-bath furnaces or salt-bath furnaces.

The surface of the bimetal element is unprotected after ageing. It is always recommended, especially if the parts are being stored, that they are treated with anti-rust oil.

3. Mounting

Uniformity and accuracy in mounting bimetal parts are necessary in order to ensure perfect function and consistency of the zero point position. We recommend spot-welding, laser welding, riveting and screwing. Brazing requires such a high temperature that the bimetal softens and new internal stresses occur during cooling.

4. Spot-Welding

With very few exceptions KANTHAL Thermostatic bimetals can be spot-welded without difficulty. However, spot-welding on the high expansion side of KANTHAL 200, 230 and KANTHAL 140R140 can sometimes cause difficulties. In such cases it is normally easier to spot-weld on the low expansion side. Since a good surface finish is a condition for good weldability, we pay special attention to the surface properties of our bimetal strips. Stamped parts should be carefully degreased so that a good contact is obtained with the welding electrode during spot-welding.

In mass production of bimetal parts and devices the surface condition is often impaired to a varying extent by different treatments and processes. In order to obtain a good spot-welded joint, it may therefore be advisable to apply a thin coating of tin or brass to the bimetal.

To ensure a defined current flow and good heat distribution during spot-welding, a small projection can be stamped into the bimetal element at a point where an increase of temperature is required.

KANTHAL and NIKROTHAL electrical resistance alloys can be spot-welded without difficulty to KANTHAL Thermostatic bimetals.

ASTM Standards Concerning Thermostatic Bimetal

B 106-78	03.04	Test method for flexivity of thermostat metals
B 223-56 (1978)	03.04	Test method for modulus of elasticity of thermostat metals (cantilever beam method)
B 305-56 (1978)	03.04	Test method for maximum loading stress of temperature of thermostat metals (cantilever beam method)
B 362-81	03.04	Test method for mechanical torque rate of Spiral coils of thermostat metals
B 388-81	03.04	Specification for thermostat metal sheet and strip
B 389-81	03.04	Test method for thermal deflection rate of spiral and helical coils of thermostat metal
B 478-79	03.04	Test method for cross curvature of thermostat metals

DIN 1715 Standards Concerning Thermostatic Bimetal (1983)

Part 1. Technical conditions of delivery

Part 2. Testing specific thermal curvature

List of Frequently Used Symbols

Symbol	Meaning	Unit
A	Deflection of the bimetal strip	mm
a	Specific deflection	K^{-1}
b	Width of the thermostatic bimetal strip	mm
c	Specific heat	$J \times g^{-1} \times K^{-1}$*
D	Diameter of bimetal disc	mm
d	Inside diameter of bimetal washer	mm
E	Modulus of elasticity	$N \times mm^{-2}$**
F	Force	N**
I	Amperage	A
i	Current density	$A \times mm^{-2}$
k	Specific curvature	K^{-1}
L	Active length of bimetal strip	mm
M	Torque	mm × N**
m	Mass	g
R	Resistance	Ω
r	Radius of coil	mm
r_1	Lever	mm
s	Thickness of the thermostatic bimetal	mm
$T–T_0$	Temperature difference	°C
T_A	The part of the temperature alteration which corresponds to the movement	
T_F	The part of the temperature alteration which corresponds to the force	
t	Time	s
V	Volume of the thermostatic bimetal	mm^3
α	Angular rotation	degrees
σ	Max. bending stress	$N \times mm^{-2}$
ρ	Resistivity	$\Omega \times mm^{-2} \times m^{-1}$
γ	Density	$g \times cm^{-3}$
~	Proportional to	
T_u	Upper snap temperature	
T_i	Lower snap temperature	
T_m	Average snap temperature	
T_r	Room temperature	
f_u	Function acc. to Wittrick	

* 1 J = 1 Ws = 0.239×10^{-3} kcal

** 1 N = 0.102 kp

Index

Temperature Conversion Table

0 to 99						100 to 1000					
°C		°F	°C		°F	°C		°F	°C		°F
–17.8	0	32.0	10.0	50	122.0	38	100	212	288	550	1022
–17.2	1	33.8	10.6	51	123.8	43	110	230	293	560	1040
–16.7	2	35.6	11.1	52	125.6	49	120	248	299	570	1058
–16.1	3	37.4	11.7	53	127.4	54	130	266	304	580	1076
–15.6	4	39.2	12.2	54	129.2	60	140	284	310	590	1094
–15.0	5	41.0	12.8	55	131.0	66	150	302	316	600	1112
–14.4	6	42.8	13.3	56	132.8	71	160	320	321	610	1130
–13.9	7	44.6	13.9	57	134.6	77	170	338	327	620	1148
–13.3	8	46.4	14.4	58	136.4	82	180	356	332	630	1166
–12.8	9	48.2	15.0	59	138.2	88	190	374	338	640	1184
–12.2	10	50.0	15.6	60	140.0	93	200	392	343	650	1202
–11.7	11	51.8	16.1	61	141.8	99	210	410	349	660	1220
–11.1	12	53.6	16.7	62	143.6	100	212	413	354	670	1238
–10.6	13	55.4	17.2	63	145.4	104	220	428	360	680	1256
–10.0	14	57.2	17.8	64	147.2	110	230	446	366	690	1274
– 9.44	15	59.0	18.3	65	149.0	116	240	464	371	700	1292
– 8.89	16	60.8	18.9	66	150.8	121	250	482	377	710	1310
– 8.33	17	62.6	19.4	67	152.6	127	260	500	382	720	1328
– 7.78	18	64.4	20.0	68	154.4	132	270	518	388	730	1346
– 7.22	19	66.2	20.6	69	156.2	138	280	536	393	740	1364
– 6.67	20	68.0	21.1	70	158.0	143	290	554	399	750	1382
– 6.11	21	69.8	21.7	71	159.8	149	300	572	404	760	1400
– 5.56	22	71.6	22.2	72	161.6	154	310	590	410	770	1418
– 5.00	23	73.4	22.8	73	163.4	160	320	608	416	780	1436
– 4.44	24	75.2	23.3	74	165.2	166	330	626	421	790	1454
– 3.89	25	77.0	23.9	75	167.0	171	340	644	427	800	1472
– 3.33	26	78.8	24.4	76	168.8	177	350	662	432	810	1490
– 2.78	27	80.6	25.0	77	170.6	182	360	680	438	820	1508
– 2.22	28	82.4	25.6	78	172.4	188	370	698	443	830	1526
– 1.67	29	84.2	26.1	79	174.2	193	380	716	449	840	1544
– 1.11	30	86.0	26.7	80	176.0	199	390	734	454	850	1562
– 0.56	31	87.8	27.2	81	177.8	204	400	752	460	860	1580
0.00	32	89.6	27.8	82	179.6	210	410	770	466	870	1598
0.56	33	91.4	28.3	83	181.4	216	420	788	471	880	1616
1.11	34	93.2	28.9	84	183.2	221	430	806	477	890	1634
1.67	35	95.0	29.4	85	185.0	227	440	824	482	900	1652
2.22	36	96.8	30.0	86	186.8	232	450	842	488	910	1670
2.78	37	98.6	30.6	87	188.6	238	460	860	493	920	1688
3.33	38	100.4	31.1	88	190.4	243	470	878	499	930	1706
3.89	39	102.2	31.7	89	192.2	249	480	896	504	940	1724
4.44	40	104.0	32.2	90	194.0	254	490	914	510	950	1742
5.00	41	105.8	32.8	91	195.8	260	500	932	516	960	1760
5.56	42	107.6	33.3	92	197.6	266	510	950	521	970	1778
6.11	43	109.4	33.9	93	199.4	271	520	968	527	980	1796
6.67	44	111.2	34.4	94	201.2	277	530	986	532	990	1814
7.22	45	113.0	35.0	95	203.0	282	540	1004	538	1000	1832
7.78	46	114.8	35.6	96	204.8						
8.33	47	116.6	36.1	97	206.6						
8.89	48	118.4	36.7	98	208.4						
9.44	49	120.2	37.2	99	210.2						

Notes

Notes

KANTHAL

Kanthal – a Sandvik brand
Kanthal AB, Box 502, SE-734 27 Hallstahammar, Sweden   Phone +44 220 21000   Fax +46 220 21166   www.kanthal.com