THE CHARACTERISATION OF BIMETAL DISKS USED FOR THERMOSTATIC CONTROL AND OVER-TEMPERATURE PROTECTION

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Abstract: In this study, the two-layer bimetal disks used for thermostatic control and over-temperature protection were investigated for the effects of the shaping procedure and heat treatments on the instantaneous specific deflection of the temperature range.

A parametric study was carried out in which several mechanical disc shaping procedure and several heat treatments on differences in accuracy of switching temperatures were considered. As a result of this study, a simple thermo-mechanical shaping procedure was discovered for the accuracy of specific working temperature range. Also digital switching action was obtained for transducer used for thermostatic control and over-temperature protection.

Keywords: Bimetal, Thermostatic Bimetal, Thermostatic Control, Instantaneous Specific Deflection, Thermo-Mechanical Shaping.

Introduction

Thermostatic Bimetal is a composite material, made up of two or more metallic layers having different coefficients of expansion. When permanently bonded together, these layers cause the material to change its curvature when subjected to a change in temperature (Khadkikar 1993). This change of curvature, or bending, in response to temperature change, (flexivity), is a fundamental property of all Thermostatic Bimetals (Freyang 1996)

Thermostatic bimetal components both simple and complex are at the heart of numerous measuring instruments, regulation systems and safety devices. In heating and sanitary equipment, in electrical engineering systems and domestic appliances, in motor protectors, automobile fan controls, and as temperature compensators in television sets, and wherever a device must react to changes in temperature (Kantal 2008).

The uses of thermostatic bimetal components fall into four general classifications as follows (Howard 1942):

- Temperature Indication
- Temperature Control
- Control of function with temperature change over a range of temperature
- Control of function by auxiliary heating of the bimetal

The shapes of bimetallic elements vary depending on the application and include beams, disks, spiral helices, and U-shaped elements. Straight strips are the commonest form of bimetals, being the simplest and cheapest. When the available space is limited, a U shape can be employed. Spiral and helical bimetals convert temperature changes into a rotational movement or torque when the displacement is impeded. A spiral shape enables a large length of bimetal to be incorporated into a small volume, producing high sensitivity, limited only by strength considerations beyond a certain length. Bimetallic discs (shallow shells) reverse suddenly at a critical temperature which depends on the grade of bimetal employed and the geometry. They are used in numerous regulation devices and protection systems (Ziga 2013).

Thin and shallow bimetallic shells with suitable material and geometric properties have the characteristic of snapping-through into a new equilibrium position at a certain temperature. The result of such a fast snap-through of a bimetallic shell, acting as a switching element in a thermal switch, is the instantaneous shutdown of electric power and the machine (Henry 1972) The snap-through of the bimetallic shell is a dynamic occurrence that lasts a very short time and as such prevents the damaging sparking and melting of electric contacts and extends the life time of the thermal switch (Jakomin 2011)

A thermostatic bimetal shallow shells are constructed from a laminated composite of metals with different thermal expansion coefficients. They deform with changes in temperature (Kosel 2007). At least one bimetallic shallow shell is used in each device; however, there are some controls that use three of them. The bimetallic shallow shell performs a snap action at defined temperatures and produces enough force to open or close electrical contacts. The temperature at which a bimetallic shallow shell "snaps through" on heating is called the "break temperature" and the temperature at which it "snaps back" on cooling is called "remake temperature".

Bimetallic shallow shells have been developed by purely empirical means. A great deal of experimentation has been carried out over the past decade to improve performance, and the improvements have been remarkable (Batista 2007).

It has been said that "Bimetallic shallow shells lend themselves poorly to calculation. They are designed empirically, based largely on experience. More than any other form of bimetal, they require starting materials whose physical and mechanical properties are precise and uniform, with small thickness variations, and excellent surface quality and flatness" (Trostel 1996).

At low temperatures, bimetallic shallow shells have a concave shape which then snaps to a convex shape at high great enough to activate a switch or make an electrical contact mechanically. As is common in discontinuous phase changes, shallow shells show considerable hysteresis behaviour (Figure 1). With adequate materials and correct shaping, the lower and upper snap temperatures, TLS and TUS, respectively, can be adjusted within a wide range.

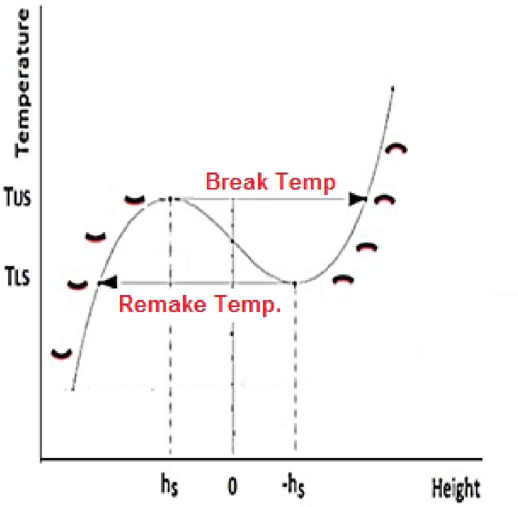

Figure 1. Qualitative characteristic of thermo-bimetal-snap disc.
The active steel layer is black and the passive invar layer is red (Ziga 2013)

The performance characteristics of the snap action disc are determined by a number of variables. These can be broadly classified into two groups: geometry and material variables. In order to optimise bimetallic shallow shell performance, it is necessary to define and understand these variables and identify the relative importance of each variable. Bimetallic shallow shell characteristics and variables are very specific, so the data about them cannot be easily found in literature. So, the effects of the shaping procedure and heat treatments of snap action disc on the instantaneous specific deflection of the temperature range will be investigated in this study.

Materials and Methods

In this study, manufacturing and calibration studies of the transducer using to control automotive engine temperature range to run on 86-94ºC were performed. For this purpose, the test unit shown in Figure 2, was carried out design and production. The test unit is designed to simultaneously perform the control of 10 transducers and continuous stirring was applied to homogenize the oil temperature. At the same time the oil temperature is kept under control in the middle level of the oil in the tank by a precision thermometer.

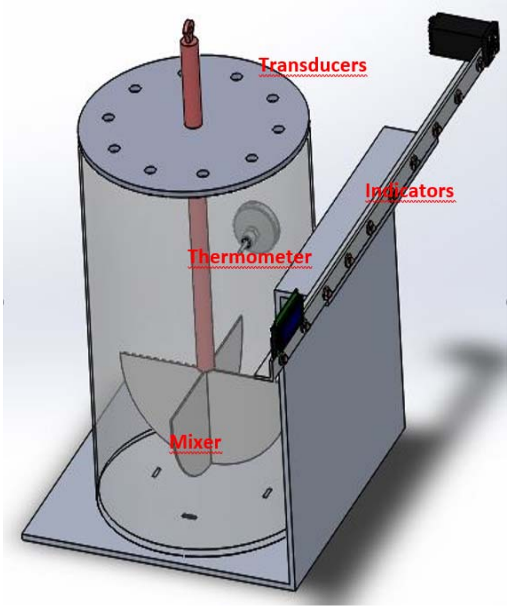

Figure 2. Test unit used in experimental studies.

A commercial bimetal strip was used for the manufacture of transducers. General properties of bimetal strip were given Table 1. The strip of bimetal material has a 0.2 mm thick and 25 mm wide was die cutted primarily in the form of a disk has a diameter 12.7 mm. Then, a hole has a diameter of 2 mm was die cutted to make it suitable for installation in disk from the centre as shown in Figure 3.

Table 1. The general properties of bimetal strip, used for manufacturing transducers

ASTM Type	TM2
High Expansion Alloy	Alloy P (72%Mn, 18%Cu, 10% Ni)
Low Expansion Alloy	Alloy 10 (36%Ni, Balance Fe)
Thickness	0,20 mm
Density	7.61 g/cm^3
Useful Deflection Temperature Range	-70 - 260 °C
Recommended Max. Temperature	430 °C
Specific Curvature (10-93°C)	39.1 x10^{-6} (mm/mm)/°C (Tolerance ±4%)
Specific Deflection	20.6 x10^{-6} (mm/mm)/ºC

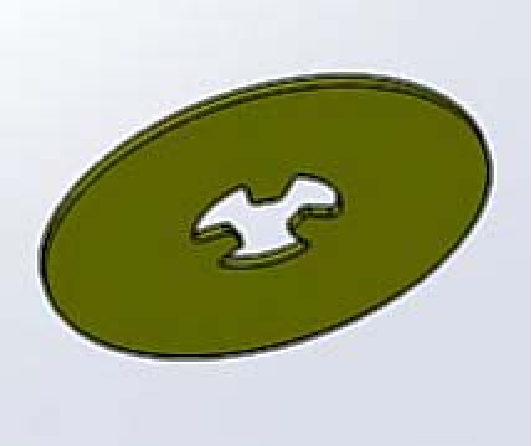

Figure 3. The schematic of the bimetal disc was die cutted for transducers

The parts of the engine temperature transducer (Figure 4a) and mounted transducers are shown in Figure 4b. The test unit was calibrated for the desired temperature range. The average values of every 10 measurements obtained from each transducer.

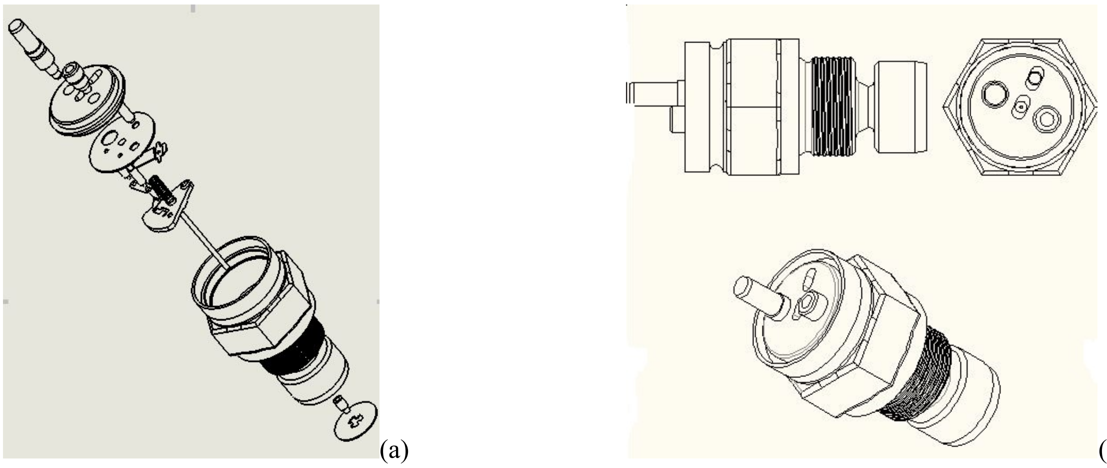
(a) (b)

Figure 4. The schematic of engine's temperature transducer used for experimental studies
a) The parts of transducer **b)** Mounted transducers

Results and Discussion

The performance of a particular bimetallic shallow shell can be summarized by the following process and material characteristics (Ziga 2013):

- Break temperature
- Remake temperature
- Force produced on snap through
- Shells life
- Temperature spread
- Specific thermal curvature of shell material

The break temperature (The Upper Snap Temperature) is the temperature at which a bimetallic shallow shell snaps from a concave to convex shape while being heated.

The remake temperature (The Lower Snap Temperature) is the temperature at which a bimetallic shallow shell snaps back from convex (broken shape) to concave shape while the blade is being cooled (Figure1). The difference between the break and the remake temperature is known as the "differential"

The test results of commercial bimetal strip used in transducers, the lower and upper snap temperatures, TLS and TUS, respectively, were given Table 2.

Table 2. Test results obtained from flat bimetal discs

Transducer	The Lower Snap Temperature (T_{LS}) (86±1°C)	The Upper Snap Temperature (T_{US}) (94±1°C)
S101	84.0	89.0
S102	83.0	88.9
S103	78.6	92.0
S104	84.0	90.0
S105	83.0	91.0
S106	87.0	98.5
S107	78.7	97.2
S108	92.8	95.4
S109	86.0	91.0
S110	86.0	98.0

Due to lack of the desired range of test results for the upper snap temperature and the most of the results are out of tolerance limit for the lower snap temperature, it was decided to form bimetal disc a shallow shell given in Figure 5. For this purpose, the bimetallic discs were loaded by a 3 MPa bending stress within 3 s to achieve desired shape has 0.50 mm height and 5° bending curvature.

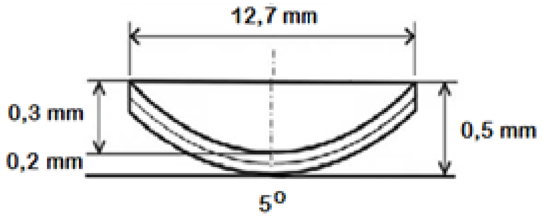

Figure 5. The schematic of the mechanically shaped bimetal shallow shell

After installation of transducers made of this shaped bimetal shallow shell were experimented in test unit. Obtained test result can be seen in Table 3.

Table 3. Test results obtained from pre-shaped bimetal shallow shell

Transducer	The Lower Snap Temperature (T_{LS}) (86±1ºC)	The Upper Snap Temperature (T_{US}) (94±1ºC)
S201	86.7	98.2
S202	87.6	91.5
S203	87.9	94.7
S204	87.5	91.0
S205	81.3	95.2
S206	82.0	95.4
S207	92.0	94.5
S208	89.5	89.6
S209	86.5	97.8
S210	85.6	93.5

Again because of the experimental results are not within the range to satisfy, it was decided to perform thermo-mechanical treatments to bimetal shallow shells. For this purpose, preformed discs heated to 350ºC in a furnace then cooled in a stagnant air. After installation of transducers made of this shaped bimetal shallow shell were experimented in test unit. Obtained test result can be seen in Table 4.

Table 4. Test results obtained from preformed discs heated to 350ºC in a furnace then cooled in a stagnant air.

Transducer	The Lower Snap Temperature (T_{LS}) (86±1ºC)	The Upper Snap Temperature (T_{US}) (94±1ºC)
S301	86.7	98.3
S302	88.0	92.0
S303	88.0	94.2
S304	87.3	91.5
S305	87.0	96.3
S306	82.4	96.3
S307	88.6	93.5
S308	86.7	90.0
S309	86.1	94.7
S310	86.2	94.9

Most of the experimental results are not within the tolerance limit, it was decided modify thermo-mechanical treatments. Firstly, preformed discs were heated to 350ºC in a furnace then cooled immediately to -30ºC. Then, discs were heated to 160ºC in a furnace then cooled immediately to -30ºC. This process was repeated 3 times. Obtained test result, after installation of transducers made of this shaped bimetal shallow shell were experimented in test unit, can be seen in Table 5.

Table 5. Test results obtained from the preformed discs were heated to 350°C in a furnace then cooled immediately to -30°C. Then, discs were heated to 160°C in a furnace then cooled immediately to -30°C. (Repeated 3 times)

Transducer	**The Lower Snap Temperature (T_{LS}) (86±1°C)**	**The Upper Snap Temperature (T_{US}) (94±1°C)**
S401	84.6	97.1
S402	88.7	95.0
S403	87.6	91.3
S404	86.9	92.7
S405	84.3	93.2
S406	87.6	90.3
S407	86.7	89.8
S408	87.4	97.2
S409	85.6	95.0
S410	86.5	92.8

Again these experimental results are not within the range to satisfy, it was concluded that the angle of curvature on the bimetal disc is insufficient. To increase bending curvature and achieve the shape has 0.60 mm height, the bimetallic discs were loaded by a 3 MPa bending stress within 3 s (Figure 6).

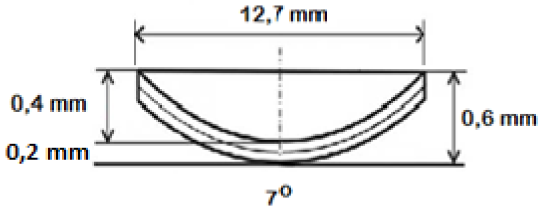

Figure 6. The schematic of the mechanically shaped bimetal shallow shell

After mechanical shaping, discs were heated to 350°C in a furnace then cooled immediately to -30°C. Then, discs were heated to 160°C in a furnace then cooled immediately to -30°C. This process was repeated 3 times. Obtained test result, after installation of transducers made of this shaped bimetal shallow shell were experimented in test unit, can be seen in Table 6.

Table 6. Test results obtained from the discs have 0.60 mm height and were heated to 350°C in a furnace then cooled immediately to -30°C. Then, discs were heated to 160°C in a furnace then cooled immediately to -30°C. (Repeated 3 times)

Transducer	**The Lower Snap Temperature (T_{LS}) (86±1°C)**		**The Upper Snap Temperature (T_{US}) (94±1°C)**	
	#10 repetitions	**#50 repetitions**	**#10 repetitions**	**#50 repetitions**
S501	86.0	85.1	94.0	93.5
S502	86.0	86.2	94.0	95.3
S503	86.0	86.7	94.0	94.0
S504	86.0	86.0	94.0	95.0
S505	86.0	87.1	94.0	93.6
S506	86.0	85.9	94.0	95.3
S507	86.0	87.1	94.0	93.6
S508	86.0	86.3	94.0	94.0
S509	86.0	86.0	94.0	94.5
S510	86.0	86.1	94.0	94.8

All transducers work at unique snap temperature. But as repetitions increase deflections from snap temperature increase. The life time of bimetallic shallow shells depends on repeatability and fatigue failure. The repeatability of bimetallic shallow shell performance characteristics under cyclic condition are of vital importance. If some significant deviation of any of these characteristics occur then appliances may not operate safely. After a sufficient number of cycles, bimetallic shallow shells will eventually fail due to fatigue. Premature failure of a bimetallic shallow shell could result in an unsafe appliance. Functional tests on controls and appliances are carried out as a matter of course to ensure the bimetallic shallow shells have sufficient fatigue life. These tests are also required to obtain necessary safety approvals for both controls and appliances.

In order to accurate exact snap temperature action for 100 recapitulate without any fatigue deflection, we decided to perform mechanical shaping process is repeated twice then the details of heat treatment mentioned above was applied. Obtained test result can be seen in Table 7.

Table 7. Test results obtained from the sample discs shaped twice by mechanically shaping process and heat treated by above procedure

Transducer	**The Lower Snap Temperature (T_{LS}) (86±1ºC)**		**The Upper Snap Temperature (T_{US}) (94±1ºC)**	
	#10 repetitions	**#100 repetitions**	**#10 repetitions**	**#100 repetitions**
S601	86.0	86.0	94.0	94.0
S602	86.0	86.0	94.0	94.0
S603	86.0	86.0	94.0	94.0
S604	86.0	86.0	94.0	94.0
S605	86.0	86.0	94.0	94.0
S606	86.0	86.0	94.0	94.0
S607	86.0	86.0	94.0	94.0
S608	86.0	86.0	94.0	94.0
S609	86.0	86.0	94.0	94.0
S610	86.0	86.0	94.0	94.0

Even after 100 repetitions no fatigue deflection was observed at any transducers. So we assured the digital behaviour for exact snap temperature and for all transducers.

Conclusion

The unique property of flexivity that characterizes thermostatic bimetals allows these materials not only to sense the temperature but also to control it by making or breaking an electrical circuit. Although the design of a thermostatic bimetal primarily depends upon the expansion characteristics of the components, resistivity is also critical in some applications. In addition, the strength and fatigue properties, interface integrity, and residual stresses play a major role in determining the behaviour of thermostatic bimetal elements.

The characteristic properties of transducers using thermostatic bimetal materials depend of mechanical shaping and heat treatments as well as materials properties. In this study, the digital switching action behaviour for exact snap temperature were assured by way of residual stress control with the application of unique mechanical shaping process and thermal treatment to stabilize the mechanical properties.

Acknowledgements

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References

Batista M., Kosel F. (2007), *"Thermoelastic Stability of Bimetallic Shallow Shells of Revolution,"* International Journal of Solids and Structures, 44. 2, pp:447-464.

Freygang M., Glosch H., Haffner H. and Messner S.(1996) *"Thermal Actuation Units for Microvalves and Micropumps",* Tech. Digest, 5th Int. Conf. New Actuators (Actuator '96), 26-28 June, 1996, pp: 84-87, Bremen, Germany.

Henry M.F, Coffin L.F. (1972), *"An Investigation of Switching Stresses in Bimetal Disks",* International Journal of Mechanical Sciences, 14.6, pp: 343-358.

Howard E. R.(1942), *"Thermostatic Bimetal",* Engineering and Science, 5.4, pp:16-24.

Jakomin M. (2011), *"Shallow Axi-symmetric Bimetallic Shell as a Switching Element in a Non-Homogenous Temperature Field."* Engineering, 3.02, 119.

Khadkikar, P (1993) *"The Principles and Properties of Thermostat Metals",* The Journal of the Minerals, Metals & Materials Society (TMS), 45.6, pp: 39-42.

Kanthal, A.B. (2008.), *Kanthal Thermostatic Bimetal Handbook*, Box 502, SE-734 27 Hallstahammar Sweden.

Kosel F, Jakomin M. (2007), “*Snap-through of the Axi-Symmetric Bimetallic Shell,”* Proceedings of the Third International Conference on Structural Engineering, Mechanics and Computation, pp: 348-356. Cape Town

Trostel H, Tiers F.J.(1996), *The Iron-Nickel Alloys*, Chapter 18, Lavoisier, New York.

Ziga G, and Kosel F (2013), "*Experimental Analysis of Kinematics of Snap-Through of the Shallow Axisymmetric Parabolic Bimetallic Shell",* International Journal of Basic & Applied Sciences IJBAS-IJENS, 13.04, pp: 23-29.