THERMOSTATIC BIMETAL

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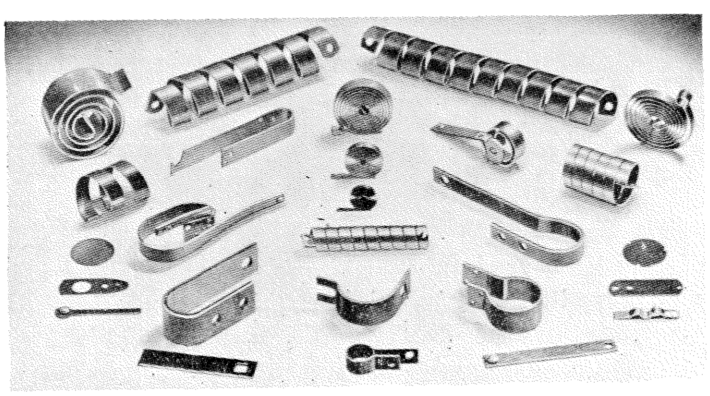
Many important problems of control in industrial processes are being solved by the use of thermostatic bimetal. Mr. Howard discusses a number of these applications and outlines the basic principles of bimetal behavior.

One of the most unique bimetal applications in production today is a circuit breaker containing a bimetal helix of two turns shunted by a piece of copper braid welded to the ends of the helix and used as the complete and short circuited secondary of a current transformer. The two turns of this secondary produce a voltage which dissipates energy into the bimetal itself, heats the bimetal helix, causes it to rotate and if primary current exceeds a given value causes the helix to trip a disconnect switch. The domestic, industrial and war world of today is literally full of applications of bimetal and possibilities for its effective use. Bimetal is used in jeep and tank, in aircraft instruments and radiator control valves of many kinds.

Let us see what properties bimetal has that it finds such diverse uses. Bimetal in general contains two layers of metal of equal thickness, one a thermally high expanding component, the other a thermally low expanding component. The American Society for Testing Materials defines bimetal or thermostatic metal as "a composite material, usually in the form of sheet or strip, comprising two or more materials of any appropriate nature, metallic or otherwise, which, by virtue of the differing expansivities of the components, tends to alter its curvature when its temperature is changed." The components used for bimetals are chosen first for their temperature characteristics and then for strength, workability, stability, heat conductivity, and electrical properties. Brass and invar make the cheapest and most common bimetal, but it can readily be seen that the temperature this metal will stand is limited by brass to about 300° F. Most of the socalled high temperature bimetals have replaced brass as the high expanding member by an iron nickel chromium alloy of the stainless steel family, and can stand subjection to temperatures of 800° F., sometimes 900 and 1000° F., but then with practically no loading. Bimetals may be made to react to change in temperature over any given range of temperature by proper choice of components, particularly those used as the low expansion component. The addition of a third or intermediate layer to bimetal is made to change electrical resistivity for certain applications which will be discussed later. In practice, the components of bimetal are welded together into a large bar which is subsequently hot and cold rolled to sheet. Most bimetal depends on final cold rolling to finish size for its physical properties and is not heat treatable in the sense of improving physical properties. A low temperature heat treatment (350° F. for the brass invar metal and 650° F. for most of the others) is given for stress removal after final fabrication. The nature of bimetal then is sheet material which may be fabricated into any of a number of forms which will be responsive to temperature changes.



Assorted bimetal shapes.

The uses of bimetal fall into four general classifications as follows: (1) Temperature Indication, (2) Temperature Control, (3) Control of function with temperature change over a range of temperature, and (4) Control of function by auxiliary heating of the bimetal. Let us consider at least one example of each of these classes. First, temperature indication is well pictured in the spiral coil or helix actuated pointer thermometers which indicate temperatures on wings of airplanes, in domestic refrigerators, in offices and factories, in laboratory baths and furnaces, in candy making and even in roast meat. In this type of service the bimetal is .005 to .015″ thick, the coil is made to fit the pointer scale and the only load requirement that the bimetal must meet is the production of enough torque to move the pointer freely. The range of temperatures covered by bimetal in temperature indication includes minus 50° F. and plus 1000° F. Angular deflection rates up to 2½ to 3 degrees per degree F. can be obtained.

The second classification, that of temperature control, can be amply illustrated by the room temperature thermostat, a device in some cases consisting of a bimetal blade upon which is mounted a current carrying contact point aligned with a mating stationary contact point which can be an adjustment. The operation consists in the bimetal blade moving the pair of contacts into open or closed circuit and thus stopping or starting the supply of heat to the room. In many applications of this type the bimetal may remain within a few degrees of its controlling temperature over an indefinite period of time.

The automatic choke on a modern gasoline engine is a good example of the third classification mentioned above. Here no attempt is made to control temperature itself, but the supply of air to a fuel-air mixture is controlled by the temperature of that air. The usual automotive type of choke control consists of a bimetal coil which positions a butterfly valve in the intake airstream so that the desired fuel air mixture is obtained for any air temperature encountered. This classification may also be considered to include the large number of applications where a piece of bimetal compensates for temperature changes in devices which are complete in themselves except when they have to operate over a range of temperature, for example voltage regulators. In the Tirrel or vibrating contact type of regulator, voltage is controlled by regulating generator field current by controlling the amount of times a certain pair of contacts are closed. One of these contacts is mounted on an armature spring and is drawn away from the other as the voltage coil underneath the armature increases its pull. This arrangement works satisfactorily for a range of loads and voltages at a given temperature, but when temperature changes, regulation too changes in the same direction. By the insertion of a piece of bimetal into the armature this voltage regulation can either be made the same for any temperature or may be overcompensated if such is the wish of the designer. In other type of voltage reguators compensation by bimetal is obtained dependent on the method of voltage regulation used.

Time delay devices and circuit breaker applications are the two main groups which compose the fourth or final classification, that is, where control of a function is effected by the introduction of heat to a piece of bimetal. In this section functions such as time and current which in themselves have no connection with temperature whatever may be controlled by the auxiliary heating of bimetal. If for instance a certain time sequence of electrical operations is desired, a number of bimetal strips (or other shapes) can be so assembled that they will provide the required making and breaking of circuits when they are heated with outside resistors or by current passing through their own electrical resistance. One of the newest fields using bimetal is that of the circuit breaker. A piece of bimetal is made the active element in a circuit breaker by passing current through it and thus having it respond to the temperature generated in it. The circuit breaker operates when the temperature built up is enough to open circuit. While in some cases this circuit opening is slow make and break, in most cases the final opening of the circuit is done quickly by snap action either inherent in the shape of the bimetal or accomplished by the tripping of a latch in the body of the circuit breaker. The circuit breaker may have either manual or automatic reset as designed. It is for use in electrical circuit breakers that the trimetals or graduated resistance metals mentioned above have been introduced. With their use a single circuit breaker design may be used for several current capacities simply by using a trimetal of different electrical resistance for each capacity. Constant mechanical properties are exhibited by these different trimetals because they are made to the same physical dimensions and have the same modulus of elasticity. Constant thermal deflection characterists are obtained because all have practically the same temperature deflection rate and all have the same I^2R heating product when used at their rated capacities. For example if a circuit breaker is designed for 15 amperes using R-440 (440 ohms, sq. mil. ft.), the same construction will produce a 20 ampere breaker using R-245, a 25 ampere breaker using R-157, a 30 ampere breaker using R-118, a 35 ampere breaker using R-77, a 40 ampere breaker using R-56, and a 50 ampere breaker using R-39.

While it is not the purpose of this article to go into details in the mathematics of bimetal, it will be well to put forth the fundamental equations which can be applied to any piece of bimetal as minutely or as roughly as required for the desired result. As stated before the fundamental characteristic of bimetal is its ability to change curvature with change in temperature. This is simply expressed as

$$\frac{1}{R} = \frac{F\,T}{t}$$

where 1/R is curvature (R in inches)
T is temperature in deg. F.
t is thickness in inches
F is flexivity in inches per inch per deg. F.
(ASTM B106)

For most bimetals F is equal to 1½ times the difference in thermal coefficient of linear expansion of the high and low expanding components. Bimetal which is free to move will change its curvature according to this formula if its temperature changes. Then if we pick up the basic flexure equation from page six of the Strength of Materials Book

$$M = \frac{EIFT}{t}$$

where 1/R is curvature (R in inches)
M is bending moment in ounce inches
E is modulus of elasticity in ounces per sq. in.
I is moment of inertia in inches fourth,

we have the whole story. Combining these two equations we get a third showing what torque a piece of bimetal will develop with change in temperature in case it is restrained from actual motion.

$$M = EI\,\frac{FT}{t}$$

Practically all bimetal formulas are combinations of the above three equations. Thus the deflection of the free end of a cantilever blade of bimetal is

$$d = \frac{F\,L^2T}{2\;\;t}$$

where d is the deflection in inches
F is Flexivity as defined above
L is free or active length in inches
t is thickness in inches
T is temperature change in degrees F.

The deflection of the free end of a spiral or helix clamped at the other end is given by

$$R = \frac{FTL}{t}$$

where R is the angular rotation in radians
F is the Flexivity
L is the developed length of the coiled strip in inches
t is the thickness in inches.

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counter-offensive against Germany. Action on the Japanese-Russian front is, it would seem, inevitable. Any serious interruption of Japanese campaigns on any other front—Australia, India, China—might well have the effect of turning Japanese energies once more against the Russian Far East and other bases in the North Pacific. The longer such a development is postponed, the better prepared will be both Russian defenses and the bases and supply lines essential to the delivery of assistance to this part of Russia from North America. In short, spectacularly successful though Japan has been in five and one-half months of warfare, she has done little more than give Germany some superficial and probably short-lived respite. Successes comparable to those in Malaya and Burma are not likely to be repeated, because not only has Japan's problem of supply become more difficult but also the opposition which bars her way has grown in wisdom and stature. And the more widely Japan spreadeagles her strength over Eastern Asia and the Southwestern Pacific, the more precarious becomes her position from sheer unbalance and the more exposed to effective counter-attack. Germany has already enjoyed the first and choices fruits of Japan's entry into the war. These have not brought victory for the Reich; they have only deferred defeat.

All this is by no means meant to suggest that the overpowering of Germany will be easy, or that her capacity and will to resist will crumble before the specter of defeat; or that, with Germany's collapse, Japan will give up. These two powers and their satellites will take a deal of beating and the United Nations cannot afford to indulge in easy optimism. For certain as is their final victory, it will be difficult and costly to achieve.

What provision the eventual peace settlement will make for the defeated Axis powers is, of course, not known. But, in all justice, severity is more to be expected than leniency. One may be permitted to wonder whether under the settlement Germany will be in a position and mood, as in 1919-20, to set up investigating committees to inquire into "the causes of the German collapse." The investigations of two decades ago were searchingly self-critical: weaknesses of the army and the home front were laid bare and mistakes of campaign were exposed. Military lessons learned from these investigations have contributed materially to the successes of German arms since 1939. These successes may be, indeed, the most important end-product of the inquiry. But there appears also to have been a not unimportant by-product. From the inquiry the German military mind seems to have emerged, as did General Hoffmann, reflecting on the first world war as one of "lost opportunities," and with the conviction that given a second chance in which weaknesses would be eliminated and mistakes corrected, new opportunities would not be lost but seized upon and victory made certain.

It would be most regrettable if, after this war, some surviving German general, titillated by the "ifs" and "might-have-beens" of history, should stamp the German war effort of 1939-194? as one of "lost opportunities," and dwell upon those moments in the war's progress where victory had barely eluded German arms. How could the German military mind be made to resist toying with the fire which such speculations would strike into flame? Surely this is one problem which will have to occupy the attention of the peace-makers, if they are to inherit the earth. Perhaps it should be made obligatory on all German army officers to take an orientation course in The Physical Principles of World History, the main lesson of which would be that he who plays with fire will surely get burned, and that, in this particular at least, history does repeat itself!

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These are basic formulas. In actual practice it is found that other factors such as width, width-thickness ratio, Cross curvature, and method of mounting may sometimes have an appreciable effect on bimetal action.

Thin bimetal responds more quickly to temperature change of the surrounding medium than does thick bimetal. Thus, if heavy bimetal must be used for power considerations and quick temperature response is a factor, rapid flow of the medium in which the bimetal is placed must be provided. There is no lag in the response of bimetal to temperature change provided that the bimetal itself has changed temperatures. Since bimetal is used in thicknesses of .002 inches to .125 inches, in widths of 1/32 inch to 2 inches, and in lengths of ¼ inch to 100 inches, it can be seen that its applications are varied and that each application may have its own peculiarities The illustration shows an assortment of various shapes and sizes covering a large number of uses.

Bimetals of course have limitations as to the temperatures they can stand and the loads they can carry. However, as engineering materials, bimetals have their place, for in many applications they are either the only solution to the problem or else offer the cheapest satisfactory solution.