English version

ULTIMHEAT® MUSEUM

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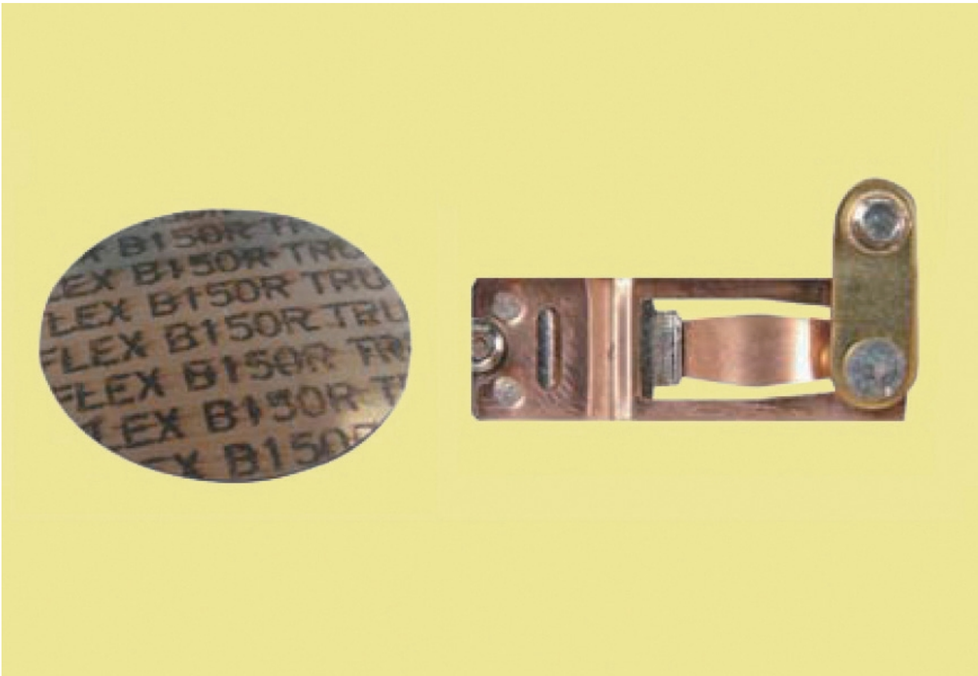
Technology of components used in heating.

Chapter 13

Introduction to thermostats technology



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1.TEMPERATURE SENSING PRINCIPLES

1.1 BIMETALS

1.1.1 BIMETAL STRIPS

The bimetal strip is formed by two co-laminated metal. One has a high coefficient of expansion, the other a lower or zero. When this strip is heated, it bends proportionally to the temperature . These bimetal blades are generally flat and fixed at one end. But they can be wound in a spiral shape, although this arrangement most often used in the construction of thermometers.

1.1.2 DISCS AND DISCS VARIATIONS

In many applications, it is needed to produce a bimetal with a snap operation with a sudden change of shape at a given temperature. For this, a bimetal disc is bumped and formed into a dome. Temperature changes cause an accumulation of energy therein, which, at a specified temperature, snaps from the concave to the convex shape. A very rigorous selection of the composition, thickness, depths of stamping and heat treatment, is requested to obtaining accurate, stable and repetitive operating temperature.
Based on original round form, were developed rectangular shapes, ovals, etc..
The main difficulty is to obtain a small tolerance and a small differential on operating temperature .
But these snap action discs are the sensing device of most temperature limiters on the market.

1.2 DOUBLE METAL EXPANSION

Double metal expansion is the differential expansion of 2 different metals, not laminated together. Metal thermal expansion produces huge force, enough for example do bend railways rails when expansion gaps are not correctly designed.

1.2.1 CARTRIDGES

The cartridge consists of an outer expandable tube, usually stainless steel, and two non-expandable internal blades, usually Invar.
The elongation of the envelope is a function of temperature. For a length of about 100 mm, this expansion is 0.0020mm per°C.

1.2.2 PARALLEL BLADES

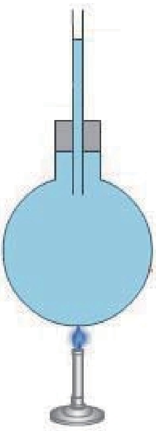
Their principle is similar to cartridges, they are made of one expandable copper

alloy blade to which is welded at each of its ends a bow shaped invar blade. Expansion of the copper alloy blade will tend to reduce the distance between the two blades.

1.2.3 RODS

The rods are formed of an outer expandable tube in stainless steel, copper or brass, and an inner invar rod. Expansions value are similar as the cartridges. This principle is the basis of most current water heater thermostats. This is a very simple, very reliable, the reaction time is very fast, as it is the outer tube itself that measures the temperature.
Through the use of expandable metal instead of Invar, it is possible to obtain devices with anticipative control action, which is very close to proportional action of electronic controllers.
Using the same metal for the outer tube and the inner rod provides controls that are only responsive to fast changes in temperature and are used in fire detectors.
In very high temperatures, invar rod can be replaced by quartz or alumina.

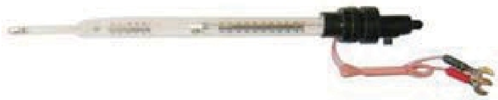
1.3 LIQUID EXPANSION



Liquids are incompressible and expand as solids. The expansion forces are very important and will develop considerable power to the mechanisms.
The expansion of liquid are used in closed subassemblies named « diastats », they consist of a bulb, a capillary, a bellows or diaphragm.
The expansion of the liquid in the bulb is transmitted through the capillary to the diaphragm which inflates and produces movement. Diaphragms expansion ranges are between 0.4 and 0.8mm for the entire measuring range. Bulbs volumes are calculated to provide a specific displacement for a given range. Freezing temperature of the liquid gives the lower limit of use, the upper limit is the boiling temperature. Raising these limits generally cause the destruction of the diastat.
The good thermal conductivity of liquids used provides short response time.

1.3.1 LIQUID METALS

Mercury was the first liquid used in thermostats.
Its first use was the traditional mercury thermometer.



Its expansion is almost linear from ambient to 500°C.
This is an excellent conductor of heat. So it was ideal for liquid thermostats. However its toxicity has done it to virtually disappear during last decade

1.3.2 LIQUID METALLOIDS

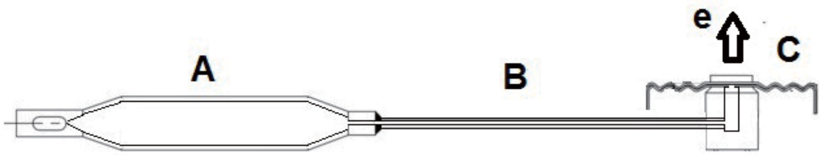
Metalloids are on the borderline between metals and other materials. In thermostats, are only used sodium and potassium, and especially an eutectic mixture of the two, NaK, which as the interesting characteristic to be liquid in a wide range of temperature, from ambient temperature to over 900°C. It is also an excellent conductor of temperature.
These two characteristics have earned him to be selected as a coolant for nuclear plants.
For temperature measurement, it also has the advantage of having a linear expansion.

Its use in thermostats is relatively recent, and arose with self-cleaning ovens, because it allows devices withstanding high temperatures.
However, it must used in protected devices, without contact with air or water, because it is particularly reactive, flammable or explosive in contact with them.
It is also corrosive and requires special stainless steel diastats.

1.3.3 OILS

Many oils are used. They are always a compromise between a high coefficient of expansion, which allows small bulbs, a boiling point as high as possible, a freezing temperature as low as possible, a good linearity in the range expansion, a good thermal conductivity, and non-toxicity .
Among the most common, we must mention the xylols, oils used in heat exchangers, and silicone oils.
It is now possible to cover with these 3 types of liquids, ranges from -40°C to 400°C.

1.3.4 THE THERMAL DRIFT (CORRECTION FACTOR) OF LIQUID FILLED BULB AND CAPILLARY THERMOSTATS



The bulb and capillary thermostats have a closed subassembly called "Diastat".
This diastat, with bulb and capillary made of copper or stainless steel, is composed of 3 parts welded together:
1.The bulb (A), which is the reservoir of the largest portion of the liquid, and which expansion as a function of temperature will be used to measure it. It is closed at its free end by welding after liquid filling.
2. The capillary (B), whose outer diameter varies depending on the manufacturer and type of thermostat, between 1 mm and 3 mm, which serves to transmit remotely the increase in volume of the liquid in the bulb
3. The bellows (C), consisting of two flexible cups welded together on their edges, having a diameter of 19 to 25 mm (sometimes up to 32 mm on industrial devices), which will convert the increase of the bulb liquid volume into mechanical displacement (e).
These three parts are filled with a liquid under vacuum. The expansion of the liquid, proportional to the temperature increase, causes the displacement "e", which is used to operate an electrical contact.
However, the expansion of the liquid in the capillary (B) and into the bellows (C) is not related to the temperature measured by the sensor (A), but to room temperature in which they are located, and cause therefore a parasite expansion of the liquid and therefore an unwanted mechanical displacement .
The design of a diastat tends to minimize this movement, by limiting the volume of liquid in (C) and (D) by 2 ways:
- By limiting the capillary internal diameter. The minimum diameter is a compromise between the technological possibilities of embodiment of the capillaries, the stresses due to bending of the capillary, and the water pressure losses permissible depending on the viscosity of the liquid used, and the pressure developed by the expansion.
- On the bellows: When filling the diastat, the two membranes forming the bellows are pressed against each other, without gap, and thus only a small amount of fluid can go between them. However the volume of liquid in the bellows increases progressively as the liquid in the bulb (A) expands by the temperature rise. The ratio of the drift therefore not only reports to the initial volume inside the bellow,

but increase with the temperatures as this volume increases with the temperature rise on the bulb.

The counterpart of this design of the bellows with a small amount of liquid when filling the diastat is that no mechanical movement is possible below this filling temperature. In assembled thermostats, adjusting the set point is not possible below this temperature at which the bellows is empty. This area below the filling temperature is called "dead zone", and typically corresponds to an area where no temperature is printed on the thermostat knob.

The parasite drift of a bulb and capillary thermostat will be given in the data sheet and expressed in°C /°C or °K /°K.

It depends on the volume ratio between the bulb and capillary + bellows. A large volume bulb is less sensitive to drift, and a short capillary also decreases it.

In the case of fixed temperature high limit thermostat, the small bulbs will lead to a high sensitivity to the ambient temperature on the thermostat body.

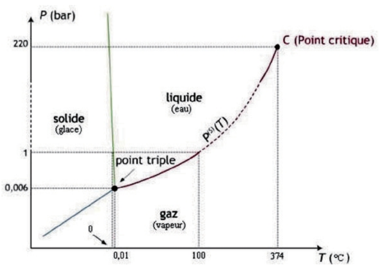
Comparative values for thermal drift in a dia. 19 mm membrane diastat, and a displacement "e" of 0.8 mm for the temperature span (approximate values)			
Temperature range	Drift with 250 mm capillary (°K/°K)	Drift with 900 mm capillary (°K/°K)	Drift with 900 mm capillary (°K/°K)
4-40°C	0.1	0.12	0.14
30-90°C	0.18	0.20	0.24
50-300°C	0.25	0.45	0.58

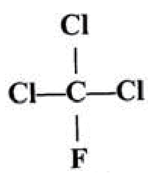
This drift explains that thermostats calibration temperature are given for a body ambient temperature of 23°C+/-2°C (standard ambient condition given by EN60068-1), and usually for an immersed capillary length of 80 to 100 mm

Examples of temperature drift on a thermostat with a 1.5 m capillary (to be added to calibration tolerances)

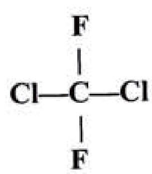
Temperature range (°C)	Set point temperature (°C)	Effective contact opening temperature if ambient on thermostat body is 0°C	Effective contact opening temperature if ambient on thermostat body is 50°C
4-40	40	40+3,2	40-3,8
30-90	90	90+5,5	90-6,5
50-300	300	300+13,3	300-15,7

1.4 VAPOR PRESSURE





Freon-11



Freon-12

This system involves in diastats a mix of liquid and its saturated vapor , just as in a butane bottle, where are coexisting gas and liquid.

In this closed environment, any increase in temperature results in an increase in pressure and significant volume changes.

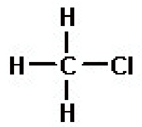
Unfortunately gases are compressible, and even if it is possible to obtain significant movements, the available force is low. Movements are not linear, and these systems are sensitive to changes in atmospheric pressure. Among the main fillers used, there are:

1.4.1 FREONS

They are used because of their availability, and existing vacuum filling systems for refrigerant circuits. They also work in low temperatures.

1.4.2 BUTANE AND PROPANE

They are used for the same reasons as above, but have the disadvantage of being flammable.



1.4.3 OTHERS: METHYL CHLORIDES

They are used in capillary thermostats and membranes room thermostat

1.5 STATE CHANGE

In state change devices, a linear displacement against temperature it not used. What is used is the instant change of volume that appears at specific temperatures at melting, freezing, and boiling points on various elements.

For example, the freezing point of water at 0°C causes an increase in volume, melting at 0°C causes a reduction in volume, but also the transition from the solid state to the liquid state : when water is boiling at 100°C steam causes large volume increase.

State change systems will therefore use these special properties of a number of elements and compounds.

1.5.1 WAXES

Thermostatic wax is a complex mixture of many components providing a different Melting / Freezing temperature depending on the composition. At this temperature there occurs a high volume change. Waxes have the characteristic increase in volume when they melt.

This system, which causes a high displacement, is used for car thermostats, to open the flow path of water. It is also common in central heating radiators thermostat, as well as in mini-jacks locking the doors of ovens, washing machines and other appliances.

1.5.2 LOW FUSE TEMPERATURE ALLOYS

These fusible alloys are all descendants of those discovered by Darcey at the beginning of the nineteenth century. An alloy of tin, antimony, lead, bismuth and other metals, will have melting temperatures between 25 and 200°C depending of the percentage of each ingredient.

Their first applications were opening the steam pressure locomotive blowdown valve. The melting of the alloy at a predetermined temperature is used to release a mechanical system (fire fusible links) or directly open an electrical circuit (thermal cut-out electrical fuses).

1.5.3 BOILING

The boiling of a liquid causes, in a closed circuit, a sharp increase in pressure. This increase in pressure may be due to local boiling in a capillary thermostat diastat. This allows to make thermostats sensitive to temperature on a long distance, detecting hot spot at any place on the capillary.

Boiling is also used in glass bulbs, which breaks when the liquid inside boils and releases a mechanical or electrical system. The best-known application is the control of the "sprinkler" systems, common in building fire detection .

1.6 OTHER SYSTEMS

1.6.1 THE CURIE POINT

The Curie temperature is the temperature at which a magnet loses its magnetization.

This temperature can be changed by altering the composition of the magnetic alloy.

This loss of magnetization releases a mechanical or electrical system.
This application is limited to a few specific uses, such as rice cookers.

1.6.2 FORM MEMORY

Some alloys or compounds, subject to a certain temperature, return to the form they had before their mechanical processing. Heat treatment and composition determine these temperatures.

1.6.3 EXPANSION OF GAS

This system is mainly used for the production of thermometer, because the available forces are weak and can hardly operate a contact. Is linear expansion and allows a linear scale in a wide range of temperatures.
The gases used are mainly helium and argon
These systems are sensitive to atmospheric pressure and demand a compensation system

2. ELECTRICAL CONTACTS




As numerous mechanisms exist, we decided not to distinguish on the basis of constructive technique, but according to their operation speed, which is the key element.

2.1 ELECTRICAL CONTACTS SYSTEMS

2.1.1 SLOW BREAK

In slow break contacts both sides deviate slowly at speeds of the order of 1/10 mm per second.
In the normal atmosphere, then an electrical arc occurs when the contacts are close together.
The duration of this arc is a function of voltage.

For voltages up to 24V DC or 110VAC, the duration of this arc is short, less than 0.1s.
For higher voltages, the arc lasts much longer, producing premature fusion of the contact, and many radio interference.
This is why it is not recommended, despite the mechanical advantages (simplicity, low cost, high precision), to use slow break (or slow make) contact in 230V electrical circuits , for fast cycling applications.

2.1.2 SNAP ACTION

On snap action contacts, the gap between contacts occurs at much higher speed, of about 1m per second (100,000 times faster than a slow break contact). The contacts spacing to extinguish the electrical arc is reached in less than 1/1000 sec. There is no radio interference, and the contact does not substantially deteriorate.
This type of contact is mechanically much more complicated, more expensive, and does not allow small differential control. It is particularly suitable for control devices in 240V or 400V. Several techniques are used to get a snap action:

- The oldest is the use of magnets on the contact blades. The magnetic field decreases with the 4th power of distance. The attraction between the two blades thus takes a very short distance. This system is highly reliable, but not currently used due to the large number of components that it requests.
It was used extensively on the needle contacts on barometers, manometers, thermometers with a circular dial, and was the first snap action system to be used in thermostats

- The most common today is the energy storage blade, whose drawings have been are simplified in recent years, largely due to the improvement of beryllium copper alloys, and new design concepts.

2.2 CONSTRUCTION

2.2.1 MATERIAL CONTACT

Before the development of silver electrical contacts, the first electric thermostats used mercury. Liquid mercury, enclosed in a glass bulb having two electrodes, established the contact between them by tilting, or more simply, a metal needle, by its movement, established the contact with the surface of the mercury.
Electrical contacts are currently rivets made of pure silver, or slightly alloyed with other metals or oxides (Cadmium, Nickel, Tin,)
Silver was chosen because it is the best known conductor of heat and electricity.
Contact wears by micro vaporization at each open and close cycle. This vaporization is proportional to the strength and duration of the electric arc.
The thermal conductivity of the silver allows it to quickly evacuate the peak temperature occurring during opening of the contacts.
Its very good electrical conductivity allows for devices with very low contact resistance, generally less than 3 milliohms.
However it is not stainless and is gradually covered by a thin layer of silver oxide which is not electrically conductive.
This layer is easily vaporized during use in common household voltages (120V, 230V). However, for use in low voltage (less than 12V) and very low currents (a few milliamperes), the arc created when opening the contact is not sufficient to vaporize the contact.
This is the reason why, for low-power circuits, the contacts are protected against the oxidation by a thin layer of gold.

2.2.2 CONTACT GAP

After opening, the contacts are spaced by a gap. This gap, according to the device may vary from 1/10th to 3mm or more. An usual value in thermostats is 0.3 to 0.4 mm, which corresponds to micro-disconnection requested by electrical standards .
Smaller gap, which is the mechanical requirement to make low differential devices (see definition belows) cannot be used in high voltages, because, although there is no mechanical contact between the 2 contacts, an electrical arc can spontaneously appears in 380 or higher voltages: just adverse weather conditions such as high relative humidity may be sufficient.
A method to increase the contacts gap without requiring thermostats to provide significant movement, is the double break, used on some manual reset thermostats, which also reduces the risk of contact welding

2.3 CONDITIONS OF USE AND ELECTRICAL LIFE

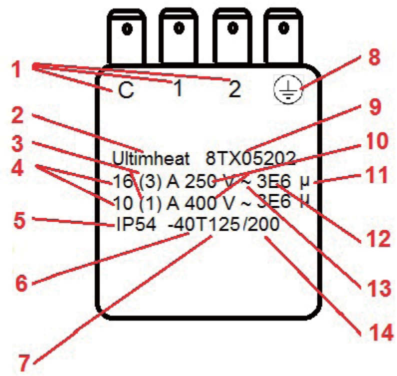
In the specifications for an electromechanical thermostat, the expected life is described in terms of mechanical and electrical.

Electrical life:
This is specified as a minimum number of cycles (action of opening and closing) will make, carry, and break the specified load without contact sticking or welding, and without exceeding the electrical specifications of the device.

Mechanical life:

This is the number of operations which a thermostat can be expected to perform while maintaining mechanical integrity. Mechanical life is normally tested with no load or voltage applied to the power contacts, and is not part of this document.
Switch performance is influenced by a variety of factors, including: frequency of operation, type of load, temperature, humidity, altitude. Electrical ratings are been tentatively standardized in UL 1054, CSA22.55 or IEC61058-1 (Switches for appliances). IEC60730-x standards have specified testing methods and preferred electrical life classes for electrical control and safety switches. These life classes are (cycles):
300 000, 200 000, 100 000, 30 000, 20 000, 10 000, 6 000, 3 000 (1), 1000(1), 300 (2), 30(2)(4), 1(3).
1) Not applicable to thermostats or to other fast cycling actions.
2) Applicable only to manual reset.
3) Applicable only to actions which require the replacement of a part after each operation.
4) Can only be reset during manufacturer servicing.
The rating tables should be considered as working maximum for most applications. Hereunder are given some limitations that apply when they are used in other loads and voltages.
The current rating of thermostat switches is given in their technical data sheets for a resistive load in 250 or (and) 400V AC and a specified number of operations. When there is enough room, these values are printed on the product. In most of case, only the minimum mandatory information is printed. The cycle number is exceptionally printed, but this is one of the most critical parameter to estimate the expected life of the thermostat.

2.3.1 EXPLANATION OF PRINTED VALUES MADE ON A THERMOSTAT UPON IEC60-730-1 § 7-2



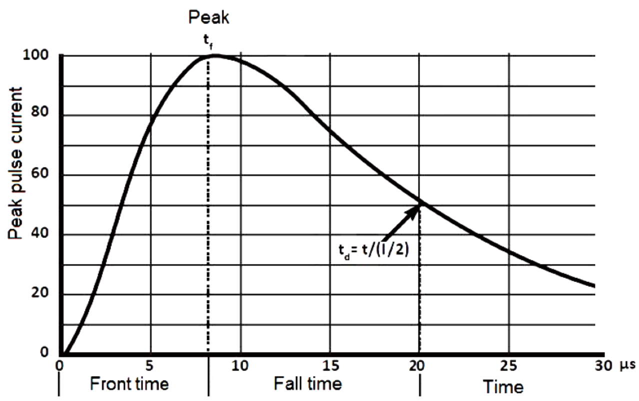
1: Identification of terminals that are suitable for the connection of external conductors, and if they are suitable for line or neutral conductors, or both.
L= must be used for line in United Kingdom, other countries no restriction. N must be used if the terminals must be used for neutral (All countries)
2: Manufacturer's name or trade mark
3: Inductive load rating with power factor = 0.6 (When inductive load value is not printed, these contacts may be used for an inductive load, provided that the power factor is not less than 0,8, and the inductive load does not exceed 60 % of the current rating provided for the resistive load.)
4: Resistive load rating with power factor = 0.95+/-0.05
5: Degree of protection provided by enclosure, does not apply to controls or parts thereof classified as IP00, IP10, IP20, IP30 and IP40.
6: High temperature limits of the switch head (Tmax), if other than 55°C.
7: Low temperature limits of the switch head, if lower than 0°C
8: Ground terminal identification (if existing)
9: Unique type reference
10:Rated voltage or rated voltage range in volts (V) (Frequency printing is

mandatory if other than for range 50 Hz to 60 Hz inclusive)
11: Micro-disconnection (reduced contact gap) Printing is not mandatory.
12: Number of cycles of actuation for each manual action (For manual reset thermostat).
Number of automatic cycles for each automatic action (for control thermostat). Printing is not mandatory
13: For use on alternative circuit, 50 to 60Hz inclusive
14: Temperature limits of mounting surfaces (Ts) if more than 20 K above Tmax

2.3.2 VOLTAGE, RESISTIVE OR INDUCTIVE CIRCUIT, SHIFTING ANGLE (cos phi)

In Europe, the most common voltage is 230 Volts AC 50Hz. In general, all devices are designed for these conditions.
400V operation must match particular contact spacing. However, particular attention must be given to the type of load to control: Electrical ratings are always given for a resistive load (cos phi = 1). Applications with inductive loads like motors, transformers, coils, ballast, or capacitive loads, like capacitors on one or 2 speed motors cause much more important electrical arcing between contacts . These inductive or capacitive loads severely limit the contact rating.

Electrical contact rating reduction on inductive loads



Overvoltage peak on inductive load circuits
When a switch breaks an inductive load, a fairly high counter electromotive force (counter emf) is generated in the switch's contact circuit. The higher the counter emf, the greater the damage to the contacts.
The quantity of electrical current which flows through the contact directly influences the contact's life. Impulse voltage is the critical value which the switch must withstand when the voltage surges momentarily due to switching an inductive load. They generate a current surge wave, witch form has generally a pulse width of 20 to 50 µs. Surge pulse rating is specified by its intensity and its width. Pulse width is time measured from pulse start to decrease to 50% of its maximum current value.
Figure shows a 8/20µs rated curve.

Motors loads impulse voltage:
During start-up, a motor can pull 600% or more of its running current. Thus, a 3 amp motor may actually pull 18 amps or more during start-up. Additionally, when disconnected, a motor acts as a voltage generator as it slows to a stop. Depending on the motor, it can feed back into the circuit voltage well in excess of rated line voltage. These voltages appearing across the separating contacts can cause a destructive arc to exist between the contacts, which can lead to early failure of the contact.

Lamp loads impulse voltage:
A tungsten filament lamp, when filament is cold, has an initial inrush current of 10 to 15 time the nominal current.

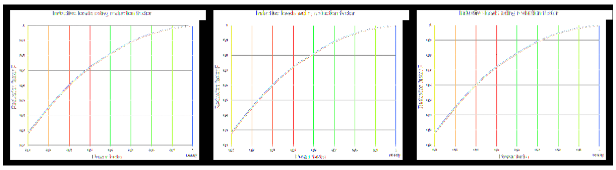
Transformers inductive loads:

When power is removed from a transformer, its core may contain remanent magnetism. If power is reapplied when voltage is of the same polarity as that of the remanent magnetism, the core may go into saturation during the first half-cycle of reapplied power. As a result, inductance will be minimal and an inrush current of perhaps 1,000% may exist for a few cycles until the core comes out of saturation. Also, as with motor loads, when power is removed from a transformer, the transformer will develop a counter voltage which can cause a destructive arc to exist between separating contacts.

Distributed line capacitance loads:

This occurs when a switch is located a considerable distance from the load to be switched. The instant the contacts close, distributed line capacitance charges before load current flows. This capacitance can appear as an initial short circuit to the contacts, and can pull a current well in excess of load current.

Average inductive loads correction factor (if no arc suppression device is used)



Self-regulating cables inrush current surge

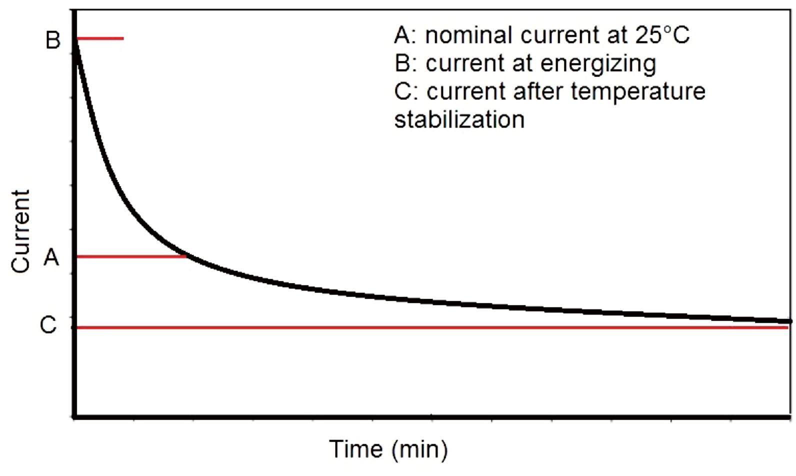
This is a completely different effect than short transient currents due to the contact switching interaction with the load.

This current surge is due to the PTC design of self-regulating cable and takes several minutes to dissipate.

Often the heating cable will be at a relatively low temperature (and hence low resistance) when initially energized. The low resistance will thus draw a high start-up current, inversely proportional to the ambient temperature. It can reach 2 times the nominal value given at 25°C by the manufacturer

Refer to records of cable manufacturers to check the inrush current value.

Self-regulating heating cable inrush current trend

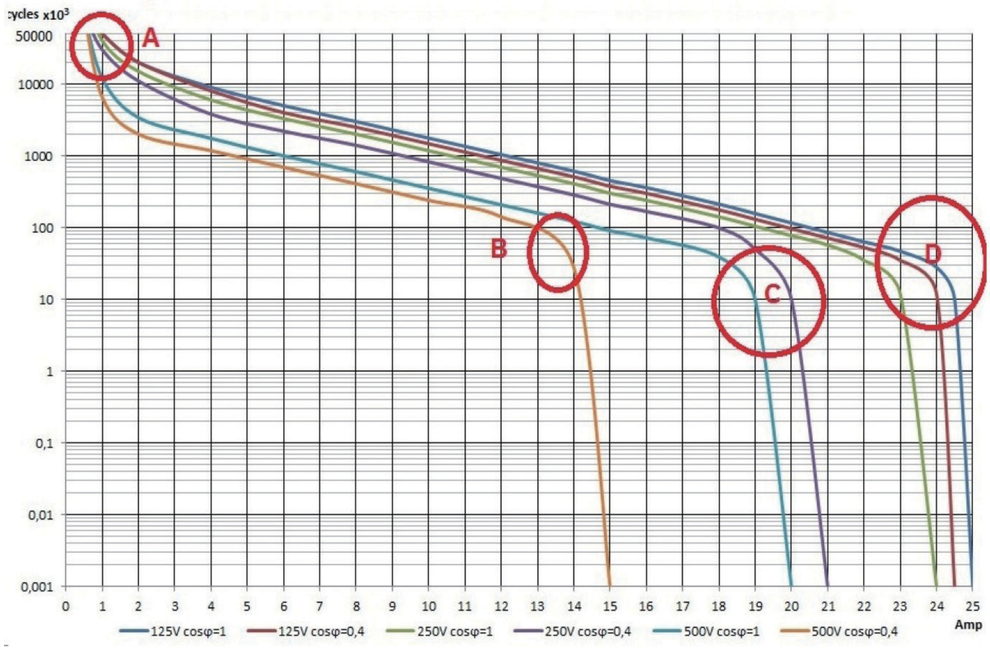


Indicative average current rating reduction coefficients (AC)

Resistive load	Filament lamp**	Electromagnetic coil	Transformer	Single phase motor	Three phase motor	Self-regulating heating cables*
1	0.8	0.5	0.5	0.12/0.24	0.18/0.33	0.6

*Average value, depending on cable ambient temperature at startup, see the manufacturers manuals and Standard CEI60898
** With hot filament.

Average electrical life of a thermostat switch rated 15A250V, 300.000 cycles



Average approximate values for a snap action mechanism with silver contacts.
Characteristic points:
A: Zone of mechanical break of the contact blade by metal fatigue.
B: Contacts fast melting zone due to combination o inductive current, high voltage and high intensity.
C: Zone of contacts rapid deterioration due to huge arcs.
D: Zone of contact damage due to heating of the contact blade by the Joule effect and the loss of its elastic characteristics, combined with the electrical arcs.

2.3.3 AC AND DC

In the alternative current, the voltage crosses zero in each cycle, causing the arc extinction.
In DC circuits the contact does not pass a zero voltage.
So, the arc will extinguish only when the contacts gap becomes large enough to break the arc (a phenomenon used in arc welding equipment).
In thermostats the contact gap is generally low, from 0.3 to 0.5 mm.
In voltages higher than 48VDC, this contact gap is insufficient to extinguish the arc, which continues through the electrical conductivity of the ionized air caused by the passage of current.
Contacts wearing is then extremely fast, and contacts can melt or weld in a few cycles, because the unidirectional flow of current causes a transfer of metal between the contacts
Any application requiring the use of a thermostat in a DC circuit above 48V should be studied carefully, in collaboration with the supplier of the thermostat, so that reliable technical solutions (increased contact gap, magnetic blow of the arc or other contact protection) can be implemented.

DC Indicative breaking capacities reduction on snap action silver contacts, with the same lifetime, in resistive circuit			
Current	0.2 mm contact gap	0.25 mm contact gap	0.5 mm contact gap
AC, 250V	15	15	15
DC, 8V	15	15	15
DC, 30V	2	2	6
DC, 120V	0.4	0.4	0.5
DC, 230V	0.2	0.2	0.25

HIGH FREQUENCY

High frequency applications should be avoided, because they initiate overheating loops in contact blades, which anneals them and modify their flexibility. The contact blade loses its snap action contact and contacts weld or have a premature wear

2.3.4 CYCLING SPEED AND NUMBER OF CYCLES

Electrical contact life is, as we have seen above, the result of many factors.
It is important that the contact has time to evacuate the heat due to the electric arc.
Too fast cycling (more than 0.5 per second) cause premature wear, since the contact can not evacuate the rise in temperature.
Most thermostats are designed to withstand:
- 100 000 cycles in control devices.
- 10 000 cycles in safety devices.

In some applications the number of cycles can be much lower. A device designed to withstand 100,000 cycles at 1A can withstand 25A for a few hundred cycles, and even 100 or 150A for 1 cycle.
Expected life and cycle is a very important parameter to know for the determination of a thermostat.

2.3.5 CONTACTS PROTECTION

(capacitors, filters, varistors, magnetic blow)
It is possible, by means of accessories external to the contact, to extend or improve its longevity.
These systems are all designed to limit the duration of the arc.
- The oldest is the capacity mounted in parallel to the contact, which allows to use it in DC. This solution was extensively used some decades ago, when there were still domestic DC power supply. It is effective and inexpensive.
- The filter (Inductance and capacitor assembly) is mainly used on slow break contacts to avoid radio interference. It significantly increases the electrical life.
- More recently discovered, Varistors, absorb surges created by contact opening, and limit the arc duration and intensity. They double or triple the life, especially in inductive circuits.
- The magnetic blow, little used, is intended only for DC currents. A strong magnet located around the contact area, deviates the ionized arc, and makes a longer path that extinguishes the arc. This is the solution for high power ratings in 120 and 230V DC loads.
- Inductance: This system is mounted in series with the switch in the immediate vicinity of the contact. When it is well engineered, it has a smoothing effect on the voltage peaks.

2.3.6 CONTACTS CONTAMINATION

The presence in the atmosphere of a number of chemicals may have an adverse effect on the contacts operation and life.
In particular:
- A high relative humidity: more intense arcs, because the air loses some of its insulating properties
- Presence of ammonia : oxidation of contact blades, which are made of copper alloys.
- Presence of silicone oil or vapors: silicone on the contacts stops the electrical

current, because when silicone is burned by the electric arc, it becomes silica (aluminum oxide), which is a high temperature resistant insulator.

2.3.7 CONTACT SYSTEMS CROSSED BY THE CURRENT

In some small devices (temperature limiting), the contact mounted bimetal strips are themselves the temperature sensing elements.
These strips are not, because of their composition, very good conductors of electricity. The current flow in them causes them to heat by Joule's effect, and this temperature comes to be added to the temperature measurement. This is named « current sensitivity » and « thermal drift » in calibration.

2.3.8 CONTACTS OXIDATION

We have seen above that the contact resistance was very low, of the order of a few milli-ohms. Whatever the current passing through it, the resistance is too low to cause significant heating. However, if for one reason or another (contamination, oxidation, insufficient contact pressure, mechanical deformation, etc..), the contact resistance increases, this resistance will heat the contacts if the current is high, and may overheat them enough to melt or burn flammable materials located nearby.

2-4 CONTROL ACTIONS

2.4.1 TEMPERATURE CONTROL

This the first function of a thermostat. A temperature control action contact is a contact that will cycle periodically, by opening and closing an electrical circuit. This is not a safety device. Contacts must withstand a high number of cycles.

2.4.2 THE AUTOMATIC RESET

The automatic reset is a temperature limiter function that does not require, in case of tripping, the intervention of an operator. This type of contact is intended to warn of a malfunction and avoid product destruction if the control device is not working or broken. It resets when the temperature returns to permitted limits.
The current number of cycles of operation of this type of action is between 300 and 10 000.

2.4.3 THE MANUAL RESET

A manual reset is a temperature limiting function, which requires, in case of tripping, the intervention of an operator to reset the device. This type of contact is intended to warn of a malfunction and protect the product by shut off the electrical power. The reset can be done when the temperature is returned to the authorized limits. Manual reset can be accessed or hidden. In general, they cannot be reset without using a tool or without removing a cover or a cap.
The current number of cycles of operation of this type of action is between 300 and 10 000.

2.4.4 ELECTRICAL RESET

This is the same function as above, but there is no reset button. It automatically resets after disconnection of the power supply.

2.4.5 RESET BY TEMPERATURE DROP

Temperature drop reset is an automatic reset after a significant drop in temperature, generally close to the ambient temperature.
This solution is very little used.

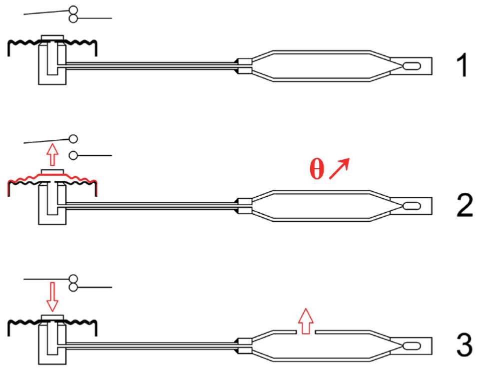
2.4.6 THE "ONE SHOT"

The "one shot" is a type of contact that can only be opened once. Its use is typically that of ultimate safety device, which definitely cut the power supply. Restarting the application needs a full replacement of it. Its number of operating cycles is 1. This function can be performed by metal alloy melting, plastic pellet melting, glass bead break, triggering of a bimetal disc whose return to the starting position is not possible even in the coldest ambient temperatures

2.4.7 FAIL SAFE

Fail safe is a positive auto control of the device. Any leakage or breakage of the temperature sensing device causes the electrical power shut-off. This function is difficult to define in bimetal thermostats (discs, rod, bimetal), but for thermostat using a bulb and capillary assembly, it defines the mode of operation when it leaks.

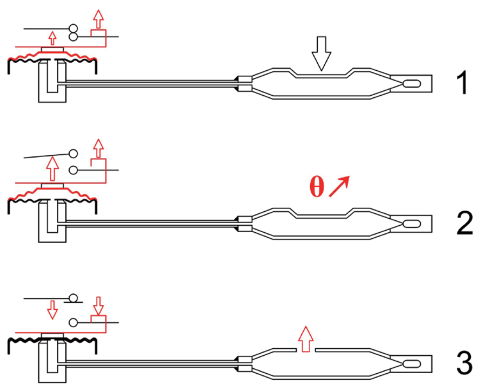
The fail-safe mechanisms in bulb and capillary thermostats



Diastat Standard Operation:

Position1: a standard diastat is shown in the starting position, at room temperature.
In position 2: the temperature of the sensor has reached the set point, and the inflation of the bellows caused the opening of the contact, stopping heating.
In position 3: the bulb (or capillary) leaks, the bellows deflates, the electrical contact closes, and the heating is switched on again. But no further expansion is transmitted to the bellows, and nothing can stop nor regulate heating. This is the dangerous situation that failsafe systems must obviate.
Positive safety is primarily used on manual reset thermostat, installed after a standard temperature control unit.
<u>There are two fail safe systems with a different mode of operation, each system having its own advantages and disadvantages.</u>

Liquid expansion type failsafe systems



In these systems, after sealing the diastat at ambient temperature, a small bump is made on the bulb, causing an artificial inflation of the bellows (1).
It is also possible to produce the same function by sealing the diastat at a negative temperature (-20, -30°C). By these ways the bellows continues to contract at temperatures below room temperature.
When the temperature on the bulb increases (2), the movable part of the electrical contact is actuated by the bellows. When the bulb or the capillary is leaking (3) the bellows is deflated under the thickness it has at ambient temperature, and an auxiliary mechanism (in red) displaces the fixed part of electrical contact out of reach of the movable part, thereby opening the contact.

This positive safety system allows easy adjustment of the thermostats trigger temperature, because the mechanism is similar to an adjustable thermostat, and calibration can therefore cover the entire temperature range of these adjustable thermostats.

However, it has two issues:

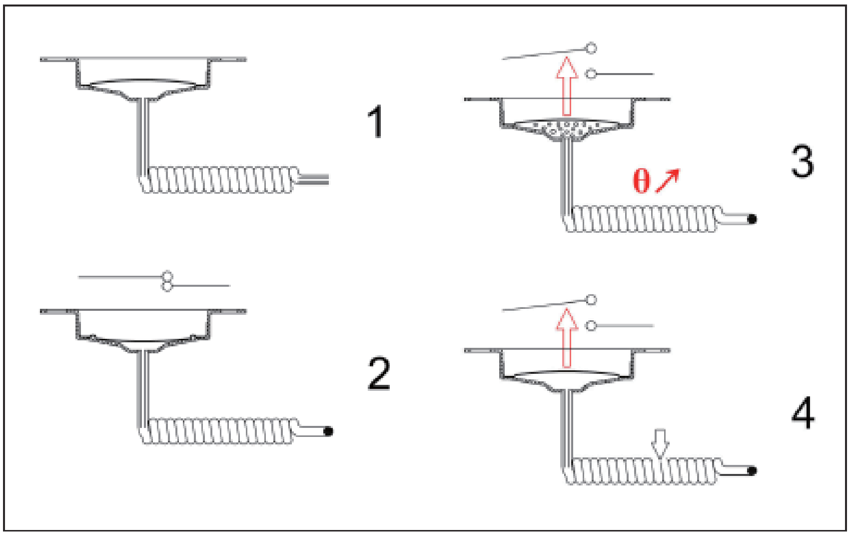
- The artificial increase of the bellows significantly increases the volume of liquid inside thereof, and thus increases its sensitivity to the ambient temperature on the thermostat head.

Examples of calibration point drift on a manual reset thermostat with 1.5 m capillary, calibrated at 90°C

Type of mechanism	Set point drift with head temperature at 0°C	Set point drift with head temperature at 50°C
With fail safe	90+8.1	90-9.5
Without fail safe	90+5.5	90-6.5

- When the ambient temperature falls under the freezing point, the bellows continues to contract, and can unexpectedly actuate the safety.
This type of false tripping is supervised by the EN60730 standard, which sets the minimum ambient temperature without triggering at -15°C.
However, when using these thermostats in areas with ambient temperature lower than this limit, it is necessary to warm up the thermostat bulb around 20°C to reset the safety when it has triggered.

Boiling style failsafe systems



In boiling type fail safe systems, the bellows of the diastat consists of two dishes, one of which is bumped. This bumping is of convex shape, as a bimetallic disc, and snaps from convex to concave when subjected to a force. The diastat, before filling (1) is constructed so that the cup is in the unstressed position is outwardly bulged.
The diastat is then filled with thermostatic liquid under vacuum, then sealed with the cup pushed inwards (2). In this position, the electrical contacts are closed.
In case of temperature rise, the liquid boils at the temperature determined by its composition. The substantial increase in volume caused by the boiling causes the change of shape of the cup, which snaps outwards and opens the contact (3). Upon cooling of the liquid, the force produced by the diastat and required for bumping inwards the cup is insufficient, and it is necessary to press it with a reset button to restore it to its inward form.
In case of punctures or leaks in the diastat, the liquid inside is set to the atmospheric pressure, and the cup snaps outwardly.
This system is particularly simple, reliable, and requires no complicated mechanism.

It is not sensitive to the ambient temperature on the capillary or on the head, does not trigger unexpectedly when ambient temperatures are too low.

It has, however, like the previous one, two flaws:

- Triggering temperature depends of boiling liquid used (Generally mixtures of water, glycol and alcohol), and therefore they are practically limited to values between 60 and 170°C.
- They are sensitive to atmospheric pressure and set point varies slightly with altitude.

2.5 MULTIPLES CONTACTS

2.5.1 CHANGE OVER CONTACTS (SPDT, for: single pole double throw)

The changeover contact is a contact with three terminals.They are a common, a normally closed contact and a normally open contact. During actuation, the contact switches from one position to another. This allows for example to switch off the heating and simultaneously turning on ventilation.

2.5.2 SIMULTANEOUS CONTACTS

Simultaneous contacts are independent contacts, with synchronous action.

This is particularly important in cutting a three-phase circuit devices, because the cut of the three phases must be done at the same time

2.5.3 STAGGERED CONTACTS

These contacts are operated by the same measuring system, but at different temperatures.

2.5.4 NEUTRAL ZONE CONTACTS

These contacts are parts of the staggered contacts, but with no electrical action between their set points. Their particular application is the air conditioning or refrigeration.

For example the contact # 1 switches off the heating at 100°C, the contact # 2 will turn on the vent at 120°C. Between these two temperatures, no action will be required: this is the neutral zone.

2.5.5 ADJUSTABLE DIFFERENTIAL CONTACTS

The differential is the temperature difference existing between the moment the device actuates (opens) a contact and when, as a result of the drop in temperature resulting from its opening action, it resets.

Depending on the type of contact, these differentials can have huge span.

The adjustable differential is a system that allow the user to change it.

For technical reasons and cost, adjustable differential mechanism is reserved for industrial type systems using gas expansion.

2.5.6 MIXED CONTACTS

Mixed contacts by means of a combination of different systems above.

The most common combination is a control and a reset contact, or a control and a one shot contact.

2.5.7 FLAMEPROOF CONTACTS

A flameproof contact is a contact does not allow the electric arc that it produces to ignite an explosion outside its enclosure.

The electrical arc is not deleted.

There is a difference between the devices whose only the electrical contact is protected and those whose entire mechanism is protected.

2.5.8 FLAMEPROOF ENCLOSURE CONTACTS

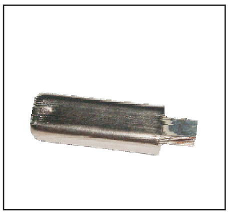
In these devices only the mechanism of the electrical contact is protected by a flameproof enclosure. The electrical connections are made at the end of a cable secured to the casing of the contact area and must be made outside the hazardous area, or in a suitable connection box.

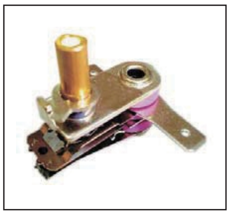
This solution provides small devices, and low cost.

2.5.9 FLAMEPROOF ENCLOSURES
Flameproof enclosures are massive envelopes where the entire device is enclosed. Electrical connections can be made inside the envelope.

3. THERMOSTATS TYPES

3.1 BIMETAL THERMOSTATS
It is currently the thermostats family where quantities are the most important. Numerous configurations exist, and the current trend is simplification and footprint reduction.



3.1.1 FIXED TEMPERATURE BIMETAL THERMOSTATS
Fixed temperature bimetals thermostats are devices whose temperatures are factory fixed, and which have no set point access by the user. They are used, depending on the model, as control devices or safety. The contacts can be slow make or break or snap action, control or reset, normally open, normally close or SPDT. Almost all contact options described above are possible.
These devices are divided in two major groups: those sensitive to the current (which are smaller) and those insensitive to the current.
The most common ranges are set from 20 to 180°C.
However, models with ceramic case can be made up to 450°C, and waterproof models to -30°C.




3.1.2 ADJUSTABLE BIMETAL THERMOSTATS
They are adjustable by screwdriver or shaft. Their main applications are in small appliances (deep fryers, irons).

They are always control type devices, using a bimetal strip.
Common temperature ranges are from 20 to 300°C.
They are current sensitive or insensitive depending on models.
Models with current sensitive bimetal or heated by a resistance, are used in energy regulators.

3.1.3 SPIRAL BIMETAL THERMOSTATS

Bimetallic spirals have been widely used for the production of thermostats. This system is now abandoned by European manufacturers, as it required using a mercury bulb contact, or a slow break contact. There are still only a few manufacturers in the USA, for 110V applications.
These bimetallic spirals (helicoil style) are still used in some air duct thermostats (Called airstats).

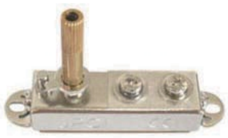
3.2 BIMETALLIC EXPANSION THERMOSTATS

3.2.1 CARTRIDGE THERMOSTATS

These control devices, adjustables, slow break, have a very high precision, and the lowest possible differential for a mechanical thermostat: less than 1/10°C. In general, they are mounted in a

15.8mm dia. bore.
However, because of their slow break, generating radio interferences in 230V, their use in Europe is marginal, restricted to uses in some laboratory hotplates. Common temperature ranges are from 20 to 300°C.

3.2.2 CONTACT THERMOSTATS



These control devices, adjustable, slow break, have a very high precision, and low differential: less than 1°C. They are mounted on a flat wall, fixed by 2 screws .
However, because of their slow break, generating radio interferences in 230V, their use in Europe is marginal, restricted to uses in some laboratory hotplates or when low differential are sought. Common temperature ranges are from 20 to 250°C.

3.2.3 BIMETAL ROD THERMOSTATS

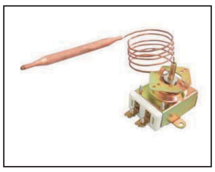
It is currently the main application of bimetallic systems. The bimetallic rod actuates a contact system. The setting can be fixed or with a graduated knob. The contacts are control , manual reset or mixed types.
The main applications are:
- Household storage water heaters. They are controlled by a screwdriver adjustment, with single-pole switching thermostat for temperature control, with temperature sensing made by the rod, and double pole switching for the manual reset, with temperature sensing usually made by a bimetal disc located at the bottom of the tank. They are protected by the cover mounted under the water heater.
- In water heaters and industrial tanks. The temperature control devices are then split: one for control and one for safety. They are mounted in IP65waterproof housings.
- In hydraulic systems, where they are use for oil temperature control. They have 1,2 or 3 staggered contacts to provide different levels of alert and security.
Current temperature ranges span from -50 to 400°C. However, some special models can reach 800°C.

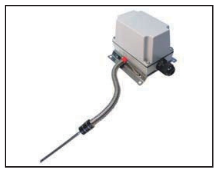
3.3 LIQUID EXPANSION THERMOSTATS

3.3.1 MERCURY EXPANSION IN GLASS TUBE

This is one of the first thermostat systems, invented after the mercury thermometers. A wire is inserted in the capillary glass tube. When the mercury touches the wire, the contact is established. This type of thermometer has long been the reference instrument for precise temperature control . It has no more serial applications .

3.3.2 BULB AND CAPILLARY THERMOSTAT





This is the most common remote measurement and temperature control. The capillary lengths can be up to 3 meters but with a significant drift due to the amount of liquid within the capillary.
In this series, fail safe devices may be produced. Current ranges of temperature span from -50°C to 400°C, exceptionally up to 760°C.

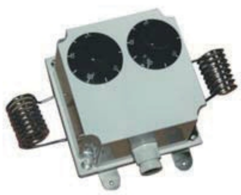
3.3.3 LIQUID FILLED ROD THERMOSTATS

This family is a variant of the bimetal expansion rod thermostat. It differs by a greater resistance to vibration but a longer response time. Applications are identical. Current ranges of temperature ranging from -50°C to 400°C, exceptionally up to 760°C.

3.3.4 PIPE THERMOSTATS

These thermostats use a bulb and capillary mechanism , but with a very short capillary and a bulb beneath the housing on a pipe radius formed plate. The housing has a system for fixing the plate on a pipe.
Usual setting of these control these devices are between 0 and 120°C.

3.3.5 ROOM THERMOSTATS



These thermostats use a bulb and capillary mechanism but with a very short capillary and a bulb located at the side or at the back of the housing. This system is particularly useful for professional and industrial equipment. Current ranges of temperature span from -40°C to 120°C.

3.4 GAS EXPANSION AND VAPOR PRESSURE THERMOSTATS

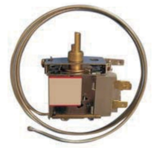
3.4.1 BULB AND CAPILLARY ROOM THERMOSTAT

These vapor pressure devices are mainly used in electric convector thermostats, due to their low differential and low thermal inertia.
Current temperature range: 4 to 40°C.

3.4.2 « WAFER » ROOM THERMOSTATS

It is currently derived from incubator thermostats used in poultry incubators since more than 50 years. The sensitive part is a barometric type capsule (Named ‘capsule de Vidie’), filled with low boiling temperature liquid. They are widely used in household room thermostats. Current range: 4 to 40°C

3.4.3 CAPILLARY THERMOSTATS



These thermostats are used for controlling the temperature of the refrigerating systems. The low thermal inertia of the capillary system, and the possibility of obtaining significant differential is the main feature of these vapor pressure devices.

3.4.4. BULB AND CAPILLARY THERMOSTATS

They are mainly used in industrial applications because the vapor pressure can achieve quite easily adjustable differential devices.

3.4.5 AIR DISPLACEMENT THERMOSTATS

These devices were using a filament style heating system in a glass bulb partially filled with air and containing mercury. Pushed by the expanding air, the mercury passed through a tube into a compartment containing an electrode with which it established an electrical contact.

This system, coupled with a slow break bimetal thermostat contact avoided contact triggering, and achieved very low differential and high electrical rating. This system ,very accurate, very reliable, has completely disappeared.

3.4.6 THERMOMETERS

The gas expansion thermometers are used in industrial applications, they have a low thermal inertia and can be used in high temperatures.

3.5 PHYSICAL STATE CHANGE THERMOSTATS

3.5.1 “CALORSTATS”

They use the wax melting temperature expansion. There is little use of them in systems operating an electrical contact, but they are widely used to provide mechanical movements (Car engine thermostats, radiator thermostats, door locks, valve control).

This system can actuate an electrical contact, or operate a valve to control the flow of water when the temperature changes.

Current ranges from 30 to 150°C.

3.5.2 THERMAL FUSES

This is the main system used in thermal cut out. Millions of these devices are currently produced in the world. It is a highly reliable system, whose operation is safe. The electrical contacts are either cut by the conductor melting (Rating generally limited to 4A) or by melting of a pellet releasing a spring contact (Rating up to 25A).

Current ranges from 60 to 300°C.

The melting part is made of metal or plastic.

This system, known as TCO (thermal cut-off) is the ultimate security system. It is inexpensive.

A variant of these systems are also used in non-electric appliances for releasing a mechanism, in particular in fire detection apparatus.

3.5.3 BOILING THERMOSTATS

The most common thermostat of this type is the failsafe capillary limiter with manual reset.

This system measures the boiling of a liquid contained in a capillary or a bulb at the end of the capillary. Temperature sensing on + / -300 mm capillary is required to operate the contact. For this reason, models often have their capillary curled at the end, with dimensions similar to a bulb. These devices are always fixed temperature types, most of time calibrated within the 50 to 170°C span, and the capillary length is limited to + / -900 mm for transmission of the excess pressure due to the boiling reasons or depression due to the rupture of the capillary.

4. APPLICATIONS

Principle	Family	Sub family	Application
Co-laminated bimetals	Fixed setting	Current sensitives	Coils protectors, small appliances, automotive, rechargeable batteries
	Fixed setting	Non sensitives to current	Small appliances, HVAC, refrigeration equipment
	Adjustable setting		Irons, grills, crêpes makers
	Spiral		Thermometers, airstats
Double metals	Cartridges Surface sensing		Heating plates, flat heaters, medical equipment
	Rod	For incorporation	Household water heaters
		Professionnels	HVAC
		Industriels	Tanks, Hydraulic power units, heaters
		ADF	Industrie chimique
Liquid expansion	Glass	Laboratory	Various
	Bulb and capillary for incorporation	Appliances OEM	Ovens, cookers, washing machines, dishwashers, boilers
	Bulb and capillary with protection housing	Semi-professionnel	OEMs electro, kilns, ovens, air heaters
	Bulb and capillary with metal protection housing	Industrial and/or hazardous area, heavy construction	Factories, maintenance, heat tracing
Vapor pressure	Bulb and capillary		Electric heaters, refrigerators thermostats
	Membrane		Household room thermostats
	Air displacement		No more used
Physical state change	Wax		Automotive, hot water central heating
	Compounds melting	Fusion du conducteur	Small appliance, coils, batteries, electronic
		Fusion de pastille	Household appliances, electric heating, motors
	Boiling	Capillaire	Heaters, electric air heaters, heat pumps
		Glass bulb	Air conditionning, fire detection

5. TERMINOLOGY AND VOCABULARY

5.1 VOCABULARY

Standards EN60730 and EN 60335 define, sometimes with differences, the vocabulary to use. However, it is often different from that used in practice.

Usual vocabulary:
Set point: The value set on the temperature control device, corresponding to the temperature to reach
Differential: the temperature difference between the opening and closing of the contact
Snap action: contacts open and close instantly
Manual reset: action to turn on by manual intervention, to heating position contacts

opened by a temperature rise that did not automatically return to closed position when the temperature drops.
Automatic reset: Contact that is automatically closed when the temperature drops.
Sensing control: automatic control in which initiation is by an element sensitive to the activating temperature.

Definitions of the different thermostatic systems according to EN60335-1
§3.7.1 Thermostat: temperature sensing system of which the operating temperature may be fixed or adjustable and which, during normal operation, maintains the temperature of the controlled part within certain limits by automatic opening and closing of a circuit
§3.7.2 temperature limiter: temperature-sensing device, the operating temperature of which may be either fixed or adjustable and which during normal operation operates by opening or closing a circuit when the temperature of the controlled part reaches a predetermined value
NOTE A temperature limiter does not make the reverse operation during the normal duty cycle of the appliance. It may or may not require manual resetting.
Temperature limiter: temperature sensing control which is intended to keep a temperature below or above one particular value during normal operating conditions and which may have provision for setting by the user
A temperature limiter may be of the automatic or of the manual reset type. It does not make the reverse operation during the normal duty cycle of the appliance.
§3.7.3 Thermal cut-out: device which during abnormal operation limits the temperature of the controlled part by automatically opening the circuit,... and is constructed so that its setting cannot be altered by the user.
Thermal cut-out: temperature sensing control intended to keep a temperature below or above one particular value during abnormal operating conditions and which has no provision for setting by the user
A thermal cut-out may be of the automatic, manual reset or non-resettable type.
§3.7.4 Self-resetting thermal cut-out: thermal cut-out that automatically restores the current after the relevant part of the appliance has cooled down sufficiently
§3.7.5 Non-self-resetting thermal cut-out: thermal cut-out that requires a manual operation for resetting, or replacement of a part, in order to restore the current
NOTE Manual operation includes disconnection of the appliance from the supply mains.
§3.7.6 Protective device: device, the operation of which prevents a hazardous situation under abnormal operation conditions
§3.7.7 Thermal link: thermal cut-out which operates only once and requires partial or complete replacement

Fail safe temperature limiter: the fail safe in a thermostat is defined by the EN60730-2-9 Standard § 6.4.3.101, as a temperature control device wherein a leakage of the filling fluid does not increase the temperature set point. More generally a system is said to be failsafe, when a loss of fluid (including electricity) leads the equipment to a stable safety state. The safety state must be maintained over time.

Thermostats recommended applications:
IEC (EN) 60730-1 Standards « Automatic electrical controls for household and similar use» and especially IEC (EN) 60730-2-9-(2008) : « Particular requirements for temperature sensing controls» are the standards that define the functional characteristics of thermostats. Appendix EE of the latest version of the standard describes all recommended applications for these devices.

5.2- COMMON VOCABULARY USED TO DESIGNATE A THERMOSTAT

Dozens of names are used by the customer to designate thermostats. We can mention:
aquastat, airstat, bimetal sensor, temperature sensor, temperature switch, temperature detector, thermal sensor, thermal switch, temperature limiter, thermal pellet, pellet thermostat, thermal protector, temperature controller, sensor, temperature probe, temperature sensor, thermostat.

Some brands have passed into the vocabulary:
Klixon: Texas trademark instrument means a bimetal disc thermostat.
Combistat: Stork trademark refers to a contact thermometer
Vigitherme: Heito trademark refers to a thermostat bimetal disc.
Ipsotherm: Comepa trademark refers to a thermostat bimetal disc.
Calorstat: brand used by Vernet thermostat, refers to an automotive water circuit valve.

6. IMPORTANT EXTRACTS OF STANDARDS RELATED TO CONTROL OR SAFETY CIRCUITS

Electrical cut out: (IEC 60335-1)
§3.8.1 All-pole cut out: Cutting in two conductors in a single operation, or for three phase units, the cut of the three conductors in a single step ... Note: for three-phase, the neutral lead is not considered as a power conductor.
§22.2: Phase cut out: single pole protection systems cutting heating elements in single pole circuits of Class 01 devices and continuously connected Class 01 devices, must be connected to the phase conductor.
Electrical conductors colors: (IEC 60446)
§3.1 … For the identification of leads the following colors are allowed: black, brown, red, orange, yellow, green, blue, purple, gray, white, pink, turquoise.
§3.2.2 Neutral conductor or center conductor: when a circuit includes a neutral conductor or neutral conductor identified by color, the color used for this purpose should be blue ...
Note 2 – In the United States of America, Canada and Japan, identifying with white or natural gray colors for the neutral conductor or center conductor is used as a replacement for the identification by the light blue color.
§3.2.3 AC phase conductors: black and brown colors are the favorite colors for the phase conductors of AC systems.
§3.3.2 Conductor protection: The two-tone green-and-yellow combination must be used for identification of the protective conductor to the exclusion of any other use. The green-and-yellow is the only recognized color scheme for the identification of the protective conductor
Note 2 – In the United States of America, Canada and Japan, identifying with green color for the protection conductor is used as a replacement for the identification by the two-tone green-and-yellow combination.
Fail safe, functional safety, safety levels:
It is required by the European Directive 97/23 dealing with heat generators, pressure equipment and boilers as follow: «The procedures for conformity assessment and the essential safety requirements of the Directive apply to the complete safety chain. The requirements for the sensor itself can be different according to the safety design principles, for instance: redundancy or fail-safe ». Many "product" standards of the IEC (EN) 60335-xxx series require this type of safety.
Definitions related to the functional safety: this concept was introduced

by the CEI 61508:1998 Standard. « Functional Safety for electrical /electronic and programmable electronic (E/E/PES) systems». This standard defines the requirements and provisions for the design of electronic and programmable complex systems and subsystems. This is a general standard that can be used in all industrial sectors. The categories of protection of industrial heating equipment have been classified into three levels by the old EN 954-1 Standard.

Level 1 includes mainly the process control instrumentation: temperature sensors, thermostats, controllers, programmers. This level provides a control either permanently or in a sequence by programmed commands initiated by the operator (for example: control disc, bimetal, bulb and capillary thermostats, electronic temperature controls).

Level 2 consists essentially of an instrumentation composition close to that of level one, but functionally completely independent of this level.

This level 2 protects the process by a discontinuous unsystematic function, that is to say not initialized by the operator, from threshold violation information on critical parameters of the process.

(For example, disc thermostat + disk limiter, bulb and capillary temperature limiters + bulb and capillary thermostat, double electronic controllers)

Level 3 is the ultimate protection of the process. It does not include identical instrumentation to those of Level 1 and 2, but devices working without auxiliary energy (for example: fixed temperature limiters with manual or automatic reset on circuits controlled by electronic controllers, thermal fuses for systems controlled by disc or bulb and capillary thermostats, or by electronic controllers).

7. INSTALLATION

The proper functioning of a thermostat depends primarily on the correct choice of the component, but also the conditions of its installation. Conditions used to calibrate regulating and control equipment in the factory are always ideal laboratory conditions, ensuring measurement accuracy and repeatability. These conditions are rarely those found in practice when installing thermostats. However, with a minimum of constraints, it is possible to optimize assemblies.

One's will always bear in mind these two essential rules:

- A thermostat measures the temperature where the sensing element is located, and it is therefore necessary that this place is representative of the temperature that must be controlled.
- The thermal inertia is the most common causes of poor regulation. A thermostat does not have an instant response to a temperature change.

7.1 GENERAL RULES

- THERMAL CONDUCTIVITY

The temperature of a medium (liquid, air, metal) decreases progressively as the distance from the heat source. This decrease, called thermal gradient is inversely proportional to the thermal conductivity of the medium. For good temperature control, first step is to make this decrease as low as possible: by stirring the liquid, stirring the air, using metals that are good conductors of heat.

In unstirred liquid baths, thermal variations that rise several tens of degrees between different measurement points are quite common. It is the same in the air.

- RESPONSE TIME

Practically speaking, the time taken by a device to change temperature is proportional to its mass and inversely proportional to its thermal conductivity.

Subject to the same variation of temperature, a large block of copper takes longer to heat up than a little. A block of pure silver of the same weight will react much more quickly.
In one room, sun exposure will raise rapidly the temperature of the ambient air because its mass is low, but the walls will react much more slowly because they are much more massive, even if their thermal conductivity is higher. Therefore, to control the air conditioner, make sure that the thermostat measure the temperature of the air and not of the walls.

Thermal conductivity of some materials

Materials	Thermal conductivity (W•m-1•K-1)	Materials	Thermal conductivity (W•m-1•K-1)
PU foam	0.025	Titanium	20
Ait (atmospheric pressure)	0.026	304 Stainlss steel	26
EPS	0.036	Mild steel	46
Fiber glass wool	0.043	Platinium	72
Cork	0.043	Iron	80
Wood (Average)	0.16	Cast iron	100
Abestos	0.17	Silicium	149
Epoxy	0.25	Aluminum alloy (with SiC)	150-200
Nylon	0.25	Pure aluminum (99.9%)	237
PPS (Ryton)	0.3	Massive silicium carbide	250
Vulcanized rubber (EPDM)	0.4	Gold	317
Water	0.63	Copper	390
Concrete	0.92	Silver	429
Glass	1.23	Graphite	500-2000
Bakelite	1.42	Diamond	1000-2600
Quartz	10	Graphene	4000-5300

It is easily possible to see that if a thermal gradient takes 1 second to be transmitted in a silver part, it will take 1.1 seconds in copper, 2.5 seconds in aluminum alloy, 4.3 seconds in iron, 6.3 seconds in mild steel, 16.5 seconds in stainless steel, 680 seconds (more than 11 minutes) in non-stirred water and 16500 seconds (more than 4 hours) in still air.

TIME NEEDED TO HEAT

An issue frequently raised, and that many consider as associated with thermostats is the time it takes to heat a product. In fact, at constant power, the amount of heat (energy) required to heat a product depends on its mass and its heat capacity, and not on the thermostat.
Specific Heat capacity (or specific thermal capacity) is the energy it takes to bring a body to raise its temperature by one degree kelvin for a mass of one kilogram. It is expressed in joules per kelvin per kilogram (J / K). It originates from the "calorie" that was defined as the amount of heat required to raise 15°C to 16°C the temperature of one gram of water.
The table below gives some common values.

Material	Specific heat capacity ($J*kg^{-1}*K^{-1}$)	Material	Specific heat capacity ($J*kg^{-1}*K^{-1}$)
Gold	129	Granite	800
Silver	240	Concrete	880

Material	Specific heat capacity (J*kg⁻¹*K⁻¹)	Material	Specific heat capacity (J*kg⁻¹*K⁻¹)
Brass	377	Alunimum	897
Copper	385	Dry Air	1005
Iron	444	Wood	1760
Diamond	502	Olive oil	2000
304 Stainless steel	510	Alcohol	2450
Graphite	720	Liquid water	4180

One can easily notice that the same power, whether 600 seconds are needed to heat one kilogram of water, it will take only 290S for oil, 145s for air, 73s for stainless steel, 55s for copper, and 18s for gold. The heat capacity is an extremely important parameter in the definition of a thermal system.

• OVERHEAT AND HEAT ACCUMULATION
Many heating systems accumulate heat before transmitting it to the environment.
This is especially the case with sheathed heating elements, where heating wires are coated with magnesia, and then covered with stainless steel tube. Before the stainless steel sheath begins to warm, the entire interior of the heating elements has heated up.
When the power is then turned off, the heat accumulated inside will continue to dissipate, and the temperature of the outer shell will continue to rise. A temperature control which regulate by measuring the temperature of the outer shell will be false.

7.2 WALL AND PIPE MOUNTING THERMOSTATS

These thermostats are intended to be mounted on walls. This covers bimetal disc thermostats, with or without bracket, and pipe formed models.
The following requirements must be respected:
- In the case of thermostats with a flat sensitive part, the mounting wall must be flat. In particular, if it is needed to measure the temperature of a small diameter tube, it is mandatory to weld or solder a heat conductive part made of copper or brass on the tube surface, with a flat surface on the side facing the thermostat.
- In the case of thermostats whose sensitive part is curved to match the shape of the wall (tanks, pipes): use thermal contact grease between the thermostat sensing face and the wall, insulate the thermostat body to limit the influence of the ambient temperature, have in mind that the whole thermostat must withstand the maximum or minimum temperature of the wall. Check if these temperatures are compatible.

7.3 AIR DUCTS THERMOSTATS

Thermostats must be installed in an area where there is good air circulation. Avoid corners, angles. The thermostat should be located close to the heating element (or cooling) to be quickly influenced by temperature changes. The extended bracket disc thermostats must be mounted on a wall that is not influenced by a temperature other than that of the air stream.
Attention to the use of bimetallic rod thermostats in air ducts: These devices generally have very fast response time to temperature changes, and some models are not suitable for use as safety device because they trigger too fast.

7.4 ROD THERMOSTATS

Rod thermostats should be mounted on fittings provided for this purpose. The rod cannot be bended, welded, soldered, and no external device must hinder the

rod expansion.
The whole sensitive part of the rod must be immersed in the air or liquid that it must control.
Do not mount the thermostat on a stack of fittings and rod must be in an area representative of the temperature of the tank. Avoid areas without natural convection or no stirring.
Whatever the installation, the thermostat head must not exceed the maximum allowable temperature. In particular, when mounting thermostats on high temperature equipment, the head must be kept away from hot walls.
Use pockets adapted to the rod diameter, and do not hinder expansion movements. If you want to get accurate settings and low differential, put thermal grease between the pocket and the rod.

7.5 BULB AND CAPILLARY THERMOSTATS

The bulb and capillary thermostats are provided to measure the temperature with the bulb located inside the medium to control. However, the capillary and the rest of the diastat are influenced moderately by temperature. It is therefore important not to expose them to temperatures too high, and in particular never exceed the maximum allowable temperature of the thermostat head. Capillaries and in particular capillary junctions with bulb are fragile and care must be taken not to bend capillaries with a radius smaller than 5 mm, or near the bulb. Breakage or leak of the capillary after sharp bending voids any warranty on the equipment. Overheating bulbs or capillaries on liquid expansion models cause unwanted boiling of the liquid and the destruction of the thermostat. Cutting or drilling capillary or bulb destroys the mechanism, and the thermostat does not stop heating when the temperature rises, If this risk is important in your application, be sure to use failsafe thermostats.

7.6 WINDINGS THERMOSTATS

Windings protectors must be installed to measure the fastest way the temperature rise of the winding. They must not be bended or distorted during installation inside the coil. Before to be incorporated into windings that must later be impregnated by resin or varnish, ensure that these thermostats support these operations. Our office is at your disposal to give you technical advice.
Calibration temperatures warning: thermal protectors are calibrated at zero current and their operating temperature is sensitive to current. In your application, depending on the current rating of your device, their set point can be shifted down. Use thermostats drift curves to define thermal drift temperatures. Many thermal protectors have metal enclosures electrically alive. Be sure to install them safely, with proper electrical insulation and not in contact with grounded or accessible parts. For these devices, class 1 and class 2 electrical insulation sleeves can be provided on request.

7.7 THERMAL CUT OUT

Thermal fuses are the components the most susceptible to wrong installations.
Their terminals are heat conductors: welding or soldering them can cause the fuse to open by thermal conductivity.
Do not make soldering at less than 15mm of the housing. The soldering duration shall not exceed 3 seconds. Terminals wires are also sensitive to strength and torsion. Be careful not to apply significant forces (1.3 N max).
Bending terminal wires should be preferably made with a wire bending machine. Do not bend or crimp at less than 5mm from the body. Do not crush the body.
Sensitivity to temperature: thermal fuses must not remain continuously exposed to

temperatures that are too close to their cutoff temperature. Respect the maximum allowed permanent temperature given in technical data sheets. They are also sensitive to current and can trigger by Joule effect if the rating is too high.

7.8 VAPOR PRESSURE BULB AND CAPILLARY THEMOSTATS

These thermostats are particularly sensitive to the position of the capillary or of the bulb relative to the thermostat head. Observe the position indicated on the data sheets for each device.

7.9 EXPLOSION PROOF THERMOSTATS

The explosion-proof devices require special care during assembly. A specific mounting and assembly instruction manual is supplied with each unit.

- Explosion-proof enclosures: These housings are designed to withstand an explosion occurring within the housing. It is therefore important to take particular care that the screws of the cover (these screws cannot be replaced by others models with different mechanical resistance), to ensure the cleanliness of the sealing surfaces, not drill holes in the boxes, not to replace original cable glands by others, properly tighten the cable glands, ensuring that their gasket is adapted to the diameter of the cable used.
- Explosion proof Switches: In thermostats using this system, only the electrical part of the switch mechanism is enclosed in a flameproof enclosure. By this way, the outer casing of the thermostat does not provide explosion protection, but only requires at least IP65 ingress protection. Electrical connections must be made on the cable coming out of the unit, outside the hazardous area or in a suitable junction box.