English version

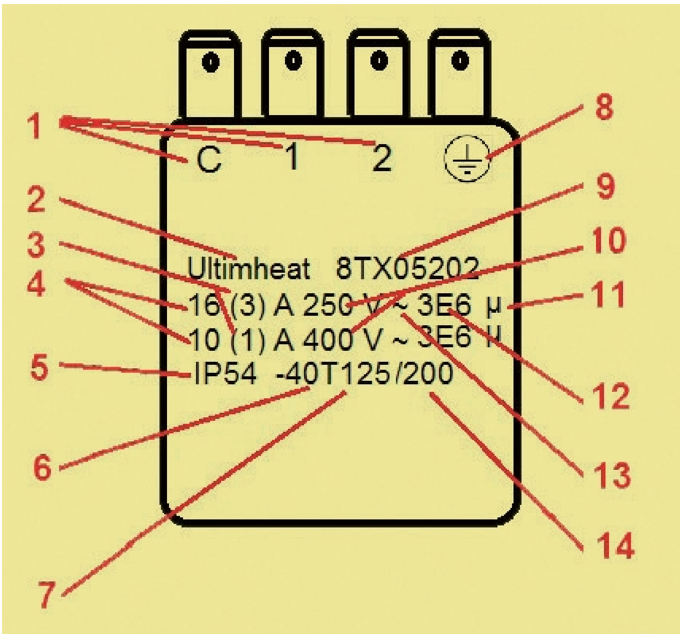
ULTIMHEAT® MUSEUM

Jacques Jumeau

Technology of components used in heating.

Chapter 19

Technical information related to the temperature control in electro-thermal applications



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Technical information related to the temperature control in electro-thermal applications

Technical information N°1 : Terminology and vocabulary

Standards EN60730 and EN 60335 define, sometimes with differences, the vocabulary to use. However, it is often different from what is 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 does not automatically return to closed position when the temperature drops
Automatic reset: Contact that automatically closes when the temperature drops
Sensing control: automatic control in which initiation is done 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.

<u>Technical information N°2 :</u> 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 follows : «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).

The design of Y6, Y7 and Y8 enclosure series allows the making of products that comply with Level 1, Level 1+2 and Level 1 +2 +3, and optionally including failsafe systems.

Technical information N°3 : cable glands selection

To fulfill its function, especially tear strength and ingress protection, cable gland must be adapted to the diameter of the cable.
This diameter is a function of several parameters: the number of conductors, electrical power, voltage insulation, cable length and type of mechanical protection depending its application.
The selection must be done in 3 steps.

Step 1: selection of cable Gauge, upon power and maximum length of cables, single phase and three phase.

Gauge, mm^2	Single phase 230V, power factor =1			3 phase, power factor = 0.8		
	Power (kw)	Electrical rating, (A)	Maximum cable length, with voltage drop less than 3% (m)	Power (kw)	Electrical rating, (A)	Maximum cable length, with voltage drop less than 5% (m)
1.5	1	4.6	50			
	1.5	6.8	33			
	2	9	25			
	2.5	11.5	20	2.5	5	190
	3	13.5	17	3	6	160
	3.5	16	14	3.5	7	135
				4	8	120
				4.5	9	105
				5	10	96
				6	12	79
				7	14	68
				8	16	60
				9	18	51
2.5	1	4.6	84			
	1.5	6.8	57			
	2	9	43			
	2.5	11.5	34	2.5	5	325
	3	13.5	29	3	6	270
	3.5	16	24	3.5	7	230
	4	18	21	4	8	200
	4.5	20	19	4.5	9	180
				5	10	165
				6	12	135
				7	14	115
				8	16	105
				9	18	92
				10	19	84
				12	23	69
4	1	4.6	135			
	1.5	6.8	90			
	2	9	88			
	2.5	11.5	54	2.5	5	510
	3	13.5	45	3	6	420
	3.5	16	39	3.5	7	365
	4	18	34	4	8	320
	4.5	20	30	4.5	9	285
	5	23	27	5	10	255
	6	27	23	6	12	210
				7	14	180
				8	16	160
				9	18	145
				10	19	130
				12	23	110
				14	27	94
				16	31	81

Step 2, depending of application, select insulation and mechanical protection, and find cable outside diameter (Most usual flexible cables)

Gauge mm²	H05-VVF 500V, PVC insulation	Cable gland size	H05-RRF 500V, rubber insulation	Cable gland size	H07-RNF, 450/750 V. Can be used in fixed installations with nominal voltages up to 1000V: see NF G 15-100, 512.1.1. Excellent resistance to weathering, oils and fats, resistance to mechanical and thermal stresses, outdoor use, hazardous areas, agricultural areas, connecting mobile devices	Cable gland size
3 x 1	6.8	M16	8.5	M16	11.5	M20, M24
3 x 1.5	7.2	M16	10.4	M20	12.5	M20, M24
3 x 2.5	8	M16, M20	12.4	M20, M24	14.5	M24, M25
3 x 4	10	M16, M20	14.5	M24, M25	16	M24, M25
5 x 1	9.8	M16, M20	10.3	M20	13.5	M24, M25
5 x 1.5	11.6	M20, M24	12.7	M20, M24	15	M24, M25
5 x 2.5	13.9	M24, M25	15.3	M24, M25	17	M25
5 x 4	16	M24-M25				

Step 3: select cable gland size upon its internal diameter ranges (standard models)

Models	M16	M20	M24	M25
Min and max dia.	6-10	8-13	11-16	13-18

<u>Technical information N°4 :</u> The different normalized thermostat electrical life classes

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

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.

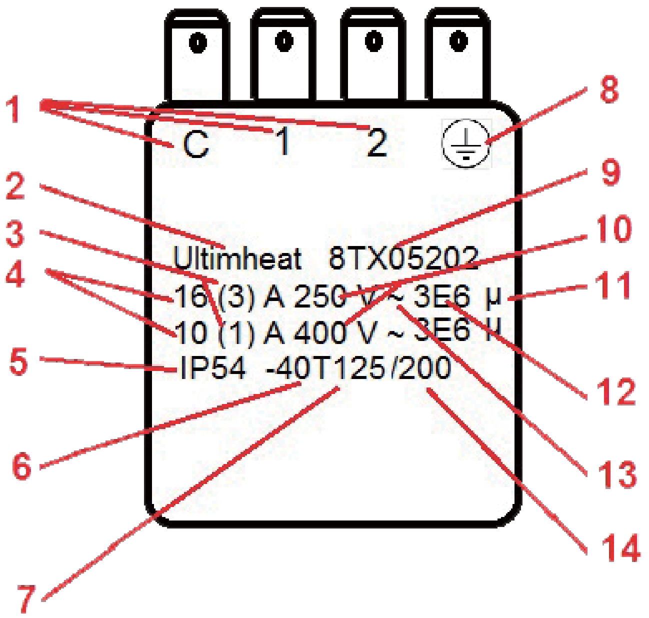
Mechanical life :
This is the number of operations which a thermostat can be expected to perform while maintaining mechanical integrity. Mechanical life is normally tested with no load or voltage applied to the power contacts, and is not part of this document.

Switch performance is influenced by a variety of factors, including: frequency of operation, type of load, temperature, humidity, altitude. Electrical ratings have 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.

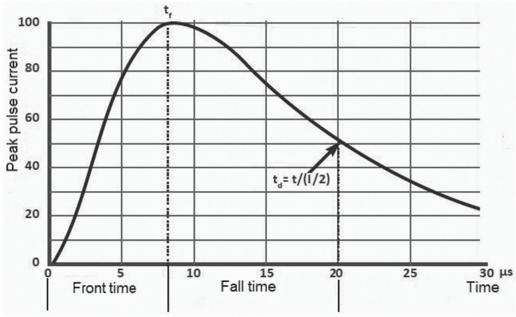
The current rating of thermostat switches is given in their technical data sheets for a resistive load in 250 or (and) 400V AC and a specified number of operations. When there is enough room, these values are printed on the product. In most cases, only the minimum mandatory information is printed. The cycle number is exceptionally printed, but this is one of the most critical parameter to estimate the expected life of the thermostat.

<u>Technical information N°5 :</u> 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 The 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.

<u>Technical information N°6 :</u> Electrical contact rating reduction on inductive loads



Impulse voltage :
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, which 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.

Switching voltage: AC and DC
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. This effect has a huge importance when switches are used in DC circuits, and will result in a significant decrease in the switching power. This is because the switch does not have a zero cross point. Once arc has been generated, it does not easily diminish, prolonging the arc time. Moreover, the unidirectional flow of the current in a DC circuit may cause metal deposition to occur between contacts and the contacts to wear rapidly.

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.

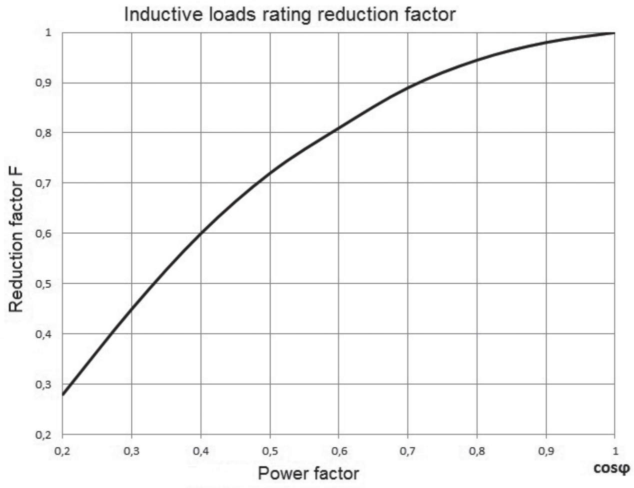
Lamp loads impulse voltage :
A tungsten filament lamp, when filament is cold, has an initial inrush current of 10 to 15 times the nominal current.

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 at 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.

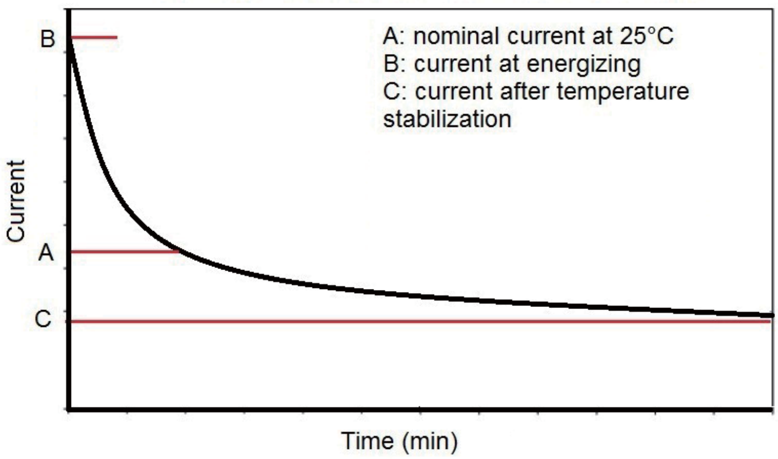
Arc suppression :
In these high inductive loads application it is desirable to suppress the arc. Techniques for arc suppression are described on our specific technical data sheets.

<u>Technical information N°7 :</u> Average inductive loads correction factor (if no arc suppression device is used)



<u>Technical information N°8 :</u> 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.

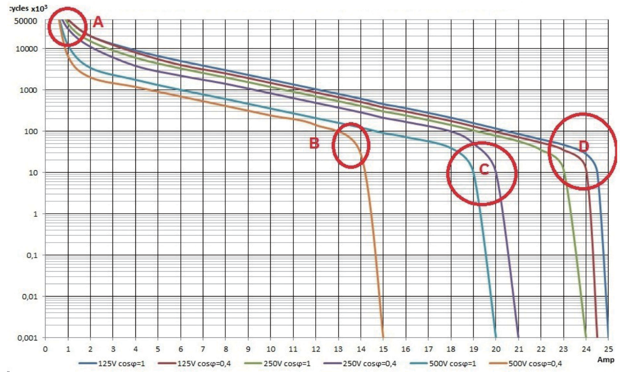


<u>Technical information N°9 :</u> Indicative average current rating reduction coefficients

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

<u>Technical information N°10 :</u> Average electrical life of a thermostat switch rated 15A250V, 300,000 cycles

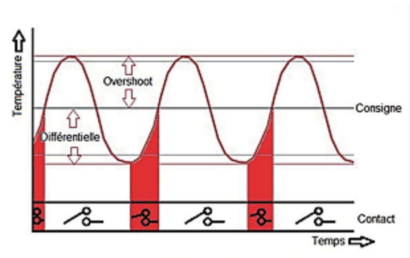


Average approximate values for a snap action mechanism with silver contacts.

Characteristic points:
A: Zone of mechanical break of the contact blade by metal fatigue
B: Contacts fast melting zone due to combination of 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.

Technical information N°11 : the temperature control modes.

While thermostats typically operate only in the on/off mode, the electronic controllers can regulate in two main modes: on/off with adjustable differential or PID.



On/off action Differential and overshhoot

On/Off action

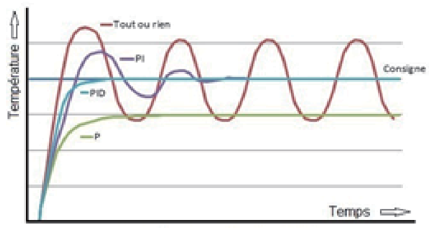
In the On/Off action, the heater is off when the set point is reached, and restarted when the temperature drops below the set point value minus the differential.This is the conventional mechanical thermostats operating mode. The successful operation of this mode mainly depends on the temperature sensor correct positioning near the heat source and the compatibility between the heating power and the need of the environment to be heated. The On/Off
action does not usually prevent temperature peaks (over-shoot) after switching off the heating, due to the system thermal inertia.

Adjustable differential: A low differential is often associated with control accuracy. However, a too low differential will cause heating short cycles and premature contact wear if a power relay is used, or a quick degradation of the compressor if the system is used to control a refrigerator. The electronic controllers have an adjustable differential to optimize this operation.

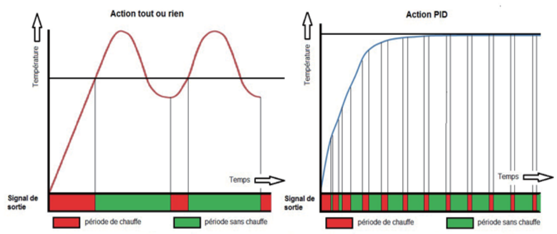
The PID action (Acronym for proportional, integral and derivative).
The PID action is a control mode that involves the concept of Feedback. Simply speaking, this means that the regulator will analyze what temperature rise will be produced by a quantity of energy supplied to the heating device and how long this rise in temperature will take. This action involves three different settings.

Proportional band: this band is an area before the set point, in which the electronic controller will gradually decrease the power it provides to the heating device. At the furthest end from the set point, the power will be 100%, to reach 0% when the set point is reached. The purpose of the proportional band is to avoid the over-shoot phenomenon. This variation of power is obtained by gradually reducing the warm-up time as the temperature approaches the set point. The larger the band is, the longer it takes to reach the set point. A proportional action only is generally not sufficient to reach the set point as the temperature stabilization is made below the set point, due to heat losses and exchanges.

This lack of proportional action is corrected by the integral action. This integral action will continue to provide a heating control signal as long as the heating temperature of the heating device is not equal to the set point. In this purpose it also integrates the time for the system to heat up.
This action is equal to the integral of the deviation from the set point divided by a time constant. This time constant corresponding to the setting I. When the integral time is set to 0, a simple proportional action is obtained. The proportional-integral action allows the set point value to be reached after a few oscillations when starting the process.
We can limit these oscillations by introducing another correction: the derivative action, which allows to anticipate overshoots.
The derivative action adjusts the output power from the temperature variation curve. It involves predicting temperature variations based on previous actions of the output signal. By predicting temperature variations based on previous actions of the output signal, it compensates the response times due to the thermal inertia, accelerates the response of the system and enhances the stability of the loop, while allowing a quick damping of the oscillations due to the occurrence of a disturbance or a sudden variation of the set point.



The control different actions



Comparison of the frequencies of opening and closing of the output signal in On/Off action and PID action

If the PID action can improve the control in a number of configurations, the drawback is that the output signal will cycle very quickly, which reduces the power relay life very extensively and requires in most cases to use solid state relays.

The Auto-tune function (self adjustable): determining the P, I, D, parameters, which is possible by calculation or by successive approximations, is a tedious and complex operation. The new generation of auto-tune regulators will analyze how the thermal system will react during two functioning On/0ff cycles, then automatically compute the optimum PID parameters.