THERMAL APPLICATION NOTE

USING THE HEATER PID METHOD SEGMENT

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The Heater PID method segment is used to change the performance of the instrument furnace during the execution of a thermal method. PID stands for Proportional, Integral, and Derivative, the three modes of traditional temperature control. The Heater PID segment specifies the control coefficients for each mode of temperature control.

The instrument furnace is run by a control system that uses factory default PID coefficients. The default coefficients are automatically set and adjusted to give excellent furnace performance under various operating conditions. However, sometimes it may be useful to further optimize furnace performance for all or part of a specific method.

The Heater PID method segment provides the ability to change control coefficients while a thermal method is running. Every time the instrument is reset or a method ends, the three PID coefficients are reset to their factory default settings. When a Heater PID segment is encountered in a running method, the current PID furnace control coefficients are immediately replaced with new coefficients from the Heater PID method segment. The new coefficients are used to control the furnace for the remainder of the method, or until another Heater PID method segment is encountered.

Determining what PID coefficients to use requires some trial and error experimentation on the part of the user. A general description of each control mode and advice for determining useful parameters is provided below.

Proportional Control

Proportional control mode provides furnace power in direct proportion to the difference (error) between the measured furnace temperature and the desired furnace temperature. When the error is zero the applied power is zero. As the error increases the applied power to the furnace is increased in proportion to the error until a maximum permitted power is reached. Beyond this maximum power point, and at zero power, the furnace is said to be “out of control”. The temperature error range between the application of zero power and maximum power is called the proportional band or “prop band”.

The PID Proportional coefficient (W °C^{-1}) determines the width of the proportional band. A coefficient of 1.0 delivers one watt of power for every °C of temperature error. The maximum power available varies depending on the furnace type in use.

Since some furnace power is required to maintain a furnace at an elevated temperature (unless there is no heat loss to the surroundings), there will always be a small temperature error that cannot be removed using only the proportional mode of control. This error is called “droop” or “offset”. The integral control mode is used to remove this type of error.

Integral Control

Integral control mode provides extra furnace power to compensate for any long-term difference between measured furnace temperature and desired furnace temperature. The amount of temperature error is measured (integrated) over time to determine the average error. A power correction based on this average error is then applied to the furnace. This type of correction is also called “reset”.

The PID Integral coefficient (W °C^{-1} s^{-1}) determines how rapidly the offset error is corrected. A coefficient of 1.0 delivers one watt of additional furnace power for every °C s of integrated temperature error.

Derivative Control

Derivative control mode is an anticipatory control function that measures the rate of change of the furnace temperature and reduces the furnace power to avoid temperature overshoot. A negative power correction is applied to the furnace based on the rate of change (°C s^{-1}) of the measured temperature. This type of correction is also called “rate”.

The PID Derivative coefficient (W °C^{-1} s^{-1}) determines how much breaking action to apply. A coefficient of 1.0 delivers minus one watt of power for every °C sec^{-1} of measured heating rate.

Determining PID Coefficients

No one set of PID coefficients will produce optimal results under all conditions. A certain amount of experimentation is required to determine the best coefficients for a particular set of conditions. Tradeoffs must be made between different aspects of furnace performance (*e.g.*, rapid furnace response time versus larger temperature overshoot).

The conventional PID coefficient tuning process involves making individual runs using empty sample containers. Each run performs the method of interest, or just the critical portion of the method of interest, such as a temperature ramp to isothermal hold, or an equilibration at elevated temperature. A Heater PID method segment is inserted as the first step of the test method, or at the critical point in the test method, so that experimental PID coefficients can be tried and the effect on furnace performance noted.

The first step in the complete PID tuning process involves making a quick estimate of a set of stable PID coefficients. This is accomplished by adjusting each coefficient in turn and observing the result of the adjustment on temperature and heating rate. Then further refinement of each coefficient is made to increase or decrease the characteristic effect of that coefficient on the furnace control.

Adjusting the Proportional Coefficient

The Proportional coefficient is adjusted first. The Integral and Derivative coefficients are set to zero during this test. The Proportional coefficient is first set to any nominal value (one tenth of the maximum furnace power is suggested). The test method is run with the Heater PID method segment inserted. Sample temperature and heating rate are plotted versus time.

If the result of the test is stable (no sustained oscillations in temperature) then increase the Proportional coefficient and repeat the test until a value of the Proportional coefficient is found that is just large enough to produce sustained oscillations in temperature around the temperature set point. Select one half of this value for the Proportional coefficient.

Alternately, the Proportional coefficient can be determined by increasing/decreasing the coefficient until the peak height of each temperature oscillation is approximately one quarter that of the peak height of the previous oscillation. Select this value for the Proportional coefficient.

Adjusting the Integral Coefficient

The Integral coefficient is adjusted next. The Proportional coefficient is set to the value determined by the previous testing. The Integral coefficient is set to any nominal value (twice the Proportional coefficient is suggested as a start). The Derivative coefficient is set to zero. The same series of test runs are made as when adjusting the Proportional coefficient. The temperature and heating rate are observed. Increase the Integral coefficient until a sustained oscillation is achieved as in the proportional testing. Select one third of this value for the Integral coefficient.

Alternately, the Integral coefficient can be determined by increasing/decreasing the Integral coefficient until the amount of observed temperature offset is acceptable. Select this value for the Integral coefficient.

Adjusting the Derivative Coefficient

The Derivative coefficient is adjusted last. The Proportional and Integral coefficients are set to the values previously determined. The derivative coefficient is set to any nominal value (two percent of the Proportional coefficient is suggested as a start). The same series of test runs are made as when adjusting the Proportional and Integral coefficients. The temperature and heating rate are observed. Increase the Derivative coefficient until the temperature overshoot is acceptable without unduly compromising the maximum heating rate required. Select this value for the Derivative coefficient.

Final Coefficient Adjustment

If desired the PID coefficients can be further adjusted to improve furnace control by adjusting one coefficient at a time and observing the effect on furnace control. The following guidelines can be used to help with this adjustment:

It is usually best to make final adjustments to the Derivative coefficient first, then the Proportional coefficient, and finally the Integral coefficient.

The Proportional coefficient controls the amount of power applied for each degree of temperature error, and the Integral coefficient controls the amount of power applied to correct for temperature offset. Larger values for each of these coefficients will increase the temperature overshoot and the amount of temperature oscillation, but will reduce the time needed to reach a set point temperature and the amount of temperature offset. Smaller values will have the opposite effect.

The Derivative coefficient controls the amount of temperature overshoot and the maximum heating rate obtainable when approaching a temperature set point. Larger values of the coefficient will reduce the temperature overshoot and reduce the maximum heating rate. Smaller values will have the opposite effect.

KEYWORDS

differential scanning calorimetry, dynamic mechanical analysis, micro thermal analysis, simultaneous thermogravimetry/differential scanning calorimetry, thermogravimetric analysis, thermomechanical analysis, theory