J. Condensed Matter Nucl. Sci. 37 (2023) 1–8

Research Article

Coupled Dual PID Feedback Improves Calorimetry

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Abstract

Good calorimetry is improved by stabilization and control of the ambient against which the device/component is tested and measured. We used multiple concentric chambers, algorithms, control of noise, interfering external gases, Benard instability, and single feedback control by commercial systems, and now coupled dual PID systems. Fast Fourier transform analysis has revealed a method to markedly improve temperature stability under some settings and conditions.

Keywords: Ambient temperature, calorimetry, fast Fourier transform, ohmic control, PID temperature control, temperature control, temperature stability, dual PID feedback

1. Introduction - Need for Very Stable Thermal Ambient Control

Calorimetry measures heat generation and the movement of heat, enabling CF/LANR researchers to evaluate when materials are active and actually producing more heat than the driven input. A good calorimeter must be linear and time invariant, and the best of them use input from multiple locations, and types of input (eg. IR emissions and/or heat flux as well as thermometry). Good calorimetry, among other things, absolutely requires control of the ambient temperature, against which the device/component/system's own temperature is measured during the test. Often this need for control and stabilization of the ambient temperature may be one of the most challenging conditions for accurate effective calorimetry.

We have tried many ways to improve stabilization and control of the ambient temperature including multiple concentric chambers [1], improved algorithms [2], [3], [4], control of noise [5], [6], interfering external gases [7], the false positive amplification by Benard instability [8], [9], [10], and the intercalation of single feedback control by commercial systems [11], [12], and now dual coupled PID control systems. This report describes the latest improvement using two interacting coupled feedback controllers to stabilize the "background" temperature in a CF/LANR experiment's calorimetry. When used correctly, this successful technique may improve calorimetry in general, and CF/LANR examinations for possible excess heat, in particular.

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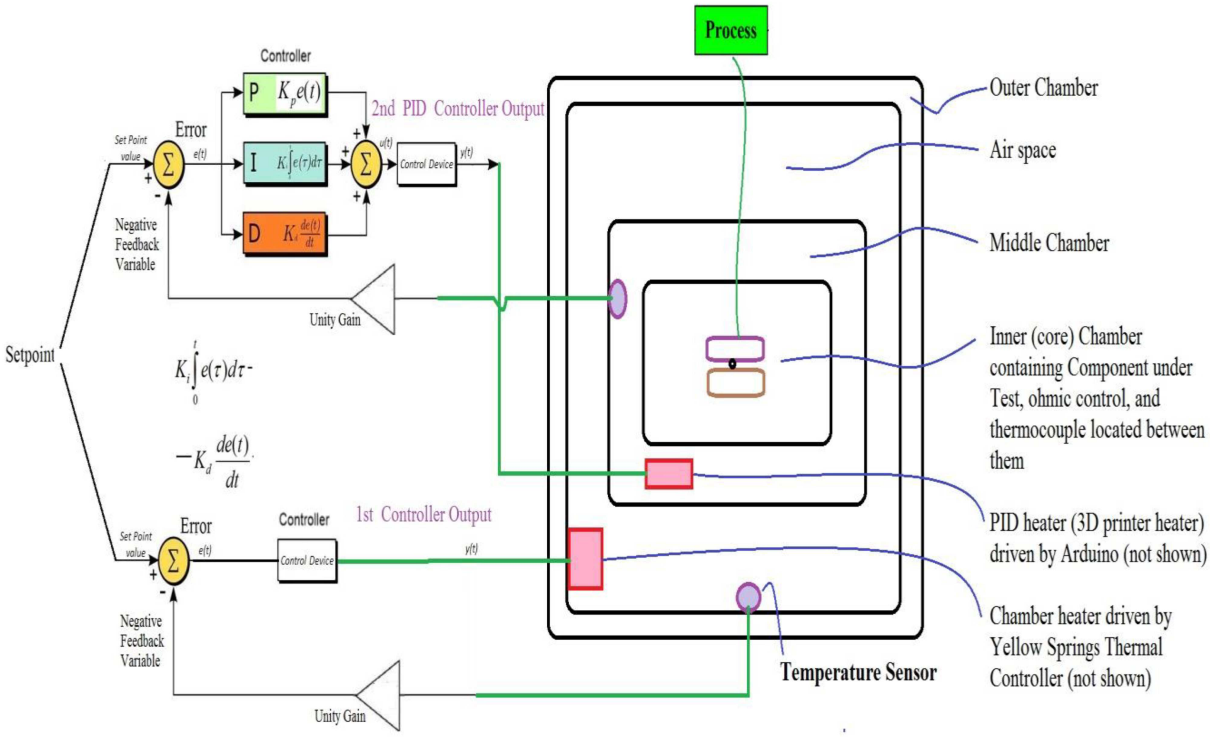

Figure 1. Block diagram of coupled dual feedback control.

2. Background - PID Temperature Control

Temperature Controllers use one, or more (as here) feedback closed-loops to control processes and force them to be as close to the setpoint as possible. For input, in temperature control feedback systems, whether PID or not, the controller uses the sensor signal, from a thermocouple, digital Dallas probe, or RTD are used to determine the present conditions from at least one location. For output, simple temperature controllers use two state systems, ON and OFF. Complex controllers today, such as using the Arduino PWM, allow a scaling of outputs at about 500 levels or more. A PID temperature controller is a software control system with temperature sensor(s) and heater(s) to attempt to stabilize ("control") temperature.

On the right side of Figure 1, this block diagram shows three concentric volumes with the component under test, ohmic control, and thermometry at core (labeled 'Process'). The power supply and leads to them are not shown; nor is the normal other thermometry and heat flow measurement used for calorimetry. Shown on the left-hand side are both coupled thermal control loops.

Before microprocessors, PID controllers were designed using analog electronic components. The first PID controller was made in 1911 by Elmer Sperry, and they now account for more than 95% of closed-loop industrial systems. Today all PID controllers are run by microprocessors. A PID temperature controller has three subsystems. The Proportional- or P-controller gives output which is proportional to current error e(t), multiplied by the proportional constant. The Integration- or I-Controller integrates the error over a recent period of time, and then multiplies it by the integration constant. The I-Controller limits the speed of response and improves system stability. The Differentiation- or D-Controller is used to better anticipate upcoming future conditions. By using the rate of change of error with respect to time which is multiplied by derivative constant, the D-Controller increases system response as needed. However, it is too sensitive to noise, and if a signal is noisy and/or the examination rate (“control loop rate”) is too slow, the derivative D-controller response may make the system unstable. After determining P, I, and D, each heater is driven to an amount of power (“Output”) proportional to the PID computation derived from each’s locally and/or regionally sampled temperatures.

$$\text{Output} = K_p e(t) + K_I \int e(t)dt + K_D \frac{d}{dt} e(t)$$
$$\text{Where : } e = \text{Setpoint} - \text{Input}$$

In single PID systems, the Steady-State error is the difference between the feedback control variable and set point. A Windup error usually means that there is insufficient output to drive the error signal to zero. One key to a working PID system is the correct choice of proportionality constants k_I, k_D, and k_P. This is called tuning. The parameters and system must be adjusted to minimize overshoot, minimize the time to achieve steady state, minimize deadtime, and maximize linearity, disturbance rejection, and time-invariance. Whether by guesstimate, or trial and error, or an algorithm such as the process reaction curve open-loop technique or the Zeigler-Nichols closed-loop technique, or AI, these are/must be adjusted to minimize oscillations. In addition, an engineer tunes the parameters by first setting k_D and k_I to zero, increasing k_P until fast, but stable, oscillation. k_I is increased to stop the oscillation, at the expense of overshoot. k_D then is adjusted to decrease overshoot.

2.1. Background - Fourier Transform

The Fourier Transform is commonly used to convert a signal in time to a frequency spectrum. Both types of Fourier Transform, Discrete and Fast (13, 14) are intended to analyze a time (or other) signal into the sum of all frequency sine waves which are equivalent to the signal. By this analysis, the Fourier Transformation is used in engineering to examine the frequencies in a signal. This knowledge is again incredibly helpful yielding natural and induced frequencies and their amplitudes, and sometimes insights into system instabilities. The potential damage is unanticipated without an analysis, and sometimes incalculable; as with the Tacoma Bridge [https://youtu.be/mXTSnZgrfxM?t=4]. In calorimetry, they can interfere with the accuracy and precision, as shown here at very low frequencies.

The Fast Fourier transform [FFT; [13], [14]] is important as an efficient algorithm for computing the discrete Fourier transform (DFT). Cooley and Tukey derived the Fast Fourier Transform (FFT) algorithm which recursively divides the DFT in a series of N smaller DFTs. This decreases the computation time, decreasing the DFT scaling of O(N2) to that of the FFT algorithm which scales as O(N log(N)). In such actual Fast Fourier spectra, such as the two in Figure 2, plotted are the amplitude (energy/Hz) at each frequency. Thus, what is shown is the absolute value of the derived FFT plotted as function of frequency. Because each discrete output of the FFT corresponds to one frequency, therefore, the frequency resolution is $\Delta f = fs/N$.

3. Experimental

In the present system with dual PID control, the temperature input is taken from two locations outside of the core (Figure 1). In addition to the thermometric connections were thermal, electrical, and sensing connections for both the single commercial temperature controller (upper curve) and the second controller [Arduino PID heating controller]. These are null runs with respect to CF/LANR and with respect to normal control experiments, so that the calorimeter itself can be optimized. To further evaluate the effectiveness, a Fourier analysis of each run was made. Fast Fourier

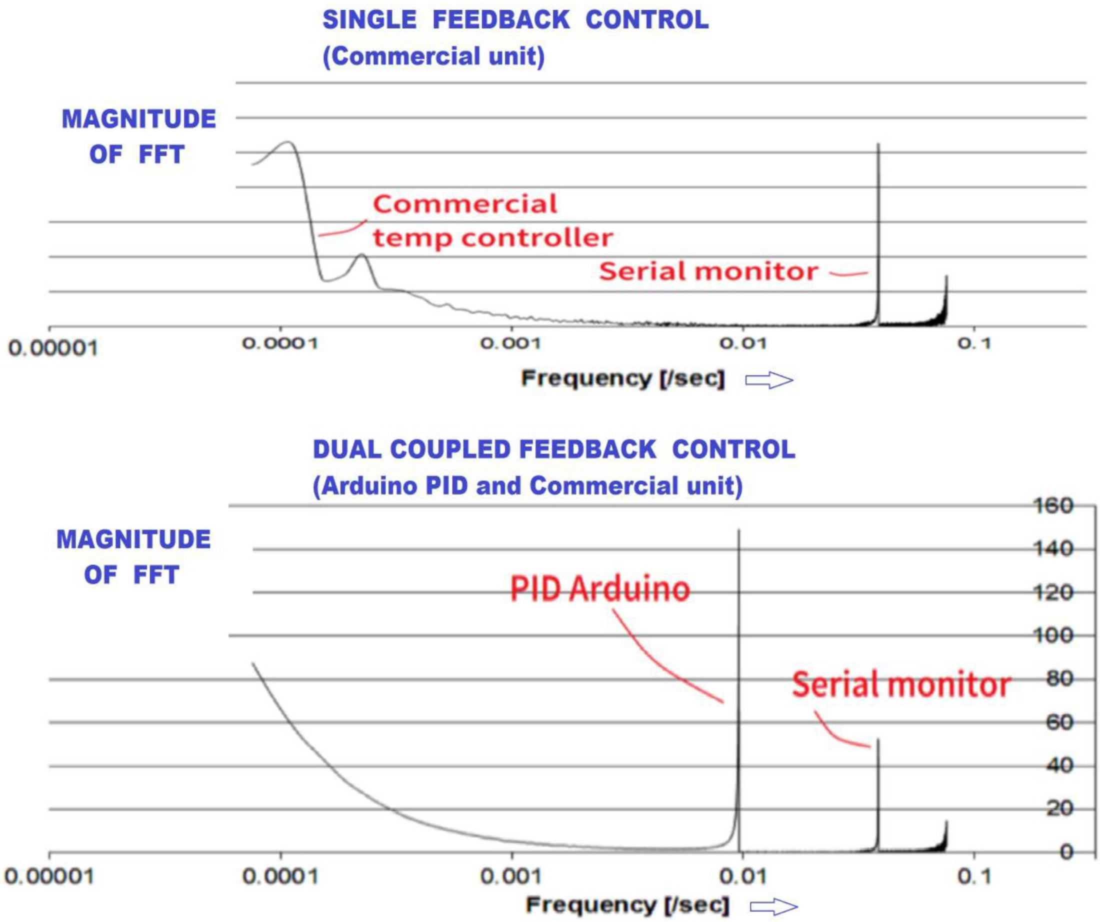

Figure 2. Two Fast Fouriuer transform (FFT) examinations of a null CF/LANR system.

Transform (FFT) analysis was used to examine both past and these ongoing efforts incorporating concentric volumes and both single and coupled dual PID thermal control loops to attempt to better maintain the temperature around the core where LANR activity is being examined. These data (including the curves in Figure 2) show the direct thermometry of the space between the LANR component and the ohmic control (both off and in equilibrium). The data is from the core of a three compartment concentric calorimetric system.

4. Results – Coupled PID Thermal Control

Figure 2 shows the FFT of detected thermometry located at the core of the calorimeter, constraining the CF/LANR component and its partnered ohmic control, but–in this control null experiment–with no electrical input to either. The figure shows two curves resulting from two Fast Fourier Transform (FFT) examinations of two nearly identical runs with no electrical input to either the component or the adjacent ohmic control. The top of Figure 2 shows only the commercial system on. Bottom: both on and with the setting as described in the text. The bottom shows the result of dual coupled PID feedback temperature controls. The curves in Figure 2 also show the features which result from the serial monitor, and the two feedback control systems: the PID Arduino, and the commercial (Yellow Springs) controller. The top curve is the run which only one PID system on; the commercial (Yellow Springs) controller. The bottom curve in Figure 2 is run with both the PID Arduino and the commercial (Yellow Springs) PID controller, at the setting as described in the text.

It is apparent that this FFT analysis shows marked improvement of the temperature stability associated with incorporation of the second PID loop. Note that the previous impact of the commercial controller is barely apparent, if at all, in the bottom curve of Figure 2.

4.1. Result – Optimal Performance of Coupled PID Thermal Control

Most interestingly, analysis has also revealed–as shown in Figure 2-the "capture" of the 1st controller in the calorimetric system (under some conditions) by the 2^{nd} Arduino PID-controller. The Arduino-controlled subsystem can easily be seen to dominate control (in Figure 2) of the composite thermal output signal.

In this limited examination, when two PID thermal control subsystems were coupled together, it is shown that there can sometimes be a marked improvement exceeding either alone. Furthermore, this preliminary survey and analysis reveals that the improvement occurs when the faster control system has the opportunity to couple and then dominate the control of both. By this method, the faster subsystem appears to obtain frequency dominance and takes a unique control of the entire system resulting in improved "ambient" stability.

What is not communicated in the two graphs in Figure 2 are the critical coupling and settings. This successful capture does not always occur, so it is necessary to correctly set the system to maximize temperature stability. Most importantly, although not every thermal probe location-configuration and stereo constellation of the concentric containers was tested, the best result was obtained when the Arduino PID cycled at a rate more often than commercial unit, and when it was located to control the innermost chamber.

5. Interpretation – Capture of Pair Is Controlled by the Higher Frequency

The results show that there may be a general possible improvement/benefit in using two (or more) coupled thermal control systems under some conditions. Here, there is an observed improvement of "ambient" stabilization using coupled PID thermal subsystems to drive PID-controlled electrical dissipation currents through two ohmic resistors. Perhaps the most important finding to share with those concerned with obtaining better quality calorimetry through improved control of the "ambient" is the superior results which accrue from a specific configuration of then two coupled PID temperature controllers. When two coupled PID temperature controllers are used in the setting of two, or more, concentric containers, with the fastest PID-subsystem located to heat the innermost container, such a setup appears to maximize the likelihood of achieving a very stable calorimetric "ambient" result. This may be, in part, the result from dominance of one controller.

This may be similar to the physiological phenomenon of capture of the human heart's rate by the faster atrial SA node [15]–[17] from its competing cardiac electrical driving systems. As seen in Figure 3, a similar requisite configuration is needed for a human heart to perform with normal good cardiac output. Shown is the human heart, and the sinoatrial (SA) node, and the electrical waveforms in a heartbeat using Eulerian coordinates as the cardiac impulse moves down the conduction bundle. The human heart's SA node must necessarily be temporally (electrically) "ahead" and lead the cardiac impulse events. Only when both driving subsystems function in the correct order at the correct timings does the heart produce a massive exit of blood, as it twists like a towel loaded with water. In that case,

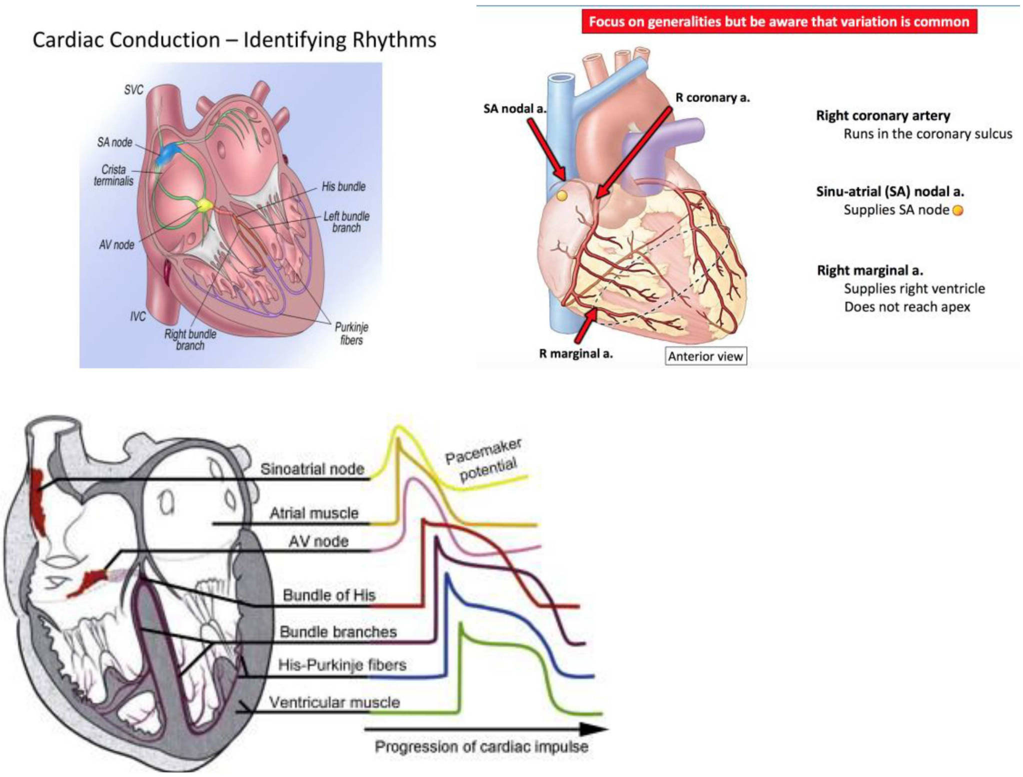

Figure 3. Dual coupled electrical control systems improve cardiac output.

the slower pacemaker becomes submissive. To enable comparison, this continuum bioelectromechanical function of the heart is shown schematically in Figure 3. It goes into more detail regarding the two (2) frequency-controlling bioielectrical subsystems. In the heart, coupled pulsatile timings must occur correctly to drive the most-desired cardiac muscular contraction configuration leading to the highest cardiac output.

5.1. Analysis of Capture Control in Coupled PID System

In the human heart, the most rapidly firing cells usually take over control of the heart; and these are located in the heart's sinoatrial (SA) node (Figure 3). These cells become the normal commanding pacemaker (because they uniquely do not have a resting phase in their action potential, and automatically immediately depolarize). Under normal conditions, other parts of the heart with lower pulse rates become functionally submissive to the controlling SA pacemaker which initiates the sinus rhythm, or normal electrical pattern followed by contraction of the heart. The SA node consists of a cluster of specialized myocytes with pacemaker activity over a few square millimeters on the posterior wall of the right atrium. These cells have a spontaneous pacemaker rate producing 100 to 110 heart beats per minute. In our body, absent excitation, this is decreased by autonomic vagus nerve to 60–80 beats/minute. However, when the normal conduction pathway is interrupted or if there is SA node malfunction, then other parts of the heart with lower pulse rates become functionally dominant! This produces lightheadedness, dizziness, pre-syncope, syncope, and possible death.

6. Conclusions

It is well known, and experimentally obvious that good calorimetry requires control of the ambient against which the component under test is examined. In addition to multiple concentric chambers [1], improved algorithms [2], [3], [4], control of noise [5], [6], interfering external gases [7], and the false positive amplification by Benard instability [8], [9], [10], and now importantly supplementing single feedback control by commercial systems [11], [12], coupled dual PID systems appear to be a significant improvement. Fast Fourier transform (FFT) analysis has revealed marked improvement of the temperature stability with incorporation of the coupled second PID loop under some conditions.

In summary, this paper recognizes and distinguishes that the coupled PID systems are not like the conventional single PID thermal control systems. Although individually each PID thermal control subsystems is regulated solely by the amplitude of its error signal, the coupled system's ultimate thermal control appears to be dominated and controlled by the faster of the two subsystems. This is easily seen to dominate control (in Figure 2) of the composite thermal output signal. Therefore, in LANR or other calorimetry, utilization of correctly coupled paired PID thermal controllers may reveal a domination of one thermal subsystem, with improvement characterized by improved control of the ambient signal with improved accuracy and resolution of the desired thermal output.

Acknowledgments

The author gratefully acknowledges and thanks David Nagel and Gayle Verner for their very helpful comments and editorial assistance. This effort has been supported by JET Energy Inc., Nanortech Inc., and the Anthroprocene Institute.

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