The Temperature Controller

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Abstract

The setpoint temperature for aluminium block was determined using a temperature controller, which uses Servo loops. By obtaining the setpoint temperature using different types of Servo loops, we were able to determine which had the greatest control. For low setpoint temperatures, the PID controller showed greatest control but lost accuracy at higher temperatures. For overall control, the PI controller displayed the greatest control. We also determined that by taking all the data with the fan on, the block would display less dependance on the room temperature.

1 Introduction

The temperature of an aluminium block can be controlled using Servo controllers. There are many different types of Servo controllers, open loop, on-off, proportional, PI (proportional - integral), and PID (proportional - integral - derivative), all with different affects on the control parametres. A temperature controller is a Servo controller that attempts to reach the desired temperature as quick as possible with minimal overshoot and maintain this temperature as accurately as possible [1]. At this desired temperature, the power will equal half of the maximum power. To determine which type of control system (type of Servo controller) is the best temperature controller, how they affect the criteria for good control must be taken into consideration. The criteria for good control are accuracy, stability, and response. Accuracy is the degree of correspondance of the measured value with the desired value. Stability is how stable the measured temperature is when it has reached the desired temperature. Response is how quickly the system brings the measured temperature to the desired [2].

An open loop temperature controller uses no use of feedback, only a fixed power, and allows the system to go to equilibrium. The system has very slow response time and is limited in its accuracy and inability to overcome environmental disturbances [3]. This type of controller allows us to see proof of Newton's law of cooling. Newton's law of cooling states that the rate of range of temperature of an object is proportional to the difference between its temperature and the ambient temperature [4].

An on-off controller is a controller that is either fully on or off. When the output is below the desired temperature, it is on but any temperature above the desired, switches the output to off. To switch from on to off, the system must pass through the setpoint, desired temperature. This means that it will overshoot the set-point. The system will continually be cycling back and forth from on to off. When hysteresis is added to this system, it will require that the setpoint temperature is exceeded by a certain value before the output will turn off or on again. This will decrease the rapid cycling from on to off and improve the system's stability [5].

Proportional control is where the controller adjusts the temperature in proportion to its deviation from the setpoint. This eliminates the cycling seen with the on-off control. As the set-point temperature is approached, the average power supplied to the heater is decreased to ensure that it won't overshoot. This proportional behaviour is observed in a band, of chosen size, around the setpoint. This band is referred to as the proportional band. Outside the band, the controller functions as an on-off controller. At the setpoint, the difference between the desired temperature and the setpoint is zero so that the on-time is equivalent to the off-time. As the temperature within the band moves away from the setpoint, the on and off times will vary in proportion to the temperature difference with the setpoint. If the band is too small then we'll observe an oscillatory response, like the cycling seen with the on-off controller [6]. The error on the band is equal to the change in temperature, from setpoint to measured, divided by the size of the band. This type of controller results in steady-state errors and an offset error, which is the result of the system reaching an equilibrium in which the control signal no longer changes. This allows for the existance of a constant error.

The integral control will eliminate the offset error produced with the proportional control. This is because an increasing signal is produced as long as the error is non-zero [7]. To prevent oscillations, the integrator is only allowed to vary slowly. Its response is characterized by its action time, which is the time taken for the output to vary from zero to full output within a proportional band of one. This control ensures accuracy and stability but will result in an initial overshoot before it settles at the setpoint [8].

By incorporating the derivative control into this proportional-integral controller, the time it takes to recover from the initial overshoot can be increased. This results in a PID controller, which ensures control accuracy, stability and response. This controller must be tuned to a particular system. This tuning allows us to determine the integral and derivative action times and proportional band that best fit the system [9].

The PID controller can be tuned using Zeigler-Nichols. It is characterized by two parametres, A and L. On the step response curve, the point with maximum slope is determined a tangent is drawn. The intersection of this tangent with the vertical axis gives A while its horizontal intersection gives L. The values of A and L give us starting points for our parametres [10].

By determining the power it takes to hold the aluminium block at several temperatures and measuring its cooling rate in that temperature range, its heat capacity can be determined and compared to the actual value, 24 J/K*mol. Heat capacity is the ability of a body to store heat as it changes temperature [11].

2 Experimental Methods

The aluminium block was connected to the Labmaster, which acted as a voltage source. When the measurements were taken the fan was on, this ensured that the values weren't as affected by the environment as they would have been if the fan was off.

3 Results and Discussion

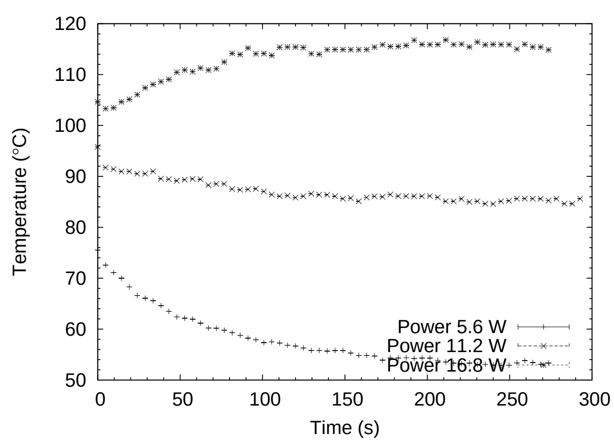

Figure 1: Open-loop control.

Using the known voltage and current, we were able to calculate the maximum power, 22.4(1) W, that can be exerted. With the open loop controller, we took measurements at a quarter, a half, and three-quarters of this maximum power. From the Figure 1, we can learn several things about the heat loss mechanism. As seen with the quarter power, it is appears constant as it approaches the room temperature. This confirms the validity of Newton's law of cooling because as the the room temperature and the block's temperature approach, their difference decreases and hence the rate of change of temperature of the block will approach constant. One can also note that when the fan was turned off, the values were more dependent on the environment.

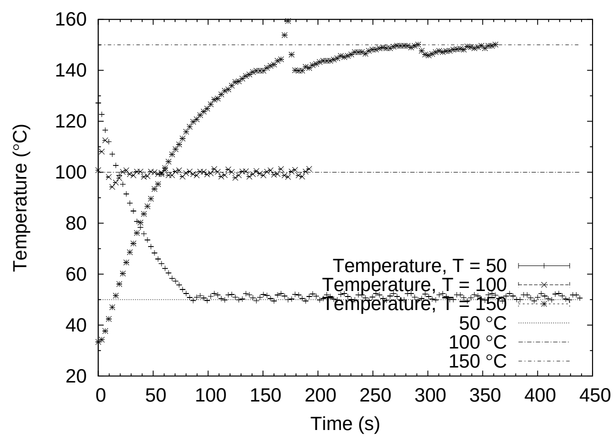

Figure 2: On-Off control.

Figure 2 shows that when the output is below the setpoint that it is on and once above it will be off. We can see the resulting oscillation clearly on the graph. This shows that this type of controller has little stability.

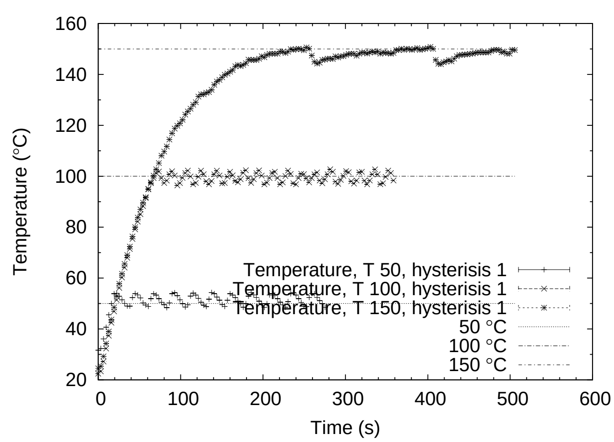

Figure 3: Hysterisis in on-off control

The hysterisis of on-off control is used in controls where it is impractal to turn them on and off rapidly, but still desire on-off control such as in a house furnace. As seen in

Figure 3, adding hysteresis to the on-off control decreases the rapid cycling about the setpoint. While we've reduced the noise we had previously viewed in Figure 2, we have lost temperature variation.

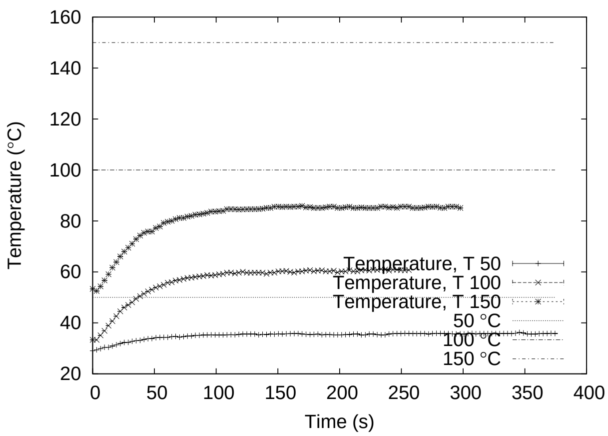

Figure 4: Proportional control.

By not incorporating a bandwidth, we can see in Figure 4 that we can not attain the setpoint temperatures. We have to minimize the size of the proportional band so that we can attain the temperatures and see good control.

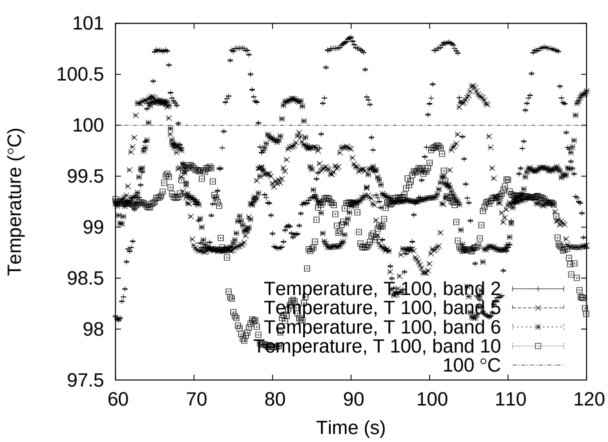

Figure 5: Proportional band calibration for larger band widths

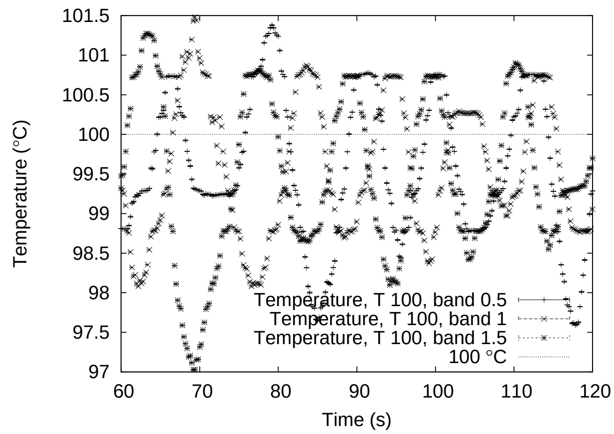

Figure 6: Proportional band calibration for smaller band widths

From Figures 5 and 6, we determine that our one proportional band is equal to 11. Any width smaller than this value will show an oscillatory response.

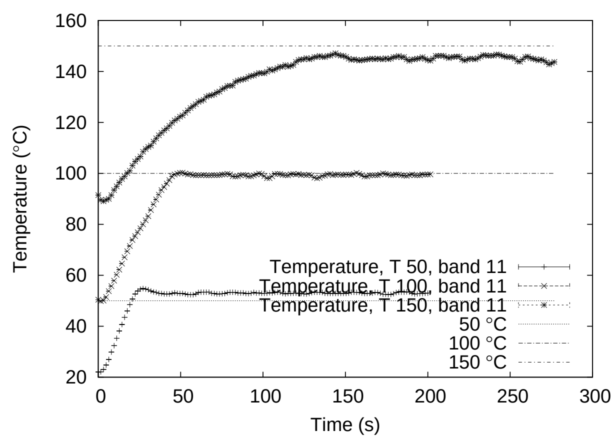

Figure 7: P control.

As seen in Figure 7, we can see that the proportional band controller has better overall control than the previous controllers. With temperatures of 50 and 150 degrees celsius, we see that there are still issues of accuracy since the setpoint isn't reached.

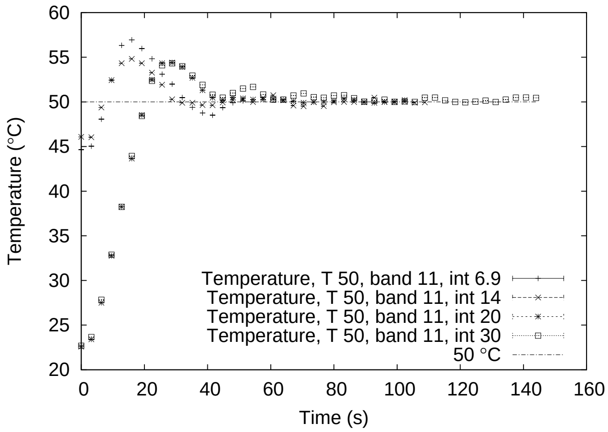

Figure 8: Calibration of the PI control

Figure 8 allows us to determine the best integral action time for the system. By trial and error, several integral action times were attempted until we found the one that had little overshoot, good response, and didn't oscillate about the setpoint. The best integral action time for this system ended up being 20.

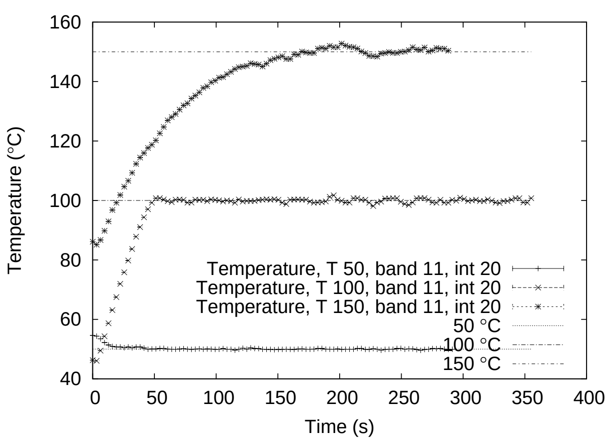

Figure 9: PI control.

We can see in Figure 9 that the PI controller shows good control, accuracy and response. At 100 degrees celsius, there is minimal overshoot and very little oscillation about the setpoint. While the overshoot is larger for 50 degrees celsius, the PI controller gives an very accurate result and stability. For 150 degrees celsius, the control is better than for the proportional band but it can be improved.

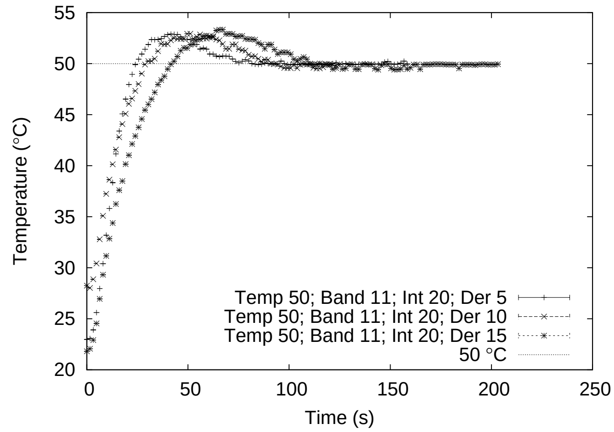

Figure 10: Calibration of the PID to determine derivative action time

By adding the derivative to the PI system, we are trying to speed up the time it takes the temperature to go from its overshot value back to the setpoint. In Figure 10, we attempted by trial and error to determine the derivative action time that would give us the best result. This gives us a derivative action time of 10.

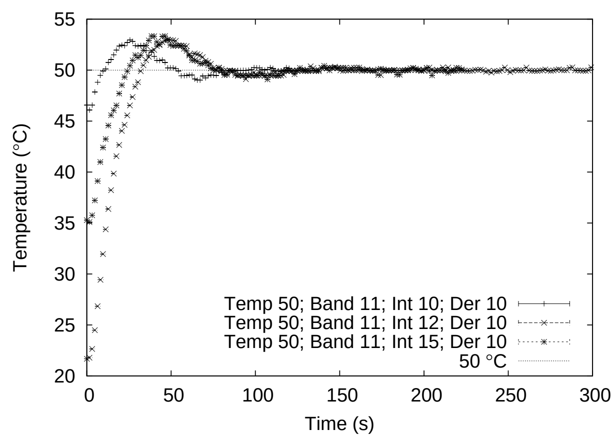

Figure 11: Calibration of the PID to determine integration action time

Since we've added the derivative component to the system, we must recalibrate the integral action time. Using the same method outlined for the PI. We determine the best integral action time from Figure 11 to be 12.

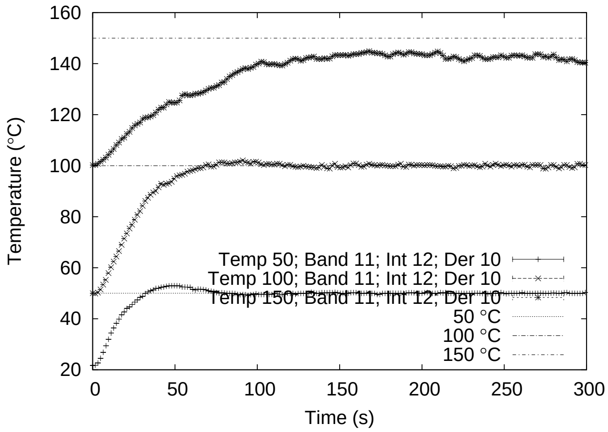

Figure 12: PID control.

As seen in Figure 12, the PID control displays very good control at low temperatures but loses a great deal of accuracy at high temperatures, 150 degrees celsius. For these high temperatures, it is apparent in Figure 9 that the PI controller shows better control. The PID isn't as effective at higher temperatures as the PI because of the incorporation of the derivative. This inhibits the temperature from reaching higher value setpoints.

Measuring the blocks volume and assuming that the block is pure aluminium, the specific heat capacity of the block was calculated to be $1.2(3) JK^{-1}g^{-1}$. The expected value is $0.900(1) JK^{-1}g^{-1}$[12].

4 Conclusion

The PID controller shows greatest control at lower temperature setpoints but loses control accuracy at higher temperatures. This is believed to be caused by the presence of the derivative factor, which inhibits the block from reaching its high setpoint temperature. For higher temperatures, the PI controller shows the greatest control. For overall control, one can conclude that the PI controller shows the greatest control because it functions for all temperature ranges. Newton's law of cooling was validated by the constant rate of change of the block as its temperature approached that of the room. It was also determined that taking measurements with the fan on ensured that the values were less dependent on the environment.

References

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