This document provides an overview of the DDI Fusion Temperature Controller and general notes on tuning PID controllers.

Definitions

Units of Measure

The unit of measure that is used to define the process, typically in ^{0}C.

TC

Thermocouple – a bimetallic sensor that generates a millivolt signal that is proportional to the temperature.

RTD

Resistance Temperature Detector -

SP

Set Point - The desired set point value in working units that the process is intended to drive.

PV

Process Value – The feedback from the system, usually from a TC or a RTD scaled to the units of measure

MV

Manipulated Value – The control loop output. Using a scale of 0-100 to represent the percentage of available power used to drive the output. When using an SSR typically PWM is used to modulate the output power; MV represents the duty cycle of the output. If an analog output is selected to drive an SCR the scale represents the percentage of available control voltage.

PID Overview

A full in-depth review of PID control is outside the scope of this document. Here we only present a quick overview of PID control and details of the DDI Fusion PID control solution. Further details of the specific Temperature control settings within Fusion can be found in the temperature control overview documentation or in the Fusion EtherCAT Programmer's Guide.

PID is a mathematical algorithm for controlling a single variable of a system to a steady-state equilibrium and continuously maintaining that equilibrium as the environment around the system changes. This equilibrium point is commonly referred to as the system's setpoint. To maintain the system setpoint over time the PID controller must be fed information about the current state of the control variable. This control variable is commonly referred to as the process variable.

PID controllers combine three metrics to maintain the system's process variable at the desired setpoint, and these three metrics provide the basis for the PID namesake: Proportional, Integral, Derivative. The Proportional output is based on the current state of the system, the Integral output is based on the historical state of the system, and the Derivative output is based on the system's current rate of change. All three sub-outputs of the PID algorithm are summed together to create the final PID control output. Additionally, prior to summation, each sub-output is scaled to match the characteristics of the system. The process of determining the scaling values is known as tuning.

The DDI Fusion PID solution is run on the Fusion processor directly and is based on standard industrial PID control methods, implementing the following discrete time ideal PID algorithm:

$$U_t = K_c\left(e_t + \frac{1}{T_i}\sum_{n=0}^{t} e_n - T_d\,(x_t - x_{t-1})\right)$$

Where U_t is the controller output at time t, x_t is the process variable (PV) and e_t is the error signal - the difference between the setpoint (SP) and process variable. K_c, T_i, and T_d are the scalars associated with the system gain, integral time, and derivative time respectively. Another common form of the PID algorithm is the standard form:

$$U_t = K_p e_t + K_i \sum_{n=0}^{t} e_n - K_d\,(x_t - x_{t-1})$$

Where $K_p = K_c \quad K_i = \frac{K_c}{T_i} \quad K_d = K_c T_d$

The derivative term in the DDI Fusion PID Controller has been modified from the canonical ideal PID algorithm to respond to the inverse of the change in the process variable as opposed to the change of error signal. This is done to prevent any potential derivative kick issues commonly associated with the ideal algorithm. The archetypal PID control diagram below has been delineated to show what happens inside the Fusion.

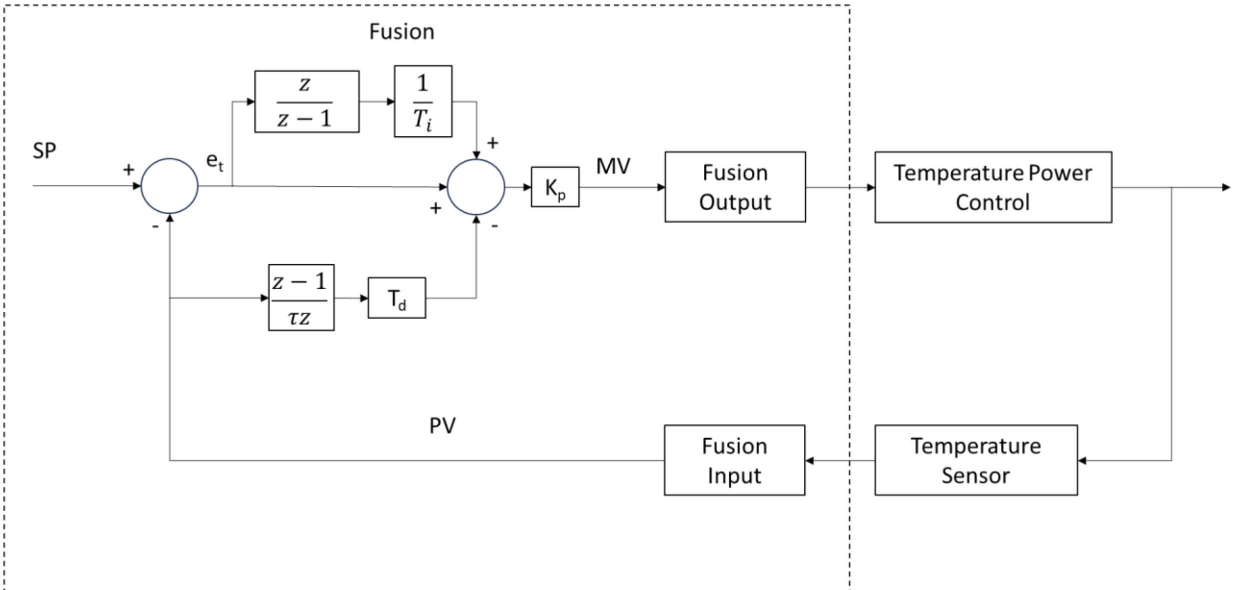

Figure 1 PID Control using a Fusion

Fusion PID Tuning

Tuning a Fusion temperature controller is done in a similar fashion to other industrial temperature control solutions. Starting with an understanding of the capabilities of the system a user will set gains to affect the proportional, integral, and derivative components of the PID control output – the Manipulated Value (MV)

Proportional Band (P_b)

DDI utilizes a proportional band to determine the proportional gain. Proportional band is in the process units of measure and is related to the unitless proportional gain K_p:

$$K_p = \frac{100}{P_b}$$

Smaller Proportional Band numbers represent a stronger K_p gain. If the system Process Variable is outside of the proportional band the control system manipulated value will be at one of the output extremes (i.e. if the process variable is below the setpoint and outside the proportional band the manipulated value will be at the maximum output, if the process value is above the setpoint and outside the proportional band the manipulated value will be at the minimum output). To prevent integrator windup the PID integrator is reset anytime the process variable is outside the proportional band.

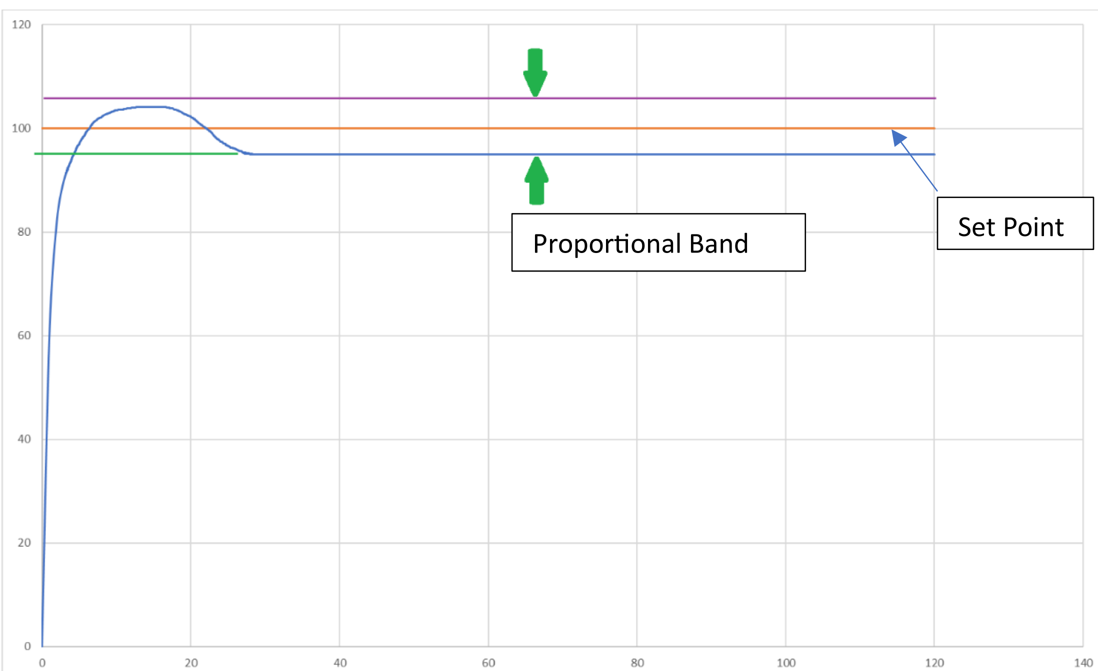

Figure 2Proportional Band

Integral Time (T_i)

DDI uses an integrator time constant. The integrator time constant is in units of seconds, and it is related to Integral gain K_i by:

$$T_i = \frac{K_p}{K_i}$$

Larger integral time values mean a smaller integrator gain, leading to more stable systems but slower response times. Smaller time values result in a stronger integrator gain, resulting in faster response times but can cause the system to become unstable.

Derivative Time (T_d)

The derivative time is set in seconds. It is related to the derivative gain K_d by the following relationship:

$$T_d = \frac{K_d}{K_c}$$

This gain is useful to counter oscillations in the Process Value caused by disturbance or a strong integrator.