# Chapter 5

# Direct Digital Control

## INTRODUCTION

DDC, which uses a digital computer with no moving parts, replaces both the conventional pneumatic control panel and the added energy management system. No control devices need to be adjusted or checked, because the microprocessor panel has no calibration or routine maintenance requirements. Operating instructions built into the software provide for simplicity and confidence of control. Cooling setpoints and strategies can be set in the winter and not tested, with complete assurance that the DDC system will perform as expected when summer arrives.

Multiple digital control microprocessors, each operating its own piece of HVAC or other equipment, can be linked to a single desktop console at a central location. Through this one desktop unit, an operator has access to all important setpoints and operating strategies. Monitoring, troubleshooting, and energy management functions are all performed from the same central console.

Applying a direct digital control computer to HVAC equipment requires only two considerations. The computer must be physically connected to the equipment and the computer must be given instructions via software on how to operate the equipment.

A DDC computer must be connected to both sensors (such as temperature sensors) and controlled devices (such as valve operators). Sensors are connected to the computer using two kinds of inputs, analog and binary. An analog input is a variable input that could be a temperature, pressure, or relative humidity reading. A binary input is a two-mode input that is either on or off at any given time, such as a motor status, filter status, or contacts with an electrical demand meter.

Controlled devices are connected to the computer using digital and analog outputs. A binary output is a two-mode output, either on or off at a given time. The time duration of either mode can be computer controlled to vary between a fractional part of a second to a full on or full off. A binary output could control a fan or pump motor or a lighting circuit. Using pulse-width modulation, it could also control a valve or damper actuator. Pulse-width modulation used bi-directional (open/close) pulses of varying time duration to position controlled devices exactly as required to satisfy demand. Wide pulses are used for major corrections, such as changes in setpoint or start-up conditions. Pulse width becomes progressively shorter as less correction is required to obtain the desired control setpoint.

Analog output is a variable output that might range, for example, between zero and ten volts. This is not usually needed with direct digital control because pulse-width modulation, using binary outputs, is a simpler and more accurate technique directly compatible with the binary form the computer uses internally to store information.

Control of valves and dampers is very accurate with DDC because of proportional-integral-derivative (PID) control, perfected years ago in the process control field. PID control techniques provide fast, responsive operation of a heating valve, for example, by reacting to temperature changes in three ways: the difference between setpoint and actual temperature (proportional), the length of time the difference has existed (integral), and the rate of temperature change (derivative) (See Figure 5-1). PID saves energy and increases accuracy at the same time by eliminating hunting and offset by decreasing overshooting of a given temperature and minimizing the amount of time required to settle at the desired temperature.

Once connections to the equipment (analog and binary inputs and outputs) have been made, the DDC microprocessor must be given instructions to operate the controlled devices. These instructions are in the form of software programs (application packages) with various control options and setpoints, all of which reside in the microprocessor's memory.

Software, though, is what primarily determines the ultimate capability of a DDC system. The changeable portions of a computer's memory provide a user flexibility of control far greater than that avail-

# 5-1. P.I.D. Control

## INTRODUCTION TO PID

PROPORTIONAL CONTROL

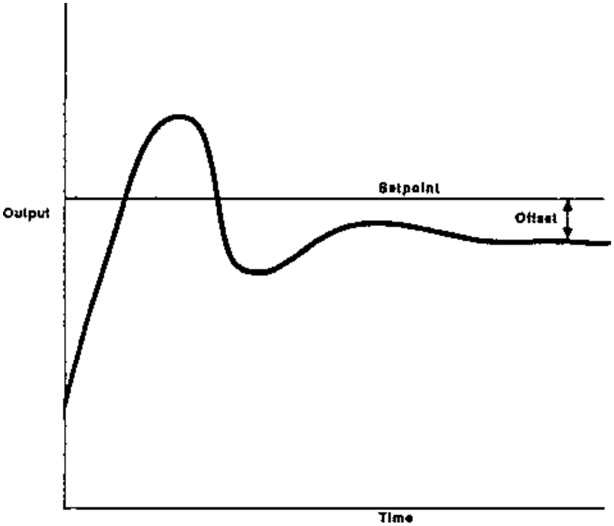

Figure 5-1a

### Proportional-Integral-Derivative Control

One of the most common terms heard in connection with today's Direct Digital Control systems is "PID"; an acronym for Proportional-Integral-Derivative control. An intimidating sounding term, PID simply refers to the 3 types of control action that are used in the control of modulating equipment such as: valves, dampers, variable speed devices etc. Surprisingly the concepts behind the 3 control actions are quite straight forward and easily grasped. Gaining an understanding of PID and its usage in control systems will provide a valuable insight into the operation of modulating control loops.

*Proportional Control* - the P of PID—is a technique where a control signal is produced based on the difference between an actual and a desired condition (i.e. a setpoint and an actual temperature). This difference is known as the "error." The control device creates an output signal that is directly related to the magnitude of the error, hence the name Proportional control.

Basic Proportional control is typical of that found in conventional closed loop temperature control systems. The weakness of Proportional Control is that it requires the existence of a significant error condition to create an output signal. Because of this, proportional-only control can never actually achieve the desired condition. Some small amount of error will always be present. This error is referred to as the OFFSET of the system.

Integral action is directed specifically at the elimination of Offset. Because the magnitude of an offset is relatively small, it cannot generate a significant change in the control signal by itself. An integrating term is used to look at how long the error condition has existed, in effect summing the error over time. The value produced by this summation becomes the basis for an additional control

(Continued)

signal, which is added to the signal produced by the proportional term. The result is that the control loop continues to produce a control action over time, allowing it to eliminate Offset.

With Proportional-Integral control we have the ability to:

1. Respond to the presence of an error in the control loop.
2. Relate the magnitude of the control signal to the magnitude of the error.
3. Respond to the existence of offset over time to achieve zero error or setpoint.

Figure 5-1b shows the control response typically produced with Proportional-Integral control. The significant difference is the elimination of Offset once the system has stabilized.

At this point one other major factor often present in modulating control loops still needs to be addressed. That factor is Overshoot.

Overshoot refers to the tendency of a control loop to over compensate for an error condition, resulting in a new error in the opposite direction.

As an example, consider a room with a setpoint of 72 degrees and an actual temperature of 68. A proportional controller would respond to this error by sending a control signal of some magnitude to the damper supplying warm air to the room. As the room heats up the magnitude of the control signal to the damper is reduced, but not until the room reaches setpoint would the control signal eliminate further heat input by closing the damper. At this point however the thermal inertia of the room causes the temperature to continue to rise for some period of time. The result is that the room "overshoots" the setpoint becoming warmer than desired. The room now requires cooling in order to return to setpoint. The Overshoot phenomenon not only impacts comfort but also results in energy waste due to overheating and overcooling. Derivative action (the D in PID) is

**PROPORTIONAL INTEGRAL CONTROL**

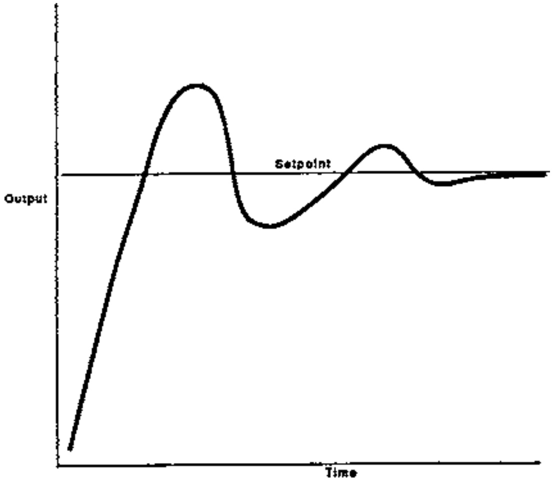

**Figure 5-1b**

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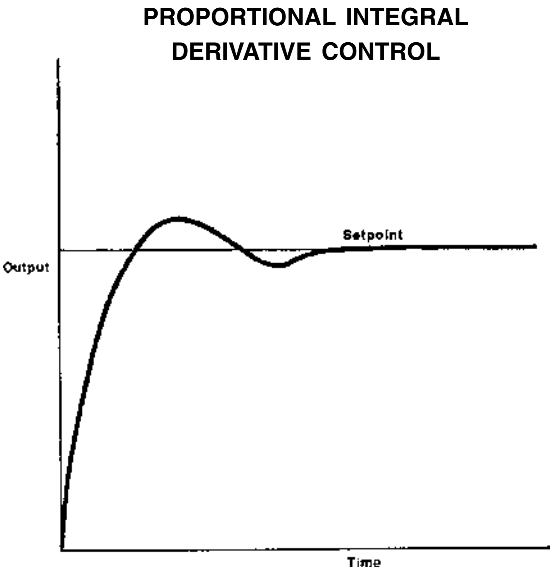


**Figure 5-1c**

designed to address Overshoot. It provides an anticipatory function that exerts a braking action on the control loop.

The Derivative term is based on the rate of change of the error. It looks at how fast the actual condition is approaching the desired condition and produces a control action based on this rate of change. This additional control action anticipates the convergence of the actual and desired conditions, in effect counteracting the control signal produced by the Proportional and Integral terms. The effect is a significant reduction in overshoot.

Combined, Proportional, Integral and Derivative action provide quick response to error, close adherence to setpoint, and control stability, as seen in Figure 4. Notice the reduction in Overshoot and elimination of Offset. (Proportional Integral Control Signal)

### Application of PID in Building Control

While the theory behind PID control is not new there has been a dramatic increase in its use due to the relative ease with which today's building control systems can implement it. Once available only in expensive process control computers, the software features of today's building control systems can provide Proportional, Proportional Integral and Proportion-Integral-Derivative action where needed, with relatively simple programming instructions.

The increased availability of PID control is to a large extent responsible for the dramatic improvements in control precision seen with the use of building control systems. Control loops such as Chiller Capacity Control, Static Pressure Control. Discharge Air Temperature Control, etc. can all be controlled reliably and precisely using PM action, providing improved operating efficiency over that available with conventional control systems.

able from pneumatic control devices. This flexibility allows changing any setpoint of control strategy without interrupting system operation. DDC software, for control of HVAC and other building systems, falls into seven basic categories.

Sensor reading programs measure temperature, relative humidity, flow, pressure, lighting level and do other things including conversion, linearization, and square roots. They also read switch inputs (two position on/off) and totalize pulsing units (such as from power meters) to measure energy consumption.

On/off control programs operate start-stop devices according to analog sensor values, such as turning on at one temperature and off at another; switch inputs, such as manual override and device status indication; and time, as in occupied and unoccupied schedules for HVAC and lighting.

Modulating control programs operate variable position devices, such as valves and dampers, based on a constant, fixed setpoint, and a reset schedule. An example would be resetting hot water supply temperatures based on the outside air temperature.

First generation DDC controllers accomplished adjust commands using proportional-integral-derivative (PID) control in 2 different methods. *One method* requires a feedback signal from the servo device in order to re-adjust a control command from the PID controller. The controlled variable is compared to the command or setpoint. The PID controller then calculates how far to move from the previous spot in order to get to setpoint. It then takes the appropriate and corrective actions to get to that spot. Seeing how re-adjusts are done, this is closed loop control. This method is used when programming needs the servo feedback variable value in order to accomplish hardware sequencing, hardware minimum positioning, etc. *The second method* of control is simply to make an adjustment based on the difference between setpoint and variable. At predetermined time intervals the variable is then retested to determine the amount of change which has occurred. This value is then used to recalculate how much further to re-adjust to obtain setpoint. This process continues until deadband is reached. Both methods use proportional, integral, and derivative gain terms in their calculations. Both methods use PWM (Pulse Width Modulation) techniques. PWM changes its positioning device or servo by sending an output of variable time length to drive a motor which varies a pneumatic or electric operator.

Present-day PID controllers can use the PWM method of control but also can use Analog control. Analog PID controllers can be tuned for each loops' individual characteristics. The servos are integral to the analog output, therefore, the output value is presented directly to the electric or pneumatic operator. This value is calibrated to be in direct proportion to the range of the controlled variable. For example, if the controlled variable is 3 degrees away from setpoint, the system knows that an increase of "x" percent will open or close the actuator the correct amount to move the controlled variable directly to setpoint. The PID controller knows this because the throttling range of the actuator is calibrated for 0.0 to 100.0 percent. PID loop tracking learns the values needed to generate the precise output value. The value of the PID commanded output is the actual percentage of actuator open position. For example, if the commanded output value is 68.0 percent, the actuator will be 68.0 percent open, considering there are no failures in the actuators themselves. This value may be read directly by the DDC for monitoring position, or can be ranged to an Analog Data point which can change the readout to any value however no additional hardware is required as in first generation DDCs with the PID feature. Changing the readout value requires additional software points and software generation. Outputs may be 0-20 mA, 0-10 vdc, or 0-20 psi, with any range of values between these minimums and maximums.

Current, modern day DDC with Analog PID is by far the best method of DDC reset control. The advantages are more accurate control with little or no hunting, and the elimination of the old reset servo devices which increases the chances of mechanical failures over time.

High level optimizing programs are used for pieces of equipment with multiple control loops and considerations, especially air handling unit optimization (including VAV systems with or without return fan tracking and guaranteeing minimum outside air ventilation) and chiller and boiler plant optimization.

Another category of programming is for energy management optimizing routines, such as load deferral (demand limiting and duty cycling), optimizing start/stop; and enthalpy changeover from air handling units.

Alarm and reporting programs provide critical and routing alarms, data and trend logging, and energy reports.

Finally, operator interface programs can display floor plans and equipment locations, display equipment schematics and real time operating data, and provide simplified menu-driven operation.

All temperature control, energy management, and automation functions can be accomplished with these software categories.

## ADJUST COMMANDS

Adjust commands on older systems were done strictly via operator commands from the central computer. When a command was given the system would compare the difference between the command and the actual position of a position of a potentiometer located in a servo type of device. The system would then send out a voltage of the proper polarity in order to force the servo feedback to match the command. This was typically done on a one shot basis meaning that if the two values did not match after one try, no other commands were issued automatically. The operator would be required to resend another command. The output of this servo was generally pneumatic, but in some cases was electric. The pressure output was in no way related to the feedback readout other than by mechanical means. The range of pressure output was not adjustable. If the setpoint of a pneumatic controller was being reset, the only indication of real setpoint was the actual value of the variable being adjusted. No controlled loop actions took place.

Later systems became more sophisticated in that the feedback for its adjust commands was the actual temperature itself. The operator command was a temperature or humidity etc. which the system compared to the controlled variable for determination of how far to move the servo device. This method was a step toward closed loop control but was not actually because the system did no re-adjusting in order to force the controlled variable to the command. In this case the output pressure ranges were adjustable but the output value did not reflect setpoint or position. The controlled variable was the only indication of setpoint or position.

## ADVANTAGES

The decision to use DDC can be based on the expected value of both energy and labor cost savings. DDC saves significant energy dollars through accurate control and by maintaining setpoint adjustments that do not change with time.

Since DDC integrates temperature control and energy management in the same system, comfort consideration can be incorporated into more sophisticated energy management programs, such as demand limiting by temperature and duty cycling within deadband setpoint.

Advanced control functions are available with the microprocessor. A prime example would be calculating minimum percent outside air, using outdoor, return, and mixed air temperature sensors. Large energy savings can be realized in this way, since almost all other control systems invariably use too much outside air. Once again, a small error here produces substantial waste of heating or cooling Btus. With air volume systems, minimum ventilation requirements can be guaranteed to prevent complaints resulting from stale air and improve indoor air quality.

The reliability, accuracy, and convenience of DDC reduces labor required for HVAC maintenance and allows for reassigning personnel to other important functions.

DDC requires both hardware and software. The hardware must be reliable, industrial grade, and engineered to interface with equipment. The software must be of a design proven to be comprehensive, flexible, and easy to use. DDC improves building operation in four ways. It reduces energy consumption, reduces HVAC maintenance labor, improves and assures occupant comfort, and provides greater operating convenience.

DDC provides enormous control flexibility and very accurate information. It allows building operators to reduce costs and provide better services at the same time. And the life-long accuracy of DDC overcomes the inevitable decay of other controls. Computer technology has finally come of age in its ability to simplify and improve building systems control.

The cost per point for the DDC system is usually higher than that of the other classes, but the following additional benefits are often sufficient to justify the extra cost.

1. DDC systems are expandable in terms of the number of points able to be monitored, software packages available, and operational functions.

2. They are more reliable than pneumatic control systems.

3. Failure of the central operator station computer does not upset the individual control units because satellite microprocessors are programmed to stand alone in such cases.

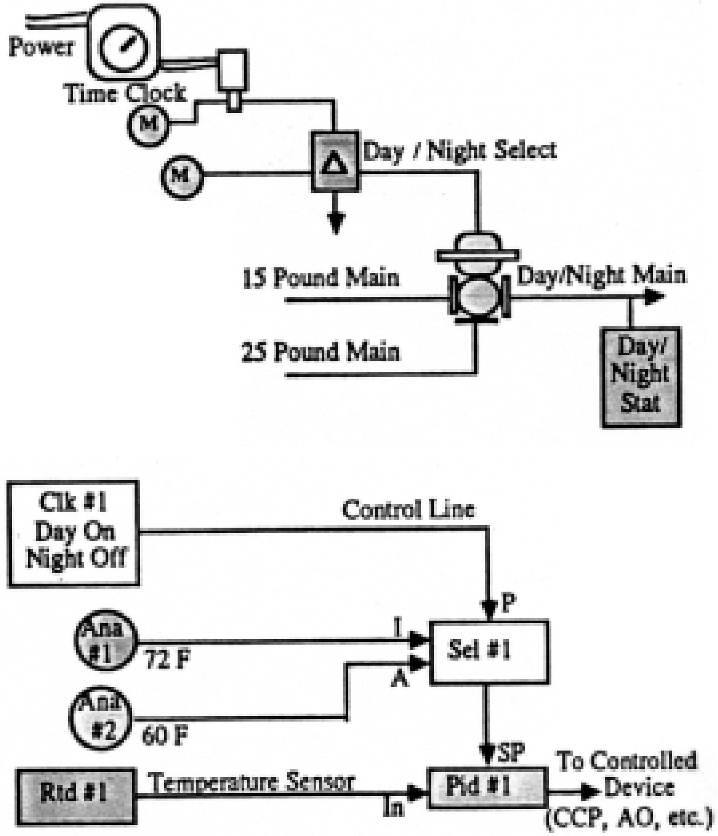
4. Larger operator station computer memory allows building management to use a preventive maintenance program and perform energy audits for the different buildings or areas of a single building.

5. Electronic components are usually available from several computer manufacturers. This has the advantage that the customer is not restricted to a particular company for equipment maintenance, and, in most cases, results in a reduction in the operation cost of the system.

6. Although the initial cost of DDC systems is relatively higher, the payback period is comparable with those of smaller systems.

7. In most cases, DDCs do not reduce manpower requirements, but a central operator-controlled system can assist in making building management and maintenance personnel more efficient, particularly when implementing effective preventive maintenance programs.

Microprocessors are quickly becoming a cost-effective method of system control offering a superior system of distributed intelligence. They minimize host computer requirements, increase the speed and accuracy of control, and drastically reduce system maintenance requirements.



5-2. Pneumatic Vs DDC-D/N Stat