Building Management System

Part 3

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Introduction to Control Electronics and other Field Devices

Introduction

Building Automation System (BMS) involves many automatic control loops to control the modulation of actuators and sequences the specific operations of mechanical and electrical equipment, to provide the desired comfort conditions and to maintain the Indoor Air Quality (IAQ) in the building.

Actuators used with motorized valves and dampers are also part of the field devices (Tier-4) category – similar to the different types of sensors that we discussed in Part 2 of this series. The actuators used with the valves and dampers are of different types like on/off, proportional, floating type, etc. and come with or without feedback. Let us look at some of the Control Electronics terminology and concepts, before we proceed with Actuators for valves and dampers.

The term Control Electronics includes all the electrical sub-systems used in BMS architecture in a building. The types of controls deployed in a BMS are *Process Control* type – i.e. process variables like temperature, humidity, flow rate, liquid level, pressure, etc. are monitored and controlled. Most of today's controllers use microprocessors and are called Digital Controllers. The traditional analog circuitry is not much preferred in these controllers.

Control Systems

Control systems can be broadly classified into *Open-loop* and *Closed-loop* systems. Taking an example of the requirement to 'cool a room', let us understand these concepts.

Open Loop

Refer *Figure 1*. Cooling of the room will result in temperature reduction. Room temperature is the process variable in this case. A cooler is used to cool the room. This is the control device. A switch is used to either supply electric power to the cooler or stop the power supply. In this case, the room temperature can be maintained at the required level, only if all the conditions affecting the process are constant (like door or window opening, outside temperature, number of people, etc.). The system does not have any automatic check to verify if any corrective action is necessary – like switching on to provide more cooling or the reverse.

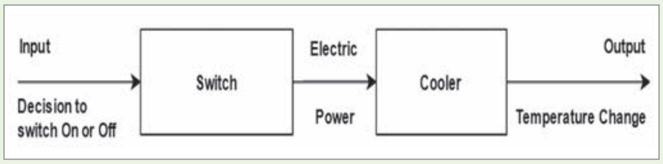

Figure 1: Open loop control system

Closed Loop

This open loop can be converted in to a closed loop (*Figure 2*) by adding a thermometer in the room. Knowing the temperature required to be maintained in the room (set point) and the actual current temperature (process variable), the operator can compare both the values and decide suitably if he needs to deliver more cooling to the room. The operator acts as the comparison element here. This can be automated by using a thermostat. So, closed loop carries out the measurement of process variable on a continuous basis, compares the required value and current value and adjusts the control device suitably.

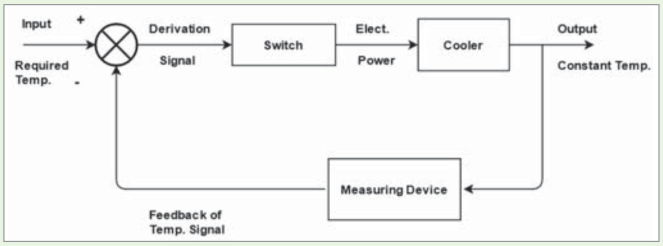

Figure 2: Closed loop control system

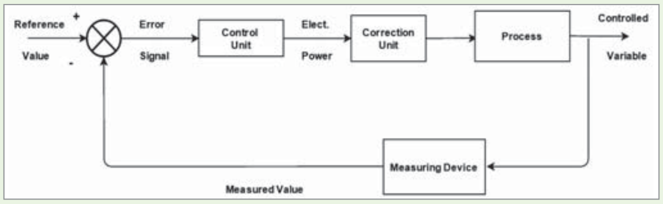

Figure 3: Closed loop control system - basic elements

All modern buildings deploying BMS use closed loop systems. The elements of a closed loop system are shown in *Figure 3*. A closed loop control has 5 basic elements: comparison element, control element, correction element, process element and measurement element. While applying this in practice, the electronic controller will usually incorporate the comparison element, control element and correction element. So, from the application point of view, in a typical field installation we get to see the control system having three basic elements, namely a sensor, a controller and an actuator.

About the Author

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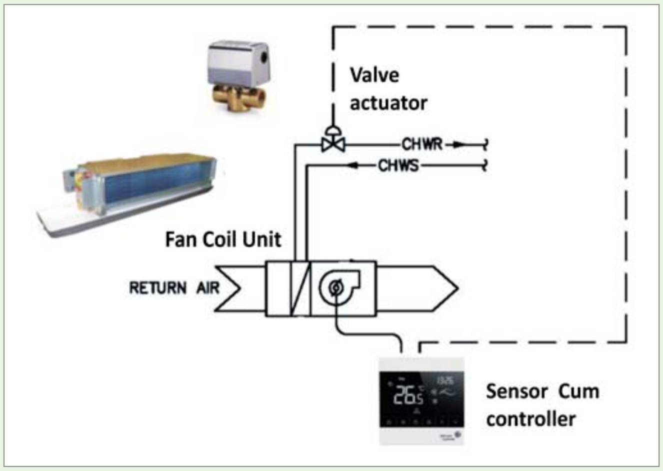

Figure 4: Examples of Closed-loop control system in field application

Example (*Figure 4*): chilled water fan coil unit (FCU).

Feedback Loop

This refers to continuous evaluation of the actual condition of the process variable, to suitably modify the process, to control and maintain the process variable as required. This is done by the comparison element by working out the error, as shown in *Figure 5*.

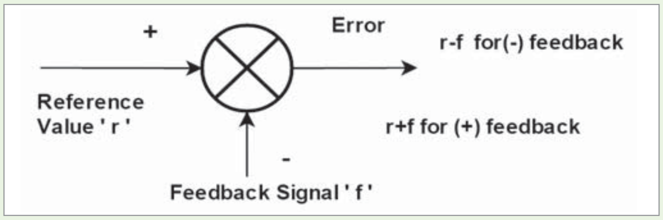

Figure 5: Feedback loop

The Reference Value is the set point, the desired value for the variable that is being controlled. This is taken as a positive. The Measured Value is the actual current value of the variable. This is considered to be negative. The error value is the sum of reference value and feedback signal.

For positive feedback, error signal = reference value – feedback signal.

For negative feedback, error signal = reference value + feedback signal.

Types of Control Actions

On/Off Control

In On/Off control, also known as two-step control, the controller output is either an On signal or an Off signal, regardless of how large the error is. Taking the FCU example, if the room temperature (say 27°C) is above the set point (say 24°C), it will switch on the cooling and vice-versa. To make the operation automatic, a *differential* or *dead-band* is defined. *Figure 6* shows the On/Off control system oscillation. The input variable's high side and low-side values are defined by the differential. In actual application, the differential is higher for On/Off control, due to inherent lag characteristics of the control and the process.

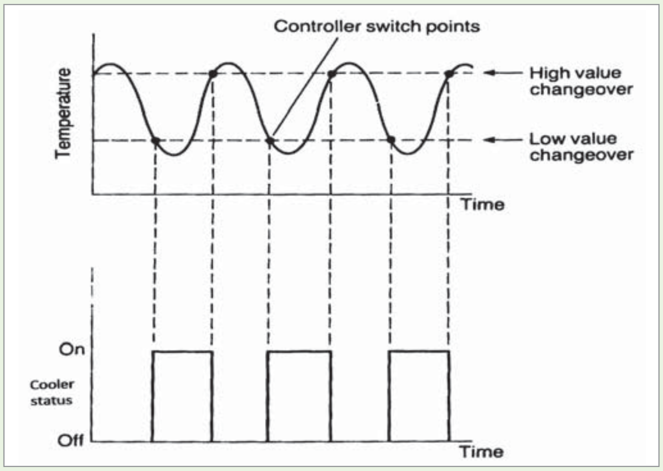

Figure 6: On/Off control system characteristics

Floating Control

In floating control, the specific output of the controller is not uniquely determined by error. If error is zero, the output does not change but remains (floats) at whatever setting it was when error went to zero. When error moves out of zero, the controller output again begins to change. Similar to two-step mode, there will be a neutral zone around zero error where no change in controller output occurs.

Modulating/Proportional Control

Here, the controller produces an output that is proportional to the error signal, i.e. the size of correction required. Hence, the correction element of a control system, say a valve, will receive a signal that depends on the size of correction required. The proportional controller gives a continuous output, as shown in *Figure 7*. Popular modulating control signals include 4-20 mA and 0-10 volts.

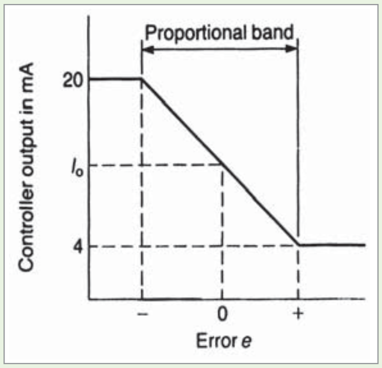

Figure 7: Proportional control characteristics

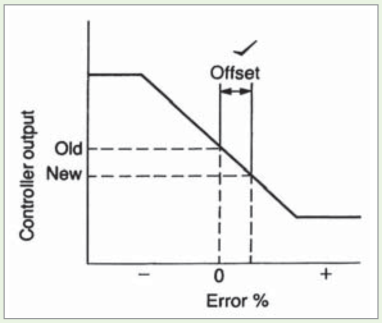

Figure 8: Offset

In *Figure 7*, the linear relationship for controller output and the error occurs only over a certain band of error values. This is known as the proportional band (also known as throttling range). Only over this band, the system will take proportional control action. The controller output is fixed at 0% for 4mA and 100% for 20mA. Generally, a 50% output is chosen to be the controller output when the error is zero, i.e. 12mA value.

For some reason, if zero error needs to be equated to a different % output (other than 50%), this requires a permanent error setting called an *offset*. Such a change is said to be a *load change* (*Figure 8*).

Integral Control

Integral control is where the rate of change of the control output is proportional to the input error signal. It can provide a control output without an offset error (*Figure 9*).

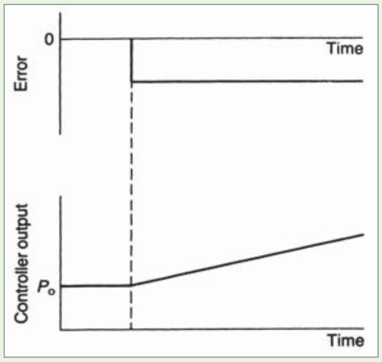

Figure 9: Integral control characteristics

Integral control is normally integrated with the proportional control to become the so-called Proportional-plus-Integral (PI) control. Adding integral control to a proportional controller compensates for the *load change* (*Figure 10*).

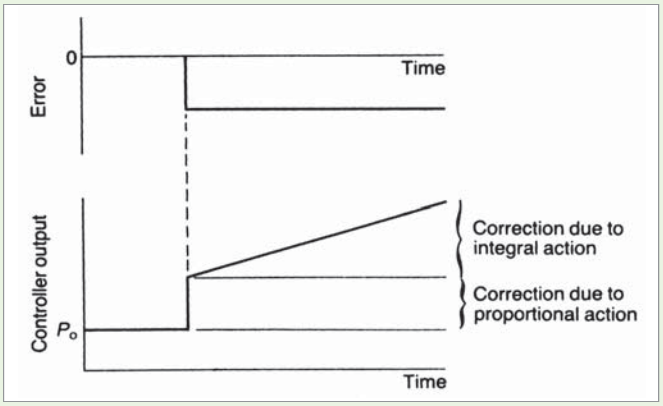

Figure 10: Proportional + Integral control characteristics

Due to lack of an *offset error*, the PI controller is used where there are large changes in the process variable. PI control is most commonly used in building systems, in particular, in the HVAC systems.

Derivative Control

With derivative control, the change in controller output from the set point value is proportional to the rate of change of error with time. The derivative control results in large control output, as soon as the error signal begins to change (*Figure 11*). This is because the function depends on rate of change and not on the absolute value itself.

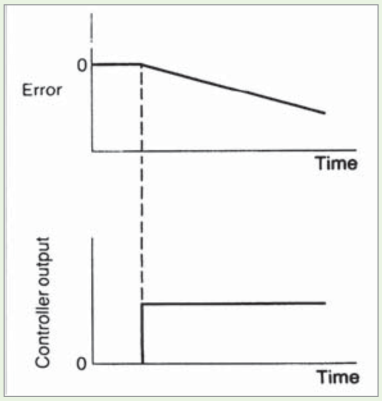

Figure 11: Derivative control characteristics

Derivative controls do not respond to steady-state error signals. Because of this, the derivative control is often combined with proportional control.

Proportional-Integral-Derivative Control

The Proportional-Integral-Derivative (PID) or three-mode controller is capable of maintaining a zero offset under steady conditions while being able to respond to sudden load changes. That is why PID controllers have been used for decades.

With proportional control only, the output is a function of the deviation of the controlled variable from the set point. As the controlled variable stabilizes, a residual load error is acquired. With the addition of the integral control, the controlled variable eventually returns to the set point because a permanent load error will produce a huge output by the integrator. Adding derivative control reduces the overshoot and the final set point can be achieved faster. The performances of the controllers are shown in *Figure 12*.

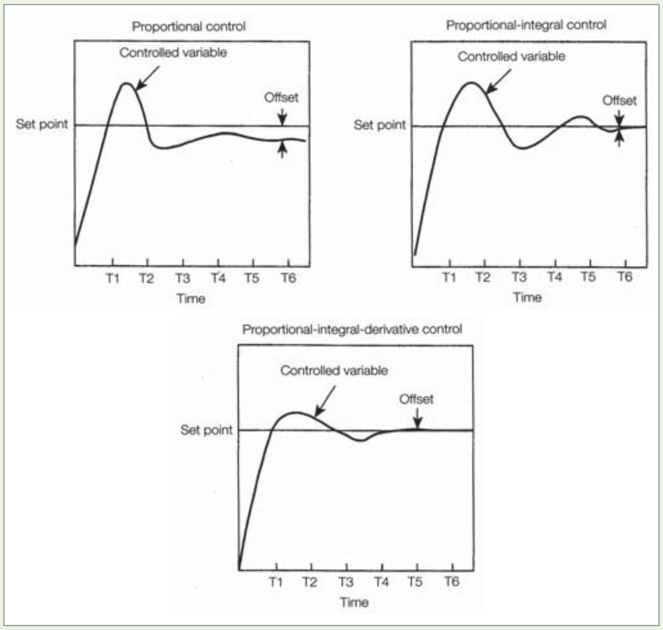

Figure 12: Performances of controllers

Field Devices: Actuators for Motorized Valves and Dampers

Valve actuators and damper actuators are field devices (Tier-4) controlled by the field controllers (Tier-3). Used to control and modulate the fluid stream in which they are used, they are suitably driven by the field controllers to achieve process variable parameter like temperature, pressure, flow, etc.

Given below is a brief description of different motorized valve and dampers used in HVAC applications. The selection of these devices has to be done carefully, understanding the application and following the manufacturers' guidelines.

Valves

A flow control valve regulates the flow or pressure of a fluid. Control valves are normally fitted with actuators and positioners. Modern-day buildings use electrically operated flow control valves. Other types of valves like pneumatic are not in use in building applications. Motorized flow control valves could be classified into plug valve, ball valve, globe valve and butterfly

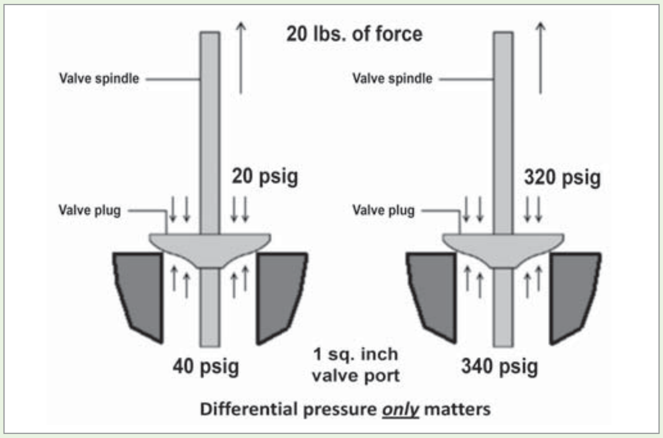

Figure 13: Close-off pressure for actuator sizing

valve, based on their construction and as 2-way or 3-way valve, depending on the outlets connected in the system. Valves are designed to handle specific fluids of design pressure and design temperature range. Their actuators are chosen to provide a tight shut-off while closing against a particular differential pressure. Refer *Figure 13*. Both the valves shown in the figure have the same ability to close, as their differential pressures are the same at 20 psid.

A *two-way globe valve* may be either single seated or double seated. A single-seated valve is designed for tight shut-off. Appropriate disk materials for various pressures and media are used. Double seated valves are widely used where fluid pressure is very high. Refer *Figure 14*. A rack and pinion arrangement converts the rotary motion of the actuator into a straight line motion of the valve spindle. The differential pressure of the water is pushing up the valve stem. If the actuator can push down with more force than the water can push up, we can close the valve. If we need a higher close-off rating, we need a bigger actuator to produce more downward force.

Figure 14: Two-way globe valve pressure directions

A *ball valve* consists of a ball with a hole drilled through it, rotating in a valve body (*Figure 15*). Ball valves are becoming increasingly popular because of their low cost and high close-off ratings. The direction of ball valve motion is perpendicular to forces caused by water pressure. In the case of a ball valve, the actuator does not push against water pressure; it just twists against the friction on the stem seals and ball seals. The close-off pressure rating of a ball valve depends on how well the ball is sealed against the body.

Figure 15: Ball valve

Figure 16: Butterfly valve

A *butterfly valve* consists of a heavy ring enclosing a disk that rotates on an axis at or near its center. Refer *Figure 16*. Even though the water is pushing against the disc and is trying to rotate it, it is doing the same thing on both sides of the disc, and so the forces of water cancel each other out. The close-off rating is really just a factor of how tightly the disc fits into the rubber seat and how hard we can push the disc into the seat.

Pressure-independent valves are control valves with integral pressure regulators (*Figure 17*). This allows the valve to maintain a constant flow proportional to the given load condition because the integral pressure regulator maintains a constant differential pressure across the valve's orifice, regardless of system pressure fluctuations.

Figure 17: Pressure independent control valve

Flow/Valve Characteristics

The flow control valve has many other performance characteristics like linear curve, equal percentage, Cv, valve authority, etc. Readers may refer standard books for details.

A typical *three-way valve* is shown in *Figure 18*. It could be either used as a mixing valve or diverting valve. If it is used as a *mixing valve*, it has two inlet connections and one outlet connection and a double-faced disk operating between two seats. It is used to mix two fluids entering through the two inlet connections and leaving through the common outlet, according to the position of the valve stem and disk. A 3-way *diverting valve* has one inlet connection and two outlet connections, and two separate disks and seats. It is used to divert flow to either of the outlets or to proportion the flow to both outlets.

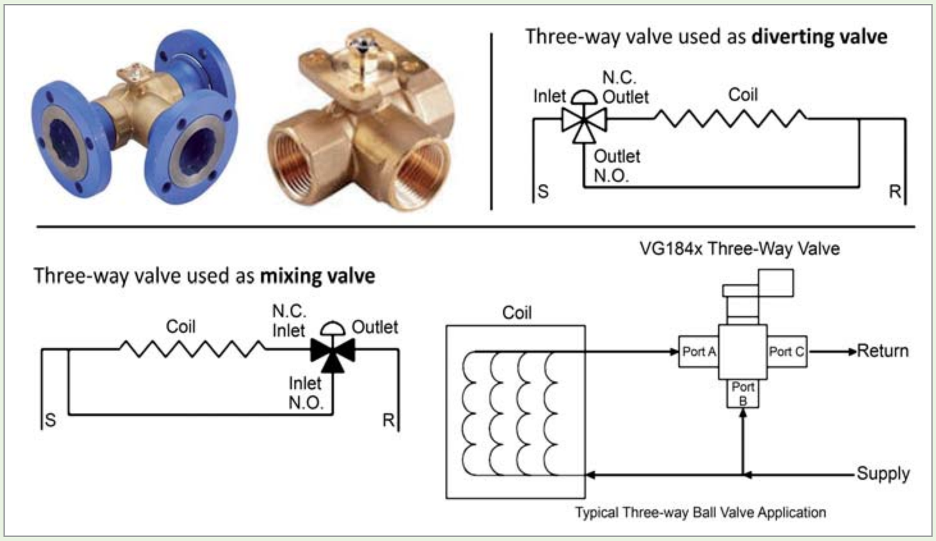

Figure 18: Three-way control valve

Three-way diverting valves are more expensive and have more complex applications, and generally are not used in typical HVAC systems.

Actuators

The commonly used terminology concerning valve actuators is given below:

Normally Open valve assumes an open position, providing full flow, when all actuating force is removed.

Normally Closed valve assumes a closed position, stopping flow, when all actuating force is removed.

Electric Actuator operates the valve stem through a gear train and linkage. Electric motor actuators are classified in the following three types:

Unidirectional, for two-position operation. The valve opens during one half-revolution of the output shaft and closes during the other half-revolution. Once started, it continues until the half-revolution is completed, regardless of subsequent action by the controller. Limit switches in the actuator stop the motor at the end of each stroke. If the controller has been satisfied during this interval, the actuator continues to the other position.

Spring-return, for two-position operation (energy drives the valve to one position and a spring returns the valve to its normal position) or for modulating operation (energy drives the valve to a variable position and a spring returns the valve to an open or closed position upon a signal or power failure) (*Figure 19*). With spring-return electric actuators, on loss of actuator power, the spring positions the valve to its normal position (either fully open or fully closed). Some electric actuators use a capacitor instead of a spring to drive the actuator to its normal position.

Reversible, for floating and proportional operation. The motor can run in either direction and can stop in any position. It is sometimes equipped with a return spring. In proportional-control applications, an integral feedback potentiometer for rebalancing the control circuit is also driven by the motor. Some electric actuators use a capacitor instead of a spring to drive the actuator to its failsafe position when primary power is lost.

The actuators have options of electrical power supply like 220V, 24V etc.

All the actuators have an IP rating to meet site safety and performance requirements.

Feedback on Valve Position: Valves with 0 to 10V DC position feedback signal (proportional control model only) provide accurate valve position indication in response to an input signal up to 10V DC. For independent verification, auxiliary switches and a potentiometer are used (mostly in larger size valves) for providing a position feedback. The auxiliary switches indicate end-stop position or to perform switching functions. Many larger size butterfly valves also feature a manual hand crank for manual positioning of the valve, independent of a power supply.

Dampers

Volume control dampers are widely used in HVAC applications for fresh air, exhaust air, etc. and for safety requirements, like fire dampers. Refer *Figure 20*. Dampers can be rectangular or round, and damper blade operation can be Parallel or Opposed. Parallel blade operation is where all the blades rotate in the same direction.

Figure 19: Type of actuators

Figure 20: Damper types

Refer *Figure 21*. Opposed blade operation is where adjacent blades rotate in opposite direction. The parallel blade damper is used with on-off actuator and opposed blade with proportional actuators. The damper actuators are also available in 'spring-return' and 'non-spring return' options for different application requirements.

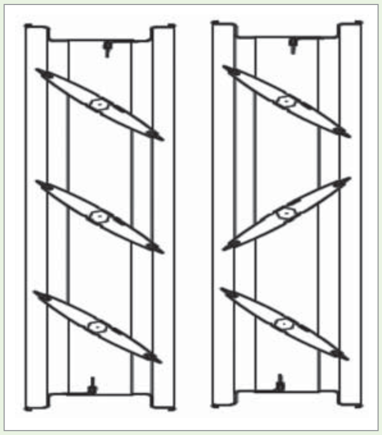

Figure 21: Dampers – parallel blades and opposed blades

A few applications of dampers in HVAC applications are listed below for better understanding:

Face/bypass damper: A pair of side-by-side, top-bottom modulating dampers that operate opposite each other, used in AHUs to direct airflow either through the face of a coil or to bypass around the coil.

Fire damper: Two-position damper that is typically found where an air duct penetrates a wall or floor. It is designed to restrict the spread of fire.

Smoke damper: Two-position or modulating damper specifically designed to restrict the flow of smoke in a building.

Fire/smoke damper: Two-position or modulating damper designed to meet the combined requirements of fire and smoke dampers. It is equipped with a thermal link and is factory-assembled with an actuator.

Mixing damper: Sets of modulating control dampers that operate opposite each other to mix outside air and return air to maintain a specified mixed-air temperature.

Multi-zone damper: Pairs of modulating control dampers located at the AHU that operate opposite each other to mix hot and cold supply air in order to maintain a specified space temperature in an individually ducted zone.

Round damper: Typically available in balancing or control damper types. It is commonly specified in higher static pressure or high flow velocity applications and is installed in spiral wound ductwork.

Fire, smoke, and fire/smoke dampers or life safety dampers are tested and approved as a damper and actuator assembly by UL. Therefore, *actuators must be installed at the factory, and the type of actuator and its mounting position cannot be changed in the field.* The temperatures need to be specified.

We will end the field devices discussion by focusing on some BMS terminology related to field devices, which are relevant while selecting the controllers and during programming.

An *analog signal* is a continuous wave denoted by a sine wave (*Figure 22*) and may vary in signal strength (amplitude) or frequency (time). Continuously measured variables like temperature, % RH, flow rate, etc. are examples of analog signals.

Analog input devices are field devices that are physically connected to the input of the controller and provide continuously varying values that are not discrete. Each analog input is measured in a different unit like °C, LPH etc.

Analog output devices are field devices that are physically connected to the output of the controller and provide continuously varying output to the equipment. Examples of analog output are control valve position output in % output format, control damper position output, etc.

Analog value: For programming in a controller, a few virtual analog points are required to be generated. But sometimes they are shown on the graphic screen also. They are called analog value points. Examples of analog value point are (a) set point value for temperature, (b) proportional gain for PID loop, etc.

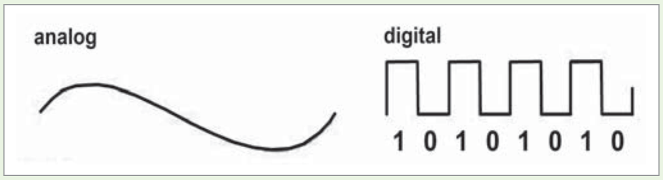

Figure 22: Analog and digital signal

A *digital signal* (also referred to as binary signal) is described as using binary digits 0 and 1 and therefore, cannot take on any fractional values. Digital signals are discrete. Refer *Figure 22*. Digital signals retain a uniform structure, providing a constant and consistent signal. A water flow switch indicating a healthy or trip status, a valve actuator remaining on or off, are a few examples of digital signals.

Binary input devices are field devices that are physically connected to the *input* of the controller and provide discrete value. Each binary input is measured in different states.

Binary output devices are physically connected to the *output* of the controller and to state output to the equipment. Examples of binary output are (a) pump command is provided in 'On/Off' states, (b) solenoid valve command is provided in 'On/Off' states.

Binary value: For programming in a controller, a few virtual binary points are required to be created. But sometimes they are shown on the graphic screen also. They are called binary value points. Examples of binary value point are: reset value in 'Off/Reset' states.

References

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In Part 4 of this Classroom series, in the March-April issue of the Journal, we shall look at Field Controllers and Control protocols.