Before you dismiss this article thinking pneumatic controls are irrelevant in a modern building environment, consider that most buildings have some form of pneumatic control. In some instances, pneumatic controls are vestiges of older systems that will remain in place until the next renovation cycle, an event that may or may not occur in the foreseeable future (Photo A).

In other cases, they are the result of a cost-cutting process that traded direct digital control (DDC) of terminal units for first cost, the latter being the case in a mid-’90s building in which I did some retro-commissioning work.

An informal survey I have been conducting asks facility personnel how long they think it will be until pneumatic controls are phased out of their facility. Answers have ranged from 10 to 15 years to never. If you are dealing with existing buildings, most likely, you are dealing with pneumatic controls, especially if you are providing retro-commissioning services.

It is important to remember that despite the phasing out of pneumatic sensing and control, pneumatic actuation will continue to be specified and installed, specifically where large valves and dampers must be positioned quickly. This is especially true on campuses on which a compressed-air system already exists.

**ANALOG TECHNOLOGY**

Most of the HVAC processes and events the buildings industry deals with are analog, rather than digital. Seasons do not change instantly from summer to winter. Loads do not change instantly from minimum to maximum. Changes occur during a finite period of time and thermal inertia. Time lags and transportation delays can have a major impact on how an HVAC system responds to a change in environment or load.

Analog control processes—whether pneumatic, electric, or electronically based—mimic this behavior. These characteristics can be a boon to a workable control approach when contrasted with digital approaches. In other instances, they can sacrifice precision, efficiency, and maintainability, all of which can be enhanced by computer-based digital technologies. But in understanding the time-based rate of change associated with analog control processes and the related lags and inertia, one gains insight into the characteristics and complexities of HVAC processes that are being controlled. This insight can be an invaluable asset if you, as a commissioning provider, are trying to understand what is making a recalcitrant HVAC process tick (or not tick).

**DIGITAL TECHNOLOGY**

Understanding analog technology can be the...
Closed- and Open-Loop-Controller Response

A well-tuned controller serving a closed-loop process will respond to a change and stabilize at the new condition (see figure). If a controller is too sensitive, a condition created by a narrowing of the proportional band or an increase in gain, it will become unstable. The trick in tuning a controller is to find gain settings that allow a controller to “capture” a set point, given the system dynamics. The dynamics include mechanical issues, such as the hysteresis of actuators and kinematics of their linkages; thermodynamic issues, such as the response of heat-transfer elements and sensors; and fluid-mechanics issues, such as transportation delays and the rate at which a disturbance propagates through a system. These issues, which are the result of a controller’s output actions, feed back into a controller via its input. As a result, a controller responds and further impacts the process, thus the term “closed loop.”

In contrast, an open-loop controller has no feedback from the process it is sensing. As a result, its output simply changes in direct relationship with changes in input to its sensing element. The relationship is established by the gain of a controller. High gains (narrow proportional bands) result in a controller in which output changes nearly instantaneously as the process variable it is sensing moves past a set point. As a result, a controller set up this way can be used to trigger actions in other systems when a specific condition exists.

The changeover controller in the sidebar “War Story: Don’t Just Do Something, Stand There” was an open-loop controller. It sensed outdoor-air temperature and switched its output from minimum to maximum when outdoor-air temperature exceeded its set point. This signal triggered switching relays and other devices that caused the economizer cycle to be terminated, returning systems to minimum outdoor air.

Most of these devices would change state at a specific pressure and change back at the triggering pressure minus a deadband. For instance, a pneumatic switching relay with a changeover setting of 12 psi and a deadband of 3 psi would switch its ports one way when a triggering signal increased to 12 psi and return to its original state if or when a triggering signal reached 9 psi (12 psi – 3 psi = 9 psi). On a rising signal, nothing would happen until the input reached a triggering condition of 12 psi. Conversely, on a falling signal, nothing would happen until the signal dropped to 9 psi. If a signal rose to 10 psi before falling again, the relay would never change state.

If the proportional band for the changeover controller was not set to a narrow range, the output change from the controller would occur over a temperature range, rather than at a specific temperature. For instance, if the sensitivity of the controller was set for 0.2 psi per degree Fahrenheit (low end of available range equals wide proportional band/low gain/low sensitivity), the temperature would have to change 60°F to cause the output pressure to change 12 psi. In contrast, if the sensitivity of the controller were set for 3 psi per degree Fahrenheit (high end of available range equals narrow proportional band/high gain/high sensitivity), a 4°F change would be required to generate the required 12-psi signal. If the operators in the sidebar “War Story: Don’t Just Do Something, Stand There” had used the manufacturer’s recommended starting point for a proportional band of 1¼ psi per degree Fahrenheit, an approximately 10°F change would be required to create a 12-psig signal change. It would appear that the controller was not working properly in its open-loop/two-position application. The same setting in a closed-loop application would provide a stable response, although some improvements could reduce proportional offset by additional tuning.

Controller outputs for a stable (green line) and unstable (orange line) controller.
War Story: Don’t Just Do Something, Stand There

The old adage, “Don’t just stand there, do something,” often is invoked in situations in which taking quick action appears to be prudent. Unless you can act with confidence, the reverse may be more appropriate. An action taken without knowledge or consideration of potential outcomes often can lead to more problems than it solves.

My first inkling of this insight occurred during my first experience working with a control system of a large, existing high-rise during the late 1970s. The company I worked for was retained by building management to help troubleshoot, solve operating problems, monitor utility consumption, and review system modifications when renovations occurred. One day, Bill, one of the firm principals, took me to the building to troubleshoot a problem while he attended a management meeting. The building was served by a large pneumatic control system that included a large engraved graphic control panel in the basement with a multitude of selector switches, set-point dials, and temperature indicators embedded in one-line graphic diagrams of the building systems, all of which purported to convey the building’s operating status. However, the panels essentially were “cast in stone” because they were engraved in plastic laminate during the construction process and did not reflect any modifications. Bill advised during the drive to the site that the gauges’ accuracy was questionable and one of the system graphics simply was wrong. I approached the troubleshooting session with a bit of anxiety, wondering what I would encounter.

Upon arrival, I was introduced to the lead operating engineer, who took me down to the control room. He started pointing at various gauges and switches on the graphics panel. He launched into a rapid-fire explanation of how the systems had gone “haywire,” causing the systems to be “starving for air” some of the time, but perfectly happy on other occasions.

Feeling slightly overwhelmed, I asked if there had been any particular event or change that had occurred around the time the problem arose. The lead operating engineer’s response was: “Absolutely. It was right after we calibrated all of the controls as recommended by your company.” At that point in my career, I was enough of an engineer to know that, properly executed, a recommendation to calibrate a control system had to be a good thing in the big picture. However, I was enough of a mechanic to believe the, “If it ain’t broke, don’t fix it,” adage and to have my own doubts about engineers (myself included).

I proceeded to ask if the building staff noticed the problem immediately after working on any particular device. I followed the lead operator as he headed for the elevator. On the way to the 20th-floor mechanical room, he showed me control drawings for the building, installation and operation instructions for a number of pneumatic control devices, and a cover letter from my company recommending a calibration effort. He also explained that the systems no longer would go off the economizer cycle automatically when it was hot outside. The staff manually had to change over the systems. This presented a problem on multiple fronts. If staff members were involved with something else in the morning, and the outdoor temperature increased more rapidly than they had anticipated, they were caught off guard, triggering complaints from building occupants. If it was not cool enough to go back off of the economizer in the evening before they went home, someone had to stay late, come in early, or both to make sure outdoor air was being used for cooling when possible to help control energy costs. All of this was costing the lead operator and his partner sleep and causing aggravation.

When we got off of the elevator, we walked into the biggest machine room I had ever seen. The lead operator led me through a maze of pipes and ducts to an innocuous-looking controller on the wall. He pulled out a screwdriver and said, “Watch this.” He then rapped the cover of the controller with the handle of the screwdriver, at which point confusion ensued. Switching relays clicked, control air hissed out of controller ports, dampers and valves moved, pump and fan sounds changed, and pipes, ducts, and pneumatic lines vibrated as water and air rushed through.

The lead operator stood there calmly, unperturbed by it all. “See what I mean?” he said. “Those units were on 100-percent outdoor air and shouldn’t have been. Before you guys told us to calibrate all of this stuff, that never happened. We’ve followed these instructions to the letter. The only way we can get the systems to change over is to do what I just did or open the controller and make a big change in the set point. If I want these units to change over at 72 F, then I should be able to set this controller at that setting and have it happen. What do you suggest I do?”

At that point, there were a lot of questions running through my mind, including:

- How could one little controller cause all of that to happen?
- Actually, I knew the answer, and it seemed pretty alarming. To make all of that happen, that one little controller had to be connected to all of that stuff.
- How was I going to trace the connections among one controller and all the other systems to figure out where the...
control system and then apply those concepts to current digital systems. This approach is exactly how many industry experts learned to deal with DDC. When they started their careers, DDC

The best way to understand control systems may be to learn how to design, install, and maintain a pneumatic control system and then apply those
der interface and knowledge of the programming language. Yet, the desired outcome and narrative description of a control sequence will be identical.
technology did not exist in the buildings industry and only was beginning to make inroads in the process-control industry. Analog control systems, particularly pneumatic analog control systems, simply were the technology used.

As DDC matured and made its way into the buildings industry, experts used their knowledge gained by working with pneumatic control systems to exploit advantages represented by digital technology, where fundamentals still applied. In many cases, similarities between the two technologies’ functions allow “cross-training.” Interestingly enough, the reverse also is true. If you understand digital technology and suddenly find yourself confronted with analog technology, you can use fundamentals as a foundation for understanding new territory.

The following sections highlight a few lessons I learned while working with pneumatic control systems.

FUNDAMENTALS

Despite significant changes in the control of HVAC processes over the last 15 to 20 years, the processes themselves and the physics underlying them are the same. For example:

• Varying flow in a pipe or duct frequently requires that the pressure driving the flow be varied, despite how it is controlled.
• The discharge temperature required from a cooling coil providing sensible cooling and dehumidification is set by the required space condition and the sensible-heat ratio, regardless of how it is controlled.

While newer technologies may allow us to optimize required control strategies and perform them with more precision and speed, the fundamental requirements of the control strategies are about the same. Competent mechanical designers have lamented their loss of control over the quality and performance of HVAC systems as reliance on pneumatic/analog technologies has shifted to digital, computer-based technologies. Because they do not understand newer control technologies and are confounded by the “black-box” concept, they feel they are at the mercy of control contractors in terms of obtaining a satisfactory HVAC system.

The reality is that a satisfactory HVAC system can be obtained if proper components are selected, installed, and operated in a manner that meets fundamental physical requirements of the process. The control system has a lot to do with achieving success, but will not perform if HVAC fundamentals have been misapplied. A lack of familiarity with DDC systems does not close the door on control of an HVAC system’s quality and performance. The key to success involves a two-pronged approach:

1) Communicate HVAC process requirements clearly and in detail so they can be implemented properly by control specialists familiar with current technology.

2) Include requisites for a commissioning process to verify that an installed system’s performance matches your requirements. Complement this verification with training of the operating staff to ensure performance continues.

DIRECT DIGITAL CONTROLS

Younger control technicians who are intimately familiar with DDC technology sometimes are confounded by the pneumatic controls they are forced to deal with. The operating principles behind many DDC technologies are not that different from those behind pneumatics. If you understand one, you likely can get up to speed on the other pretty quickly. Figure 1 is a common example. Proportional-control theory (see the sidebar “Closed- and Open-Loop-Controller Response”) is another. While DDC has opened the door to proportional-control alternatives, the proportional-control algorithm or one of its variations still is very common. Many problems encountered with DDC systems have roots in system instability and frequently can be solved by applying proportional-control theory and tuning techniques.

The presentation of control information for some digital systems is similar to the presentation of information for pneumatic control systems. Many manufacturers offer a graphic programming language option or as a method for setting up their system’s software. If you compare a pneumatic control drawing to a DDC program implemented in a graphic programming language, you will discover they are quite similar. Again, if
you can interpret one, you can interpret the other.

PROBLEMS AND SOLUTIONS

A problem that seems extremely complicated and affects several different components may have a simple solution that can be implemented at one location, solving the problem everywhere.

HVAC systems always have been integrated and interactive assemblies. The increasing predominance of variable-flow technologies, driven by a desire to conserve energy, tends to compound the interactive nature. Frequently, an interactive response of an HVAC system that is in trouble can make a problem seem overwhelming and intimidating.

The accompanying war story is an example. When I was first exposed to a changeover problem demonstrated by the lead operator, I was overwhelmed by the buildingwide reaction. What I failed to appreciate was the fact that his action at one point in the system triggered all of the problems. Focusing attention on that one point in the system solved the dilemma.

It can be easy to dive into the complexity and get lost, missing an obvious answer right under your nose. Take a few minutes to be sure you understand the technology you are dealing with before diving in. A pause often saves time in the long run. Don’t just do something, stand there.

WE ALL HAVE SOMETHING TO LEARN

Throughout my career, I have benefited immeasurably from mentors providing me with challenging problems to solve and taking the time to explain things to me when I was stuck. Of course, for that to work, you have to be willing to admit you do not know something, recognize you may have made a mistake, and ask questions. These things are not easy, but generally are well worth the effort.

WE ALL HAVE SOMETHING TO TEACH

In the sidebar “War Story: Don’t Just Do Something, Stand There,” Bill needed me to be his eyes and ears in the field, freeing him to deal with other issues. I needed his insight and knowledge to interpret and correct the things I was seeing. The operators in the high-rise needed what I learned to help them solve their problem and correctly implement engineering recommendations from my company. I needed their knowledge of the building to implement the solution I identified. My company and the operators’ management needed the problem to be solved to allow efficiency improvements associated with calibration efforts to be realized.

The bottom line is that most problems lend themselves to a team solution, especially when dealing with high technology and the specialization that goes along with it. Learning to be a team player can be a valuable asset when commissioning buildings and their control systems, regardless of the type of technology employed.

TEAMWORK

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