

TERMINAL INPUT AND OUTPUT DEVICES

*A discussion of the selection and specification
of input and output devices as well as some new,
inexpensive approaches to I/O device configuration*

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On the two previous articles of this series, I have discussed current trends in DDC system architecture toward what many in the industry call full DDC systems. Full DDC systems are those that incorporate terminal control as well as system control. To develop successful high-performance configurations of full DDC systems requires special attention to some of the features of the DDC system.

The previous articles focused on evolving capabilities of terminal controllers and programming languages. They suggested ideas for improvements in those areas that may be beneficial for this current trend toward full DDC systems.

The purpose of these articles is to encourage a dialog within the industry aimed at defining features useful in high-performance applications of full DDC systems. The

view of many who are successful with DDC systems is that the industry is flying blind. Manufacturers are developing products based on criteria that may be flawed or lack relevance. Many A/E firms continue to employ DDC specifications and procurement procedures that display a profound lack of knowledge about the features that are most crucial to a successful DDC system.

Recent research conducted by trade associations on DDC seems to have reached at least as many wrong conclusions as correct ones about what ingredients are necessary for successful DDC implementation. As the DDC revolution continues, our industry needs to attract and make better use of the ideas from those associated with successful high performance DDC systems.

This final article will focus on input and output devices employed for terminal control. We will start by considering how the evolution to full DDC is placing enormous importance on how the designer

chooses terminal input/output devices. Then, we will look at some of the newer hardware that may reduce the cost of full DDC systems without compromising their quality. Finally, we will explore some approaches DDC system manufacturers could incorporate in their products and interface schemes to provide more functional and economical terminal control.

Terminal control devices

DDC system inputs and outputs (commonly referred to as points) have increased enormously in significance as terminal control opportunities have encouraged the use of full DDC system configurations. DDC systems that control only fans, chillers, and central plant equipment often require 200 points or less to control a large size building effectively.

Full DDC configurations that incorporate lighting and temperature control for every space may require 5000 or more points. This 25-fold increase in points has changed the rules by which DDC systems are

I/O devices

configured to be cost effective and perform successfully.

The role of input/output device cost has changed from a minor item to the leading factor in determining DDC system cost effectiveness. A rule of thumb is that the installed cost of a full DDC system must be kept under \$200 per point to have a chance of being cost effective when compared to other approaches from a purely economic standpoint. This objective can be achieved only if the system designer pays close attention to the selection of input and output devices employed for terminal control.

A strong emphasis needs to be placed on the terminal control input/output devices because these often represent more than 90 percent of the total input/output devices in a full DDC system. The designer's task is to select components that provide desired sensing or control characteristics at the lowest possible cost. To do this, the designer must first determine what characteristics are realistic. For example, precision RTD temperature sensors are still commonly specified for space temperature sensors. Such devices can cost up to \$100 or more apiece. But the limiting factor in space temperature sensing accuracy is almost never the sensing device. The end-to-end accuracy of space temperature sensing for DDC systems involves a number of considerations, the most important of which is usually the space itself.

Consider that typical occupied spaces in buildings are supplied with air that is 20 F warmer or cooler than the space. As this air is circulated to mix with the space air to add or reject heat, temperature gradients within spaces are often significant. If several independent instruments are placed within a few inches of a space temperature sensor, their readings will frequently differ by 0.2 to 0.5 F. Stable thermistor-based space temperature sensors cost only a fraction of precision RTD sensors yet provide

stable operation and precision that is far better than the 0.2 to 0.5 F precision that can be realistically achieved in space sensing applications.

In selecting input/output devices, designers should remind themselves that if their full DDC systems are configured such that they cannot be economically justified over pneumatic alternates, their clients and the building occupants are the big losers. Compare the precision and stability of pneumatic thermostats and humidistats to those of the most economical electronic devices. If DDC systems cannot be configured to meet budgetary and/or cost benefit requirements, the lower cost alternative is usually pneumatic controls. But pneumatic devices provide control that is several orders of magnitude less precise and also require constant calibration to maintain even that low level of precision.

Such an understanding of the role and importance of cost considerations is required for a designer to make reasonable choices for terminal input/output devices. Terminal output devices such as damper actuators and reheat valves have often been considered to be perfect applications for pneumatic actuators. However, when the applications are scrutinized more closely, pneumatic devices are often not a good choice at all for terminal control applications. Furthermore, pneumatic devices do not interface well with electronic control systems. As a result, a number of new economical actuation devices have been growing in popularity over the last few years.

Electric actuators

Modulating electric actuators have been manufactured for many years, but they have not been widely employed in North American HVAC applications. Until recently, these devices were generally comparatively expensive and not noted for durability. Electric controls of different manufacturers were often incompatible with one

another. The increasing demand for electric control devices that can be interfaced directly with DDC systems appears to be improving the situation.

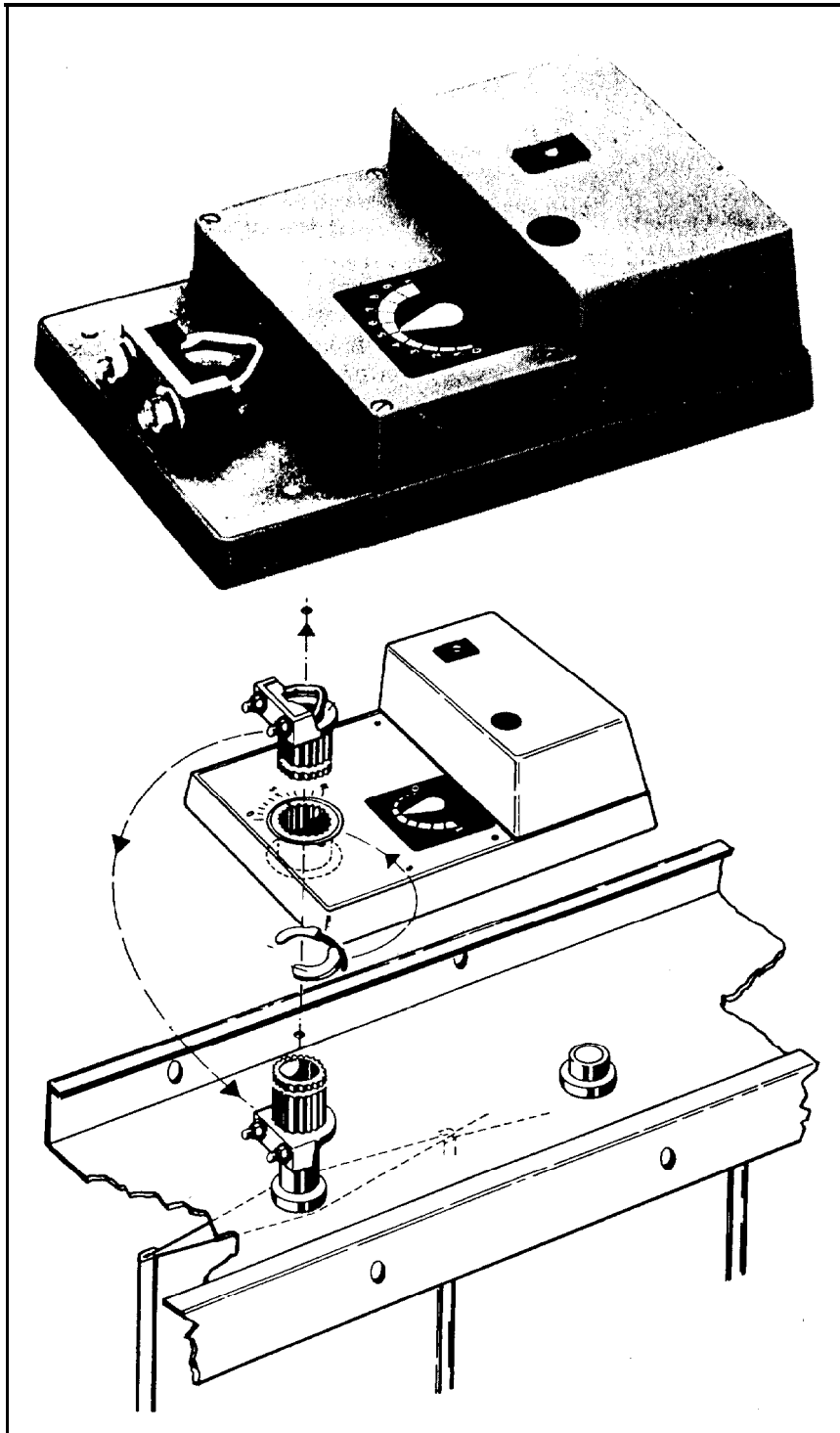
Electric actuators are falling in price and are becoming more standardized on the 0 to 10 v DC control signal to modulate their position. An electric modulating actuator of the type employed to control a VAV box damper is shown in Fig. 1. This type of actuator is now becoming available for \$100 to \$200. Electric actuators have several features that make them desirable for the control of small dampers. Generally, a unit modulates by comparing the modulating voltage from the DDC system with a voltage that depends on the position of the actuator.

Unlike pneumatic actuators whose force is related to the output and position, most electric actuators provide constant force (or torque) at all outputs and stop only when the position corresponding to the DDC voltage is reached. This eliminates the uneven movement that is often associated with pneumatic actuation. Some electric actuators also maintain constant torque whether running or stalled. This feature is particularly useful in applications that require torque to be applied at the end stops to hold dampers fully open or fully closed.

Two-motor actuators

A more economical electric zone damper actuator employs two small constant-speed clock motors connected together. These, as do the previously described actuators, rotate the shaft collar or clamp through a gear drive. The two-motor type actuator is interfaced with the DDC system through two digital output points. The two motors run in opposite directions. One motor drives the damper open, the other drives the damper closed. This device is commonly called a floating control actuator.

An example of a two-motor actuator is shown in Fig. 2. This type of



1 Electric actuator 0 to 10 v DC modulating signal, 24 v (AC or DC) power.

actuator typically costs under \$50. The speed of rotation of each motor is constant and generally geared to be slow—1 to 3 min to rotate fully each direction.

In the past, reliability problems with the two-motor actuator some-

times resulted when the control system provided continuous power to the controlling motor at the fully open or fully closed position. The resulting locked rotor condition appears to have led to abnormal failures of the motor or gear train. Re-

liability problems also may have resulted from the mechanical switching mechanism that operates the motors. Switches or relays in the control circuit are subject to a great deal of cycling, and unreliable contact closure may have also caused some problems in the past.

Although many of the two-motor actuators are built much sturdier than they were a few years ago, proper operation by DDC controllers have also contributed to reduced reliability problems. Because DDC systems today typically drive their outputs with solid state triacs, there are no mechanical components involved in running or switching the motors.

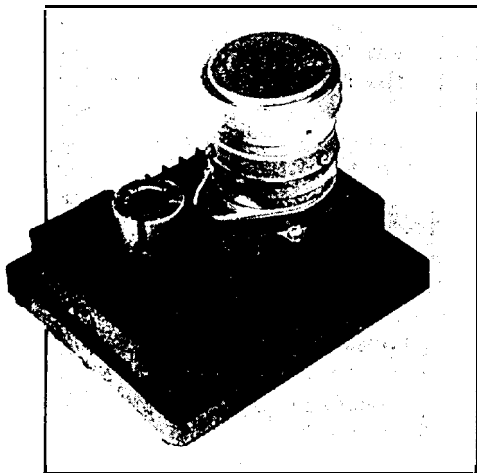
To eliminate locked rotor problems and to provide improved control, several DDC manufacturers have provided special interfaces for the two-motor actuator so that it looks like any other analog point to the operator. The interface automatically calculates the position of the actuator by keeping track of the time each motor has operated. When the actuator reaches one extreme or the other, the position is automatically reset, and the power to the motor is shut off. This approach works well and usually permits two-motor actuators to operate by standard PID controllers just like other analog outputs. Because each motor is shut off at extreme positions, locked rotor problems are eliminated.

The two-motor controller provides economical modulating control that is adequate for most terminal control applications. These devices are typically configured with low-speed gear trains because hunting problems can result when the devices are controlled by simple floating-point controllers. The low speeds may not be adequate for opening or closing in certain circumstances. However, with output controllers that permit PID control of the two-motor actuators, much higher speeds can be controlled with ease, and some two-motor actuators are now becoming available that operate at greater speeds.

Air velocity sensors

One of the most noticeable advantages of DDC terminal VAV control is the ability to provide air balancing of terminal boxes with the DDC system. DDC air balancing is much easier than traditional methods. The maximum and minimum air flows for each box are set by the DDC system, and each VAV box damper operates to provide a specific air flow within that range based on space conditions. Duct pressure compensation is automatic.

To achieve all these features requires an air flow sensor at each VAV box, connected to the DDC system. At present there are two approaches employed by the HVAC industry to measure air flow at terminal boxes. Both actually measure air velocity, which is mul-



2 Two-motor electric actuator, 24 v AC.

tiplied by a constant (the constant includes factors for duct area and flow profile compensation) to obtain air flow.

One approach employed to determine air velocity at terminal units is to measure the velocity pressure of the air through the use of a pitot tube arrangement. Some of these velocity pressure devices actually measure the average velocity pressure with a series of upstream orifices to help compensate for the irregular velocity profiles

that occur in many ducts.

The velocity pressure air flow measurement technique has one serious limitation. At low air velocities, the velocity pressure of air is very small. Much literature recommends the velocity pressure technique be limited to air velocities above 300 fpm. Tests conducted by our firm found reasonable accuracy somewhat below that figure under certain conditions, but the bottom limit of accurate flow measurement is still above the lowest velocities encountered at VAV terminal boxes.

Another problem with velocity pressure type sensors is that the differential pressure/electric transducer required to convert the velocity pressure into an electric signal and the sensing equipment can be costly. Some DDC manufacturers include the pressure/electric transducer with their box controller, which seems to reduce transducer cost dramatically. Controllers incorporating the transducers are usually competitively priced with those not including transducers.

A second approach to measuring air flow is to determine the air velocity by measuring its capacity to provide cooling. Methods that employ this approach are sometimes referred to as "hot wire" or "heated thermistor" techniques. There are a number of variations in operation from manufacturer to manufacturer and depending on the exact devices incorporated in the design. Fig. 3 shows one type of heated thermistor air velocity sensor.

Essentially, one device is heated while some mechanism determines the cooling effect of air passing over it by measuring the actual temperature of the device (or the current required to maintain the device at a constant temperature).

The cooling effect approach has one big advantage over the velocity pressure technique: it can accurately measure air velocities as low as 50 fpm.

The most economical of the cooling effect velocity sensors employs several thermistors. Exact oper-

ation varies, but a popular technique is to employ one thermistor to measure the ambient temperature of the air stream. The second thermistor (slightly downstream of the first) has a voltage applied to it, and the current required to maintain the voltage is measured. Because the resistance of the thermistors varies with temperature, the temperature of the heated thermistor can be calculated. The combination of ambient temperature, heated thermistor temperature, and energy to the heated thermistor can be used to calculate the air velocity in smoothly flowing air.

This sequence may seem complicated, but these comparisons are usually made in a small IC chip. The cost of thermistor-based cooling effect air velocity sensors is about \$25 or less, and some of them automatically provide leads that can be connected to another input of the DDC system to provide the air temperature as well. Most do not provide a linear output. Far more expensive devices are required for that. But most DDC systems offered today have the ability to linearize such signals with calibration tables that are included in their input point databases.

A disadvantage of the cooling effect air flow measurement technique is that it provides a reading of air flow at only one point in the air stream. To read more points for average air flow (which is easily accomplished with the velocity pressure technique) requires an array of a number of individual sensors. Thus, a sensor designed to measure several points can become expensive.

Our firm has also conducted performance tests of air flow measuring devices. The tests concluded that by following some basic rules for sensor location, we can employ a single-point velocity sensor to measure air flow in the duct sizes typically employed for VAV terminal units with adequate precision. In addition to sensor location, these tests found that how the velocity-to-flow factor is determined

Photo courtesy of Kreuter Mfg. Co

is important in achieving accurate measurements.

Because they generally offer the lowest cost air flow measurement option, thermistor-based air flow measurement has a jump on other techniques. However, thermistor-based velocity sensors have pitfalls that designers should consider when selecting air flow devices. The low-cost thermistors employed in HVAC applications are generally stable and drift-free in applications up to about 300 F. Above this temperature many are subject to drift.

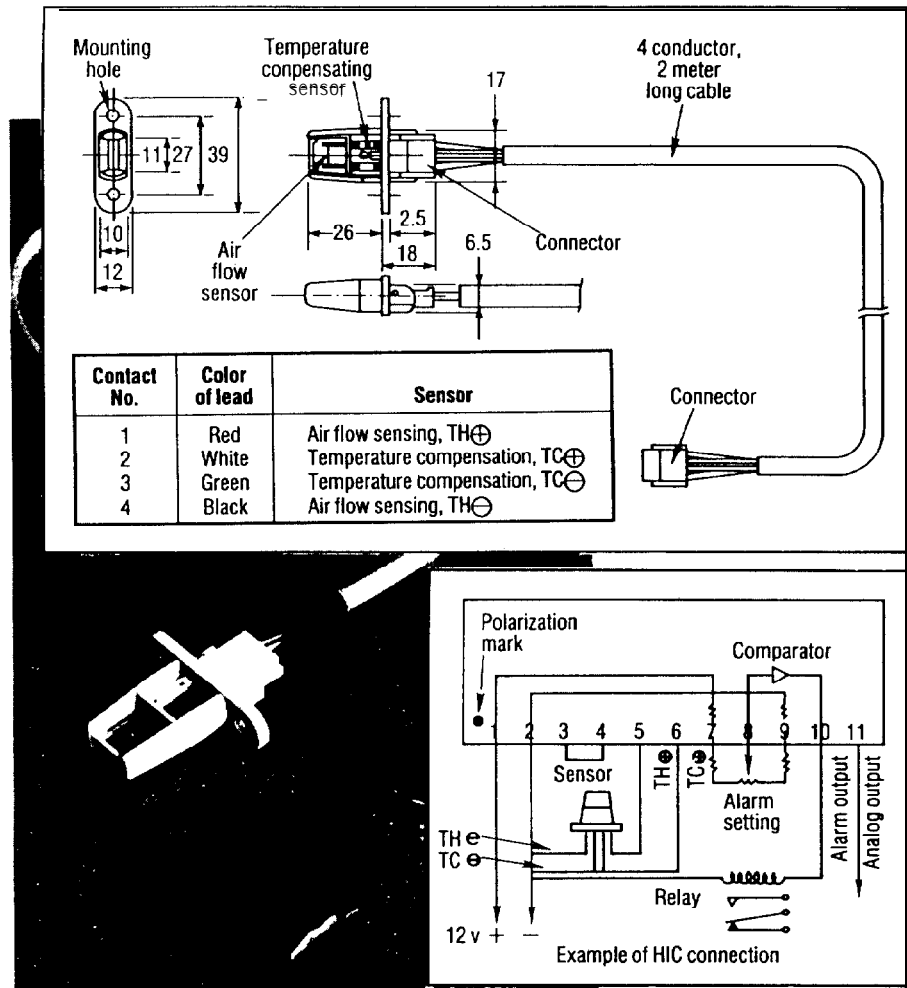
Because the heated thermistor in an air flow sensor usually operates at about 300 F, some in the industry have expressed concern that periodic recalibration of air flow sensors may be required. I have seen no conclusive evidence on the subject of drift for heated thermistor sensors. However, most of the installations we are familiar with are only several years old. Meanwhile, manufacturers are very short on facts that might prove drift will not be a problem.

One solution to the drift problem is to employ sensors that use stable RTD sensors in hot wire configurations. Another is to select higher quality thermistors that are not subject to drift at elevated temperatures. Glass-encapsulated thermistors are generally very stable at higher temperatures. A recent entry into the air velocity sensor market utilizes glass-encapsulated thermistors that are still priced at about \$20 apiece in quantity.

Other sensing devices

Temperature sensors, air flow sensors, relays, and damper actuators currently represent the vast majority of terminal end devices typically associated with DDC terminal units. A number of other devices will become widely used as high-performance DDC systems gain in popularity.

Occupancy sensing is becoming standard fare for high-performance DDC systems as lighting control is integrated with HVAC terminal control strategies. The simplest



3 The photo on the left shows a heated thermistor-type velocity sensor and integrated circuit chip. The upper diagram shows dimensions in millimeters. The diagram on the right shows connection to IC chip.

type of occupancy sensing device is a button on the space temperature sensor that occupants push when they arrive at the zone. When the button is pushed, the DDC system turns on the lights and establishes an HVAC occupancy mode for the zone. Typically, the zone remains in the occupied mode for the remainder of the day if the button has been pushed during normal working hours, or for a predetermined time if it is activated during off hours.

Many manufacturers now incorporate such buttons in versions of their temperature sensors. The temperature sensor input is also used by some to transmit the occupancy signal to the DDC system. The result is that this type of oc-

cupancy device can be very inexpensive to provide—adding only a few dollars per zone to the cost of the system.

A more effective, but also more costly, occupancy sensing device is an infrared or ultrasonic sensor. Such sensors—usually mounted on the ceiling or high on the wall—detect movement and can thus be employed to establish occupancy automatically as people arrive at each zone. This type of occupancy sensor costs about \$50 to \$100. The added cost over pushbuttons can often be justified because the motion type sensor offers greater energy savings and less inconvenience to building occupants.

It is a nuisance for zones to lapse out of occupancy while still oc-

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cupied, so most pushbutton occupancy strategies employ long periods of occupancy each time the button is pushed. If someone comes into an office to pick up some papers, the zone may remain in the occupied mode for several hours or all day. But an occupancy sensor can automatically return the zone to the unoccupied mode after just a few minutes.

Other devices that are growing in popularity are humidity sensors and various kinds of air quality sensors. Such sensors are not required in every zone. But sensors that provide VOC (volatile organic compounds) and CO, readings in typical and critical areas can provide useful information to the building control system. The trend is clearly toward considering air quality control as important as temperature control. Most sensors that measure the quality of the building environment are becoming very economical as new inexpensive technologies are developed to accomplish the measurements.

What's needed next

The quality of typical input/output devices for DDC terminal control is improving while costs are falling. These are good trends, but further improvements are possible, and cooperation with DDC system manufacturers is required to see them through. There remain a number of possible improvements in terminal input/output devices that can increase the cost effectiveness of DDC systems in the short term.

Modulating digital outputs

A variety of electrical actuation approaches are offered for reheat valve operation. Those that involve modulation are often more expensive than pneumatic alternates. However, several manufacturers offer small electric two- and three-way valves that employ a very inexpensive method of actuation that could be easily modulated by a DDC terminal controller. These

valves are actuated by thermostatic elements similar to the bimetal device that regulates the water temperature in automobiles. But instead of water temperature, these actuators are energized by a small resistance wire that is heated by just a few watts of power. The power requirement is small enough that the valves can be powered directly from the triacs that drive digital output points in most DDC terminal controllers. While these valves are generally used as two-position valves, they can be modulated by pulse-width modulation of the digital output points to which they are connected. These valves cost less than many pneumatic actuated reheat valves and have a good record for reliability.

Similarly, electric reheat coils can be modulated by pulse-width modulation of a digital output signal to solid-state power relays. Fig. 4 shows a typical connection for such modulation devices connected to a single DDC digital output.

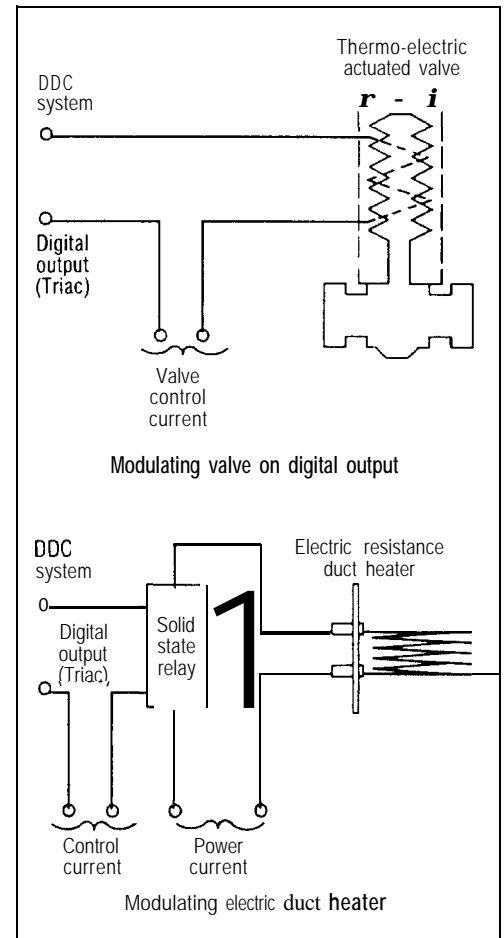
To make effective use of such modulation techniques, DDC products require the capacity for operators to configure digital output points to look like analog points. This is already done by manufacturers who configure two-motor electric actuators to look like single analog outputs. Unfortunately, these configurations are not now very flexible. Rather, they are typically incorporated into dedicated controller outputs that are generally unusable for any other purpose.

As was pointed out in the article on terminal controllers, developing products to be more flexible should be the goal of every DDC system manufacturer today. Flexibility in points configuration is extremely helpful to operators. With a configuration option that permits a system to be easily configured with digital outputs operating as analog points, the devices shown in Fig. 4 could be operated with standard PID loop control to provide effective modulating terminal control despite the fact that they are digi-

tal output points.

DDC system suppliers and manufacturers appear at times to be poorly informed about interface options for their systems. This is understandable since they generally do not manufacture many of the input/output devices employed by their systems. However, if a greater effort were made to seek out effective and economical I/O device options for their DDC systems, controls companies would find a substantially greater demand for their terminal control products.

Those manufacturers who are willing to spend the effort to provide effective and flexible interfaces to operate special I/O devices in a manner that is consistent with more standard devices are the ones



4 Typical connection for a modulating valve on digital output and modulating electric duct heater connected to a single DDC digital output.

that will dominate the full DDC market in the years ahead.

Summary

Terminal DDC input/output devices are becoming more effective and lower in cost. Unfortunately, many DDC systems presently do not fully exploit low cost terminal control concepts. As a result, many DDC systems cannot provide cost-effective full DDC for high-performance applications. Such DDC systems are losing out in a very important new DDC market.

In these articles, I have suggested three areas that need the attention of manufacturers, engineers, and users to exploit the growing full DDC market fully. These are DDC terminal controllers, programming languages, and terminal control input/output devices.

The views I have expressed have been developed from our firm's experience and include ideas we have gleaned from our more successful clients. There are many other viewpoints and ideas about the best way to configure full DDC systems for high performance applications. All who have successfully implemented cost effective DDC systems should be heard.

Important upcoming forums to discuss high-performance DDC systems will be conducted at AEE's **WORLDCON'90** this spring and ASHRAE's annual meeting this summer. It's time those who are associated with successful high-performance DDC systems get together and share ideas so manufacturers and designers can get a better picture of what users need to continue their successful trends into the era of full DDC systems.

The primary purpose of this article series was to stimulate much needed discussion within the industry about full DDC system function. Everyone stands to benefit from such an exchange as the HVAC controls industry attempts to take the two giant steps to full DDC system configuration and high-performance DDC system operation. Ω