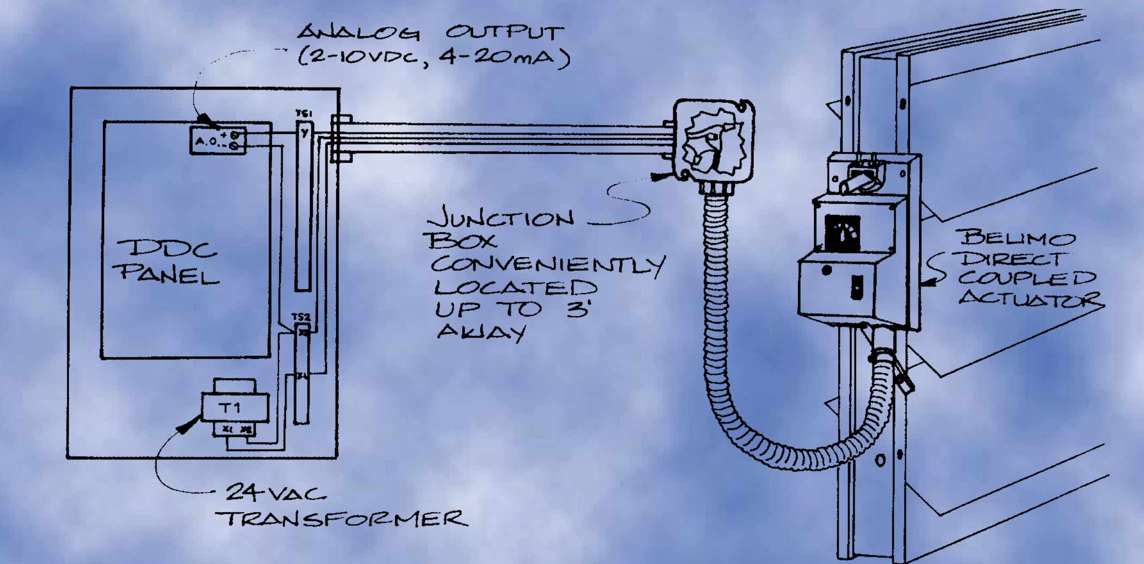
Actuators for heating, ventilation, air-conditioning

Electronic or Pneumatic Actuation?

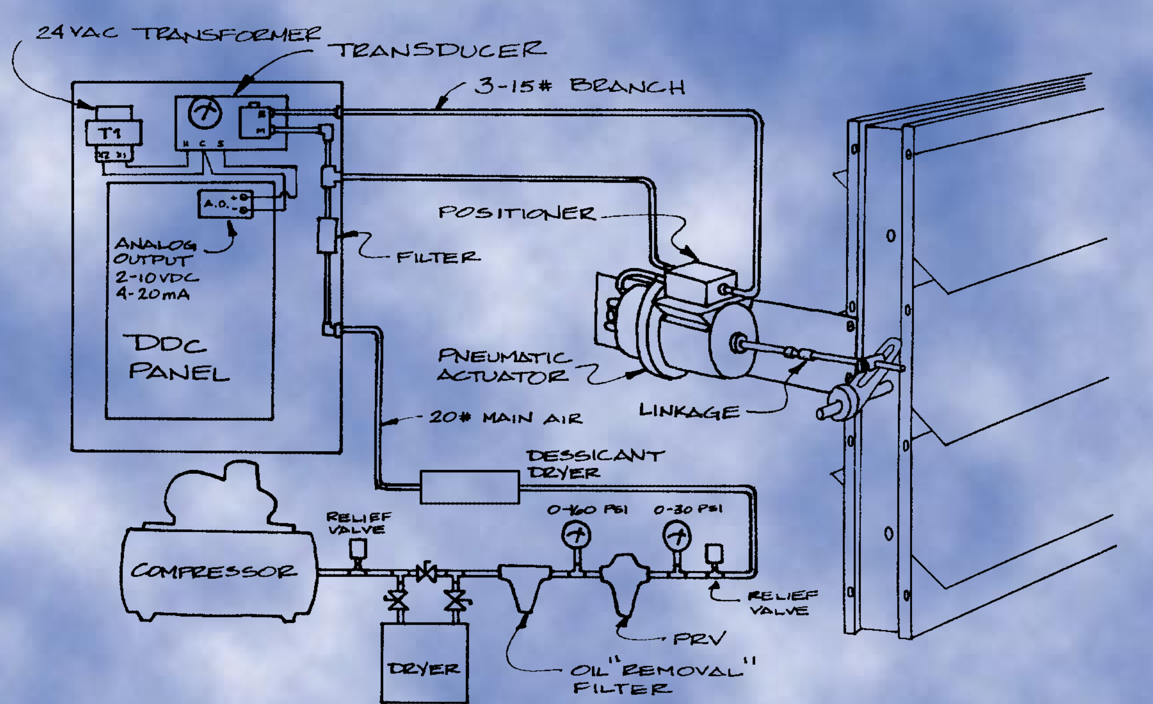
Advantages of Belimo electronic direct coupled actuators

5.4

Typical Elements of Belimo Electronic Actuation



Typical Elements of Pneumatic Actuation



ELECTRONIC OR PNEUMATIC ACTUATION?
ADVANTAGES OF BELIMO ELECTRONIC DIRECT COUPLED ACTUATORS

In 1975, when BELIMO was established, pneumatic actuators accounted for 50% of the actuators used in Europe. Today, 95% of those installed are electronic and, in Japan, 80%. BELIMO electronic has over 60% marketshare in both Europe and Japan. Recognition of the cost/benefit ratio of high quality electric actuation can be expected in the U.S. also during the next few years.

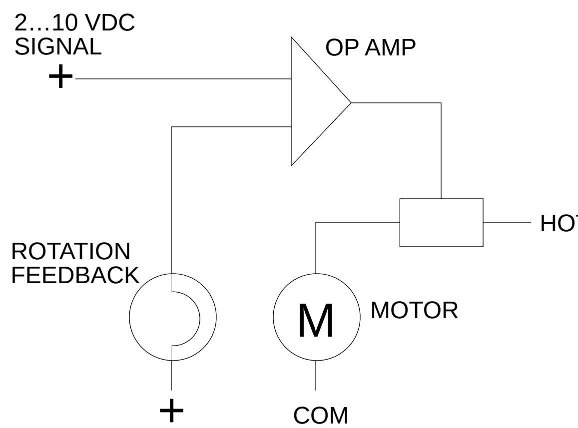
Pneumatic actuators, at one time cost effective, are no longer well-suited for modern electronic controllers. They need interfaces which add expense and degrade the signal from the high quality control outputs now available.

To meet the needs of DDC processor control, BELIMO has introduced a precision direct coupled actuator which is more reliable than the pneumatic hybrid (actuator, positioner and transducer), has a lower first cost in 90% of applications, a significantly lower life cycle cost in just about 100% of applications, and has all the advantages of pure electric (outside use and no compressor problems).

BELIMO electric actuators provide: simpler installation, control features which pneumatic cannot provide, maintenance free longer life, flexibility for changes, and a positioning resolution as high as 160:1 - accuracy as high as the DDC electronic output signal.

THE ISSUES

In deciding between electronic or pneumatic actuation, the real factors should be: accuracy, reliability, first cost and life cycle cost. The remainder of this article addresses these issues.



BELIMO SIGNAL POSITIONING CIRCUIT
.03 TO .15 V RESOLUTION

Fig. 1

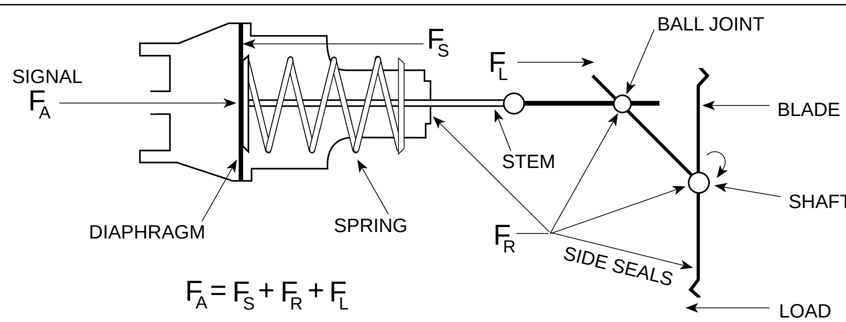
IMPORTANCE OF ACCURACY

The BELIMO 2 to 10 VDC (4 to 20 mA with 500 Ω load resistor) control signal is now an international standard used by all control manufacturers. The worst case hysteresis is 1%. The BELIMO is positive positioning using a precision feedback circuit with an op amp comparing input signal with position feedback. Newer models use ASICs and microprocessors. Over the 20 year life of the BELIMO actuator, no degradation of accuracy will occur. *See Figure 1.*

HYSTERESIS

On the other hand, depending upon which pneumatic actuator manufacturer's specifications are consulted, the gradual operation damper area is from 50%-20% of that recommended for 2-position operation. This is because the hysteresis of the pneumatic actuator is 1.5 PSI over the 5 PSI spring range. Further loading of the actuator will increase the hysteresis. *Figure 2* shows the main points which cause mechanical resistance (F). Binding of stem against the hole through which it passes, linkage stiffness, axle bind and side seals cause delay in movement.

Since the signal is also the power source it must increase beyond setpoint to break free. As a result the stem jumps forward and overshoot occurs. On the return stroke the



$$F_A = F_S + F_R + F_L$$

F_A =	AIR SIGNAL (POWER)	POSITIVE
F_S =	SPRING	POSITIVE
F_R =	RESISTANCE & FRICTION	ALWAYS RESISTS CHANGE
F_L =	DAMPER LOAD	NEGATIVE AND/OR POSITIVE

PNEUMATIC MECHANICAL RESISTANCE

For any value of F_A (signal) the actuator takes a position dependent on the forces acting on it. Repeatability is low. The hysteresis is high. With age, F_R increases. 1.5 PSI hysteresis is normal over 5 PSI span.

Fig. 2

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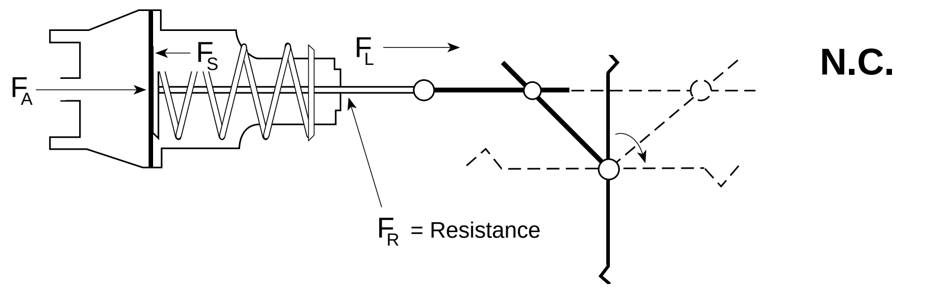
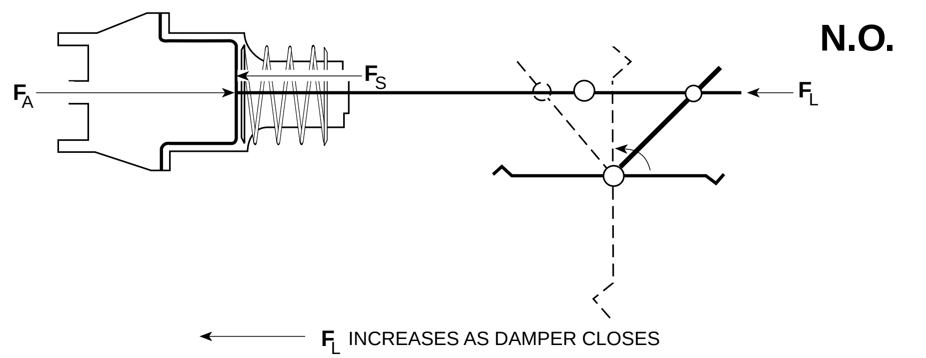
signal must drop far enough below the spring force to allow it to overcome the resistance. With a 4” stroke actuator a 1” hysteresis is normal. Differences among the manufacturers in recommendations is due to differences in effective diaphragm area and judgement rules of thumb for allowable inaccuracy.



8 to 13 PSI is the control range only if F_R and $F_L = 0$. Installed range is from 1 to 20 PSI.

In this example, $F_S = 8 \times 15 = 120$ Lbs., $F_L = -60$ lbs. and when $F_A = 60$ lbs. movement occurs.
60 lbs. ÷ 15 sq. in. = 4 PSI. F_R resists movement so actual start point cannot be predicted, but it could be as low as 4 PSI!

Fig. 3



To close, F_A must equal $F_S + F_L$. In the example, $F_S = 195$ lbs. (15 x 13), $F_L = 60$, and F_A must equal 255. 255 lbs. ÷ 15 sq. in. = 17 PSI. Actual shift usually lower since F_L falls as full open position is reached. 17…22 is the approximate spring range.

Fig. 4

PNEUMATIC SPRING RANGE SHIFT
A pneumatic actuator starts to move and assumes its final position based not in accordance with its control signal, but upon the forces acting on it. This results in variations in positioning independent of the hysteresis.

Given a damper with a 8…13 PSI spring range actuator, 15 sq. in. diaphragm, 60 lb. load on the damper (F_L). $F_s = 8$ lb. X 15 sq.in. = 120 lb. Assume $F_R = 0$. F_L is negative. (With a N.C. damper it is the spring return force which limits the allowable damper size.) *See Figure 3.*

$F_S + F_L = 120 - 60 = 60$. When $F_A = 60$ the damper starts to move. 60 lbs. / 15 sq.in. = 4 PSI. When $F_A = 4$ PSI the actuator can start to move in spite of the spring range 8…13 since the damper load works in the same direction as the air signal.

When F_L is positive the damper/actuator has a shift causing the effective spring range to be 8…17 PSI. *See Figure 4.*

The situation is actually much more complex than explained here due to variations in the value of F_L. It can change from positive to negative during rotation and changes magnitude based on damper type, blade type, degree of rotation, air flow profile, pressure and velocity variations and turbulence. The torque requirement at any point in a damper’s rotation cannot be predicted except in general terms and the pneumatic actuator cannot be positioned accurately.

POSITIVE POSITIONERS
The pneumatic accuracy problems detailed above can only be improved by using a positive positioner. More actuators or larger ones can be used to reduce the shift, but some shift still exists.

While the accuracy of the actuator alone is ±15%, the accuracy with a positioner is 1/4 PSI or 5% (.25/5). The deadband is fairly stable regardless of torque loading, but 66% loading is recommended by some to reduce the constant repositioning which occurs as the actuator is pushed outside the deadband range.

Decent maintenance of setpoint is possible since the controller can reposition the actuator frequently based on temperature. However, this does lead to extra wear on the transducer and positioner. Unfortunately, the positioners used in HVAC control, unlike the electronic versions used in process, are mechanical and wear on pivot points, spring elasticity and diaphragm stretch occurs, and initial calibration error leads to control point inaccuracy.

The positioner for pneumatic actuation is essentially an amplifying relay and its repeatability and gain vary. The range must be very carefully adjusted so that the minimum and maximum signals correspond to exactly closed and open. The time to check and recheck to see if the positioner is following the signal is at least a half hour and must be coordinated with not only the 8…13 PSI pneumatic air but also the 2…10V electronic signal.

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Within weeks of installation, the positioning is approximate and calibration drift causes a slow and steady loss of accuracy. Recalibration brings the control and setpoints back into proximity but does not reduce deadband or continued drift.

TRANSDUCERS
The quality of I to P transducers varies significantly but the inexpensive ones used in the HVAC industry are not precision devices. The specifications can use various methods of presenting the minimum output signal deviation from input, repeatability, and drift due to temperature changes. A ± 3% accuracy is the best that can be achieved after the first year of operation. The transducer is also a weak point in the reliability of the hybrid system. The life span is questionable.

CHAIN OF SIGNALS
The hybrid actuation system ends up with a ± 5% accuracy. 5% positioner, 3% transducer, 2% linkage = ±5%. This is a worst case since the inaccuracies are not additive and usually cancel each other out. The signal degrades as it goes thru the chain of devices. The actuator hunts due to the load variations on the blade. The transducer and positioner bleed air and correct over a few minute time frame while the control signal is held steady.

BELIMO RESOLUTION
The analog output signal of a DDC controller has at least .1 VDC resolution (some are better); this corresponds to a 80:1 resolution. The hybrid chain of signals produces a 20:1 resolution at best with suspect setpoint and degrading accuracy over time. The BELIMO electronic direct coupled actuator has a minimum 160:1 resolution allowing precision positioning with respect to the control signal.

ELECTRONIC TEMPERATURE CONTROL
The concept of using DDC control and pneumatic actuation (the hybrid) is illogical and technically inferior to pure electronic.

Using a sophisticated PI control loop with pneumatics is like driving a Corvette with bald tires. The lack of

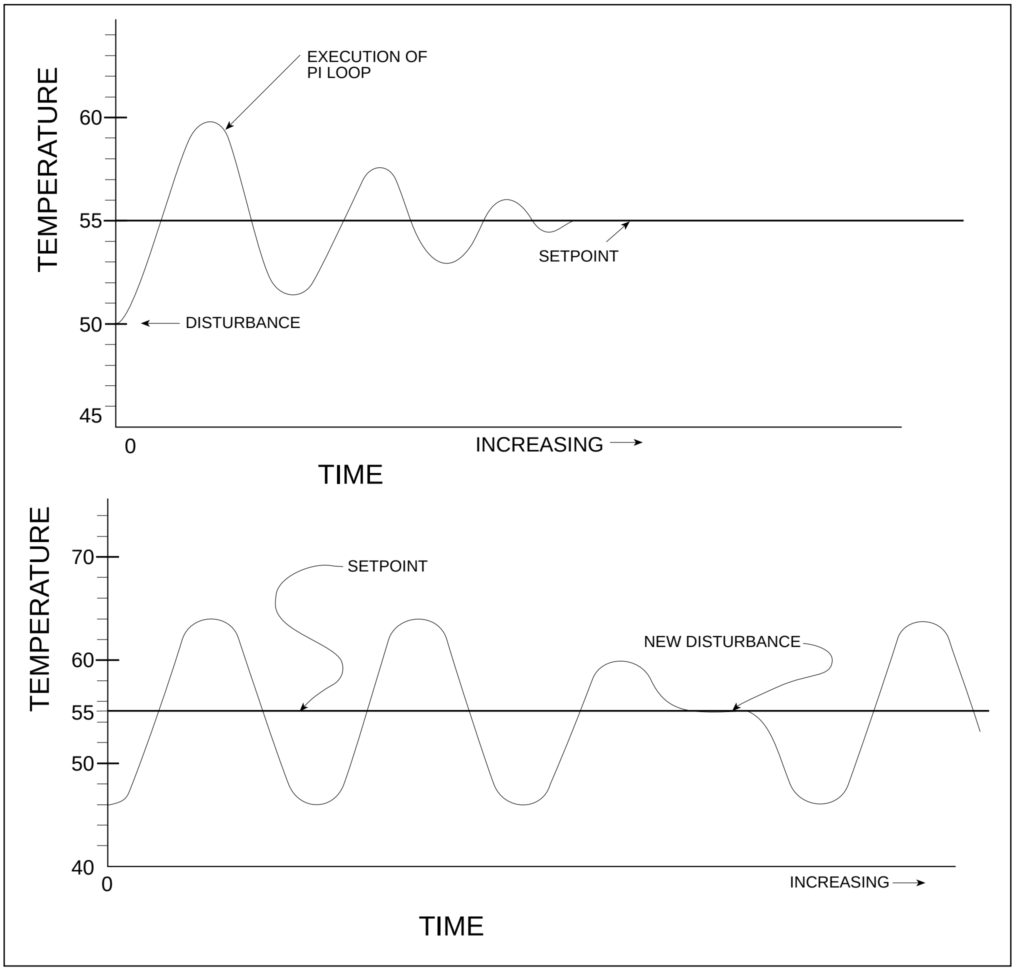
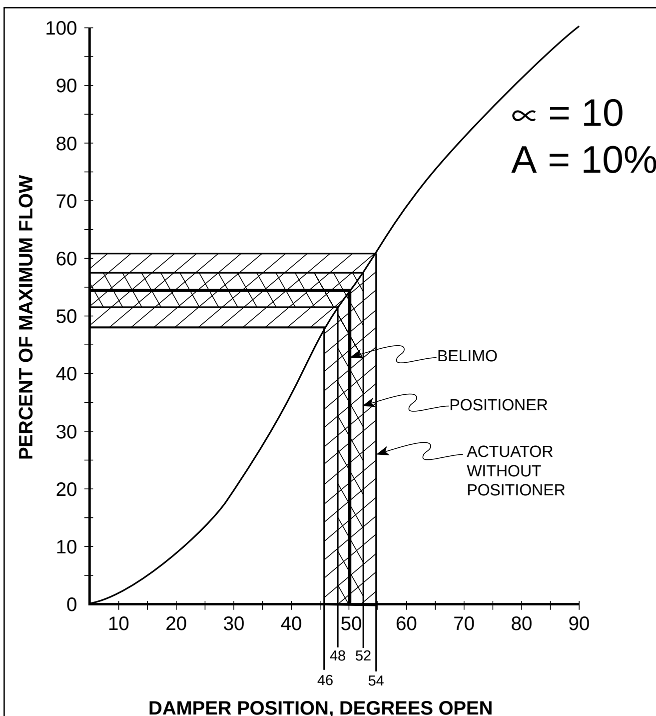


Fig. 5



Given a 40° OA temp, 70° RA temp, MA setpoint of 55° (50% flow).
With 5% hybrid accuracy with positioner, the MA could vary from 50° to 60° and the air flow from 80% to 120% of design. Instead of the PI loop controlling the MA, the error causes repositioning of the actuator when deviation from setpoint is sensed. Given stable conditions an average over time near 55° can be maintained but sophisticated reset and control are not realizable with full confidence. Observation of installed systems indicates this is a worst case since repositioning of the actuator is frequent. But the Belimo worst case is 1% accuracy and confidence in positioning is assured.

Fig. 6 - Opposed Blade Damper Flow Characteristics

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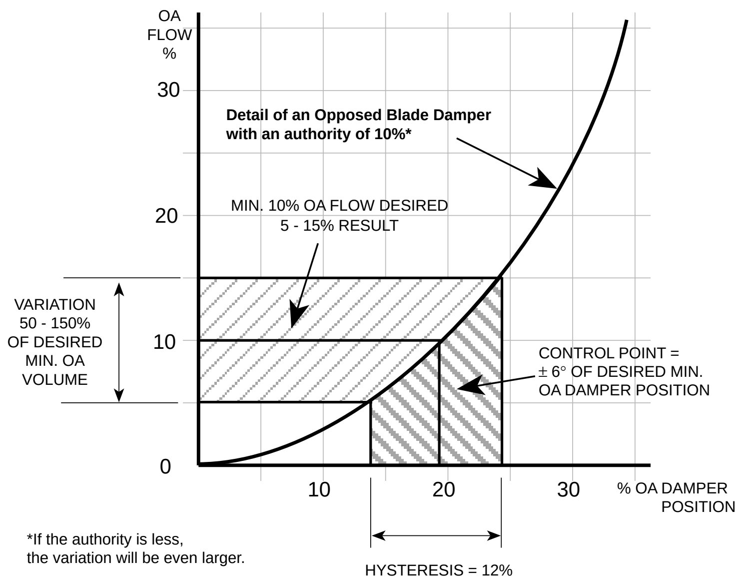

Given a 10% OA (20 CFM per person) minimum requirement and use of the same damper for minimum and economizer air. From the chart observe that 20 degree opening is needed but 5% accuracy is all that is possible. Actual intake could be from 5% to 15%. A more sophisticated control scheme using 5% OA when partially occupied would be impossible. Flow stations could be installed, but could be very expensive if a large number of smaller units were used. Position feedback and commissioning data could be used to get higher accuracy for lower cost with BELIMO electronic actuation.

Fig. 7

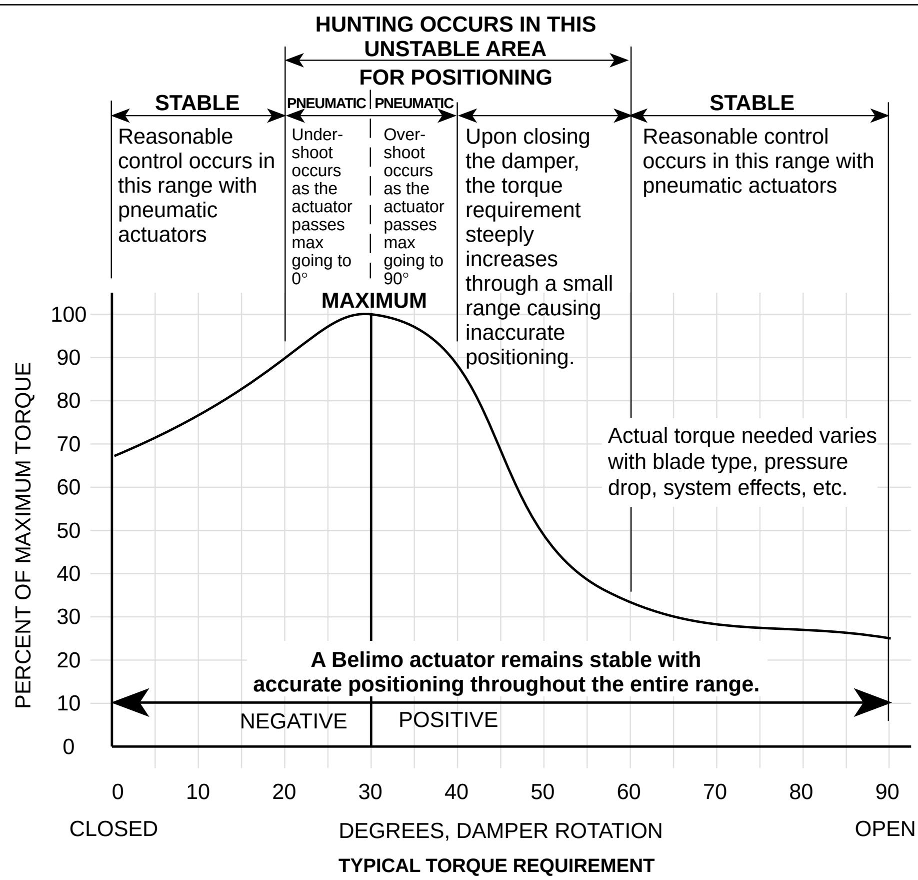

Fig. 8

resolution in final control elements frequently renders the PI loop ineffective. The control point rarely equals the setpoint. *See Figures 5 and 6.* In survey after survey, the number one reason for tenant dissatisfaction is poor temperature control and half the time controls are at fault. With estimates of $3.00/year/ sq.ft. for lost productivity and $2.00/sq.ft. installed for controls, the increased control using electronics is necessary.

ENVIRONMENTAL CONCERNS

While automation is often the motivation for DDC installation today, the energy conservation goal will again be the dominant reason and is always a legitimate engineering objective. The alternate heating and cooling of air required to gain comfort using pneumatics is wasteful and unnecessary.

The IAQ requirements for ventilation accuracy are becoming very important. Liability aside, it is the engineer's responsibility to provide what protection he can from environmental dangers while keeping energy costs and comfort at optimum levels. *See Figure 7.*

PNEUMATIC HUNTING

Energy waste and tenant dissatisfaction are inevitable by-products of pneumatic hunting. Because a pneumatic actuator, even one with a positioner, is completely subject to the forces opposing it, the non-linear dynamic torque loading of a damper as it moves through its rotation will cause the actuator to hunt. At the point where maximum torque is required, pneumatics will hunt for position, resulting in under and over shoot at the max torque threshold. This phenomenon can also occur any time there is a substantial change in torque through a small range of rotation.This problem becomes more pronounced at higher air velocities or static pressures. *See Figure 8.*

A BELIMO actuator is inherently positive positioning. It utilizes an internal potentiometer to verify its position with respect to the control signal. It simply obeys the relationship between control signal and potentiometer between ± .05 volts DC regardless of opposing forces acting on it.

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OTHER CONSIDERATIONS
Future flexibility for code changes, new techniques (e.g., VAV box type OA intake control) requiring feedback and high accuracy, or operational changes are more easily accomplished with electronic actuation.

Pneumatic actuators are fast moving which is good in some process applications, but unnecessary in temperature control. Either the actuator or control loop must be slow enough to allow system stability.

In 2-position spring return applications the pneumatic actuator will deliver more torque for the cost. In low ambient applications - outside or outside airstream mounting - electric must be used since even dessicant driers cannot prevent freezing of positioners and air lines.

Spring return is not desirable in some applications and this is more easily done with electronic actuators. VAV reheats should fail in last position to alleviate overheating the space when air is lost. With inlet vanes it is inconsequential since proof of closure or feedback is best to prove position before starting the fan.

RELIABILITY
The rudimentary construction of the pneumatic actuator makes it rugged and long lived; however, the transducer, compressor and other interfaces needed with the pneumatic often fail well before the actuator itself.

Given the too early failure rate of the transducer, as reported by contractors, it is unlikely that any will survive the life of the system. Transducers cannot handle the oil and dirt even with regular much less deferred maintenance. The best quality I-P transducers are discreet devices with a modulating valve and branch position feedback but are rarely used due to their high cost.

The compressor is particularly maintenance intensive and the source of oil which contaminates the air lines. Pressure lubricated oil compressors have a life of 20-30 years and require less maintenance but are 3 times the cost of compressors normally used. Splash lubricated is standard and has a life of 10 years - if maintained well. Lubrication, cleaning air filters, changing oil, draining the tank and cleaning auto drains require weekly care.

Fittings are a source of leaks and maintenance. Those at the panel are minor compared to those within the structure.

The drier is a refrigeration machine with normal maintenance problems. The dew points of the instrument air are as low as 35° when new and rises to 45° when the condenser is dirty. If it isn't cleaned soon after that point, it will burn out the compressor. Auto blowdowns can fail leading to water problems. Refrigerant leaks as the machine ages eventually leading to water entering the system.

The oil removal filter must be maintained regularly. Coalescing filters must be sized carefully or oil carryover occurs. Less than half are sized properly.

On the other hand, the BELIMO actuator has the pneumatic actuator's durability but without the troublesome interfaces and many maintenance items included in the pneumatic structure: 23 maintenance items with the pneumatic actuator vs. 3 with the electric actuator (wiring, DDC panel and transformer).

The first BELIMO actuators made in 1976 were put through rigorous test cycles involving temperature extremes, positive and negative loading, sudden load changes during cycling and other extreme procedures. 10,000 full cycles were achieved. Over half of these are still in service today. Today, production lasts 60,000 minimum full stroke test cycles. The result will be an average life of 15-20 years for all BELIMO actuators. Actual installed life span is affected by water damage, heat, corrosion due to atmospheric conditions, torque loading, incorrect voltage, lightning and dithering. The lower limit of number of actuations is about 1,000,000 given 5° to 10° movements with each actuation. This amounts to 15 to 20 years under normal conditions.

BELIMO has ISO 9001 certification, the International Standards organization highest level of quality recognition. BELIMO actuators have a proven published failure rate of only .3% over the 2 year warranty period. This is why BELIMO feels secure in extending a 2 year unconditional warranty from date of installation - the best warranty in the industry.

FIRST COST
Fig. 9 shows the approximate costs of BELIMO actuators vs. pneumatic actuators for new construction. Installation costs for tubing and wiring are essentially equal except where wire must be in conduit or copper must be used for air lines. Cost cutting methods such as the use of 1 positioner to feed actuators on different dampers exist to save money but are bad practices.

Simple pneumatic stat and actuator control of VAV is less expensive than electronic if enough boxes are installed to cover the air station first cost - about 25 to 50 boxes. But, when DDC control is installed, the transducer alone drives the price of pneumatic above electronic. Hybrid (DDC with transducer and pneumatic actuation) is not worth considering on a cost basis. If future DDC is planned, then electronic stat and actuator should be considered during the first stage construction to save expense later in wiring and another actuator. However many cheap electric VAV actuators exist due to the mass market and low first cost orientation.

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FIRST COST

25 sq.ft DAMPER, SPRING RETURN

Number of Actuators		1	2	3
BELIMO				
ACTUATOR		250	500	750
LABOR (1)		20	40	60
	Total	***$270***	***$540***	***$810***
PNEUMATIC				
ACTUATOR		100	200	300
TRANSDUCER (2)		100	100	100
POSITIONER (3)		100	200	300
LABOR		100	150	200
AIR STATION (4)		50	100	150
	Total	***$450***	***$750***	***$1050***

50 sq.ft. DAMPER, SPRING RETURN

Number of Actuators		1	2	3
BELIMO				
ACTUATORS		500	1000	1500
LABOR		40	80	120
	Total	***$540***	***$1080***	***$1620***
PNEUMATIC				
ACTUATORS (5)		200	400	600
TRANSDUCER		100	100	100
POSITIONER		100	200	300
LABOR		150	250	350
AIR STATION		100	200	300
	Total	***$650***	***$1150***	***$1650***

(1) .2 hrs/BELIMO, .7 hrs/pneumatic
(2) 1 transducer for all actuators, may require more
(3) 1 positioner per damper, 2nd actuator paralleled
(4) Compressor, drier, pressure reducer, blow downs, etc. About $4000 installed for good duplex, 80 actuators =$50 each
(5) 2 actuators per damper, 1 positioner, 1 transducer Actuators are 4" stroke, 15 sq.in diaphram, mounting hardware not included.

Prices used are approximate cost to user for new construction.

Fig. 9

LIFE CYCLE COST

Because of the many pneumatic maintenance factors for the many pneumatic components (23) described above, the yearly maintenance contract for pneumatics is about 7% of the installed contract. BELIMO with 4 component items requires no maintenance. In addition, with electronic actuation, energy cost avoidance, tenant satisfaction, and increased productivity are so high that no comparison exists.

If life cycle cost is considered, then replacing old pneumatics with BELIMO will be most cost effective. Oil in air lines of older pneumatic systems may no longer be able to be removed. If built up oil can be removed, compressors will eventually contaminate them again and replacement of one or several of the many pneumatic components will be required long before the actuators wear out.

CONCLUSION

BELIMO electronic actuation offers the following advantages:

Direct Coupled	Very fast installation
Pure Electronic	Accuracy ±1% with no degrading over time.
Overload Protected	Electronic protection prevents jammed damper from burning out motor
ISO 9001	Quality is the number one issue.
0.3% Failure Rate	Lowest in the industry.
2 Year Warranty	Possible because of high quality, low failure rate
Spring Return Models	Belimo has a wide range of both non-spring return and spring return models; spring return models employ a reliable mechanical spring for fail safe operation.

The specifications and engineering manuals of the various HVAC pneumatic manufacturers can be examined to verify data. Nevertheless, observation of installed systems is the best verification of the advantages of electronic actuation.

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BELIMO

Actuators for heating, ventilation, air-conditioning

Air Damper Actuator Documentation

Overview

Doc. 1.0	Product Guide and Company Profile (list prices)

Spring Return Actuators

Doc. 2.1	AF Series, 133 in-lb
Doc. 2.2	NF Series, 60 in-lb
Doc. 2.3	LF Series, 35 in-lb

Non-Spring Return Actuators

Doc. 3.1	GM Series, 266 in-lb
Doc. 3.2	AM Series, 166 in-lb
Doc. 3.3	NM Series, 70 in-lb
Doc. 3.4	LM Series, 35 in-lb

Accessories

Doc. 4.1	Electronic Accessories
Doc. 4.2	Mechanical Accessories

Application Information

Doc. 5.1	Mounting Methods Guide
Doc. 5.2	Wiring Guide
Doc. 5.3	Damper Applications Guide
Doc. 5.4	Pneumatic vs Electronic Actuation
Doc. 5.5...	Actuator submittal sheets

Product/Application News

Control Valve Documentation

Documentation/Price List

Doc. V2.1	Characterized Control Valves
Doc. V2.2	Electronic Globe Valves (1/2”-2”)
Doc. V2.2-1	Electronic Globe Valves (2 1/2”-6”)
Doc. V2.3	Electronic Zone Valves
Doc. V2.4	Electronic Butterfly Valves

Application Information

Doc. V4.1	Sizing and Selection
Doc. V4.2	Valve Applications Guide

Product/Application News

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