FACTORS THAT WORK TO DEFEAT THE APPLICATION OF THE "SPRING AND CONE" TYPE VALVES IN LABORATORY AND OTHER PRECISION AIRFLOW SYSTEMS

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Beginning in the mid-1960s, Dimiter and Hend Gorchev were issued a series of patents. Of special interest is one patent[1] regarding their design of a pneumatic actuated airflow control valve intended for VAV control for occupant comfort/commercial space temperature control. A Massachusetts company, MITCO Corporation, was formed to market this "spring and cone" control valve in commercial building applications[2]. While other companies were pursuing valve and control system designs that addressed the same concerns but in different ways, the MITCO valve design was unique. It employed a spring-loaded assembly (which is referred to as the "plunger") that is cone shaped that slid axially on a concentric shaft used to throttle flow through the valve. This cone represented a fixed valve "seat" arrangement. The cone, and to a lesser degree the movable seat, slid back and forth on the shaft, and it was shaped in the form of a parabola, thus giving rise to the term "Venturi valve."

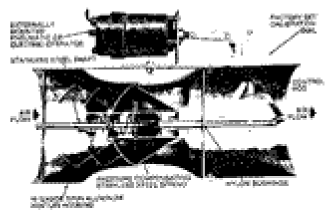

Figure 1 illustrates the valve and seat arrangement.

THE PARABOLIC VALVE PLUG AND THE "VENTURI" VALVE CONCEPT

The idea of using a parabolic valve plug (parabolic or "Venturi" body or seat elements) in HVAC air side applications[3] resulted from well known control valve technology that produced flow control characterized by a linear relationship between the displacement of the valve plug and the flow rate through the valve[4]. Valve ratings and the performance flow characterization resulting from tests of valves in liquid services, when subject to constant pressure differential across the valve, has been an industry recognized means of rating and evaluating performance for some time. Many variations of "linear flow" control response with plug travel were accomplished by contouring, porting, or fluting the flow-restriction portion of the valve plug or seat arrangement. The most common way was to modify the shape of the valve plug as it mated into a fixed (orifice) valve seat.

VARYING (DIFFERENTIAL) PRESSURE CONDITIONS ACROSS AIR VALVES IN VAV SERVICE AND HYSTERESIS

Because duct system pressures in HVAC applications most often vary significantly, valves used to throttle flow in this application are practically never subjected to constant differential pressures across them. Thus, a fixed parabolic throttling valve relationship between valve plunger and seat, yielding a linear relationship between flow and plunger, does not and can not exist in situations were the differential pressure across the valve is not held constant.

In an attempt to overcome this problem and produce a "linear" flow vs. valve plunger throttling response, the MITCO valve design included a floating cone assembly that was spring loaded. With this configuration, the valve plunger is theoretically subject to a balanced force relationship resulting from the force of the spring (contained in the plunger assembly) and the aerodynamic drag-induced forces acting on the cone. Ideally, the plunger should "float" between stops associated with course positioning achieved by the external actuator assembly mounted on the valve. As the differential pressure across the valve changes, greater or lesser aerodynamic drag is induced on the cone, which is compensated for by the action of the spring in the plunger assembly. In theory, the same flow is "automatically" maintained by the aerodynamics by spring force as differential pressures across the valve changes[5]. However, since the plunger is in contact with the shaft that supports it, frictional forces (especially static) act to retard the movement of the plunger when repositioning is required. This causes the valve to always exhibit hysteresis.[6] This problem of plunger movement along the shaft is also often compounded when dirt or other foreign material builds up on the shaft. The problem becomes more pronounced when the bearing surfaces of the cone or shaft becomes abraded and marred. Failures resulting from foreign material build-up and binding axial movement of the plunger assembly have commonly been observed with this type valve.

In addition to these problems, other factors contributing to the non-linear response of the valve have to do with the shape of the cone and bearing surface locations in the plunger. Under ideal conditions, as the cone moves toward or away from the valve seat, the shape of the cone should change to optimize the influence of aerodynamic drag acting on it. This is similar to having the shape of an airplane wing change while in flight to enhance lift and drag for low and high-speed situations. However, the shape of the cone is fixed; it's shape can not change. Another problem with the valve is that the slide type bearing surface(s) is (are) located in the plunger assembly. If the valve is mounted horizontally with a single bearing surface located in the forward part of the plunger toward the valve seat, the weight of the plunger, being cantilevered and not centered over the bearing, theoretically induces a moment that contributes to binding across the bearing/shaft contact surfaces.

Throttling through this valve, because it lacks a flow measuring feedback control mechanism, is not independent of differential pressure across the valve[7]. The Phoenix system offering, utilizing the "spring and cone" type valve design, is an "open loop" control arrangement that lacks continuous flow rate "feedback" necessary to ensure flow set point, or "closed loop" control, across a valve, regardless of the differential pressure applied across the valve. Because of the "spring and cone" type features of the valve and the sometimes quasi-linear response that can be demonstrated under controlled throttling conditions, the valve has been falsely promoted as a "linear" flow control valve capable of accurate and, more especially, required precision[8] of flow control needed in fume hood exhaust flow situations. Tests of the control system offerings based on the "Venturi" or "spring and cone" valve do not work consistently as needed or as advertised. The valve's throttling response is non-linear or 100% pressure independent. The valve itself is plagued with inherent, basic mechanical problems that no one has satisfactorily overcome as of this time. This lack of "linearity" is illustrated by the original MITCO data below. MITCO never claimed linearity with this concept and their differential pressure across the valve versus fixed valve position clearly indicates non-concurrent fixed flow versus theoretical flow. (The elongated "S" flow lines are not co-linear and atop the fixed horizontal flow lines.)

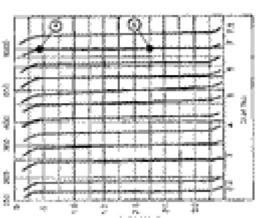

Figure 2. The original MITCO data.

One of the first reported attempts to apply the MITCO valve in VAV laboratory airflow control service was at Argonne National Laboratory in 1978[9]. The principal investigator, Josip Vresk, used this effort as the basis of his Master's Thesis that he submitted to the Illinois Institute of Technology. Vresk's test results, exhibited in Figure 3 below, indicated that significant control loop hysteresis (friction) was present. Argonne, after the conclusion of the tests, never elected to go forth with additional work using this valve design. The valve design simply could not consistently produce required flow as duct system static pressure, hood sash position, and "spring and cone" assembly changed.

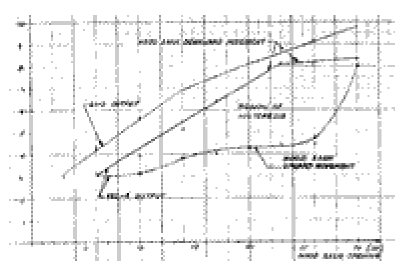

Figure 3. Argonne National Laboratory Data .

In 1980, a series of tests of several laboratory airflow control system vendor concepts and offerings was done for Exxon Research and Engineering[(10)] in Rosselle, New Jersey. Testing with MITCO valves was discontinued because of the same valve problems encountered in the Argonne study. These tests were performed totally independent of the Argonne effort, yet they reached the same conclusions. Were halted because all four valves, each serving a fume hood in the mock-up, became "sticky" and would not correctly respond, partially because of dirt built up on the valve's shafts. No chemicals were used during the testing, and it was recognized that in those situations where the valves were subject to chemicals and material deposits on the valves' shafts, that this would only accelerate and aggravate existing problems associated with this valve design.

In a report published in 1986, the U.S. Army Corp of Engineer's Construction Engineering Research Laboratories (CERL)[(11)] confirmed that the "spring and cone" type valve, as well as two other air valves that were claimed as being static and independent of pressure, did not function as claimed. The "spring and cone" valve tests exhibited significant hysteresis, and tests with this device were discontinued. The CERL report concerning "spring and cone" type valves states:

"To obtain better results, several other tests were performed to examine the characteristics of the spring and cone type arrangement. Changing spring constants did not seem to improve the test results much. Upon disassembling the spring and cone mechanism, a great deal of abrasion was noted and reducing the amount of contact area by sanding did not seem to reduce the problem. Problems with this box were so great that it was deemed unlikely to function in a VAV system; therefore, tests on this box were discontinued."

Figure 10 of the CERL report, below, indicates that not only was the valve static pressure dependent, but also the problem becomes more severe with higher valve actuator signal pressure and as the differential pressure across the valve is increased. These results indicate that characterization of pressure loss versus flow across the valve was not possible.

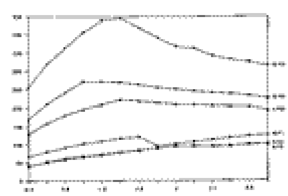

Figure 4. US Army CERL report.

On or about this time, the MITCO Corporation ceased to exist, and the production rights to the valve design were reportedly sold to four companies. The demise of the MITCO Corporation resulted largely because of consistent improper functioning of their "spring and cone" type valve in an ever growing number of field installations. Most of these field installations were installed in clean supply air delivered systems for commercial space temperature control.

In 1985, Gordon Sharp, a graduate of MIT and later reportedly, an employee of the Physical Plant Department at MIT, reportedly became aware of the Argonne study. In his work for the facilities group at MIT, Mr. Sharp tested the "spring and cone" valve in a laboratory application at MIT. He then identified an opportunity and applied for a patent that appears to have been based on an electronic version of the Argonne study. With this patent, he sought venture capital and formed a company, Phoenix Controls Corporation, to market and sell a laboratory airflow control concept that centered around the use of the "spring and cone" valve. Since 1985, because of an excellent marketing effort, Phoenix Controls has sold numerous laboratory airflow control systems based on their "Linearized Control Valve". Their sales literature and efforts have continued to emphasize proper system performance resulting from speed of response, implied closed loop control, proper functioning in a "linear" "static pressure independent" control mode, and a valve system free of hysteresis. It must be noted that hysteresis detrimentally impacts the needed proper control, and, more importantly, fugitive emission containment within a fume hood. During the ensuing years, while Phoenix's valve design and construction materials have improved, the fundamental flaws (especially removing friction) of the valve have not been overcome.

VAV Venturi Corporation[(12)] is also a manufacturer of "spring and cone" type valves. VAV Venturi has invested in a significant redesign effort to improve the valve and has tested the Phoenix and other competitors' "spring and cone" type valves. These tests have confirmed, independently of tests by others, that hysteresis is an inherent problem with this type of valve.

The severity of hysteresis, and other negative characteristics of the "spring and cone" type valve systems used in fume hood exhaust or laboratory room supply or similar critical airflow control situations, can be demonstrated by instrumenting and recording real-time dynamics of the control loop responses. Instrumenting and measuring the response of a typical fume hood control loop involves measuring the change in height of a fume hood sash and plotting that response against the resulting change of airflow exhausted through the fume hood. The relationship between these two variables can then be clearly seen, especially through maximum sash height, and computer analysis can calculate the response time of the airflow. A technical paper[13] discussing and illustrating such a procedure, the instrumentation and sensors used, and the results were presented in 1987. While the paper illustrates several situations where the room supply flow was reset and slaved to hood exhaust flow, the data presented was from several field and mock-up situations. Monitoring and displaying hood sash opening with hood exhaust flow to determine bulk hood face velocity, repeatability, and time responses were recorded using the same system. This real-time measuring, displaying, and analysis methodology has provided results of special significance, especially in diagnosing air system control performance problems in "troubled," but operating laboratories.

"SPRING AND CONE" VALVE CONCERNS

The "spring and cone" type system has been installed in numerous laboratories across this country by owners and consulting engineers who do not understand how the increase in hysteresis (friction) may subject workers in the laboratory to unknown health hazards. These deficiencies can cause environmental illnesses associated with the failure of the system to contain materials within a fume hood or laboratory room. While inhalation exposure resulting from such poor containment may be an anomaly in some situations, with select or multiple chemical exposures the deficiencies of this control system promote a very high probability of exposure to facility occupants. The "spring and cone" type system installed in at least two petrochemical/refinery laboratories, we have first-hand knowledge, are not capable of functioning in accordance with needed precision and accuracy requirements to ensure proper containment under all operating conditions. Problems have always occurred; the owner and the specifying engineer have:

> refused to examine and acknowledge previous testing and field experiences with this system;
> published biased and, in some cases, untruthful reports of the experience of others with this system and;
> been unwilling to conduct qualifying tests of the system, especially after installation, that focuses on or at least considers and attempts to quantify the known system/valve defects.

We now find ourselves concerned with a number of things in this situation, including:

> possible endangerment of people in this work place[14] where carcinogenic materials are routinely handled;
> the negative publicity being given to Swiki Anderson & Associates for exposing and bringing attention to the system design defects resulting from use of this valve and;
> possible future unwarranted litigation against specific professional design engineers for the failure of the system to perform in a consistent and safe manner if chronic industrial hygiene problems later occur.

Concerns have been especially heightened by the fact that the Phoenix Controls system still utilizes the "spring and cone" type valve design with its known defects.

The Phoenix Control system was installed in the Amoco's Naperville, Illinois laboratory some years ago.[15] Chronic industrial hygiene problems are now occurring in the Naperville laboratory[16], which we believe, based on our past tests and experience, are directly attributable to the observed lack of consistent and precise hood face velocity control. That stems from the use of Phoenix's system in the laboratory buildings. Amoco never conducted competitive mock-up testing of control concepts, never recorded the data on a real-time basis in a way that allowed for quantitative system performance evaluation, and never observed the problems identified above. Amoco thus lacked a quantitative basis for evaluation of vendor proof-of-concept offerings.

CONCLUSION

Our experience has shown us that true precision airflow control, especially in dirty fume hood exhaust airflows, cannot occur with the "spring and cone" type valve system. The lack of pressure independence and the increase in hysteresis will lead to a containment loss, and possible exposure to the personnel. To quote from the U.S. Army Corp of Engineer's study:

> **"Problems with this box were so great that it was deemed unlikely to function in a VAV system."**

1. U.S. Patent # 3,204,664, "FLUID FLOW REGULATING VALVE."

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2. Excerpts from MITCO sales catalog.

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3. Throttling devices used in HVAC applications are normally referred to as "dampers," with the more general term "valve" applying to HVAC throttling and especially liquid services.

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4. Excerpt from *Control Valve Handbook*, Fisher Governor Company, Marshalltown, Iowa, Robert Lasher, editor, pp. 27-31 and excerpt from 1991 ASHRAE *FUNDAMENTALS*, Chapter 41, pp. 41.1 - 41.15 and 41.25 -41.27.

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5. ASHRAE definition of independent system static pressure in excerpt from 1992 ASHRAE *SYSTEMS*, pp. 2.10 and 2.11.

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6. Refer to Bourns' *Transmitter Terminology* for definitions of term to include hysteresis.

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7. This condition is termed "system static pressure dependent."

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8. "The *accuracy* of an instrument indicates the deviation of the reading from a known input," i.e., ability to read a true value. "The *precision* of an instrument indicates its ability to reproduce a certain reading with a given accuracy," i.e., the ability to consistently repeat the same reading. "Accuracy...as relating the deviation of an instrument reading from "a *known* value. The deviation is called the *error*. In many situations we may not have a known value which to compare instrument readings, and yet we may feel fairly confident that the instrument is within a certain plus or minus range of the true value. In such cases, we say the plus or minus range expresses the *uncertainty* of the instrument reading." *Experimental Methods for Engineers*, 3rd edition, by J.P. Holman, McGraw-Hill Book Company, pp. 7 and 8.

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9. ANL/ENG-76-03, "Mock-up and Testing of a Variable Volume Laboratory Fume Hood Exhaust System."

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10. "A Laboratory and Fume Hood Air Flow and Control Study for The Clinton Facilities Project Sponsored by Exxon Research and Engineering Company," December 1980, Swiki Anderson and Associates, Inc.

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11. Lynn Krajnovich and Douglas C. Hittle, **"Measured Performance of Variable-Air-Volume Boxes,"** US Army Corps of Engineers, Construction Engineering Research Laboratory, Interim Report E-86/07, September, 1986.

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12. Al Jacobs, President, VAV Venturi Corporation 211 Legion St., Vernoa, WI 53593, (608) 845-8368

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13. "Comparisons of Variable-Volume Fume Hood Controllers" by Rabiah, et. al. is included because it is extremely well written and objectively qualifies the metering basis for properly judging control system performance. The second paper, "Air Balance of Laboratory VAV System," indicates how the same metering and analysis concepts have successfully been used to evaluate or diagnose causes of problems in laboratory and other air flow performance situations. This is especially important in field situations associated with operating, but troubled, jobs. A "REPORT of TEST FINDING for PHOENIX CONTROLS, CORP. Variable Air Volume Air Valve" done by Atkinson Koven Feinberg, Engineers, Mount Laurel, New Jersey is included for comparison purposes.

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14. The State of Texas Law and Rules Concerning the Practice of Engineering and Professional Engineering Registration, Rev. 09-01-94. Refer to § 131.151, Professional Responsibility. The engineer shall not prepare, complete, revise, alter, sign or seal any designs, plans, specifications, reports, analyses, or orders, or in any manner participate in any engineering practice, judgement, or decisions which, when measured by generally accepted engineering standards or procedures, is reasonably likely to result in any utility, structure, building, machine, equipment, process, product, device, work or project endangering the property, lives, safety, health, or welfare of the general public.

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15. In 1990, SAAI made a presentation in Naperville, at Amoco's request, for initiating and conducting a full scale mock-up qualifying test program of vendor system offerings to be used to retrofit of this facility. The proposal was not accepted. Gary LeBlanc was the facility manager at that time at that site and Linda Hubbard was the project engineer.

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16. See news clips, **"Oil Company Looking For Cause of Employee Brain Tumors"** By HERBERT G. McCANN Associated Press Writer, AP news release #15447077 dated 8/27/96.

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