TERMINAL UNIT
AIRFLOW MEASUREMENTS

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OVERVIEW

The control of airflow rate in VAV systems is important for several reasons, including acoustics, ventilation, energy management and occupant comfort. Most VAV terminals today are supplied with pressure independent controllers of some type (pneumatic, analog electronic and digital electronic), and all require an inlet flow sensor supplied by the VAV box manufacturer. Indeed, upcoming revisions to ASHRAE Standard 62 will likely require pressure independent controls to assure minimum ventilation rates in spaces.

In 2003, Krueger introduced an advanced design cross flow sensor (the K4 “LineaCross”) that provides the most powerful set of inlet sensor attributes available in the industry today. This paper discusses many aspects regarding inlet sensing of VAV terminals.

CONTROL ISSUES

The goals of a flow control design must be understood before deciding on the best solution to inlet flow sensing.

- Acoustics: In order to have the lowest sound generation, a VAV terminal box is usually selected as large as possible. A larger size usually (but not always) results in lower sound generation due to the lower velocities for a given flow rate, than a smaller one. At the same time, units are selected at the highest flow-rate as possible, to achieve the best flow signal at minimum flows. Additionally, the supply diffusers are selected as small as possible, to maximize air distribution performance (see white paper on diffuser selection). If a unit delivers more air than designed during maximum flow conditions, it is therefore probable that excessive noise will be noticed in the occupied space. Therefore, maximum flow limiting needs to be as accurate as possible.

  At the low end of the control range, if the airflow set-point is below the working range of the velocity controller, the unit may cycle between closed and partially open, causing some varying sound levels leading to occupant complaints.

- Ventilation: Minimum ventilation rates demand that low-end flows be as accurate as possible to ensure that adequate ventilation is supplied during periods of low sensed load. This requires the flow at the low end of the scale be as accurate as possible. In addition to poor ventilation, space sub-cooling can create occupant comfort problems if minimum flows are set at too high a level.

- Energy Management: The temperature feedback loop with pressure independent controls probably takes care of any flow errors that might be experienced in the mid range of a VAV boxes flow range, which should be most of the time if the unit is sized properly. As a space becomes too warm or too cold, the damper will be adjusted to respond to the sensed temperature change. With Single Duct VAV boxes during reheat, however, the heating airflow set point is typically constant, and if more air is supplied than desired, energy is wasted as excessive chilled primary air is reheated. With Series Fan Terminals, excessive primary airflow at the maximum VAV damper flow setting can cause overpressure of the unit, sending chilled primary air into the plenum, with a number of negative consequences.

- Occupant Comfort: The purpose of the pressure independent VAV controller is to maintain occupant comfort at the lowest possible airflow rate. Poor airflow sensing can create uncomfortable temperature swings, again resulting in occupant complaints. This often results in excessive energy use from uncontrolled supplemental fans or space heaters employed by occupants to augment a poorly controlled system.

Therefore, the maximum, minimum and minimum reheat flow points are probably critical for acoustical and energy control. Intermediate control is not as sensitive, but excessive swings in flow are to be avoided. The selection and design of an inlet sensor can have a significant impact on the resulting space conditions and building energy consumption.

INLET CONDITIONS

The inlet conditions to a VAV box are difficult to control. Often there are field conditions that prevent the ideal '3 diameters of straight duct' often seen in specifications. (A recent paper claimed that 10 diameters of straight duct was insufficient to determine accurate flow!) Flexible duct is almost always used at the inlet to connect the unit to primary ductwork. This flexible duct can sag if too much is used, or if a long unsupported run is employed between the unit and the supply duct.

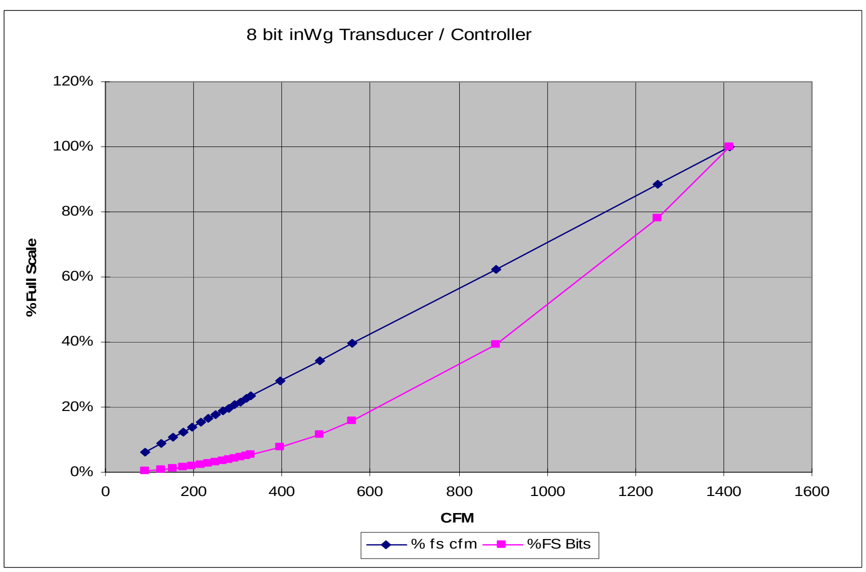
Early VAV terminals with single point sensors in the inlet often had serious flow measurement and control problems. A number of multipoint sensors have been developed to overcome this problem. Types of sensing include flow rings (round or square), orifice plates, annubar-type and flow crosses (including 'stars'), both center averaged and edge sensed. With all, there is a necessary compromise between overall pressure drop, noise generation and developed signal, not to mention cost and ruggedness.

Tests conducted with flexible duct supplying a VAV terminal, a movable stand, and an accurate flow station upstream of the unit, have been used to verify the sensing accuracy as a function of inlet conditions for all of these types of sensors. Not surprisingly, the greatest response factor to flow accuracy is the inlet duct configurations, and to a lesser extent, flow rates and inlet pressures. The more measuring points in the pickup, the more accurate the flow determination. An ideal pickup (such as the Krueger "LineaCross") will comply with the ASHRAE "equal-area" rule, which requires many points at different spacings to represent equal cross sectional areas.

Tests showed, moreover, that if a flow constant is developed at a relatively high flow rate (as would be established by the balancer at design flow rates), the error using this 'configured' flow constant is minimal at any flow or pressure! This means that in the field, an accurate field balance should result in excellent flow control, regardless of the inlet sensor employed, as long as it has multiple averaged sensing points. What a more accurate averaging sensor offers is a closer "first cut" flow determination for the balancer. See the following section on balancing.

INLET SENSOR ISSUES

A Pitot tube, and traditional multipoint flow stations based on the Pitot tube, generates 1" of differential pressure at about 4005 fpm (depending on atmospheric and duct pressure, humidity, etc). This results in very low signals at the 200 – 400 fpm required for most designs. 400 fpm = a velocity pressure of 0.01" wg, and 200 fpm = 0.002"! This problem is exaggerated when the signal is converted to bits, as done in a DDC controller. Shown here is a chart expressing both the % full-scale airflow and the sensor



output expressed as bits as would be seen by an 8-bit DDC velocity controller in a typical application. As can be seen, there is little change in bits for a great change in flow at the low end of the scale. This creates the need for both high amplification and/or a clever control algorithm to resolve flows accurately at the low end.

Regardless of the inlet sensor employed, flow at the low end of the operating range of any controller will not be as accurate as at high flows. Specifications requiring 5% accuracy over the full range of the unit cannot be met with any VAV box / controller combination available today (in spite of claims by some to be able to do so). An 8" VAV box, typically sized for 800 cfm, would have to be accurate to 5% of 160 cfm (at Krueger's recommended minimum airflow for that size), or +/-8 cfm, to comply with this requirement! It is more likely, however, that with reasonable inlet conditions, and a multi-point averaging sensor, most systems can be within 5% at rated flow, (or, in sensor terminology, 5% FS, or full scale) which is typically 2000 fpm.

MAGNIFICATION

Magnification is achieved by locating the static pressure pickup point on the backside of a velocity sensor, rather than on the side as in a pitot tube. One method is to increase the cross-sectional area of the probe so that the static pressure port is in the aerodynamic 'shadow' of the probe. Typically, the greater the cross sectional area, the greater s the resulting magnification.

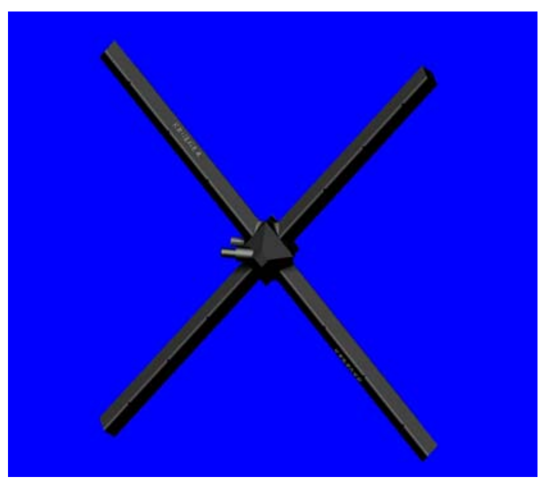
There are other strategies for increasing magnification without increasing the cross section of the probe (which may generate turbulence and noise). While the flow constant for a Pitot tube is typically 4005 fpm (at standard conditions), amplified probes typically exhibit constants on the order of 2600-3500 fpm. In practice, it is also essential that the total pressure pickups (on the upstream side) be averaged to get the best representation of average flow with non-ideal inlet velocity profiles.

THE KRUEGER SOLUTIONS

When developing a flow probe for the 1986 design of VAV terminals, Krueger discovered that placing the linear averaging probe at a 45^{o} angle resulted in a significant reduction in both discharge and radiated sound levels, resulting in one of the quietest designs available in the industry. In addition, the magnification of the linear probe with the unique side-by-side design, has resulted in as high a magnification as is available with any competitive unit, around 1" pressure @ 2600 fpm.

NEW K4 "LINEACROSS" FLOW PROBE

Now available as a standard option, a newly developed equal-area center averaging flow cross may be ordered on all Krueger VAV terminals. This sensor has a 12-point total pressure, center averaging flow cross-type design. Using an equal area layout, the sensor complies with ASHRAE's recommended measurement points for accurate determination of duct air velocity.



By careful design of the total and static pressure pickup points, the new K4 "LineaCross" sensor has the same flow constants as the proven linear averaging flow probe. This means that no matter what sensor is installed, the balancer can use the same flow constant, or table, for all Krueger VAV terminals. By providing the equal area layout, in combination with the high magnification, the Krueger "LineaCross" flow sensor offers the most accurate and consistent flow sensor available today, and makes the process of balancing as easy as possible.

FLOW CONSTANTS

The controls on most new projects are Direct Digital (DDC) Controls. These controls require that flow parameters be loaded during start-up to translate the sensed pressure into a measured flow rate. There are several conventions (and no universally accepted method) in use for representing this flow factor:

1.) Magnification Factor **-** The magnification factor may be expressed as the ratio of either velocity or pressure, of the output of the sensor to that of a pitot tube.
   a. For example, a velocity magnification may be used. All Krueger probes develop an average signal of 1" w.g. @2625 fpm. This gives a velocity magnification of 4005/2625, or 1.52.
   b. The magnification factor may be a pressure factor. In this case, the ratio of pressures at a given air velocity is presented. For a velocity constant of 2626, at 1000 fpm, this is 0.1451 / 0.0623 = 2.33.

2.) K-Factor**:** The 'K-factor' may be represented in two ways –
   a. It may be a velocity K-factor, which is the velocity factor times the inlet area, (which for all Krueger probes, both Linear and the new "LineaCross", is 2625fpm/in w.g.).
   b. Alternatively, it may be the airflow K-Factor, which is the velocity factor times the inlet area. For an 8 inch Krueger unit, therefore, this would be 2625 * 0.349, or 916. A separate factor is required for each size. All Krueger VAV terminals have round inlets. Below is a K-Factor table for all Krueger VAV terminal inlets.

Inlet Probe Area and K Factor

LMHS,LMHD	04	05	06	07	08	09	10	12	14	16	22
Inlet Diameter, in.	4	5	6	7	8	9	10	12	14	16	22
Velocity Magnification	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52
Velocity Constant	2625	2625	2625	2625	2625	2625	2625	2625	2625	2625	2625
CFM K Factor.	229	358	515	702	916	1160	1432	2062	2806	3665	7000
Inlet Area, Sq. ft.	0.087	0.136	0.196	0.267	0.349	0.442	0.545	0.785	1.069	1.396	2.667
Recommended Min cfm	40	62	89	122	159	201	248	357	486	635	1212

As there is no standard method of description for this factor, care has to be taken when providing data to the controls person setting up a DDC VAV box to ensure that both parties are using common terminology.

By designing the Krueger probes so that all models and sizes use a common velocity K-Factor, regardless of flow sensor type, both the design engineer and the controls contractor have a consistent reference for selection and installation of the units.

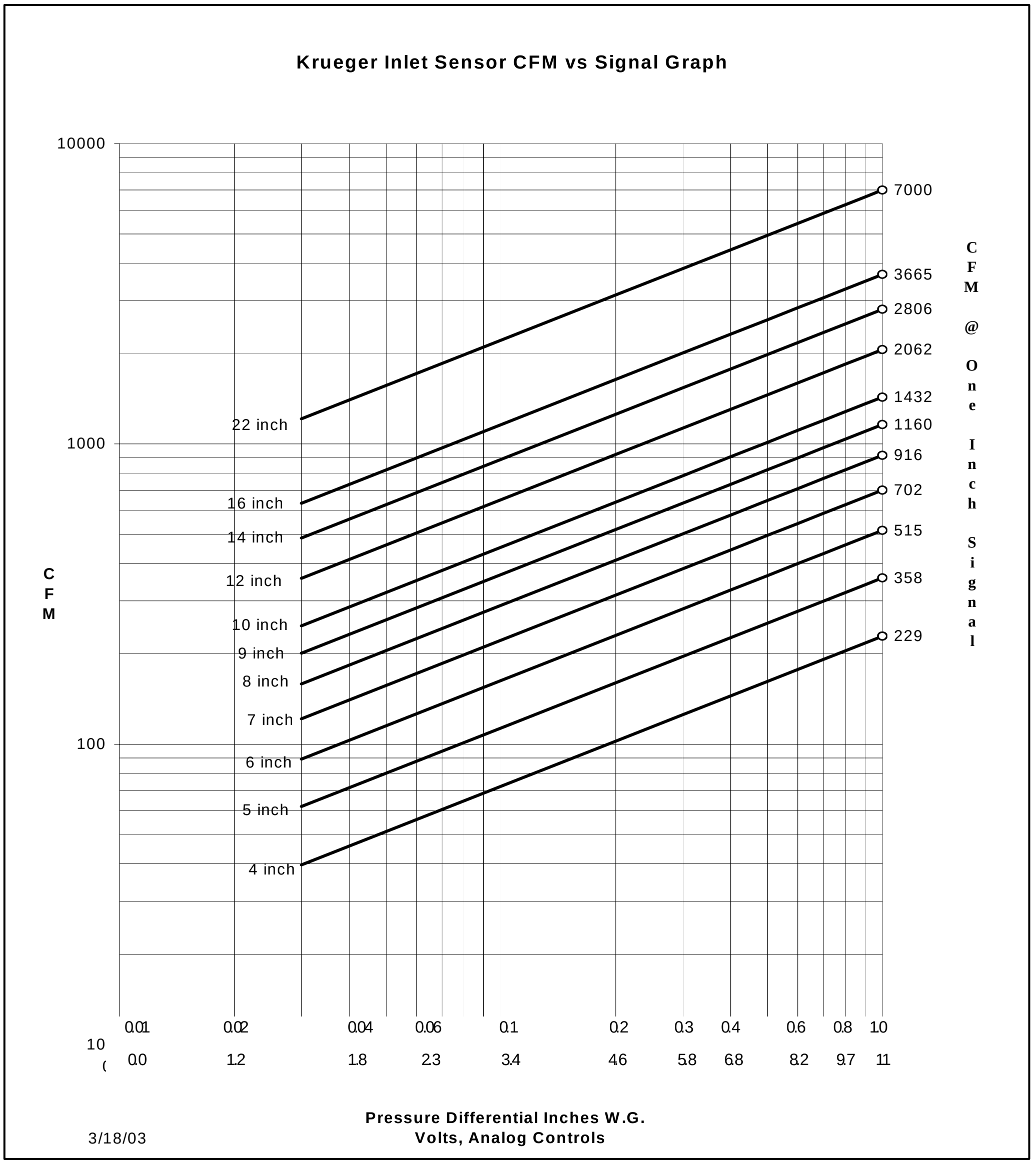
MINIMUM FLOW

The minimum flow shown in the table above, and on the following graph, is based on a flow signal of 0.03". Flows below this value cannot be assured to be able to be controlled by all available DDC controls. When attempting to control below these levels, erratic performance may result, and objectionable sounds may be produced. Additionally, electric heat is not permitted to be set below these values as the flow safety switches will probably not energize, and discharge temperatures will probably be too high. See a separate document of recommendations for overhead heating with VAV terminals.

BALANCING

Often, the air balancer will measure the flows through the supply diffusers, and establish an 'effective flow constant' for the unit in that application. While ideally the flow should agree closely with what the 'factory' setting indicates, this may not be the case when either non-ideal inlet conditions are present or there is significant discharge duct leakage. The use of equal-area total pressure sensing with the Krueger "LineaCross" will result in the most accurate initial balance possible.

With the Krueger inlet sensors we have found that whatever balancing constant is loaded into the controller at maximum flow, this is usually a very close approximation to the effective constant at minimum flow, regardless of the system conditions, down to our minimum recommended 0.03” sensed pressure limit. What this means is that the established flow data will probably result in satisfactory performance over the range of expected flows.



SUMMARY

Krueger’s VAV terminals employ either a linear averaging annubar-type sensor at a 45-degree angle, or the new K4 “LineaCross”, a low cross-section, 12-point flow cross, on all sizes to minimize the sound generated by the probe and to offer as high a magnification and flow accuracy as any in the industry.