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IN-SITU FIELD CALIBRATION: CAL-016, REV. G

REVISION HISTORY				
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	A	Initial release per DRF #490319	BBB	12-15-2000
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APPROVALS/SIGN-OFF			
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1.0 Purpose:

This procedure defines how an insertion flow meter may be checked or calibrated as installed in the application, or in-situ calibrated. This process allows the absolute accuracy to be set based on local factors which influence the readings, velocity profile, for example.

2.0 Scope:

This procedure is intended for use by engineers and technicians who are familiar with performing velocity traverses for the reference flow measurement and can setup the correction factors in the program mode of the 155 Mass Flow Computer. The general method and a specific example using a Kurz 2440 as the traverse point-velocity meter in a round and rectangular duct are provided.

Tracer Gas dilution field calibration methods are not covered in this procedure.

3.0 References/Standards:

ISO 9001:2000	8.2.3	Monitoring and measurement of processes.
DCN 360304		Series 155 Mass Flow Computer Summary Guide
DCN 360202		Series 2440 Portable Thermal Anemometer User's Guide
DCN 360205		Series 2440 Pocket Guide

4.0 Procedures:

Outline

- 4.1 Measure the average flow or velocity with a reference method at each flow rate of interest and the DUT (Device Under Test) indicated flow rate and correction factor at the same time.
- 4.1.1 Monitoring the DUT during the reference method testing can be done manually by reading flow rates from a display, and noting the correction factor in force at that time. The correction factor in force depends on the velocity so must be logged at the same time as the indicated flow. This is then used to compute the raw indicated velocity:

$$\text{"Raw-Velocity"} = \text{Indicated Flow}/(\text{Area} * \text{CF})$$

With a multipoint system, the output of the K-BAR is generally raw-velocity but for single point meters, the output will be flow which then requires back computing the raw-velocity. The Kurz program "Modbus Client" which is shipped with the product or can be downloaded from the Kurz website supports logging of multiple meters (like in a K-BAR array or even just single point sensors) in a comma separated variable (.csv) file format that

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a spreadsheet can easily read. Then the simple conversion from indicated flow to raw-velocity can be computed in the spreadsheet.

If the older 155 Data logging program is used to monitor the DUT during the field calibration, you must temporarily assign a meter to each input channel if you want to record the raw-velocity from each sensor.

- 4.2 Finally, enter the reference velocity and indicated raw-velocity of each K-BAR sensor for each flow rate or system operating point in the DUT to compute the correction factors. Working with the raw-velocity and reference velocity will result in the proper correction factors being loaded into the meter whether or not it is a new system or a recalibration in the field. Any Bias or Sensor Blockage Correction Factors must be accounted for too when loading new VCF or CCF data, the CF logged was the net from the Bias * SBCF * VCF. After loading the new VCF/CCF data the DUT will read the flow rate as measured by the reference method.

- 4.3 **Velocity Traverse Reference Method:** A popular method to compute the average velocity in a large process duct or stack is to perform a velocity traverse. In its classic form you divide the duct area into equal areas then measure the velocity in the center of each equal area piece. The average velocity is computed by numerically averaging the data (sum the data and divide by the number of samples).

Alternately you can take the data at convenient positions (recording both the reading and position) then numerically integrate the data. This method allows you to do a traverse at convenient locations, i.e. 50, 100, 150, 200, 250, mm insertion points instead of the equal area, location centers, which are not uniform values. A computer program is used to curve fit the observed velocity profile then integrate the flow and compute an average velocity. If the same convenient locations are used for all traverse ports and for all flow rates tested, less data needs to be entered into the program for evaluations. This alternative method will not be described here as it requires numerical integration methods/tools best done by a computer program like MathCAD.

For either method above use the table below for determining the minimum number of sample points to be taken for each flow rate:

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		Diameters downstream from the nearest flow disturbance such as a bend, expansion or contraction assuming > 2 diameters upstream from the nearest flow disturbance.				
Cross sectional area of sampling site		>8	>6...8	4...6	2...<4	<2
m ²	ft ²	Minimum number of sample points per flow rate				
<0.2	<2	4	6	8	Determined Case-by-Case	Unusable Data
0.2...2.3	2...25	12	18	24	Determined Case-By-Case	Unusable Data
>2.3	>25	20	30	40	Determined Case-By-Case	Unusable Data

4.4 **Equal Areas Rectangular Duct:** For rectangular ducts, it is easy to compute sample locations by dividing the duct cross-section into small equal area rectangles than measuring at the center of each rectangle. If you have enough access ports, you can get an accurate estimate of the duct's flow profile. The sampling is ideally made at least eight equivalent diameters downstream and at least two equivalent diameters upstream from the nearest flow disturbance such as a bend, expansion or contraction.

To find the equivalent diameter for a rectangular duct for use with the chart above we use the following equation:

$$ED = (2HW) \div (H + W)$$

Where:

ED is the equivalent diameter of a rectangular duct.

H is the height of the duct.

W is the width of the duct.

To find the correct sensor insertion depth for each rectangle along the traverse axis in a particular access port we use the following equation:

$$\text{For } i = 1 \dots n, ID_i = \{ (i - 0.5) \div n \} * TD$$

Where:

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i indicates the specific rectangle being measured starting from the wall closest to the access port and continuing out along the traverse axis.

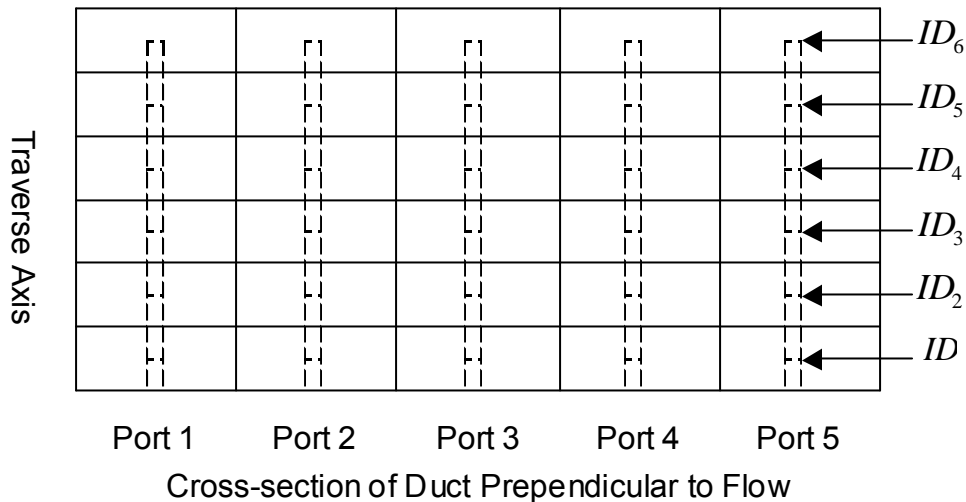
n is the number of rectangles along the traverse axis.

ID_i is the sensor insertion depth for each specific rectangle along the traverse axis.

TD (Traverse Dimension) is the inner duct dimension along the traverse axis.

Example:

A test matrix might have six traverse positions (different insertion depths) along the traverse axis, and five access ports perpendicular to the traverse axis allowing for a total of 30 test points (see illustration below).



The recommended access ports are 19.1 mm (3/4") compression fittings with a Nylon, Teflon or other plastic ferrule which does not swage on to the 19.1 mm test probe.

So for a rectangular duct with a 1000 mm inner duct dimension along the traverse axis, assuming six insertion depths we have:

$$ID_1 = [(1 - 0.5) \div 6] * 1000 \text{ mm} = 83 \text{ mm}$$

$$ID_2 = [(2 - 0.5) \div 6] * 1000 \text{ mm} = 250 \text{ mm}$$

$$ID_3 = [(3 - 0.5) \div 6] * 1000 \text{ mm} = 417 \text{ mm}$$

$$ID_4 = [(4 - 0.5) \div 6] * 1000 \text{ mm} = 583 \text{ mm}$$

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$$ID_5 = [(5 - 0.5) \div 6] * 1000 \text{ mm} = 750 \text{ mm}$$

$$ID_6 = [(6 - 0.5) \div 6] * 1000 \text{ mm} = 917 \text{ mm}$$

To put this all together, we collect data at each traverse port, at each insertion depth as defined below:

Flow Rate 1, 30 points (75 max per set, see section 4.9)						
ID _n	Insertion Depth (mm)	Velocity				
		Port 1	Port 2	Port 3	Port 4	Port 5
ID ₁	83					
ID ₂	250					
ID ₃	417					
ID ₄	583					
ID ₅	750					
ID ₆	917					

From this table we compute the average fluid velocity by summing the data and dividing by the number of points. The 2440 portable will do the data logging and math internally (See Section 4.11).

This process is repeated at each flow rate, up to four sets using CCF in the 155 (See DCN 360204 Series 155 Mass Flow Computer Summary Guide).

- 4.5 **Equal Areas Circular Duct:** A circular duct may be divided along the circumference into equal area wedges like slices of a pie and/or along the radius into equal area concentric rings (the lesser diameter of the center ring is considered to be equal to zero). See Table in Section 4.3 for the minimum number of sample points depending on the duct size and upstream disturbances.

Example: A test matrix might have five traverse positions (different insertion depths) along the duct radius starting from the duct wall closest to each of two access ports spaced 180° from each other and continuing toward the center of the duct and 10 traverse positions starting from the duct wall closest to a third access port spaced 90° from the other two and continuing to the other side of the duct allowing for a total of 20 test points (see illustration below).

To divide the duct along the radius into equal area concentric rings we use the following equation:

$$\text{For } i = \dots n, LD_i = \sqrt{1 - (i \div n)} * DD$$

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Where:

i identifies the specific ring being measured along the duct radius referenced to the inner duct wall.

n is the total number of rings being measured.

LD_i is the lesser diameter boundary (see illustration below) of the specific ring being measured along the duct radius referenced to the inner duct wall.

DD is the inside diameter of the duct wall.

Once the number and location of the equal area center points are known they will be used to position the probe at the center of each area. To find the correct sensor insertion depth for each sector along the duct radius starting from the particular access port we will use the following equations:

$$\text{For } i = 1 \dots n, ID_i = \{2 - \sqrt{1 - [(i-1) \div n]} - \sqrt{1 - (i \div n)}\} * DD \div 4$$

$$\text{For } i = n + 1 \dots 2n, ID_i = \{2 + \sqrt{[(i-1) \div n] - 1} + \sqrt{(i \div n) - 1}\} * DD \div 4$$

Where:

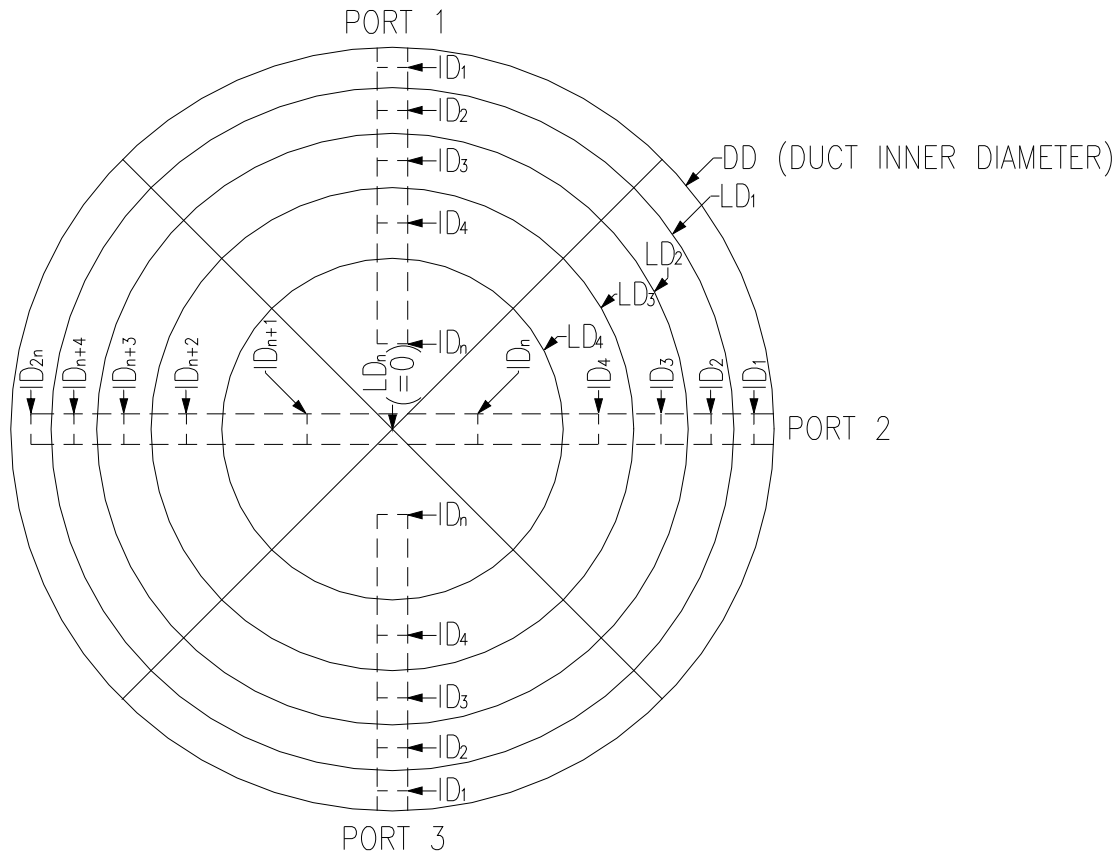
i indicates the specific sector being measured along the duct radius referenced to the inner duct wall closest to the access port.

n is the total number of sectors being measured along the duct radius between the duct wall closest to the access port and the center of the duct only. Do not include sectors on the other side of the center of the duct from the access port.

ID_i is the sensor insertion depth for the specific sector being measured along the duct radius referenced to the inner duct wall closest to the access port.

DD is the inside diameter of the duct.

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Cross-Section of Duct Perpendicular to Flow

The recommended access ports are 19.1 mm (3/4") compression fittings with a Nylon, Teflon or other plastic ferrule which does not swage on to the 19.1 mm test probe. So for a circular duct with a 1400 mm diameter, assuming five insertion depths each imports 1 & 3 and 10 insertion depths in Port 2, we have:

$$\begin{aligned}
 ID_1 &= \{2 - \sqrt{1 - [(1-1) \div 5]} - \sqrt{1 - (1 \div 5)}\} * 1400 \text{ mm} \div 4 = 37 \text{ mm} \\
 ID_2 &= \{2 - \sqrt{1 - [(2-1) \div 5]} - \sqrt{1 - (2 \div 5)}\} * 1400 \text{ mm} \div 4 = 116 \text{ mm} \\
 ID_3 &= \{2 - \sqrt{1 - [(3-1) \div 5]} - \sqrt{1 - (3 \div 5)}\} * 1400 \text{ mm} \div 4 = 208 \text{ mm} \\
 ID_4 &= \{2 - \sqrt{1 - [(4-1) \div 5]} - \sqrt{1 - (4 \div 5)}\} * 1400 \text{ mm} \div 4 = 322 \text{ mm} \\
 ID_5 &= \{2 - \sqrt{1 - [(5-1) \div 5]} - \sqrt{1 - (5 \div 5)}\} * 1400 \text{ mm} \div 4 = 543 \text{ mm} \\
 ID_6 &= \{2 + \sqrt{[(6-1) \div 5]} - 1 + \sqrt{(6 \div 5) - 1}\} * 1400 \text{ mm} \div 4 = 857 \text{ mm} \\
 ID_7 &= \{2 + \sqrt{[(7-1) \div 5]} - 1 + \sqrt{(7 \div 5) - 1}\} * 1400 \text{ mm} \div 4 = 1078 \text{ mm} \\
 ID_8 &= \{2 + \sqrt{[(8-1) \div 5]} - 1 + \sqrt{(8 \div 5) - 1}\} * 1400 \text{ mm} \div 4 = 1192 \text{ mm} \\
 ID_9 &= \{2 + \sqrt{[(9-1) \div 5]} - 1 + \sqrt{(9 \div 5) - 1}\} * 1400 \text{ mm} \div 4 = 1284 \text{ mm} \\
 ID_{10} &= \{2 + \sqrt{[(10-1) \div 5]} - 1 + \sqrt{(10 \div 5) - 1}\} * 1400 \text{ mm} \div 4 = 1363 \text{ mm}
 \end{aligned}$$

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To put all this together, we collect data at each traverse port, at each insertion depth as defined below:

Flow Rate 1, 20 points (75 max per set, see Section 5.1.4.1)				
ID _n	Insertion Depth (mm)	Velocity		
		Port 1	Port 2	Port 3
ID ₁	37			
ID ₂	116			
ID ₃	208			
ID ₄	322			
ID ₅	543			
ID ₆	857	N/A		N/A
ID ₇	1078	N/A		N/A
ID ₈	1192	N/A		N/A
ID ₉	1284	N/A		N/A
ID ₁₀	1363	N/A		N/A

From this table we compute the average fluid velocity by summing the data and dividing by the number of points. The 2440 portable will do the data logging and math internally (See Section 4.11).

This process is repeated at each flow rate, up to four sets using CCF in the 155 (See DCN 360204 Series 155 Mass Flow Computer Summary Guide).

- 4.6 **Velocity Traverse Data Acquisition.** During the traverse procedure, the process flow rate must be at equilibrium so the computed average from the traverse is for the same flow rates on all test ports. The traverse average velocity is obtained using either the rectangular duct or circular duct methods described above. The indicated average velocity on the device being calibrated (the 155C-2) is recorded by logging each sensors velocity while the traverse is performed. (See DCN 360204, Series 155 Mass Flow Computer Summary Guide) which describes how to setup the log interval and record it on a computer or printer.
- 4.7 **Traverse Probe Blockage.** For small ducts, the sensor and probe support blockage must be accounted for. As the probe is inserted deeper in the duct, it blocks off more of the flow causing an increase in local velocity due to the smaller duct area. If this error is greater than 0.25%, a Sensor Blockage Correction Factor (SBCF) can be defined to convert the observed reading to that which an ideal (no sensor blockage) reading would have been.

To determine if a SBCF is needed we use the following equation:

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If $ID_i \geq 0.0025 * AD \div DP$, then a SBCF is needed.

Where:

ID_i is the sensor insertion depth for the specific cell being measured.

AD is the inner cross-sectional area of the duct.

DP is the diameter of the probe.

Example: For a circular duct with an inner diameter of 1400 mm being sampled with a 19.05 mm (3/4") diameter probe, the minimum insertion depth for which a SBCF is needed is:

$$ID_i \geq 0.0025 * \pi * (1400 \text{ mm})^2 \div 4 \div 19.05 \text{ mm} = 202 \text{ mm}$$

To first order, the SBCF can be defined with the following equation:

$$SBCF_i = 1 - [(ID_i * DP) \div AD]$$

Where:

$SBCF_i$ is the SBCF at the specific insertion depth being measured.

ID_i is the sensor insertion depth for the specific cell being measured.

DP is the diameter of the probe.

AD is the inner cross-sectional area of the duct.

Example: For a circular duct with an inner diameter of 1400 mm being sampled with a 19.05 mm (3/4") diameter probe at a depth of 1363 mm for the 10th sampling point in a particular port, the SBCF is:

$$SBCF_{10} = 1 - \{(1363 \text{ mm} * 19.05 \text{ mm}) \div [\pi * (1400 \text{ mm})^2 \div 4]\} = 0.9831$$

The true velocity (VT) is found using the following equation:

$$VT = VI * SBCF$$

Where:

VT is the true velocity.

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VI is the indicated velocity.

SBCF is the Sensor Blockage Correction Factor (which is insertion depth dependent).

- 4.8 **Velocity Probe Type, Series 2440.** A thermal anemometer reads standard velocity corrected to reference conditions, for example: 25°C, 101.325 kPa). The readings are logged, then directly averaged using the equal area method.

To use the insertion depth information in the above example you must note the center of the velocity probe sensing element. The center of the sensing location on the sensor is 20 mm from the probe end. This start point is Y mm beyond the compression fitting's outside edge (site specific depends on duct wall thickness and tread adaptors used etc.). Once the probe center is located at the near wall edge, you mark the zero on the probe support when flush with the compression fitting collar. Then you just mark the computed traverse locations on the probe using a tape measure with a line. A permanent marker pen or finger nail polish work fine.

The 2440 portable flow meter can average a set of traverse data of equal areas by simply setting up a test-set memory log whose size is that of the traverse array (See DCN 360202—Series 2440 Pocket Guide). This method is faster and less error prone than filling out a table as shown above and computing the average by hand. The following sections define how to do this.

- 4.9 **Configuring the 2440.** To configure the 2440 to internally log data to its test-set memory, you must do the following: Set up the internal memory log for enough memory to cover the traverse size. The internal memory log has 2300 points split between trending and test-set data point storage. Say at least 10% of the 2300 point internal memory size is allocated to test-sets which are programmed to have a maximum of 90% designated for trend memory. Then the test set memory is turned on and a set number is defined with the total number of traverse points needed for the test.

Specific steps for configuration of the 2440 are:

First you press **P** of program mode then the user access code **123456** followed by the **E** or the enter key then advance through the program menus with the **P** key until you see the menu category:

PRESS E TO SET MEMORY DATA LOG

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and press **E** to enter. The next menu is:

SETUP: EVENTS
NEXT CHOICE ^v

and your choices are for **Events** (which are alarms, kick outs, etc.), **Tests** (which are the test-sets we will be using for logging our traverse data) and **Trends** (which records the real-time history at a programmable time interval to the internal memory). You select Trends using the **v** or **^** keys followed by **E** to accept this area. Next you see:

TRENDS LOG: ON
^=ON v=OFF

You turn the trends ON with the **^** key followed by the **E** key. You will see a warning screen that says:

LOG DATA MAY BE
LOST IF CHANGE!

Which is the currently stored data in the internal log. You pass the screen with the **P** or **E** key. The next screen:

ENTER PERCENT
OF MEMORY USE: 0

Defines the percentage of internal memory allocated to trends, select 50 (or 50% of the 2300 total internal data records possible) by typing the 5 key and 0 key on the 2440 front panel followed by **E** to accept this. Now use the **P** key to advance past the trend interval time screen:

ENTER INTERVAL
TIME(S): 60

You should now be back at the:

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SETUP: TESTS
NEXT CHOICE ^v

Menu and if not, navigate to it then press **E**. Next you turn on the test-set memory by pressing the ^key at the menu:

TEST LOG: ON
^ = ON v= OFF

Followed by **E** to accept the entry. You will see the memory log warning screen:

LOG DATA MAY BE
LOST IF CHANGE!

Which you pass by pressing **P** or **E**. Now you specify the number of test-sets to use (the test-set memory will be split into this many equal size sets). The screen will read:

ENTER MAX # OF
TEST SETS 10

Use the default 10 followed by **E** for now (this splits the 50% of 2300 into 10 units of equal size or 115 samples). You should see the screen which says:

MAX. SAMPLES PER
TEST SET IS 115

Press **E** or **P** to clear this screen. You now press **C** to leave the SET MEMORY DATA menus category. You should now see the screen:

PRESS E TO
ACCESS MEM LOG

Which is where we start to record data during our traverse.

While we set up the 2440 for ten test sets, the configuration correction factor CCF software on the 155C-2 will only allow up to four flow rates to be field calibrated so we will be using four or less test-sets. Alternately,

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you could save the results of each traverse on paper than keep using the same test-set number for all flow rates on each duct to be calibrated.

- 4.10 **Storing data in the Test Memory.** If you are not all ready in program mode at the menu category:

PRESS E TO
ACCESS MEM LOG

Then go there not and press **E** to enter. The screen will say:

SELECT TASK ^v
VIEW TEST DATA

And you use the **^** or **v** keys to chose RECORD TEST DATA followed by **E** to accept this task. Now you chose which test-set identification number to use:

ENTER TEST SET
NUMBER: 1

(1 to 10 based on our previous setup) followed by **E** to chose which test-set memory to record. If you have data already stored in the test-set number selected, you will be asked if you want to OVERWRITE the data where you can say YES or NO with the **^** or **v** and then press **E** and select. You will be asked for a different test-set number if you said NO. Now you chose the specific traverse array size for this specific test-set:

ENTER # OF TEST
SAMPLES: 30

(This should be less than 115 based on our previous setup example of 1150 records/ten). The next screen will ask if the:

LOG IS AUTO: NO
^ = YES v= NO

And select **v** for NO and **E** to accept this. We do not want an automatic time spaced logging unless you want both hands on the probe and can move to each point on the time interval you specify in the following screen. Now you will see the screen you have been waiting for:

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PRESS E TO START
AND E TO RECORD

Following this screen after pressing **E** you will see:

10.98 SMPS
24.6 DEGC

The velocity and temperature filtered to the settings of meter filter values set elsewhere. Each time you press **E**, you will see a momentary menu:

SAMPLE #2
IS RECORDED

Stating which test-set number you just logged and this will continue until the whole test-set has been defined. This data viewing screen can be changed from velocity/temp to temp/flow or flow/velocity by pressing **^** or **v** keys. This allows you to see any two of the three variables on the screen and you can switch back and forth if you like while taking data. When recording data into the test-set memory, the 2440 will hold at the selected display screen indefinitely until all the data for the test-set are entered. Other menus under program model will automatically exit after two minutes of inactivity.

After a test-set is completed, the unit will be back at the screen to select which memory log task you are interested in, record test data, view test data or log to com port.

Note that the above data were acquired while the device under test (155C-2) was being monitored with its Log Command. Its individual sensor channel velocity will be used to with the average velocity from the traverse to compute the correction factor for this flow rate on each input channel of the 155. You can log this to a PC using a terminal emulator program which comes with Windows like HyperTerminal. You set the 155 for a one minute log interval then plug the logging computer or printer into the data logging serial port. See DCN 360204 Series 155 Mass Flow Computer Summary Guide for more on this topic.

- 4.11 **Viewing the Data Stored in the Test Memory.** To view the internally stored data from a test-set, you must enter Program Mode and advance to the following screen:

PRESS E TO
ACCESS MEM LOG

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You press **E** to enter this menu category which will preset the next screen:

SELECT TASK ^v
RECORD TEST DATA

Where you use the **^** or **v** keys to choose VIEW TEST DATA followed by pressing the **E** key. The next screen will be the test-set number to view followed by **E** to accept this:

ENTER TEST SET
NUMBER 1

So you select the test-set of interest where you will then select which variable to view:

AVERAGE DATA
10.879 SMPS

and you use the **^** or **v** keys to select from: VELOCITY, TEMPERATURE OR FLOW RATE, choose VELOCITY followed by **E** to accept this. You will next see the average velocity:

AVERAGE DATA
10.879 SMPS

Then press **E** to advance to the next parameter of the velocity which will show the standard deviation, then the maximum value followed by the minimum value and the individual array data points will be shown. For our purposes, we need to note just the average velocity.

- 4.12 **Velocity Probe, Pitot Tube** The Pitot tube is a classic velocity-sensing device, which works on the principle of converting the kinetic energy of the flow stream to potential energy as a pressure by stopping the flow. It has an impact port and a static port that does not receive any kinetic contribution. There is the S-Type Pitot which has an upstream impact port and downstream port which is under slight vacuum. So the differential signal generated is higher than a classic Pitot tube which improves the

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turn-down ratio. This increased differential pressure (dP) comes at the price of a correction factor K which is velocity dependent so the device must be calibrated against the classic Pitot design whose K factor is 1.0 by definition. See Section 2.15 of Process Measurement and Analysis by Bela G. Liptak, Third Edition or any physics book on hydraulics for a reference.

The basic Pitot tube equation is:

$$v = k (2gdP/\rho)^{0.5} \text{ in actual velocity,}$$

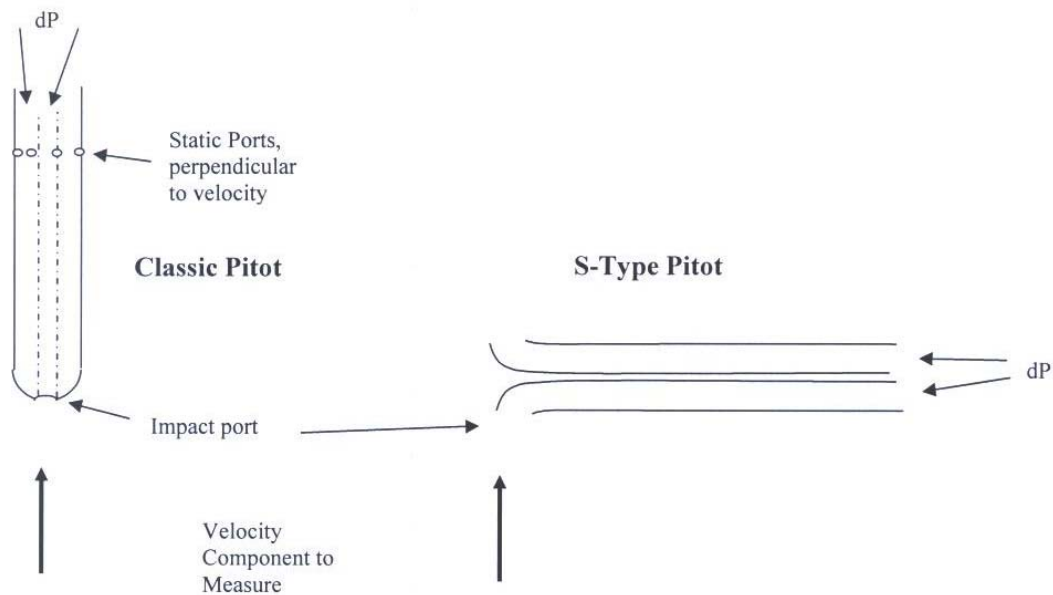
Where (In English Units):

k is the correction factor, 1.0 for classic designs, about 0.84 for the S-type.

g is the acceleration of gravity, 32.2 ft/s²

dP is the differential pressure between the impact and static ports in lb/ft²

ρ is the density of the gas, lb/ft³



To make this more useful we need to convert the dP units to inches of H₂O water column and convert the gas density to a function of pressure and temperature. Second, we would like the results in standard velocity instead of actual velocity.

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The density of any ideal gas can be written as a function of pressure and temperature as follows:

$$\rho = \rho_s (T_s/T_a)(P_a/P_s)$$

Where:

P_s is the standard gas density, 0.07387 lb/ft³ and
 MW is the gas molecular weight, $MW = 28.96$

T_s is 77°F or 25°C in absolute units so 460 + °F or 273.15 + °C

T_a is the actual temperature in absolute units.

P_a is the actual pressure in absolute units, PSIA or in Hg etc.

P_s is the standard pressure which is 101.325 kPa, 14.69 PSIA, 760 mmHg or 29.92 in Hg.

If we convert the dP from inches H₂O into lb/ft² needed above we get:
inches H₂O/(27.68 in H₂O/lb/in²) x (144 in²/ft²) = (144/27.68) x lb/ft²

Putting it all together we have:

$$V = k [dP (144/27.68) (2) (32.2)/(MW 0.07387/28.96) (T_s/T_a) (P_a/P_s)]^{0.5} (60)$$

$$V = 21745 k [(dP/MW) (T_a/T_s) (P_s/P_a)]^{0.5} \text{ FPM}$$

(Note: $X^{0.5}$ is the same as the square root of X)

For Air whose $MW = 28.96$ the above reduces to:

$$V = k 4041 [dP (T_a/T_s) (P_s/P_a)]^{0.5} \text{ FPM}$$

Where V is actual velocity in ft/min, dP is in H₂O, k is the correction factor.

The standard velocity (SFPM) we have:

$$V_s = V (T_s/T_a) (P_a/P_s)$$

So:

$$V_s = 21745 k [(dP/MW) (T_s/T_a) (P_a/P_s)]^{0.5} \text{ SFPM}$$

And for Air we have:

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$$V_s = 4041 k [dP (T_s/T_a) (P_a/P_s)]^{0.5} \quad \text{SFPM}$$

4.13 **Examples with a Pitot tube.**

Example A. Say the measured dP is 7.53 in H₂O on a classic Pitot tube, the gas is Air, Temperature is 20.1 °C and pressure is 28.05 in Hg. What is the standard velocity?

$$V_s = 4041 (1.0) [7.53 (273.15 + 25) / (273.15 + 20.1) (28.05/29.92)]^{0.5}$$

$$= 10826 \text{ SFPM}$$

Example B. Now if we have a measurement in Flue Gas from a typical power plant, the readings are as follows: an S-Type Pitot measured a dP of 2.04 in H₂O, temperature is 460°F, pressure is 28.45 in Hg in the stack with a gas mix of 15% CO₂, 10% H₂O, 73% N₂, 2% O₂. What is the actual velocity and standard velocity?

First we compute the MW = 0.15 x (12 + 2x16) + 0.10 (2x 1+16) + 0.73 (2 x 14) + 0.02 (2x16) = 29.48

The actual velocity is:

$$V = 21745 (0.84) [2.04/29.48 (460 + 460)/(460 + 77) (29.92/28.56)]^{0.5}$$

$$= 6437 \text{ FPM}$$

Standard velocity:

$$V_s = 21745 (0.84) [2.04/29.48 (460 + 77) / (460 + 460)(28.56/29.92)]^{0.5}$$

$$= 3587 \text{ SFPM}$$

Example C. A digester gas flow example: Customer wants to know the flow rate in his 8" schedule 40 pipe. You use your S-Type Pitot and record the following data, dP = 0.42 in H₂O, temperature was 37.2°C and the pressure was 0.68 PSIG. The ambient air pressure was 27.56 in Hg that day. The customer says his gas composition is 70% CH₄ and 30% CO₂.

First we will convert our pressure in to the same units:

$$P_a = (0.68 \text{ PSIG}/14.69\text{PSI}) * 29.92 \text{ in Hg} + 27.56 \text{ in Hg} = 28.94 \text{ in Hg.}$$

Now we will compute the MW of the gas mix:

$$\text{MW} = 0.7 (12 + (4x1)) + (0.3 (12 + (2x16))) = 24.4$$

Now to compute the standard velocity:

$$V_s = 21745 k [(dP/MW) (T_s/T_a) (P_a/P_s)]^{0.5} \quad \text{SFPM}$$

$$V_s = 21745 (0.84) [0.42/24.4 (273.15 + 25)/(273.15+ 37.2)(28.94/29.92)]^{0.5}$$

$$= 2310 \quad \text{SFPM}$$

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Note: If we assume this measurement was in the center of the 8" duct and the ID = 7.981, we compute the following flow rate:

$$\begin{aligned} \text{SCFM} &= \text{SFPM} * \text{Area} * \text{CF} \\ &= 2310 * 3.1416 (7.981/2/12)^2 * 0.80 = 642 \text{ SCFM}. \end{aligned}$$

This would be a large digester flow on a good day. Note: the 0.80 CF is a typical V_a/V_p correction factor observed with Tracer Gas Testing on an 8" line. If we accounted for the Pitot tube blockage during the measurement we would need to reduce the area by its projection blockage (0.25 inch x 4") = 1 in². Converting this to ft² then running the math above we get:

$$\text{SCFM} = 2310 * [3.1416 (7.981/2/12)^2 - 1/144] * 0.8 = 629 \text{ SCFM}$$

Accounting for the test probe blockage is a 2% lower flow rate but slightly more accurate calculation.

- 4.14 **Entering the data in the 155 Mass Flow Computer.** DCN 360204 Series 155 Mass Flow Computer Summary Guide explains how to navigate the 155C-2 menus to load the data in the CCF section of the METER being field calibrated.

In summary, you take the average velocity computed from the traverse (2440 data), and the individual sensor channel velocities (acquired with the 155 data log, one minute summaries) and enter this at the CCF menu prompts.

If data were taken at other average velocities or flow rates, they too would be entered into the 155 as another set up to a maximum of four data sets.