USER'S GUIDE

TO

FLOW PERFECT™

Automatic Configuration Correction Factor

For Kurz Multi-Point Mass Flow Elements

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I. **INTRODUCTION**:

Flow Perfect™ is a user friendly software routine developed for the Series 155 Mass Flow Computers used with Multi-Point Thermal Mass Flow Elements. It's purpose is to increase relative accuracy, automatically correct for the deletion of one or more sensors and provide unexcelled reliability because of the overall system redundancy. Generally, Flow Perfect™ is used with the Series K-BAR 24 Multi-Point Mass Flow Elements to measure the mass flow rate of larger pipes, ducts or stacks. Because of the extreme reliability and accuracy requirements (and eventually sizable penalties), the currently most popular application is for stack flow monitoring required under the U.S. EPA, 40 CFR 75 regulations for the measurement of sulfur dioxide and other pollutants in large fossil fuel electric power plants. An equally important application is for combustion air flow measurement and control.

Although Kurz provides an accurate (NIST Traceable) wind tunnel velocity calibration of each independent mass velocity sensor, a non-uniform velocity profile, lack of an adequate number of sensing points, or effects of the gas thermal properties caused by the products of combustion (mainly water and carbon dioxide), requires that an insitu, field calibration be performed to certify the system under the rules of 40 CFR 75. Furthermore, a semi-annual or annual **R**elative **A**ccuracy **T**est **A**udit (RATA) must be passed. The system under test is compared against an approved **R**eference **M**ethod (RM). In most cases, this is the U.S. EPA Method II, which utilizes a Type S Pitot Tube used under very well defined procedures. Flow Perfect™ utilizes the Reference Method Test Data to automatically compute the flow **C**onfiguration **C**orrection **F**actor (CCF) over a wide range of flow rates (typically 20-100%), in the event of a change in configuration. Such a change may occur under the following conditions:

A) A sensor has failed due to damage, corrosion or a bad connection,

B) A K-BAR has been purposefully removed from the system for routine maintenance.

The most important advantage of Flow Perfect™ is that it allows system <u>redundancy</u>. Unlike single sensor flow monitors that fail completely when the single sensing system fails, the Kurz system with Flow Perfect™ keeps on operating at nearly the same accuracy, giving the user time to fix a problem or to do a scheduled maintenance without requiring a recertification simply because of the removal of one or more independent, redundant sensors. It is our opinion that Flow Perfect ™ eliminates any requirement to recertify a Kurz system simply because of a sensor failure.

II. MATHEMATICAL BASIS FOR FLOW PERFECT™.

The corrected flow rate is the product of the average measured velocity taken at the centroid of equal areas (same as the EPA Reference Method) times one or more appropriate experimental determined correction factors, times the flow area of the pipe duct or stack:

Equation (1):

$$Q = (BCF)(CCF)(V_{AVG}) \times AREA$$

Where: Q = The corrected flow rate (SCFM)
BCF is the bias correction factor
CCF is the configuration correction factor
V_{AVG} is the average velocity of the active mass velocity sensors in the meter array (SFPM)
Area = the cross sectional area of the duct (FT^2)

BCF is usually applied after the reference method tests are completed. It is used to make small changes in the output or to correct for different standard conditions and is a constant.

When a Kurz multi-point mass flow system is installed, there is a wealth of information regarding the velocity profile because of the ability of the ADAM Mass Flow Computer to display the individual velocity readings of each sensor. Since most stack flow systems produce a fairly repeatable velocity profile under normal conditions, this information can be used to correct the measured average velocity in the event that one or more sensors are deactivated, whether for test, for inspection, or maintenance or due to an equipment failure. If one sensor continuously indicates a significantly higher reading than the average, if it were

deactivated, and the remaining sensors were used to compute the average, a significant error would be made if Flow Perfect™ were not used.

Since the ADAM Mass Flow Computer “knows” which sensors are inactive, it can correct the output based upon what the correction factor would have been if the inactive sensors had not been included in the average during the reference test. By using the Reference Method Test average velocity (V_{RM}) and the simultaneously measured readings on each velocity sensor (V_{ds}) for each stack flow data set the Flow Perfect™ software automatically calculates a correction factor for each data set whenever the sensor array configuration changes.

Therefore, whenever there is a configuration change, a new set of correction factors are generated as a function of the measured average velocity of the remaining sensors for each data set (four are allowed): This is a variable velocity correction factor such that different correction factors may be used at each data set. A lagrangian interpolation route is used to calculate the appropriate correction factors for intermediate velocities.

Therefore:

$$C.F.\#1 = \frac{V_{RM1}}{(V_{ds1chA1} + V_{ds1chB} .... V_{ds1chV})/N} = \frac{V_{RM1}}{V_{ds1AVG}} \qquad \textbf{(2)}$$

$$C.F.\#\,4 = \frac{V_{RM2}}{(V_{ds2chA1} + V_{ds2chB} + ... V_{dschV})/N} = \frac{V_{RM4}}{V_{ds4AVG}}$$

Where: V_{RM1} is the Reference Method Average Stack Velocity for Data Set 1, etc.

V_{ds1CHA} is the velocity of the sensor at input Channel “A” for Data Set 1, etc.

N = Number of active sensor channels

C.F. #1 = Correction Factor for Data Set #1, etc.

A simple example:

Assume that two reference data sets have been measured, and we have an array of four independent sensors and a 100 square foot duct. The collected data is:

Date Set #1:

V_{RM1} = 2000 SFPM, Q = 200,000 SCFM
V_{ds1chA} = 1500 SFPM
V_{ds1chB} = 2500 SFPM
V_{ds1chC} = 2500 SFPM
V_{ds1chD} = 1500 SFPM
V_{ds1AVG} = 2000 SFPM
C.F. #1 =1.00 @ V_{AVG} = 2000 SFPM with all four sensors working.

Data Set #2:

V_{RM2} = 4000 SFPM, Q = 400,000 SCFM
V_{ds2chA} = 3000 SFPM
V_{ds2chB} = 5000 SFPM
V_{ds3chC} = 5000 SFPM
V_{ds3chD} = 3000 SFPM
$V_{ds2AVG.}$ = 4000 SFPM
C.F. #2 = 1.00 @ V_{AVG} = 4000 SFPM with all four sensors working.

Next assume that the sensor at Channel B has been “kicked-out” by the Flow Perfect™ Software. ADAM will calculate new Correction Factors:

C.F. #1:

V_{RM1} = 2000, N=3

$$V_{ds1AVG} = \frac{1500 + 0 + 2500 + 1500}{3} = 1833.33\ SFPM$$

$$C.F.\#1 = \frac{2000}{1833.33} = 1.090909\ @\ 1833.33 SFPM$$

C.F.#2:

VRM2 = 4000; N = 3

$$V_{ds2AVG} = \frac{3000 + 0 + 5000 + 3000}{3} = 3666.66 SFPM$$

$$C.F.\#2 = \frac{4000}{3666.66} = 1.090909\ @\ 3666.66\ SFPM$$

Since the Correction Factor is the same as for Test Data Sets, the Correction Factor is constant and no interpolation is required for an indicated average velocity of 3666.66 SFPM, the corrected flow rate (with a BCF = 1.0) is

Q = (1.0) x 1.090909 x 366.66 x 100

= 400,000 SCFM which is the correct value.

Our simple example has assumed that the velocity profile doesn’t change with flow rate. In actually use, the velocity profile may change, however, our velocity sensors change accordingly, and pick-up most of the non-uniform behavior, even though wemay use a small number of sensors. Obviously, a larger number of sensors will pick up more of these changes and give more accurate numbers. Flow Perfect™ works so well because it has knowledge of the output of each sensor; something a multi-point Pitot tube or Ultrasonic system cannot duplicate.

III. SETTING UP FLOW PERFECT™:

Please refer to the attached menu for Flow Perfect™. For other programming information refer to the ADAM Mass Flow Computer Manual. This program is used for Multi-Point Insertion Mass Flow Elements such as the K-BAR 16, K-BAR 24 or Multiple Single-Point Insertion Mass Flow Elements such as a Series 450.

Display	Description
DISPLAY NEXT ^V FLOW IS SCFM	Press the up (YES) or down (NO) arrow to select flow measurement in SCFM,SCFH or PPH. If the instrument is programmed for International units, the choices will be SCMM, SCMH or KGH.
SPECIFIC GRAVITY IS 1.000	This message will only be displayed if the user has selected PPH or KGH in the previous step. Use the numeric keys to specify the specific gravity of the gas to be measured, then press E. The default value is 1 (air).
INCLUDE CH X ^-YES V-NO	Press the up (YES) arrow to include the indicated channel in average flow calculations for this METER. Press the down (NO) arrow to exclude the indicated channel from average flow calculations for this METER.
ENTER FLOW AREA xxxxxx SQ. FT	Use the numeric keys to specify the area of the stack or duct where the probe is mounted. Engineering Units will be in square feet for instruments programmed in English Units or square meters when programmed for International Units.
CF TYPE ^=CCF V=VCF	CCF is the correct correction factor for using Flow Perfect™. Press the up (YES) arrow, then press E.
BCF = 1.000	BCF = Bias Correction Factor. It is a fixed correction

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r the entire measurement range. It is usually used to adjust the output after the CCF data has been installed. The default value = 1.000, press E.

ENTER # OF RM DATA SETS x	Use the numeric keys to enter the number of Reference Method calibration measurement data sets taken up to a maximum of 4. Generally, these represent approximately 25, 50, 75, 100% of the maximum average velocity. Press E to continue.
Enter RM Data Set 1	This data must be entered in ascending order of velocity. Press E to continue.
V_{RM1} xxxxxx SFPM	V_{rm1} is the averge velocity measured by the Reference Method (RM) for the first data set. Press E to continue.
V_{ds1} CHA XXXXXXX SFPM	V_{ds1chA} is the simultaneously measured indicated velocity for each channel that constitute the Multi-Point Insertion Meter for Data Set 1. Similarly enter data for other channels and other data sets.
C.F. #1 = X.XXX AT xxxxx SFPM	This is the calculated value of the Correction Factor for Data Set #1. It is displayed for convenience. The C.F. is the ratio of the Reference Method Average Velocity (SFPM) divided by the average of the active channels indicated velocities $V_{ds1\ chA,\ B\ ....V.}$ Press E to continue to enter the V_{RM} and V_{ds} for the remainder of the data sets. When completed, the LCD will prompt you to set meter data for the next METER, if

appropriate.

Below is an example of the sequential ADAM display while programming Flow Perfect™ for a Multi-Point System (Channels A, B, C and RM data sets). By using the ECHO terminal while in the program mode, this can be logged and printed by using a PC.

PRESS ENTER TO SET METER #1
ENTER METER ID: METER-000001
NEXT TYPE vw INSERTION FLOW
DISPLAY NEXT vw FLOW IS SCFM
INCLUDE CH A v=YES w=NO:YES
INCLUDE CH B v=YES w=NO:YES
INCLUDE CH C v=YES w=NO:YES
ENTER FLOW AREA 1 SQ FT
CF TYPE CCF v=CCF w=VCF
BCF = 1
ENTER # OF RM DATA SETS 3
ENTER RM DATA SET 1
V_{RM1} 750 SFPM
V_{DS1} CH A 500 SFPM
V_{DS1} CH B 500 SFPM
V_{DS1} CH C 500 SFPM
C.F. #1 =1.5 AT 500 SFPM
V_{RM2} 3250 SFPM
V_{DS2} CH A 2500 SFPM
V_{DS2} CH B 2500 SFPM
V_{DS2} CH C 2500 SFPM
C.F. #2 = 1.30 AT 2500 SFPM
V_{RM3} 5000 SFPM
V_{DS3} CH A 4000 SFPM
V_{DS3} CH B 4000 SFPM
V_{DS3} CH C 4000 SFPM
C.F. #3 = 1.250 AT 4000 SFPM
PRESS ENTER TO SET METER #2

IV. THE NEED FOR FLOW PERFECT™:

In the early stages of the development of the ADAM Mass Flow Computer and the K-BAR 24 Multi-Point Mass Flow Elements, we used VCF (Variable **V**elocity **C**orrection **F**actors). These were calculated based on Reference Method Tests. The Kick-Out Software routine was used to obtain the average velocity of the remaining sensors. However, unless there are enough sensors to "swamp-out" the effects of an "outlaw" sensor that is substantially higher or lower than the average, serious error can develop when the configuration changes due to a deactivated sensor. This is why Kurz developed Flow Perfect™.

Some users have suggested that we certify several configurations and obtain correction factors ahead of time. Since most large stack flow monitors have 12 sensors, one would need to compute 4096 separate configurations! This is why we used the intelligence and on-line computational power of ADAM. It only calculates a new set of correction factors when required, and does so automatically, to cover all 4096 possibilities!

One reason for developing Flow Perfect™, is to improve availability and accuracy, by having redundancy. Another is (unlike single sensor systems that are required by EPA to recertify whenever the sensor fails) we can continue to operate with nearly the same accuracy. We see no reason to force a recertification due to the removal for maintenance or replacement of sensors. Tennesse Valley Authority's test studies using Flow Perfect™ (removing 6 or 7 out of 8 sensors) had no noticeable effect at Widow's Creek, for example. We are certain that a user can remove up to at least 50% of the original sensors, and still maintain 7.5% relative accuracy.

We recommend that our customers fully document Flow Perfect™ by removing sensors and recording the results before and after. A random selection of sensors removable under operating conditions is very easy. If this data were taken carefully and documented to show how many sensors can be removed before affecting the results by a certain percentage, the Environmental

Protection Agency and other agencies should approve Flow Perfect™. By using the “Kick-Out Count” feature of Flow Perfect™, the number of allowable deactivated sensors may be set before an alarm relay is triggered. Our goal is to provide extremely high reliability and to simplify and reduce the cost of maintenance and truly unneccessary recertification testing.

We are asking the EPA to work with the Utilities and Kurz to verify the advantages and give approval to the use of Flow Perfect™ and our multi-point, independent sensor technology to improve the customer’s availability, reliablility, and reduce service and recertification expenses.