SEMI E56-0314
TEST METHOD FOR DETERMINING ACCURACY, LINEARITY, REPEATABILITY, SHORT-TERM REPRODUCIBILITY, HYSTERESIS, AND DEAD BAND OF THERMAL MASS FLOW CONTROLLERS

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1 Purpose

1.1 The purpose of this Document is to provide a standardized method to quantify the accuracy, linearity, repeatability, short-term reproducibility, hysteresis, and dead band of a thermal mass flow controller.

1.2 The intent of this Document is not to suggest any specific testing program but to specify the test method to be used when testing for parameters that are covered by this method. The user might use this Document to check significant performance characteristics such as accuracy, precision, bias, repeatability, linearity, short-term reproducibility, and dead band under a set of closely controlled test conditions.

1.3 The significance of the accuracy calculations in this method is to allow an MFC user to transfer a process from one manufacturing tool to another and to exchange MFCs within a single manufacturing tool while maintaining process control.

2 Scope

2.1 This Document describes the conditions and procedures for testing the accuracy, linearity, repeatability, hysteresis, and dead band of thermal mass flow controllers (MFCs). Because of the generic nature of this Document, not all test procedures apply to all types of MFCs.

2.2 This Document provided a common basis for communication between manufacturers and users.

NOTICE: SEMI Standards and Safety Guidelines do not purport to address all safety issues associated with their use. It is the responsibility of the users of the Documents to establish appropriate safety and health practices, and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 It is not practical to evaluate performance under all possible combinations of operating conditions. This test procedure should be applied under laboratory conditions; its intent is to collect sufficient data to form a judgement of the field performance of the MFC being tested.

4 Referenced Standards and Documents

4.1 *SEMI Standards and Safety Guidelines*

SEMI E17 — Guide for Mass Flow Controller Transient Characteristics Tests

4.2 *ASME Standard*[1]

ASME MFC-10M — Method for Establishing Installation Effects on Flowmeters

4.3 *ISA Standard*[2]

ISA S51.1 — Process Instrumentation Terminology

NOTICE: Unless otherwise indicated, all documents cited shall be the latest published versions.

[1] American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5990, USA; Telephone: 973.882.1170, Fax: 973.882.1717, https://www.asme.org

[2] Instrument Society of America, 67 Alexander Drive, Research Triangle Park, NC 27709, USA; Telephone: 919.549.8411; http://www.isa.org

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5 Terminology

5.1 *Abbreviations and Acronyms*

5.1.1 A — measured value (units of flow, sccm, slm, etc.)

5.1.2 A_a — average measured value (units of flow)

5.1.3 A_{fs} — average measured value at full scale set point (units of flow)

5.1.4 AD — accuracy of the DUT (%)

5.1.5 AD_f — accuracy of the flow standard (%)

5.1.6 AS — accuracy of set point (%)

5.1.7 A_l — measured value, down cycle (units of flow)

5.1.8 A_u — measured value, up cycle (units of flow)

5.1.9 B — bias (units of flow)

5.1.10 D — dead band value (units of flow)

5.1.11 DBD — dead band of device (units of flow)

5.1.12 DBS —dead band of set point (units of flow)

5.1.13 D_l — lower dead band value (units of flow)

5.1.14 D_u — upper dead band value (units of flow)

5.1.15 DUT — device under test

5.1.16 FS — full scale flow rate (units of flow)

5.1.17 HD — hysteresis of device (units of flow)

5.1.18 $HDBS$ — hysteresis plus dead band at a set point (units of flow)

5.1.19 HS — hysteresis at a set point (units of flow)

5.1.20 i — reading number in a cycle for a given set-point (unit-less)

5.1.21 I — intermediate value (units of flow)

5.1.22 j — cycle for a given set point (unit-less)

5.1.23 k — up cycle number for a given set point (unit-less)

5.1.24 kPa — kilopascal

5.1.25 LD — linearity of DUT (%)

5.1.26 LS — linearity of set point (%)

5.1.27 m — down cycle number for a set point (unit-less)

5.1.28 n — number of readings (unit-less)

5.1.29 NC — normally closed

5.1.30 n_j — number of readings at a set point at a given cycle (unit-less)

5.1.31 NO — normally open

5.1.32 P — precision (units of flow)

5.1.33 $psia$ — pounds per square inch absolute

5.1.34 RPD — repeatability of the DUT (%)

5.1.35 RPS — repeatability at a set point (%)

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5.1.36 s — slope (unit-less)

5.1.37 S — set point (units of flow)

5.1.38 S_a — average of set point (units of flow)

5.1.39 *sccm* — standard cubic centimeters per minute

5.1.40 S_l — set point, down cycle (units of flow)

5.1.41 S_u — set point, up cycle (units of flow)

5.1.42 *slm* — standard liters per minute

5.1.43 *SRD* — short-term reproducibility of the device (%)

5.1.44 *SRS* — short-term reproducibility at a set point (%)

5.1.45 v_i — the ith measured value at a set point for a given cycle (unit-less)

5.1.46 Y — ideal linearity value (units of flow)

5.1.47 Z — zero offset of DUT (units of flow)

5.1.48 Z_a — indicated flow at zero actual flow (units of flow)

5.2 *Definitions*

5.2.1 *accuracy* — the closeness of agreement between an observed value and the true value; the total uncertainty of an observed value, including both precision and bias.

5.2.2 *accuracy curve* — the curve fitted through the average measured values over the specified range of the device under test.

5.2.3 *accuracy device* — the total uncertainty over a specified range of the device. Device accuracy over a range is stated as the worst case accuracy taken over all tested set points in this range.

5.2.4 *actual flow* — the gas flow as measured by an external standard, not the electrical output of a mass flow meter.

5.2.5 *bias* — the difference, at a set point, between the measured value and the sum of the set point value and the zero offset. The measured values of a flow standard include its total uncertainty.

5.2.6 *cardinal set point* — a specific set point to assess the accuracy of the device under test (DUT). For this test method, the cardinal set points are 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% of full scale.

5.2.7 *cycle* — a data acquisition set for a specific set point. There are two categories of cycles: increasing and decreasing direction with respect to the set point value. It can be visualized as ¼ of the typical definition of cycle where the start and end points are the same.

5.2.8 *dead band* — the range through which a set point may be varied, upon reversal of direction, without initiating an observable change in output signal.

5.2.9 *device under test* — mass flow device is being tested by this method.

5.2.10 *down cycle reading* — a reading approached from a set point greater than the current set point and beyond the dead band.

5.2.11 *down cycle value, average* — the sum of all down cycle readings, in one cycle, at a single set point, divided by the number of these values.

5.2.12 *drift* — the change in output over a specified time period for a constant input under specified reference operating conditions.

5.2.13 *drift, long-term* — the drift between a series of tests over a specified time interval. This specified time interval is generally much greater than the time necessary to run an individual test.

5.2.14 *drift, short-term* — the drift between sets of measurements over the duration of the test.

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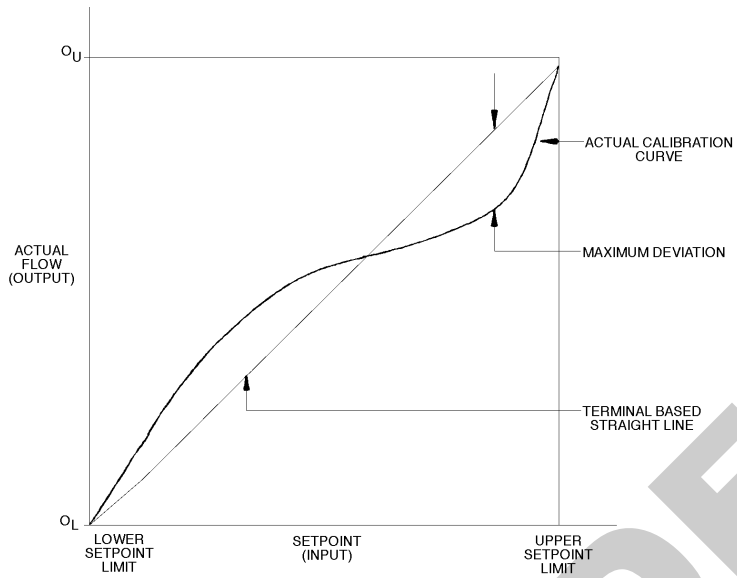

Figure 1
Terminal-Based Linearity for Mass Flow Controller

5.2.15 *hysteresis* — that property of an element evidenced by the dependence of the value of the output, for a given excursion of the input, upon the history of the prior excursions and the direction of the current traverse.

5.2.16 *indicated flow* — flow indicated by MFC under test. Electrical output of the DUT.

5.2.17 *linearity* — the closeness to which a curve approximates a straight line.

5.2.18 *linearity, terminal-based* — the maximum absolute value of the deviation of the accuracy curve (average of up cycle and down cycle values) from a straight line through the upper and lower set point limits of the accuracy curve (see Figure 1).

5.2.19 *measured value* — the actual flow through a device under test, expressed in sccm or slm, as measured by a standard, preferably primary.

5.2.20 *measured value, average* — the sum of all readings (both up cycle and down cycle) for all cycles, at a single set point, divided by the number of these readings.

5.2.21 *operating conditions, normal* — the range of operating conditions within which a device is designed to operate and for which operating influences are stated. [ISA S51.1]

5.2.22 *operating conditions, reference* — the range of operating conditions of a device within which operating influences are negligible. [ISA S51.1]

5.2.23 *operating influence* — the change in a performance characteristic caused by a change in a specified operating condition from reference operating conditions, all other conditions being held within the limits of reference operating conditions. [ISA S51.1]

5.2.24 *pneumatic noise* — localized, random variations in pressure and flow.

5.2.25 *precision* — the closeness of agreement among the measured values at a set point. It is often expressed as a standard deviation.

5.2.26 *repeatability* — the closeness of agreement among a number of measured values at a set point, under the same operating conditions, operator, apparatus, laboratory, and short intervals of time. It is usually measured as a nonrepeatability and expressed as repeatability in percent of reading.

5.2.27 *reproducibility* — the closeness of agreement among repeated measured values at a set point, within the specified reference operating conditions, made over a specified period of time, approached from both directions. Reproducibility includes hysteresis, dead band, long-term drift, and short-term reproducibility.

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NOTE 1: Between repeated measurements, the input may vary over the range, and operating conditions may vary within normal operating conditions.

5.2.28 *reproducibility, short-term* — the closeness of agreement among a number of measured values at a set point, under the same operating conditions, operator, apparatus, laboratory and short intervals of time, approached from both directions. The approach must be from beyond the dead band. Short-term reproducibility includes repeatability, hysteresis, dead band, and short-term drift.

5.2.29 *set point* — the input signal provided to achieve a desired flow, reported as sccm, slm, or percent-full scale.

5.2.30 *set point limit, lower* — the lowest set point at which the instrument is specified to operate.

5.2.31 *set point limit, upper* — the highest set point at which the instrument is specified to operate, usually full scale.

5.2.32 *settling time* — the time between the set point step change and when the actual flow remains within the specified band (see SEMI E17).

5.2.33 *span* — the full-scale range of the DUT.

5.2.34 *stability* — the ability of a condition to exhibit only natural, random variation in the absence of unnatural, assignable-cause variation.

5.2.35 *standard conditions* — 101.32 kPa, 0.0°C (14.7 psia, 32°F).

5.2.36 *uncertainty, total* — the range within which the true value of the measured quantity can be expected to fit; an indication of the variability associated with a measured value that takes into account the two major components of error, bias and the random error attributed to the imprecision of the measurement process.

5.2.37 *up cycle reading* — a reading approached from a set point less than the current set point and beyond the dead band.

5.2.38 *up cycle value, average* — the sum of all up cycle readings, in one cycle, at a single set point, divided by the number of these values.

5.2.39 *zero drift* — the undesired change in electrical output, at a no-flow condition, over a specified time period, reported in sccm or slm.

5.2.40 *zero offset* — the deviation from zero, at a no-flow condition, reported in sccm or slm.

6 Summary of Test Method

6.1 Specific procedures are given for characterizing MFCs discharging to atmospheric pressure or into a vacuum using accepted reference standards to determine accuracy, linearity, repeatability, short-term reproducibility, hysteresis, and dead band (see Figure 2).

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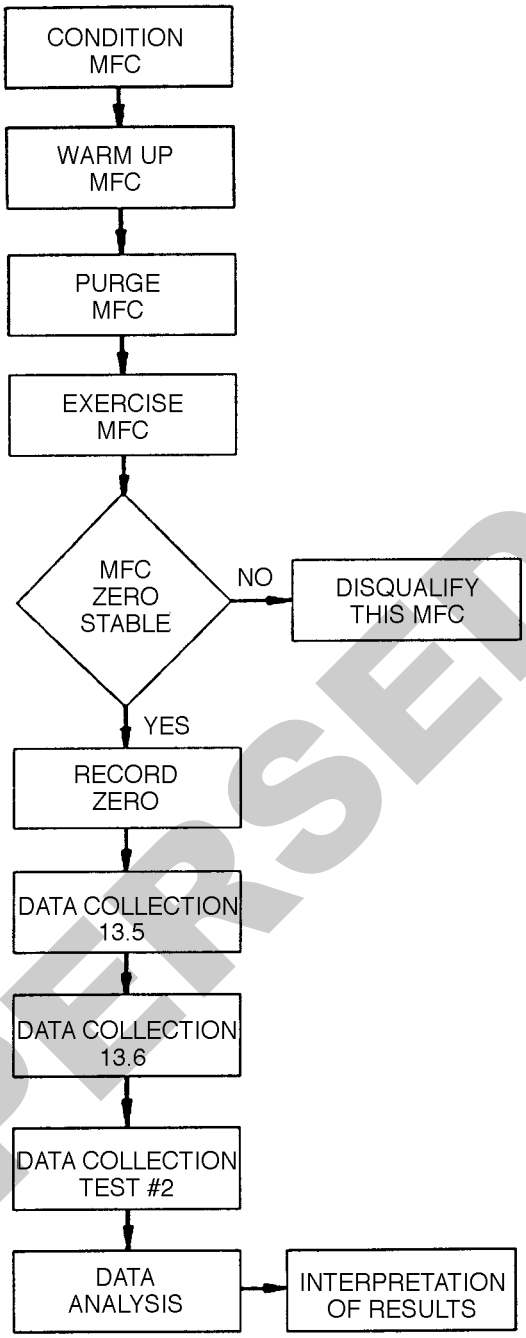

Figure 2
Test Flowchart

7 Interferences

7.1 The accuracy rating of the measuring equipment must include superior measurement capability compared with that of the DUT. In no instance should the accuracy rating of the measuring equipment be less than twice that of the DUT (e.g., if the accuracy of the DUT is ±1 sccm, then the accuracy of the measuring device must be better than or equal to ±1/2 sccm). The traceability of all the pertinent measuring instruments and devices should be realistically established and quantified.

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