

SEMI F64-0701

TEST METHOD FOR DETERMINING PRESSURE EFFECTS ON INDICATED AND ACTUAL FLOW FOR MASS FLOW CONTROLLERS

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1 Purpose

1.1 The purpose of this document is to define a method for characterizing a MFC being considered for installation into a gas distribution system. This method will quantify the effect of transient and steady state inlet and outlet pressure conditions on the performance of the MFC.

1.2 This document provides a common basis for communication between manufacturers and users regarding testing and describing MFC pressure effects.

2 Scope

2.1 This test method measures the upstream (inlet) and downstream (outlet) transient pressure influences on indicated and actual flow.

2.2 This test method yields the results of actual output flow versus MFC set-point and indicated flow as influenced by steady state inlet pressure.

2.3 This test method applies to MFCs with maximum flow ranges of up to 1000 sccm.

NOTE 1: Due to the higher sensitivity of lower flow rate MFC's when pressure transients occur, the flow range for this document is limited to 1000 sccm.

2.4 This standard does not purport to address safety issues, if any, associated with its use. It is the responsibility of the users of this standard to establish appropriate safety health practices and determine the applicability or regulatory limitations prior to use.

3 Limitations

3.1 This test method is limited to analyzing the effect of pressure on performance characteristics of MFCs and is not a verification of the state of calibration, linearity, or accuracy.

3.2 This test method does not address pressures in excess of the DUT's maximum working pressure as specified by the manufacturer.

3.3 This test method is limited to reasonable pressure transients; i.e., fluctuations that are otherwise tolerated by common semiconductor process equipment.

3.4 This test method does not address operational influences outside of the manufacturer's published limitations.

3.5 This test method does not address the effects of interruptions of the gas supply.

4 Referenced Standards

4.1 None.

5 Terminology

5.1 Definitions

5.1.1 *actual flow* — flow as indicated by flow standard (see Figures 1 and 2).

5.1.2 *indicated flow* — flow as indicated by the device under test (DUT).

5.1.3 *ramp* — constant rate of change in pressure ($dp/dt = k$).

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

5.1.5 *step change* — an exponential step in pressure with a time constant of one second or less.

5.2 Abbreviations and Acronyms

5.2.1 δM — deviation of mass of material relative to steady-state mass delivery.

5.2.2 ΔP — change in pressure with respect to time

5.2.3 ΔQ — steady state deviation of actual flow during inlet pressure ramp from that while inlet pressure is constant.

5.2.4 δQ_- — maximum negative deviation of actual flow from nominal.

5.2.5 δQ_+ — maximum positive deviation of actual flow from nominal.

5.2.6 τ — pneumatic time constant

5.2.7 *DUT* — device under test

5.2.8 *MFC* — mass flow controller

5.2.9 *MV* — metering valve

- 5.2.10 P_I — inlet pressure
- 5.2.11 P_2 — outlet pressure
- 5.2.12 PC_A — pressure coefficient of actual flow per pressure change at a set point.
- 5.2.13 PC_O — pressure coefficient of indicated flow per pressure change at zero flow.
- 5.2.14 PC_S — pressure coefficient of span flow per pressure change.
- 5.2.15 $Psia$ — pounds per square inch absolute
- 5.2.16 $Psig$ — pounds per square inch gauge
- 5.2.17 Q_A — actual flow
- 5.2.18 Q_{FS} — rated full scale flow
- 5.2.19 Q_I — indicated flow
- 5.2.20 Q_N — nominal actual flow during steady state conditions.
- 5.2.21 Q_R — steady state actual flow while inlet pressure is being ramped.
- 5.2.22 Q_{SP} — set-point flow
- 5.2.23 T — time
- 5.2.24 t_f — time when Q_A is within 0.5% of reading of Q_N .
- 5.2.25 t_o — time when pressure transient is initiated.
- 5.2.26 t_s — settling time to Q_N
- 5.2.27 v — voltage
- 5.2.28 V_{eq} — equivalent internal control volume of the DUT.
- 5.2.29 V_{ip} — valve, pump isolation

6 Summary of Test Method

6.1 *Inlet Pressure Step and Ramp Change* — The effects of fast-step and slow-ramp changes to the pressure on actual flow out of the MFC is observed. See Figures 6 and 7.

6.2 *Inlet Pressure Effect Steady State* — The effects of a pressure increase/decrease on actual flow is observed once the increase/decrease has reached steady state. See Figure 8.

6.3 *Outlet Pressure Step Change* — The effects of an outlet pressure change on actual flow is observed. See Figure 9.

6.4 *Crosstalk Pressure Effect* — The effects of pressure changes due to switching multiple flow devices on the same gas line. See Figure 11.

7 Interferences

7.1 The accuracy rating of the measuring equipment shall be superior to that of the DUT. Preferably the measuring equipment will have an accuracy that is four times better than the DUT. Calibration equipment must have a valid calibration certificate.

7.2 Take care when using test instruments with a specified accuracy expressed in percent of full scale as the accuracy is limited at lower percentages.

7.3 Installation effects on the flow should be minimized.

7.4 Verify electrical signals directly at the DUT connector to ensure that the signals at the DUT and standard agree with the signals at the data recording equipment.

7.5 All electrical measurements should be read on devices with at least 4.5 digits of resolution. These devices must have valid calibration certifications.

7.6 The results of this test method depend on the accuracy and repeatability of the pressure measurement devices used in the test system. Take care to stay within the specified pressure ranges of these devices and verify their accuracy prior to and following MFC evaluation activities.

7.7 The cleanliness level of the test gas should be compatible with the DUT. The minimum requirement placed on the test gas is that it be free of contamination that could influence the operational characteristics of the test article and instruments.

7.8 The test gas source and delivery system must be capable of satisfying the test volume flow rate at a constant pressure ± 0.7 kPa (± 0.1 psi).

7.9 The ambient temperature should be held to $22^\circ\text{C} \pm 2^\circ\text{C}$ for the duration of each analysis.

8 Significance and Use

8.1 The significance of the stability calculations in this method is to allow the MFC user to assess the transient pressure effects on the DUT. In application, this method will provide a consideration affecting gas system designs and MFC selection.

9 Apparatus

9.1 *Equipment Required for Methods A-1 and A-2*

9.1.1 Inlet test gas filter

9.1.2 Shutoff valve (qty 2).

9.1.3 Pressure transducers, available range 0–446 kPa (0–50 psig), with measurement accuracy of $\pm 0.2\%$ and time constant less than 20 msec (qty 2).

9.1.4 Dome-loaded pressure control, or other device capable of producing specified pressure transients.

9.1.5 Flow standard, with time constant less than 20 msec and with full scale that is 200% of the DUT's full scale, accurate to 1% of full scale, linear to 0.5% of full scale, and capable of resolving to 0.2% of full scale.

9.1.6 Data acquisition system measures the electrical signals from the device under test. The data acquisition system may also read the signals from the flow standard, record test data and control the test sequence.

9.2 Equipment Required for Method B

9.2.1 Inlet test gas filter.

9.2.2 Shutoff valve (qty 2).

9.2.3 Pressure transducer, available range 0–791 kPa (0–100 psig), with measurement accuracy of $\pm 0.1\%$ and time constant less than 20 msec.

9.2.4 Two-stage pressure regulator, capable of 0–690 kPa (100 psia) control.

9.2.5 Flow standard, with full scale that is at least 120% of the DUT's full scale, accurate to 1% of full scale, linear to 0.5% of full scale, and capable of resolving to 0.2% of full scale.

9.2.6 Data acquisition system measures the electrical signals from the device under test. The data acquisition system may also read the signals from the flow standard, record test data and control the test sequence.

9.3 Equipment Required for Method C

9.3.1 Inlet test gas filter.

9.3.2 Manual metering valve.

9.3.3 Pressure transducer, available range 0–446 kPa (0–50 psig), with measurement accuracy of $\pm 0.2\%$ and time constant less than 20 msec.

9.3.4 Pressure transducer, 0–101.325 kPa $\pm 1\%$ and with time constant less than 20 msec (qty 1).

9.3.5 Shutoff valves (qty 2).

9.3.6 Isolation valve (qty 1).

9.3.7 Vacuum pump, with pumping speed of at least 30 lpm, with throttling and isolation valve.

9.3.8 Flow standard, with time constant less than 20 msec and with full scale that is 200% of DUT full scale accurate to 1% of full scale, linear to 0.5% of full scale, and capable of resolving to 0.2% of full scale.

9.3.9 Data acquisition system measures the electrical signals from the device under test. The data acquisition system may also read the signals from the flow standard, record test data and control the test sequence.

9.4 Equipment Required for method D

9.4.1 Pressure transducer, available range 0–446 kPa (0–50 psig), with measurement accuracy of $\pm 0.2\%$ and time constant less than 20 msec. (2)

9.4.2 Flow standard, with time constant less than 20 msec and with full scale that is 200% of DUT full scale accurate to 1% of full scale, linear to 0.5% of full scale, and capable of resolving to 0.2% of full scale.

9.4.3 Isolation valve (qty 1).

9.4.4 Data acquisition system measures the electrical signals from the device under test. The data acquisition system may also read the signals from the flow standard, record test data and control the test sequence.

9.4.5 MFC with time constant less than 20 msec and a full scale flow rate that is 10 times the full scale flow rate of the DUT.

10 Materials

10.1 Clean, dry nitrogen, with a dew point less than or equal to -40°C , at a delivery pressure of 791 kPa (100 psig).

11 Safety Precautions

11.1 This test method may involve hazardous materials, operations, and equipment. This test method does not purport to address the safety considerations associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and to determine the applicability of regulatory limitations before using this method.

12 Test Specimen

12.1 Allow all components in the test apparatus to warm up following the manufacturer's specification.

12.2 Take necessary steps when switching gases to ensure that only the desired gas is in the DUT and flow standard at the time the test is performed.

13 Preparation of Apparatus

13.1 *Setup and Schematic* — See Figures 1, 2, and 10.

13.2 *Plumbing Design Requirements for Methods A and C*

13.3 The test system must be highly conductive and must have no changes in direction closer than 20 tubing diameters upstream of the DUT.

13.4 The pneumatic time constant for the system shall be calculated as shown below:

$$\tau = (\text{Volume} \times \text{Pressure Drop}) / (\text{Pressure} \times \text{Volumetric Flow})$$

where:

- Volume is measured between the flow standard and the DUT
- Pressure drop is across the flow standard
- Pressure is the pressure in the defined volume
- Volumetric flow is as measured by the standard

13.5 The pneumatic time constant added to the flow standard time constant should ideally be less than 100 msec and should be recorded if larger. For method C, the volume between MV and V_{ip} should be kept to a minimum.

13.6 The system must be relatively leak free, i.e., the maximum inboard leak rate should be 2×10^{-7} atm cc/s He.

13.7 The system must be supported and isolated in a manner that keeps it from vibration, shock, and other conditions that could influence the results of this test.

14 Procedure

14.1 Inlet Transient Pressure Effects (Method A-1)

14.1.1 Assemble the test MFC into the test apparatus. (See Figure 1.)

14.1.2 Satisfy the manufacturer's warm-up requirements for the MFC.

14.1.3 Set the inlet pressure (P_1) to 274 kPa (25 psig).

14.1.4 Give the DUT a 50% set-point ($Q_{SP} = \frac{1}{2}Q_{FS}$) and wait for Q_I to reach stability.

14.1.5 Adjust the pressure control device to initiate a step in P_1 to 287 kPa (27 psig) with a time constant of one second (see Figure 3c).

14.1.6 Wait until Q_I and Q_A have reached stability.

14.1.7 Using the pressure control device, initiate a step in P_1 to 274 kPa (25 psig) with a time constant of one second.

14.1.8 Give the DUT a 100% set-point ($Q_{SP} = Q_{FS}$) and wait for stability.

14.1.9 Repeat Sections 14.1.5 through 14.1.7.

14.2 Process Side Effects (Method A-2)

14.2.1 Assemble the test MFC into the test apparatus (see Figure 1).

14.2.2 Satisfy the manufacturer's warm-up requirements for the MFC.

14.2.3 Set the inlet pressure (P_1) to 274 kPa (25 psig).

14.2.4 Give the DUT a 50% set point ($Q_{SP} = \frac{1}{2}Q_{FS}$) and wait for Q_I to reach stability.

14.2.5 Using the pressure control device, initiate a ramp in P_1 to 356 kPa (37 psig) (see graph in Figure 4c). Use a ramp rate between 0.7 kPa (0.1 psi) per second and 21.0 kPa (3psi) per second. Record the ramp rate used on the data sheet.

14.2.6 Wait until Q_I and Q_A have reached stability.

14.2.7 Using the pressure control device, initiate a ramp as in 14.2.5, initiate a ramp in P_1 to 274 kPa (25 psig) (see graph in Figure 4c).

14.2.8 Repeat Sections 14.2.5 through 14.2.7.

14.3 Inlet Pressure Effects, Steady State (Method B)

14.3.1 Assemble the DUT in the test apparatus (see Figure 1).

14.3.2 Satisfy the manufacturer's warm-up requirements for the DUT.

14.3.3 Set the inlet pressure (P_1) to 205 kPa (15 psig).

14.3.4 Close V_{io} , open DUT control valve.

14.3.5 Wait until Q_R and Q_A have reached stability. Record P_1 , Q_I and Q_A (see Table A3.1).

14.3.6 Open V_{io} and give the DUT a 50% set-point. ($Q_{SP} = \frac{1}{2}Q_{FS}$).

14.3.7 Wait until Q_I and Q_A have reached stability. Record P_1 , Q_I and Q_A (see Table A3.1).

14.3.8 Give the DUT a 100% set-point ($Q_{SP} = Q_{FS}$).

14.3.9 Wait until Q_I and Q_A have reached stability. Record P_1 , Q_I and Q_A (see Table A3.1).

14.3.10 Set inlet pressure (P_1) to 446 kPa (50 psig) and repeat Sections 14.3.4 through 14.3.9.

14.4 Outlet Pressure, Step Change (Method C)

14.4.1 Assemble the test MFC into the test apparatus. (See Figure 1.)

14.4.2 Satisfy the manufacturer's warm-up requirements for the MFC.

14.4.3 Set the inlet pressure (P_1) to 274 kPa (25 psig) (see Figure 9).

14.4.4 Give the DUT a 50% set point ($Q_{SP} = \frac{1}{2}Q_{FS}$).

14.4.5 Throttle the pump rate until $P_2 = 26.664$ kPa.

14.4.6 Open V_{io} and adjust the metering valve, MV, until $P_2 = 101.325$ kPa.

14.4.7 Allow Q_I to reach stability. Record P_1 , Q_I , and Q_A (see Table A3).

14.4.8 Close V_{io} . P_2 should = 26.664 kPa.

14.4.9 Allow Q_I to reach stability. Record P_1 , Q_I , and Q_A (see Table A3).

14.4.10 Give the DUT a 100% set point and repeat Sections 14.4.5 through 14.4.9.

14.5 Crosstalk Pressure Effect (Method D)

14.5.1 Assemble the DUT in the test apparatus (see Figure 10).

14.5.2 Satisfy the manufacturer's warm-up requirements for the DUT.

14.5.3 Set the inlet pressure (P_1) to 274 kPa (25 psig)

14.5.4 Give the DUT a 100% set point ($Q_{SP} = Q_{FS}$).

14.5.5 Give the 10× MFC a 100% set point ($Q_{SP} = Q_{FS}$).

14.5.6 Wait until the DUT and MFC achieve stability.

14.5.7 Record P_1 , P_2 , the indicated flow from the DUT, the indicated flow from the MFC and the indicated flow from the flow standard continuously with the data acquisition system.

14.5.8 While monitoring command the 10 × MFC to a zero set-point. Wait until the DUT becomes stable then command the 10× MFC to a 100% set Point.

14.5.9 Sample Plot is shown in Figure 11.

15 Calculations or Interpretation of Results

15.1 See Appendix 1 for detailed information on data collection and interpretation for Methods A-1, A-2, B, and C.

15.2 *Calculations* — The indicated MFC flow output data and the flow standard output data should be converted to percent of full scale flow as follows:

$$\% \text{ of full scale flow} = \frac{\text{output data (v)}}{\text{full scale output (v)}} \times 100 \quad (1)$$

15.3 *Interpretation* — Collect the following data and report as an effect of transient pressure conditions:

15.4 Plot of indicated flow, actual flow, and flow set point versus time.

15.5 Duration of instability. Maximum and minimum deviations from the steady state actual and indicated flows. Calculate the positive and negative integrals, along with the total integral of variations in the actual and indicated flows.

15.6 Inlet (P_1) and outlet (P_2) values.

15.7 The number of repetitions required to achieve a confidence factor of 95% for each test step.

15.8 Data plots for the measured values must be generated and presented in a manner similar to that shown in Figures 3, 4, and 5 and in Table 1.

16 Related Documents

16.1 *Military Standards*¹

MIL-STD 45662 — Calibration Systems Requirements

¹ Naval Publication and Forms Center, 5801 Tabor Avenue, Philadelphia PA 19120 U.S.A