



# AEROSPACE RECOMMENDED PRACTICE

Society of Automotive Engineers, Inc.  
TWO PENNSYLVANIA PLAZA, NEW YORK, N.Y. 10001

ARP 1254

Issued March 1972  
Revised

## FLUIDICS TEST METHODS AND INSTRUMENTATION

CANCELLED

### 1. SCOPE

#### 1.1. Purpose:

This recommended practice establishes acceptable methods, procedures and instrumentation required for testing fluidic devices. The tests described include only those necessary to predict the performance of a device when used in a system or circuit. The term "device" is understood to include such items as amplifiers, active elements, passive elements, integrated circuits, logic modules, operational amplifiers and the like, as well as sensors and transducers. The term "instrumentation" is understood to include all laboratory instrumentation (electrical, fluidic or mechanical, etc.). The test methods described herein have been prepared to serve the following purposes:

- (a) To specify suitable conditions obtainable in the laboratory which, insofar as possible, resemble those encountered by the device under service use. The tests described herein may not be interpreted as an exact representation of actual service operation at a specific geographic location or altitude or outer space location.
- (b) To describe in one document all of the tests required (excepting possibly certain tests applicable to unique operating principles) to predict the behavior of pneumatic fluidic devices when operated under specific conditions with specific performance indices. Where practicable, the tests have been made adaptable to a broad range of devices.

### 2. REFERENCED DOCUMENTS

- 2.1 The issues of the following documents in effect on the date of invitation for bids or request for proposals form a part of this document to the extent specified herein:

#### SPECIFICATIONS:

|                   |             |                                  |
|-------------------|-------------|----------------------------------|
| <u>Military:</u>  | MIL-C-45662 | Calibration System Requirements  |
| <u>Standards:</u> | ARP 993A    | Fluerics Terminology and Symbols |

(Copies of specifications, standards, drawings and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

### 3. ABBREVIATIONS, SYMBOLS AND DEFINITIONS

- 3.1 Abbreviations, Symbols and Definitions: For the purpose of this document, the abbreviations, symbols and definitions specified in ARP 993A shall apply. Additionally, the following symbols shall apply.

#### 3.1.1 Abbreviations:

- (a)  $\dot{m}$  - mass flow rate

#### 3.1.2 Symbols:

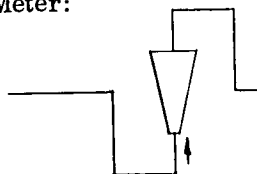
- (a) Return of a Fluid Transmission Line to Atmosphere:

SAE Technical Board rules provide that: "All technical reports, including standards approved and practices recommended, are advisory only. Their use by anyone engaged in industry or trade is entirely voluntary. There is no agreement to adhere to any SAE standard or recommended practice, and no commitment to conform to or be guided by any technical report. In formulating and approving technical reports, the Board and its Committees will not investigate or consider patents which may apply to the subject matter. Prospective users of the report are responsible for protecting themselves against liability for infringement of patents."

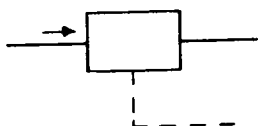
(b) Electrical Transmission Line:



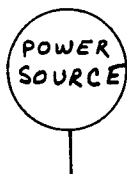
(c) Flow Meter:



(d) Flow Transducer:



(e) Power Supply:



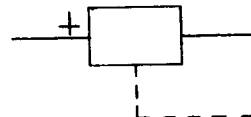
(f) Pressure Gauge:



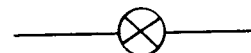
(g) Manometer:



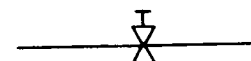
(h) Pressure Transducer:



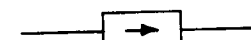
(i) Regulator:



(j) Valve:



(k) Flow Measuring Instrument General:



## 3.1.3 Definitions:

(a) Quiescent - at rest; no signal present.

## 4. GENERAL REQUIREMENTS

4.1 Numbering System: The test methods are designated by numbers assigned in accordance with the following scheme.

4.1.1 Classification of Test Methods: The tests are divided into five classes: test methods numbered 1001 to 1999 inclusive cover performance tests of digital elements; those numbered 2001 to 2999 inclusive cover performance tests of analog elements; those numbered 3001 to 3999 inclusive cover performance tests of multi-element devices (modules, operational amplifiers, integrated circuits, etc.), both digital and analog; those numbered 4001 to 4999 inclusive cover performance tests of sensors, transducers and signal generators; those numbered 5001 to 5999 inclusive cover performance tests of hybrid (digital-to-analog, analog-to-digital) modules, and majority logic devices. Test methods and procedures are serially numbered in the order in which they are introduced into this document.

4.1.2 Revisions: Revisions are numbered consecutively using a period to separate the test method number and the revision number. As examples, 1001.1 is the first revision of Method 1001; 5999.11 is the eleventh revision of Method 5999.

4.2 Method of Reference: When applicable, test methods contained herein shall be referenced in the individual specification by specifying this ARP, the method number and the details required in the summary paragraph of the applicable method. To avoid the necessity for changing specifications which refer to this ARP, the revision number should not be used when referencing test methods. For example, a procurement specification referring to a revised test method would specify Method 2020, not 2020.2.

- 4.3 Test Conditions: Unless otherwise specified herein, or in the applicable procurement documentation, all measurements and tests shall be made at ambient temperature  $20 \pm 5$  C ( $67 \pm 9$  F) and at ambient atmospheric pressure and relative humidity. Whenever these conditions must be closely controlled in order to obtain reproducible results, the reference shall be as follows: temperature 19 to 21 C (65.2 to 68.8 F), relative humidity 50% maximum and atmospheric pressure from 740 to 780 millimeters of mercury (14.3 to 15.1 psia). In the event condensation is noted anywhere within the test system envelope, the test must be repeated under humidity-controlled conditions.
- 4.3.1 Permissible Temperature and Pressure Variation in Environmental Chambers: When chambers are used, specimens under test shall be located only within the working area defined as follows:
- (a) Temperature variation within working area: The controls for the chamber shall be capable of maintaining the temperature of any single reference point within the working area within  $\pm 2\%$  of the absolute temperature scale.
  - (b) Pressure variation within working area: The controls for the chamber shall be capable of maintaining the chamber absolute pressure within  $\pm 2$  percent.
  - (c) Local temperature variation within working area: Chambers shall be so constructed that at any given time the temperature of any point within the working area shall not deviate more than 2 percent of Kelvin scale.
- 4.3.2 Accuracy: The specified limits are for values obtained with the specific test conditions. Proper allowance shall be made for measurement errors in establishing the working limits to be used for the measured values so that the actual values of the device parameters are within the specified limits.
- 4.3.3 Instrument Calibration: Calibration of all test equipment used in the performance testing shall be in accordance with MIL-C-45662 and with requirements included in Appendix A. Additionally, all electrical test equipment shall be calibrated at periodic intervals and all acceptable equipment shall display a record of calibration dates and responsible individual or activity. The interval shall be based on the class of equipment and its history. Calibration check readings shall agree with the values recorded for each control device within the accuracy requirements of 4.3.2.
- 4.3.4 Data Reporting: The data resulting from application of any test method or procedure shall be reported in terms of standard test conditions and results. Extrapolations or "equivalent" results (e.g. performance in a non-standard atmosphere derived from standard atmospheric test conditions) may be reported in addition to the standard results, but shall not be acceptable as an alternative to actual results. Results of any test method or procedure shall be accompanied by information on the total quantity of devices in each lot being tested, the number of rejections in each lot being tested, and the test method(s) under which failure criteria were established.
- 4.3.5 Test Sample Disposition: Unless otherwise specified in the applicable procurement document, devices subjected to tests may be included in the delivery. If the lot is numbered serially, the test sample serial numbers shall be noted. Otherwise, the test specimens shall be clearly identified.
- 4.4 Orientation: For test methods which involve observation of the effects of applied displacements, rotations, rates, accelerations, or external forces which must be related to the orientation of the device, such orientation and direction shall be identified as follows:
- 4.4.1 In a sensing device with a single sensitive axis (or axis of rotation), the sensitive axis shall be specifically designated, the other two axes to be designated in such a way that the axes form a right-handed coordinate system.
  - 4.4.2 In a box-shaped package containing substrate planes, mounting surfaces, or laminae, the orientation with respect to applied displacements, rotations, rates, accelerations, or external forces shall be specifically designated.

#### 4.5 General Precautions:

- 4.5.1 Test-induced Mechanical Defects: While a set of tests for mechanical integrity does not form a part of this document, test specimens subjected to repeated connections and disconnections during the testing procedures shall be examined for leaks and fractures. Such test-related mechanical defects shall be included in reported data.
- 4.5.2 Test Methods and Circuits: Unless otherwise stated in the specific test method, the methods and circuits shown are given as the basic measurement method. They are not necessarily the only method or circuit which can be used. The supplier shall demonstrate to the procuring activity that alternate methods or circuits which he has desired to use are equivalent and give results within the desired accuracy of measure (see 4.3.2).

PREPARED BY  
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APPENDIX A  
INSTRUMENTATION

A.1 The instruments described below are widely used in carrying out the test procedures of Appendix B. While the list is not exhaustive, choices are mentioned for most applications.

## A.2 PRESSURE

A.2.1 Gages:

Diaphragm: A simple to use, low range gage for the fluidic laboratory is the device which utilizes a diaphragm and magnetic coupling to sense and indicate differential pressure.

The diaphragm assumes an equilibrium position between the two pressures. This position is transmitted to the rotary pointer by means of magnetic coupling.

The range of operation extends from .5 inch H<sub>2</sub>O to 5 psi.

Accuracy can be  $\pm 2\%$  of indicated value throughout the entire range. Accuracy is not affected by ordinary changes in ambient temperature or pressure. How much the accuracy is affected by proximity of the gage to ferromagnetic materials is open to reasonable question.

Bourdon Tube: The bourdon tube gage is manufactured to a variety of cost and accuracy specifications. The end of the curved tube deflects with increasing internal-external differential pressure.

This deflection is transmitted to the rotary pointer assembly through gearing and linkages.

Accuracy varies, but quality instruments are accurate to within 2% at mid-range and to within 3% near the end points.

Bourdon tube gages can measure pressures ranging from laboratory vacuum to thousands of atmospheres.

A.2.2 Manometer: The U tube manometer is the most straightforward pressure sensor in the laboratory. With reasonable caution, the manometer can be used with the greatest accuracy of any of the pressure sensors. The meniscus height in each leg is measured and the product of the height difference and the fluid density equals the difference in pressure in the legs. The fluid density determines the scale factor.

There are sources of errors inherent in any manometer; a common one being the difficulty in reading the meniscus. Other factors affecting accuracy are:

- (a) Contamination due to oxidation for the case of the mercury manometer.
- (b) Effects of capillary action.
- (c) To a very small degree, temperature changes can cause error due to the associated change of density in the manometer fluid.

The manometer becomes a highly precise pressure sensor if it is equipped with an automatically controlled meniscus of the opaque fluid. A photo tube is located so that it will be struck by the portion of light beam not interrupted by the fluid. A signal proportional to the remaining beam area is generated and activates the motor moving the scanner beam by means of a lead screw until it is centered on the meniscus and the resulting signal is at null. The position of the scanner is geared to a counter indicating the height of the fluid column to the nearest 1/1000 of an inch.

A source of error in the system is non-uniformity among replacement sensing and control system components.

A.2.3 Transducers:

Strain Gage: The strain gage transducer consists of an electrical network whose resistive elements are mechanically deformed as a function of the applied stress (pressure). The mechanical deformation causes changes in the electrical characteristics of the resistive elements. A change in the network output is functionally related to the change of applied pressure.

The operating range of strain gage transducers extend from 0 to .25 psi to 0 to 12,000 psi.

Some strain gage units have a frequency response greater than 1000 Hz with accuracies of better than 1% of full scale reading.

Piezo Electric: The piezo electric transducer consists of a quartz crystal and a charge detecting and amplifying network.

A charge proportional to force (pressure) is generated on the quartz crystal. The charge sensing network must have a high input impedance; generally, the lower the frequency the higher must be the input impedance of the detecting network.

The piezo electric transducer can sense pressures to 3000 psi at frequencies of 50 KHz.

Other: A pressure sensitive transistor has been developed. The emitter base junction of a NPN transistor is subjected to a force mechanically transmitted from a diaphragm which is the pressure sensor. The output voltage is a linear (within 1%) function of pressure applied to the diaphragm.

Ranges extend from .1 to 20 psi. The major disadvantage is output null shifting due to temperature change which can be as much as .2V/°C.

The frequency response is high, greater than 10 KHz.

## A.3 FLOW

A.3.1 Flow Meters:

Float/Variable Area Flow Meter: This device is placed in the line in a vertical position. The tube is tapered inside so that the area increases slightly as the fluid stream courses upward.

The stream exerts forces on the float which are functions of fluid velocity and density. The float comes to rest (under conditions of steady flow), when these forces balance the weight of the float.

Interchangeable floats of various densities extend the range of measurement over which a given tube can be used. The limiting factor is usually impedance, since it is desirable to keep the impedance of instrumentation as low as possible.

Accuracy is affected by dirt, moisture and grease. Under some conditions, electrical charge can accumulate causing the float to cling to the tube walls until a substantial mechanical force overcomes the electrical force.

Quality instruments are accurate to within 3% over the entire scale except for the lower quarter.

Rates as high as 500 cubic feet per minute and as low as a fraction of a cubic inch per minute can be measured with flow meters of this type.

Changing flow rates cannot be measured except for very rough approximations.

Linear Resistor: A resistor (or set of resistors) whose pressure/flow characteristics are linear can be a convenient way to measure flow. The pressure drop across the device is a measure of the flow.

Pneumatic flow rates measurable by this type of flow meter range from .1 SCFM to 100 SCFM.

Accuracy is .5% of full scale, depending on the pressure instrumentation used.

A.3.2 Anemometer: This type of instrument can be used to measure fluid velocity. The quantity of heat convectively transferred from a hot wire to a moving fluid in which the wire is immersed is a nonlinear function of the velocity of the fluid. A change in the rate of heat transfer can similarly be related to a change in the fluid velocity. The heat transfer can be detected in either of two ways,

If a constant current can be maintained through the hot wire, irrespective of resistance and temperature changes due to flow rate variations, then the voltage required to maintain constant current is a function of the fluid velocity. This scheme and its associated control network is called a constant current anemometer.

If a constant temperature can be maintained by regulating the current to maintain constant resistance (and thus constant temperature) then the voltage required to maintain constant temperature is also related to fluid velocity. This scheme and its associated control network is called a constant temperature anemometer.

In the constant current anemometer, the transducer is the variable resistance leg of a bridge circuit which is excited by a power amplifier. Initially, the bridge circuit is balanced and any change of the transducer's resistance is detected by a differential amplifier. This voltage, after amplification, drives the current to its initial value regardless of the resistance value assumed by the transducer. The voltage is then a function of the fluid velocity.

Constant current operation does not utilize the hot-wire concept to its maximum potential. The range and frequency response can be extended by maintaining the hot wire at constant temperature, minimizing the time required for heating and cooling to register their effect.

The transducer is one arm of a bridge circuit which has another arm with variable resistance. Any small change in the resistance of the transducer probe due to fluid velocity change, will cause a small unbalance voltage which after amplification will adjust the probe current to restore balance to the bridge. Thus, the temperature variations are kept very small and the frequency response is improved more than 100 fold.

The velocity measurable by the constant temperature operation extends from a few inches per second to beyond sonic velocity with appropriate adjustments for various mean velocities throughout the total range.

The frequency response is from DC to more than 20 KHz.

#### A.4 TEMPERATURE

A.4.1 Resistance Sensor: A wire or film sensor is connected as one arm of a bridge. The output voltage of the bridge circuit is a function of resistance change (and minus of the temperature change) of the sensor. The range depends on the choice of material and its resistance-temperature characteristics, but temperatures exceeding 1500 F have been measured with accuracy.

A.4.2 Thermistor Resistance Sensor: The sensor is a semiconductor connected as one arm of a Wheatstone bridge. There will be a unique temperature at which the bridge will balance. Bridge voltage resulting from imbalance will then be a function of temperature variation. The range of this instrument is up to 600 F with accuracy of  $\pm 1\%$ .

APPENDIX B  
TEST METHODSINDEX

| <u>Method No.</u>              | <u>Title</u>                                                     |
|--------------------------------|------------------------------------------------------------------|
| <u>Digital Elements</u>        |                                                                  |
| 1001                           | Power Nozzle Characteristics                                     |
| 1002                           | Control Port Characteristics                                     |
| 1003                           | Output Characteristics                                           |
| 1004                           | Switching Time                                                   |
| <u>Proportional Elements</u>   |                                                                  |
| 2001                           | Power Supply and Quiescent Characteristics                       |
| 2002                           | Differential Input and Output Characteristics<br>Transfer Curves |
| 2003                           | Dynamic Testing                                                  |
| 2004                           | Signal-to-noise Ratio                                            |
| <u>Multi-element Devices</u>   |                                                                  |
| 3001                           | Evaluation of a Fluidic Operational Amplifier                    |
| <u>Transducers and Sensors</u> |                                                                  |
| 4001                           | Electromechanical Signal Generator Output<br>Characteristics     |

Method 1001

Power Nozzle Characteristics of  
an Active Digital Device

1. PURPOSE

This method establishes the means of determining the power nozzle characteristics of certain active digital devices.

As a preliminary consideration, it should be mentioned that fast-moving fluid can cause erroneous readings. The usual practice is to measure pressures from an expansion tank inserted into the line for the purpose of slowing the flow to a negligible magnitude. Also, unless otherwise specified,  $\pm 5\%$  error is assumed to be a reasonable accuracy for quantities required in the summary section of this and other test methods.

1.1 Definitions: The following definitions shall apply for the purpose of this test method.

1.1.1 Nominal Power Supply Pressure: That pressure for which the device was designed. If the device was designed to be operated within a range of power supply pressures, the nominal power supply pressure shall be the mid point of this range.

1.1.2 Efficiency: The ratio of signal power output to total power input. The concept of efficiency is applicable to any active device, although the efficiency of a given device may not always be a primary consideration.

1.1.2.1 Efficiency Memory Devices: The efficiency of a memory device is the ratio of the output quantity to the supply quantity with a specified resistive load.

1.1.2.2 Efficiency Non-Memory Devices: Flow efficiency is the ratio of the output flow to the sum of the control flow and the power supply flow. Pressure efficiency is the ratio of the output to the power supply pressure. Both quantities must be given with a specified resistive load.

2. APPARATUS

2.1 Pressure Regulators: The pressure regulators must be capable of maintaining constant pressure ( $\pm 10\%$ ) through and beyond the maximum anticipated flow rate. This is particularly true if the flow measuring device is dependent on a constant upstream pressure for accurate flow indication. In any case, downstream pressure adjustment becomes a much simpler task, if the upstream source is maintained at constant pressure.

2.2 Pressure Sensors: The pressure sensors should be connected to the fluid lines through expansion tanks. While this gives rise to longer transients, it may be necessary in order that pressure readings represent total pressure.

2.3 Flow Sensors: Flow sensors should be used at line pressures and ranges affording the greatest accuracy. The effects of resistance can be reduced by operating at higher line pressures.

3. PROCEDURE

Connect circuit as shown in Figure 1001.

3.1 Jet Interaction Devices: The power valve must be opened slowly so that transient effects are minimal. Plot or record flow (mass, weight, or standard volume) versus pressure. To investigate, for load sensitivity, repeat the procedure with a high resistance load (a power nozzle of an identical device and/or blocked load). Control signals should be applied to determine their effect on supply nozzle impedance.

3.2 Turbulence Amplifiers: The power valve must be opened slowly so that transient effects are minimal. Plot or record flow versus pressure. Monitor the output to determine the maximum useful supply pressure. (The output pressure will drop off sharply with the onset of turbulence in the power supply jet.)



## 4. SUMMARY

The following information shall be specified:

- (a) Ambient conditions.
- (b) Minimum and maximum power supply pressures, and criteria used to determine limits, nominal power supply pressure and flow rates at each. These may appear as specifically labeled points on the power supply characteristic curve (see Figure 1001) or as tabulated data. If these data are effected by application of control signals, so indicate on the characteristic curve.
- (c) Whether or not device is stable with blocked output.

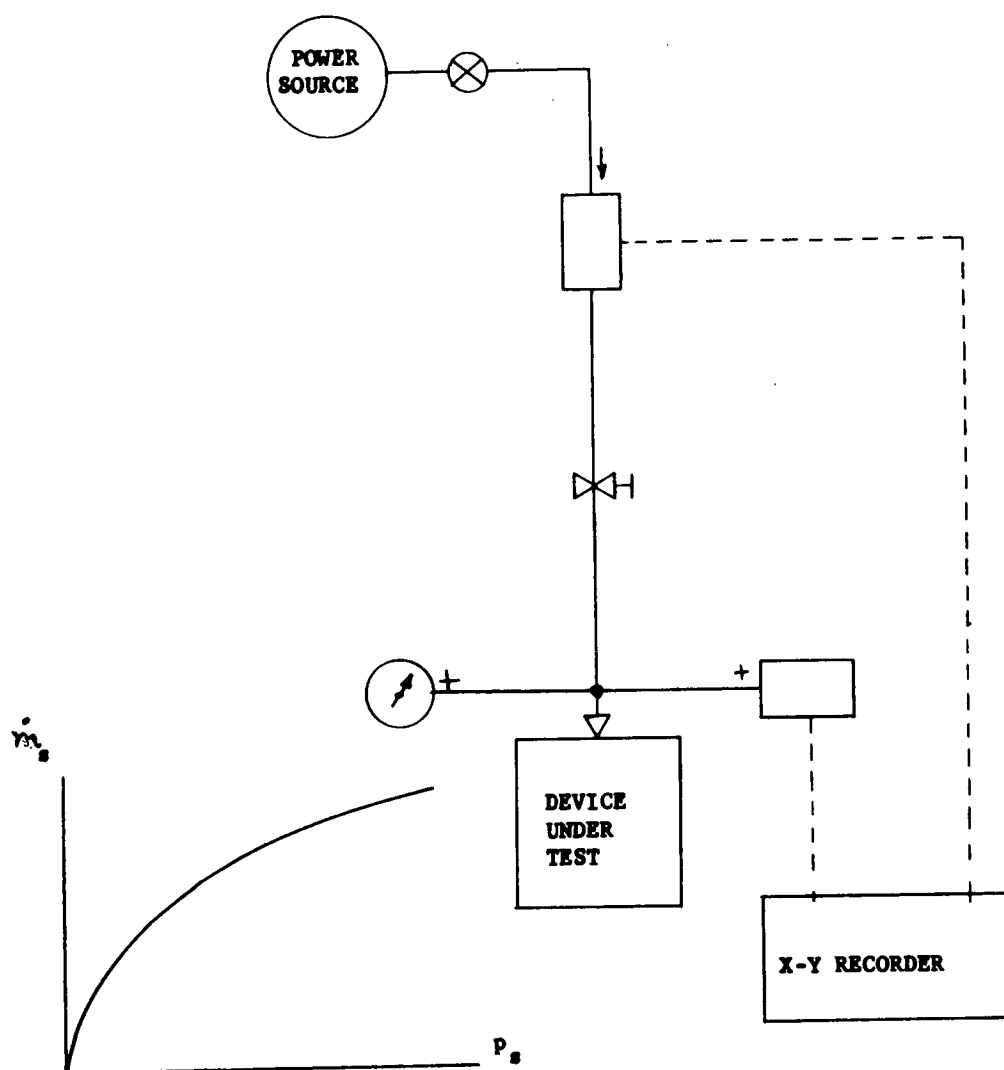


FIGURE 1001

Method 1002

Control Port Characteristics

1. PURPOSE

This method establishes the means of determining the control port characteristics of certain active digital devices. These characteristics, in conjunction with the output characteristics, enable the user to determine gains and fanout for a specific supply pressure. If the tests are repeated for several supply pressures, gains and fanout, values can be determined as functions of power supply pressure. Depending on vent geometry, load sensitivity can be an important parameter in most jet deflection amplifiers, so that input characteristics change with load impedance. When load sensitivity is suspected, the device should be loaded with various resistances (blocked, open, and the power nozzle of a like device, for example) to determine how loading effects the input characteristics.

If it is determined that the device is load sensitive, specified load resistances must accompany all input data.

2. APPARATUS

The instrumentation should be connected as shown in Figure 1002. The characteristic curve shown in the figure may lie in more than one quadrant. The control impedance may undergo an abrupt change when the switching pressure is reached.

3. PROCEDURE

The power supply pressure should be set to nominal as defined in paragraph 1.1.1 of Method 1001. The control valve must be opened slowly so that transient effects are minimized. Continue increasing the control flow after switching occurs, then slowly decrease the control flow to zero. Depending on the type of the device, the switching pressures and flows may not be obvious. If not, the output pressure transducer must be monitored to determine the level of control pressure when switching occurs. Repeat the process for each control port. Unused control ports may be left open to atmosphere, blocked or restricted with a one-nozzle impedance.

Repeat the process for supply pressures above and below nominal supply pressure.

4. SUMMARY

- 4.1 Input characteristics for each control port at the three different supply pressures shall be provided unless otherwise specified by the applicable procurement document. Where appropriate, a single characteristic curve normalized with respect to supply conditions may be provided for each control port. Specify or label the switching points on the input characteristic curve. Indicate the condition of the unused control ports. If the control characteristics are load sensitive, specify the load impedance used in gathering the input data.

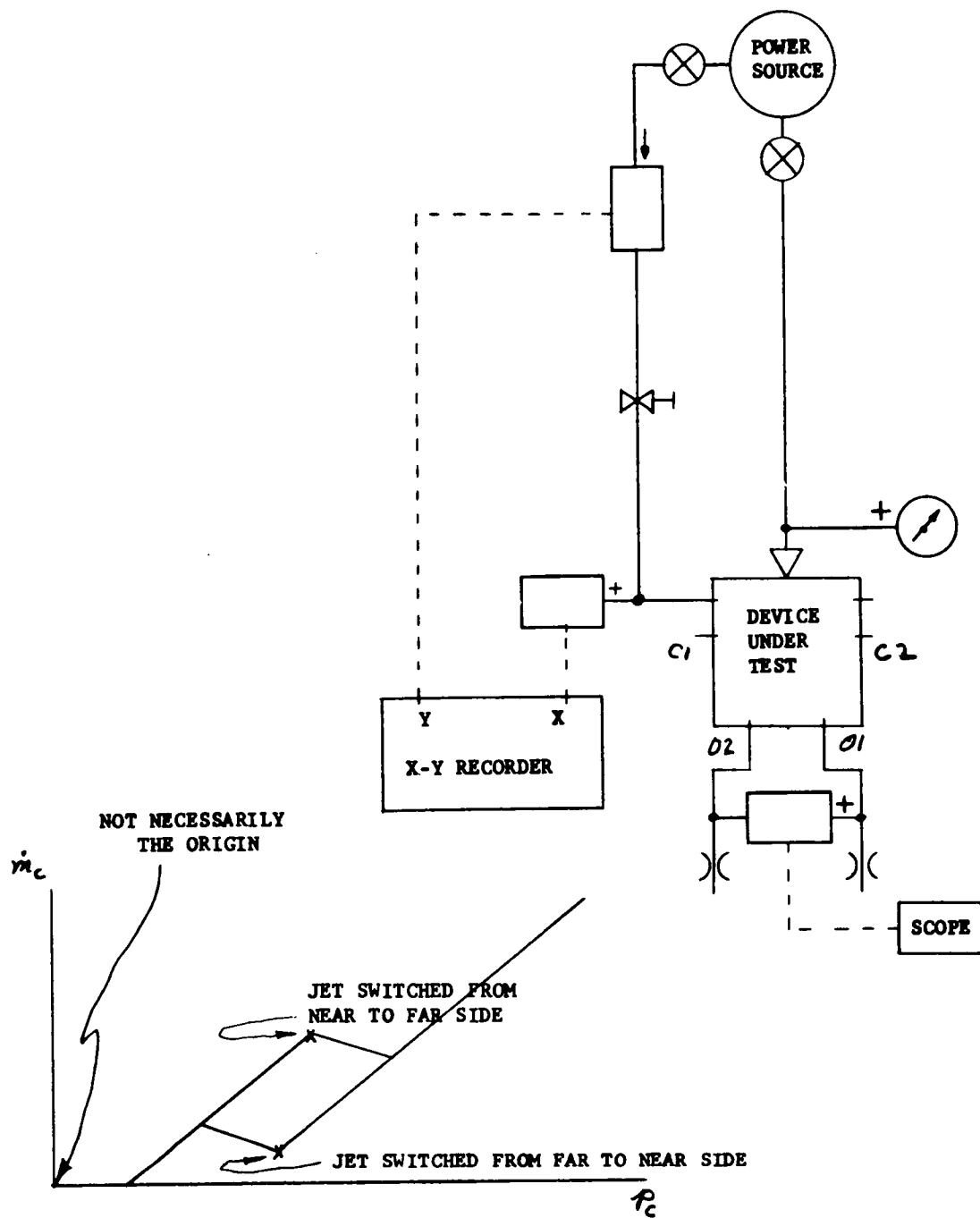


FIGURE 1002