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Standard

Dynamic Response Testing of Process Control Instrumentation

ISA-S26 — Dynamic Response Testing of Process Control Instumentation

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Foreword

This Foreword is included for informational purposes and is not part of Standard S26.

This revision to the earlier series of ISA Recommended Practices has been prepared as a continuing part of the service of ISA toward a goal of uniformity in the field of instrumentation. To continue to be of service to those organizations and individuals who use it, this document should not be static. The Society welcomes all comments and criticism; address letters to the Standards and Practices Board Secretary, ISA, 67 Alexander Drive, P.O. Box 12277, Research Triangle Park, North Carolina 27709, telephone 919-549-5411, e-mail: standards@isa.org.

This document is an integration of four parts covering general recommendations for dynamic response testing, techniques for devices with pneumatic output signals, techniques for devices with electric output signals, and techniques for closed loop actuators for final control elements. The original editions were published in 1957, 1960, and 1961. The revisions providing pulse testing techniques, completed in 1966, have been added to the basic sine wave and step testing techniques. New or altered material is indicated by a vertical bar beside the text or drawing.

This composite ISA Standard was prepared by the Dynamic Response Testing Committee (SP26), established in 1956 with F. H. Winterkamp as Chairman. C. E. Ryker became Chairman in 1962. The purpose of this committee has been to establish guidelines for the successful application of dynamic response testing techniques to modern instruments and process lines. This subject has developed considerable interest among scientists and engineers concerned with accurate and efficient information from instrumental testing. The recommendations in this document are up-to-date with respect to the equipment commercially available to perform this type of testing.

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Contents

1 Purpose

This ISA Standard constitutes a series recommending dynamic test procedures for measurement and control equipment for production processes.

With the continuing development and application of dynamic analysis to systems engineering, dynamic response test data are becoming an increasingly important part of overall performance data. Proper use of this standard should result in:

a) Data that will characterize dynamic performance in a uniform comparable manner,

b) data of value for control systems design as well as for performance characterization, and

c) a maximum amount of useful data per testing dollar.

2 Scope

This ISA Standard establishes the basis for dynamic response testing of measurement and control equipment with pneumatic output and electric output and for closed loop actuators for externally actuated control valves and other final control elements. General recommendations applicable to all dynamic response testing and a brief glossary, defining terms as used in this standard, are also included. Tabular format is used to simplify application in the laboratory by those familiar with dynamic response testing. A minimum of discussion and descriptive material precedes the tabulation of recommended tests. Methods for sine wave, step, and pulse-type signals are included.

Final control elements take many forms, and the actuators may be powered and signalled pneumatically, electrically, or in combination. Externally actuated valves for controlling flow are most common in the process industries, but the final control element can be a controlled volume pump, motor speed control, or many others.

It would, of course, be desirable to have a system which relates the flow response of a control valve or a variable speed pump to the input signal of the closed loop actuator. It was the committee's feeling that it would not be practical to require this.

For the purpose of this ISA Standard, all final control elements will be considered as having an input signal and an output motion or rotation and no distinction will be made between power media.

3 Factors to be considered in dynamic response testing

3.1 Use of data

The application of dynamic response test data can be generally divided into two categories:

1) characterization of a control or measuring device.

2) control system design.

Non-specific designations such as *flat response* or *good response* should not to be used in interpreting dynamic response test data for measurement and control devices. Such terms, which are borrowed from audio work, are not applicable in the control field. It is recommended that data be taken and presented according to the appropriate sections of this standard and that the performance be judged only in the light of requirements for a specific application. For example, a device whose dynamic response is too slow for one application might be ideal for another where undesirable high frequency noise signals are present.

3.2 Interaction

A control system usually consists of a number of elements. Each element has one or more input and output signals. Two elements are said to be interacting when the relation between input and output of one element is affected by changing the characteristics of the other element. In studying dynamic response of a control system, elements which interact are often considered as a unit. It is important to note that interaction is not necessarily mutual.

An example of interacting elements is a pneumatic transmitter and the pneumatic tubing which is attached to it. The response of the transmitter (measured at the point where the tubing is attached) for a given input disturbance depends upon the amount of tubing attached. In the usual case the greater the amount of tubing, the slower the response. This system could be made non-interacting by placing a booster relay between the transmitter and the tubing. Then the speed of response of the transmitter would be virtually independent of the amount of tubing attached to the booster.

3.3 Nonlinearity

Nonlinearity can have a profound effect on the dynamic response of a device, particularly in causing large variations in performance with changes in output load or input signal size. Some common types of nonlinearities are dead spot, friction, hysteresis, velocity limiting, saturation, exponential measurements, and valve characteristics. Nonlinearity not only causes distortion of the signal shape, but also may result in additional phase shift and attenuation.

3.4 Power supply to device being tested

The performance of the power supply system used for the device under test can exert considerable influence on the dynamic test results. A power supply that is adequate for static calibration may be totally inadequate for the large power demands that can occur when high frequency input signals are used. It is common practice for vendors to specify the energy level to be used, but only in the electrical field is it common practice to specify a degree of regulation also.

Since these tests are to characterize devices in a uniform, comparable manner, it is recommended that the energy level specified by the vendor be used, and that the power supply be capable of regulating to ±2% of this level at all test conditions. It is extremely important to check this regulation immediately at the power input connection of the device being tested because in pneumatic and hydraulic work unexpected, large supply line drops can occur during high frequency tests.

3.5 Test signals

This ISA Standard outlines methods for obtaining two types of dynamic data. The first are data that can be used for mathematical analysis, for graphical solution of control problems and for characterization of dynamic performance. These data can be obtained by use of either sine-wave or pulse-type forcing functions. The second type of dynamic data provides a qualitative evaluation of the nonlinearity of the device under test and are obtained by use of step tests.

The choice of whether to use sine-wave or pulse-type forcing functions is a matter of convenience and is left to the discretion of the person performing the test. Either type forcing function when used as outlined in this standard, will yield the same information. The committee is in agreement that the pulse method provides a marginal advantage over the sine-wave method for obtaining dynamic data of instrument components. However, the pulse method does offer distinct advantages when the generation of sinusoidal input signals for a given device is difficult. The committee feels the greatest potential use of the pulse method is not on certain instrument components but on plant process equipment and processes themselves. The scope of this standard is limited to instrument components.

This Standard is organized in a manner that, it is hoped, will be convenient to the user. All references to sine wave and step tests appear before all reference to pulse tests. Redundancy has been kept to a minimum.

3.6 Qualifications of personnel performing tests

This ISA Standard, as stated in the Purpose, is designed to present standardized procedures for performing dynamic tests. It is not the intent of the committee that this document be used as a textbook or instruction sheets but that it serve as a guide for use by personnel trained in the field of dynamic analysis.

4 Recommended tests — sine wave and step

4.1 Input signals

It is recommended that sine wave and step input signals be used with various output loads.

Sine wave test data are most generally useful for mathematical analysis, for graphical solution of control problems, and for characterization of dynamic performance.

In order to arrive at a practical number of recommended tests, the number of output load and input signal configurations must be minimized. This could result in nonlinearities being unnoticed. To permit a qualitative evaluation of the nonlinearity of the device under test, step tests are recommended.

It is realized that the total data from both the recommended step and sine wave tests will not suffice to describe nonlinearity in the device being tested quantitatively. However, this standard is a practical compromise which will give actual data useful for most applications, and a qualitative indication of the effect of unusually large signals or loads.

Sine wave and step tests shown in Figure 1 below are recommended. The input span referred to here is that input signal that will drive the output signal through its full range.

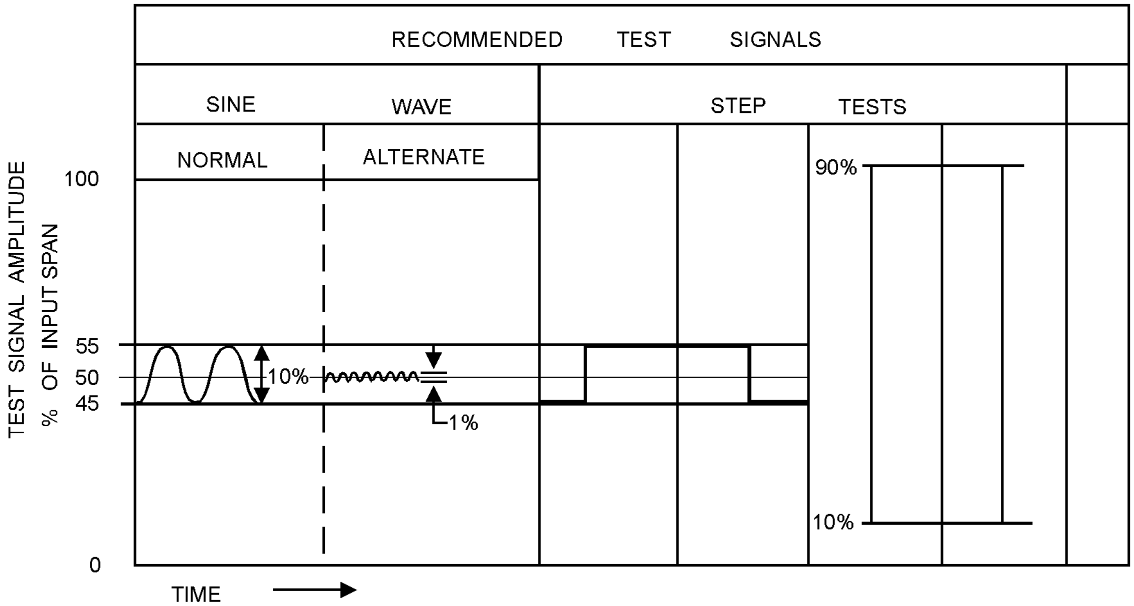


Figure 1 — Recommended test signals

4.1.1 Sine wave input signals

It is recommended that a sine wave input signal be used whose peak-to-peak magnitude is 10 percent of the actual input signal span of the device being tested. The sine wave should have the arithmetical midpoint of the input signal span as its center. The input span preferred is that span which will drive the output signal through its full range. Qualifications of the recommendation are discussed in the later documents.

The test should start at a frequency low enough that the magnitude of the output sine wave essentially equals that of the steady state output for the same input and there is essentially no phase shift between them (except if the device has pure integral or derivative functions). The frequency should be increased until the magnitude of the output sine wave is 10 percent or less of the output signal at zero frequency or the phase lag is 300°. Generally speaking, a response test should cover a frequency span of at least three decades.

Care should be taken to vary the frequency in small enough increments to describe abrupt changes in the response curve.

4.1.2 Step input signals

It is recommended that the following step input signals be used (in percent of actual input span):

1) 45 to 55

2) 55 to 45

3) 10 to 90

4) 90 to 10

4.2 Loading

The load presented to the output of the device has a very significant effect on dynamic performance (see Section 3.2). In selecting loadings to be used, two factors must be considered:

1) The loadings should be as representative of actual field conditions as possible, not only to make the data useful for system design, but to permit realistic characterization of the element.

2) The number of tests should be kept to a minimum.

Detailed load configurations for the various tests are specified below.

4.3 Load configurations

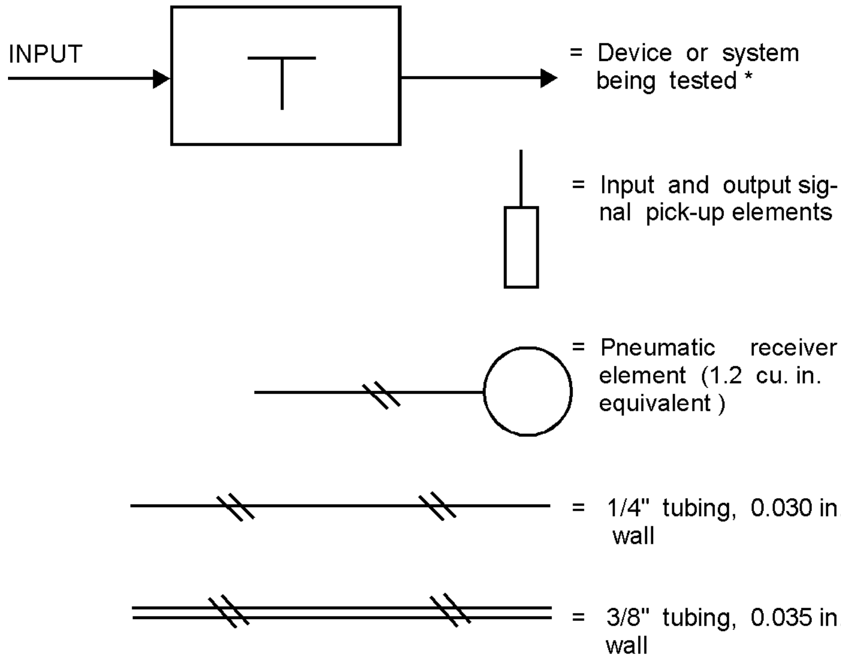
4.3.1 Pneumatic

Five standard load configurations are recommended in Figures 2-6. It should be noted that the recommended location of the pick-off point before the load will result in data which give the response of the device or system *alone* when coupled to the given load. To get the over-all response, it is necessary to combine the device or system response with that of the load. (See references 1-8 for dynamic response of pneumatic signal tubing.) Fewer load configurations are needed to describe typical field installations when this pick-off point location is used, than when the device or system and load are tested as a unit. For example, there can be several typical field piping configurations which appear the same to a transmitter, even though the over-all response, including load, of these installations might be quite different. The effect of the load on the response of the device or system only, when tested as recommended, reaches a limiting value as the load gets greater. For example, there is usually a difference in the system or device response if the load is changed from ten to fifty feet of one-quarter-inch tubing, but experience indicates little difference between the response curves for the device or system alone when the load is changed from 100 feet of one-quarter-inch tubing and a volume to 200 feet of one-quarter-inch tubing (see Section 4.2). To avoid restrictions due to flattened tubing, minimum coil diameter for one-quarter-inch copper tubing should be 16 inches; for 3/8-inch tubing, 30 inches.

The following symbols, used to illustrate typical load configurations, are consistent with ISA Standard S5.1(Y32.20).*

*ANSI accepted Standard Y32.20

Load configurations for pneumatic devices



*If the device being tested is a controller, the automatic-manual switch or cutoff relay should be included as part of the controller and the controller should be piped for bumpless transfer.

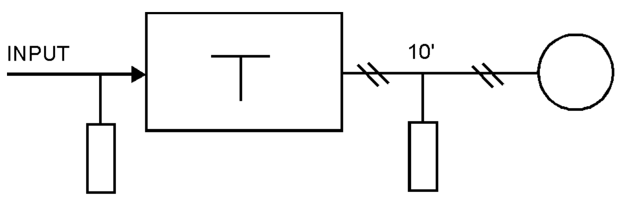


Figure 2 — Configuration A

If manufacturer's recommended minimum is more than 10 ft., use this minimum to prevent instability. This test will then give data for the smallest load the device or system can handle. This configuration represents a typical close-coupled pneumatic device such as a field transmitter and a controller with no long branch lines.

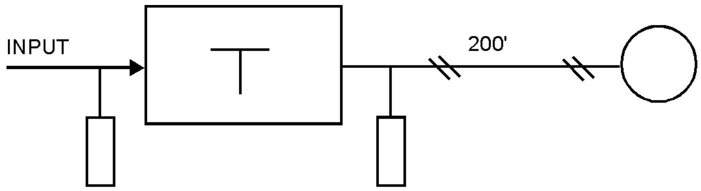


Figure 3 — Configuration B

This load looks like a long transmission line to the transmitter, or a short transmission line with a long branch. The response at the transmitter is the same for either case. In using the data for a field installation, it will be necessary to add the effects of the particular load used. Experience indicates that longer transmission lines will not significantly affect the response at the transmitter.

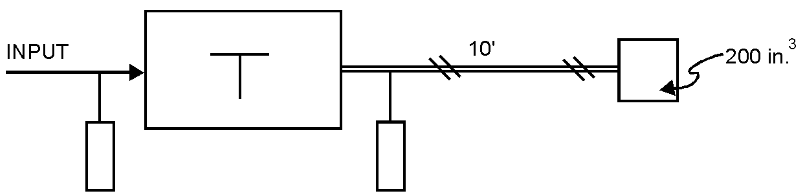


Figure 4 — Configuration C

This configuration represents the case of a large load such as a diaphragm motor. It was not felt that another test with longer tubing and this large load was needed since a booster or positioner would normally be interposed if dynamic response was critical. Also, experience indicates that this load is large enough that increasing it by lengthening the tubing will not have a significant effect on the response at the instrument.

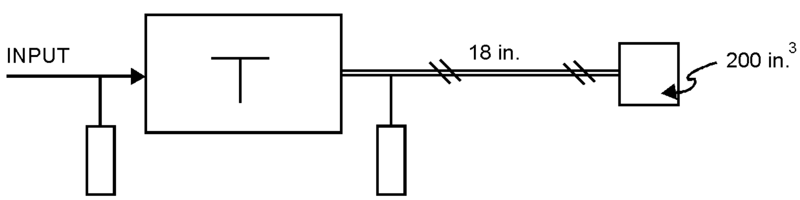


Figure 5 — Configuration D

This configuration represents the case of a close-coupled large load such as would be seen by a device intended primarily to deliver pneumatic power such as a booster or positioner.

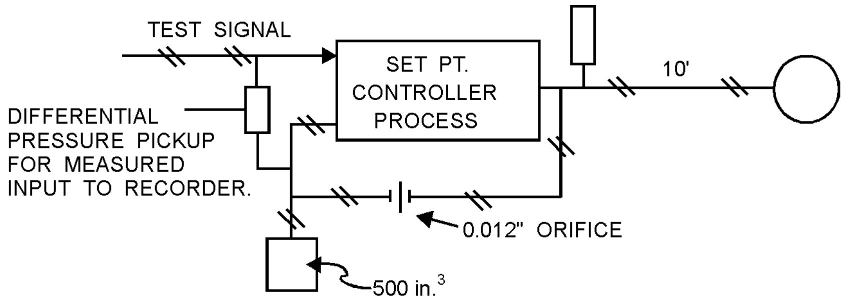


Figure 6 — Configuration E

This configuration is used to test the reset function in a pneumatic controller. The controller feedback connection should be hooked up in a normal way, in addition to the connections shown above. It is possible to make dynamic tests of controller reset functions with an open loop hookup, but it requires meticulous care and very stable test signals. For this reason, the above hookup, with a feedback loop to stabilize the controller, is recommended. The restriction and volume provide sufficient time delay to permit the effects of the reset circuit to be seen. (See the section on Integral or Reset Action and reference 17.)

4.3.2 Electrical

Devices designed for a specific receiving element or load, such as commercial electronic control systems, should be tested with the actual element they would normally use as the load. Equivalent resistive loads should be used only if the element thus replaced would present a purely resistive load to the unit under test.

A special load configuration is recommended for the optional dynamic test of controller reset or integral action.

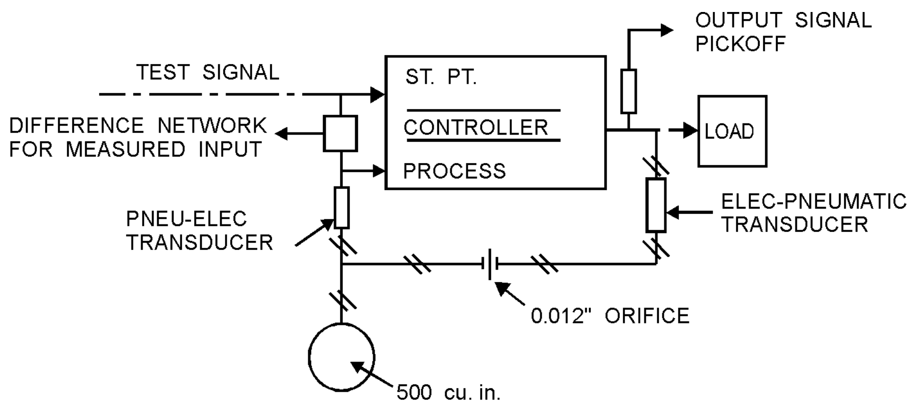


Figure 7 — Test configuration for reset function

The configuration of Figure 7 is used to test the reset function in an electronic controller. The controller feedback connection should be hooked up in a normal way, in addition to the connections shown above. It is possible to make dynamic tests of controller reset functions with an open loop hookup, but it requires meticulous care and very stable test signals. For this reason, the above hookup, with a feedback loop to stabilize the controller, is recommended. The restriction and volume provide sufficient time delay to permit the effects of the reset circuit to be seen.

It is easier to introduce the delay pneumatically, since many electronic controller output signals are not compatible with the input signals, and hardware of some sort is needed in any case (see Reference 18 and Section 4.5.2).

4.4 Signal generation

The general recommendations of this ISA Standard cover signal generation for standard pneumatic pressure ranges or electrical inputs. In the case of process variable transmitters, signal generation can become a considerable problem. Where extremely high-range instruments are involved, it may be necessary to test similar instruments of lower range, because the test signals needed are too large to be practical. The following recommendations and comments on generating test signals for three of the more difficult types of measurements are intended to provide uniform and realistic tests.

4.4.1 Differential pressure

It is recommended that dynamic tests be run on differential pressure measuring devices first with air and then with water in the measuring chamber and connecting piping. In a liquid-filled system, even a slight movement of the measuring element displaces the liquid into or from the measuring chamber through the impulse lines. The mass of liquid in the lines is moved due to the incompressibility of the liquid. Experience indicates that this can significantly affect the dynamic response of the differential pressure device. The magnitude of the effect depends on measuring element size, port size, measuring chamber geometry, and mass of liquid in the impulse lines. Figure 8 illustrates the recommended setup for the input side of the transmitter for the "wet test."

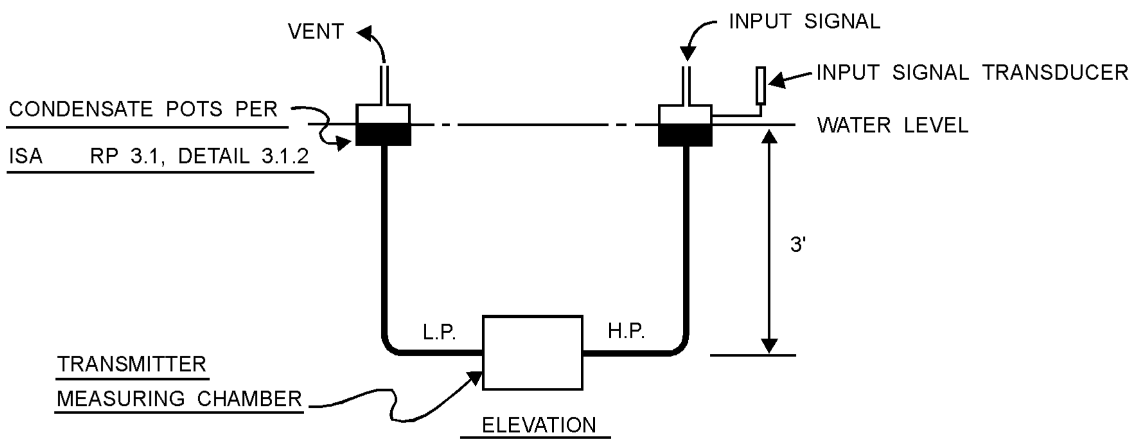


Figure 8 — Recommended wet test setup

Even a slight amount of unvented gas in the measuring chamber will change the test results markedly. Experience indicates that a system left standing overnight should be vented in case there are trapped bubbles coming from air that had been dissolved in the water.

In both the "wet" and "dry" tests, the low-pressure connection should be vented to atmosphere rather than held at a reference pressure level, to prevent the dynamic effects of a reference pressure system from affecting the test.

4.4.2 Temperature

Generation of sinusoidal, step, or pulse-type temperature signals which will provide useful data not only for comparison but for control system design requires that the heat transfer coefficient of the film surrounding the temperature element be known, since this is the dominant resistance to heat flow. Response in any other liquid or gas may then be computed, if the heat transfer coefficient surrounding the temperature element in the process fluid is known. Treatment of this technique is beyond the scope of this Standard (see references 12-14).

In order to obtain dynamic data with a known heat transfer coefficient, it is recommended that the sensing element be installed in a 2-inch Schedule 40 pipe tee or equivalent so that the axis of the element is parallel to the flow axis, and a flow of water at two feet/second impinges on the end of the element, well, or bulb. A bare thermocouple of #22-gauge wire with smallest feasible junction should be used to measure temperature of the stream just upstream of the element, well, or bulb. The temperature of the flowing water stream can be modulated approximately sinusoidally by switching from hot to cold sources. (Such test units are described in references 9 and 10.)

The following method has been tried and used successfully to generate sine wave and pulse input signals for the dynamic testing of temperature measuring devices:

A steam water mixer was used to change the temperature of the water impinging upon the temperature measuring element. This device is designed to mix steam and water to produce relatively instantaneous hot water. The temperature of the water leaving this unit is directly proportional to both the entering steam and water pressures. The entering water pressure was held constant by a conventional pneumatic pressure indicating controller (PIC) system.* The pressure of the entering steam was controlled by an electric pressure indicating controller. The output of an electronic sine wave generator was cascaded into the steam PIC loop and used to obtain sinusoidal and pulse variations in water temperature.

It should be pointed out that calculation of sine wave response data from step test data or from physical dimensions is preferred by many, in the case of temperature instruments, because of the difficulties encountered in generating a signal and converting the data to the case at hand. (Such methods are described in references 11 and 15.)

However, if a step test is made by plunging the element, well, or bulb into an agitated temperature bath, it is almost impossible to determine a reasonable film coefficient value for the test conditions, hence the data are difficult to apply to process control design. It is recommended that such step tests, and calculated sine wave response data, be clearly labelled as such.

For three reasons the test should be made with the element unprotected unless this is physically impossible:

1) The size and configuration of possible protecting tubes or wells are so varied as to make data for any specific one applicable only to a few cases.

2) Where dynamic response is critical, a minimum mass protecting well is often built if the element cannot be inserted unprotected. The dynamic effects of such a well can be estimated fairly accurately or determined separately by a dynamic test.

3) The data with the element unprotected are the best possible data for design or comparison purposes, since it describes the ultimate capability of the device.

It should be emphasized that this standard is intended to present an acceptable minimum number of tests, and not to exclude any other tests that might be desired for a particular case. Response data for all sine wave tests of temperature instruments should indicate whether the element was unprotected or in a thermowell.

4.4.3 Liquid level

The geometry of possible purchased or field fabricated displacer chambers and their connecting piping and valves is so varied that no attempt is made to recommend testing in a particular chamber, although these configurations can significantly affect the overall dynamic response. These effects can be calculated or determined by tests of the particular installation. The tests

*Abbreviation taken from ISA S5.1 (Y32.20), Instrumentation Symbols and Identification.

recommended below will be more generally useful for performance characterization and design work. (See reference 16.)

Very few tests have been run to date in which a displacer or float was actually disturbed by a sinusoidal level change. Most tests have been made by mechanical coupling of a sinusoidal motion to the dry float or displacer. Such testing, without actual level changes, omits the resonant effects of the displacer (or float) and torque tube, which can be significant in practical process control problems.

It is possible to calculate the resonant frequency of the displacer (or float) and torque tube, and combine this data from a dry test of the remainder of the instrument. This will normally result in reasonable accuracy for control design purposes. Any data so obtained should be clearly identified as such.

A proper dynamic test should include this spring-mass relationship. A chamber whose diameter is at least four times that of the float or displacer should be used for the dynamic testing and the liquid level should be varied by:

1) raising and lowering a sinusoidally driven cylinder in the level chamber to generate a sinusoidal level change by displacement,

2) raising and lowering the whole level chamber around the float or displacer by a mechanical drive, or

3) coupling a reciprocating piston to a level chamber to generate sinusoidal level changes. (This might be a modified positive displacement pump piston and cylinder.)

It is known that the first scheme has been used successfully. Such a test will give the frequency response the instrument would have if the float or displacer were placed directly in the process vessel. It does not take the varying viscosities of process fluids into account, but such a test could be run for any process fluid once the apparatus is built.

Any of the three methods above could be used to generate a pulse input by removing the sinusoidal driving mechanism and actuating the cylinder, level chamber, or piston manually or with a programmed pulse source.

4.5 Parameters

The recommended tests are a compromise between the desire to reduce testing costs and keep the amount of data to a minimum and the desire for a detailed study of the effect on dynamic response of parameters such as proportional band, reset rate, derivative action, damping, and loading.

It is not intended that these recommendations be construed to exclude other tests under a greater variety of conditions. Rather, they should be considered as the minimum needed for a practical description of the dynamic response of a device.

4.5.1 Transmitting devices

Damping adjustments on transmitting devices should be set to give minimum damping consistent with stable operation, usually 3 db down from first sign of instability. Where Figures 26 and 27 call for 100% proportional band, or gain of one, this setting should be determined by actual measurement, not by dial markings.

4.5.2 Controllers

Dynamic response testing of pneumatic or electric controllers can be divided into two parts:

1) Finding the dynamic response of the controller with various loads, when the parameters are set at an arbitrary fixed value.

2) Defining the dynamic response of the various controller parameters at several significant settings, with a constant load.

Item 1) is self-explanatory, but item 2) requires additional explanation. The test recommendations for this item are considered optional by the writing committee and are included to provide a uniform way of performing the tests if they are desired.

Rate or derivative action

Testing for dynamic response of the rate or derivative function can be performed in a relatively straight-forward manner, using an open-loop test configuration. Reset action should be minimized or removed during this test. The gain of the rate circuit will tend to cause saturation at higher test frequencies.

For this reason, the input signal magnitude should be such that at high test frequencies the output signal is 10 percent of the output span of the device. The required input signal value can be calculated by dividing 10 percent of the output signal span by the derivative or rate gain. It can also be determined by experimenting with the test setup.

Integral or reset action

The reset circuit of practically all process controllers has a magnitude ratio response curve as shown in Figure 9.

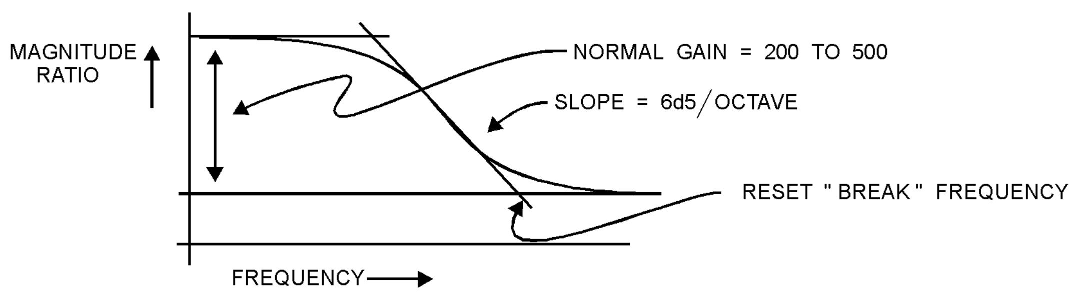


Figure 9 — Magnitude ratio response

It is worthwhile to run step or static tests to recalibrate the reset gain and to determine the maximum dc gain of the reset circuit. Details of this procedure are not within the scope of dynamic testing. (See Reference 17 for further discussion.)

Dynamic testing of reset circuits is difficult to perform sinusoidally, especially with an open-loop design. The closed-loop test setup of Figure 6 is recommended. Dynamic testing of reset circuits is a relatively simple and straight-forward task when performed by the pulse method (see Section 7.4).

If the controller design is such that the set point is adjusted by a mechanical knob or link, the test setup of Figure 6 requires that a pneumatic-mechanical link, such as a bellows, be provided to move the set point from the test signal. The other choice for such controllers is to use an open loop test which is very difficult to perform without meticulous care and extremely stable test signals.

The time constant of the feedback network, with a 0.012 inch orifice, is such that the feedback system dynamics can be neglected for test frequencies of 0.01 cps and up. Lower test frequencies will require a smaller orifice diameter or larger tank volume. This network is included only to provide correction of any dc drift that may occur. The differential pickup measures the actual input of the reset circuit (deviation). Thus, any slight dynamic effects of the feedback circuit are eliminated by measuring the effective input signal to the controller. Sine wave tests of reset circuits require low frequency test signals and much time. Care must be taken to minimize or remove rate or derivative action.

Other tests Further testing can be done to determine the degree of interaction between reset, derivative, and proportional settings, as desired. These are not recommended as standard tests.

4.6 Air or power supply and operating conditions

The air supply pressure, electrical power, or hydraulic pressure should be set at the level recommended by the equipment manufacturer. Where pressure or electrical settings are provided within the equipment (cushion load pressure, second-stage hydraulic booster, Wheatstone Bridge supply voltage) they should be set at the level recommended by the equipment manufacturer.

Provisions should be made to measure the power supply value immediately before it enters the equipment. The supply source should be capable of regulating to ±2% of the desired level at all test conditions.

4.7 Final control elements

Final control elements may be divided into two classes, open-loop devices and closed-loop devices. For example, the pneumatic spring-opposed diaphragm-actuated control valve is an open-loop device. If a positioner is added, it becomes a closed-loop device.

The frequency response of an open-loop actuating device is principally dependent upon the dynamic characteristics and ability to deliver power of the controlling instrument as well as the impedance of the connecting tubing and parts, and therefore cannot be determined by itself.

The familiar spring and diaphragm actuator on a valve body is usually also nonlinear to some degree due to dead band caused by stuffing box or other friction forces and frequency response data may have limited significance (see Sections 3.1 and 7.1). Methods have been developed to compute the response of open-loop actuators from knowledge of physical dimensions, spring constants, and mass of plug or load. The discussion of these methods is beyond the scope of this Standard (see Reference 35). Such a computation, combined with a dynamic test of the pneumatic power source can yield reasonable results for a specific system, as can in some cases a dynamic test of the power source and actuator as one single system. This practice however, is limited to recommendations for testing closed-loop systems.

Sine wave and step tests as given in Figure 1 are recommended. The input span referred to here is that input signal that will drive the output signal through its full range.

If the recommended 10 percent peak-to-peak sine wave signal size causes excessive distortion, indicative of saturation, of the output signal before the attenuation or phase shift limits indicated below are reached, the test should be stopped and rerun with a 1 percent peak-to-peak sine wave signal. If the 10 percent signal causes excessive distortion, and the 1 percent signal is too small to be practical for the device being tested, a test may be run at an intermediate amplitude. This should be done only if the 10 percent and 1 percent signals provide results which are not usable.

The data for both tests should be plotted and clearly identified.

4.7.1 Testing of closed-loop actuators alone

The number of different loadings that might be put on a closed-loop actuator when it is used with some final element are so varied that there is little purpose to recommending an arbitrary loading when testing the actuator alone. Tests of closed-loop actuators alone should be made without a load. These data might be useful for comparison purposes and also for applications where the element being moved presents a negligible load to the actuator.

4.7.2 Testing of closed-loop actuators coupled to final control elements

In the case of control valves, it is extremely desirable to test the valve and actuator assembly under flowing conditions. The infinite variety of pressure drop, damping, and coercive forces presented by varying process fluids and conditions make this impractical, in the opinion of the committee. Actuators coupled to control valve bodies should be tested under no load conditions, with the valve body drained and open to the atmosphere. The packing or stuffing box should be tightened as required to hold a hydrostatic test pressure equal to the nominal valve body pressure rating. In most cases, the response under flowing conditions will not be significantly different from the response under such a dry test (see Reference 36).

When the actuator is coupled to other elements such as variable speed drive cranks or electrical rheostats, the possible parameters should be adjusted to simulate as closely as possible the normal operation of the system. For example, in case of a variable speed drive or a metering positive displacement pump, the pump or drive should be running so that the actuator makes its excursions against the resistance it normally encounters.

It is of prime importance in all cases that the adjustments of all parameters be clearly described in the data or on the curves that are plotted from the data.

4.7.3 Test configurations

The discussions of loading in the previous sections lead to the recommendation that in all cases the motion delivered by the actuator be measured as the output signal and the pneumatic, hydraulic, or electrical signal to the actuator as the input (see Figure 10).

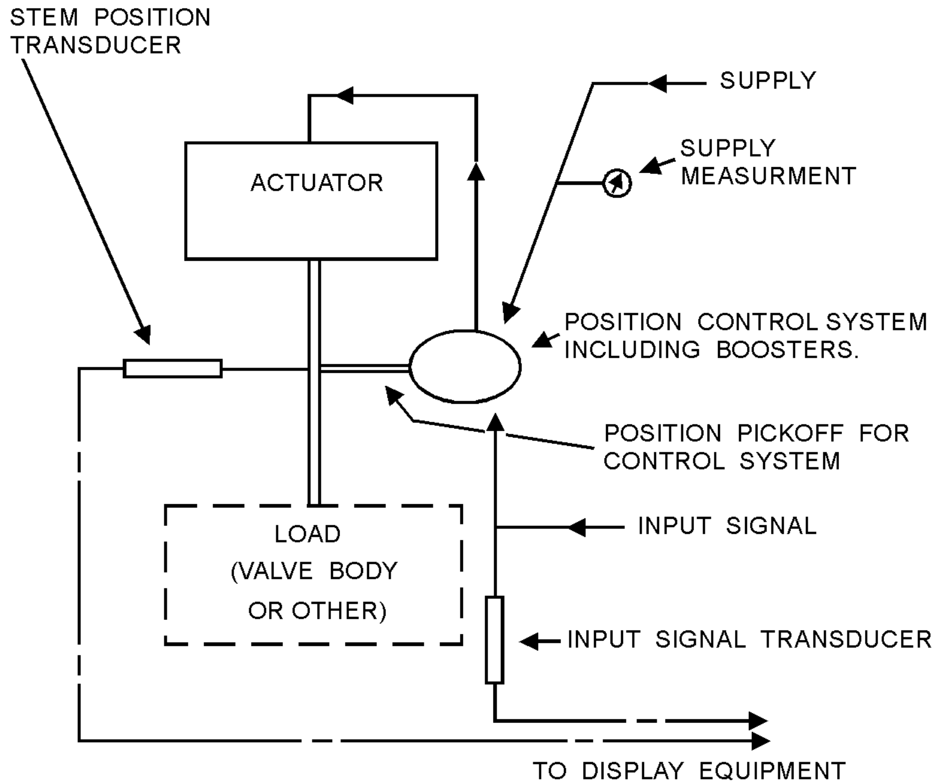


Figure 10 — Recommended loading test configuration

5 Test equipment and procedures — sine wave and step

5.1 Data required

5.1.1 Sine wave tests

1) Signal frequency.

2) Amplitude of input and output signals at each frequency.

3) Phase relationship of input and output signals at each frequency.

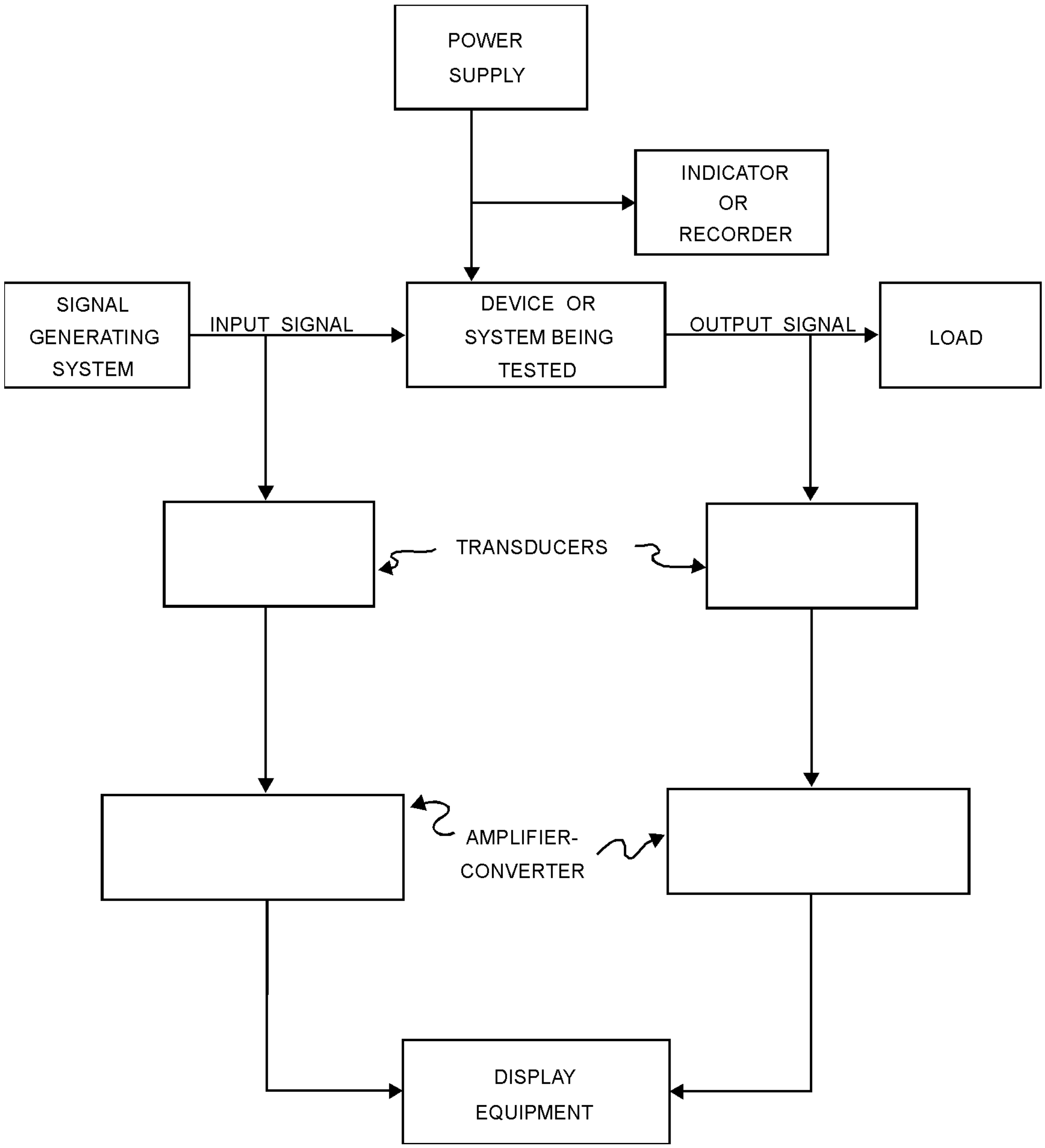


Figure 11 — Generalized dynamic test setup

4) Power supply variation (to device being tested) from lowest to highest frequency at greatest load.

5) Condition of system (adjustments, etc.).

5.1.2 Step tests

1) Input signal form from time zero to steady state.

2) Output signal form from time zero to steady state.

3) Power supply (to device being tested) variation during test.

4) Condition of system (adjustments, etc.).

5.1.3 Supporting data

See Section 6.3.

5.2 Generalized test setup

5.2.1 Block diagram (refer to Figure 11)

The transducers and amplifier-converters convert the input and output signals to the form required for the display equipment. With certain combinations of input signal type and display equipment (for example, electrical sine wave signals and oscilloscope) the transducers or amplifier-converters or both would not be necessary.

5.2.2 Location of output signal pickoff point

The output signal can be measured at either point "A" or "B" in Figure 12.

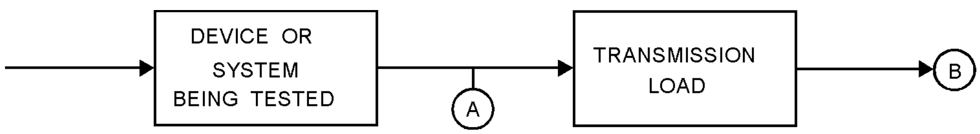


Figure 12 — Measurement points

If there is no interaction between the load and the device, it is obviously better to pick off the output at point "A." In system design, the response of the device can then be combined with the response of any load since the load does not affect the device response.

If the load will interact and affect the response of the device being tested, a case can be made for measuring the output at point "B." A thorough study has led to the recommendation that point "A" be used in all cases.

This choice does not affect the characterization function of these tests since the only requirement here is that all tests be on the same basis.

The choice of point "A" as the output pickoff point gives the system designer response data for the device alone (with the specific loads employed). He must then add the response of the load itself. The choice of point "B" would give response data for the device plus the load as a unit, for different loads.

This recommendation is based primarily on the fact that fewer tests are needed if point "A" is used, due to the nature of the various load configurations encountered (primarily in pneumatic work, where there is a major problem).

5.3 Test equipment

5.3.1 Signal generation

Sine Waves

Many devices for generating electrical sine waves are commercially available. Pneumatic and hydraulic sine wave generators are not as generally available, although some commercial units are made. One solution is to use an electrical sine wave generator with a commercial signal converting device (usually an electromechanical servo operating a pilot valve) whose output signal is pneumatic or hydraulic. Many combinations of adjustable speed sinusoidal mechanical drives coupled to a rheostat, pneumatic regulator, hydraulic regulator, or a combination of these can be constructed.

It is recommended that the sine wave generating device meet the following criteria:

1) Although the frequency range to be covered will vary (see Paragraph 5.1.1) for process control work, the generator should cover frequencies from 0.001 cps to 20 cps.

2) The sine wave generator must be capable of holding a given frequency without a great deal of variation.

It is recommended that acceptable performance be defined as shown in Figure 13.

At a given frequency, the period (A, B, C) of any two cycles should not vary more than ±2%.

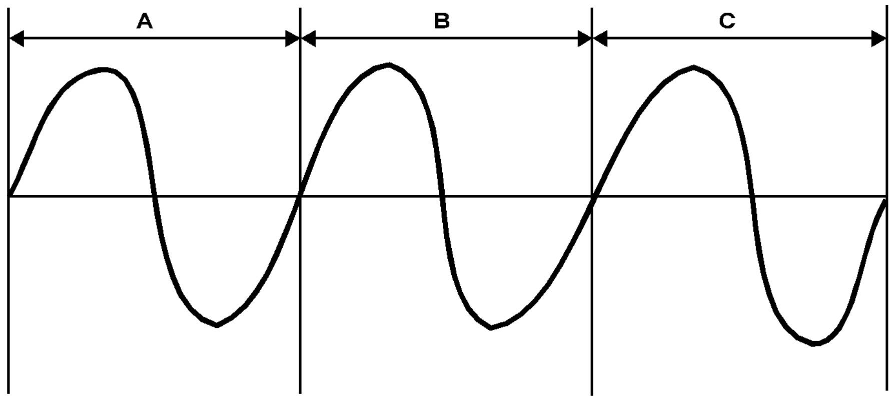


Figure 13 — Definition of acceptable performance

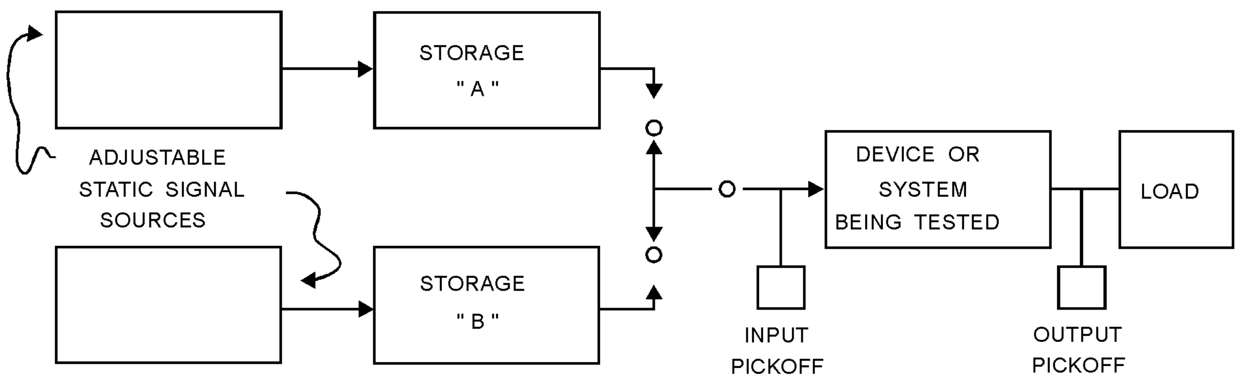


Figure 14 — Step signal generating circuit

Step Tests

Step signals can be generated by a signal generator-transducer combination similar to that mentioned above. A basic circuit for generating a step signal is given in Figure 14.

The following criteria should be met in constructing such a device for either electrical, pneumatic, or hydraulic testing:

1) The connecting wiring or piping between the storage units and the device being tested (including the switch) should present as small a resistance as possible.

2) The step input signal should rise to 95 percent of the final value in five percent or less of the time required for the output of the device under test to rise to 95 percent of the final value.

5.3.2 Display equipment

A multi-channel high speed recorder is the fundamental tool for dynamic test work. This recorder plots both input and output sine or step signals on the same time axis. Magnitude ratio is obtained by measurements of the relative peak-to-peak distances. Phase shift is determined by measuring displacement on the time axis and converting to angular units. Step test input and output are recorded and can be read directly. Such a recorder leaves a permanent record for re-examination. This method is recommended even though the data conversion for sine wave tests can be quite time consuming.

Various combinations of types of oscilloscopes can be used to display input and output sine wave signals. Lissajous figures or calibrated phase shift networks can be used to determine phase relationship, while the magnitude ratio can be determined by peak-to-peak measurement.

Camera attachments permit a permanent record to be made; however, these methods can cause considerable error unless used with extreme care by experienced personnel. They are not generally recommended.

5.3.3 Transducers and amplifier-converters

The transducer and amplifier-converter systems needed will depend upon the type of signal needed to drive the display equipment as well as the nature of the signals used for the test, i.e., pneumatic, electrical, hydraulic, or mechanical. Strain-gage transducers are commonly used for converting pressures to electrical signals. Linear variable differential transformers or multi-turn variable resistors are used for mechanical motion. The amplifier-converter units normally can best be selected by consulting the display equipment vendor, or in some cases the transducer manufacturer.

5.3.4 Test equipment performance specifications

From the standpoint of results only, the following transducer-amplifier/converter display equipment system performance is recommended.

1) Signal Amplitude — ±1 db from 0.001 cps to maximum frequency of test (at least to 20 cps).

2) Phase shift — less than 5° from 0.001 cps to maximum frequency of test (at least to 20 cps(Hz).

3) It is a general rule that the response criteria for test equipment should hold over a frequency range ten times as great as the frequency range over which the equipment being tested will meet this response criteria.

To minimize test difficulties, the following items should be carefully considered and compared before selecting test equipment:

1) Drift, whether due to ambient temperature, supply voltage, or equipment instability, can cause hours of extra test time. Overall drift should be less than 5% of the full span in four hours.

2) The chart scribing mechanism can cause difficulties at high speeds unless it is in excellent operating condition.

3) Mechanical components (chart drives, generator linkages, etc.) should be rugged and easy to change and adjust.

5.4 Test procedures

The following procedures are recommended as good practice and will aid in giving reliable results in minimum time.

5.4.1 Blank run

Whenever a new test setup is completed, make a "blank" run, bypassing the device being tested in such a manner that the phase shift and attenuation remain at zero, as frequency increases. Points deserving particular attention are:

1) Attenuation of one or both signals, phase shift, mechanical problems of inking and chart drive.

2) If the equipment is new, reworked, or has not been in use, leave all equipment "on" in about mid-scale position, noting displayed readings and intermediate signals if possible. Recheck after four hours in "on" position, drift should be less than 5 percent of full scale of display equipment.

3) Insert device to be tested and run quick check from minimum to maximum frequency, reading power supply level, at the device being tested, to check for ±2% specification (see Paragraph 3.4).

4) If step tests are to be run, check test setup as specified above.

5) Check referencing of traces of simultaneous recorder pens with respect to time. There may be an initial offset due to imperfect alignment of the pens.

5.4.2 Static calibration

It is recommended that the overall system be statically calibrated with an independent standard (manometer or VTVM) on the actual signals. The display equipment reading is thus known accurately at the start of the test. If drift is a problem, this should be repeated periodically. Calibration by test equipment knob settings should not be substituted for the above.

5.4.3 Selecting test frequencies

The frequency points should be selected as the test progresses in order to provide small increments at the critical points and avoid abrupt changes in the phase or magnitude curves. A general rule is to use at least twenty points for three decades of frequency.

5.4.4 Correlating results

Interpretation of the display equipment information is generally straightforward except when the sine wave is quite distorted. In this case, it is recommended that phase shift be determined as shown in Figure 15, assuming a multichannel recorder is used for display.

In such a case, where precise results are desired, the magnitude ratio and phase shift may be obtained by a Fourier analysis of the output wave. Procedures for this analysis are given in many standard reference works in the electrical field. The use of Lissajous figures can be helpful in obtaining accurate phase shift data where distortion is a problem.

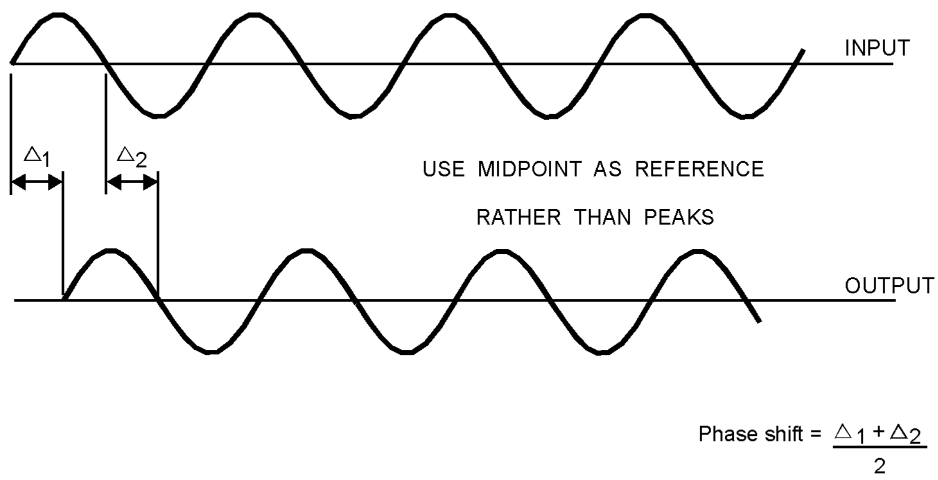


Figure 15 — Determination of phase shift

6 Data presentation — sine wave and step

6.1 Sine wave test data

Data from each sine wave test should be presented as two curves. One curve should show the magnitude ratio of the output signal to the input signal as a function of frequency, the other curve should show the phase shift of the output signal from the input signal as a function of frequency. Actual data points should be shown on curves.

The choice of type and size of paper, as well as the number of tests recorded on each sheet of paper are left to the discretion and needs of the originator of the data, with the exception of the recommended coordinates and list of supporting data given below.

The recommendations below are based on the standards recommended by the ASME/IRD Dynamic Systems Committee in ASME Standard 107, "Preferred Standards for the Presentation of Frequency Response Data." The recommendations in this document differ from those of the ASME/IRD only in having added some recommendations for the vertical axis of the magnitude ratio plot, and in recommending semi-log paper rather than log-log paper as a first choice for this plot.

6.1.1 Magnitude ratio plot

1) The preferred recommendation is that semi-log paper be used with magnitude ratio plotted in decibels linearly on the vertical axis, which should have an absolute magnitude ratio scale superimposed. Frequency should be plotted in cycles per unit time on the horizontal, logarithmic axis.

2) An alternate recommendation is to use log-log graph paper, with magnitude ratio plotted in absolute units on the vertical logarithmic scale, with a decibel scale superimposed. Frequency should be plotted in cycles per unit time on the horizontal logarithmic axis.

6.1.2 Phase shift plot

Phase shift should be plotted on semi-log paper, with phase plotted linearly on the V axis, and frequency in cycles per unit time on the horizontal logarithmic scale. Phase shift in degrees should be identified by a plus sign when the output leads the input, and by a minus sign when the output lags behind the input.

6.2 Step test data

Step test data should be presented on linear coordinate paper, with input and output signal magnitude in percent of its steady state change plotted on the vertical scale (which may be suppressed to bring out detail), and elapsed time in appropriate units on the horizontal scale.

In all step test plots the input signal should be plotted with a dashed or broken line, the output signal with a solid line. It is important to choose a time axis such that dead time and deviations from a true step input can be seen clearly. Since the step tests consist of a given step upset "upward" and the same size step signal "downward," these companion tests should be presented on the same graph to reduce the number of plots.

6.3 Supporting information

The following information should be included on each plot of dynamic response data:

1) Title of test;

2) Description of device or system tested, including model numbers, serial numbers, and sketch of test setup if appropriate;

3) Curve identification for each tabulation as follows:

Curve	Input Signal	Loading (Including Transmission)
Identifying code	Peak-to-peak magnitude and level for sine wave, direction and size for step test.	Description or code to sketches on plot

4) Description of test conditions.

   It is suggested that for brevity's sake the statement "Tested according to ISA Standard S26" be used. Otherwise, supply regulation, details of loading circuits, pickoff points, and any other pertinent data on test conditions such as gain setting, packing friction, or reset, should be included.

5) Supply voltage or pressure to device being tested.

6) Date, location of test, and supervisor's initials or names.

7 Recommended tests — pulse type

7.1 Input signals

Dynamic response testing by the pulse method consists of exciting a system with one pulse and obtaining, by mathematical analysis, the same data as those obtained by sinusoidal testing.

The pulse shape is not critical and does not have to follow a specific mathematical form. There are wave shapes that yield more useful information than others. The following pulse shapes are arranged in order of increasing frequency content.

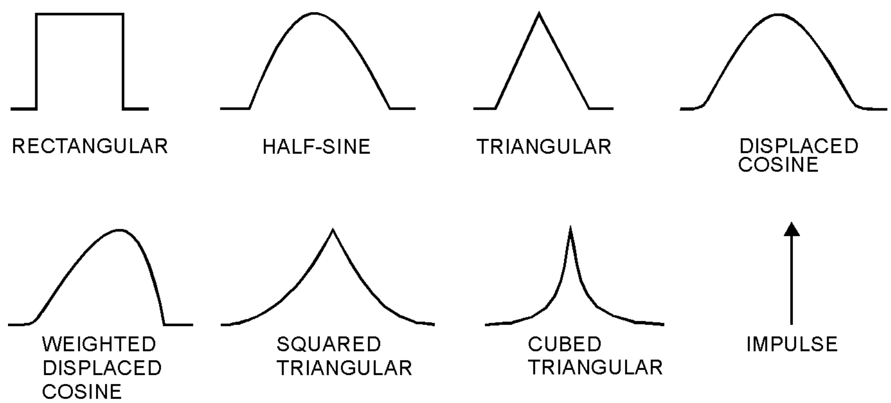


Figure 16 — Pulse input wave shapes

For laboratory testing of instrument components, the recommended pulse test signal is the displaced cosine. This signal shape possesses the greatest frequency content of those shapes for which signal generators are commercially available.

The recommended amplitude of the input pulse test signal is 10 percent of the actual input signal span of the device being tested. The input pulse should have the arithmetical mid-point of the input signal span as its center. The recommended input span is that span which will drive the output signal through its full range. Qualifications of this recommendation are discussed in the other documents on this series.

The degree of success achieved when a pulse-type forcing function is used to obtain dynamic data depends upon the width of the pulse used. The pulse width must be such that the system is properly excited. When the pulse width is long compared with the response of the system, the system is only moderately excited, thus suppressing high frequency information.

If the pulse width is too narrow, the device or system being tested will be forced into a region of saturation or nonlinear operation. When this happens the data obtained from the pulse test are not valid just as are the data obtained from a sine wave test at too great an amplitude or too high a frequency.

A general rule for predetermining the proper pulse width does not exist. The problem is that the shape of the output pulse does not change markedly as the device under test approaches saturation. The correct pulse width is the one that excites the device or system adequately, but does not force it into a condition of saturation. The problem of pulse width selection can be minimized by use of the guides given in this standard. Pulse widths determined by use of these guides have a reliability factor greater than 95 percent.

7.1.1 Tests when response is unknown

When the response of the device or system under test is completely unknown and cannot be determined even in general terms, it is recommended that a minimum of two pulse tests at different pulse widths be processed. The pulse widths should be in the general area of the width determined by Guide 1 stated in the following paragraph. The reason for running two or more tests is to ensure that the saturation or nonlinear region has not been entered.

Guides for obtaining valid tests are:

1) The proper pulse width should possess two characteristics:

   a) the peak of the output pulse shall be well removed timewise from the peak of the input pulse, and

   b) the output pulse peak should rise to 50-75% of the input pulse peak with a system gain of unity.

2) When input signal generating equipment that includes a selection of sine wave or pulse-type signals is used, determine the sine wave frequency at which the output wave is attenuated to 30 percent of the input wave. Then use a pulse width which has a period of twice this frequency.

These guides are not valid for obtaining the rate or reset characteristics of controllers. These special cases are discussed in Sections 4.2 and 7.4. Examples of good and poor tests are shown in Figures 17, 18, and 19.

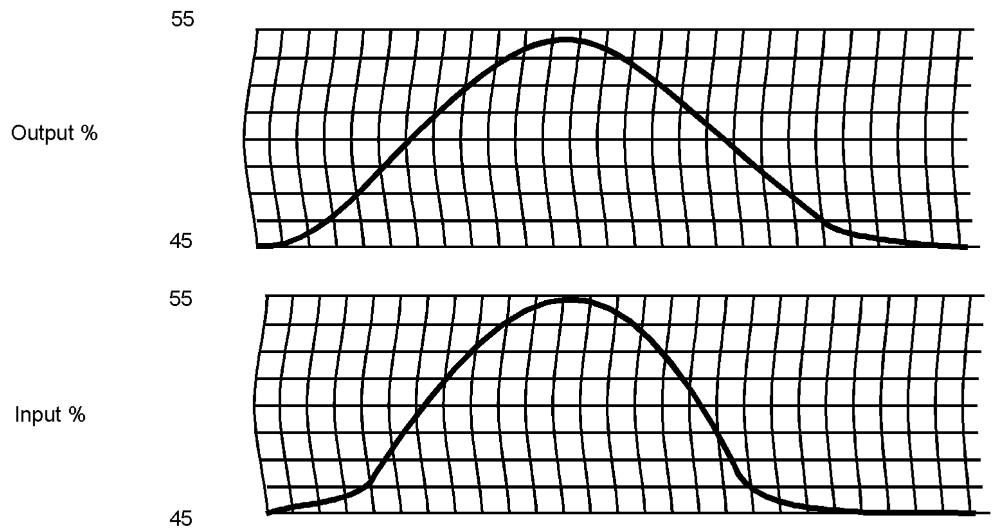


Figure 17 — Poor test, pulse width too long

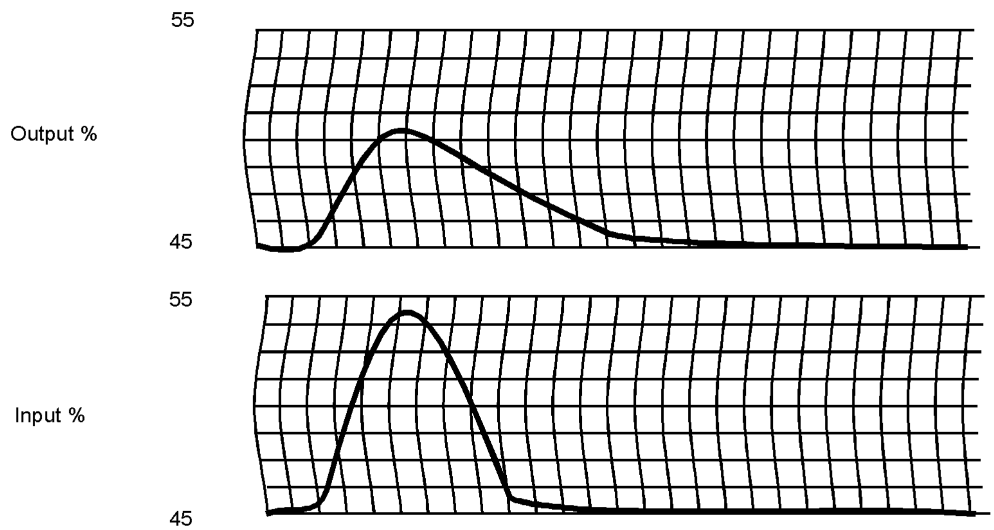


Figure 18 — Good test, pulse width satisfactory

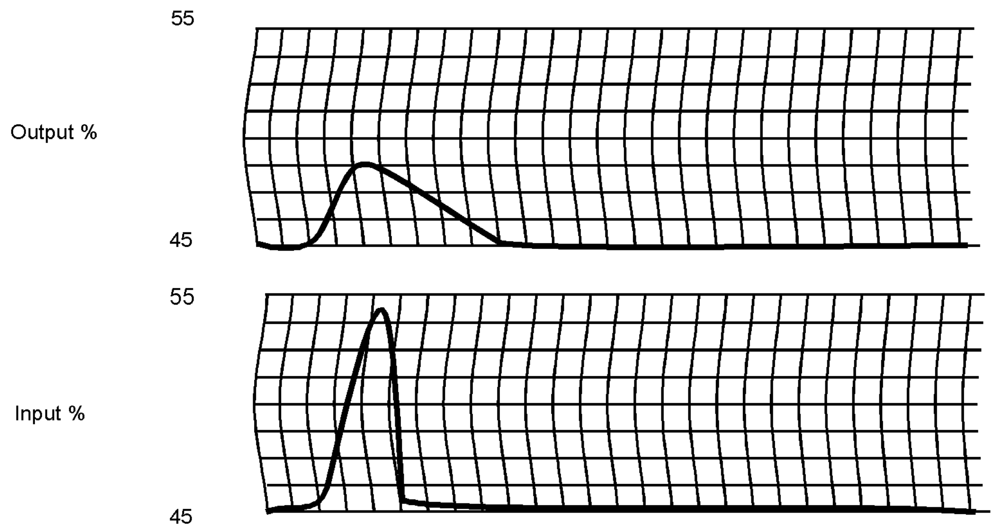


Figure 19 — Poor test, pulse width too narrow

7.1.2 Analysis of test data

The mathematical analysis of the input and output pulse data requires the use of either an analog or a digital computer. To perform these computations manually would be very laborious and time-consuming and outweigh any advantages gained by the use of this method. The necessity of requiring a computer to perform the mathematical computation is not considered a serious limitation. There are analog computers currently available that are especially designed to perform the necessary computation. The use of a digital computer requires a program, available from ISA for a nominal fee. Address request to ISA, P.O. Box 12277, Research Triangle Park, NC 27709. The items and figures listed under Section, 8.1 "Data Required" refer specifically to the ISA program.

7.2 Load configurations

See Sections 4.2 and 4.3.

7.3 Signal generation

See Section 4.4.

7.4 Parameters

See Section 4.5.

Rate or Derivative Action

See Section 4.5.2.

An example of a good pulse test for obtaining the rate characterization of a controller is shown in Figure 20.

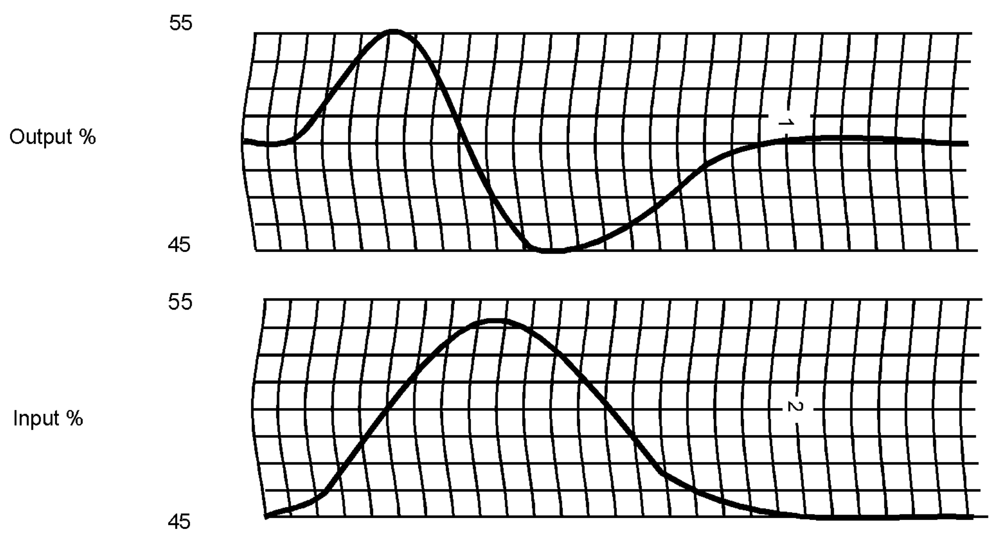


Figure 20 — Good pulse signal for rate characterization test

Integral or Reset Action

See Section 4.5.2.

The pulse method permits the procurement of the integral or reset characterization of a controller in a relatively straightforward manner, using an open-loop test configuration. A ramp-type input signal is recommended for the integral characterization test. The availability of a signal generator that can produce one triangular wave at will is desirable for this test. For reset times greater than 0.05 minute set the frequency of the triangular wave generator to $\frac{9}{8\ (\text{reset in seconds})}$ cps and for reset times less than 0.05 minute set the frequency to $\frac{9}{4\ (\text{reset in seconds})}$ cps . The period of the ramp signal should be of sufficient duration for the new steady state level of the output signal to increase 15 percent of full scale calibration for reset times greater than 0.05 minute and 33 percent of full scale calibration for reset times less than 0.05 minute. An example of a good test is shown in Figure 21.

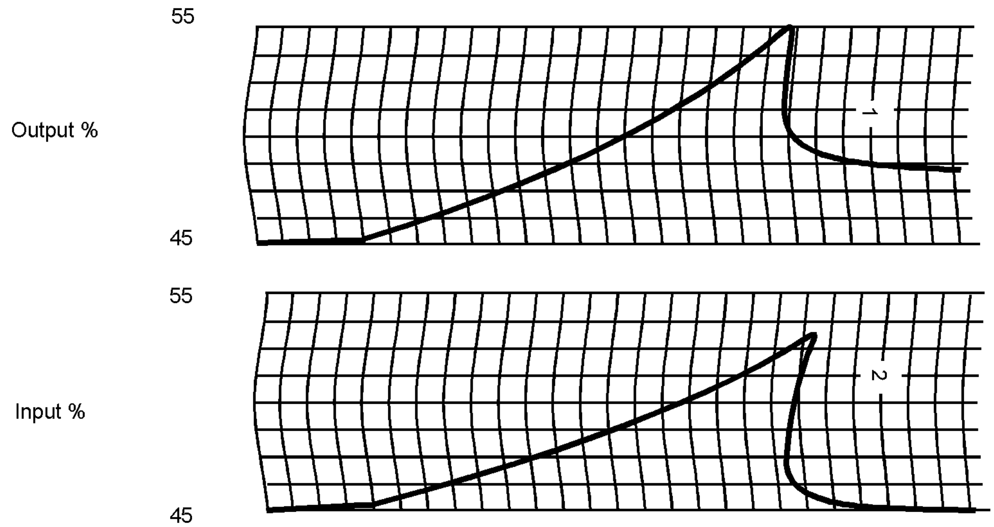


Figure 21 — Good ramp test for reset action

Other Tests

Further testing can be done to determine the degree of interaction between reset, derivative, and proportional settings, as desired. These are not recommended as standard tests.

7.5 Air or power supply

See Section 4.6.

8 Test equipment and procedures — pulse type

8.1 Data required

8.1.1 Analog computer

All scaling information such as transducer ranges and amplifier sensitivities should be tabulated. In addition to recording the input/ output curves on paper, the curves shall be recorded in an electrical form such as on magnetic tape. The electrical recordings are used as input signals to the analog computer.

8.1.2 Digital computer

Refer to Figure 22 for items 1-5.

1) total number of points in each curve.

2) the Δt values in unit time.

3) the number of points using each Δt value.

4) the amplitude at each point.

5) the specific frequencies at which calculations are to be made.

6) variations in power supply to device being tested during test.

7) conditions of systems, including necessary adjustments.

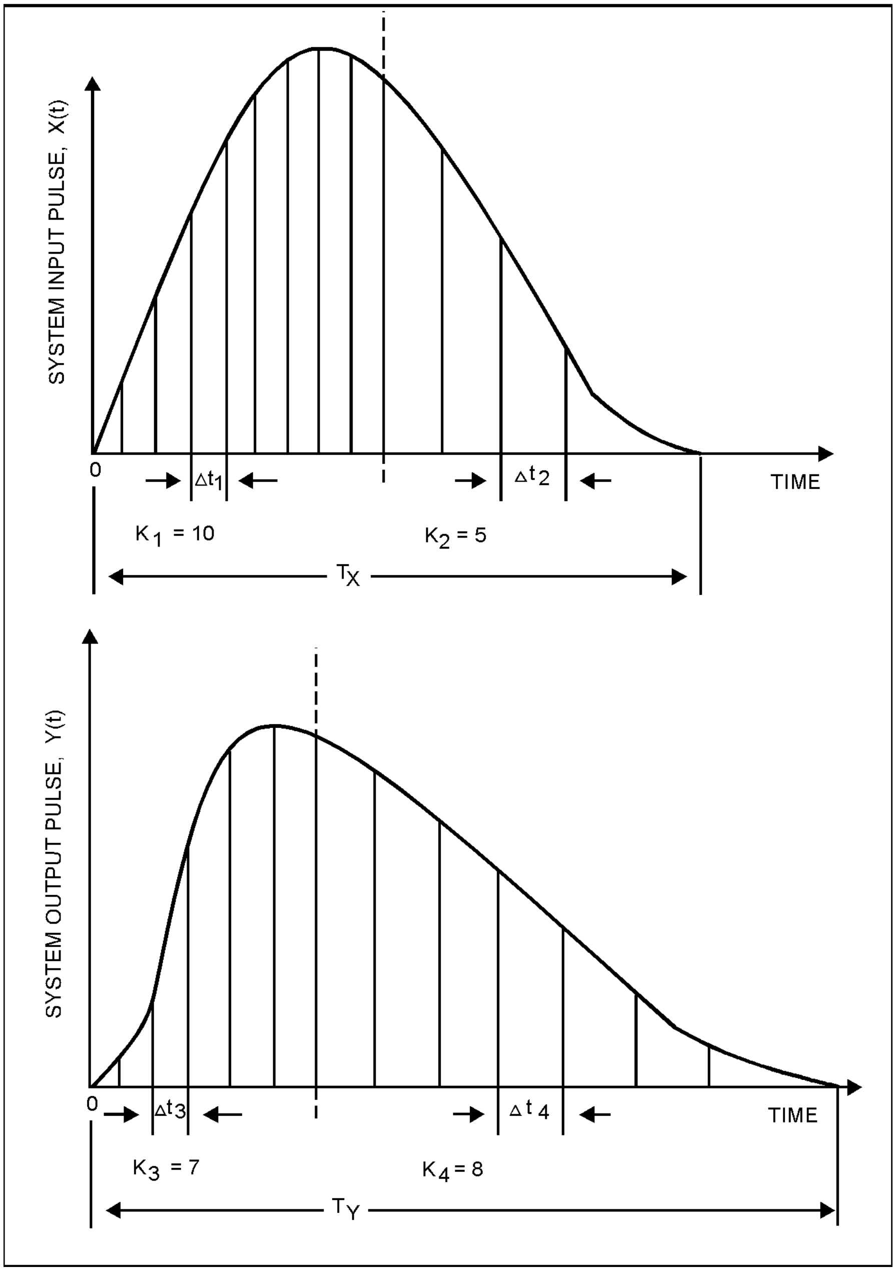


Figure 22 — Typical input and output pulses and their dissection.

In many cases, as in this illustration, one portion of the curve changes more rapidly than another portion. In such cases it is convenient to read a large number of points in the portion of fastest change, and fewer points when the change is more gradual. The digital computer program mentioned in Section 7.1.2 is written to accept two different increments of time on both the input and output pulses. Thus the program input consists of the input data points, x_o through x_n; the output data points, y_o through y_n; the four Δt values, two for x(t) and two for y(t); and the number of points read using Δt.

8.2 Generalized test setup

See Section 5.2.

8.3 Test equipment

8.3.1 Signal generation

Many devices for generating electrical sine waves are commercially available. A device which can be modified to generate a displaced cosine wave of one period duration at will is recommended for pulse testing. A signal converting device can then be used to obtain a pneumatic or hydraulic signal as the situation requires.

It is recommended that the sine wave generating device meet the following criteria:

1) The frequency range to be covered will vary (see Section 7.1); however, for process control work, it is recommended that the generator cover frequencies from 0.001 to 20 cps.

2) The sine wave generator must be capable of holding a given frequency without a great deal of variation.

It is recommended that acceptable performance be defined as shown in Figure 13.

8.3.2 Display equipment

See Section 5.3.2.

8.3.3 Transducers and amplifier-converters

See Section 5.3.3.

8.3.4 Test equipment performance specifications

See Section 5.3.4.

8.4 Testing procedures

The following procedures are recommended as good practice and will aid in giving reliable results in minimum time.

8.4.1 Blank run

See Section 5.4.1.

8.4.2 Static calibration

See Section 5.4.2.

8.4.3 Selecting test frequencies

The pulse width is selected as outlined in Section 7.1. The selection of the frequencies used for calculation is arbitrary. The highest frequency used, however, should not be more than three times the frequency whose period is equal to that of the pulse width. A rule of thumb is to have 20 points for three decades of frequency.

9 Data presentation — pulse type

9.1 Pulse test data

See Section 6.1.

9.2 Step test data

See Section 6.2.

9.3 Supporting information

See Section 6.3.

10 Glossary

Attenuation: see *Gain*.

Decibel or dB: a measure of magnitude ratio; magnitude ratio is dB=20 $\log_{10}$ (magnitude ratio).

Distortion: deformation of signal shape by device or system to which it is applied.

Gain: ratio of output signal magnitude to input signal magnitude; when less than one this is usually called attenuation.

Impedance, input: the impedance presented by a device or system output element to the input.

Impedance, output: the internal impedance of an output element which limits that element's ability to deliver power.

Linearity: characteristic of a device or system which can be described by a linear differential equation with constant coefficients.

Lissajous figure: pattern on an oscilloscope screen which indicates relative phase and magnitude of sinusoidal signals.

Loading: that system connected to the output of a device, including the transmission network.

Magnitude ratio: ratio of output signal magnitude to input signal magnitude (see also *Gain*).

Magnitude signal: peak-to-peak value of signal.

Octave: any group or series of eight.

Phase shift: difference between corresponding points on input and output signal wave shapes, disregarding any difference in magnitude (see Figure 23).

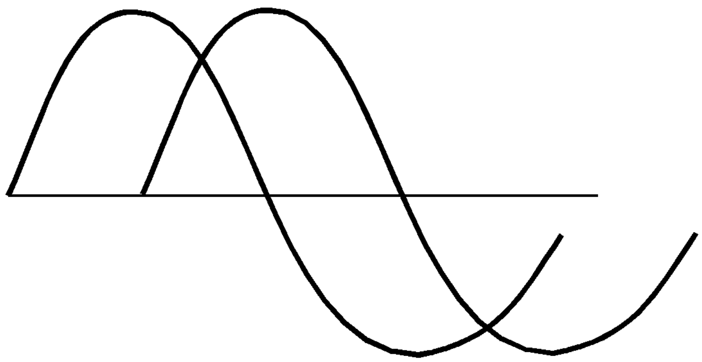


Figure 23 — Phase shift

Phase lag: phase shift when the output lags the input.

Pulse: a variation of a signal whose magnitude is normally constant; this variation is characterized by a rise and a decay, and has a finite duration.

Range: the range of an instrument is the region covered by the span and is expressed by stating the two end-scale values.

Response: the change in output of a device in relation to a change of input.

Span: the span of an instrument is the algebraic difference between its end-scale values.

Sine wave: a signal varying with time which can be obtained through projection of a rotating vector of constant magnitude with constant angular velocity on a linear scale (see Figure 24).

Step function signal: signal shown in Figure 25.

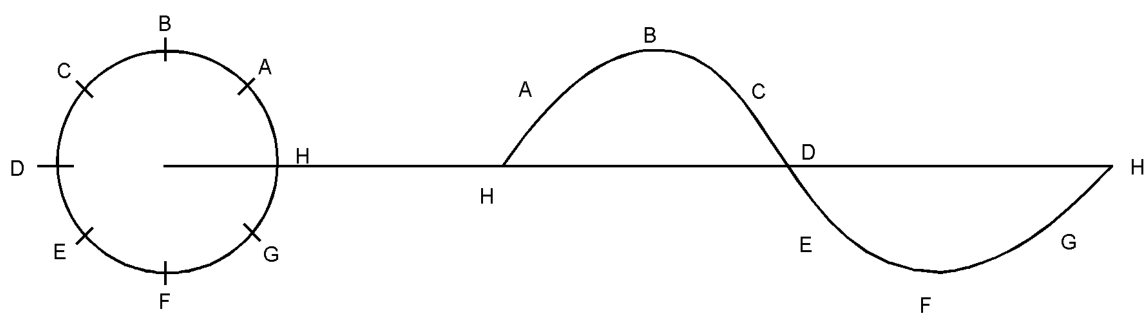


Figure 24 — Definition of a sine wave

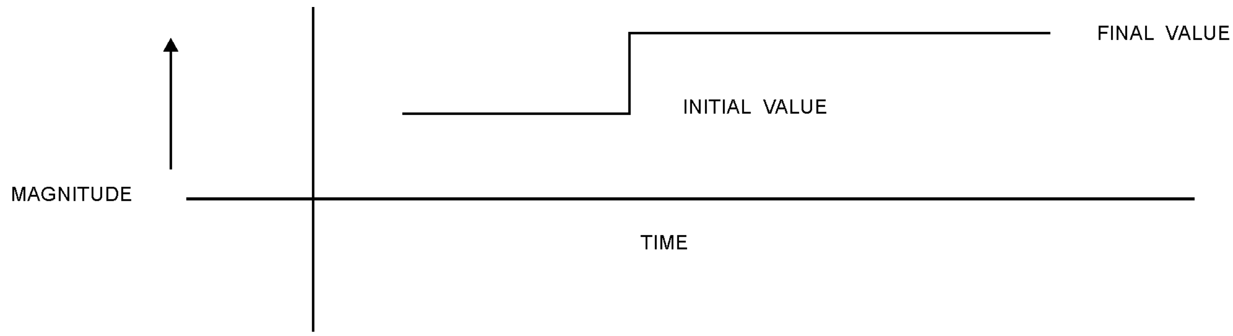


Figure 25 — Definition of a step signal

11 Recommended test tabulations

The following tabulations, Figures 26, 27 and 28, summarize the number of signal, loading, and parameter combinations recommended for dynamic response testing of each type of device.

Figure 26 — Recommended test tabulation for devices with pneumatic output

Component	Test No.	Test Signal*	Load** Configuration	Parameter Settings & Other Remarks
Differential Pressure Transmitter	1 2 3	Sine Wave or Pulse Sine Wave or Pulse Step tests	A B B	Test with water legs on each impulse connection per Section 4.4.1. Adjust damping to minimum possible value. Set span adjustments to midpoint of the values possible for the physical components of the transmitter. Separate tests are needed for each of measuring or feedback element size.
	4 5 6	Sine Wave or Pulse Sine Wave or Pulse Step Tests	A B B	Same as above, except dry test (no water legs), per Section 4.4.1.
Temperature Transmitter	1 2 3	Sine Wave or Pulse Sine Wave or Pulse Step Tests	A B B	Use unprotected sensing element. Test without rate (derivative) action, or with such action adjusted to give minimum effect. Separate tests are required for each change in measuring elements or internal parts such as are used for changing spans. See Section 4.4.2 for geometry of test system. Additional tests with a particular thermowell may be desirable. Data from such tests should be clearly identified.
Displacer or Float-Type Level Transmitters	1 2 3 4	Sine Wave or Pulse Sine Wave or Pulse Sine Wave or Pulse Step Tests	A B C C	See Section 4.4.3 for discussion of signal generation. For displacer-type instruments, adjust transmitter for 100% proportional band (gain of one)† for smallest displacer size regularly supplied. Separate tests are needed for other displacer sizes. If any other control modes are included, remove or adjust for minimum effect.
Transmitters General (Transducers)	1 2 3	Sine Wave or Pulse Sine Wave or Pulse Step Tests	A B B	Adjust parameters per Section 4.5.
Controllers	1 2 3 4	Sine Wave or Pulse Sine Wave or Pulse Sine Wave or Pulse Step Tests	A B C C	Adjust all controller modes (derivative, reset) to minimize or remove their effect. Set proportional band at 100% (gain of one)†. Automatic to manual switching devices must be in circuit for tests, per Section 4.3.
	5	Sine Wave or Pulse	B	With controller modes as above, set proportional band at 50% (gain of 2)†.
	6	Sine Wave or Pulse	B	With controller modes as above, set proportional band at 200% (gain of 1/2)†.
				Tests 7 through 11 are intended to provide a recommended standard method for characterizing the controller parameters by dynamic tests and are optional.
Optional reset or integral action characterization tests	7	Sine Wave or Pulse	E	With 100% proportional band, and minimum or zero derivative, set reset at 1 repeat/min.
	8	Sine Wave or Pulse	E	Same as Test 7, except set reset at maximum repeats/min.
	9	Sine Wave or Pulse	E	Same as Test 7, except set reset at minimum repeats/min.
Optional derivative or rate characterization tests	10	Sine Wave or Pulse††	B	With 100% proportional band, and minimum or no reset, set derivative for minimum effect.
	11	Sine Wave or Pulse††	B	Same as Test 10, set derivative at 1 repeat/min.
Devices Designed for Power Output to Pneumatic Actuators	1 2 3	Sine Wave or Pulse Sine Wave or Pulse Step Test	B D D	

* As defined in Figures 1 and 10.

** See Section 4.3 for details.

† Actually measured, not based on knob setting.

†† See Section 4.5.2 for methods of determining magnitude of test signals.

Figure 27 — Recommended test tabulation for devices with electric output

Component	Test No.	Test Signal per Figs. 1 and 10.	Parameter Settings & Other Remarks
Differential Pressure Transmitter	1 2	Sine Wave or Pulse Step Tests	Test with water legs on each impulse connection per Section 4.4.1. Adjust damping to minimum possible values. Set span adjustment to midpoint of the values possible for the physical components of the transmitter. Separate tests are needed for each change of measuring or feedback element size.
	3 4	Sine Wave or Pulse Step Tests	Same as above, except dry test (no water legs), per Section 4.4.1.
Temperature Transmitter	1 2	Sine Wave or Pulse Step Tests	Use unprotected sensing element. Test without rate (derivative) action, or with such action adjusted to give minimum effect. Separate tests are required for each change in measuring elements or internal parts such as are used for changing spans. See Section 4.4.2 for geometry of test system. Additional tests with a particular thermowell may be desirable. Data from such tests should be clearly identified.
Displacer or Float-Type Level Transmitters	1 2	Sine Wave or Pulse Step Tests	See Section 4.4.3 for discussion of signal generation. For displacer-type instruments, adjust transmitter for 100% proportional band (gain of one) * for smallest displacer size regularly supplied. Separate tests are needed for other displacer sizes. If any other control modes are included, remove or adjust for minimum effect.
Transmitters General (Transducers)	1 2	Sine Wave or Pulse Step Tests	Adjust parameters per Section 4.5.
Controllers	1 2	Sine Wave or Pulse Step Tests	Adjust all controller modes (derivative, reset) to minimize or remove their effect. Set proportional band at 100% (gain of one)*.
	3	Sine Wave or Pulse	With controller modes as above, set proportional band at 50% (gain of 2)*.
	4	Sine Wave or Pulse	With controller modes as above, set proportional band at 200% (gain of 1/2)*. Tests 5 through 9 are intended to provide a recommended standard method for characterizing the controller parameters by dynamic tests and are optional.
Optional derivative or rate characterization tests	5	Sine Wave** or Pulse	With 100% proportional band, and minimum or no reset, set derivative, for minimum effect.
	6	Sine Wave** or Pulse	Ditto, set derivative knob at 1 min.
Optional reset or integral action characterization tests	7	Sine Wave or Pulse	Set up test per Fig. 10 with 100% proportional band, and minimum or zero derivative, set reset at 1 repeats/min.
	8	Sine Wave or Pulse	Ditto, set reset at maximum repeats/min.
	9	Sine Wave or Pulse	Ditto, set reset at minimum repeats/min. possible with knob setting or ability of test equipment.

* Actually measured, not based on knob setting.

** See Section 4.5.2 for method of determining test sine wave magnitude.

Figure 28 — Recommended test tabulation for closed loop final control elements and actuators

SYSTEM BEING TESTED	TEST SIGNALS	PARAMETER SETTINGS	REMARKS
1) Actuator Alone	a) Sine Wave	Adjust gain (or other adjustments available) to give minimum damping consistent with stable operation (usually 3 db down from first sign of instability).	Recommended Test
	b) 10% Step c) 80% Step Per Section 4.7		
	d) Pulse Test Per Sections 4.2 and 4.3	(Instead of Sine Wave)	
2) Actuator on Valve Body	Same as 1)	Tighten valve packing to hold nominal body rating pressure of valve. Adjust gain or other adjustments per 1) above. Run tests with valve body open to atmosphere.	Recommended Test
3) Actuator on Other Final Element (Pump, Rheostat, etc.)	Same as 1)	Set up final element to duplicate as nearly as possible actual operating conditions. Adjust actuator system gain or other adjustments per 1) above.	Recommended Test
4) Actuator on Valve Body at Flowing Conditions	Same as 1)	Same as 2)	Optional Test

NOTES: (1) Describe loading and adjustments of parameters clearly and completely on all data or curves obtained from these tests.

(2) In all cases, measure actuator stem motion as output signal.

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13 Index

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