Designation: E 317 – 94

An American National Standard

Standard Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Systems Without the Use of Electronic Measurement Instruments[1]

This standard is issued under the fixed designation E 317; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This practice describes procedures for evaluating the following performance characteristics of ultrasonic pulse-echo testing systems: Horizontal Limit and Linearity; Vertical Limit and Linearity; Resolution-Entry Surface and Far Surface; Sensitivity and Noise; Accuracy of Calibrated Gain Controls. Relevant terminology can be found in Terminology E 1316 and IEEE Standard 100.

1.2 Ultrasonic test systems using pulsed-wave trains and A-scan presentation (rf or video) may be evaluated.

1.3 The procedures are applicable to shop or field conditions; additional electronic measurement instrumentation is not required.

1.4 This practice establishes no performance limits for test systems; if such acceptance criteria are required, these must be specified by the using parties.

1.5 The specific parameters to be evaluated, conditions and frequency of test, and report data required, must also be determined by the user.

1.6 This practice is intended primarily for the evaluation of a complete testing system, including search unit, instrument, interconnections, and fixtures. However, certain characteristics of the instrument alone can be determined within the limitations discussed.

1.7 Required test apparatus includes selected test blocks and a precision external attenuator (where specified) in addition to the system to be evaluated.

1.8 Precautions relating to the applicability of the procedures and interpretation of the results are included.

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 114 Practice for Ultrasonic Pulse-Echo Straight-Beam Examination by the Contact Method[2]

E 127 Practice for Fabricating and Checking Aluminum Alloy Ultrasonic Standard Reference Blocks[2]

E 214 Practice for Immersed Ultrasonic Examination by the Reflection Method Using Pulsed Longitudinal Waves[2]

E 428 Practice for Fabrication and Control of Steel Reference Blocks Used in Ultrasonic Inspection[2]

E 1316 Terminology for Nondestructive Examinations[2]

2.2 *Other Standard:*

IEEE Std 100, *IEEE Standard Dictionary of Electrical and Electronic Terms*[3]

3. Summary of Practice

3.1 A testing system to be evaluated comprises an ultrasonic pulse-echo instrument, search unit, interconnecting cables, and couplant; for immersion testing systems suitable fixturing is required.

3.2 Test conditions are selected that are consistent with the intended end-use of the inspection system, as determined by the user.

3.3 The ultrasonic response from appropriate test blocks is obtained, and presented in numerical or graphical form.

3.4 The test data can be used to characterize the related system parameters in accordance with user requirements.

4. Significance and Use

4.1 This practice describes procedures applicable to both shop and field conditions. More comprehensive or precise measurements of the characteristics of complete systems and their components will generally require laboratory techniques and electronic equipment such as oscilloscopes and signal generators. Substitution of these methods is not precluded where appropriate; however, their usage is not within the scope of this practice.

4.2 This document does not establish system acceptance

[1] This practice is under the jurisdiction of ASTM Committee E-7 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.06 on Ultrasonic Testing Procedures.

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[2] *Annual Book of ASTM Standards*, Vol 03.03.

[3] Published by Wiley-Interscience, New York, NY.

limits, nor is it intended as a comprehensive equipment specification.

4.3 While several important characteristics are included, others of possible significance in some applications are not covered.

4.4 Since the parameters to be evaluated and the applicable test conditions must be specified, this practice should be prescribed only by those familiar with ultrasonic NDT technology and the required tests should be performed either by such a qualified person or under his supervision.

4.5 Implementation may require more detailed procedural instructions in the format of the using facility.

4.6 Selection of the specific tests to be made should be done cautiously; if the related parameters are not critical in the intended application, then their inclusion may be unjustified. For example, vertical linearity may be irrelevant for a go/no-go test with a flaw gate alarm, while horizontal linearity might be required only for accurate flaw-depth or thickness measurement from the CRT display.

4.7 No frequency of system evaluation or calibration is recommended or implied. This is the prerogative of the using parties and is dependent on application, environment, and stability of equipment.

4.8 Certain sections are applicable only to instruments having receiver gain controls calibrated in decibels (dB). While these may sometimes be designated "gain," "attenuator," or "sensitivity" on various instruments, the term "gain controls" will be used in this practice in referring to those which specifically control instrument receiver gain but not including reject, electronic distance-amplitude compensation, or automatic gain control.

4.9 These procedures can generally be applied to any combination of instrument and search unit of the commonly used types and frequencies, and to most straight-beam testing, either contact or immersed. Certain sections are also compatible with angle-beam, wheel, delay-line, and dual-search unit techniques. Their use, however, should be mutually agreed upon and so identified in the test report.

4.10 The validity of the results obtained will depend on the precision of the CRT readings. This is assumed to be ±0.04 in. (±1 mm), yielding between 1 % and 2 % of full scale (fs) readability for available instrumentation having suitable screen graticules and display sharpness.

5. Procedures for Obtaining Ultrasonic Response Data

5.1 *General*:

5.1.1 For each procedure determine from the requesting documents the instrument test range to be evaluated, select the appropriate search unit, fixtures, and test blocks, and establish the required display conditions. Unless otherwise required for the test, mid-range values are suggested for most panel controls; reject must be off unless specifically allowed. To obtain the exact display conditions required for certain tests, it may be necessary to vary the instrument controls from these initial values. It is important to observe and report any anomalous effects on the parameters being evaluated when the controls are varied over the full range of intended use.

5.1.2 When a procedure requires a change in receiver gain by the use of a calibrated control, it is assumed that those which increase sensitivity with higher panel readings are designated "gain" and those which decrease sensitivity with higher readings are designated "attenuation." Fine (reference) gain controls when available are usually not calibrated in decibels and increase sensitivity with clockwise rotation.

5.1.3 Although the procedures in this practice do not describe the use of electronic distance-amplitude compensation, its use is not precluded. If it is used to affect any one or combination of characteristics, measured under this document, then all characteristics should be evaluated with the same level of compensation as was used on any one, and this level should be referenced in the report. If desired by the using parties, a dual set of test data may be made both with and without distance-amplitude compensation.

5.1.4 If the CRT display does not provide a suitable internal graticule, and deflection measurements are being made, fix the eye relative to the external scale to minimize parallax. This practice assumes reading precision of within 2 % of full scale. If, for any reason, this is not feasible for the system under test, estimate the probable accuracy and include this in the report. Readability can sometimes be improved by the use of an external scale attached to the CRT face having 50 or 100 divisions for full scale.

5.1.5 When tests are being done by the contact method, position the search unit securely and make certain that couplant changes are not measurably affecting the results. Refer also to Practice E 114.

5.1.6 When using the immersion method, allow adequate time for thermal stabilization; remove bubbles and particles from search unit and test surfaces; maintain the search-unit manipulator and test blocks in stable positions. Refer also to Practice E 214.

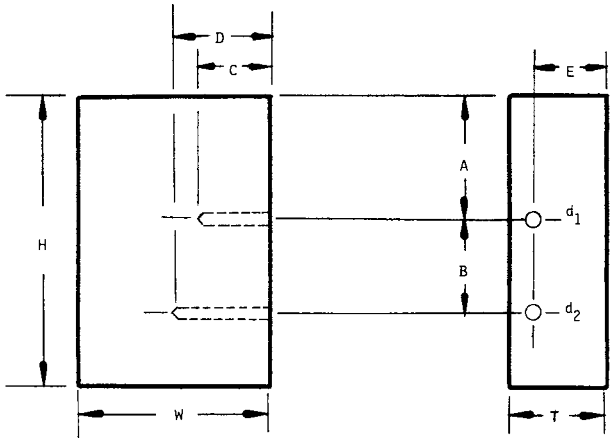
5.2 *Horizontal Limit and Linearity* :

5.2.1 *Significance*— Horizontal limit and linearity have significance when determination of depth of a discontinuity is required. A specified minimum trace length is usually necessary to obtain the horizontal readability desired. Nonlinearity of sweep trace may affect accuracy of flaw depth or thickness determination made directly from the CRT.

5.2.2 *Apparatus*—A test block is required that will give several (preferably eleven) noninterfering multiple back reflections for the sweep range and other test conditions of interest. Any block having good ultrasonic transmittivity, flat parallel faces, and a thickness of about one tenth of the specified sweep range will usually be adequate. The aluminum blocks shown in Fig. 1 will be satisfactory for mid-range frequencies and sweep settings on most instruments when the beam is directed through the thickness T. For other test frequencies or very large search units, different block dimensions or other block designs may be required to eliminate interferences. The couplant system used, either contact or immersed, must provide stable indications during the measurements. A horizontal scale permitting reading accuracy as specified in 5.1.4 is required.

NOTE 1—An encapsulated transducer-targets assembly may be used for this purpose.

5.2.3 *Procedure*—Couple the appropriate block to the search unit so that the sound beam does not intercept any test



Material: 7075T6 aluminum
Plug drilled holes with water-insoluble plastic.

FIG. 1 Suggested Test Blocks for Evaluation of Horizontal and Vertical Linearity

	Table of Dimensions			
	US Customary Block (in.)		Metric Block (mm)	
	Dimension	Tolerance	Dimension	Tolerance
A	1.25	0.05	32	1
B	1.00	0.05	25	1
C	0.75	0.05	19	1
D	1.00	0.05	25	1
E	0.75	0.05	19	1
H	3.00	0.05	75	1
T	1.00	0.01	25	0.2
W	2.00	0.05	50	1
d_1 and d_2	0.047 dia.	0.005	1.2 dia.	0.1
All surfaces:				
Flatness	...	0.001	...	0.02
Parallelism	...	0.001	...	0.02
Finish	63 µ in. or smoother		1.5 µm or smoother	

holes. Adjust the instrument gain, sweep-delay, and sweep-length controls to display eleven noninterfering back reflections. Set the amplitude of each back reflection at 50 % fs before measurement of its position. Further adjust the sweep controls (range, centering, or delay) to position the leading edge of the third and ninth back reflections at the 20 % and 80 % scale divisions respectively (with each set in turn at 50 % fs). After the third and ninth back reflections are positioned accurately on the 20 % and 80 % divisions as described, read and record the scale positions of each other multiple. Alternatively, if sweep-delay is not available, position the second and eighth back reflections at the 20 % and 80 % scale divisions respectively; read and record the scale positions of the initial pulse start and of the remaining multiples.

NOTE 2—Either more or fewer reflections can be used by suitably modifying the procedure. For example, six back reflections may be used if interference echoes are obtained with eleven, in which case the second back reflection is positioned at the 20 % scale division and the fifth back reflection at the 80 % scale division. Measurement of the horizontal position of each multiple echo, should be made at the same amplitude on the leading edge of the indication. Any specific value may be selected if it is used consistently. Typically used values are baseline break, half amplitude, or signal peak.

5.2.4 *Interpretation of Data*:

5.2.4.1 Horizontal limit is given by the maximum available trace length falling within the CRT graticule lines expressed in linear units (inches or millimetres). Unless otherwise noted, this is also assumed to represent 100 % fs. Failure to obtain full-scale deflection may indicate an equipment malfunction.

5.2.4.2 Linearity test results may be presented in tabular form or, preferably, plotted in the manner shown in Fig. 2. The deviation is given by the displacement (in % full scale) from the straight line through the set-up points representing ideal linearity. For the test point shown (sixth multiple at 55 % fs) the error is 5 % fs. Maximum nonlinearity is given by the "worst case" test point. Linear range is given by the set of contiguous points falling entirely within a specified tolerance.

5.3 *Vertical Limit and Linearity*:

5.3.1 *Significance*— Vertical limit and linearity have significance when echo signal amplitudes are to be determined from the CRT or corresponding output signals, and are to be used for evaluation of discontinuities or acceptance criteria. A specified minimum trace deflection and linearity limit may be required to achieve the desired amplitude accuracy. For other situations they may not be important, for example, go/no-go tests with flaw alarms or evaluation by comparison with a reference level using calibrated gain controls. This practice describes both the two-signal ratio technique (Method A) and the input/output attenuator technique (Method B). Both methods assume that the test indications used for measurement are free of interferences resulting from nearby signals such as the initial pulse,

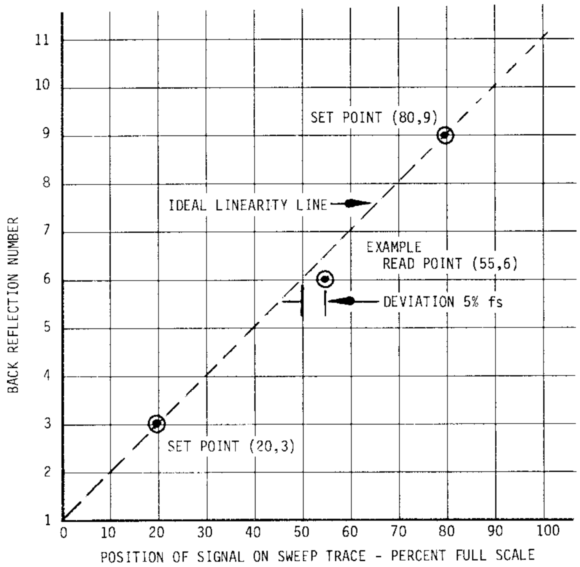


FIG. 2 Example of Data Plot for Determination of Horizontal Linearity

interface echo, or adjacent multiples. If linearity is of concern under such conditions, for example for near-surface signals, it may be evaluated by the procedure in 5.4.3. Method A (ratio technique) will disclose only nonlinearity that occurs in the instrument circuitry between the gain controls being used to set the amplitudes and the display. Method B (input/output technique) evaluates the entire receiver/display system at constant gain as established initially by the panel controls. Because of this and other differences, the two methods may not give identical results for linearity range. Further, Method A may not disclose certain types of nonlinear response shown by Method B.

5.3.2 *Method A*:

5.3.2.1 *Apparatus*—A test block is required that produces two noninterfering signals having an amplitude ratio of 2 to 1. These are compared over the usable screen height as the instrument gain is changed. The two amplitudes will be referred to as H_A and H_B($H_A > H_B$). The two signals may occur in either screen order and do not have to be successive if part of a multiple-echo pattern. Unless otherwise specified in the requesting document, any test block that will produce such signals at the nominal test settings specified can be used. For many commonly used search units and test conditions, the test block shown in Fig. 1 will usually be satisfactory when the beam is directed along the *H* dimension toward the two holes. The method is applicable to either contact or immersion tests; however, if a choice exists, the latter may be preferable for ease of set-up and coupling stability.

NOTE 3—An encapsulated transducer-targets assembly may be used for this purpose.

5.3.2.2 *Procedure*—To obtain test data, position the search unit so that two echo signals are obtained having amplitudes in the ratio of about 2 to 1. Determine that there is sufficient range in the gain controls to vary H_A(the larger) from 10 % fs to 100 % fs. Manipulate the search unit and adjust the instrument controls until H_A and H_B meet the conditions in Table 1. The preferred values are desired because the data may be most easily presented and evaluated. However, positioning difficulties or lack of a fine gain or pulse-length control may not permit obtaining the exact values. When optimum set-up conditions are established, secure the search unit in place, observing the precautions noted in 5.1. Adjust the gain controls in steps so that H_A is set in increments of 10 % or less from 10 % fs to 100 % fs. Read and record the values of H_A and H_B within the accuracies prescribed in 5.1.4.

TABLE 1 Vertical Linearity Range by Method A Using Two-Signal (Ratio) Technique/Initial Values for H_A and H_B Giving Ratios of 1.8 to 2.2

NOTE 1—Preferred setup values permit determination of vertical linearity range directly from the data plot of Fig. 3.

H_A % Full Scale	H_B % Full Scale
Preferred Values	
60	30
Acceptable	
65	30–36
64	29–36
63	29–35
62	28–34
61	27–34
60	27–33
59	27–33
58	26–32
57	26–32
56	25–31
55	25–31

NOTE 4—To better define the response characteristic, particularly near the upper and lower limits, additional readings may be taken at smaller gain increments.

5.3.2.3 *Interpretation of Data*—Vertical limit is given by the maximum vertical deflection (baseline to peak for video and peak to peak for rf) within the usable graticule range that can be obtained from a large reflector (for example, the test block surfaces) as the gain is increased. Report this in linear units (inches or millimetres) and note equivalent graticule divisions. Unless otherwise stated, this is assumed to represent 100 % fs. Failure to obtain full-scale deflection may indicate an equipment malfunction. Linearity test data may be reported in tabular form or preferably presented graphically. Unless otherwise specified in the requesting document, vertical linearity range should be determined graphically using the method shown in Fig. 3. If the preferred set-up condition (H_A = 60 % fs, H_B = 30 % fs) is established initially, the test results may be plotted directly on the scales shown. The limit lines provide a graduated tolerance for H_B of ±1 graph division starting at the set-up point (to provide for reading error) to ±6 divisions at the extremes. Ideal linearity is defined by a straight line extending from the origin through any set-up point to full scale. The linear range is determined by interconnecting adjacent data points and noting the first locations above and below set-up intersecting the limit lines. The upper linearity limit is given by the corresponding value for H_A and the lower limit by that for H_B. If the preferred set-up values were not obtained, a new linearity line and corresponding limits should be constructed following the same approach.

NOTE 5—If the requesting document specifies that the test results be presented in ratio form (that is, H_A/H_B versus H_A) the necessary values

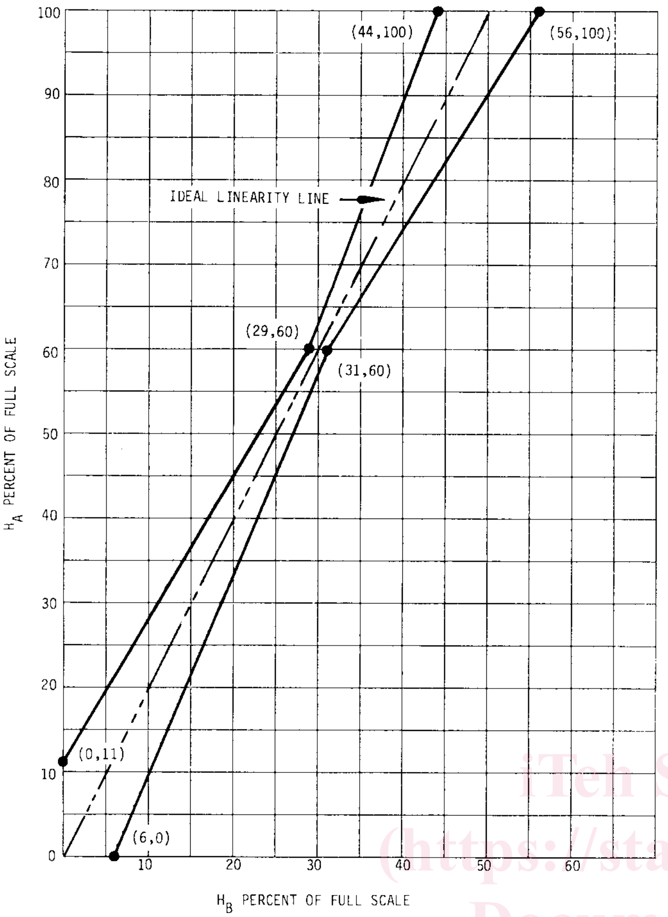


FIG. 3 Data Plot for Determination of Vertical Linearity Range by Method A (Ratio Technique)

can be calculated from the tabular data and presented in any format specified. To establish linearity limits the desired tolerances must also be stated.

NOTE 6—If the instrument graticule cannot be read directly in % of full scale, the recorded values of H_A and H_B should be converted to percentages of full scale before plotting. If that is not done, new coordinates with appropriate scale and limit lines must be constructed.

5.3.3 *Method B*:

5.3.3.1 *Apparatus*—This method requires the use of an auxiliary external-step attenuator meeting the following minimum specifications which are usually certified by the supplier:

Frequency range	dc to 100 MHz
Attenuation	0 to 80 dB in 1-dB steps
Impedance	50 or 75 Ω
Accuracy	±0.2 dB per 20-dB step

The instrument must be operable in a through-transmission mode with the attenuator inserted between the source of the received signal and the receiver input jack as shown in Fig. 4. Either single-search-unit or the alternative two-search-unit configuration can be used. The attenuator should be connected to the receiver input with a coaxial cable having the same impedance as the attenuator and the terminator. However, negligible error will result if short lengths, that is 6 ft (1.8 m) or less, of commonly used low-capacitance cables are used at mid-range test frequencies. The terminator should be a shielded, noninductive resistor preferably mounted in a coaxial connector. Refer to Note 7 regarding termination errors. In the single-search-unit configuration the pulser is shunted by the attenuator input. Therefore, to isolate the pulser and protect the attenuator if its input rating is exceeded, a dropping resistor may be desirable. If the two-search-unit arrangement is used, no further isolation is required. The path length provided by the test medium should be adequate to separate the initial pulse (or any instrument cross-talk) from the desired signal, usually that from the first back reflection or interface echo (single-search-unit method) or the first transmitted signal (two-search-unit method). For most test situations a total material path of 2 in. (50 mm) of water or 6 in. (150 mm) of metal such as aluminum will be satisfactory.

NOTE 7—It is assumed that, as is typical of most commercial instruments when operated in the through-transmission mode, the receiver input impedance is large (at least ten times) compared with that of the attenuator. This can usually be determined from the manual or from the manufacturer, and the terminator suitably adjusted. However, when there is a question, a minimum of one 20-dB step should always be left in the attenuator, and terminator errors will be negligible. Proper operation of the

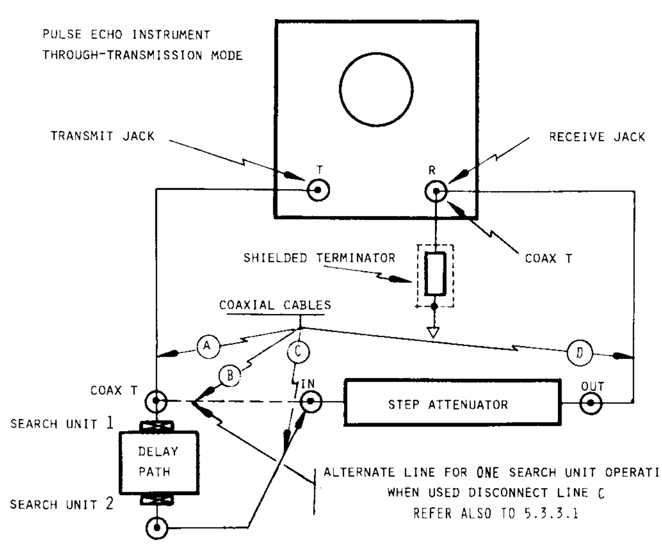


FIG. 4 Recommended System Configuration for Determination of Vertical Linearity (Method B) and Gain Control Calibration

attenuator can be checked by determining that any combination of steps having an equivalent value, produces the same signal change. For example, an increase of attenuation from 20 dB to 26 dB should produce the same display change as the increase from 30 dB to 36 dB.

5.3.3.2 *Procedure*—With approximately 30 dB of attenuation in the external attenuator, adjust the instrument sweep and gain controls to produce a center screen deflection of 50 % fs within readability tolerance (that is, 2 % fs or better). Decrease the external attenuation in 1-dB steps until full-scale deflection is reached and record the signal amplitude for each step in percent of full scale. Reset the external attenuator to again give 50 % fs and increase the external attenuation in 2-dB steps for five steps, and then in 4-dB steps thereafter until the signal essentially disappears; record signal amplitudes for each step.

NOTE 8—Smaller attenuation increments may be used to better define the linearity response. Optional values are given in Table 2.

5.3.3.3 *Interpretation of Data*—Deviations from ideal linearity may be determined either by comparison with tabular values or graphically. Vertical linear range can then be established for any specified deviation, usually stated in percent of full scale. This practice, unless modified by the requesting document, prescribes a tolerance of ±5 % fs in determining upper and lower linearity limits. In addition ±1 % fs is allowed for reading error. To use the tabular method, subtract the amplitude readings obtained for each step from that for the appropriate attenuator step as given in Table 2. The difference (which may be either positive or negative) is the deviation from ideal linearity in percent of full scale. The linear range extends from the lowest to the highest values of sequential amplitudes all falling within prescribed limits. Graphic methods require either logarithmic scales or inverse log calculations to give a straight linearity plot. The preferred format that is convenient to use is shown in Fig. 5. Deviation from ideal linearity can be read directly in percent of full scale, and vertical linearity range established by the limit lines shown. Other limit lines for any specified tolerances may be constructed in a similar manner.

5.4 *Resolution*:

5.4.1 *Significance*—Depth resolution has significance when it is important to identify and quantify reflectors positioned closely together along the depth axis whether they are internal discontinuities or a discontinuity and a boundary. This procedure is concerned with entry and back surface resolution only. Since vertical linearity of signals within interference regions (for example, near surface indications) may sometimes be required, provision is also made for checking this. Resolution, as determined by this practice, includes the combined effects of instrument, search unit, and interconnects and is therefore a system check for the specific components and test conditions used.

5.4.2 *Apparatus*—Select test blocks that provide metal distances corresponding to the resolution range and hole diameters specified in the requesting document. For comparative evaluations blocks may be of any agreed-on material; however, if values for specific test applications are desired, the blocks should be made from material having ultrasonic properties similar to that to be inspected. Specimen characteristics such as metallurgical structure, contour, surface condition, and dimensions can significantly affect results. Further, search unit, test frequency, and operating conditions are major factors. Many types of test blocks have been used for resolution measurements including (*1*) aluminum alloy standard reference blocks as specified in Practice E 127, (*2*) steel or other metal-alloy reference blocks made in accordance with Practice E 428, (*3*) various commercially available "resolution blocks" having a

TABLE 2 Determination of Vertical Linearity Range by Method B Using Input/Output Technique with External Attenuator

Vertical Signal Amplitude versus Relative Attenuation							
Decreasing External Attenuation				Increasing External Attenuation			
−dB	H_R[A] % fs	H_T[B] % fs	$H_R - H_T$ % fs	+dB	H_R % fs	H_T % fs	$H_R - H_T$ % fs
0	50	50	0	0	50	50	0
0.5[C]		53		1[C]		45	
1.0		56		2		40	
1.5[C]		59		3[C]		35	
2.0		63		4		32	
2.5[C]		67		5[C]		28	
3.0		71		6		25	
3.5[C]		75		7[C]		22	
4.0		79		8		20	
4.5[C]		84		9[C]		18	
5.0		89		10		16	
5.5[C]		94		12[C]		13	
6.0		100		14		10	
6.5[D]		106		16[C]		8	
7.0[D]		112		18		6	
7.5[D]		119		20[C]		5	
8.0[D]		126		22		4	
...		...		24[C]		3	
...		...		26		2.5	
...		...		28[C]		2	
...		...		30		1.5	
...		...		32[C]		1.2	
...		...		34		1.0	

[A] H_R Read value of vertical indication from test fixture.
[B] H_T Theoretical value for ideal linear response.
[C] Suggested optional attenuator increments.
[D] Increments possibly required for full-scale deflection.