Standard Practice for Verification of Constant Amplitude Dynamic Forces in an Axial Fatigue Testing System[1]

This standard is issued under the fixed designation E467; 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.

1. Scope

1.1 This practice covers procedures for the dynamic verification of cyclic force amplitude control or measurement accuracy during constant amplitude testing in an axial fatigue testing system. It is based on the premise that force verification can be done with the use of a strain gaged elastic element. Use of this practice gives assurance that the accuracies of forces applied by the machine or dynamic force readings from the test machine, at the time of the test, after any user applied correction factors, fall within the limits recommended in Section 9. It does not address static accuracy which must first be addressed using Practices E4 or equivalent.

1.2 Verification is specific to a particular test machine configuration and specimen. This standard is recommended to be used for each configuration of testing machine and specimen. Where dynamic correction factors are to be applied to test machine force readings in order to meet the accuracy recommended in Section 9, the verification is also specific to the correction process used. Finally, if the correction process is triggered or performed by a person, or both, then the verification is specific to that individual as well.

1.3 It is recognized that performance of a full verification for each configuration of testing machine and specimen configuration could be prohibitively time consuming and/or expensive. Annex A1 provides methods for estimating the dynamic accuracy impact of test machine and specimen configuration changes that may occur between full verifications. Where test machine dynamic accuracy is influenced by a person, estimating the dynamic accuracy impact of all individuals involved in the correction process is recommended. This practice does not specify how that assessment will be done due to the strong dependence on owner/operators of the test machine.

1.4 This practice is intended to be used periodically. Consistent results between verifications is expected. Failure to obtain consistent results between verifications using the same machine configuration implies uncertain accuracy for dynamic tests performed during that time period.

1.5 This practice addresses the accuracy of the testing machine's force control or indicated forces, or both, as compared to a dynamometer's indicated dynamic forces. Force control verification is only applicable for test systems that have some form of indicated force peak/valley monitoring or amplitude control. For the purposes of this verification, the dynamometer's indicated dynamic forces will be considered the true forces. Phase lag between dynamometer and force transducer indicated forces is not within the scope of this practice.

1.6 The results of either the Annex A1 calculation or the full experimental verification must be reported per Section 10 of this standard.

1.7 This practice provides no assurance that the shape of the actual waveform conforms to the intended waveform within any specified tolerance.

1.8 This standard is principally focused at room temperature operation. It is believed there are additional issues that must be addressed when testing at high temperatures. At the present time, this standard practice must be viewed as only a partial solution for high temperature testing.

1.9 The values stated in inch-pound units are to be regarded as standard. No other units of measurement are included in this standard.

1.10 *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:*[2]

E4 Practices for Force Verification of Testing Machines

[1] This practice is under the jurisdiction of ASTM Committee E08 on Fatigue and Fractureand is the direct responsibility of Subcommittee E08.03 on Advanced Apparatus and Techniques.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

E6 Terminology Relating to Methods of Mechanical Testing
E1823 Terminology Relating to Fatigue and Fracture Testing
E1942 Guide for Evaluating Data Acquisition Systems Used in Cyclic Fatigue and Fracture Mechanics Testing

2.2 *Military Standard:*[3]
1312-B Fastener Test Methods

2.3 *ANSI Standard:*[4]
Z540-1-1994 Calibration Laboratories and Measuring and Test Equipment—General Requirements

2.4 *NCSL Standard:*[4]
Publication 940830/1600 NCSL Glossary of Metrology—Related Terms

3. Terminology

3.1 Terminology used in this practice is in accordance with Terminology E1823. Definitions provided in this practice are considered either unfamiliar or not included in Terminology E1823.

3.2 *Definitions:*

3.2.1 *accuracy, n*—The quantitative difference between a test measurement and a reference value.

3.2.2 *amplitude, n*—one-half the peak-to-peak measurement of the cyclic waveform.

3.2.3 *cal factor, n*—the conversion factor between the dynamometer force and the indicated force.

3.2.4 *conditioned force, n*—the high level voltage or digital data available from the dynamometer or force transducer's signal conditioning instrumentation; it is frequently of value during dynamic verification as it can be more conveniently monitored by stand alone measurement instrumentation.

3.2.5 *corrected force, n*—the force obtained after applying a dynamic correction factor to the force transducer's indicated force.

3.2.6 *data acquisition equipment, n*—the equipment used to convert a conditioned force to an indicated force.

3.2.7 *dynamic dynamometer forces, n*—the maximum and minimum forces produced in the dynamometer during a portion of a dynamic test.

3.2.8 *dynamic errors, n*—errors in the force transducer's corrected force output that occur due to dynamic operation (with specimen bending errors intentionally corrected out).

3.2.9 *dynamic indicated forces, n*—the maximum and minimum forces reported by the test machine during a portion of a dynamic test. These values are typically obtained using an oscilloscope, peak-valley meter, or files generated by computerized data acquisition.

3.2.10 *dynamometer, n*—an elastic calibration device used to indicate the forces applied by a fatigue testing system during dynamic operation. A strain gaged specimen is often used as the dynamometer. Suitable transducer instrumentation is also required to provide accurate readings over the intended frequency and force range. (Refer to Practice E467, Annex A2 for detailed information about the dynamometer and instrumentation.)

3.2.11 *dynamometer force, n*—the force value provided by the dynamometer's readout.

3.2.12 *endlevel, n*—either a maximum or minimum level for a cyclic waveform.

3.2.13 *fatigue testing system, n—for the purpose of this practice*, a device for applying repeated force cycles to a specimen or component, which applies repeated force cycles of the same span, frequency, waveshape, mean level, and endlevels.

3.2.14 *force command, n*—the desired force to be applied to the specimen or dynamometer by the testing machine.

3.2.15 *force transducer, n*—a measuring device that can provide an output signal proportional to the force being applied.

3.2.16 *indicated force, n*—the force value provided by the force transducer or dynamometer's readout (for example, a numeric or graphical output for reading by a human including a peak picking capability); these values are typically obtained from a digital volt meter (DVM) or files generated by a computerized data acquisition.

3.2.17 *instrumentation, n*—the electronics used with a transducer providing excitation for the transducer, conditioning of the measured signal, and readout of that signal; typically the conditioned signal is a voltage and the readout is a numerical display or printout.

3.2.18 *peak, n*—the maximum endlevel of a cycle.

3.2.19 *peak picking, n*—the process of determining the peak or valley of a cyclic waveform.

3.2.20 *repeatability, n*—the closeness of agreement among repeated measurements of the dynamic forces under the same conditions.

3.2.21 *span, n*—the absolute value of the peak minus the valley for a cyclic waveform.

3.2.22 *transducer, n*—a measuring device which has an output signal proportional to the engineering quantity being measured.

3.2.23 *true force, n*—the actual force applied to the specimen or dynamometer.

3.2.24 *valley, n*—the minimum endlevel of a cycle.

4. Significance and Use

4.1 It is well understood how to measure the forces applied to a specimen under static conditions. Practices E4 details the required process for verifying the static force measurement capabilities of testing machines. During dynamic operation however, additional errors may manifest themselves in a testing machine. Further verification is necessary to confirm the dynamic force measurement capabilities of testing machines.

NOTE 1—The static machine verification accomplished by Practices E4 simply establishes the reference. Indicated forces measured from the force cell are compared with the dynamometer conditioned forces statically for

[3] Available from the U.S. Government Printing Office, Washington, DC 20402.
[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

confirmation and then dynamically for dynamic verification of the fatigue testing system's force output.

NOTE 2—The dynamic accuracy of the force cell's output will not always meet the accuracy requirement of this standard without correction. Dynamic correction to the force cell output can be applied provided that verification is performed after the correction has been applied.

NOTE 3—Overall test accuracy is a combination of measurement accuracy and control accuracy. This practice provides methods to evaluate either or both. As control accuracy is dependent on many more variables than measurement accuracy it is imperative that the test operator utilize appropriate measurement tools to confirm that the testing machine's control behavior is consistent between verification activities and actual testing activities.

4.2 Dynamic errors are primarily span dependent, not level dependent. That is, the error for a particular force endlevel during dynamic operation is dependent on the immediately preceding force endlevel. Larger spans imply larger absolute errors for the same force endlevel.

4.3 Due to the many test machine factors that influence dynamic force accuracy, verification is recommended for every new combination of potential error producing factors. Primary factors are specimen design, machine configuration, test frequency, and loading span. Clearly, performing a full verification for each configuration is often impractical. To address this problem, dynamic verification is taken in two parts.

4.3.1 First, one or more full verifications are performed at least annually. The main body of this practice describes that procedure. This provides the most accurate estimate of dynamic errors, as it will account for electronic as well as acceleration-induced sources of error.

4.3.2 The second part, described in Annex A1, is a simplified verification procedure. It provides a simplified method of estimating acceleration-induced errors only. This procedure is to be used for common configuration changes (that is, specimen/grip/crosshead height changes).

4.4 Dynamic verification of the fatigue system is recommended over the entire range of force and frequency over which the planned fatigue test series is to be performed. Endlevels are limited to the machine's verified static force as defined by the current static force verification when tested in accordance with Practices E4.

NOTE 4—There is uncertainty as to whether or not the vibration in a frame will be different when operating in compression as opposed to tension. As a consequence, this practice recommends performing verifications at maximum tension and maximum compression endlevels. The total span does not need to be between those two levels, but can be performed as two tests.

NOTE 5—Primary electronic characteristics affecting dynamic measurement accuracy are noise and bandwidth. Excessive noise is generally the dominant effect at the minimum test frequency. Insufficient bandwidth-induced errors are generally most significant at the maximum test frequency.

5. Apparatus

5.1 *Dynamometer Construction*—A dynamometer is required. The strongly preferred dynamometer is an actual specimen, suitably strain gaged to provide a signal when loaded axially. Where a strain gaged specimen is not practical, an alternative dynamometer must be made. Annex A2 provides more detailed instructions on the preparation of a typical dynamometer.

5.2 *Dynamometer Instrumentation*—Dynamometer instrumentation is also required. The overall accuracy of the dynamometer and the associated instrumentation shall contribute less than 25 % of the total error of the dynamic measurement being made. Refer to Annex A2 for guidance on suitable instrumentation for both the dynamometer and the machine being verified. Calibration of the dynamometer instrumentation must be current and traceable to the National Institute of Standards and Technology (NIST) or some other recognized national standards organization.

5.3 *Dynamometer Static Calibration*—An absolute calibration of the dynamometer as tested in accordance with Practices E4 is not required. It is only necessary to statically calibrate the dynamometer indicated forces to the force transducer indicated forces at the force levels corresponding to the desired dynamic force endlevels. It is this relationship that will be verified under dynamic conditions to assure acceptable levels of additional errors due to dynamic operation. Details of the static calibration of the dynamometer are included in Section 6 as an integral part of the practice.

6. Procedure—Full Verification

NOTE 6—The objective of a full verification is to show that the force transducer corrected force accuracy is within an acceptable range when all sources of dynamic error have been taken into account.

6.1 *Designing the Test*—Prepare a matrix of configurations, test frequencies, and loading spans which address the following issues:

6.1.1 *Machine Configurations*—Ideally, the machine should be configured exactly as it will be used for material testing including grips or fixturing, or both. Where it is not practical to test all expected configurations, test the configuration(s) with the largest expected acceleration errors. In this case, Annex A1 must be used to verify additional test set-ups. It is recommended that at least two machine configurations be verified, and that the ability to detect acceleration errors against the true errors measured with the full verifications be tested.

6.1.2 *Test Frequencies*—Where the testing machine will only be used at a few discrete frequencies, perform the verification at those frequencies. Where the machine will be used at a variety of frequencies, the minimum and maximum frequencies must be verified using the full verification procedure. Any operating frequency between those frequencies may be verified using Annex A1. A dynamic error graph may prove useful for identifying sources of dynamic errors and is recommended though not required. See Annex A3 for an example.

6.1.3 *Loading Spans*—A recommended test would be with the machine configured for minimum motion and another would be with the machine configured for maximum motion. Also, due to the uncertainty of differences in machine vibration when operating in tension as opposed to compression, it is recommended that loading spans be applied in each region where the machine be operated and through zero force if the machine is to be operated under that condition.

NOTE 7—In some tests, for example, a fatigue crack growth determination, the specimen stiffness may vary significantly during the test. To simulate this situation, a range of specimens with differing notch or crack depths may be needed.

6.2 *Conducting the Test:*

6.2.1 *Preliminary:*

6.2.1.1 Assemble the test machine in the configuration to be tested.

6.2.1.2 Ensure that the force transducer indicated force accuracy has been statically verified meeting the requirements of Practices E4.

NOTE 8—Some testing machines include a dynamic force compensation feature which is adjusted to correct the force transducer indicated force for effects due to acceleration of the mass of the force transducer element and associated grips. This feature may be applied in the transducer instrumentation or in the test machine's data acquisition equipment. When present and required for acceptable dynamic accuracy, follow the manufacturer's instructions for this adjustment before performing any fatigue test or dynamic verification. After adjustment, verify that the dynamic force compensation has had no effect on the static calibration.

6.2.2 *Verification Method*—Do 6.2.2.1 – 6.2.2.3 for each combination of machine configuration defined in 6.1.1. Do 6.2.2.7 – 6.2.2.9 for each combination of machine configuration, endlevels, and test frequency defined in 6.1.2.

Basic Machine Configuration

6.2.2.1 Install the dynamometer in the system to be verified.

6.2.2.2 Connect the strain gage bridge of the dynamometer to the associated instrumentation. Connect the verification data acquisition equipment to the dynamometer conditioned force output and the force transducer conditioned force output. Turn power on to all devices and allow sufficient time for the dynamometer and associated instrumentation to stabilize.

NOTE 9—Where a separate verification system is used to perform the data acquisition of the force transducer conditioned force output, then the test machine's data acquisition and peak picking elements must be separately verified. Conversely, where the test machine's data acquisition system is used to perform the data acquisition of the dynamometer conditioned force output that portion of the test machine's data acquisition system must first be verified as in 5.2.

6.2.2.3 Report the machine configuration in the final report, as in Section 10.

Static Calibration of the Dynamometer

6.2.2.4 Exercise the dynamometer three times to the maximum endlevel plus 5 % of the test span being verified, return to zero force and zero the dynamometer indicated force and the force transducer indicated force outputs.

6.2.2.5 Using the Set-The-Force method defined in Practices E4, load the dynamometer to the maximum endlevel and calibrate the dynamometer indicated force to the force transducer indicated force. Scale the dynamometer output to units appropriate for performing the test. Although not necessary, it may be convenient to use the same scaling as on the test machine.

6.2.2.6 Using the Set-The-Force method defined in Practices E4, calibrate the dynamometer indicated force to the force transducer indicated force at the six discrete points and in the order, defined below:

Maximum endlevel – 5 % of span
Maximum endlevel
Maximum endlevel + 5 % of span
Minimum endlevel + 5 % of span
Minimum endlevel
Minimum endlevel – 5 % of span

This provides a verified force range accounting for hysteresis at the minimum endlevel and compensating for a poorly controlled machine. Record the force transducer indicated force and the dynamometer indicated force. When static calibration is performed in accordance with Practices E4, the repeatability of the error associated with the maximum force of the dynamometer shall not exceed ±0.25 % of the maximum force applied by the testing machine.

NOTE 10—Assure that the value calibrated is within the machine's current static verification range in accordance with Practices E4.

Cyclic Test

6.2.2.7 Set the machine controls to operate in the same manner as the actual test. Cycle the test machine at the desired test frequency. Utilize peak/valley readout monitoring or amplitude control as appropriate to assure test endlevels are achieved.

(1) Force Indication Verification Method—Adjust the machine controls so that the dynamometer indicated force endlevels during dynamic operation correspond to the maximum and minimum endlevels obtained statically as measured by the dynamometer.

NOTE 11—Force indication verification is only applicable where real time output of the force transducer indicated force is available.

6.2.2.8 Wait for the system to stabilize. After stability has been achieved, record a minimum of 50 dynamometer indicated force peaks and the associated 50 dynamometer indicated force valleys.

(1) Force Indication Verification Method—Where real time output of the force transducer indicated force is available, simultaneously record the associated force transducer indicated force peaks and valleys

NOTE 12—Simultaneous in this context does not mean at the exact same instant in time. Rather, it means within the same test cycle. Differences in phase shift and noise conditions on the two signals make it extremely unlikely that both peaks or both valleys, or both of each will occur at exactly the same point in time.

NOTE 13—Dynamic Correction Factors: If a dynamic correction factor is to be applied to the force cell output, it must be applied at this point. The analysis done as in 6.3 must be done on the corrected data (that is, correct the data first, then check the correction process by performing the error analysis).

6.2.2.9 If the testing system has a peak/valley readout (either digital or analog), confidence in the peak/valley readout can be gained by acquiring data with the peak/valley readout at the same time dynamometer indicated force data sets are being acquired. The data acquired from the peak/valley readout and the data acquired from the dynamometer are not synchronized so no comparison of individual peaks or valleys is possible. The peak and valley indication can however, be compared to the dynamometer data to gain confidence in the system's ability to acquire the maximum peak and valley indication. To gain confidence in the peak/valley readout, it is recommended that 3 sets of peak/valley readout data consisting of a minimum of 50 cycles per data set be acquired and shall be run simultaneously with the dynamometer acquisition.

Analyze Test Data

6.3 Analyze all data according to the instructions in Section 8.

Document Test Results

6.4 Generate a report, detailing the system fatigue testing capabilities (see Section 10).

7. Time Interval Between Verifications

7.1 Periodic verification is required to ensure constant performance of the fatigue testing system.

7.2 Whenever there is a reason to doubt the accuracy of the results, the fatigue testing system shall be verified immediately without regard to the time interval since the last verification.

7.2.1 Examples for reverification are a new test specimen configuration, changing fixtures, changing the mounting of the machine, or physically moving the system. Use of Annex A1 is recommended in cases of specimen and grip changes to minimize the effort required to verify dynamic accuracy.

7.3 Even in cases of constant use with the same configuration, verification at intervals of 6 months or less is recommended. With intermittent use, reverify every 12 months.

8. Data Reduction

8.1 Dynamic errors are computed using the raw data obtained in Section 6. For each nominal frequency range tested, establish the calibration between the dynamometer and the force transducer under static conditions as given in 8.1.1 – 8.1.4. Evaluate errors introduced as functions of frequency as shown in 8.1.5.

8.1.1 Calculate the difference between maximum and minimum endlevels under "static" conditions using the following formula:

$$\text{Static Span} = \text{Maximum Static} - \text{Minimum Static} \quad (1)$$

8.1.2 Calculate the allowable endlevel error in force transducer indicated force units using the following formula:

$$\text{Allowable Endlevel Error} = \pm 1.0\,\% \times \text{Static Span} \quad (2)$$

8.1.3 If a dynamic error graph will be used, plot the allowable endlevel errors as two parallel lines on the graph, referencing the example in Annex A3. Plot as % span.

8.1.4 Use the applicable terminology when performing the analysis of 8.1.5.

8.1.4.1 Force Control Verification Method

UUT Force is the Desired Force

8.1.4.2 Force Indication Verification Method

UUT Force is the Force Transducer Corrected Force

8.1.5 For all 50 cycles at each frequency perform the following:

8.1.5.1 Calculate the difference between reference force valley and UUT force valley using the following formula:

$$\text{Valley Endlevel Error} = \quad (3)$$

$$\text{UUT Force Valley} - \text{Dynamometer Indicated Force Valley}$$

8.1.5.2 Calculate the difference between reference force peak and UUT force peak using the following formula:

$$\text{Peak Endlevel Error} = \quad (4)$$

$$\text{UUT Force Peak} - \text{Dynamometer Indicated Force Peak}$$

8.1.5.3 Identify the maximum endlevel errors for both the peak and valley endlevels.

NOTE 14—Static Correction Factors: Both the peak and valley endlevel errors need to be corrected for the dynamometer static calibration errors obtained in 6.2.2.6 of this practice.

NOTE 15—Dynamic Correction Factors: If a dynamic correction factor is to be applied to the force cell data, it must be applied to the raw data reduction specified in Section 6. This may require the user to initially do a limited verification test to define the expected correction factors. Then the user must perform a full verification test to assure the correction factors chosen and process to apply them are appropriate.

8.1.5.4 Report the values computed in 8.1.5.3 on the final report. Express as a percentage of the span of the cycle which had the maximum peak or valley error. Report these spans also.

8.1.5.5 If a dynamic error graph will be used, plot the values computed in 8.1.5.3 on the graph. (See 6.1.2 of this practice).

9. Accuracy

9.1 This practice recommends the following error tolerance, expressed as the percentage of the span for that cycle:

$$\text{Maximum Dynamic Endlevel Error (Peak or Valley)} = \pm 1.0\,\% \quad (5)$$

9.1.1 This tolerance is to be specified on the verification test report.

10. Report

10.1 The primary objective of the report is to document all information necessary to demonstrate the testing machine's dynamic accuracy for a specific configuration. All factors which affect the accuracy of the reported data must be included. A separate report shall be generated for each verification test and may be attached to the applicable certificate as given in Practices E4 as an addendum indicating allowable frequencies of operation. A sample report is included as Annex A3. A new verification is required for each machine configuration. This section addresses the report requirements for a complete verification. Annex A1 provides a method for estimating measurement errors associated with changes in the principal test system parameters (that is, specimen stiffness, grip weight, crosshead height, and frequency) for inclusion in the report. Since dynamic accuracy is specimen dependent, a verification statement must be included in any test report. Although the test results can not be entered before the test has been conducted, as much of the report as possible should be completed in advance of the test. This will help prevent use of equipment that is not calibrated or that has been improperly adjusted. The report shall contain the following information:

10.1.1 *Measurement Equipment Description*—Include sufficient information to reassemble the test hardware. It is assumed that the manufacturer's name, model number, and serial number are sufficient to obtain complete documentation of a particular piece of equipment. Where it is not, provide additional documentation. A critical part of the description will be the specimen grip/fixturing used.

10.1.1.1 *Fatigue Testing Machine*—Report the manufacturer's name and model number and the serial number.

10.1.1.2 *Testing Machine Force Transducer*—Report the manufacturer's name and model number, and the serial number.

10.1.1.3 For each item of transducer instrumentation (both test machine and dynamometer), report the manufacturer's name and model number, serial number, and the calibration date.

10.1.2 *Dynamometer Description*—Include sufficient information to recreate the dynamometer, if required. The information can be directly attached in the report, or may refer to a controlled piece of documentation, which in turn adequately describes the dynamometer. The most important characteristics of the dynamometer are those that affect its stiffness and mass. Provide at least the following:

10.1.2.1 Dimensional description,

10.1.2.2 Dynamometer stiffness, and

10.1.2.3 Gaging information.

10.1.3 *Machine Settings*—Include information pertaining to how the testing machine was configured when the test was conducted. For machine setting information that varies with each test result, a tabular format is recommended with individual settings listed for the following for each set of test results:

10.1.3.1 Crosshead/baseplate positions,

10.1.3.2 Vibration isolation configuration,

10.1.3.3 Additional column restraints,

10.1.3.4 Feedback conditioner settings, including but not limited to: filter selected, transducer excitation, and transducer gain.

NOTE 16—Items specified in 10.1.3.4, must match the settings reported on the static calibration certificate for the transducer under test.

10.1.4 *Test Parameters*—Some test parameters are only needed once per series. Report the following:

10.1.4.1 Waveform shape,

10.1.4.2 Force settings, including: maximum endlevel and minimum endlevel, or, mean force setting and span, and

10.1.4.3 Frequency settings.

10.1.5 Data and calculation of static error obtained from the six point dynamometer calibration to the system being verified.

10.1.6 *Test Results*—At each frequency/span pair there will be four pieces of data. They are:

10.1.6.1 The maximum endlevel(s) errors, and

10.1.6.2 The average test span for both the test machine and dynamometer.

10.1.7 *Dynamic Verification Error Graph*—The graphical presentation of the error versus frequency data also shall be included with the report if required.

10.1.8 Date test performed.

10.1.9 Initials of individual conducting the test.

10.1.10 Include the following type of note on the certificate, filling in the % region according to the actual test criteria, and referring to Section 9 for the preferred percentage. Verification was performed according to the latest version of Practice E467. It established the force transducer corrected force errors due to dynamic operation to be less than ±1.0 % of span at any force transducer indicated force endlevel within the tested range of spans and frequencies. Correlation between the test machine force command and the force transducer indicated force was not evaluated.

ANNEXES

(Mandatory Information)

A1. ESTIMATE OF SYSTEM INERTIAL ERRORS

A1.1 Conditions of Use

A1.1.1 The body of Practice E467 describes in detail the testing necessary to do a full verification of a test machine's dynamic force measurement capability. Due to its relative complexity, and the need to do a dynamic verification each time specimen stiffness/grip weight/crosshead height and frequency are changed, this annex was created. This annex provides a method for estimating the force measurement errors resulting from acceleration of any mass between the specimen gage section and the force transducer sensing element. As long as inertial errors are the dominant source of dynamic error, this method provides a reasonable verification of dynamic accuracy. In cases of significant electronic effects, use of Annex A1 will be non-conservative. Users must consider this possibility when using Annex A1.

A1.2 General

A1.2.1 Force measuring devices in materials testing systems are most often calibrated statically by comparison to transfer standards traceable to the National Institute for Standards and Technology (NIST). Systems used in axial fatigue testing are designed to operate dynamically as well as statically, and, under certain conditions, the static calibration may be inadequate or in error for some domains of dynamic testing. This annex provides a method for estimating that error. If the estimated force error is greater than 0.5 % of the loading span, then the error must be quantified by experimental verification as described in the main part of Practice E467.

A1.3 Source of Error

A1.3.1 The main source of indicated force error in a typical test machine axial load train consisting of a specimen, gripping devices, adapters, force transducer, and a dynamic actuator will be generated from acceleration of the mass between the force transducer sensing element and the specimen. In the case of constant amplitude sinusoidal fatigue testing, there will be a consequential finite displacement of this mass. This creates an inertial loading component which will be indicated by the machine but not experienced by the specimen.

A1.4 Computation of Error: Accelerometer Method

A1.4.1 The preferred method of computing error is to attach an accelerometer to the fixturing at the position of maximum displacement between the force transducer and the specimen. Using the maximum acceleration indicated, along with the fixturing weight, calculate the force error as:

$$Fi = W/g \cdot a \quad (A1.1)$$

where:

Fi = the inertial force,
W = the weight of the inertial mass,
g = gravitational acceleration, and
a = the inertial mass acceleration.

A1.5 Computation of Error: Displacement Method

A1.5.1 For purely sinusoidal motion of the force transducer, an alternative method is to measure the displacement of the force transducer and calculate an error. This may be calculated by:

$$Fi = Ma = -M(2 \cdot \pi \cdot f)^2 X \quad (A1.2)$$

where:

M = the inertial mass,
f = the operating frequency, Hz,
X = the inertial mass displacement, and
a = the inertial mass acceleration.

NOTE A1.1—The inertial mass (M) or the inertial weight (W) must include everything between the sensing element of the force transducer and the specimen. If the exact location of the force transducer element is unknown, then the entire force transducer mass or weight should be used.

A1.5.1.1 *SI Units*—If the inertial mass (M) is in kilograms, the inertial force (Fi) is in Newtons, and the displacement (X) is in millimeters, then

$$Fi = -(0.0395)\, Mf^2X \quad (A1.3)$$

A1.5.1.2 *English Units*—If the inertial mass (M) and the inertial force (Fi) are in pounds and the displacement (X) is in inches, then

$$Fi = (-0.102)\, Mf^2X \quad (A1.4)$$

The essential variable in this equation is the displacement of the inertial mass.

A1.5.1.3 One method of measuring the displacement of the inertial mass would require a measuring microscope, a pen-light source, and some 400 or 320 grit emery cloth. Attach the emery cloth to the fixturing at the position of maximum displacement between the force transducer and the specimen. Anchor the measuring microscope to the floor at the same height as the emery cloth and in position to view the emery cloth. When the emery cloth is illuminated and the machine is operating, focus the microscope on the emery, and a series of lines will be produced with the length equal to the displacement of the fixture. That displacement can then be used to calculate the force error for that specific condition. It should be noted that the inertia force so calculated will be a peak-to-peak value if a peak-to-peak displacement is used and an amplitude value if the displacement amplitude is used.

A1.6 Report

A1.6.1 When using Annex A1, the errors computed must be added to a reference dynamic verification. That verification report, as well as this Annex calculation constitutes the report for the specific configuration being used.

A2. INSTRUMENTATION REQUIREMENTS

A2.1 Dynamometer

A2.1.1 The dynamometer is an elastic calibration device for use in verifying the indicated forces applied by a fatigue testing system. The preferred dynamometer is a strain gaged member having similar mass, stiffness, and end displacement as typical test specimens. A strain gaged specimen is often used as the dynamometer and is considered ideal. A dynamometer of any suitable configuration and material may be used. Final verifications for a specific specimen and grip configuration will add calculated inertial errors to those determined by the verification (see Annex A1). Using a dynamometer of similar stiffness to the actual specimen minimizes uncertainty in the acceleration correction.

A2.1.2 The dynamometer is to be instrumented to accurately measure the applied dynamometer static and dynamic forces. The dynamometer shall be sensitive to force changes of 0.2 % of the maximum force of the dynamometer range. The strain gage approach assumes that the force-strain relationship for the dynamometer is the same under cyclic loading as it is under static loading. The instrumentation shall permit an accurate determination of the magnitude of the average strain in a region of the uniform transverse cross section when the dynamometer is subjected to a tensile or compressive force along its longitudinal axis.

A2.1.3 One acceptable dynamometer, to represent an axially symmetric specimen, consists of not less than four nominally identical electrical resistance strain gages mounted to form a full Wheatstone bridge and to produce an electrical signal proportional to the average applied axial force. If each gage is mounted at 90° from the previous gage around the circumference of the dynamometer and oriented at right angles to the previous gage, then the bridge will be insensitive to any bending loads being applied to the dynamometer.

A2.2 Typical Instrumentation

A2.2.1 The dynamometer and machine instrumentation, including both the system high level indicated force and the dynamometer conditioners, shall not be significantly affected by line voltage fluctuations of less than ±10 %. The same instrumentation must be used to record the static and dynamic response of the dynamometer and the system's indicated force. The instrumentation shall have an output display capable of resolving at least one part out of 10 000 when the maximum force is applied to the dynamometer.

A2.2.2 *Automated System*—A typical system used to measure the output of the dynamometer and achieve high resolution and accuracy is an automated data acquisition system utilizing a digital computer combined with an analog to digital (A to D) converter and associated input conditioning. The per channel sampling rate of the digital computer system must be sufficiently fast to collect the peak dynamometer signal within 0.2 % of the true peak. If the dynamometer signal is free of noise and is a sine wave function, this would require 50 data points per sine wave cycle to ensure that the peak dynamometer signal values are within 0.2 % of the acquired data. For example, if the testing is using a sine wave function at a frequency of 100 Hz, then the computer system sampling rate per channel must exceed 5000 data points per s.

A2.2.3 *Manual Analog System:*

A2.2.3.1 Another typical system which may be used is a null-reading system that allows the output of the dynamometer to be biased such that the maximum or minimum outputs during the cycle are separately adjusted to zero. It is then necessary only to detect zero output of the transducer at both maximum and minimum force. The maximum force can be obtained by accurately measuring the bias voltage required to produce zero output voltage from the dynamometer bridge at maximum force. The minimum force can be obtained by accurately measuring the bias voltage required to produce zero output voltage at minimum force.

A2.2.3.2 A convenient method of accomplishing this is to have the dynamometer output connected to an adjustable circuit fed from a dc supply and to observe the zero output on an oscilloscope. The bias voltage can be adjusted to produce zero output voltage of the complete bridge at either maximum or minimum applied force. The value of the adjustable bias voltage is proportional to the applied force.

A2.2.3.3 The oscilloscope must be sensitive to force changes of 0.2 % of maximum force when the strain gage bridge is in a nearly balanced condition. It is necessary to ensure that the output of the bridge circuit and any amplifier between the bridge and the oscilloscope is linear with amplitude and independent of frequency throughout the frequency range over which the force will be cycled.

A2.3 Data Acquisition and Instrumentation Requirements and Limitations

A2.3.1 Refer to Guide E1942 for specific information about data acquisition and instrumentation requirements and limitations.

A3. SAMPLE REPORTS

A3.1 As of this revision, Annex A3 has been dramatically shortened and subsequent sections have been removed. These sections were excerpts taken from a pending ASTM Recommended Practice on Data Acquisition being developed by the E08.03.04 task group.

A3.2 One possible format of a test report is shown in Fig. A3.1. It is an illustration only and is not a mandatory format.

DYNAMIC VERIFICATION REPORT per ASTM E467
Example

VERIFICATION # XXXXX

System ID #	XXXXX	**Customer**	XXXXX	**Servicing Org**	XXXXX
System Mfg/Model #	XXXXX	**Location**	XXXXX	**Date**	XXXXX
System Serial #	XXXXX				

FORCE TRANSDUCER		**DYNAMOMETER**		**MECHANICAL CONFIGURATION**	
Mfg/Model #	XXXXX	**Mfg/Model #**	XXXXX		
Serial #	XXXXX	**Dynamometer ID #**	XXXXX	**B-plate to Crosshead**	xx mm
		Type/Configuration	XXXXX	**Grip to Grip**	xx mm
		Dimensions	XXXXX	**Vibration Isolation**	XXXXX
		Stiffness	XXXXX	**Column Restraints**	XXXXX
		Gaging Information	XXXXX		
		Temp Comp	XXXXX		

FORCE TRANSDUCER CONDITIONING		**DYNAMOMETER CONDITIONING**		**GRIP CONFIGURATION**	
Mfg/Model #	XXXXX	**Mfg/Model #**	XXXXX	**Mfg/Model #**	XXXXX
Conditioner ID #	XXXXX	**Conditioner ID #**	XXXXX	**Type**	XXXXX
Conditioner Gain	xxx V/V	**Conditioner Gain**	xxx V/V	**Attachments**	XXXXX
Excitation	xxx V	**Excitation**	xxx V	**Wedge Type/Size**	XXXXX
Filter	XXXXX	**Filter**	XXXXX		

FORCE TRANSDUCER DATA ACQUISITION		**DYNAMOMETER DATA ACQUISITION**			
Mfg/Model #	XXXXX	**Mfg/Model #**	XXXXX		
Conditioner ID #	XXXXX	**Conditioner ID #**	XXXXX		
Conditioner Gain	xxx V/V	**Conditioner Gain**	xxx V/V		
Digital Gain	XXXXX	**Digital Gain**	XXXXX		
Force Scaling #	xxx lb/V	**Force Scaling #**	xxx lb/V	**Verified by**	XXXXX
Throughput	xxx Khz	**Throughput**	xxx Khz		
Filter	XXXXX	**Filter**	XXXXX	**Approved by**	XXXXX

Verification was performed according to the latest version of ASTM E467.
It established the force transducer corrected force errors due to dynamic operation to be less than +/– 1.0%
of span at any force transducer indicated force end level within the tested range of spans and frequencies.
Correlation between the test machine force command and the force transducer indicated force was not evaluated.

FIG. A3.1 Possible Format of a Test Report

DYNAMIC VERIFICATION REPORT per ASTM E467
Example

STATIC VERIFICATION DATA

Applied Load	Indicated Force	Dynamometer Force	Error	
(lbs)	(lbs)	(lbs)	(lbs)	(% Indicated Force)
Maximum Ind Endlevel –5% of Ind Span	9555	9553	–2	–0.02
Maximum Ind Endlevel	10002	9998	–4	–0.04
Maximum Ind Endlevel +5% Of Ind Span	10454	10450	–4	–0.04
Minimum Ind Endlevel +5% Of Ind Span	1446	1448	2	0.13
Minimum Ind Endlevel	998	1000	2	0.21
Minimum Ind Endlevel –5% of Ind Span	550	554	5	0.88

DYNAMIC VERIFICATION DATA

	Peak Error			Valley Error			
Freq	Maximum Value		Ind Span	Maximum Value		Ind Span	Pass/Fail
(Hz)	(LBS)	(% Ind Span)	(LBS)	(LBS)	(% Ind Span)	(LBS)	
1.25	13	0.15	9040	–12	–0.14	9015	Pass
2.5	14	0.16	9031	–12	–0.13	9022	Pass
5	16	0.18	8989	–14	–0.15	8954	Pass
10	12	0.13	9030	–13	–0.14	8979	Pass
20	7	0.07	9000	–6	–0.07	9015	Pass
25	22	0.25	9077	–12	–0.13	9060	Pass
30	11	0.12	9058	1	0.01	9125	Pass
40	–5	–0.05	9255	13	0.14	9311	Pass
60	–21	–0.23	9258	13	0.14	9541	Pass
80	–12	–0.17	7182	22	0.30	7210	Pass

The results of this verification are in accord with the latest version of ASTM E467 and are valid only for the machine and dynamometer configurations, frequency range and force spans specified in this report. The dynamometer static calibration range is within the current ASTM E4 Static Verification range.

FIG. A3.1 Possible Format of a Test Report *(continued)*

DYNAMIC VERIFICATION REPORT per ASTM E467
Example

DATA ACQUISITION SAMPLING INFORMATION

TEST FREQUENCY (Hz)	1.25	2.5	5	10	20	25	30	40	60	80
SAMPLES/SECOND	62.5	125	250	500	1000	1250	1497	2000	3012	4000
SAMPLES/CYCLE	50	50	50	50	50	50	50	50	50	50
TEST DURATION (SEC)	40	20	10	5	2.5	2	1.67	1.25	0.83	0.625

Test Parameters			
FORCE SETTINGS		WAVEFORM	Sine
Maximum Endlevel (lbs)	10000		
Minimum Endlevel (lbs)	1000		

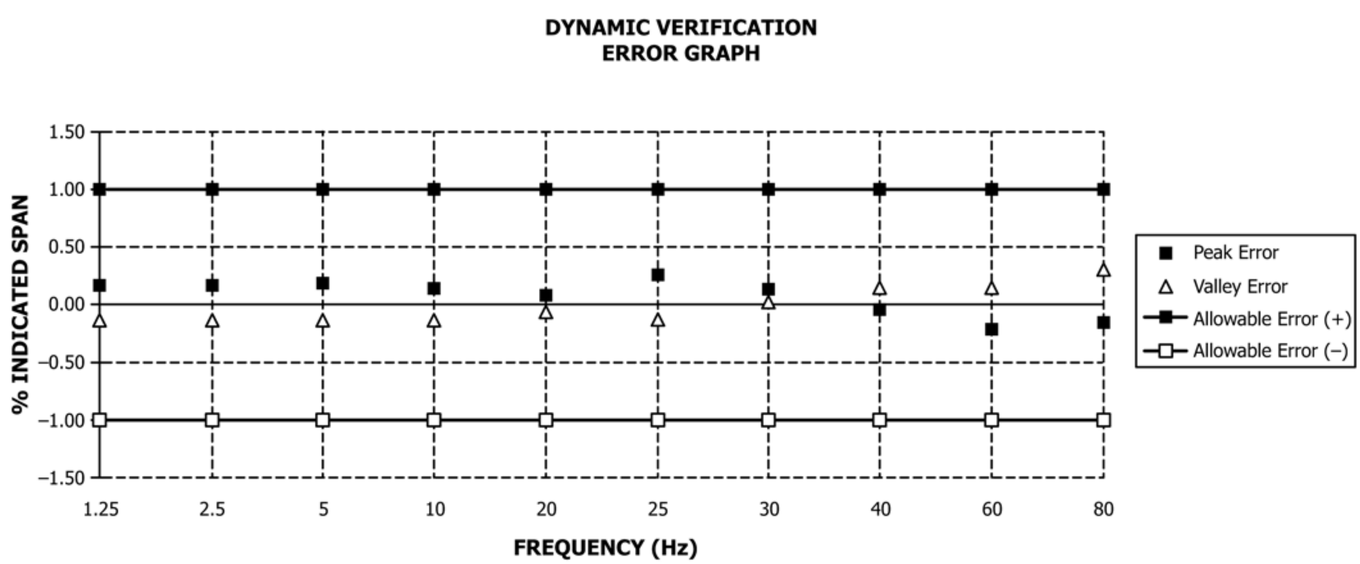

FIG. A3.1 Possible Format of a Test Report *(continued)*