

# Appendix A—Nomenclature

In this appendix, the ASTM Definitions of Terms Relating to Fatigue Testing and the Statistical Analysis of Fatigue Data (E 206-72) is reproduced in its entirety, followed by a brief listing of terms used in transducer technology.

## ASTM E 206-72

### 1. Scope

1.1 These definitions cover the principal terms and symbols relating to fatigue testing and the statistical analysis of fatigue data.

### 2. Index of Terms

2.1 The definitions appear in the following sections:

#### A. GENERAL

For the following definitions see ASTM Definitions E 6, Terms Relating to Methods of Mechanical Testing.<sup>1</sup>

| Term                  |
|-----------------------|
| mechanical properties |
| mechanical testing    |
| strain                |
| stress                |
| stress-strain diagram |

#### B. DEFINITIONS RELATING TO FATIGUE TESTS AND TEST METHODS

| Term                                 | Section   |
|--------------------------------------|-----------|
| constant life fatigue diagram        | 21        |
| corrosion fatigue                    | 5         |
| cycle ratio                          | 17        |
| fatigue                              | 3         |
| fatigue life                         | 4         |
| fatigue limit                        | 16        |
| fatigue notch factor                 | 19        |
| fatigue notch sensitivity            | 20        |
| fatigue strength at $N$ cycles       | 15        |
| macrostrain (see Definitions E 6)    |           |
| maximum stress                       | 7         |
| mean stress                          | 9         |
| microstrain (see Definitions E 6)    |           |
| minimum stress                       | 8         |
| nominal stress (see Definitions E 6) |           |
| range of stress                      | 10        |
| S-N diagram                          | 13        |
| "static fatigue"                     | 3, Note 1 |

| Term                                               | Section   |
|----------------------------------------------------|-----------|
| steady component of stress                         | 9         |
| strain (see Definitions E 6)                       |           |
| stress (see Definitions E 6)                       |           |
| stress amplitude                                   | 11        |
| stress concentration factor                        | 18        |
| stress cycle                                       | 6         |
| stress cycles endured                              | 14        |
| stress ratio                                       | 12        |
| stress-rupture strength (see also Definitions E 6) | 3, Note 1 |
| theoretical stress concentration factor            | 18        |
| variable component of stress                       | 11        |

#### C. DEFINITIONS RELATING TO STATISTICAL ANALYSIS OF FATIGUE DATA

| Term                                                    | Section |
|---------------------------------------------------------|---------|
| arithmetic mean                                         | 40      |
| confidence coefficient                                  | 47      |
| confidence interval                                     | 45      |
| confidence level                                        | 47      |
| confidence limits                                       | 46      |
| estimate                                                | 37      |
| estimation                                              | 36      |
| fatigue life for $p$ percent survival                   | 23      |
| fatigue limit for $p$ percent survival                  | 26      |
| fatigue strength for $p$ percent survival at $N$ cycles | 25      |
| frequency distribution                                  | 33      |
| group                                                   | 32      |
| interval estimate                                       | 44      |
| median fatigue life                                     | 22      |
| median fatigue strength at $N$ cycles                   | 24      |
| parameter                                               | 34      |
| point estimate                                          | 38      |
| population                                              | 30      |
| response curve for $N$ cycles                           | 29      |

<sup>1</sup> These definitions are under the jurisdiction of ASTM Committee E-9 on Fatigue.

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<sup>2</sup> Annual Book of ASTM Standards, Parts 27, 31.

| Term                                           | Section |
|------------------------------------------------|---------|
| sample                                         | 31      |
| sample average                                 | 40      |
| sample median                                  | 39      |
| sample percentage                              | 43      |
| sample standard deviation                      | 42      |
| sample variance                                | 41      |
| significance level                             | 54      |
| significant                                    | 51      |
| <i>S-N</i> curve for 50 percent survival       | 27      |
| <i>S-N</i> curve for <i>p</i> percent survival | 28      |
| statistic                                      | 35      |
| test of significance                           | 53      |
| test-statistic                                 | 52      |
| tolerance interval                             | 48      |
| tolerance level                                | 50      |
| tolerance limits                               | 49      |
| universe                                       | 30      |

#### D. TENSION, COMPRESSION, SHEAR, AND TORSION TESTING

For the following definitions, see Definitions E 6:

##### Term

angular strain  
axial strain  
biaxial stress  
chord modulus  
compression modulus  
compressive strength  
compressive stress  
ductility  
elastic constants  
elastic limit  
elongation  
fracture stress  
gage length  
initial tangent modulus  
linear strain  
macrostrain  
malleability  
mechanical hysteresis  
mechanical properties  
mechanical testing  
microstrain  
modulus of elasticity  
modulus of rigidity  
modulus of rupture in bending  
modulus of rupture in torsion  
multiaxial stress  
nominal stress  
normal stress  
Poisson's ratio  
principal stress (normal)  
proportional limit  
reduction of area  
secant modulus  
set  
shear fracture  
shear modulus  
shear strain  
shear strength  
shear stress  
strain  
stress  
stress-strain diagram  
tangent modulus

Term  
tensile strength  
tensile stress  
torsional stress  
transverse strain  
triaxial stress  
true strain  
true stress  
uniaxial stress  
yield point  
yield strength  
Young's modulus

#### A. GENERAL DEFINITIONS

NOTE—The general terms listed in Section 2 under the Index of Terms are defined in Definitions E 6.

#### B. DEFINITIONS RELATING TO FATIGUE TESTS AND TEST METHODS

**3. fatigue** (Note 1)—the process of progressive localized permanent structural change occurring in a material subjected to conditions which produce fluctuating stresses and strains at some point or points and which may culminate in cracks or complete fracture after a sufficient number of fluctuations (Note 2).

NOTE 1—In glass technology static tests of considerable duration are called "static fatigue" tests, a type of test generally designated as stress-rupture (see Definitions E 6, Section 46).

NOTE 2—Fluctuations may occur both in stress and with time (frequency), as in the case of "random vibration".

**4. fatigue life, *N***—the number of cycles of stress or strain of a specified character that a given specimen sustains before failure of a specified nature occurs.

**5. corrosion fatigue**—fatigue aggravated by simultaneous corrosion.

The following definitions 6 to 21, inclusive, apply to those cases where the conditions imposed upon a specimen result or are assumed to result in uniaxial principal stresses or strains which fluctuate in magnitude. Multiaxial stress, sequential loading, and random loading require more rigorous definitions which are, at present beyond the scope of this section.

**6. stress cycle**—the smallest segment of the stress-time function which is repeated periodically.

**7. maximum stress,  $S_{\max}$  [FL<sup>2</sup>]**—the stress having the highest algebraic value in the

stress cycle, tensile stress being considered positive and compressive stress negative. In this definition as well as in others that follow, the nominal stress is used most commonly.

8. **minimum stress**,  $S_{\min}$  [ $\text{FL}^{-2}$ ]**—**the stress having the lowest algebraic value in the cycle, tensile stress being considered positive and compressive stress negative.
9. **mean stress (or steady component of stress)**,  $S_m$  [ $\text{FL}^{-2}$ ]**—**the algebraic average of the maximum and minimum stresses in one cycle, that is,

$$S_m = (S_{\max} + S_{\min})/2$$

10. **range of stress**,  $S$  [ $\text{FL}^{-2}$ ]**—**the algebraic difference between the maximum and minimum stresses in one cycle, that is

$$S = S_{\max} - S_{\min}$$

11. **stress amplitude (or variable component of stress)**,  $S_a$  [ $\text{FL}^{-2}$ ]**—**one half the range of stress, that is

$$S_a = S/2 = (S_{\max} - S_{\min})/2$$

12. **stress ratio**,  $A$  or  $R$ **—**the algebraic ratio of two specified stress values in a stress cycle. Two commonly used stress ratios are: The ratio of the alternating stress amplitude to the mean stress, that is,

$$A = S_a/S_m$$

and the ratio of the minimum stress to the maximum stress, that is,

$$R = S_{\min}/S_{\max}$$

13.  **$S$ - $N$  diagram****—**a plot of stress against the number of cycles to failure. The stress can be  $S_{\max}$ ,  $S_{\min}$ , or  $S_a$ . The diagram indicates the  $S$ - $N$  relationship for a specified value of  $S_m$ ,  $A$ , or  $R$  and a specified probability of survival. For  $N$  a log scale is almost always used. For  $S$  a linear scale is used most often, but a log scale is sometimes used.
14. **stress cycles endured**,  $n$ **—**the number of cycles of a specified character (that produce fluctuating stress and strain) which a specimen has endured at any time in its stress history.
15. **fatigue strength at  $N$  cycles**,  $S_N$  [ $\text{FL}^{-2}$ ]**—**A hypothetical value of stress for failure at exactly  $N$  cycles as determined from an  $S$ - $N$  diagram. The value of  $S_N$  thus determined is subject to the same conditions as those which apply to the  $S$ - $N$  diagram.

NOTE—The value of  $S_N$  which is commonly found in the literature is the hypothetical value of  $S_{\max}$ ,  $S_{\min}$ , or  $S_a$  at which 50 percent of the specimens of a given sample could survive  $N$  stress cycles in which  $S_m = 0$ . This is also known as the median fatigue strength for  $N$  cycles (see Section 24).

16. **fatigue limit**,  $S_f$  [ $\text{FL}^{-2}$ ]**—**the limiting value of the median fatigue strength as  $N$  becomes very large.

NOTE—Certain materials and environments preclude the attainment of a fatigue limit. Values tabulated as "fatigue limits" in the literature are frequently (but not always) values of  $S_N$  for 50 percent survival at  $N$  cycles of stress in which  $S_m = 0$ .

17. **cycle ratio**,  $C$ **—**the ratio of the number of stress cycles,  $n$ , of a specified character to the hypothetical fatigue life,  $N$ , obtained from the  $S$ - $N$  diagram, for stress cycles of the same character, that is,  $C = n/N$ .

18. **theoretical stress concentration factor (or stress concentration factor)**  $K_t$ **—**the ratio of the greatest stress in the region of a notch or other stress concentrator as determined by the theory of elasticity (or by experimental procedures that give equivalent values) to the corresponding nominal stress.

NOTE—The theory of plasticity should not be used to determine  $K_t$ .

19. **fatigue notch factor**,  $K_f$ **—**the ratio of the fatigue strength of a specimen with no stress concentration to the fatigue strength at the same number of cycles with stress concentration for the same conditions.

NOTE—In specifying  $K_f$  it is necessary to specify the geometry and the values of  $S_{\max}$ ,  $S_m$ , and  $N$  for which it is computed.

20. **fatigue notch sensitivity**,  $q$ **—**a measure of the degree of agreement between  $K_f$  and  $K_t$ .

NOTE—The definition of fatigue notch sensitivity is  $q = (K_f - 1)/(K_t - 1)$ .

21. **constant life fatigue diagram****—**a plot (usually on rectangular coordinates) of a family of curves, each of which is for a single fatigue life,  $N$ , relating  $S_a$ ,  $S_{\max}$  and/or  $S_{\min}$  to the mean stress  $S_m$ . The constant life fatigue diagram is generally derived from a family of  $S$ - $N$  curves each of which

represents a different stress ratio ( $A$  or  $R$ ) for a 50 percent probability of survival.

#### C. DEFINITIONS RELATING TO STATISTICAL ANALYSIS OF FATIGUE DATA

- 22. median fatigue life**—the middlemost of the observed fatigue life values, arranged in order of magnitude, of the individual specimens in a group tested under identical conditions. In the case where an even number of specimens are tested it is the average of the two middlemost values.

NOTE—The use of the sample median instead of the arithmetic mean (that is, the average) is usually preferred.

NOTE—In the literature, the abbreviated term "fatigue life" usually has meant the median fatigue life of the group. However, when applied to a collection of data without further qualification the term "fatigue life" is ambiguous.

- 23. fatigue life for  $p$  percent survival**—an estimate of the fatigue life that  $p$  percent of the population would attain or exceed at a given stress level. The observed value of the median fatigue life estimates the fatigue life for 50 percent survival. Fatigue life for  $p$  percent survival values, where  $p$  is any number, such as 95, 90, etc., may also be estimated from the individual fatigue life values.

- 24. median fatigue strength at  $N$  cycles** [ $FL^{-2}$ ] $^{-1}$ —an estimate of the stress level at which 50 percent of the population would survive  $N$  cycles.

NOTE—The estimate of the median fatigue strength is derived from a particular point of the fatigue life distribution, since there is no test procedure by which a frequency distribution of fatigue strengths at  $N$  cycles can be directly observed.

NOTE—This is a special case of the more general definition (Section 25).

- 25. fatigue strength for  $p$  percent survival at  $N$  cycles** [ $FL^{-2}$ ] $^{-1}$ —an estimate of the stress level at which  $p$  percent of the population would survive  $N$  cycles;  $p$  may be any number, such as 95, 90, etc.

NOTE—The estimates of the fatigue strengths for  $p$  percent survival values are derived from particular points of the fatigue life distribution, since there is no test procedure by which a frequency distribution of fatigue strengths at  $N$  cycles can be directly observed.

- 26. fatigue limit for  $p$  percent survival** [ $FL^{-2}$ ] $^{-1}$ —the limiting value of fatigue strength for

$p$  percent survival as  $N$  becomes very large;  $p$  may be any number, such as 95, 90, etc. (Note 5, Section 16).

- 27.  $S$ - $N$  curve for 50 percent survival**—a curve fitted to the median values of fatigue life at each of several stress levels. It is an estimate of the relationship between applied stress and the number of cycles-to-failure that 50 percent of the population would survive.

NOTE—This is a special case of the more general definition (Section 28).

NOTE—In the literature, the abbreviated term " $S$ - $N$  Curve" usually has meant either the  $S$ - $N$  curve drawn through the means (averages) or the medians (50 percent values) for the fatigue life values. Since the term " $S$ - $N$  Curve" is ambiguous, it should be used in technical papers only when adequately described.

- 28.  $S$ - $N$  curve for  $p$  percent survival**—a curve fitted to the fatigue life for  $p$  percent survival values at each of several stress levels. It is an estimate of the relationship between applied stress and the number of cycles-to-failure that  $p$  percent of the population would survive.  $p$  may be any number, such as 95, 90, etc.

NOTE—Caution should be used in drawing conclusions from extrapolated portions of the  $S$ - $N$  curves. In general, the  $S$ - $N$  curves should not be extrapolated beyond observed life values.

- 29. response curve for  $N$  cycles**—a curve fitted to observed values of percentage survival at  $N$  cycles for several stress levels, where  $N$  is a preassigned number such as  $10^6$ ,  $10^7$ , etc. It is an estimate of the relationship between applied stress and the percentage of the population that would survive  $N$  cycles.

NOTE—Values of the median fatigue strength at  $N$  cycles and the fatigue strength for  $p$  percent survival at  $N$  cycles may be derived from the response curve for  $N$  cycles if  $p$  falls within the range of the percent survival values actually observed.

NOTE—Caution should be used in drawing conclusions from extrapolated portions of the response curves. In general, the curves should not be extrapolated to other values of  $p$ .

- 30. population (or universe)**—the hypothetical collection of all possible test specimens that could be prepared in the specified way from the material under consideration.

- 31. sample**—the specimens selected from the population for test purposes.

NOTE—The method of selecting the sample determines the population about which statistical inference or generalization can be made.

- 32. **group**—the specimens tested at one time, or consecutively, at one stress level. A group may comprise one or more specimens.
- 33. **frequency distribution**—the way in which the frequencies of occurrence of members of a population, or a sample, are distributed according to the values of the variable under consideration.
- 34. **parameter**—a constant (usually unknown) defining some property of the frequency distribution of a population, such as, a population median or a population standard deviation.
- 35. **statistic**—a summary value calculated from the observed values in a sample.
- 36. **estimation**—a procedure for making a statistical inference about the numerical values of one or more unknown population parameters from the observed values in a sample.
- 37. **estimate**—the particular value, or values, of a parameter computed by an estimation procedure for a given sample.
- 38. **point estimate**—the estimate of a parameter given by a single statistic.
- 39. **sample median**—the middle value when all observed values in a sample are arranged in order of magnitude if an odd number of samples are tested. If the sample size is even, it is the average of the two middlemost values. It is a point estimate of the population median, or 50 percent point.
- 40. **sample average (arithmetic mean)**—the sum of all the observed values in a sample divided by the sample size. It is a point estimate of the population mean.
- 41. **sample variance,  $s^2$** —the sum of the squares of the differences between each observed value and the sample average divided by the sample size minus one. It is a point estimate of the population variance.

NOTE—This value of  $s^2$  provides both an unbiased point estimate of the population variance and a statistic that is used in computing the interval estimates and several test-statistics (Sections 44 and 52). Some texts define  $s^2$  as “the sum of the squares of the differences between each observed value and the sample average divided by the sample size” but this statistic is not as useful.

- 42. **sample standard deviation,  $s$** —the square root of the sample variance. It is a point estimate of the population standard deviation, a measure of the “spread” of the frequency distribution of a population.

NOTE—This value of  $s$  provides a statistic that is used in computing interval estimates and several test-statistics (Sections 44 and 52). For small sample sizes,  $s$  underestimates the population standard deviation. (See the ASTM Manual on Quality Control of Materials, *STP 15C*, or texts on statistics for an unbiased estimate of the standard deviation of a normal population.)

- 43. **sample percentage**—the percentage of observed values between two stated values of the variable under consideration. It is a point estimate of the percentage of the population between the same two stated values. (One stated value may be  $-\infty$  or  $+\infty$ .)
- 44. **interval estimate**—the estimate of a parameter given by two statistics, defining the end points of an interval.
- 45. **confidence interval**—an interval estimate of a population parameter computed so that the statement “the population parameter lies in this interval” will be true, on the average, in a stated proportion of the times such statements are made.
- 46. **confidence limits**—the two statistics that define a confidence interval.
- 47. **confidence level (or coefficient)**—the stated proportion of the times the confidence interval is expected to include the population parameter.
- 48. **tolerance interval**—an interval computed so that it will include at least a stated percentage of the population with a stated probability.
- 49. **tolerance limits**—the two statistics that define a tolerance interval. (One value may be  $-\infty$  or  $+\infty$ .)
- 50. **tolerance level**—the stated probability that the tolerance interval includes at least the stated percentage of the population. It is not the same as a confidence level but the term confidence level is frequently associated with tolerance intervals.
- 51. **significant**—statistically significant. An effect or difference between populations is said to be present if the value of a test-statistic is significant, that is, lies outside of predetermined limits.

NOTE—An effect which is statistically signifi-

cant may or may not have engineering significance.

**52. test-statistic**—a function of the observed values in a sample that is used in a test of significance.

**53. test of significance**—a test which, by use of a test-statistic, purports to provide a test of the hypothesis that the effect is absent.

NOTE—The rejection of the hypothesis indicates that the effect is present.

**54. significance level**—the stated probability

(risk) that a given test of significance will reject the hypothesis that a specified effect is absent when the hypothesis is true.

#### D. TENSION, COMPRESSION, SHEAR, AND TORSION TESTING

NOTE—The terms on tension, compression, shear, and torsion testing listed in Section 2 under the Index of Terms are defined in ASTM Definitions E 6, Terms Relating to Methods of Mechanical Testing.<sup>2</sup>

### APPENDIX

#### A1. SYMBOLS AND ABBREVIATIONS

A1.1 The following symbols and abbreviations are frequently used in lieu of or along with the terms covered by the preceding definitions. For stress, the use of  $S$  with appropriate lower case subscripts is preferred for general purposes; for mathematical analysis the use of Greek symbols is generally preferred.

| Symbol               | Term                                                                                 | Symbol                | Term                                            |
|----------------------|--------------------------------------------------------------------------------------|-----------------------|-------------------------------------------------|
| $A$                  | area of cross section, stress ratio                                                  | $S_{cy}$              | compressive yield strength                      |
| $C$                  | cycle ratio                                                                          | $S_m$                 | mean stress                                     |
| $c$                  | distance from centroid to outermost fiber                                            | $S_{max}$             | maximum stress                                  |
| $D$ or $d$           | diameter                                                                             | $S_{min}$             | minimum stress                                  |
| $E$                  | modulus of elasticity in tension or compression                                      | $S_N$                 | fatigue strength at $N$ cycles                  |
| $\epsilon$ (epsilon) | strain                                                                               | $S_r$                 | range of stress                                 |
| $F$                  | force                                                                                | $S_s$ (or $\tau$ )    | shear stress                                    |
| ft. lbf              | a unit of work <sup>1</sup>                                                          | $S_t$                 | tensile stress                                  |
| $G$                  | modulus of elasticity in shear                                                       | $S_{ty}$              | tensile yield strength                          |
| $\gamma$ (gamma)     | shear strain                                                                         | $S_u$                 | tensile strength                                |
| $I$                  | moment of inertia                                                                    | $\sigma$ (sigma)      | standard deviation, nominal stress <sup>2</sup> |
| $i$                  | subscript denoting $i$ th term                                                       | $\hat{\sigma}$        | estimate of standard deviation                  |
| in. lbf              | a unit of work <sup>1</sup>                                                          | $\sigma^2$            | variance                                        |
| $J$                  | polar moment of inertia                                                              | $\sigma_x$            | standard deviation of $x$                       |
| ksi                  | thousands of pounds-force per square inch or kips-force per square inch <sup>1</sup> | $\sigma_x^2$          | variance of $x$                                 |
| $K_f$                | fatigue notch factor                                                                 | $T$                   | torque, temperature                             |
| $K_t$                | theoretical stress concentration factor                                              | $t$                   | time                                            |
| $L$                  | length                                                                               | $\tau$ (tau) or $S_s$ | shear stress                                    |
| lbf. ft              | a unit of torque <sup>1</sup>                                                        | $w$                   | load per unit distance or per unit area         |
| lbf. in.             | a unit of torque <sup>1</sup>                                                        | $wA$                  | total distributed load for a given area         |
| $M$                  | bending moment                                                                       | $wL$                  | total distributed load for a given length       |
| $\mu$ (mu)           | Poisson's ratio                                                                      | $W$                   | work or energy                                  |
| $N$                  | fatigue life (number of cycles)                                                      | $Z$                   | section modulus <sup>3</sup>                    |
| $n$                  | number of stress cycles endured, sample size                                         |                       |                                                 |
| $P$                  | concentrated load                                                                    |                       |                                                 |
| psi                  | pounds-force per square inch <sup>1</sup>                                            |                       |                                                 |
| $p$                  | probability                                                                          |                       |                                                 |
| $q$                  | fatigue notch sensitivity                                                            |                       |                                                 |
| $R$                  | stress ratio                                                                         |                       |                                                 |
| $s$                  | sample standard deviation                                                            |                       |                                                 |
| $s^2$                | sample variance                                                                      |                       |                                                 |
| $S$                  | nominal stress                                                                       |                       |                                                 |
| $S$ (or $\sigma$ )   | normal stress                                                                        |                       |                                                 |
| $S_a$                | stress amplitude                                                                     |                       |                                                 |
| $S_o$                | compressive stress                                                                   |                       |                                                 |
| $S_r$                | fatigue limit                                                                        |                       |                                                 |

<sup>1</sup> Because it is general engineering practice in the USA to use "pound" rather than the technically correct term "pound-force," the symbol "lb" rather than "lbf" may be used in some standards. Similarly, in the abbreviations "ksi" and "psi" the "pound-force" is the unit involved.

<sup>2</sup>  $\sigma$  (mu) is preferred in applied mechanics.

<sup>3</sup> This may be probability of failure or probability of survival; the meaning should be specified.

<sup>4</sup>  $\sigma$  is preferred in applied mechanics but should not be used when statistical treatments are involved.

Many handbooks use  $S$  for section modulus, but  $Z$  is preferred since  $S$  is so widely used for nominal or normal stress.

## Transducer Terminology

While it is recognized that a variety of terms are used by manufacturers for product description, a minimum number of key terms have been selected which are necessary to obtain, in a clear, and concise manner; descriptive data to make the ISA Transducer Compendium a valuable reference to those actively engaged in this area of instrumentation.

### *Measurand and Output*

**measurand**—is the physical quantity, property, or condition which is measured.

**measurand range**—are the minimum and maximum values of the measurand.

**measurand properties**—are the inherent properties of the measurand which must be maintained while a transducer operates within a specified range. (These properties are not to be confused with environmental characteristics.) For example, consider a flowmeter measuring the flow rate of water in a pipe. Unless the water pressure is within certain limits the flowmeter will not operate correctly; therefore, the minimum and maximum pressure limits of the water would have to be listed under measurand properties.

**operating principle**—is the nature of the sensing technique and the transducer principle necessary to sense the measurand and to produce an output signal, for example, bourdon tube, bellows, resistive, capacitive, inductive, etc.

**output characteristics**—are the nature of the output signal (electrical, pneumatic, hydraulic), output range (s), power output, and output impedance.

**sensitivity**—is the ratio of full-scale output to full-scale measurand value. (Identify units clearly.)

**excitation**—is the nature and magnitude of all external energy required for proper transducer operation; this, of course, excludes the measurand. This includes power requirements, comparative circuits, pneumatic or hydraulic pressures, etc.

### *Operating Characteristics*

**theoretical transfer function**—is the theoretical relation between measurand and output values as determined by inherent principles of operation. It is expressed as common functions, for example, linear, parabolic, logarithmic, sinusoidal, etc.

**static error band**—is the deviation from the theoretical transfer function under constant environmental conditions. This, of course, includes

effects of hysteresis, friction and repeatability, as well as other sources of error which are not due to environmental variations.

Example:

| <u>Range</u>                      | <u>Maximum Error</u>           |
|-----------------------------------|--------------------------------|
| (percent of full-scale measurand) | (percent of full-scale output) |
| from 0 to 20                      | $\pm 6.0$                      |
| from 20 to 75                     | $\pm 5.0$                      |
| from 75 to 100                    | $\pm 10.0$                     |

environmental conditions: 25°C

**repeatability**—is the ability of a transducer to reproduce and output signal when the same measurand value is applied to it three successive times, under the same conditions and direction. It is expressed as the maximum difference between output readings in terms of percent of full-scale output.

Example

| <u>Range</u>                      | <u>Repeatability</u>           |
|-----------------------------------|--------------------------------|
| (percent of full-scale measurand) | (percent of full-scale output) |

**resolution**—is the smallest change of measurand that produces a recognizable change in output, expressed as a percentage of full-scale measurand. Resolution is sometimes referred to as “threshold” in certain specific applications.

Example

| <u>Range</u>                      | <u>Resolution</u>                 |
|-----------------------------------|-----------------------------------|
| (percent of full-scale measurand) | (percent of full-scale measurand) |
| from 0 to 70                      | 0.1                               |
| from 70 to 100                    | 0.2                               |

environmental conditions: standard temperature and pressure

**overrange**—is the maximum magnitude of the measurand that can be applied to a transducer without causing a change in performance beyond the specified tolerances (expressed as percent of full-scale measurand). An overrange factor may sometimes be referred to as “overload” factor.

**zero shift**—is a displacement of the entire calibration curve expressed as a percent of full-scale output.

**time constant**—is the time required for the transducer output to reach 63 percent of its final output value as a result of a step change in the measurand.

### *Environmental Characteristics*

**environmental ranges**—The range of environmental conditions under which a transducer will perform within static error band limits. Typical environmental conditions are temperature, pressure, humidity, acceleration, vibration (includes resonant and natural frequencies), magnetic and electrical effects, shock, noise, and radiation.

**environmental effects**—Are the changes in output due to change in the environmental conditions, expressed as the change in output (percent of full-scale) per unit of environmental change.

**standard temperature and pressure**—are 25.0°C (77°F) and one atmosphere (29.92 in. Hg or 14.69 psia), respectively. The standard temperature and pressure condition also includes zero vibration and acceleration.

### *Physical Characteristics*

**size**—the overall physical dimensions of the transducer.

**mounting**—the mounting specifications, for example, end clamp, flange, screw, etc.

**connections**—the type of connections to the transducer, for example, receptacle, solder terminals, threaded inlet, etc.

**materials of construction**—the principal materials of construction, for example, stainless steel, plastic, etc.

**weight**—the weight of the transducer and its required auxiliary equipment.

**life expectancy**—the transducer life expressed in terms of full-scale cycles, or exposure time under operating conditions before the transducer performance exceeds static error band limits.

**interchangeability**—is the extent to which individual transducers of a model series can be interchanged.

### *Terminology Related to Readout Equipment Transducers*

**natural frequency**—frequency at which transducer will resonate.

**temperature sensitivity**—percent of full-scale output per 100°F increase in temperature.

**hysteresis**—when two separate data points for one certain level of measurand input are compared, one point having been determined, following an increasing input from zero to full range, the other

following a decrease in input from full scale to zero, the deviation in output between the two data points is defined as hysteresis.

**repeatability**—the difference between successive calibrations of the same transducers under identical test conditions is defined as repeatability. At least three complete full-scale transducer cycles for most transducers are applied prior to starting the initial calibration.

**sensitivity**—transducer full scale output per volt of excitation.

**excitation**—the nature and magnitude of all external energy required for proper transducer operation.

**resolution**—the smallest change of measurand that produces a recognizable change in output expressed as percent of full-scale measurand—sometimes referred to as “threshold.”

**time constant**—the time required for the transducer output to reach 63 percent of its final output value as a result of a step change in the measurand. Usually only applicable in first order system.

**dependent linearity**—maximum deviation from a straight line drawn through the zero and full output points. Given as a percent of full output.

**independent linearity**—maximum deviation from a straight line that is positioned on the transfer characteristic in such a manner as to result in the smallest deviation.

## Appendix B—Specifications in the Field of Fatigue Testing

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This chapter will list the various specifications relating to fatigue testing in general, and fatigue tests for various products.

### International Standards

#### *The ISO Standards and Recommendations*

The following countries are members of the International Organization for Standardization (ISO):

|                |             |                          |
|----------------|-------------|--------------------------|
| Australia      | France      | Poland                   |
| Austria        | Germany     | Portugal                 |
| Belgium        | Greece      | Romania                  |
| Bulgaria       | Hungary     | Spain                    |
| Burma          | India       | Sweden                   |
| Canada         | Ireland     | Switzerland              |
| Chile          | Italy       | Turkey                   |
| Czechoslovakia | Japan       | United Kingdom           |
| Denmark        | Morocco     | United States of America |
| Egypt          | Netherlands | U.S.S.R.                 |
| Finland        | New Zealand | Yugoslavia               |
|                | Norway      |                          |

This group has prepared a number of recommendations and standards relating to fatigue (Table 2).

ISO Recommendation R373—General Principles for Fatigue Testing of Metals.

ISO Recommendation 733E (Draft)—Methods of Fatigue Testing Part 3: Axial Load Fatigue Testing.

ISO Recommendation 1350 (Draft)—Rotating Bar Bending Fatigue Testing.

ISO Recommendation 1352 (Draft)—Torsional Stress Fatigue Testing.

Work is presently underway on a proposal for Dynamic Force Calibration of Direct Stress Fatigue Machines.

The member bodies (the national standards organizations of the

TABLE 2—ISO proposals for fatigue testing.

| Method                  | Rotating Bending                                                                                                                                                                                                                                                                                                                         | Axial Loading                                                                                     | Torsion Loading        |
|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|------------------------|
| Scope                   | 0.02 to 0.5-in. diameter circular cross-section, unnotched specimens tested in air at room temperature                                                                                                                                                                                                                                   |                                                                                                   |                        |
|                         |                                                                                                                                                                                                                                                                                                                                          | 0.05 to 1.0 sq. in. area—rectangular cross-section                                                |                        |
| Specimen Size           | figures, dimensions, and tolerances                                                                                                                                                                                                                                                                                                      |                                                                                                   |                        |
| Specimen Preparation    | machine such that work-hardening of surface is minimized, avoid overheating. Detailed procedures for turning, milling (in case of axial loading), grinding, surface finish, and storage.                                                                                                                                                 |                                                                                                   |                        |
| Specimen Mounting       | coaxiality of machine and specimen                                                                                                                                                                                                                                                                                                       |                                                                                                   |                        |
|                         | allowable eccentricity                                                                                                                                                                                                                                                                                                                   | avoid twisting specimen                                                                           | avoid bending stresses |
| Test Frequency          | 1000 to 12 000 cpm                                                                                                                                                                                                                                                                                                                       | 250 to 18 000 cpm                                                                                 | depends on machine     |
| Load Application        | bring up to speed, then apply moment                                                                                                                                                                                                                                                                                                     | apply mean, then fluctuating component, monitor during test. <i>Calibrate dynamically.</i>        |                        |
| Accuracy                | ±1% of nominal moment                                                                                                                                                                                                                                                                                                                    | dynamic mean and range, ±3% of their nominal value or ±¼% machine capacity, whichever is greater. |                        |
| Failure Criterion       | complete fracture                                                                                                                                                                                                                                                                                                                        |                                                                                                   |                        |
| Run-out                 | 10 <sup>7</sup> cycles—structural steels.                                                                                                                                                                                                                                                                                                | 10 <sup>8</sup> cycles—other steels,                                                              | nonferrous metals.     |
| Presentation of Results | graphic presentation as per R373. Include details of specimen material and condition, type of specimen and machine, frequency, temperature and relative humidity (if outside range of 50 to 70%), criterion of failure, any deviations from required conditions (and stress ratio or mean stress in case of axial or torsional loading). |                                                                                                   |                        |

countries just listed) can approve or oppose these recommendations. Specific information on these specifications should be obtained from the appropriate national standards organization (for example, in the United States, National Bureau of Standards; in the United Kingdom, the British Standards Institution). The British Standards Institution serves as the secretariat for many of these specifications, while the main secretariat is:

ISO Central Secretariat  
1, rue de Varembe  
1211 Geneve 20  
Switzerland

### National Standards

#### *West Germany*

The German Standards (DIN) are well developed and cover aspects of

fatigue test methods as well as special product-oriented tests. They can be obtained from:

Deutscher Normenausschuss (DNA)  
1 Berlin 30  
Burggrafenstrasse 4-7

Most of the relevant standards are available in English as well, though only the German language versions are official.

DIN 50100: Testing of Materials, fatigue test, definitions, symbols, procedure, evaluation.

DIN 51228: Fatigue testing machines, definitions, general requirements.

#### *The United Kingdom*

The British Standards Institution (British Standards House, 2 Park Street, London W.1, England), developed the following standards in the field of fatigue testing. These have been approved by the Mechanical Engineering Industry Standards Committee and endorsed by the Chairman of the U.K. Engineering Divisional Council.

Methods of Fatigue Testing Parts 1-5, British Standards Institution B.S. 3518

|        |      |                                         |
|--------|------|-----------------------------------------|
| Part 1 | 1962 | General Principles.                     |
| Part 2 | 1962 | Rotating Bending Fatigue Tests.         |
| Part 3 | 1963 | Direct Stress Fatigue Tests.            |
| Part 4 | 1963 | Torsional Stress Fatigue Tests.         |
| Part 5 | 1966 | Guide to the Application of Statistics. |

#### *The United States*

While there are numerous specifications relating to fatigue, many of them emanate from professional bodies directly, rather than from governmental institutions. There is, however, a trend at present, for many of these specifications to have complete governmental backing from a legal viewpoint.

*Military Handbook 5*—"Strength of Metal Aircraft Elements." This document was prepared and is maintained by the U.S. Department of Defense with the assistance of the Federal Aviation Agency. It contains data on material properties required of manufacturers by the U.S. Government for military equipment. It contains fatigue data, but not detailed fatigue specifications at present.

*American Standards Institute (USASI)*—The organization has been active in converting professional specifications into federal specifications.

A number of "codes" bear on fatigue and flaw growth implicitly:

Welding Society Pressure Vessel Research Committee  
American Petroleum Institute (API)  
American Gas Association

The following professional groups have specifications of materials and products some of which bear on fatigue:

Society of Automotive Engineers AMS Committee  
ASME Metals Engineering Division, Code Committees

*American Society for Testing and Materials*—Work is underway on the development of other test method standards in fatigue; those available are:

- ASTM Recommended Practice for Constant Amplitude Axial Fatigue Tests of Metallic Materials (E 466-72T)
- ASTM Recommended Practice for Verification of Constant Amplitude Dynamic Loads in an Axial Load Fatigue Testing Machine (3 467-72T)
- ASTM Recommended Practice for Presentation of Constant Amplitude Fatigue Test Results for Metallic Materials (E 468-72T)
- ASTM Test for Shear Fatigue of Sandwich Core Materials (C 394-62)
- ASTM Testing Automotive Hydraulic Brake Hose (D 571-72)
- ASTM Tests for Compression Fatigue of Vulcanized Rubber (D 623-67)
- ASTM Test for Flexural Fatigue of Plastics by Constant-Amplitude-of-Force (D 671-71)
- ASTM Test for Crack Growth of Rubber (D 813-59)
- ASTM Specifications and Tests for Latex Foam Rubbers (D 1155-69)
- ASTM Specifications and Tests for Flexible Foams Made from Polymers of Copolymers of Vinyl Chloride (D 1565-70)
- ASTM Testing Molded Flexible Urethane Foam (D 2406-68)

## Appendix C—Professional Society Groups Related to Fatigue Testing

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The techniques of fatigue testing draw heavily upon various technical areas which are presently experiencing rapid growth. Computer technology, for example, must be monitored almost weekly to appreciate the possibilities which become available for incorporation into fatigue testing.

Because of these continuing opportunities for improvement, the scientist or engineer concerned with fatigue is well advised to become a member of one or more of the professional groups in fatigue research. This chapter will briefly describe as many of these groups as possible, pointing out the aspects which differentiate them one from another.

### **International Groups Concerned with Fatigue**

#### *The International Committee on Aeronautical Fatigue (ICAF)*

The International Committee on Aeronautical Fatigue (ICAF) is composed of one representative of each of ten countries having an interest in aeronautical fatigue. In almost all cases that representative is actively engaged in fatigue research at the national aeronautical research establishment of his country.

#### *The Federation Internationale des Societes d'Ingenieurs des Techniques de l'Automobile (FISITA)*

This international organization is a federation of national societies for automotive engineering. While it has no formal subdivision for the subject of fatigue, its meetings, held every two years, are often used by fatigue researchers connected with automotive science to publish their results.

### **National Organizations**

#### *American Organizations*

#### *The American Society for Testing and Materials (ASTM)*

#### *Committee E-9 on Fatigue*

This organization has had a standing committee for fatigue (Committee

E-9) for over 25 years, and in 1949 published their *Manual on Fatigue Testing, STP 91*. Committee E-9 has been the focal point of a very large portion of the fatigue activity in the United States. It has several subcommittees which are restructured from time to time to serve the interests of the members. The scope of this committee is as follows.

### Scope

The promotion of research on the nature of fatigue behavior and methods for improving fatigue behavior.

The development of methods for determining fatigue characteristics of simple and *composite* materials, components, processed parts, and complete assemblies.

The development of analytical procedures for interpreting fatigue test results and for designing against fatigue.

The coordination of activities in these areas wherever they might be conducted.

And the standardization of nomenclature, definitions, data evaluation, and methods.

### Area of Interest

Included in this scope is any engineering application in which the materials, processed parts, components, or complete assemblies used are subjected to stresses and strains that might result in fatigue damage or failure. Among the *parameters* of interest are:

Environment

Physical deformation mechanisms

Fatigue crack propagation

Fracture

Relation between stress, strain level and life

Behavior of specific materials

Metallurgical considerations

Processing variables

Residual stresses

Stress and strain concentrations

Stress analysis (elastic and plastic)

Variable amplitude and random loadings

Joints—methods, fasteners, welds, spot welds

Fretting

Corrosion

Vacuum

Temperature

Statistical analysis

Rolling contact  
 Speed of testing  
 Size  
 Damage detection  
 Methods of test  
 Test equipment  
 Effect of damage accumulation

The present structure is as follows:

### **Subcommittee .01 Research**

The purposes of the Research Subcommittee of E-9 are as follows:

1. To keep membership of the main committee informed of advances in the understanding of fatigue.
2. To promote the development of further understanding of the fatigue process as influenced by both internal (material) and external (load and environment) parameters.
3. To meet these objectives the subcommittee will sponsor symposia on topics of current interest in fatigue research and assist in the publication of the proceedings of such meetings where appropriate.

### **Subcommittee .02 Papers**

The papers subcommittee is concerned with timely and effective presentation and publication of papers in the field of fatigue of materials. To this end it shall,

1. Invite, review, and schedule papers for sessions and conduct these sessions at annual meetings and other occasions except when these functions are delegated to others, such as symposia chairmen.
2. Assist symposia chairmen and others in planning, organizing, and conducting meetings.
3. Review papers submitted for publication and maintain a list of reviewers and their fields of competence.
4. Maintain and improve the quality of papers, of their delivery in meetings, and of their discussion. (An annual award for the best presented paper is made by this subcommittee.)
5. Submit broad plans for sessions and symposia to the executive committee.

### **Subcommittee .03 Fatigue of Composite Materials**

1. Develop standard fatigue test methods and materials specifications for fatigue resistance.

2. Promote research on and an understanding of the mechanisms of fatigue failure in composite materials.
3. Organize and sponsor working-group sessions and technical symposia on fatigue of composite materials.
4. Coordinate committee activities with other technical societies and ASTM committees having an interest in the fatigue of composite materials.
5. Provide a source of expert opinion through subcommittee members on composite fatigue problems.

#### **Subcommittee .04 Apparatus and Test Methods**

The activities of Subcommittee .04 may include study, discussion, and investigation of any problems relating to the procedures for testing materials and structures under fluctuating load. The objectives of these activities are to develop and disseminate information that will help to make these procedures more accurate, more reproducible, and more significant.

#### **Subcommittee .05 Structural Fatigue Problems**

1. The promotion of research on the nature of structural fatigue behavior and methods for improving structural fatigue behavior and the correlation of this work with work on basic fundamentals.
2. The development of methods for determining the fatigue behavior of structural components and complete assemblies.
3. The development of analytical procedures for interpreting fatigue test results and for designing against fatigue.
4. The development of methods for assessing and/or detecting the fatigue damage incurred by structures.

#### **Subcommittee .06 Statistical Aspects of Fatigue**

1. To bring probabilistic and statistical methods of experimental design, data gathering, and analysis within the grasp of the practicing fatigue engineer with the aid of handbooks (91-A).
2. To organize symposia for the dissemination of new and current information.
3. To encourage researchers, material suppliers and designers in the publication and use of statistically meaningful data and parameters.
4. And to oversee the writing and publication of definitions for all subcommittees of Committee E-9.

Current and future areas of interest include: design of experiments, random load fatigue, small sample statistics, proof testing, censoring of data, computer programs for data reduction, reliability, early failure

analysis, safety factors and scatter factors, simulation of the interactions between the fatigue process, and environmental effects based on probabilistic considerations.

### **Subcommittee .08 Fatigue Under Cyclic Strain**

Subcommittee .08 is concerned with fatigue under those conditions where strain rather than stress is the controlling variable. Further, the strains of interest are of such a magnitude that macroscopic plastic strains must be considered. In this regime deformation and failure mechanisms, material behavior, property information, testing methods and design are areas of concern, both at high and low temperatures or under cyclic temperatures.

### *Committee E-24 on Fracture Toughness*

This committee is concerned mainly with final rupture or failure of materials, when flaws within the material have reached a critical size, Subcommittee E24.04. Subcritical flaw growth often concerns itself with the growth of flaws due to fatigue loading. This is, of course, fatigue crack propagation and represents part of the area discussed in Chapter 8 of this manual. The scope of this committee is:

### **Scope**

To promote knowledge and advancement in the field of fracture testing by:

1. Promoting research and development on methods for appraisal of the fracture resistance of metals.
2. Developing recommended practices, methods of test, definitions, and nomenclature for fracture testing of metals, exclusive of fatigue testing.
3. Sponsoring technical meetings and symposia independently or in cooperation with other organizations.
4. Coordinating the committee activities with those of other relevant ASTM committees and other organizations.

### **Subcommittee .01 Fracture Mechanics Test Methods**

To implement the functions of Committee E-24 as applied specifically to the development of test methods based directly or indirectly upon fracture mechanics. This includes methods for directly determining parameters defining or describing the stress-crack size conditions under which fracture takes place, and methods for screening and quality control.

**Subcommittee .02 Fractography and Associated Microstructures**

1. To relate fracture and crack growth properties and micromechanisms to material structural and fractographic features.
2. To advance failure analysis techniques and procedures.
3. To assist the Main and other Subcommittees both in an advisory capacity, and through mutual cooperation in joint Task Groups.

**Subcommittee .03 Dynamic Testing**

1. To develop test methods for measuring the toughness of metals under dynamic loading conditions.
2. To establish relationships between empirical measures of toughness obtained in dynamic tests and basic fracture mechanics toughness parameters.

**Subcommittee .04 Subcritical Crack Growth**

1. To promote research on subcritical-crack growth and to develop methods for appraisal of subcritical-crack growth resistance of materials.
2. To develop recommended practices, methods of tests, definitions, and nomenclature for testing of subcritical-crack growth resistance of materials in cooperation with other appropriate ASTM committees, (for example, Committees E-9 and G-1).

**Subcommittee .05 Nomenclature and Definitions**

To formulate proposed standard nomenclature and definitions that fall within the scope of Committee E-24, and to cooperate with Committee E-8 on Nomenclature and Definitions.

**Subcommittee .06 Applications**

1. To assess the adequacy of current fracture test methods from an applications standpoint and define industry and government needs for additional test methods. To advise the main and other subcommittees of these needs.
2. To develop improved methods and techniques for applying the results of fracture and subcritical flaw growth tests to the solution of engineering problems and the design of fracture resistant structures.
3. To act as a forum for the exchange of concepts, approaches, and detailed technical information related to the application of fracture test data.

### *American Society of Civil Engineers (ASCE)*

#### *Task Committee on Structural Fatigue*

This group of civil engineers is concerned with fatigue, and is subdivided into four areas:

1. Fatigue analyses and theories.
2. Fatigue of members and details.
3. Loading of histories and cumulative damage.
4. Design.

### *American Society of Mechanical Engineers (ASME)*

There are several subcommittees within this group concerned with fatigue.

### *American Society for Metals (ASM)*

This organization, composed primarily of metallurgists, but lately including a growing number of those working with non-metals, often has activities centered around the subject of fatigue.

### *Society of Automotive Engineers (SAE)*

#### *Fatigue Design and Evaluation Committee*

This is the location, within the American automotive field, of the group interested in the durability of automobiles and other terrestrial vehicles. This permanent committee has several divisions, the titles of which make them self-explanatory:

1. Cumulative Fatigue Damage Division
2. Fatigue Design Analysis Division (This group is primarily interested in the ways field data may be obtained to permit sound fatigue life analysis.)
3. X-Ray Fatigue Division (X-Rays as a Non-Destructive Test Technique in Fatigue)
4. Inclusion Fatigue Division
5. Mechanical Prestress Division
6. Fracture Control Division (A new division concerned with fracture toughness of automotive materials.)

### *Additional Groups*

In addition to the previous groups, there are several groups which, from time to time, concern themselves with matters involving fatigue.

1. Metal Properties Council
2. Engineering Joint Council
3. ASTM-ASME Joint Committee on Effect of Temperature  
Low Temperature Panel  
Test Methods Panel
4. U.S. National Academy of Engineering  
Materials Advisory Board  
Advisory Group on Fracture
5. U.S. Department of Transportation  
Highway Research Board
6. U.S. Department of Commerce

### *United Kingdom*

#### *The Royal Aeronautical Society*

Since 1940 the Royal Aeronautical Society has produced and issued authoritative data on aeronautical engineering and science in the form of data sheets and data memoranda.

The *Aeronautical Series* in this set of publications has six sub-series, of which one is titled "Fatigue."

The aim of these data sheets in fatigue is to provide, in a form convenient to designers and others, information relating to fatigue. The results of much valuable work, both theoretical and practical, are frequently not applied because they are buried in a large number of technical reports which potential users have the time neither to discover nor to read. Further, experience in dealing with certain aspects of fatigue problems is often not suitable as a basis for the writing of conventional technical reports and, in the absence of a suitable publication, such experience disseminates only very slowly. Accordingly, after a survey of the situation by the Society's Structures Committee, a special committee was appointed to examine reports, to correlate and check their conclusions, and to review combined experience in dealing with fatigue problems.