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Pneumatic fluid power — Assessment of component reliability by testing —

Part 1:
General procedures

Transmissions pneumatiques — Évaluation par essais de la fiabilité des composants —

Partie 1: Procédures générales

Reference number
ISO 19973-1:2007(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 19973-1 was prepared by Technical Committee ISO/TC 131, *Fluid power systems*.

ISO 19973 consists of the following parts, under the general title *Pneumatic fluid power — Assessment of component reliability by testing*:

— *Part 1: General procedures*

— *Part 2: Directional control valves*

— *Part 3: Cylinders with piston rod*

— *Part 4: Pressure regulators*

Introduction

In pneumatic fluid power systems, power is transmitted and controlled through a gas under pressure within a circuit. Pneumatic fluid power systems are composed of components and are an integral part of various types of machines and equipment. Efficient and economical production requires highly reliable machines and equipment.

It is necessary that machine producers know the reliability of the components that make up their machine's pneumatic fluid power system. Knowing the reliability characteristic of the component, which can be determined from laboratory testing, the producers can model the system and make decisions on service intervals, spare parts inventory and areas for future improvements.

There are three primary levels in the determination of component reliability:

a) preliminary design analysis: finite element analysis (FEA), failure mode and effect analysis (FMEA);

b) laboratory testing and reliability modelling: physics of failure, reliability prediction, pre-production evaluation;

c) collection of field data: maintenance reports, warranty analysis.

Each level has its application during the life of a component. A preliminary design analysis is useful to identify possible failure modes and eliminate them or reduce their effect on reliability. When prototypes are available, in-house laboratory reliability tests are run and initial reliability can be determined. Reliability testing is often continued into the initial production run and throughout the production lifetime as a continuing evaluation of the component. Collection of field data is possible when products are operating and data on their failures are available.

Specific component test procedures and exclusions are provided in ISO 19973-2, ISO 19973-3 and ISO 19973-4.

Pneumatic fluid power — Assessment of component reliability by testing —

Part 1: General procedures

1 Scope

This part of ISO 19973 provides general procedures, the calculation method for assessing the reliability of pneumatic fluid power components and the methods of reporting. These procedures are independent of the kinds of components and of their design.

This part of ISO 19973 also provides general test conditions and a method for data evaluation.

NOTE Because the service life of any component is subject to variations, a statistical evaluation assists the interpretation of the test results.

The methods specified in this part of ISO 19973 apply to the first failure without repairs (see IEC 60300-3-5) [4], but exclude outliers; however, because outliers can be highly significant, information about how to deal with them is given in Annex D.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1000, *SI units and recommendations for the use of their multiples and of certain other units*

ISO 3534-1, *Statistics — Vocabulary and symbols — Part 1: General statistical terms and terms used in probability*

ISO 5598, *Fluid power systems and components — Vocabulary*

IEC 60050-191, *International Electrotechnical Vocabulary, chapter 191: Dependability and quality of service*

IEC 61649, *Goodness-of-fit tests, confidence intervals and lower confidence limits for Weibull distributed data*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 3534-1, ISO 5598 and IEC 60050-191 and the following apply.

3.1
catastrophic failure
sudden failure of an item that results in its complete inability to perform all required functions

[IEC 60050-191]

3.2
confidence coefficient
confidence level
value $(1 - \alpha)$ of the probability associated with a confidence interval or a statistical coverage interval

NOTE 1 See also 3.6.

NOTE 2 See ISO 3534-1 for notes related to this term and definition.

3.3
confidence limit
either of the limits, T_1 or T_2, of the two-sided confidence interval, or the limit, T, of the one-sided confidence interval

NOTE See ISO 3534-1 for notes related to this term and definition.

3.4
failure
termination of the ability of an item to perform a required function

[IEC 60050-191]

NOTE In the ISO 19973 (all parts), the reaching of a threshold level for statistical calculation is also considered a failure.

3.5
mean time to failure
MTTF
expectation of the time to failure

[IEC 60050-191]

NOTE In ISO 19973-2 to ISO 19973-4, the concept of time is expressed as either cycles or distance.

3.6
one-sided confidence interval
T
interval estimator for a population, Θ, comprised of the interval from the smallest possible value of the population, Θ, up to T or the interval from T up to the largest possible value of Θ, where the probability $p(T \geqslant \Theta)$ or $p(T \leqslant \Theta)$ is at least equal to $(1 - \alpha)$, where $(1 - \alpha)$ is a fixed number, positive and less than 1

NOTE See ISO 3534-1 for notes related to this term and definition.

3.7
relevant failure
failure that should be included in interpreting test or operational results or in calculating the value of a reliability performance measure

[IEC 60050-191]

3.8
reliability
probability that an item can perform a required function under given conditions for a given time interval

[IEC 60050-191]

3.9
sample
one or more test units taken from a population and intended to provide information on the population

NOTE A sample can serve as a basis for a decision on the population or on the process that produced it.

3.10
sample size
number of test units in the sample

NOTE In a multi-stage sample, the sample size is the total number of test units at the conclusion of the final stage of sampling.

3.11
threshold level
value of a performance characteristic (for example, leakage, flow rate, current, etc.) against which the component's test data is compared

NOTE This is an arbitrary value defined by the experts as the critical value for performance comparisons, but is not necessarily indicative of a component failure.

4 Symbols and units of measurement

4.1 The symbols used in this part of ISO 19973 are given in Table 1.

Table 1 — Symbol list

Symbol [a]	Definition
B_{10}	Expected time at which 10 % of the population fails (10 % fractile of the lifetime)
η	Scale parameter (characteristic life) of the Weibull distribution
$F(t)$	Probability of failure, expressed in percent
β	Shape parameter (slope) of the Weibull distribution
$R(t)$	Reliability value of the entire sample; cumulative reliability

[a] Other symbols can be used in other documents and software.

4.2 Units of measurement are in accordance with ISO 1000.

5 Concept of reliability

For the purposes of this part of ISO 19973, reliability is the probability that a component does not have a relevant failure for a specified interval of time, number of cycles or distance when it operates under stated conditions.

A relevant failure occurs when a component

— exceeds any of its defined threshold levels, or

— experiences a catastrophic failure (burst, fatigue or functional failure, etc.).

Threshold levels of the components covered by ISO 19973 (all parts) are specified in the component-specific parts of this International Standard.

This probability can be determined by analysing the results of a series of tests and describing the population failure by statistical methods. There are many different statistical distributions that describe the population of failures that result from testing.

NOTE See Annex C for information about verifying the minimum life of a component at a specified reliability and one-sided confidence level.

6 Strategies for conducting testing

6.1 Accelerated life testing

One of the major difficulties encountered in specifying a reliability test is the time it takes to reach the threshold levels without accelerating the test. Accelerated testing, in which a component is subjected to environmental conditions more severe than those for which the component is rated, is sometimes necessary in order to keep the test time at a reasonable length. The degree and amount of accelerated testing specified in ISO 19973 (all parts) reflect the best judgement of, and agreement among, those who developed these International Standards. The primary criterion for determining test acceleration factors is that the failure mode or failure mechanism should not change or be different from that expected from a non-accelerated test.

6.2 Test stand and measurement of parameters

Two other important factors are the test stand and measurement of parameters. The test stand shall be designed to operate reliably within the planned environmental conditions. Its configuration shall not affect the results of the test being run on the component. Evaluation and maintenance of the test stand during the reliability test program is critical. The accuracy of parameter measurement and control of parameter values shall be within the specified tolerances to assure accurate and repeatable test results.

6.3 Test planning

Proper test planning is essential in order to produce results that accurately predict the component's reliability under specified conditions. The goals and objectives of the test program shall be clearly defined if a supplier and user agree to apply ISO 19973 (all parts).

7 Statistical analysis

The resulting test data shall be evaluated for calculating an assessment of the reliability. One of the most commonly used methods is the Weibull analysis because of its versatility in modelling various statistical distributions. This method shall be used for the analysis of the test data to ensure comparability of the results. Examples of applying Weibull analysis are given in Annex A.

NOTE Commercial software can be helpful for this purpose.

8 Test conditions

8.1 Testing shall be carried out in accordance with the provisions defined in the part of ISO 19973 that relates to the component tested, including the test parameters that are measured and threshold levels specified for each test parameter.

8.2 No repairs are permitted on the samples during the reliability test.

8.3 Unless otherwise specified in the relevant part of ISO 19973 that relates to the component being tested, or when agreed between the user and supplier, all tests shall be carried out under the conditions specified in Table 2.

Table 2 — General test conditions

Parameter	Value	
Working pressure	630 kPa ± 30 kPa (6,3 bar ± 0,3 bar)	
Ambient temperature	23 °C ±10 °C	
Temperature of the medium	23 °C ±10 °C	
Air quality	Filtration: nominal filtration rating	5 µm
	Dryer: maximum pressure dew point	+3 °C
	Lubrication	None

8.4 During the endurance test, the test operator shall determine the measuring intervals in relation to the total number of cycles expected. Perform measurements more frequently at the beginning of the test until confidence with the operation is assured. It is up to the experience and judgement of the people in the test laboratory to determine effective measuring intervals; test intervals that are too long can reduce the statistically-determined lifetime of the test unit (see 10.2); measuring intervals that are too short increase the cost of testing. The first measurement shall be done within 10 % of the expected lifetime of the test unit. Test units shall be operated continuously and checked periodically for proper functioning.

9 Sample size and selection criteria

9.1 The samples shall be representative of the population and shall be selected randomly.

9.2 The minimum sample size shall be seven units.

NOTE It is important to have at least seven samples in order that the first data point on the Weibull graph is below the 10 % cumulative-failure point. This allows a more accurate projection of the lower confidence limit lines to intersect the 10 % cumulative-failure point and determine a B_{10} life.

9.3 For a product series with the same design principle, it is not necessary to test all types or sizes. However, the test program shall include the type with the most critical conditions, for example, highest velocity.

10 End of test

10.1 Minimum number of failures required

The minimum number of test units that are required to fail (e.g. reach a threshold level) is described in Table 3. This number does not include suspensions, which are not considered failures.

NOTE It is desirable to achieve at least 10 failures in accordance with IEC 61649. Fewer failures result in a wider confidence interval and a shorter B_{10} life at the lower confidence limit.

Table 3 — Minimum number of failures for evaluation of the characteristic life

Sample size	7	8	9	10	> 10
Minimum numbers of failures	5	6	7	7	70 % of the sample size, truncated [a]

[a] For example, if the sample size is 11, the minimum number of failures is 7.

10.2 Termination cycle count

When a test unit fails between consecutive observations, the data collected is referred to as left-censored interval data; in this case, both the last cycle count at which the test unit was operating properly and the cycle count at which the test unit failed shall be recorded. In some cases, when a more precise determination of a failure point is desired, it can be necessary to continuously monitor the performance of a test unit by using limit switches or other suitable means to detect failures when they occur.

10.3 Suspended test unit

Testing on an individual test unit may be stopped before a relevant failure occurs. This is known as a suspension. Some examples of suspensions include

— a unit which has been disassembled for inspection, or

— a unit which has been accidentally crushed.

However, these units had achieved a number of cycles until the point of suspension and these data have a positive influence on the calculation of the statistical parameters.

10.4 Censored test

If the test is stopped after the minimum number of failures specified in Table 3 is reached but the remaining samples are still operating, the test shall be considered censored. If the censored test does not include any suspensions, the method specified in Annex A shall be used to calculate the statistical parameters. If the censored test includes one or more suspensions, the method specified in Annex B shall be used to calculate the statistical parameters.

11 Evaluation of reliability characteristics from the test data

11.1 To improve the interpretation of the calculation results, the failure mode shall be specified and recorded.

11.2 Calculations shall be made from the test data to determine

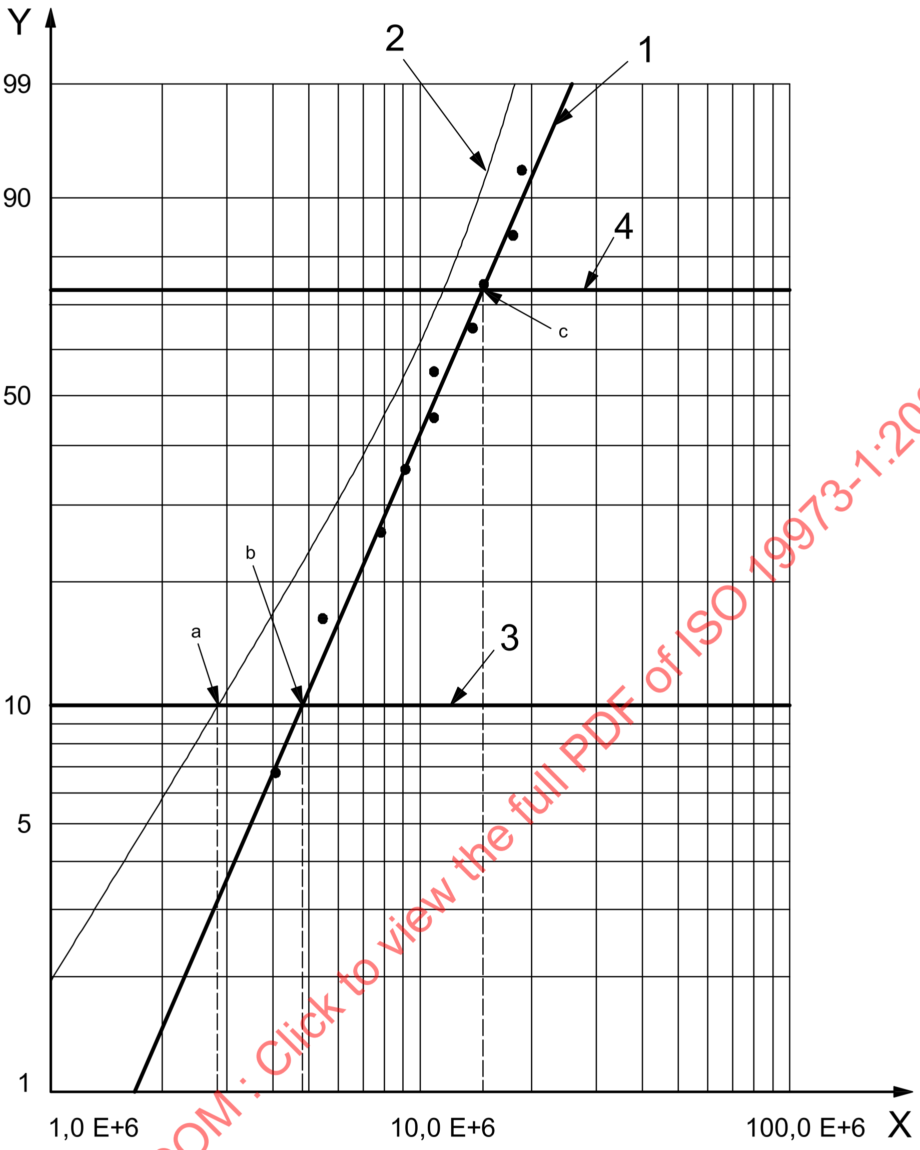
— characteristic life, η : relative location of the straight line in the Weibull plot relative to the x-axis (time or scale parameter);

— Weibull shape parameter, β : slope of the straight line in the Weibull plot.

11.3 Calculate B_{10} life at the median ranks (see Figure 1, footnote a).

NOTE See Annex B for information on how to deal with censored data with suspensions.

11.4 Calculate the confidence limit of the B_{10} life at the one-sided 95 % confidence level using Fisher Matrix (see Figure 1, footnote a).



Key

X number of cycles until failure, t

Y probability of failure, $F(t)$, expressed in percent

1 best fit line

2 confidence limit, one-sided 95 %, obtained by Fisher Matrix

3 10 % fractile line

4 line at which 63,2 % of test units failed

a B_{10} life at the one-sided 95 % confidence level.

b B_{10} life.

c Characteristic life, η.

NOTE 1 The MTTF value can be calculated using the characteristic life.

NOTE 2 Commercial software can be useful in constructing the graphs.

Figure 1 — Example of how B_{10} life value is determined

12 Test report

The test report shall include at least the following data:

a) number of the relevant part of ISO 19973, including the component-specific part number (for example, ISO 19973-2 for valves);

b) date of the test report;

c) component description (manufacturer, type designation, series number);

d) sample size;

e) test conditions (working pressure, temperature, air quality, frequency, load, etc.);

f) threshold levels;

g) type of failure for each test unit;

h) B_{10} life at the median rank and confidence limit of B_{10} life at one-sided 95 % confidence level;

i) characteristic life, η;

j) number of failures considered;

k) method used to calculate the Weibull data (for example, maximum-likelihood, rank regression, Fisher Matrix);

l) other remarks, as necessary.

13 Identification statement (reference to this part of ISO 19973)

It is strongly recommended to manufacturers who have chosen to conform to this part of ISO 19973 that the following statement be used in test reports, catalogues and sales literature:

"General procedures for assessing pneumatic component reliability by testing performed in accordance with ISO 19973-1, *Pneumatic fluid power — Assessment of component reliability by testing — Part 1: General procedures.*"

Annex A
(informative)

Calculation procedures for censored data without suspensions

A.1 Example using maximum-likelihood estimates

A.1.1 Consider a test run on a sample of seven test units of a component, and parameters related to three failure modes (1, 2, 3) are measured during a reliability test. Raw data from each parameter is collected as the test progresses. When a failure occurs (either by no longer being able to perform a required function or by reaching a threshold level; see 3.4), the cycle count at which the test unit was last observed in satisfactory condition is recorded, along with the cycle count at which it was first noticed that the failure had occurred. In this case, the termination cycle count is somewhere between the two observed cycle counts.

For the example shown in Table A.1, test unit number 5 experiences a mode 3 failure somewhere between the two cycle counts shown. The data for other test units are likewise determined from the observations when a test unit experiences any failure mode for first time. These are shown as shaded cells in Table A.1. The test is concluded when the minimum number of test units specified in Table 3 fail, in this case, five test units.

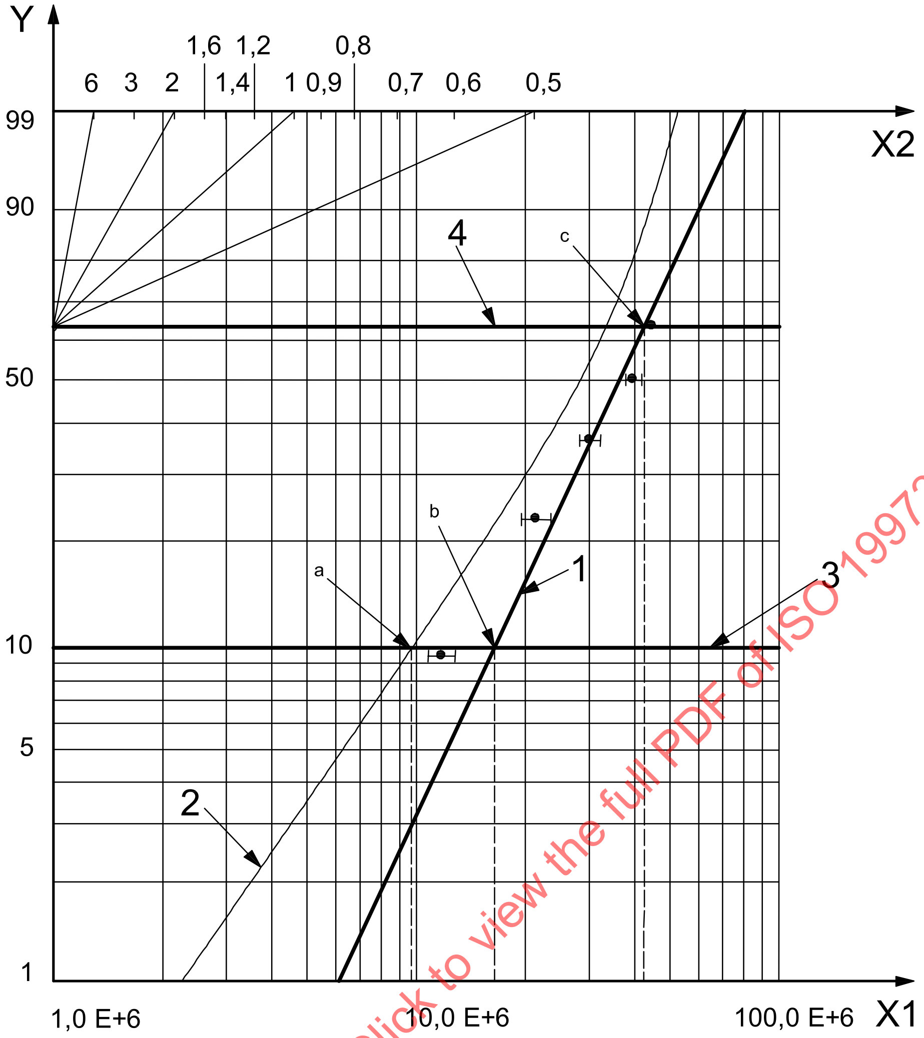
If the manufacturer desires to know more information about any test unit that has failed by reaching a threshold level, testing on that unit may continue. However, further data, such as observed at $36,6 \times 10^6$ and $43,1 \times 10^6$ cycle counts for test unit 5, shall not be considered in the reliability analysis.

Table A.1 — Example of test unit cycle counts and failure modes

Cycle count at observation of last satisfactory operation	Cycle count at observation of failure	Failure mode 1 (leakage – seal A)	Failure mode 2 (leakage – seal B)	Failure mode 3 (shifting time)
$10,8 \times 10^6$	$12,8 \times 10^6$	—	—	Test unit number 5
$19,5 \times 10^6$	$23,5 \times 10^6$	—	Test unit number 1	—
$28,2 \times 10^6$	$32,2 \times 10^6$	—	Test unit number 2	—
$34,2 \times 10^6$	$36,6 \times 10^6$	Test unit number 2	Test unit number 5	—
$37,8 \times 10^6$	$41,8 \times 10^6$	Test unit number 3	—	Test unit number 1
$42,9 \times 10^6$	$43,9 \times 10^6$	Test unit number 5	—	—
$44,9 \times 10^6$	$44,9 \times 10^6$	Test unit number 6	—	—
$44,9 \times 10^6$	—	Test ended – test units 4 and 7 removed from test		

NOTE The example illustrates how test units can reach several threshold levels if they continue to be tested beyond the point at which they experience their first failure mode. The shaded cells indicate which test units experienced a failure mode for the first time. Note also that some test units did not experience a failure mode and were censored at the end of the test. This example shows termination-cycle counts for test units that were continuously monitored.

A.1.2 In this example, the Weibull parameters are then determined from a maximum-likelihood estimation, using both cycle counts for each test unit. Results are graphed on a Weibull plot, as shown in Figure A.1. The failure points use the cycle-count range in Table A.1, and the plot line and Weibull parameters are based on the maximum-likelihood calculation. The confidence limit is based on a Fisher Matrix calculation.



Key

X1 number of cycles to failure, t

X2 slope of the Weibull distribution, β, equal in this case to 2,382 3

Y probability of failure, $F(t)$, expressed in percent

1 best fit line

2 95 % one-sided confidence limit

3 10 % fractile line

4 line at which 63,2 % of test units fail

├●┤ Weibull data point

[a] B_{10} life at the one-sided 95 % confidence level.

[b] B_{10} life.

[c] Characteristic life, η, is equal to $42,365 \times 10^6$.

Figure A.1 — Weibull plot for maximum-likelihood estimation
(data from Table A.1)

A.1.3 Results for the median conditions are

— characteristic life: $42,37 \times 10^6$ cycles;

— slope: 2,38.

A.1.4 Calculate the B_{10} life at median ranks from the two-parameter Weibull equation, with $F(B_{10}) = 0{,}1$, as follows:

$$F(B_{10}) = 1 - e^{-(B_{10}/\eta)^{\beta}}$$

$$0{,}1 = 1 - e^{-\left(B_{10}/42{,}37\times 10^{6}\right)^{2{,}38}}$$

B_{10} median life: $16{,}47 \times 10^{6}$ cycles.

A.1.5 From the Weibull plot, B_{10} life at the 95 % confidence level is equal to $8{,}42 \times 10^{6}$ cycles.

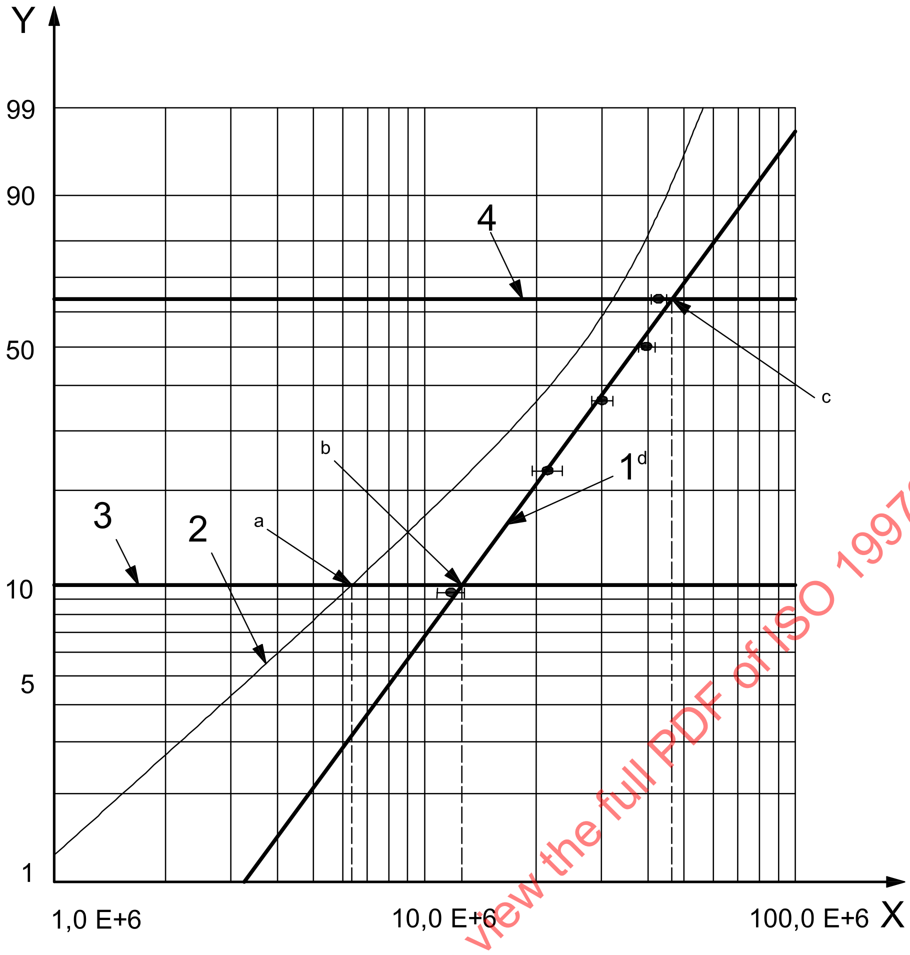
A.2 Example using the rank-regression method

A.2.1 All of the conditions described in Clause A.1, including the data in Table A.1, are applied to this example also, except that a termination cycle count is determined. In this example, the termination cycle count is considered to be midway between the last cycle count at which satisfactory operation was observed and the cycle count at the observed failure. However, if the test equipment is able to indicate the cycle count at which the failure actually occurred, that cycle count may be used as the termination cycle count. It is also permissible to use any other method to estimate the termination cycle count. The termination cycle counts used in this example are summarized in Table A.2, along with the corresponding median ranks (from standard tables) based on a sample size of seven test units.

Table A.2 — Data used to create a Weibull plot for the rank-regression method

Termination cycle count	Median ranks
$11{,}8 \times 10^{6}$	0,094 3
$21{,}5 \times 10^{6}$	0,228 5
$30{,}2 \times 10^{6}$	0,364 1
$39{,}8 \times 10^{6}$	0,500 0
$42{,}9 \times 10^{6}$	0,635 9

A.2.2 Results are graphed on the Weibull plot shown in Figure A.2. The failure points use the termination cycle counts in Table A.2, but the range is shown from Table A.1. The plot line and Weibull parameters are based on the rank regression method and the confidence limit is based on a Fisher Matrix calculation.



Key

X number of cycles to failure, t

Y probability of failure, $F(t)$, expressed in percent

1 best fit line

2 95 % one-sided confidence limit

3 10 % fractile line

4 line at which 63,2 % of test units fail

⊢•⊣ Weibull data point

a B_{10} life at the one-sided 95 % confidence level.

b B_{10} life.

c Characteristic life, η, is equal to 46,155 9 × 10^6.

d The slope, β, of the Weibull distribution is equal to 1,735 1 and the coefficient, ρ, of best fit to the curve is equal to 0,994 4.

Figure A.2 — Weibull plot for rank-regression method
(data from Table A.2)

A.2.3 Results for the median conditions are

— characteristic life: η = 46,2 × 10^6 cycles;

— slope: 1,74.

A.2.4 Calculate the B_{10} life at median ranks from the two-parameter Weibull equation, with $F(B_{10}) = 0{,}1$, as follows:

$$F(B_{10}) = 1 - e^{-(B_{10}/\eta)^{\beta}}$$

$$0{,}1 = 1 - e^{-\left(B_{10}/46{,}15\times 10^{6}\right)^{1{,}74}}$$

B_{10} median life: $12{,}66 \times 10^{6}$ cycles

From the Weibull plot, B_{10} life at the 95 % confidence level is equal to $6{,}35 \times 10^{6}$ cycles.

Annex B
(informative)

Calculation procedures for censored data with suspensions

B.1 Introduction

This example illustrates a case in which some test units are removed from testing prior to failure, while others continue to be tested. Reasons for such removal shall not be related to the objective of the test; acceptable reasons include equipment failures, external damage (e.g., fire, falling object, etc.), removal for inspection or any other reason. Any unit that is removed shall not be returned to the test program and shall be classified as a suspension. See Clause A.1 for an explanation of failed test units that may be returned to testing.

B.2 Example using maximum-likelihood estimates

B.2.1 Consider a test run on a sample of 12 test units and parameters related to three failure modes (1, 2 and 3) are measured during a reliability test. Raw data from each parameter are collected as the test progresses. When a failure occurs (either by no longer being able to perform a required function or by reaching a threshold lever; see 3.4), the cycle count at which the test unit was last observed in satisfactory condition is recorded, along with the cycle count at which it was first noticed that the failure had occurred.

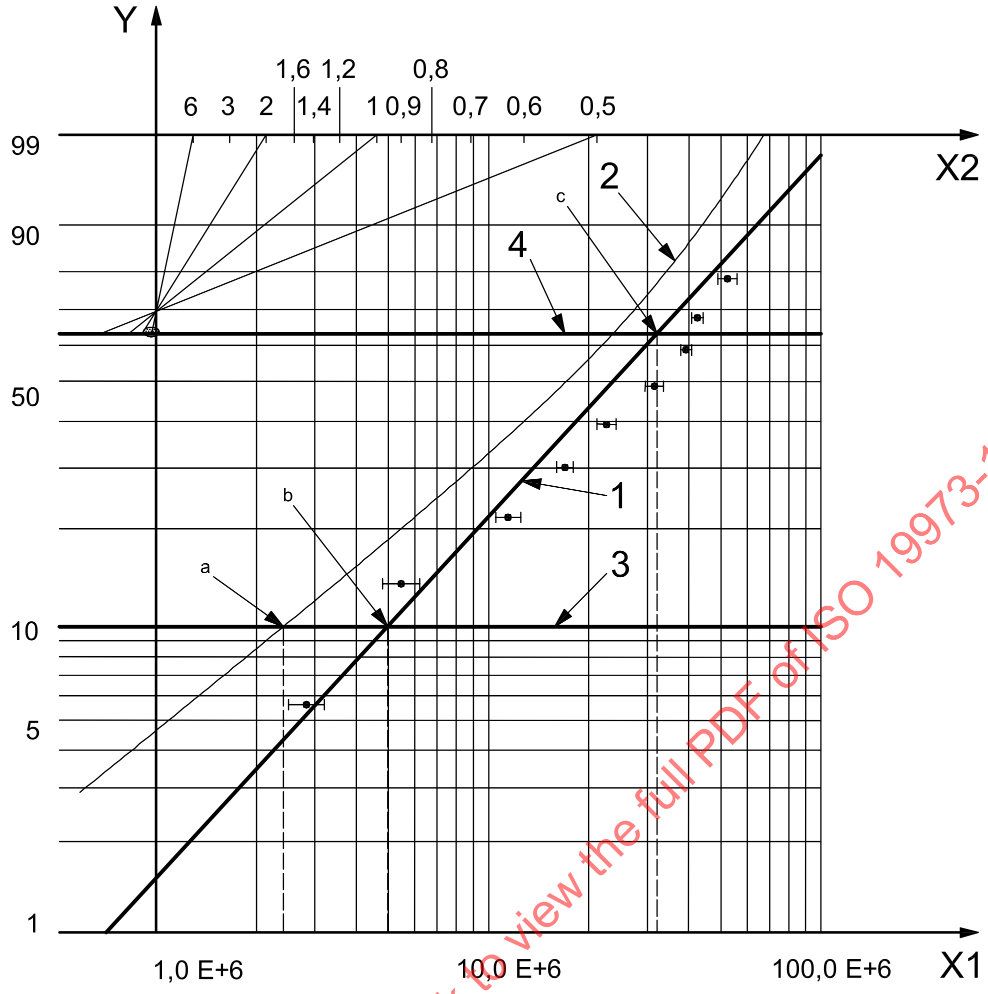
See Table B.1 for an example of the data collected during such a test. The data for the test units are recorded from the observations when a unit fails by any failure mode for the first time; these data are shown in the shaded cells in Table B.1, along with data from suspended test units. For example, test unit number 5 reaches a threshold level for a mode 3 failure (shifting time) somewhere between the two cycle counts shown. According to Table 3, it is necessary for at least 70 % of the sample size (that is, nine test units) to fail in order for the test to be considered complete.

Table B.1 — Example of test-unit cycle counts and failure modes for a sample that contains suspended test units

Cycle count at observation of last satisfactory operation	Cycle count at observation of failure	Failure mode 1 (leakage – seal A)	Failure mode 2 (leakage – seal B)	Failure mode 3 (shifting time)
$2{,}5 \times 10^6$	$3{,}2 \times 10^6$	—	—	Test unit number 5
$4{,}8 \times 10^6$	$6{,}2 \times 10^6$	—	Test unit number 12	—
$10{,}5 \times 10^6$	$12{,}5 \times 10^6$	—	Test unit number 1	—
$15{,}0 \times 10^6$	$15{,}0 \times 10^6$	Test unit number 4 removed from test for detailed inspection.		
$16{,}0 \times 10^6$	$18{,}0 \times 10^6$	Test unit number 9	—	—
$21{,}2 \times 10^6$	$24{,}2 \times 10^6$	—	—	Test unit number 2
$29{,}6 \times 10^6$	$33{,}6 \times 10^6$	Test unit number 2	Test unit number 8	
$35{,}0 \times 10^6$	$35{,}0 \times 10^6$	Test unit number 10 removed from test due to test equipment failure.		
$37{,}8 \times 10^6$	$40{,}8 \times 10^6$	—	—	Test unit number 3
$40{,}8 \times 10^6$	$44{,}1 \times 10^6$	Test unit number 11	Test unit number 5	—
$48{,}9 \times 10^6$	$55{,}9 \times 10^6$	Test unit number 6	—	Test unit number 1
$55{,}9 \times 10^6$	$55{,}9 \times 10^6$	Testing ended – Test unit number 7 still operating.		

NOTE The example illustrates how test units can reach several threshold levels if they continue to be tested beyond their first failure mode. The shaded cells indicate which test units experienced a failure mode for the first time. Note also that one test unit did not experience a failure mode and was censored at the end of the test. This example shows termination-cycle counts for test units that were continuously monitored.

B.2.2 In this example, Weibull parameters are then determined from a maximum-likelihood estimation, using both cycle counts for each test unit. Results are graphed on a Weibull plot as shown in Figure B.1. The failure points use the cycle count range in Table B.1, and the plot line and Weibull parameters are based on the maximum-likelihood calculation. The confidence limit is based on a Fisher Matrix calculation.



Key

X1 number of cycles to failure, t

X2 slope of the Weibull distribution, β, equal in this case to 1,360 4

Y probability of failure, $F(t)$, expressed in percent

1 best fit line

2 95 % one-sided confidence limit

3 10 % fractile line

4 line at which 63,2 % of test units fail

|—●—| Weibull data point

a B_{10} life at the one-sided 95 % confidence level.

b B_{10} life.

c Characteristic life, η, is equal to $36{,}538 \times 10^6$.

Figure B.1 — Weibull plot for a sample that contains suspended test units
(data from Table B.1)

B.2.3 Results for the median conditions are

— characteristic life: $\eta = 36{,}54 \times 10^6$ cycles;

— slope: 1,36.

B.2.4 Calculate the B_{10} life at median ranks from the two-parameter Weibull equation, with $F(B_{10}) = 0{,}1$, as follows:

$$F(B_{10}) = 1 - e^{-(B_{10}/\eta)^{\beta}}$$

$$0{,}1 = 1 - e^{-\left(B_{10}/36{,}54\times 10^{6}\right)^{1{,}36}}$$

B_{10} median life $6{,}98 \times 10^{6}$ cycles

B.2.5 From the Weibull plot, B_{10} life at the 95 % confidence level is equal to $3{,}61 \times 10^{6}$ cycles.

B.3 Example using the rank-regression method

B.3.1 All of the conditions described in Clause B.1, including Table B.1, are applied to this case also, except that a termination cycle count is determined. In this example, the termination cycle count is considered to be midway between the last cycle count at which satisfactory operation was observed and the cycle count at the observed failure. However, if the test equipment is able to indicate the cycle count at which the failure actually occurred, that cycle count may be used as the termination cycle count. It is also permissible to use any other method to estimate the termination cycle count. The termination cycle counts used in this example are summarized in Table B.2, along with the results of separate calculations for the plotting position and the median ranks, as shown in B.3.2 and B.3.3.

B.3.2 Calculate plotting positions, P_{plot}, using the modified Johnson formula, as given in Equation (B.1):

$$P_{plot} = \frac{S_r\left(P_{plot} - 1\right) + \left(N_{test} + 1\right)}{S_r + 1} \qquad \text{(B.1)}$$

where

S_r is the reverse sequence;

$(P_p - 1)$ is the previous position number;

N_{test} is the number of test units tested (12 in this example).

The previous position number is the same as the plotting position for the previous entry; for the first entry in this example,$(P_{plot} - 1)$ is zero. When a suspension is encountered, the previous position number is the same as the plotting position for last failed entry.

B.3.3 Calculate the median ranks, r_M, using Benard's approximation, as given in Equation (B.2):

$$r_M = \frac{P_{plot} - 0{,}3}{N_{test} + 0{,}4} \qquad \text{(B.2)}$$

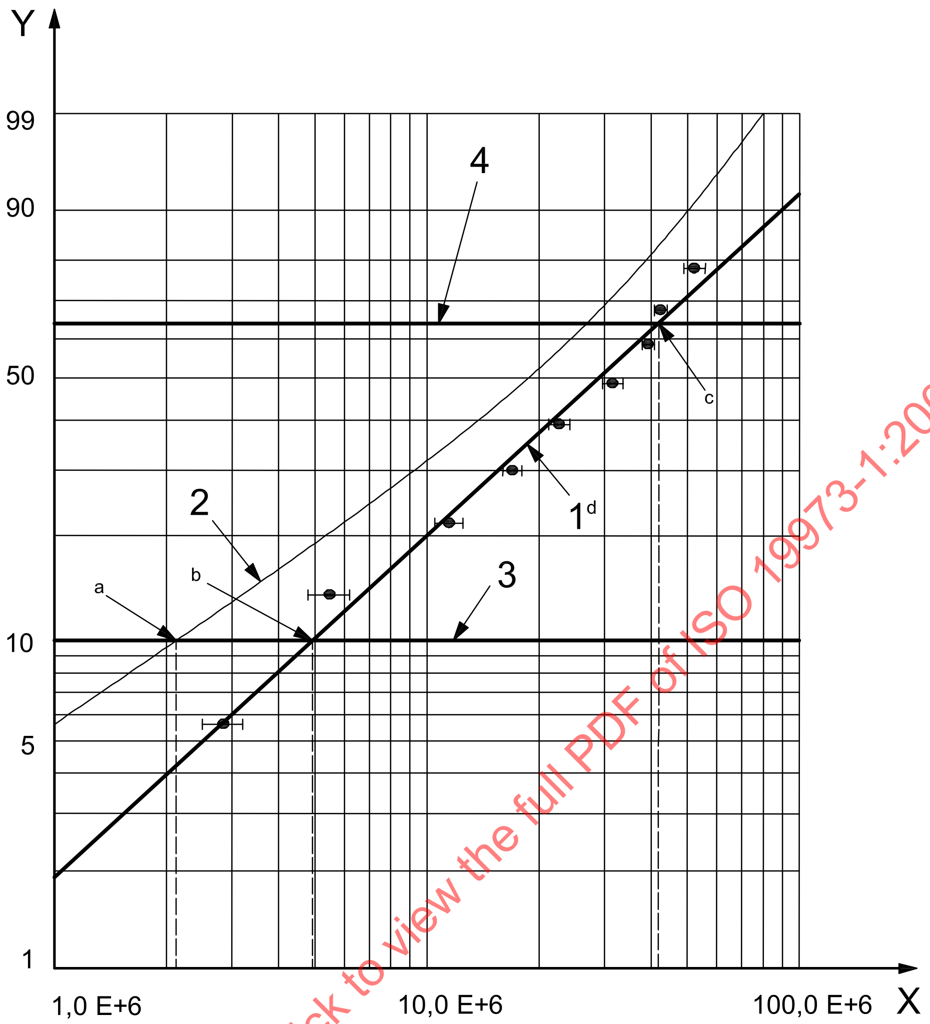
B.3.4 Table B.2 summarizes the observed and calculated data used to create the Weibull plot for this example.

Table B.2 — Data used to create a Weibull plot for example using rank-regression method for test data with suspensions

Termination cycle count	Unit number	Sequence	Reverse sequence	Status	Plotting position	Median rank
$2,85 \times 10^6$	5	1	12	Failed	1	0,056 5
$5,5 \times 10^6$	12	2	11	Failed	2	0,137 1
$11,5 \times 10^6$	1	3	10	Failed	3	0,217 7
$15,0 \times 10^6$	4	4	9	Suspended	—	—
$17,0 \times 10^6$	9	5	8	Failed	4,11	0,307 3
$22,7 \times 10^6$	2	6	7	Failed	5,22	0,396 8
$31,6 \times 10^6$	8	7	6	Failed	6,33	0,486 3
$35,0 \times 10^6$	10	8	5	Suspended	—	—
$39,3 \times 10^6$	3	9	4	Failed	7,66	0,593 5
$42,4 \times 10^6$	11	10	3	Failed	9,00	0,701 6
$52,4 \times 10^6$	6	11	2	Failed	10,33	0,808 9
$55,9 \times 10^6$	7	12	1	Suspended	—	—

NOTE The first three entries do not require calculation by the modified Johnson equation. Their median ranks can be determined from a standard table (resulting in slightly lower numbers) or they can be calculated from Benard's approximation, which is used for all test units in this example, to be consistent.

B.3.5 Results are graphed on the Weibull plot shown in Figure B.2. The failure points use the termination cycle counts in Table B.2, but the range is shown from Table B.1. The plot line and Weibull parameters are based on the rank regression method and the confidence limit is based on a Fisher Matrix calculation.



Key

X number of cycles to failure, n_T

Y probability of failure, $F(n_T)$, expressed in percent

1 best fit line

2 95 % one-sided confidence limit

3 10 % fractile line

4 line at which 63,2 % of test units fail

├●┤ Weibull data point

[a] B_{10} life at the one-sided 95 % confidence level.

[b] B_{10} life.

[c] Characteristic life, η, is equal to 41,001 0 × 10^6.

[d] The slope, β, of the Weibull distribution is equal to 1,063 8 and the coefficient, ρ, of best fit to the curve is equal to 0,993 3.

Figure B.2 — Weibull plot for a sample that contains suspended test units
(data from Tables B.1 and B.2)

B.3.6 Results for the median conditions are

— characteristic life: $\eta = 41{,}00 \times 10^6$ cycles;

— slope: 1,06.

B.3.7 Calculate the B_{10} life at median ranks from the two-parameter Weibull equation, with $F(B_{10}) = 0,1$, as follows:

$$F\,(B_{10}) = 1 - e^{-(B_{10}/\eta)^{\beta}}$$

$$0,1 = 1 - e^{-\left(B_{10}/41{,}00 \times 10^{6}\right)^{1{,}06}}$$

B_{10} median life: 4,91 × 10^6 cycles

B.3.8 From the Weibull plot, B_{10} life at the 95 % confidence level is equal to 2,1 × 10^6 cycles.

Annex C
(informative)

Verification of minimum life at a specified reliability and one-sided confidence level

C.1 Objective

It is desired to conduct a test to verify that a product has a certain minimum life at a specified reliability and one-sided confidence level. Such a test does not generate a failure distribution; it only proves that a distribution might exist that is greater than the one used for the verification. The advantage of this method is that the testing time is shorter than that specified in Clauses 9, 10 and 11 of this part of ISO 19973.

C.2 Assumption

The reliability distribution is Weibull and its slope is known, either from historical data, engineering judgment or a combination of both. The life at a given reliability value and one-sided confidence level is declared and a test is conducted to verify that the declaration is true.

C.3 Procedure

The test is conducted in accordance with the relevant parts of ISO 19973, following the same procedures as for a standard reliability test. A test duration is calculated and none of the samples may fail during the conduct of the test. An alternate procedure is also available that allows one failure, but it requires longer testing time. If the test is successful, the product has at least the life at the reliability value and one-sided confidence level declared. It is also possible that the life can be longer.

C.4 Symbols

Symbol	Definition
t	Test duration for testing without failures
t_p	Minimum life at the declared reliability value and confidence level
n	Number of test units tested
β	Shape parameter (slope) of the Weibull distribution
B_i	Expected time at which i % of the population fails
$R(t_p)$, also $1 - p$	Declared reliability value of the entire sample
p	Probability of an individual test unit failing the test
T_d	Declared one-sided confidence level

C.5 Problem

C.5.1 Definition of problem and development of equations

C.5.1.1 Develop an equation to calculate the duration or a test that verifies the minimum life of a component at a declared reliability value and one-sided confidence level, using a given Weibull slope.

C.5.1.2 There are only two possibilities for the test to verify the declaration statement: either it succeeds or it fails. Thus, a binomial equation can characterize the test outcome, where the probability of test success, $p(y)$, is as given in Equation (C.1):

$$p(y) = C_y^n p^y q^{(n-y)} \tag{C.1}$$

where

$$C_y^n = \frac{n!}{y!(n-y)!} \tag{C.2}$$

C.5.1.3 In this case, $p(y)$ is the probability that from a group of n test units, y test units fail before the end of the test. Because the objective is for all test units to pass, y is set equal to 0 and the terms in Equation (C.1) reduce to those given in Equations (C.3) to (C.6):

$$C_y^n = 1 \tag{C.3}$$

$$p^y = 1 \tag{C.4}$$

$$q = 1 - p \tag{C.5}$$

$$p(0) = (1 - p)^n \tag{C.6}$$

C.5.1.4 The probability, p, of an individual unit failing before the end of the test is as given in Equation (C.7):

$$p = 1 - R(t) \tag{C.7}$$

where $R(t)$ is the reliability of entire sample.

C.5.1.5 The overall probability, $p(0)$, of the test succeeding is as given in Equation (C.8):

$$p(0) = (1 - T_{\mathrm{d}}) \tag{C.8}$$

Equations (C.9) and (C.10) can be derived by substitution into Equation (8):

$$(1 - T_{\mathrm{d}}) = (1 - p)^n = \{1 - [1 - R(t)]\}^n = R(t)^n \tag{C.9}$$

$$\ln R(t) = \frac{1}{n} \ln(1 - T_{\mathrm{d}}) \tag{C.10}$$

C.5.1.6 The cumulative reliability, $R(t)$, can be expressed in terms of the Weibull equation, as given in Equations (C.11) to (C.13):

$$R(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}} \tag{C.11}$$

$$\ln R(t) = -\left(\frac{t}{\eta}\right)^{\beta} \tag{C.12}$$

$$\left[-\ln R(t)\right]^{\frac{1}{\beta}} = \frac{t}{\eta} \tag{C.13}$$

For a particular value at t_p, Equations (C.11) to (C.13) take on the form of Equations (C.14) to (C.16), respectively:

$$R(t_p) = e^{-\left(\frac{t_p}{\eta}\right)^{\beta}} \tag{C.14}$$

$$\ln R(t_p) = -\left(\frac{t_p}{\eta}\right)^{\beta} \tag{C.15}$$

$$\left[-\ln R(t_p)\right]^{\frac{1}{\beta}} = \frac{t_p}{\eta} \tag{C.16}$$

C.5.1.7 Taking the ratio of Equations (C.13) and (C.16) results in Equation (C.17):

$$\frac{t}{t_p} = \left[\frac{\ln R(t)}{\ln R(t_p)}\right]^{\frac{1}{\beta}} \tag{C.17}$$

Substituting Equation (C.10) yields Equation (18):

$$t = t_p \left\{\frac{\frac{1}{n}\ln\left[1-T_d\right]}{\ln R(t_p)}\right\}^{\frac{1}{\beta}} \tag{C.18}$$

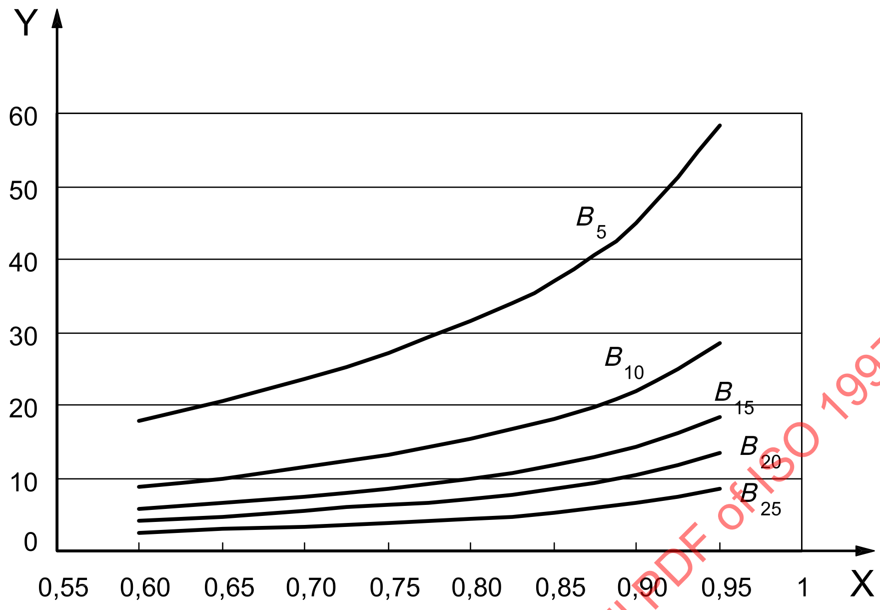
$$t = t_p \left[\frac{\ln(1-T_d)}{n \ln R(t_p)}\right]^{\frac{1}{\beta}} \tag{C.19}$$

$$t = t_p \left(\frac{A}{n}\right)^{\frac{1}{\beta}} \tag{C.20}$$

where

$$A = \left[\frac{\ln(1-T_d)}{\ln R(t_p)}\right] \tag{C.21}$$

C.5.1.8 If $R(t_\text{p}) = 1 - p_i$, where p_i is the proportion of test units failing at level i (for example, B_{10} is the number of cycles (time) that it takes for 10 % of the sample to fail), then the A values in Figure C.1 can apply to many circumstances.



Key

X confidence level

Y A values

Figure C.1 — A values for various B_i at various declared one-sided confidence levels, T_d

C.5.2 Example problem

For how long is it necessary to test 10 pneumatic cylinders to demonstrate that they represent a population with a B_{10} life of 10 000 km at a one-sided 95 % confidence level, if a similar design has a Weibull slope of 2,0?

Using Equation (20):

$$t = t_\text{p}\left(\frac{A}{n}\right)^{\frac{1}{\beta}} = 10^4\,\text{km}\left(\frac{28,43}{10}\right)^{\frac{1}{2}} = 16\,860\ \text{km}$$

C.6 Specific application

C.6.1 Definition of problem and development of equations

Consider the case for B_{10} life at a one-sided 95 % confidence level. Rearrange Equation (C.20) and designate the resulting ratio as the test life ratio, L, as given in Equation (C.22):

$$\frac{t}{t_\text{p}} = \left(\frac{A}{n}\right)^{\frac{1}{\beta}} = L \qquad \text{(C.22)}$$

where $t = t_\text{p} \cdot L$.