TECHNICAL REPORT

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Pneumatic fluid power — Assessment of component reliability by accelerated life testing — General guidelines and procedures

Transmissions pneumatiques — Évaluation de la fiabilité du composant par essai de durée de vie accélérée — Lignes directrices générales et modes opératoires

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Foreword

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ISO/TR 16194 was prepared by Technical Committee ISO/TC 131, *Fluid power systems.*

Introduction

This document is being released to document progress that the working group has developed for accelerated testing. It is a new method with which the working group members have very little experience, but has been used by institutional laboratories and taught at academic levels.

Some experimentation on air cylinders has been done at the Korean Institute of Machinery and Materials (KIMM), but the application to pneumatic components in general has not been evaluated.

This document is offered to members as a reference and model procedure, so that they can develop experience with its use in their own laboratories.

Pneumatic fluid power — Assessment of component reliability by accelerated life testing — General guidelines and procedures

1 Scope

This document provides general procedures for assessing the reliability of pneumatic fluid power components using accelerated life testing and the method for reporting the results. These procedures apply to directional control valves, cylinders with piston rods, pressure regulators, and accessory devices – the same components covered by the ISO 19973 series of standards.

This document does not provide specific procedures for accelerated life testing of components. Instead, it explains the variability among methods and provides guidelines for developing an accelerated test method.

The methods specified in this document apply to the first failure, without repairs.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5598, ISO 19973-1 and the following apply. ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
B_x life
life of a component or assembly that has not been altered since its production, where its reliability is $(100-x)$ %; or the time at which $(100-x)$ % of the population has survived

Note 1 to entry: The cumulative failure fraction is x %. For example, if x = 10, the B_{10} life has a cumulative failure probability of 10 %.

3.2
acceleration factor
AF
ratio between the life at the normal use stress level and the life at the accelerated stress level

3.3
accelerated life test
ALT
process in which a component is forced to fail more quickly that it would have under normal use conditions and which provides information about the component's life characteristics

3.4
destruct limit
stress level at which one or more of the component’s operating characteristics is no longer within specification or the component is damaged and cannot recover when the stress is reduced

Note 1 to entry: Destruct limits are classified as a lower destruct limit and upper destruct limit.

3.5
failure mechanism
physical or chemical process that produces instantaneous or cumulative damage to the materials from which the component is made

3.6
failure mode
manifestation of the failure mechanism resulting from component failure or degradation

Note 1 to entry: The failure mode is the symptom of the aggressive activity of the failure mechanism in the component’s areas of weakness, where stress exceeds strength.

3.7
failure rate
λ
frequency at which a failure occurs instantaneously at time t, given that no failure has occurred before t

3.8
highly accelerated life test
HALT
process in which components are subjected to accelerated environments to find weaknesses in the design and/or manufacturing process

Note 1 to entry: The primary accelerated environments include pressure and heat.

3.9
model for accelerated life testing
model that consists of a life distribution that represents the scatter in component life and a relationship between life and stress

Note 1 to entry: Life distribution examples: Weibull, Lognormal, Exponential, etc.

Note 2 to entry: Life and stress examples: Arrhenius, Eyring, Inverse Power Law, etc.

3.10
normal use conditions
test conditions at which a component is commonly used in the field, which can be less strenuous than rated conditions

3.11
termination cycle count
number of cycles on a test item when it reaches a threshold level for the first time

4 Symbols and units

Symbol [a]	Definition
B_{10}	Time at which 10 % of the population is estimated to fail
η	Scale parameter (characteristic life) of the Weibull distribution
$F(t)$	Probability of failure of a component up to time t
β	Shape parameter (slope) of the Weibull distribution
$R(t)$	Reliability of a component at time t; $R(t) = 1 - F(t)$
$\lambda(t)$	Failures per unit time
[a] Other symbols could be used in other documents and software.	

Units of measurements are in accordance with ISO 80000-1.

5 Concepts of reliability and accelerated life testing

Reliability is the probability (a percentage) that a component does not fail (for example, exceed the threshold level or experience catastrophic failure) for a specified interval of time or number of cycles when it operates under stated conditions. This reliability can be assessed by test methods described in the ISO 19973 series.

Generally, reliability analysis involves analysing time to failure of a component, obtained under normal use conditions in order to quantify its life characteristics. Obtaining such life data is often difficult.

The reasons for this difficulty can include the typically long life times of components, the small time period between design and product release, and the necessity for testing components under normal use conditions. Given this difficulty and the need to observe failures of components to better understand their life characteristics, procedures have been devised to accelerate their failures by overstress, thus forcing components to fail more quickly than they would under normal use conditions. The term accelerated life testing (ALT) is used to describe such procedures.

However, a relationship between the reliability of a component determined by ALT, and its reliability at normal use conditions, is necessary. This can be assessed by extrapolating the test results obtained from an accelerated life test and comparing it to that obtained from testing at normal use conditions. Figure 1 shows the graphical concept for this relationship.

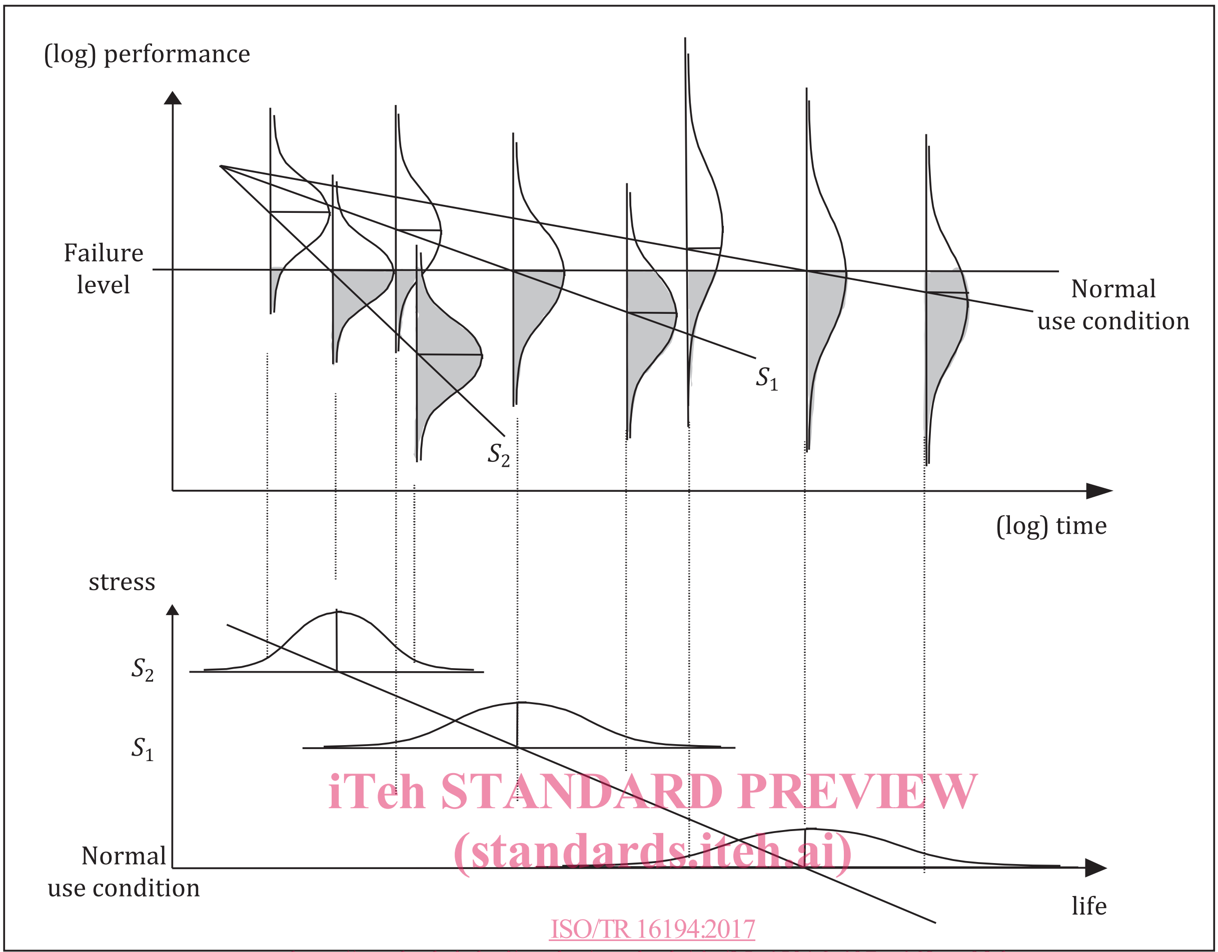

Figure 1 — Graphical explanation of relationship between S-N curve and accelerated life testing

NOTE Distributions in this concept Figure 1 are not defined.

In Figure 1, failures under normal use conditions are represented by the distribution S_3, and the accelerated conditions are distributions S_1 and S_2. Their relationship is shown by the connecting line(s).

6 Failure mechanism and mode

The failure mechanism is the physical or chemical process that produces instantaneous or cumulative damage to the materials from which the component is made. The failure mode is the manifestation of the failure mechanism resulting from component failure or degradation. The failure mode is the symptom of the aggressive activity of the failure mechanism in areas of component weakness where the stress exceeds the strength.

It is necessary that the failure modes observed in accelerated life test conditions are identical to those defined for normal use conditions.

7 Strategy of conducting accelerated life testing

Before starting an accelerated life test, it is important to identify the types of failures that might occur in service; especially any feedback from the field. Several methods are available to assist in this effort: design analysis and review using the quality function deployment (QFD), fault tree analysis (FTA), and failure modes and effect analysis (FMEA). Another method is a qualitative test like highly accelerated life testing (HALT). Qualitative tests are used primarily to reveal probable failure modes, but they do not quantify the life (or reliability) of the component under normal use conditions.

Accelerated life testing involves acceleration of failures with the single purpose of quantification of the life characteristics of the component at normal use conditions.

Therefore, accelerated life testing can be divided into two areas: qualitative accelerated testing (HALT) and quantitative accelerated life testing. In qualitative accelerated testing, the objective is to identify failures and failure modes without attempting to make any predictions as to the component's life under normal use conditions. In quantitative accelerated life testing, the objective is predicting the life of the component (life characteristics such as MTTF, B_{10} life, etc.) at normal use conditions from data obtained in an accelerated life test.

The strategy for effectively conducting an accelerated life testing program includes the following:

— establishing a stress level that can be referred to as normal use conditions;

— determining the stress levels to use for accelerated testing; and

— determining the number of components to be tested at each stress level.

8 Design of accelerated life testing

8.1 Normal use conditions

Normal use conditions can often be defined from the ratings of the component's characteristics, for example: pressure, temperature, voltage, duty cycle, lubrication requirements, etc. However, these ratings often represent a maximum condition that is above commonly used conditions. Therefore, a definition for normal use conditions needs to be established from these characteristics before starting an accelerated test. An example definition for a pneumatic valve is shown in Table 1.

Table 1 — Definition of normal use conditions for a pneumatic valve

Characteristic	Typical rating value	Common use application value	Proposed normal use value for testing
Pressure	1 000 kPa (10 bar)	630 kPa (6,3 bar)	630 kPa (6,3 bar)
Temperature	50 °C	25 °C	25 °C
Voltage	24 VDC	24 VDC	24 VDC
Duty cycle	Continuous	On-off varies	10 % on / 90 % off
Lubrication	Sometimes required	Sometimes applied	Not used
Air dryness	Dew point < 0 °C	Dew point ≤ 10 °C	Dew point = 10 °C

It is necessary to define this normal use conditions before starting an ALT program.

8.2 Preliminary tests

It is also necessary to determine the highest stress to be tested that does not result in failure modes different from those that occur under normal use conditions. Typically, these stresses or limits are unknown, so qualitative tests (HALT) with small sample sizes can be performed in order to determine the appropriate stress levels for use in the accelerated life test. Design of Experiments (DOE) methodology is a useful technique at this step.

The following steps can be taken to determine three stress levels:

a) Propose the highest possible stress that might yield failure in less than 1 day of testing (approximately).

b) Reduce this stress level to 90% of that value and test at least two test units to failure at this stress level, using the test procedures of one of the parts of the ISO 19973 series (modified for the conditions of the stress level).

c) Examine the failure mode to determine if it is the same type of failure as would be experienced under normal use conditions. If it is not, reduce the level of stress and repeat steps b) and c) until failures are the same as would be experienced under normal use conditions. Identify this as stress level S_1.

d) Reduce the stress level by another 10% to 20% from step b) and test at least two more test units to failure. Again, examine the failure mode to determine if it is the same type of failure as would be experienced under normal use conditions. If it is not, modify the stress conditions and repeat the test. Identify this as stress level S_2. See Figure 2.

e) Identify a third, yet lower stress level S_3 that results in failures within the project timing constraints. This third level of stress is identified by extrapolating from the previous pairs of failures as shown in Figure 2. As an alternative, S_3 can be estimated by using an average value of S_1 and S_2, so that $S_3 = ½ (S_2 – S_1)$.

f) Test at least two more test units to failure at this third level of stress S_3. Again, examine the failure mode to determine if it is the same type of failure as would be experienced under normal use conditions. If it is not, modify the stress conditions and repeat the test.

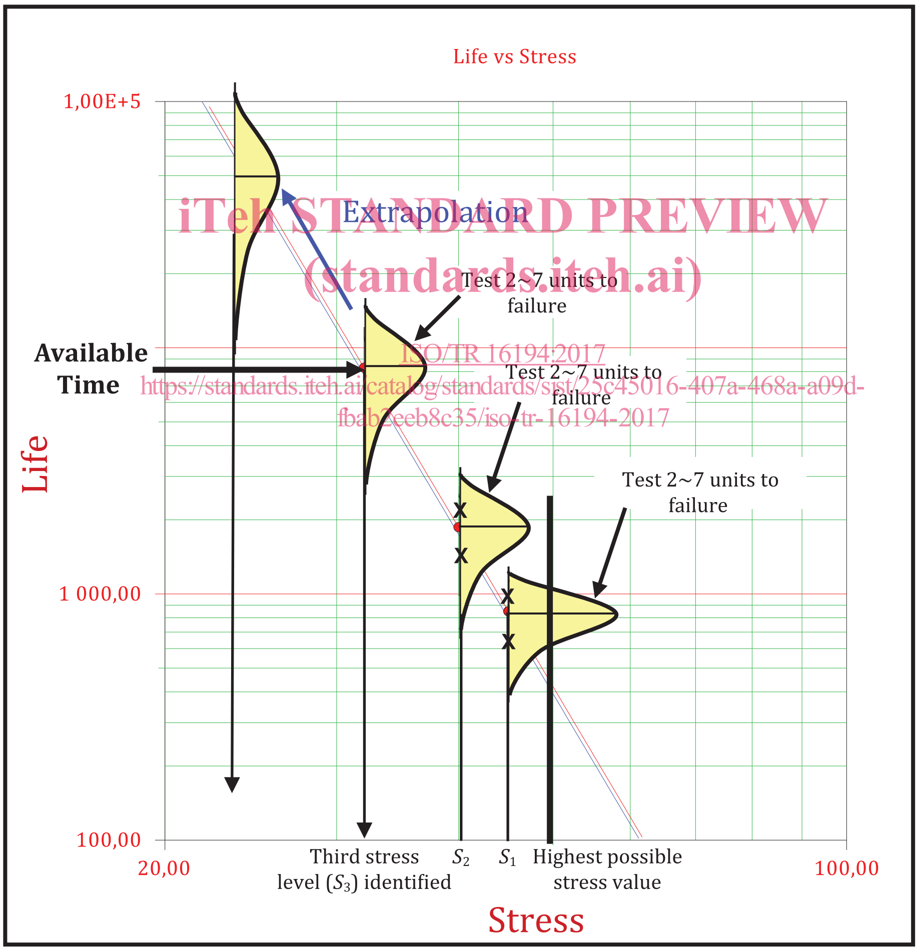

Figure 2 — Graphical explanation of determining stress levels during preliminary tests

These preliminary tests might have to be conducted several times before the necessary stress levels are determined.

8.3 Levels of accelerated stress

The levels of stress identified from 8.2 are used to conduct a series of accelerated tests on randomly selected test units, in accordance with one of the parts of ISO 19973. Generally, these stress levels fall outside of the limits of the component's specification. It is important, therefore, to constantly examine the types of failures obtained to be sure they are the same as those experienced at normal use conditions. If they are not, the test units would be designated as suspensions, or the test conditions would be modified and the testing restarted.

Conduct the tests at each of the selected stress levels. It is also helpful to conduct at least one test at a stress level that is as close as possible to the normal use conditions.

At the higher levels of stress in an accelerated test, the required test duration decreases, and the uncertainty in the extrapolation increases. Confidence intervals provide a measure of the uncertainty in extrapolation.

The most common stresses for pneumatic fluid power components are pressure and temperature. Testing can be conducted either at one set of stress conditions on a sample lot, or two stresses on different sample lots. Cylinder speed, and cycle rate of valves and regulators are other possibilities.

Temperature of the process air used to test components is usually heated (or cooled) to approximately equal the environmental test temperature.

When conducting an accelerated life test, arrangements are made to ensure that the failures of the components are independent of each other (e.g. so that failures due to temperature do not influence the failures due to pressure).

8.4 Sample size

Ideally, at least seven test units are subjected to each stress level for the accelerated life test. However, the number of test units allocated to each stress level is usually inversely proportional to the level of applied stress; that is, more test units are subjected to lower stress levels than to higher stress levels because of the higher proportion of failures expected at the higher stress levels. A good ratio for the number of test units among the stress levels, from highest to lowest, is 1:2:4. If test units are expensive, four test units each at stress levels S_1 and S_2 would be tested; and five or more test units would be tested at stress level S_3. As an option, the number of test units could be two if time is limited, but the estimation uncertainty at the normal use condition will increase.

8.5 Data observation and measurement

No repairs are made to the test units during accelerated life testing.

The test operator determines the intervals between measurements to obtain data during accelerated life testing. Short intervals between measurements give better statistical results and are conducted during testing at the high stress level. At the low stress levels, longer intervals between measurements are adequate.

8.6 Types of stress loading

There are two possible stress loading schemes: loading in which the stress is time-independent (where the stress does not vary over time), and loading in which the stress is time-dependent (where the stress does vary over time). This document uses constant time-independent stress loading, which is the most common type used in an accelerated life test; see Figure 3. However, non-constant stress loads, such as step stress, cycling stress, random stress, etc., can be used. These types of loads are classified according to their dependence on time and are described in Annex A. The method specified in Annex A is used where a time-dependent analysis is required.

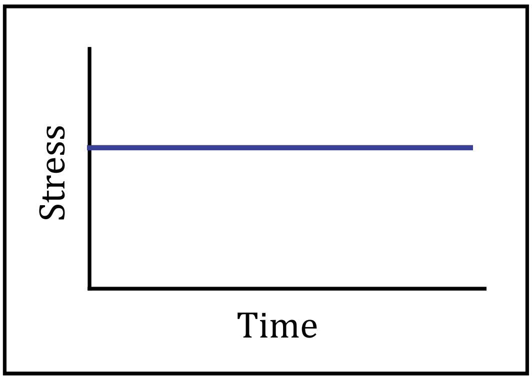

Figure 3 — Constant stress model

Time-independent stress loading has many advantages over time-dependent stress loading. Specifically:

— most components are assumed to operate at a constant stress under normal use conditions;

— it is far easier to run a constant stress test;

— it is far easier to quantify a constant stress test;

— models for data analysis are widely publicized and are empirically verified; and

— extrapolation from a well-executed constant stress test is more accurate than extrapolation from a time-dependent stress test.

9 End of test

9.1 Minimum number of failures required

Confidence levels are generated when at least four test units have failed (which includes their reaching a threshold level) at each stress level.

9.2 Termination cycle count

When a test unit fails between consecutive observations, the data collected is referred to as left-censored or 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 was observed to have failed, are recorded. This data is usually processed in accordance with ISO 19973-1:2015, 10.2.

9.3 Suspended or censored test units

Individual test units on which testing was stopped before failure occurred are known as suspensions. Some examples of suspensions include:

— the test unit needed to be disassembled for inspection;

— the test unit experienced a failure mode different than the type being considered; and

— the test unit was accidentally damaged from a source not related to the test.

Because these test units had achieved a number of cycles before the point of suspension, the data has a positive influence on the calculation of the statistical parameters. However, they cannot be returned to the testing program.

If the minimum number of failures has been reached, but some test units have not failed (reached a threshold level), the test can be stopped. The remaining test units are designated as censored.

Data from suspended test units is considered the same as data from censored test units. The method specified in Annex D allows calculation of the statistical parameters for these types of data

10 Statistical analysis

10.1 Analysis of failure data

The failure data from testing at all stress levels is analysed in accordance with 10.2, 10.3 and 10.4.

10.2 Life distribution

Select an initial life distribution (it can be changed later, if necessary). For pneumatic components, the Weibull distribution is commonly used, and its scale parameter, η , is selected to be the life characteristic that is stress-dependent; while the slope β is assumed to remain constant across different stress levels.

Plot the raw data from all stress levels on one graph and obtain a best fit straight line to the data from each stress level (see Figure 4 for an example). If the slopes β from each stress level are not parallel, consider a compromise slope for each set of stress levels (see Figure 5). A judgment is necessary as to whether the compromise slope is statistically acceptable (see example in Annex C), and if it is judged not acceptable, the testing program is restarted with improved data collection methods. It is necessary to have a constant value of the slope β for each stress level.

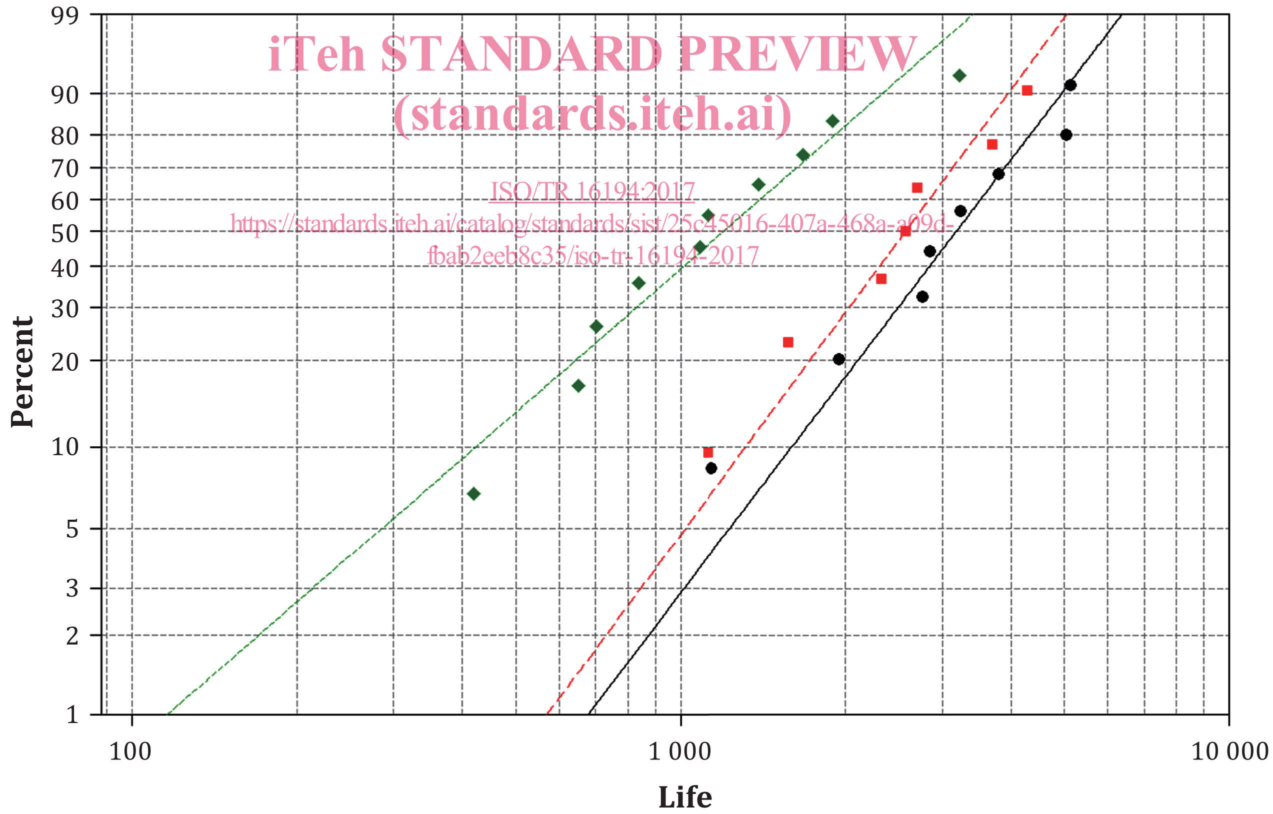

Figure 4 — Best fit slope to raw data

