# INTERNATIONAL STANDARD

# NORME INTERNATIONALE

**IEC**
**CEI**
**60605-6**

Third edition
Troisième édition
2007-05

## Equipment reliability testing –

## Part 6:
## Tests for the validity and estimation of the constant failure rate and constant failure intensity

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## Essais de fiabilité des équipements –

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## Partie 6:
## Tests pour la validité et l'estimation du taux de défaillance constant et de l'intensité de défaillance constante

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**Partie 6:**
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

# EQUIPMENT RELIABILITY TESTING –

## Part 6: Tests for the validity and estimation of the constant failure rate and constant failure intensity

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International Standard IEC 60605-6 has been prepared by IEC technical committee 56: Dependability.

This third edition cancels and replaces the second edition, published in 1997, and constitutes a technical revision.

The major technical changes with respect to the previous edition concern the inclusion of corrected formulae for tests previously included in a corrigendum, and the addition of new methods for the analysis of multiple items.

The text of this standard is based on the following documents:

| FDIS | Report on voting |
|---|---|
| 56/1181/FDIS | 56/1191/RVD |

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

A list of all the parts in the IEC 60605 series, under the general title *Equipment reliability testing*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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# INTRODUCTION

The techniques given in this part of IEC 60605 for testing constant failure rate or constant failure intensity assumptions are numerical and graphical procedures. The graphical methods allow patterns, such as early failures and non-constant failure rates and intensities, to be identified and estimated. The techniques are appropriate for analysing test or field data.

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# EQUIPMENT RELIABILITY TESTING –

## Part 6: Tests for the validity and estimation of the constant failure rate and constant failure intensity

## 1 Scope

This standard specifies procedures to verify the assumption of a constant failure rate or constant failure intensity, as defined in IEC 60050(191), and to identify patterns in the failure rate or intensity. These procedures are applicable whenever it is necessary to verify such assumptions. This may be due to a requirement or for the purpose of assessing any variation with time of the failure rate or failure intensity.

The objectives of the methods specified in this standard are as follows:

– to test whether the times to failure of non-repaired items are exponentially distributed, i.e. the failure rate is constant;

– to test whether the times between failures of repaired item(s) have any time trend, i.e. the failure intensity does not exhibit an increasing or decreasing trend;

– to construct graphs that allow the patterns in the failure rate or failure intensity to be displayed, with a view to verifying whether they can be assumed constant, to estimate their values or to identify the nature of any departure from constancy.

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## 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.

IEC 60050(191), *International Electrotechnical Vocabulary (IEV) – Chapter 191: Dependability and quality of service*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050(191) apply. However, the following clarifications should be noted:

a) the term "time" can refer to length, cycles or other quantities;

b) the term "failure" can also refer to other specified events such as repair completion or any other particular event;

c) the term “failure rate” is used to mean the instantaneous failure rate, also known as the hazard function;

d) the procedures are applicable for time-to-failure data collected from both test as well as from in the field. In this standard, the term “test” is used in Clauses 6 and 7 and can refer to time data collected from both test as well as from in the field.

## 4 Symbols

| | |
|---|---|
| $i, j, k, l$ | indicator variables |
| $H_i$ | cumulative hazard function at $i$-th time to failure |
| $M(T_j)$ | mean accumulated number of failures at time $T_j$ |
| $M(t)$ | mean accumulated number of failures per 100 systems |
| $m$ | number of unique times to failure accumulated over all repaired items |
| $N(T_l)$ | total number of items on test or in use at time $T_l$ |
| $N_i(T_j)$ | indicator variable, set to 1 if failure of $i$-th item is observed at time $T_j$, set to 0 if failure of $i$-th item is not observed at time $T_j$ |
| $n$ | sample size, the total number of non-repaired items tested for constant failure rate |
| $R(i,n)$ | estimate of the reliability at the $i$-th ordered time to failure $t_i$ used by the graphical procedure when testing $n$ items for constant failure rate |
| $R_i$ | reliability function computed for $i$-th ordered failure |
| $r$ | number of relevant failures during test |
| $r(T_l)$ | total number of failures for multiple repaired items at time $T_l$ |
| $r_i(T_j)$ | number of failures for item $i$ at accumulated time $T_j$ |
| $r_k$ | number of relevant failures during test for $k$-th item |
| $S_i$ | total time on test value for $i$-th time to failure |
| $S_0$ | initialization value for total time on test value, where $S_0 = 0$ |
| $T_i$ | accumulated time to the $i$-th relevant failure |
| $T_r$ | total time accumulated to the $r$-th failure |
| $T_{ij}$ | accumulated time to $j$-th failure of $i$-th item |
| $T_j$ | ordered accumulated time to $j$-th failure $T_1 < T_2 < ... < T_m$ |
| $T^*$ | total time accumulated on test time |
| $T_k^*$ | total time accumulated on test for $k$-th repaired item |
| $t_i$ | time corresponding to the $i$-th ordered failure, used when testing $n$ items for constant failure rate |
| $t^*$ | termination time of test for constant failure rate |
| $U$ | value of the statistic calculated from observed values, used when testing for constant failure intensity or constant failure rate |
| $U_\alpha$ | $\alpha$ quantile of the standardized normal distribution |

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$Var(T_j)$ variance of $M(T_j)$ used in the calculation of the confidence interval

$Z_i$ normalized total time on test value for $i$-th failure

$\alpha$ risk of wrongly rejecting the assumption that the (instantaneous) failure rate or the (instantaneous) failure intensity are constant, when they really are constant, often known as the significance level.

## 5 Requirements

In order for the procedures specified in this standard to be valid, the following requirements shall be satisfied.

When testing $n$ non-repaired items, for the constant failure rate assumption,

– for the numerical procedures, at least six *times to failure* are required;

– for the graphical procedure, at least four *times to failure* are required.

When testing one or more repaired items, for the constant failure intensity assumption,

– for the numerical procedures, at least six *times between failures* are required;

– for the graphical procedure, at least four *times between failures* are required.

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NOTE 1 For repaired items, the repair time is assumed to be negligible.

NOTE 2 Numerical procedures are given in the statistical tests for constant failure rate and constant failure intensity (see 6.2, 7.2 and 7.3) and the confidence intervals (see 7.4). Graphical procedures are outlined in the plotting methods given in Clauses 6 and 7.

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NOTE 3 The justification of the minimum number of failures can be found in the references given in the Bibliography.

## 6 Test for constant failure rate

### 6.1 General remark concerning Clause 6

This clause deals with tests for constant failure rate for non-repaired items. The test procedure is shown in the form of a chart (see Figure 1).

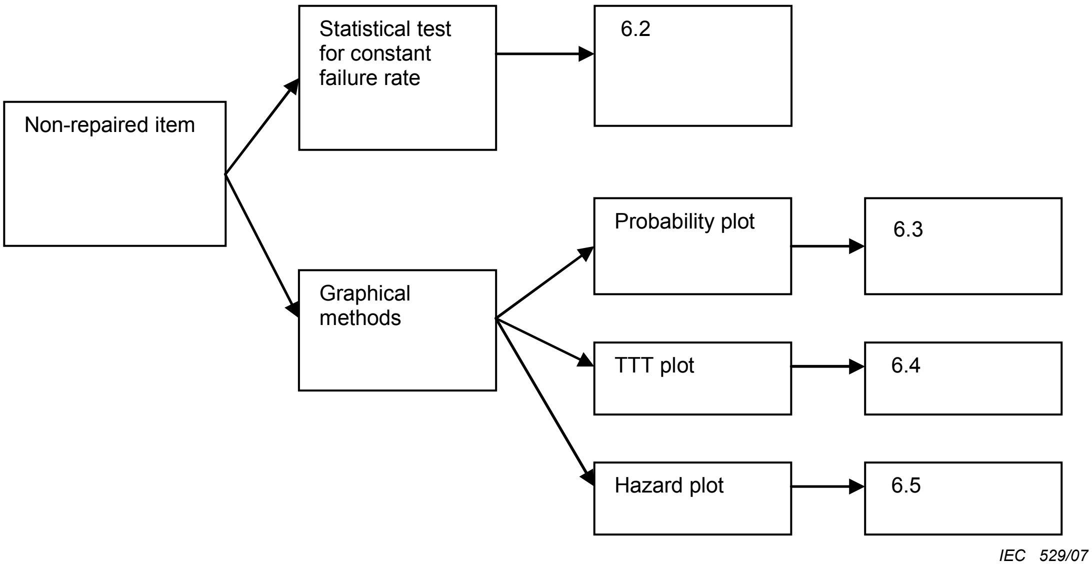


**Figure 1 – Tests for constant failure rate – Chart showing structure of Clause 6**

A formal statistical test for constant failure rate is given for tests terminated at a predetermined time or failure.

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Three graphical procedures are given as follows:

a) the probability plot is based on a linear transformation of the exponential distribution function and is suitable when the set of times to failure are known for every non-repaired item tested or when the test of all items is terminated at a predetermined time or failure;

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b) the total time on test plot (TTT plot) is an empirical and scale-independent plot suitable for data where the times to failure are known for all non-repaired items;

c) the hazard plot is a linear transformation of the cumulative hazard function for the exponential distribution and is appropriate when the set of times to failure are known for every non-repaired item tested, when the test of all items is terminated at a predetermined time or failure, or when the times to failure of a non-repaired item are mixed with the running times for items that have been removed from test at arbitrary points.

### 6.2 Statistical test for constant failure rate

This subclause applies when a sample of $n$ items is put on test that is terminated at the time of a pre-specified number of failures, $r$ (failure terminated), or at a pre-specified time, $t^*$ (time terminated).

The operating environment shall be the same for all the items tested. At the end of the testing period, not all of the items will have necessarily failed. There will be a total of $r$ recorded relevant times to failure.

*Step 1*

Order the times to failure in increasing order of magnitude and denote the ordered sample $t_1, t_2, \ldots, t_r$ .

For $i = 1$ to $r$, compute the accumulated time to the $i$-th failure as

$$T_i = \sum_{k=1}^{i} t_k + (n-i)\, t_i$$

For failure terminated tests, the total time accumulated on test at the $r$-th failure is given by

$$T_r = \sum_{k=1}^{r} t_k + (n-r)\, t_r$$

and for time terminated tests, the total time accumulated on test at $t^*$ is given by

$$T^* = \sum_{k=1}^{r} t_k + (n-r)\, t^*$$

*Step 2*

For each relevant accumulated test time $T_i$ compute the appropriate quantity $U$.

If failure terminated then $$U = \frac{\sum_{i=1}^{r-1} T_i - (r-1)\frac{T_r}{2}}{T_r\sqrt{\frac{r-1}{12}}}$$

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If time terminated then: $$U = \frac{\sum_{i=1}^{r} T_i - r\frac{T^*}{2}}{T^*\sqrt{\frac{r}{12}}}$$

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*Step 3*

Specify the significance level $\alpha$ to reject wrongly the assumption of constant failure rate, given that it really is constant. Recommended values of $\alpha$ are given in Table 1.

**Table 1 – Critical value $U_\alpha$ as a function of $\alpha$**

| $\alpha$ | Critical value of $U_\alpha$ |
|---|---|
| 0,025 | 2,24 |
| 0,050 | 1,96 |
| 0,100 | 1,64 |

*Step 4*

Reject the assumption of constant failure rate if the absolute value of $U$ is greater than the critical value given in Table 1. Otherwise, the assumption is not rejected.

Large positive values of $U$ occur whenever there is an increasing failure rate. Conversely, large negative values of $U$ occur whenever the failures occur at a decreasing rate.

## 6.3 Probability plot

This method is appropriate when the set of times to failure are known for every non-repaired item tested or when the test of all items is terminated at a predetermined time or failure.

*Step 1*

Order the times to failure events $t_1,\ t_2,...,t_r$ from smallest to largest.

*Step 2*

Calculate the auxiliary function $R(i,n)$ where $i$ is the index of the corresponding time to failure $t_i$, and $n$ is the sample size corresponding to the number of non-repaired items tested:

$$R(i,n) = \frac{n - i + 0{,}7}{n + 0{,}4}$$

NOTE It should be noted that $R(i,n)$ is an estimate of the reliability at the $i$-th ordered time to failure $t_i$ when testing $n$ items for constant failure rate. Strictly the auxiliary function is an estimator of the reliability function and conventionally would be represented by $\hat{R}(i,n)$. However the 'hats' have been omitted within this standard as there is no need to distinguish between the estimate and the true value.

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*Step 3*

Plot the logarithm of $R(i,n)$ against the corresponding time to failure or plot the auxiliary function $R(i,n)$ on the logarithmic scale of a semi-log paper.

NOTE Special probability paper can be used to construct the exponential probability plot.

*Step 4*

If the plot of this function looks linear, then there is no evidence to reject the assumption that the failure rate is constant and the failure rate may be estimated as the absolute value of the slope of the line. If the plot does not look linear then the assumption of constant failure rate should be rejected.

## 6.4 Total time on test plot

The method is appropriate when the set of times to failure are known for every non-repaired item tested.

*Step 1*

Order the times to failure events $t_1,\ t_2,...,t_n$ from smallest to largest, where $t_1 \le t_2 \le ... \le t_n$.

*Step 2*

Calculate the total time on test (TTT) values, $S_i, i = 1, 2, ..., n$, corresponding to each time to failure, setting $S_0 = 0$:

$$S_i = nt_1 + (n-1)(t_2 - t_1) + ... + (n-i+1)(t_i - t_{i-1})$$

*Step 3*

Normalize the TTT-values by calculating

$$Z_i = \frac{S_i}{S_n}$$

*Step 4*

Plot the normalized TTT-values $Z_i$ against the proportion of items that have failed by this time, $\frac{i}{n}$, for $i = 1, 2, ..., n$, on linear scale paper and join the plotted points by line segments.

*Step 5*

If the TTT plot looks linear, then there is no evidence to reject the assumption that the failure rate is constant and the failure rate may be estimated as the absolute value of the slope of the line. If the plot does not look linear, then the assumption of constant failure rate should be rejected.

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### 6.5 Hazard plot

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This method is appropriate when the set of times to failure are known for every non-repaired item tested or when the test of all items is terminated at a predetermined time or failure. This method is also appropriate when the times to failure of non-repaired items are mixed with the running times for items that have been removed from test at arbitrary points.

*Step 1*

Order the event times, both failure and running, from smallest to largest and denote the $i$-th ordered time by $t_i$ (i.e. $t_1 \le t_2 \le ... \le t_i \le ... \le t_n$).

*Step 2*

Compute the reverse ranks of all the times, $n, n-1, n-2, ...., 2, 1$, where $n$ represents the number of events. The reverse rank of the $i$-th event is given by $n-i+1$.

*Step 3*

Calculate the hazard function at each failure time only as the ratio of 100 to the corresponding reverse rank. Hence the hazard function at the $i$-th time, corresponding to a failure, is given by

$$\frac{100}{n-i+1}$$