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Edition 1.0 2020-02

TECHNICAL SPECIFICATION

colour inside

Reliability of industrial automation devices and systems –
Part 1: Assurance of automation devices reliability data and specification of their source

IEC TS 63164-1:2020-02(en)

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RELIABILITY OF INDUSTRIAL AUTOMATION DEVICES AND SYSTEMS –

Part 1: Assurance of automation devices reliability data and specification of their source

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- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical Specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

Technical Specification IEC TS 63164-1 has been prepared by IEC technical committee 65: Industrial-process measurement, control and automation.

The text of this technical specification is based on the following documents:

DTS	Report on voting
65/744/DTS	65/767/RVDTS

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 63164 series, published under the general title, *Reliability of industrial automation devices and systems*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability 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

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

Reliability data of automation devices is often used by assessors and system integrators to predict the properties of a complete system. The assessors and system integrators need to know how this data was acquired. This specification gives guidance to device manufacturers on how to present the reliability data of their devices and how to indicate the source of the reliability data in a manner that assessors and system integrators can make best use of. This includes the specification of reference conditions.

Three methods of data acquisition are distinguished:

1) Calculation. This is the preferred method for electronic devices.
2) Observation of devices in the field. This is the preferred method if no relevant data is available to make a forecast by calculation.
3) Laboratory tests. This is the preferred method for mechanical and electromechanical devices. Laboratory durability tests are, however, not deemed to be suitable if said devices will operate in the low demand mode (in the sense of IEC 61508-4:2010, 3.5.16).

NOTE Burn-in and break-in are not considered in this specification and will be addressed in future documents.

This specification is the first part of the series. This part of IEC 63164 concentrates on reliability data, including assurance of reliability data and methods of field reliability data collection. How to get data from calculation and laboratory tests is described in other documents. Therefore, this part will concentrate on random hardware failures, but it is recognized that it is difficult to distinguish between random hardware failures and systematic failures when collecting field data.

Future parts can include following subjects:

– reliability at system level;
– monitoring the automation device in the field;
– user guide.

RELIABILITY OF INDUSTRIAL AUTOMATION DEVICES AND SYSTEMS –

Part 1: Assurance of automation devices reliability data and specification of their source

1 Scope

This part of IEC 63164 provides guidance on the assurance of reliability data of automation devices. If the source of this data is calculation, guidance is given on how to specify the methods used for this calculation. If the source is from observation of devices in the field, guidance is given on how to describe these observations and their evaluations. If the source is the outcome of laboratory tests, guidance is given on how to specify these tests and the conditions under which they have been carried out.

This document defines the form to present the data.

The components considered in this document are assumed not to need any break-in phase before full range usage.

When devices are used for functional safety application, the requirements of IEC 61508 (all parts) and related standards are considered.

2 Normative references

The following documents are referenced in the text in such a way that some or all of their content constitutes requirements for 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 60300-3-2:2004, *Dependability management – Part 3-2: Application guide – Collection of dependability data from the field*

IEC 60300-3-5:2001, *Dependability management – Part 3-5: Application guide – Reliability test conditions and statistical test principles*

IEC 61649:2008, *Weibull analysis*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions 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

3.1.1
assurance of reliability data
outcome of having the needed supporting information such that the reliability data can be trusted, verified and audited

3.1.2
B_{10} threshold
time until 10 % of the components fail

Note 1 to entry: The applicable time interval is dependent on the nature and application of the asset and can be elapsed time, operating hours, number of cycles, etc.

Note 2 to entry: For this document, an average failure rate is calculated from the B_{10} threshold by dividing 10 % with the B_{10} threshold in hours. The influence of infant mortality is neglected and increasing failure rate is assumed only significant after B_{10}.

Note 3 to entry: Once the B_{10} threshold is reached, the failure rate is assumed unacceptable for pneumatic and electromechanical components.

3.1.3
burn-in
process conducted with the sole intention of stabilizing parameters

Note 1 to entry: Burn-in is an accelerated conditioning by operating the item under its operating electrical load at an elevated temperature, which is generally the maximum operating temperature that does not exceed the thermal rating of the device.

3.1.4
failure rate
λ
limit, if it exists, of the quotient of the conditional probability that the failure of a non-repairable item occurs within time interval $(t, t + \Delta t)$ by Δt, when Δt tends to zero, given that failure has not occurred within time interval $(0, t)$

Note 1 to entry: See IEC 61703, *Mathematical expressions for reliability, availability, maintainability and maintenance support terms*, for more detail.

[SOURCE: IEC 60050-192:2015, 192-05-06, modified – The formula and Note 2 to entry have been deleted]

3.1.5
failure in time
FIT
the number of failures in 10^9 component hours of operation

[SOURCE: IEC 60947-5-3:2013, 2.3.18, modified – "device" has been replaced by "component"]

3.1.6
field data
reliability data observed in the field

Note 1 to entry: The word “field” means the normal working environment of the device.

3.1.7
mean operating time between failures
MTBF
expectation of the duration of the operating time between failures

Note 1 to entry: Mean operating time between failures should only be applied to repairable items. For non-repairable items, see mean operating time to failure (192-05-11).

[SOURCE: IEC 60050-192:2015, 192-05-13, modified – "MOTBF" has been deleted]

3.1.8
mean operating time to failure
MTTF
expectation of the operating time to failure

Note 1 to entry: In the case of non-repairable items with an exponential distribution of operating times to failure (i.e. a constant failure rate) the *MTTF* is numerically equal to the reciprocal of the failure rate. This is also true for repairable items if after restoration they can be considered to be "as-good-as-new".

[SOURCE: IEC 60050-192:2015, 192-05-11 – modified: Note 2 to entry has been deleted]

3.1.9
mission time
T_{M}
period of time covering the intended use

[SOURCE: ISO 13849-1:2015, 3.1.28, modified – "of an SRP/CS" has been deleted]

3.1.10
random hardware failure
failure, occurring at a random time, which results from one or more of the possible degradation mechanisms in the hardware

[SOURCE: IEC 61508-4:2010, 3.6.5]

3.1.11
reliability
ability to perform as required, without failure, for a given time interval, under given conditions

Note 1 to entry: The time interval duration can be expressed in units appropriate to the item concerned, e.g. calendar time, operating cycles, distance run, etc., and the units should always be clearly stated.

Note 2 to entry: Given conditions include aspects that affect reliability, such as: mode of operation, stress levels, environmental conditions, and maintenance.

[SOURCE: IEC 60050-192:2015, 192-01-24 – modified: Note 3 to entry has been deleted]

3.1.12
systematic failure
failure, related in a deterministic way to a certain cause, which can only be eliminated by a modification of the design or of the manufacturing process, operational procedures, documentation or other relevant factors

Note 1 to entry: Corrective maintenance without modification will usually not eliminate the failure cause.

Note 2 to entry: A systematic failure can be induced by simulating the failure cause.

Note 3 to entry: Examples of causes of systematic failures include human error in

– the safety requirements specification;
– the design, manufacture, installation, operation of the hardware;
– the design, implementation, etc. of the software.

Note 4 to entry: In this standard, failures in a safety-related system are categorized as random hardware failures (see 3.1.10) or systematic failures.

[SOURCE: IEC 61508-4:2010, 3.6.6]

3.1.13
useful life
time interval, from first use until user requirements are no longer met, due to economics of operation and maintenance, or obsolescence

Note 1 to entry: In this context, “first use” excludes testing activities prior to hand-over of the item to the end-user.

[SOURCE: IEC 60050-192:2015, 192-02-27]

3.2 Abbreviated terms

For the purposes of this document, the following abbreviated terms apply.

FIT Failures in time

MTBF Mean time between failures

MTTF Mean time to failure

T_M Mission time

4 Form to present reliability data

Generally, the reliability data can be considered from the following aspects.

– Source of data: how to get the reliability data, from calculation/observation of devices in the field/ laboratory test, standards or database.
– Reliability data: Common reliability data such as *MTBF*, λ, *MTTF*, and B_{10}.
– Period of validity, such as T_M.
– Reference conditions: Information about deployment conditions under which a device was observed or which are assumed for its future deployment, such as operating time, exposure time, operating voltage, operating current, duty cycle.
– Reference environment conditions: Information about the reference environment conditions under which the field data was acquired or which are assumed for further deployment, such as temperature, humidity, pressure, corrosion, vibration.
– Events: Information about anything that happened to the automation device during its life and might influence reliability, including failures, repairs, etc.

5 Conformance

A manufacturer of an automation device presenting reliability data of said device in accordance with this document shall provide data according to at least one subclause of Clause 6.

6 Requirements on the assurance of reliability data

6.1 Assurance of reliability data derived from calculation

6.1.1 General requirements

This is the preferred method for electronic devices.

The reliability data derived from calculation shall be obtained according to the following provisions.

– The calculation is based on statistical failure rates obtained from e.g. the manufacturers of components or databases.
– The statistical data obtained are valid only during the mission time of the device.
– The failure rate of the device is derived from calculation based on the failure rates of all the components.

Information about calculation of *MTTF* and *MTBF* derived from λ for a device or subsystem can be found in Annex B.

6.1.2 Method based on calculation

The method based on calculation is assuming constant failure rate for random hardware failures.

The calculation shall consider typical environmental conditions.

NOTE Typical environmental conditions are: temperature 40 °C, cyclic duration factor 100 %; humidity, I_e (if applicable), U_e (if applicable), etc.

For additional information, see Annex B.

6.1.3 Data information

A set of reliability data of the product shall include a combination of the following characteristics where relevant:

– failure rate λ or *MTBF*;
– mission time T_M;

NOTE Generally, a mission time of 20 years is used as a statistical reference for reliability analysis.

– maximum voltage if different from U_e;
– maximum operational current if different from I_e;
– environmental conditions if different from the typical conditions.

6.2 Assurance of reliability data derived from observations of devices in the field

6.2.1 General requirements

Only random hardware failures shall be regarded when evaluating field data, see Annex A.

Environmental conditions under which the field data was gained (observed) shall be comparable, otherwise no meaningful results from observation of devices in the field can be obtained.

6.2.2 Method based on observations of devices in the field

Step 1: Observation

In order to address random hardware failure, the method is based on observations of devices in the field. Observation of devices in the field means that all failures shall be documented. To distinguish between random hardware failure and systematic failure, the checklist in Annex C may be used.

Step 2: Calculation

Calculation of a failure rate λ or *MTBF* is based only on the random hardware failures.

NOTE For example, λ = number of random hardware failures/sum of operating hours of all devices.

Only failures during the useful life shall be considered.

Conditions for observation of devices in the field are described in IEC 60300-3-2:2004.

6.2.3 Data information

A set of reliability data of the product shall include the following characteristics where relevant:

– failure rate λ or *MTBF*;
– mission time T_M;

NOTE Generally, a mission time of 20 years is used as a statistical reference for reliability analysis.

– environmental conditions under which the field data was gained (observed).

6.3 Assurance of reliability data derived from laboratory tests

6.3.1 General requirements

Reliability data derived from laboratory tests shall be obtained with the following provisions.

The procedure is based on statistical analysis of test results in order to generate reliability data.

The requirements may be further specified by the relevant product standard in terms of relevant tests, failure modes and their ratios.

The confidence level related to failure rate calculation during the useful life of the device shall be at least 60 %.

The statistical data obtained are valid only during the useful life of the device.

It is assumed that no parts of the devices during test and application are replaced or repaired.

6.3.2 Method based on durability test results

Durability test methods like IEC 61649 will often determine non-constant failure rate (wear out). The result of the test will be a B_{10} threshold (see IEC 61649). In order to combine these data with constant failure rate data, an average failure rate is calculated from the B_{10} threshold by dividing 10 % with the B_{10} threshold in hours (see Clause B.2).

The test environment and the test procedure shall be in accordance with the relevant product standard.

The number of samples to be tested has to be chosen as a matter of engineering judgment according to IEC 61649 and IEC 60300-3-5. This determination of number of samples should take into account the statistical method (see Clause 4 of IEC 61649:2008) and the confidence level of the reliability data to be obtained.

NOTE Accelerated testing is a method to find failure mode of certain devices. The test result could be used for reliability calculation and could be used to improve reliability of the device. For more details, refer to IEC 62506:2013.

6.3.3 Data information

A set of reliability data of the product shall include a combination of the following characteristics where relevant:

– failure rate λ (time based);

– B_{10} threshold (wear based);

– mission time T_M;

NOTE Generally, a mission time of 20 years is used as a statistical reference for reliability analysis.

– confidence level if different from 60 %;

– no-make-break-current or utilization category;

– maximum switching rate;

– maximum voltage if different from U_e;

– maximum operational current for the specified utilization category if different from I_e;

– environmental conditions if different from the typical conditions.

Annex A
(informative)

Methods to collect reliability data from the field

A.1 General

The collection and analysis of failure and usage data from the field may provide, among other objectives, an important source of information that can be used in order to assess and predict the reliability of industrial automation and control devices, equipment and systems. A comprehensive overview and guidelines related to these activities are given in IEC 60300-3-2 and IEC 60605-6. IEC 60706-5 covers testability and diagnostic testing.

In the following, some of the material from IEC 60300-3-2 is summarized and adapted to the specific needs of field data of industrial automation and control devices, equipment and systems. In addition, the impact of recent technological developments on collection of field data is discussed.

It is important to realize that data collection usually cannot be performed without cooperation of all the parties involved. This may include automation device manufacturers, suppliers, users and customers.

The focus of Annex A is on the collection and analysis of data related to reliability. Other aspects of dependability data, e.g. data related to maintainability, availability and maintenance support performance are not covered by this annex.

A.2 Objectives of reliability data collection

The objectives of reliability data collection for industrial automation and control devices, equipment and systems can include:

– assessment of the reliability of an existing automation device in the field and, possibly, comparison of observed values with those obtained from theoretical calculations;
– prediction of the reliability of a new automation device based on observed values for similar automation device in the field;
– information about operational and environmental conditions that influence the reliability of an automation device.

A.3 Specification of the type of data collected

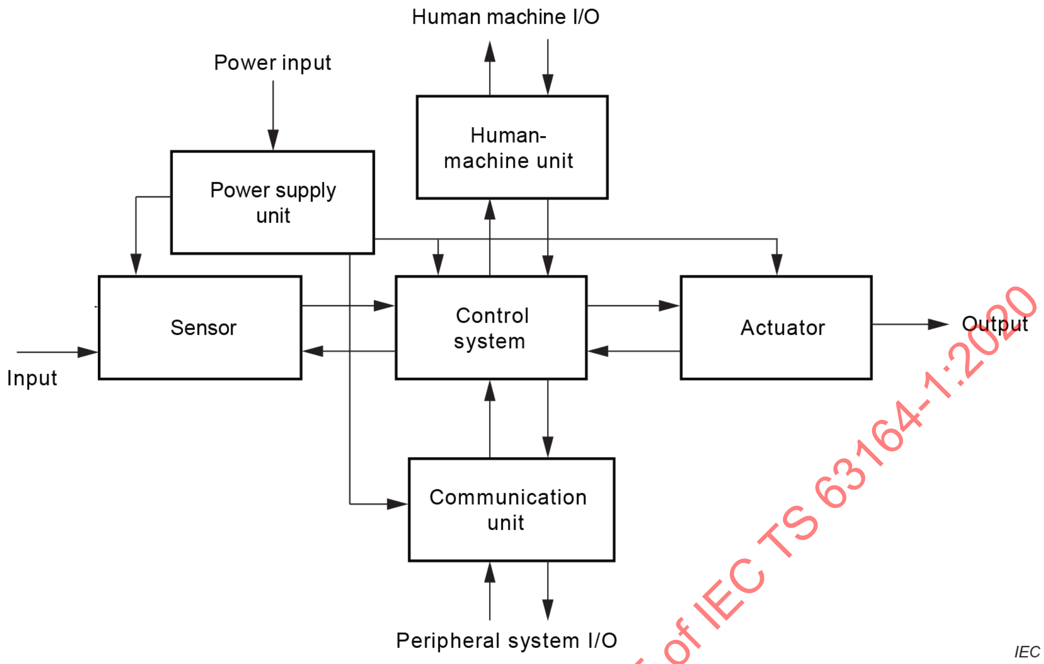


Figure A.1 – Exemplary definition of automation device

The devices for which data is collected should be clearly defined. Figure A.1 shows an example of such definition.

The data collection can be qualified as belonging to meaningful phases, like early operation phase, warranty period, or long-term behaviour.

The data collection typically aims at calculating:

– number of events: The most basic level of analysis is the calculation of the number of events during a particular period or within several sub-periods. The number of events can be broken down into appropriate sub-divisions, such as events relating to critical shutdowns, customer complaints, safety involvement, and then further broken down into modules causing such problems. Examination of numbers of events will enable identification of specific areas that warrant further investigation;

– general rates: A rate is the number of events that occur per unit time, per operation, or per cycle. Calculating rates can give some indication of how the number of events will change with time. Rates can be modelled as being approximately constant or as non-constant.

Depending on these two objectives, the type of data to be collected is determined.

Generally, the data that is required in order to perform a thorough analysis can be separated into several categories as explained below. However, it is often not possible to obtain all the data that would be required, perhaps because of operational issues or because it is too expensive to collect such data. In these cases, it is often necessary to perform a trade-off analysis between the benefit of the data collection and the expenses it would cause.

The required data falls into the following categories.

- Inventory and configuration data: Inventory records are often retained that identify original build state, manufacturer, batch number, modification state, repair history and other information. These data are particularly important when assessing the factors that govern susceptibility to various events. Without such information, dependability analysis will never be able to identify trends that apply only to specific sub-groups of otherwise identical automation devices.
- Usage: Usage is a measure of what functions are being demanded from a product or system during customer service, how long and how often. If a device is switched on during 100 % of the time, then the usage is easy to calculate. But let us assume that two devices are supplied with one of them operated continuously and the other one occasionally as a back-up. It is difficult to estimate then what the average usage of the equipment type is. It is often not possible to determine the usage of a device and so it becomes necessary to determine an average usage for the device type. Usage may not only be time based, it may also be operations or cycle based (e.g. how many times the automation device is used). Some products may have an internal counter.
- Environment: A more severe environment may cause an event to occur sooner than for one that is less severe. There are usually several environmental conditions that contribute to the cause of a specific event and, depending on the analysis required, all may need recording.
- Events: events can include failure, maintenance actions, etc. Failure can include system failures, secondary failures, and failures in redundant systems, failures that do not cause systems failures and hidden failures. If a failure has occurred, analysis begins with its verification. If no failure is found, this leads directly to the "no failure found categorization". When a failure is verified, detailed fault analysis can begin to isolate the actual failure mode and mechanism that caused the failure.

A.4 Data sources

Many reliability data sources exist, such as listed in Annex H of IEC 61709:2017, although the availability and utility of these sources may vary across product types and company structure. Direct information is the information collected by the manufacturer. Indirect information is information collected from a third party that has knowledge of the product from sales, repairs, etc.

A.5 Analysis methods and their required data

There are many IEC standards and guidance documents that give instructions and assistance in the analysis of reliability data. Table A.1 lists all the dependability standards that have data requirements. The standards are listed in reference number order. Table A.1 indicates which methods in each standard can be used for and what data would need to be collected in order to use the techniques given in the standard.

Table A.1 – Data requirements for dependability methods, why they should be used, and IEC reference

What is it for?	Required data	IEC reference	Method
How to estimate constant failure rates	Times to failure of automation device	IEC 60605-4	Point estimates, confidence intervals, prediction intervals and tolerance intervals
How to establish that failure rates are constant	Times to failure for every relevant failure	IEC 60605-6	Tests for the validity and estimation of the constant failure rate and constant failure intensity
How to test for a wear-out situation	Number of automation device on test, and times to failure of each failed automation device	IEC 61649 IEC 61710	Weibull analysis

A.6 Planning

Data collection should have a strategy with clearly stated objectives, traceability of products such as components, parts or equipment, repair and maintenance procedures, self-test and built-in diagnosis abilities, etc.

A.7 Approaches to data collection

See Clause 12 of IEC 60300-3-2:2004.

A.8 Methods of condition monitoring and required resources

Reliability data are often collected over several years and this will involve many different persons. This applies especially to field data. It is recommended to use automation technology to collect data, such as automated identification (AutoID), radio frequency identification (RFID), laser scanners, optical character recognition (OCR), and even hand-held devices. Intelligent devices have the ability to provide real time condition monitoring and asset health information that can be used to calculate system reliability. Refer to IEC 63082-1 for how to effectively access this information.

Annex B
(informative)

Calculation of *MTTF* and *MTBF* derived from λ for a device or subsystem

B.1 General

In order to assess the reliability of plants or systems, it is necessary to determine failure rates for devices and subsystems. Based on the failure rates of the constituent components, reliability parameters are calculated, taking into account the operating conditions.

B.2 Determination of the failure rate λ under operating conditions

Values of failure rate λ at reference conditions are given by the manufacturer of the component or device or can be found in various available databases (see IEC 61709:2017 Annex H).

For electromechanical devices, an average failure rate can be determined using the B_{10} threshold and the number of operating frequency C (expressed as the number of operating cycles per hour) of the application as specified, see IEC 62061:2005, 6.7.8.2.1 NOTE 2.

$$\lambda = \frac{0{,}1 \times C}{B_{10}}$$

where

λ is the failure rate, expressed in *FIT*;

C is the number of operating frequency;

B_{10} is the B10 threshold.

Depending on the environmental conditions and the kind of components, a failure rate λ should be calculated for a device in accordance to IEC 61709.

B.3 Determination of *MTBF*

Approximately, a formula is given for calculating the *MTBF* of a device/subsystem from failure rate λ for components with a constant failure rate (see e.g. IEC 61025:2006 or IEC 61078:2016):

$$MTTF \sim MTBF \sim 1/\lambda$$

Calculation from device level to system level for series architecture systems:

$$\frac{1}{MTBF_{\text{system}}} = \frac{1}{MTBF_{\text{device1}}} + \frac{1}{MTBF_{\text{device2}}} + \frac{1}{MTBF_{\text{device3}}} + \frac{1}{MTBF_{\text{device4}}}$$

where

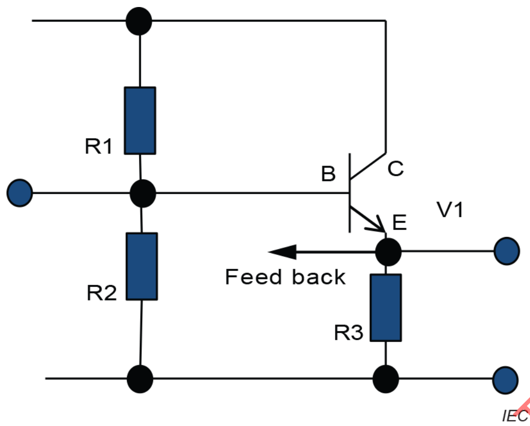
$MTBF_{\text{system}}$ is the *MTBF* of the system, expressed in years [a];

$MTBF_{\text{device}i}$ is the *MTBF* of device *i*, expressed in years [a].

For more complex architectures and further examples, see IEC TR 63164-2[1].

B.4 Example of electronic circuit

Figure B.1 shows an example of an electronic circuit.



Key

V1 transistor

B base of transistor

E emitter of transistor

C collector of transistor

R1 resistor

R2 resistor

R3 resistor

Figure B.1 – Example of electronic circuit

Resistor:

$\lambda_{ref} = 0{,}3\,FIT$ (SN 29500-4)

$\lambda = \lambda_{ref} \times \pi_T$ (IEC 61709:2017, 10.2.1)

Transistor:

$\lambda_{ref} = 3\,FIT$ (SN 29500-3)

$\lambda = \lambda_{ref} \times \pi_U \times \pi_T$ (IEC 61709:2017, 7.2.1)

[1] Under preparation. Stage at the date of publication: IEC TR 63164-2/CDTR:2020.

Assumed conditions:

Transistor:

θ_{ref} = 55 °C; θ_{op} = 50 °C ➔ π_T = 0,82 (IEC 61709:2017, Table 23)

U_{OP} = 24 V; U_{rat} = 50 V ➔ π_U = 1 (IEC 61709:2017, Table 21)

Resistors:

θ_{ref} = 55 °C; θ_{op} = 50 °C ➔ π_T = 0,89 (IEC 61709:2017, Table 43)

Calculation for a device:

R1: $\lambda_{R1} = \lambda_{refR1} \times \pi_{TR1}$ = 0,3 *FIT* × 0,89 = 0,267 *FIT*

R2: $\lambda_{R2} = \lambda_{refR2} \times \pi_{TR1}$ = 0,3 *FIT* × 0,89 = 0,267 *FIT*

R3: $\lambda_{R3} = \lambda_{refR3} \times \pi_{TR1}$ = 0,3 *FIT* × 0,89 = 0,267 *FIT*

V1: $\lambda_{V1} = \lambda_{refV1} \times \pi_{TV1} \times \pi_{T\ V1}$ = 3 *FIT* × 0,82 × 1 = 2,46 *FIT*

1 *FIT* = 1 × 10^{-9} [1/h]

$\lambda_{Device} = \lambda_{R1} + \lambda_{R2} + \lambda_{R3} + \lambda_{V1}$ = 0,267 *FIT* + 0,267 *FIT* + 0,267 *FIT* + 2,46 *FIT* = 3,261 *FIT* = 3,261 × 10^{-9} [1/h]

$$MTBF_{device} = \frac{1}{3{,}261 \times 10^{-9} \frac{1}{\text{h}} \times 8\,760 \frac{\text{h}}{\text{a}}} \quad 35\,000 \text{ a}$$

where

λ	is the failure rate under operating conditions, expressed in *FIT*;
λ_{ref}	is the failure rate under reference conditions, expressed in *FIT*;
π_T	is the temperature dependence factor;
π_U	is the voltage dependence factor;
U_{op}	is the operating voltage, expressed in volts [V];
U_{rat}	is the rated voltage, expressed in volts [V];
θ_{ref}	is the reference temperature, expressed in degree centigrade [°C];
θ_{op}	is the operating temperature, expressed in degree centigrade [°C];
$MTBF_{device}$	is the *MTBF* of the whole device, expressed in years [a];
h	means hour;
a	means year.

Annex C
(informative)

Differentiation between systematic failure and random hardware failure

C.1 General

In order to determine failure rates on the basis of field experience, it is necessary to identify the failures as random hardware failures and systematic failures, because typically random hardware failures need to be quantified with statistical methods.

C.2 Criteria for failure classification

To differentiate between systematic failure and random hardware failure, a failure determination with questions can be helpful.

Failure analysis is necessary to judge the systematic failure and random hardware failure. Table C.1 and Table C.2 show some possible incidents and their classification, whether they are assumed to be a systematic failure or a random hardware failure, for reference only.

Table C.1 and Table C.2 do not contain a complete list of failures. Other failures are possible.

Table C.3 provides an example for failure collection and evaluation.

Table C.1 – Classification of failures by cause

Cause	Systematic failure	Random hardware failure
Aging / Wear out[a]	x	x
Fatigue[a]	x	x
Corrosion	x	
Design error	x	
Electro-magnetic influence	x	
Influence of environment	x	
Installation fault	x	
Internal device fault		x
Software error / Programming fault	x	
Incorrect test procedure	x	

[a] It is random hardware failure during the useful life, but it comes into systematic failure afterwards.

Table C.2 – Classification of failures by phenomenon

Phenomenon	Systematic failure	Random hardware failure
Leakage current		x
Frozen signal, Stuck-at		x
Communication fault[a]	x	x
Mechanical blockage	x	
Unauthorized intervention / Sabotage	x	
Inaccuracy of measurement	x	
Signal drift		x
Open circuit / Short circuit		x
[a] If the failure could be reproduced, it is a systematic failure. If not, it is a random hardware failure.		

Table C.3 – Example for failure collection and evaluation

Number of years		6	5	4	3	2	1
Number of devices		2 500	3 000	3 500	3 200	2 800	2 200
Systematic failure caused by:							
Aging / Wear out		6	8	11	10	12	14
Fatigue		0	0	0	0	0	0
Corrosion		0	0	0	0	0	0
Design error		2	3	2	3	2	3
Electro-magnetic influence		0	0	0	0	0	0
Incorrect test procedure		0	0	0	0	0	0
Communication fault		5	5	4	4	3	3
Mechanical blockage		0	0	1	0	1	0
Unauthorized intervention / Sabotage		0	0	0	0	0	0
Inaccuracy of measurement, signal drift		8	7	9	8	11	12
Random hardware failure caused by:							
Leakage current		0	0	0	0	0	0
Frozen signal, Stuck-at		4	5	6	7	8	9
Open circuit / Short circuit		6	5	6	7	8	7
Number of systematic failures		21	23	27	25	29	32
Number of random failures		10	10	12	14	16	16
Operating hours	[h]	$1,3110^8$	$1,31 \times 10^8$	$1,23 \times 10^8$	$8,41 \times 10^7$	$4,91 \times 10^7$	$1,93 \times 10^7$
Σ Operating hours	[h]	$5,38 \times 10^8$	/	/	/	/	/
Σ Failures		78	/	/	/	/	/
Lambda λ	[1/h]	$1,45 \times 10^{-7}$	/	/	/	/	/
MTBF	[year]	787	/	/	/	/	/

Table C.3 uses the following formulas:

$$\lambda = \frac{\Sigma \text{failures}}{\Sigma \text{operating hours}}$$

$$MTBF = \frac{1}{\lambda \times 8\,760}$$

NOTE 1 The unit of failure rate λ is either 1/h or *FIT*.

NOTE 2 The unit of *MTBF* is the year.

NOTE 3 In this example, all failed devices were replaced by a substitute device.

C.3 Examples

C.3.1 Fatigue

Failure phenomenon: A field relay terminal board had abnormal adhesion, caused the relay terminal board unable to operate.

Failure mechanism: By means of metallographic microscope, microscopic observation was carried out on the fracture positions and traces to confirm that the fracture mechanism of relay reeds was metal fatigue caused by repeated bending. Figure C.1 shows an example of fatigue.

Figure C.1 – Example of fatigue

C.3.2 Installation fault

Failure phenomenon: After the installation of a certain site type terminal board, the measurement of several channels displayed abnormal signal.

Failure mechanism: The inductance suffered from mechanical stress and induced pins deformation. The X-ray inspection showed that the internal winding of inductance was fractured, which caused the inductance open-circuits. Figure C.2 shows an example of installation fault.