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Road vehicles — Application of predictive maintenance to hardware with ISO 26262-5

Véhicules routiers — Application de ~~l'entretien~~la maintenance prédictive au matériel ~~avec ISO~~ à l'aide de l'ISO 26262-5

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO ~~documents~~document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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Field Code Changed

This document was prepared by Technical Committee ISO/TC 22, *Road ~~Vehicles~~vehicles*, Subcommittee SC 32, *Electrical and electronic components and general system aspects*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Hardware elements wear out or degrade with time and usage. The presence of certain faults can cause the rate of degradation to increase. If the rate of degradation exceeds critical thresholds, then a hardware element can fail during its normal expected lifespan. Addressing fault behaviours which change over time is difficult. Functional safety standards such as the ISO 26262 series have traditionally addressed degrading faults with avoidance measures and simplified assumptions of static behaviours.

Understanding of degrading faults is improving over time. Many industries are taking proactive steps to control degrading faults using predictive maintenance. Predictive maintenance can detect degrading faults and predict remaining useful life. Safety mechanisms based on predictive maintenance are not explicitly discussed in the ISO 26262~~:2018~~ series.

This document provides a survey of current state of the art for degrading faults and predictive maintenance techniques. Approaches are presented to consider degrading faults and predictive maintenance techniques in an ISO 26262 safety argument. Much of the content is focused on semiconductors, but the concepts can be applied to other hardware elements.

Road vehicles — Application of predictive maintenance to hardware with ISO 26262-5

1 Scope

This document is intended to be applied to the usage of predictive maintenance methods for the detection of degrading faults in safety related E/E hardware elements. It applies to hardware elements developed for compliance with the ISO 26262[1] series in which degrading faults are shown to be relevant due to, for instance, the technology used.

Specific technical implementations of predictive maintenance solutions are not in scope of this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 26262-1: 2018, *Road vehicles — Functional safety — Part 1: Vocabulary*

~~*ISO 26262-5: 2018 Road vehicles — Functional Safety — Part 5: Product development at the hardware level*~~

43 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 26262-1:2018 and the following apply.

ISO and IEC maintain terminological terminology databases for use in standardization at the following addresses:

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

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

3.1
degrading fault
fault whose characteristics are not constant and degrade over time, that can result in an error or failure when stimulated after degradation exceeds a critical threshold

Note 1 to entry: Permanent and intermittent faults can first manifest as degrading faults. Transient faults do not manifest as degrading faults.

Note 2 to entry: Degrading faults do not create errors or failures until degradation exceeds critical thresholds. The capability to generate an error or failure is related to the current state of degradation.

Note 3 to entry: Degrading faults exhibit abnormal conditions which can cause an error or failure over time. Normal degradation does not exhibit abnormal conditions which are necessary to be classified as a fault. Normal degradation can result in a loss of functionality after expected lifespan has elapsed but cannot be considered a fault as it is not abnormal.

3.2
degrading fault detection time interval
~~{~~**DFDTI**~~}~~
timespan from the occurrence of a *degrading fault* ~~{~~{3.1) to its detection

3.3
degrading fault handling time interval
{DFHTI}
sum of the *degrading fault detection time interval* {(3.2) and the *degrading fault reaction time interval* {(3.4).

Note 1 to entry: The degrading fault handling time interval is a property of a *predictive maintenance* (3.5) related safety mechanism.

Note 2 to entry: The degrading fault handling time interval is considered in addition to the fault handling time interval. See Figure 4.

Note 3 to entry: The timespan from occurrence of a *degrading fault* {(3.1) until it has the capability to generate an error or failure is the maximum degrading fault handling time interval that can be specified for a predictive maintenance related safety mechanism to support the functional safety concept.

Note 4 to entry: A *degrading fault* {(3.1) is covered in a timely manner by the corresponding safety mechanism if there is detection and reaction within the degrading fault handling time interval.

3.4
degrading fault reaction time interval
{DFRTI}
timespan from the detection of a *degrading fault* {(3.1) to reaching a safe state or reaching emergency operation

3.5
predictive maintenance
techniques that are used to detect *degrading faults* {(3.1), predict *remaining useful life* {(3.6), and react appropriately

Note 1 to entry: Approaches include the use of data driven methods such as machine learning applied locally or on a remote system. Guidance for developing safety related ML systems can be found in ISO/IEC TR 5469 and ISO PAS 8800 [2].

Note 2 to entry: Prediction of *remaining useful life* {(3.6) can be used to replace a faulty element before it can cause an error or failure.

3.6
remaining useful life
{RUL}
length of time from the present time to the estimated time that the item or element is expected to no longer perform its intended function within desired specifications

[SOURCE: IEEE Std 1856-2017, modified for compliance to ISO directives]

Note 1 to entry: RUL can be estimated using *predictive maintenance* {(3.5) or with other approaches.

Note 2 to entry: RUL can be estimated for expected degradation or degradation in the presence of a fault.

[SOURCE: IEEE 1856-2017[3], modified for compliance to ISO directives]

54 Abbreviated terms

ADAS Advanced Driver Assistance System

ADS Automated Driving System

AI	Artificial Intelligence
BEoL	Back End of Line (sometimes BEOL)
BFR	Base Failure Rate
BIST	Built-In Self-Test
BLM	Barrier Layer Material
CHC	Channel Hot Carrier
COTS	Commercial Off The Shelf
DC	Diagnostic Coverage
DFDTI	Degrading Fault Detection Time Interval
DFHTI	Degrading Fault Handling Time Interval
DFRTI	Degrading Fault Reaction Time Interval
DRAM	Dynamic Random Access Memory
EM	Electromigration
ESD	Electrostatic Discharge
FEoL	Front End of Line (sometimes FEOL)
FET	Field Effect Transistor
FDTI	Fault Detection Time Interval
FHTI	Fault Handling Time Interval
FTTI	Fault Tolerant Time Interval
HCI	Hot Carrier Injection
ILD	Inter-Layer Dielectric
LFM	Latent Fault Metric
ML	Machine Learning
MoL	Middle of Line (sometimes MOL)
MEoL	Middle End of Line (sometimes MEOL)
MPFDTI	Multiple Point Fault Detection Time Interval
NBTI	Negative Bias Temperature Instability
NVM	Non-Volatile Memory
PCM	Phase Change Memory

~~PHM~~	~~Prognostics and Health Management~~
~~QMS~~	~~Quality Management System~~
~~RUL~~	~~Remaining Useful Life~~
~~SBD~~	~~Soft Breakdown~~
~~SHE~~	~~Self Heating Effect~~
~~SILC~~	~~Stress Induced Leakage Current~~
~~SM~~	~~Stress Migration~~
~~SoC~~	~~System on Chip~~
~~SPFM~~	~~Single Point Fault Metric~~
~~TDDB~~	~~Time Dependent Dielectric Breakdown~~
~~TDJD~~	~~Time Dependent Junction Degradation~~
~~TID~~	~~Total Ionizing Dose~~
ADAS	Advanced Driver Assistance System
ADS	Automated Driving System
AI	Artificial Intelligence
BEoL	Back End of Line (sometimes BEOL)
BFR	Base Failure Rate
BLM	Barrier Layer Material
CHC	Channel Hot Carrier
COTS	Commercial Off The Shelf
DC	Diagnostic Coverage
DFDTI	Degrading Fault Detection Time Interval
DFHTI	Degrading Fault Handling Time Interval
DFRTI	Degrading Fault Reaction Time Interval
DRAM	Dynamic Random Access Memory
EM	Electromigration
ESD	Electrostatic Discharge
FEoL	Front End of Line (sometimes FEOL)
FET	Field Effect Transistor
FDTI	Fault Detection Time Interval
FHTI	Fault Handling Time Interval
FTTI	Fault Tolerant Time Interval
HCI	Hot Carrier Injection

ILD	Inter-Layer Dielectric
LFM	Latent Fault Metric
ML	Machine Learning
MoL	Middle of Line (sometimes MOL)
MEoL	Middle End of Line (sometimes MEOL)
MPFDTI	Multiple Point Fault Detection Time Interval
NBTI	Negative Bias Temperature Instability
NVM	Non-Volatile Memory
PCM	Phase Change Memory
PHM	Prognostics and Health Management
RUL	Remaining Useful Life
SBD	Soft Breakdown
SHE	Self-Heating Effect
SILC	Stress-Induced Leakage Current
SM	Stress Migration
SoC	System on Chip
SPFM	Single Point Fault Metric
TDDB	Time Dependent Dielectric Breakdown
TDJD	Time Dependent Junction Degradation
TID	Total Ionizing Dose

~~6~~5 Literature survey of degrading faults

5.1 General

This ~~technical report~~document reviews many technical documents to summarize the current state of the art understanding of degrading faults in industry standards and technical publications.

NOTE ~~:~~ Terminology in the referenced publications and standards is not always aligned to ~~ISO 26262~~ terms and definitions of the ISO 26262 series. When referencing publications and standards, the terminology of the referenced work is used.

~~6.1~~5.2 Degrading faults in industry standards

~~6.1.1~~5.2.1 JEDEC JEP122H[~~1~~]

The JEDEC Solid State Technology Association is a semiconductor industry trade association and standardization body. JEDEC has over 300 companies as members and publishes electronics standards on a wide variety of topics.

~~The~~ JEDEC JEP122H ~~standard~~ is the latest revision on JEDEC's standard for "Failure Mechanisms and Models for Semiconductor Devices," last updated in 2016. The standard describes eighteen different failure mechanisms, classifying them as being related to the die ~~Front End~~front end of ~~Line~~line (FEoL), die ~~Back End~~back end of ~~Line~~line (BEoL), or packaging. Models are provided for estimating the rates of degradation per failure mode. The information provided in JEP122H is validated by a team of reliability experts from the SEMATECH/ISMI Reliability Council and supported by extensive references to technical publications.