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Automation - Functional Safety

Report about the evaluation of safety mat and safety edge sensor and their safety controller of Dongguan DADI Electronic Technology Co., Ltd

Report-No.: 968/FSP 1773.00/19
Date: 2019-06-03

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Date:	2019-06-03
Number of pages (excl. appendices):	35
Product / Project:	Safety mat sensor: DT series Safety edge sensor: DB series Safety controller: Ter-A series
Customer / Manufacturer:	Dongguan DADI Electronic Technology Co., Ltd Room 321 & 323, Building A1 No 10, Sanjiang Industrial Zone, Hengli Town, Dongguan City, Guangdong Province Dongguan 523460 P.R. China
Customer-Order-No. / Date:	8200706 dated 2017-07-11
Certification Body:	TÜV Rheinland Industrie Service GmbH Automation - Functional Safety (A-FS) Am Grauen Stein 51105 Köln Germany TÜV Rheinland (China) Ltd. Unit 707, AVIC Bldg.No.10B, Central Road East 3rd Ring Road, Chaoyang District Beijing 100022 P.R. China
TÜV-Quotation-No. / Date:	8200706 dated 2017-07-11
TÜV-Order-No. / Date:	1150020361 dated 2017-07-20
Assessor/Expert:	Yunxi Zhang (responsible for project) Xiaoyi Hu
Duration:	July 2017 - February 2019

The results are exclusively related to the product/project.

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1. Scope

Within the scope of this assessment the safety mat sensor (DT series), safety edge sensor (DB series) and their corresponding safety controller (Ter-A series) shall be approved against the requirements of ISO 13856-1 and ISO 13856-2 and SIL CL 2 according to IEC 62061, as well as Cat. 3 / PL d according to ISO 13849-1.

This test report contains the essential safety engineering aspects, that were assessed during the inspection and identifies the various test steps that were performed to provide evidence that the test object complies with the safety-relevant requirements of the product specification and the relevant standards.

2. Standards forming the basis for the requirements

[N1] **ISO 13856-1:2013**
Safety of machinery - Pressure-sensitive protective devices -
Part 1: General principles for design and testing of pressure-sensitive mats and pressure-sensitive floors

[N2] **ISO 13856-2:2013**
Safety of machinery - Pressure-sensitive protective devices -
Part 2: General principles for design and testing of pressure-sensitive edges and pressure-sensitive bars

[N3] **ISO 13849-1:2015**
Safety of machinery - Safety-related parts of control systems
Part 1: General principles for design

[N4] **IEC 62061:2015**
Safety of machinery - Functional safety of safety-related electrical, electronic and programmable electronic control systems

3. Identification of the product / project under assessment

3.1. Description of the product / project

The safety mat sensor and safety edge sensor are designed and developed by Qingdao DADI Tech Co., Ltd., while the safety controller is designed and developed by 3rd party company Shanghai Chenzhu Instrument Co., Ltd.

Safety mat sensor and safety edge sensor

Both DT series safety mat sensor and DB series safety edge sensor support two kinds of wiring mode i.e. 2-wire and 4-wire, as listed in Table 3-1.

- The DT series safety mat sensors are designed to detect persons weighing more than 35 kg and persons (e.g. children) weighing more than 20 kg, and it is not applicable to the detection of persons weighing less than 20 kg.
- DB series safety edge sensors are intended to be used to detect the parts of body typically where trapping or crushing hazards exist at machinery.

The safe state of both DT series safety mat sensor and DB series safety edge sensor is to set the output resistance to < 200ohm or > 2Kohm.

Safety controller

The Ter-A series safety controller includes two sub-series i.e. as listed in Table 3-1, which are intended to be used in combination with DT series safety mat sensors to detect the presence of persons, and in combination with DB series safety edge sensors to detect parts of body typically where trapping or crushing hazards exist at machinery.

The GBSR8302 series safety controller must be powered by an external SELV/PELV power supply with the output voltage in the range of 24V AC/DC (-15% ~ +10%), while the GBSR8303 series safety controller must be powered by an external AC power supply with the output voltage in the range of 100VAC ~ 260VAC. The external power supplies are ***not*** in the scope of this assessment.

Safety controller in combination of safety mat sensor or safety edge sensor

The Ter-A series safety controller in combination with DT series safety mat sensors can be used to detect the presence of persons, while in combination with DB series safety edge sensors can be used to detect parts of body typically where trapping or crushing hazards exist at machinery.

The output signals of safety mat sensor or safety edge sensor are connected to the inputs of the safety controller. In case the safety mat sensor (or safety edge sensor) is activated, this demanded condition is relayed via the safety contacts of the safety controller to the machine control circuitry to remove power of actuator in order to stop the hazard.

Product types and their revisions

The following types and their revisions (see [T3]) are covered by this assessment:

Product Types	HW Rev.	SW Rev.*	Remarks
DT series safety mat (for details refer to Figure 3-1)	1.0	-/-	-/-
DB series safety edge (for details refer to Figure 3-3)	1.0	-/-	-/-
Ter-A	3.2	-/-	Output contacts : 3N/O+1N/C
Note*: There is no software involved to perform the safety functions.			

Table 3-1: Product types and revisions covered by the assessment

D	T	A	B	C
Area A	Size	Length × Width, unit=cm		
Area B	1	With 1.2K resistor inside the sensor		
	2	Without 1.2K resistor inside the sensor		
Area C	default	Black layer		
	Y	Yellow layer		

Figure 3-1: Product types of DT series safety mat sensor

Standard Size Specification		
Safety mat codes	Outer size（without aluminum edge）	Area（m^2）
DT-30x30	30 cm X 30 cm	0.09
DT-40x40	40 cm X 40 cm	0.16
DT-50x25	50 cm X 25 cm	0.125
DT-50x40	50 cm X 40 cm	0.2
DT-50x50	50 cm X 50 cm	0.25
DT-60x40	60 cm X 40 cm	0.24
DT-75x25	75 cm X 25 cm	0.1875
DT-75x50	75 cm X 50 cm	0.375
DT-75x75	75 cm X 75 cm	0.5625
DT-100x25	100 cm X 25 cm	0.25
DT-100x50	100 cm X 50 cm	0.5
DT-100x75	100 cm X 75 cm	0.75
DT-100x100	100 cm X 100 cm	1
DT-150x50	150 cm X 50 cm	0.75
DT-150x75	150 cm X 75 cm	1.125
DT-150x100	150 cm X 100 cm	1.5

Figure 3-2: Standard size of DT series safety mat sensor (Area A)

D	T	A	B	C	D

Area A	First Number		Second and third number	
	Edge width	Code	Edge height	Code
	25mm	2	30mm	30
Area B	The sensor length (from 100 to 6000) unit=mm			
Area C	1	With 1.2K resistor inside the sensor		
	2	Without 1.2K resistor inside the sensor		
Area D	1	C-type profile		
	2	L-type profile		

Figure 3-3: Product types of DB series safety edge sensor

3.2. Documents provided by the customer

The complete project documentation for design, development, testing and quality management as listed in [D1] were provided by the manufacturer.

Among other documents as detailed in [D1] the following superior documents have been taken into account during the assessment:

No.	Documents	Rev.	Date
[D1]	Document List File: 05_DL_Ter-A_V1_6_20181128.doc 01_DL_DADI_PSM_V1.2_20190215.doc	 1.6 1.2	 2018-11-28 2019-02-15

No.	Documents	Rev.	Date
[D2]	Safety Plan File: 03_SP_Ter-A_V1_1_20180502.doc 03_SP_DADI_Safety_sensor_V1.5_20190119.doc	 1.1 1.5	 2018-05-02 2019-01-19
[D3]	Verification & Validation Plan File: 04_V&V-Plan_Ter-A_V1_0_20171129.doc 04_VVP_DADI_Safety_sensor_V1.2_20190119.doc	 1.0 1.2	 2017-11-29 2019-01-19
[D4]	Safety Requirements Specifications of DT series safety mat, DB series safety edge and GB SR8300 series safety controller File: 01_SRS(HW)_Ter-A_V1_2_20180930.doc 02_SRS_SC_DADI_safety_sensor_V1.5_20181217.docx	 1.2 1.5	 2018-09-30 2018-12-17
[D5]	Safety concept design of DT series safety mat, DB series safety edge and Ter-A series safety controller File: 02_SC_Ter-A_V1_4_20181030.docx 02_SRS_SC_DADI_safety_sensor_V1.5_20181217.docx	 1.4 1.5	 2018-10-30 2018-12-17
[D6]	Component level FMEA of GBSR8302-3A1B and GB SR8302-2A2B safety controller File: 13_Failure rate prediction_GBSR8302-3A1B-2A2B_V1_0_20171218.xlsx 14_Interim component FMEA_GBSR8302-3A1B-2A2B_V1_2_20181030.xlsx 15_Component FMEA_GBSR8302-3A1B-2A2B_V1_2_20181030.xlsx	 1.0 1.2 1.2	 2017-12-18 2018-10-30 2018-10-30
[D7]	Component level FMEA of GBSR8303-3A1B and GB SR8303-2A2B safety controller File: 23_Failure rate prediction_GBSR8303-3A1B-2A2B_V1_1_20180930.xlsx 24_Interim component FMEA_GBSR8303-3A1B-2A2B_V1_3_20181030.xlsx 25_Component FMEA_GBSR8303-3A1B-2A2B_V1_3_20181030.xlsx	 1.1 1.3 1.3	 2018-09-30 2018-10-30 2018-10-30
[D8]	Circuit schematics of Ter-A series safety controller File: 07_GBSR8302.0(YL)_V3_2_20180104.pdf 17_GBSR8303.0(YL)_V3_1_20180930.pdf	 3.2 3.1	 2018-01-04 2018-09-30
[D9]	PCB Gerber files of Ter-A series safety controller File: 10_CAM FOR GBSR8302_V3_2_20171204.PDF 20_CAM FOR GBSR8303_V3_1_20180930.PDF	 3.2 3.1	 2017-12-04 2018-09-30

No.	Documents	Rev.	Date
[D10]	Electrical safety design document of Ter-A series safety controller File: 38_Ter-A_Electrical safety design specification_V1_1_20180930.doc	1.1	2018-09-30
[D11]	FMEA of DT series safety mat and DB series safety edge (incl. mechanical components) File: 06-1_FMEA_GB PSM_safety_sensor_V2.0_20190129.xlsx 06-2_FMEA_GB -_safety_sensor_V2.0_20190129.xlsx	2.0 2.0	2019-01-29 2019-01-29
[D12]	Detail design drawings of DT series safety mat and DB series safety edge File: D012 Design drawings for transition.rar	-/-	-/-
[D13]	Enclosure protection degree IP test report of DT series safety mat, DB series safety edge and GB SR8300 series safety controller File: 27_ DMEN-T4P IP20 test Report_V1_0_20151130.pdf 22-1-6_DT IP65_QTC-822000900_from QTC.pdf 22-2-6_DB IP65_QTC-822000948_from QTC.pdf	1.0 -/- -/-	2015-11-30 -/- -/-
[D14]	Ter-A series safety controller integration test plan (incl. general function, environment, EMC, electrical safety, etc.) File: 12_TP_GBSR8302-8303_V1_4_20181106.docx	1.4	2018-11-06
[D15]	Ter-A series safety controller integration test report (incl. general function, environment, EMC, electrical safety, etc.) File: 26_ITR_GBSR8302-8303_V1_1_20181128.pdf	1.1	2018-11-28
[D16]	DT series safety mat and Ter-A series safety controller integration test plan (incl. general function, environment, EMC, electrical safety, etc.) File: 05-1_DT safety sensor test plan_V1.5_20190115.docx	1.5	2019-01-15

No.	Documents	Rev.	Date
[D17]	DT series safety mat and Ter-A series safety controller integration test report (incl. general function, environment, EMC, electrical safety, etc.) File: 22-1_DT safety sensor test result_V1.5_20190118.pdf **with attachments as following:** 22-1-1_DT _GB20180918001.pdf 22-1-2_DT _EMC_B1-201809003_from Chenzhu.pdf 22-1-3_DT _EMC_QTC-822002080_from QTC.PDF 22-1-4_DT -1_Vibration Shock_QTC-822002025_from QTC.zip 22-1-5_DT -2_Vibration Shock_QTC-822002026_from QTC.zip 22-1-6_DT IP65_QTC-822000900_from QTC.pdf 22-1-7_DT _Calculation_B10d_without failures.xlsx	1.5	2019-01-18
[D18]	DB series safety edge and Ter-A series safety controller integration test plan (incl. general function, environment, EMC, electrical safety, etc.) File: 05-2_DB safety sensor test plan_V1.5_20190115.docx	1.5	2019-01-15
[D19]	DB series safety edge and Ter-A series safety controller integration test report (incl. general function, environment, EMC, electrical safety, etc.) File: 22-2_DB safety sensor test result_V1.5_20190115.pdf **with attachments as following:** 22-2-1_DB TEMPERATURE_GB 20180918002.pdf 22-2-2_DB_EMC and Humidity_B1-20181108_from Chenzhu.pdf 22-2-3_DB_EMC_QTC-822002081_from QTC.PDF 22-2-4_DB-1_Vibration Shock_QTC-822002027_from QTC.zip 22-2-5_DB-2_Vibration Shock_QTC-822002028_from QTC.zip 22-2-6_DB IP65_QTC-822000948_from QTC.pdf 22-2-7_DB_Calculation_B10d_without failures.xlsx	1.5	2019-01-15

No.	Documents	Rev.	Date
[D20]	Requirements traceability of DT series safety mat, DB series safety edge and Ter-A series safety controller File: 39_Traceability_GB SR8300_V1_1_20180502.xlsx 09_Requirements_Traceability_DADI_safety_sensor_V1.1_2019-02-16.xls	1.1 1.1	2018-05-02 2019-02-16

Table 3-2: Documents provided by the manufacturer

Besides the above listed documents, the manufacturer has provided the following user manuals:

No.	Document	Rev.	Date
[U1]	Safety manual for Ter-A series safety controller File: 28_Safety manual-Ter-A-V1_2_20181115.doc	1.2	2018-11-15
[U2]	Safety manual for DT series safety mat (incl. also the instructions for the combinations of DT series safety mat and Ter-A series safety controller) File: 07_DT safety and operation manual_V1.1-20190129.docx	1.1	2019-01-29
[U3]	Safety manual for DB series safety edge (incl. also the instructions for the combinations of DB series safety edge and Ter-A series safety controller) File: 08_DB safety and operation manual_V1.1-20190206.doc	1.1	2019-02-06

Table 3-3: Documents provided by the manufacturer

3.3. Documents compiled by TÜV Rheinland

The following table shows the main documents, complied by the Certification Body:

No.	Documents compiled by the Certification Body
[T1]	List of Open Points (LOP) File: 2019-02-12_LOP-DADI_safety sensor and control.xlsx
[T2]	Fault-Insertion-Test report File: DADI_FIT_PSM and - with controller_V1.2_2018-11-06.doc
[T3]	Revision Release List File: 01_205_5709_00_19_RL_2019_02_18_PSM.pdf 01_205_5710_00_19_RL_2019_02_18_-.pdf

Table 3-4: Documents prepared by TÜV Rheinland

Most of the test activities were based on the review of documents, which were provided by the manufacturer. In addition, practical tests have been performed by the Certification Body together with the design engineers during the fault insertion tests (see [T2] for details). The IDs of the used test samples are documented and can be found in the inspectors fault insertion test documents.

4. Objectives and results of the assessment

4.1. Evaluation procedure

The following points have been assessed in accordance with [N1] - [N4]:

- Management of functional safety on project level / product level
- Documentation over the entire safety lifecycle
- Measures for fault avoidance (QM) over the entire safety lifecycle
- Safety structure
- Measure for detection and control faults in HW
- Safety related parameters PFD_{AVG}/PFH, SFF and B10d
- Fault insertion tests and functional test
- Electrical safety
- Environmental (ENV) tests
- Electromagnetic compatibility (EMC) tests
- Enclosure protection degree
- Inspection and review of the documentation for user
- Assessment against the requirements of product standards

The following subchapters provide assessment results regarding the above listed topics.

4.2. Results of the assessment of the individual objects

4.2.1. Assessment of management of functional safety

The assessment of Functional Safety Management of the DT series safety mat sensor, DB safety edge sensor and Ter-A series safety controller project is mainly based on the review of documents Safety Plan and Verification & Validation Plan (see [D2] and [D3]) provided by manufacturer. Open items have been discussed and clarified together with the manufacturer (see [T1]).

Result:

The Safety Plan and Verification & Validation Plan fulfill the requirements of the [N3] and [N4].

4.2.2. Assessment of documentation over the entire safety lifecycle

The Documentation Plan, Safety Plan and Verification & Validation Plan (see [D1] - [D3]) include the planned documentation over the entire safety life cycle. Open items have been discussed and clarified together with the manufacturer (see [T1]).

Result:

The assessment of the documentation of the DT series safety mat sensor, DB safety edge sensor and Ter-A series safety controller project confirmed that the respective requirements of [N3] and [N4] are fulfilled.

4.2.3. Assessment of measures for fault avoidance (QM) over the entire safety lifecycle

The measures for fault avoidance of the DT series safety mat sensor, DB safety edge sensor and Ter-A series safety controller were part of the functional safety management assessment (see chapter 4.2.1 and 4.2.2). Open items have been discussed and clarified together with the manufacturer (see [T1]).

Result:

The assessment has shown that the respective requirements of [N3] and [N4] are fulfilled.

4.2.4. Description and result of the inspection of the safety structure

4.2.4.1. Safety mat sensor

DT series safety mat sensor is designed acc. to [N1] and the working principle is shown in Figure 4-1, entering the pressure sensitive area initiates shut down of dangerous motion via Ter-A series safety controller.

All product types of DT series safety mat sensor have the same safety architecture (see [D5]), as shown in Figure 4-2 and Figure 4-3 they consist of 1.2Kohm resistor (except 4-wire safety mat sensor), sensor element strips, multiple copper strands, filler strips and edge strips. The main differences among types of DT series safety mat are the size and whether the 1.2Kohm terminal resistor is included or not (see also chapter 3.1):

- For 2-wire type, it includes the 1.2Kohm terminal resistor and can therefore be combined individually with Ter-A series safety controller for a specific safety application.
- For 4-wire type, it does not include the 1.2Kohm terminal resistor and can therefore be used only as the bridging sensor as shown in Figure 4-1.

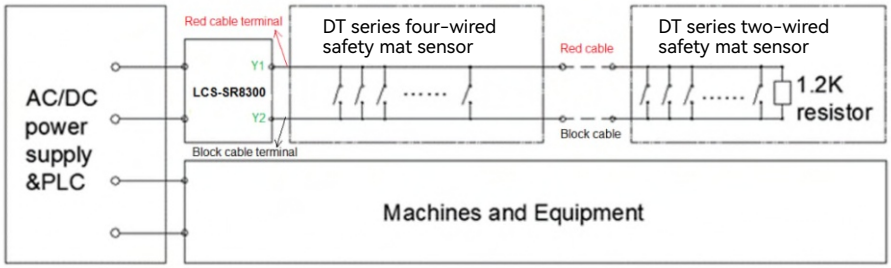

Figure 4-1: Working principle schematic diagram of 2-wire type and 4-wire type safety mat sensors

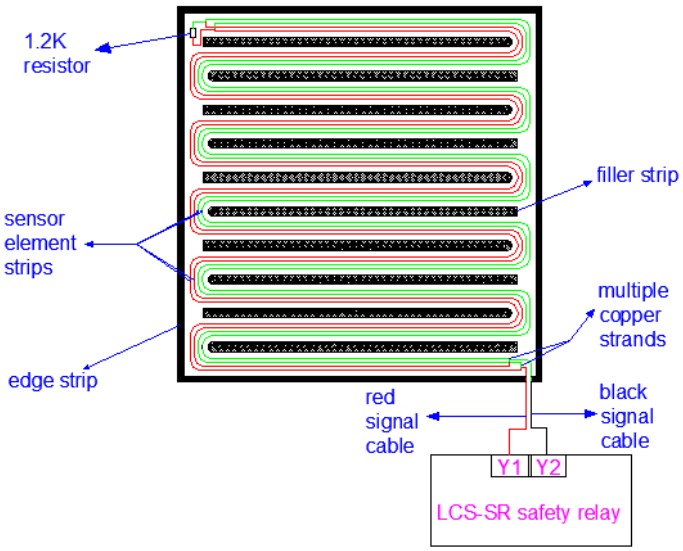

Figure 4-2: Wiring Schematic Diagram of 2-wire safety mat sensor

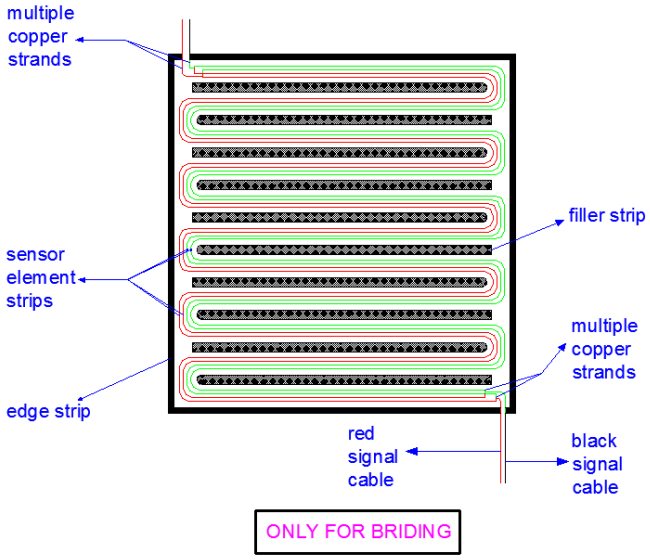

Figure 4-3: Wiring Schematic Diagram of 4-wire safety mat sensor

As Figure 4-4 shows the sensor element strips consists of multiple copper strands, conductive elastomers, rubber elastic materials. Furthermore as Figure 4-5 shows the multiple copper strands consists of copper strands and anti-broken wire. And as Figure 4-4 shows multiple copper strands are surrounded by the conductive elastomers, to ensure the adequate flexible conductive contact area for providing the highly sensitive electrical signals. The output signal of DT series safety mat sensor is an analog resistance signal as following:

- When no person stand on it, the output resistance crossing the Red cable terminal and Black cable terminal is 1.2Kohm±10%,
- When a person weighing more than 20 kg stand on the safety mat, the pressure will push the upper conductive elastomers (red part as shown in Figure 4-4) are in contact with the lower conductive elastomers (green part as shown in Figure 4-4). This will lead to a resistance of < 200ohm crossing the Red cable terminal and Black cable terminal.
- In case short circuit happens the output resistance will be < 200ohm, and In case open circuit happens the output resistance will be > 2Kohm.

Therefore the safety architecture Category 1 is achieved for the safety mat sensor alone (without safety controller).

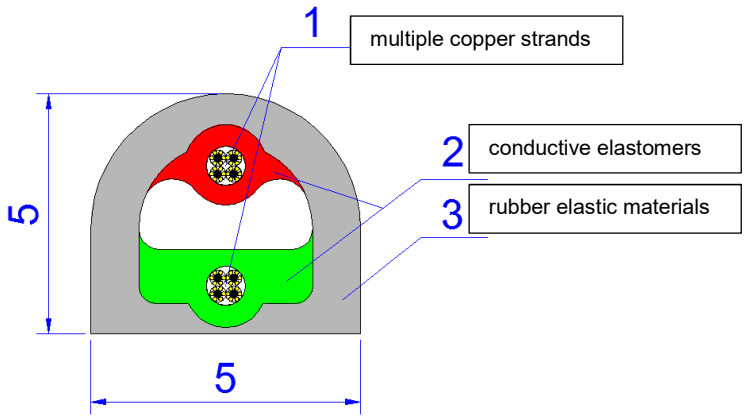

Figure 4-4: Sketch of sensor element strips

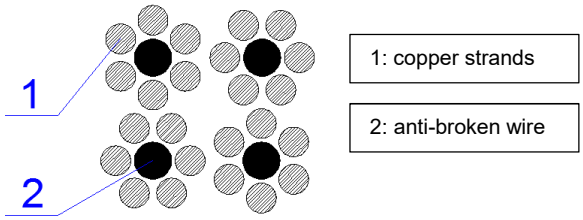

Figure 4-5: Structure of multiple copper strands

Result:

The safety structure of the DT series safety mat sensor fulfils the requirements for Cat. 1 acc. to [N3] and safety structure 1oo1 acc. to [N4].

To achieve the requirements for Cat. 3 / PL d acc. to [N3] and SIL 2 acc. to [N4], DT series safety mat sensor must be used always in combination with Ter-A series safety controller, for details see chapters 4.2.4.4 and 4.2.5. And a corresponding alarm has been added to the safety manual [U2].

4.2.4.2. Safety edge sensor

The DB series safety edge sensor is designed acc. to [N2] and only mounting orientation B acc. to [N2] is supported, and the working principle is shown in Figure 4-6, detecting of parts of the body typically where trapping or crushing hazards exist at machinery.

All product types of DB series safety edge sensor have the same safety architecture (see document [D5]), and as Figure 4-7 shows it consists of sensor element strips, outer layer, mounting base and multiple copper strands. The main differences among types of DB series safety edge are the length and whether the 1.2Kohm terminal resistor is included or not (see chapter 3.1).

- For 2-wire type, it includes the 1.2Kohm terminal resistor and can therefore be combined individually with Ter-A series safety controller for a specific safety application.
- For 4-wire type, it does not include the 1.2Kohm terminal resistor and can therefore be used only as the bridging sensor as shown in Figure 4-6.

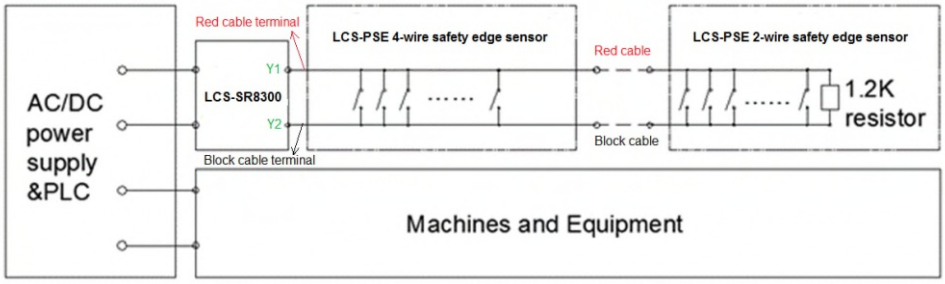

Figure 4-6: Working principle schematic diagram of 2-wire type and 4-wire type safety edge sensors

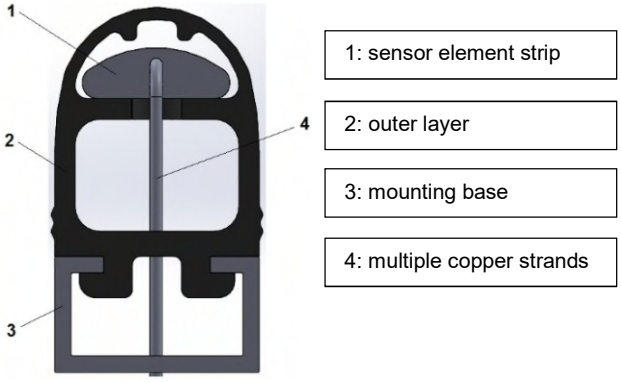

Figure 4-7:Cross-section diagram of the DB safety edge sensor

The output signal of DB series safety edge sensor is an analog resistance signal as following:

- Under without demand condition, the output resistance is 1.2Kohm±10%,
- Under on demand condition or fault status, the output resistance crossing the Red cable terminal and Black cable terminal is less than 200ohm or greater than 2Kohm.
- In case short circuit happens the output resistance will be < 200ohm, and In case open circuit happens the output resistance will be > 2Kohm.

Therefore the safety architecture Category 1 is achieved for the safety edge sensor alone (without safety controller).

Result:

The safety structure of the DB series safety edge sensor fulfils the requirements for Cat. 1 acc. to [N3] and 1oo1 acc. to [N4].

To achieve the requirements for Cat. 3 / PL d acc. to [N3] and SIL 2 acc. to [N4], DB series safety edge sensor must be used always in combination with Ter-A series safety controller, for details see chapters 4.2.4.4 and 4.2.5. And a corresponding alarm has been added to the safety manual [U3].

4.2.4.3. Safety controller

All product types of Ter-A series safety controller have the same safety architecture (see [D5]) i.e. 1oo1 and 1oo2 mixed safety structure, as Figure 4-8 shows it consists of power supply module and input module for both channel 1 and channel 2, and also transform module, prepare module, start-up module, self-locking module and output module (output contacts) of each channel. In addition, the main differences among product types of GB SR8300 series safety controller are the power supply module and the number of NO / NC contacts (see chapter 3.1).

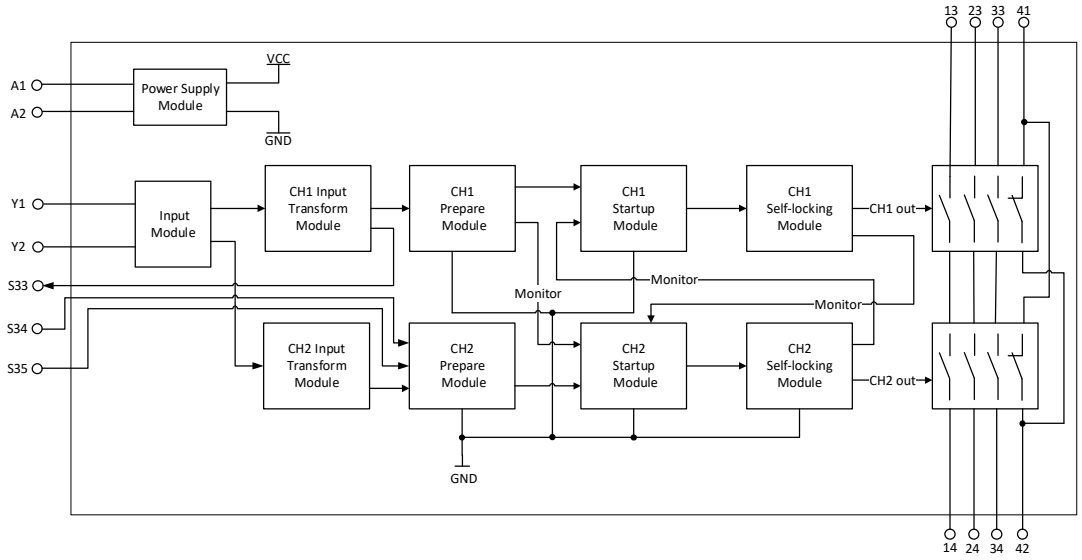

Figure 4-8: Functional Block Diagram of e.g. GBSR8302-3A1B

If the resistance at the input ports Y1/Y2 of the safety controller is less than 400ohm or greater than 1.8Kohm, the internal safety relays of channel 1 and channel 2 are de-energized, the normally opened safety relay contacts (GBSR8302-3A1B / GBSR8303-3A1B: 13/14, 23/24, 33/34. GBSR8302-2A2B / GBSR8302-2A2B: 13/14, 23/24) will be opened and the normally closed contact (GBSR8302-3A1B / GBSR8303-3A1B: 41/42. GBSR8302-2A2B / GBSR8302-2A2B: 31/32, 41/42) will be closed. The stop condition is relayed via the safety contacts of the safety controller to the machine control circuitry to remove the electrical power and stop the hazardous movement, which corresponds to the safe state.

When removing the stop condition, the normally closed safety contacts of safety controller are closed again and the safety controller is ready to be restarted. User can use two kinds of start modes through different connection methods (see [U1]) i.e. manual start mode and automatic mode:

- For manual start mode, a push-button needs to be pushed and released, to energize the internal safety relays of channel 1 and channel 2. The normally opened safety contacts will be closed and the normally closed contact will be opened, allowing the machine to operate.

- For automatic start mode, the internal safety relays of channel 1 and channel 2 will be energized automatically after the resistance at the input ports Y1/Y2 of the safety controller is greater than 400ohm and less than 1.8Kohm.

The described hardware structure corresponds to a dual redundant channel structure. The relays of channel 1 and channel 2 are de-energized immediately, if one or both of the independent input channels are opened. This corresponds to stop category 0 according to IEC 60204-1. At the outputs, the normally opened contacts are connected in series and the normally closed contacts in parallel to achieve redundancy. The monitoring logic is able to detect different faults within the system and the dual channel structure of the hardware ensures multiple-fault tolerance due to the following design features (see chapter 4.2.5 for details):

- 1oo1 parts: even two faults exist at the same time, it will not lead to the loss of the safety function (see [T2], chapters 2.3.1 and 2.4.1 for details).

- 1oo2 parts: each channel has implemented appropriate diagnostic measures with a DC of up to 99%, therefore no fault accumulation will happen.

The applied relays within the Ter-A series safety controller are certified safety relays with forcibly guided contacts of the manufacturer Tyco (Model type: SR6) based on standards EN 60947-5-1:2005, EN 61810-1:2008 and EN 50205:2003. The application of these relays ensures the detection of faults at the output contacts with a high DC (see chapter 4.2.5)

Result:

The safety structure of Ter-A series safety controller alone fulfils the requirements for Cat. 4 / PL e acc. to [N3] and SIL CL 3 acc. to [N4].

4.2.4.4. Safety controller in combination of safety mat sensor or safety edge sensor

The Ter-A series safety controller in combination of DT series safety mat sensor can be used to detect the presence of persons, while in combination with DB series safety edge sensor can be used to detect parts of the body typically where trapping or crushing hazards exist at machinery.

As Figure 4-9 shows the output signals (Red cable terminal and Black cable terminal) of safety mat sensor or safety edge sensor are connected to input ports Y1/Y2 of safety controller, then the safety controller can monitor the output resistance of a safety mat sensor or a safety edge sensor.

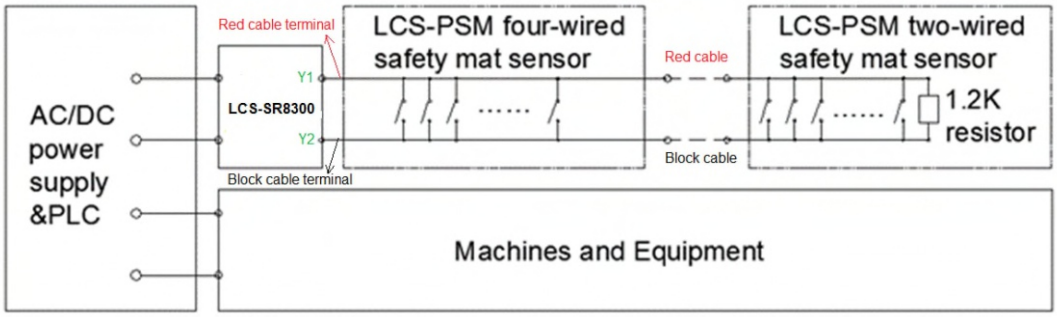

Figure 4-9: Wiring for combination of safety mat sensor (or safety edge sensor) and safety controller

In case of on demand or fault happens, the output resistance DT series safety mat sensor and DB series safety edge sensor will be < 200ohm or > 2Kohm, therefore the resistance at the input ports Y1/Y2 of Ter-A series safety controller is < 400ohm or > 1.8Kohm, and then the output contact of the Ter-A series safety controller is opened, de-energized state.

Due to the many safety measures e.g. dual channel redundant, Idle-current principle and Fail-safe technology are adopted within the combination of safety controller and safety mat sensor or safety edge sensor, single-fault tolerance in case of undetected failures is ensured (see chapter 4.2.5).

Result:

The safety structure of the combination of Ter-A series safety controller and GB PSM series safety mat sensor or DB series safety edge sensor fulfils the requirements for Cat. 3 / PL d acc. to [N3] and SIL CL 2 acc. to [N4].

4.2.5. Assessment of the measures for detection and control of faults in HW

The customer has performed a component level Failure Mode and Effects Analyses (FMEA, see documents [D6] - [D7] and [D11] for details) on each functional block of DT series safety mat sensor, DB series safety edge sensor and Ter-A series safety controller, against failures which have to be assumed acc. to table A.1 of IEC61508:2010 part 2 and also the specified mitigations were weighted in terms of their effectiveness, in order to show that the SIL 2 and PL d / Cat. 3 are complied with.

As far as possible, the design uses the most appropriate diagnostic measures of tables A.2 to A.17 of IEC61508:2010 part 2 as mitigations. Additionally, various other measures depending on the technical realization were implemented to achieve the high diagnostic coverage (DC=99%) on each functional block.

Fault control measures of safety controller

For Ter-A series safety controller, the electronic circuit of the start logic is implemented by both the prepare module and the start-up module within channel 2.

For the manual start / restart, the required electric energy for the start logic is transferred to the circuitry by pressing and releasing the external start button, and the start signal is transmitted via optocouplers to stop logic of channel 1 and channel 2, and energizes the coil of the relays to allow the restart of machinery. If a failure occurs in one of the stop logic circuits and one of the relays will not be de-energized (dangerous failure), a restart of the machine is prevented by using an NC contact of the concerning relay within the start logic. The design of pressing and releasing the external start button (falling edge) to trigger the restart logic can prevent an automatic restart in case that a short circuit occurs at the start button or if it is blocked.

For the automatic start / restart, the internal safety relays of channel 1 and channel 2 will be energized automatically after removing the demanded condition. According to IEC 60204-1:2016 automatic restart is not allowed after a stop. For this reason the machine control must prevent an automatic start after stop (or risk analysis must show that automatic restart is allowed for the specific application). And a corresponding warning was added to the safety manual [U1].

The welding fault of relay output contacts can only be detected during the start or restart of the safety controller. Therefore an appropriate test interval of every month has been required in the safety manual [U1]. All other faults within safety controller can be detected immediately.

Fault control measures of safety mat sensor and safety edge sensor

The DT series safety mat sensor and DB series safety edge sensor are powered or excited by the Ter-A series safety controller. The output signals of safety mat sensor and safety edge sensor are monitored by safety controller, this allows further possible diagnostics for those safety sensors, but all the diagnostics on safety sensors are implemented by the safety controller.

The customer has performed a Failure Mode and Effects Analyses (FMEA, see document [D11] for details) on each component of those safety sensors, to show that fault of the actuation mechanism, fault of the wiring inside the safety mat and between the safety mat and the safety controller and the wiring to further safety mats connected in series, fault of terminal resistor can either be detected immediately by the safety controller or be fault excluded, with the help of implemented safety measures e.g. Idle-current principle, Fail-safe technology, etc.. But the aging fault of conductive elastomers of safety mat and safety edge cannot be detected online, therefore a corresponding alarm and required offline tests performed by end user with an appropriate test interval of every month have been added in the safety manuals [U2] - [U3]. With the help of all those above in combination, DT series safety mat sensor and DB series safety edge sensors can achieve a DC of up to 99%.

Result:

The effectiveness and suitability of the implemented measures is given for the required hardware fault tolerance, safe failure fraction (SFF) and diagnostic coverage (DC) for a device conforming to Cat. 3 / PL d acc. to [N3] and SIL CL 2 acc. to [N4].

4.2.6. Safety related parameters PFDav/PFH, SFF and B10d

Ter-A series safety controller

The calculations of the safety relevant parameters of Ter-A series safety controller were based on the resulting FMEA on component level (see [D6] - [D7]) by the customer, under considerations of the following assumptions:

- Source of the reliability data of the components: SIEMENS SN 29500.
- The failure rate data from SIEMENS SN 29500 was adapted to a maximum average temperature of 60°C also plus the temperature rise due to component power dissipation.
- It is assumed that the failure rate of the components remains constant over the period of use and the early phase of higher failure rates has been passed when system goes into operation.
- The failure mode of the components is from ISO 13949-2. And equally distributed failure mode is used.
- Each detected failure results in a shut-down of the system. Therefore the MTTR (Main Time to Restoration) value is set to 0h.
- All external elements such as buttons, contacts, switches, valves, motors, etc. as well as external cabling were not considered within the failure rate calculation.
- Diagnostic elements and electronic devices used in non-safety related functions were not included in failure rate calculations.
- For this system the Common Cause Failure (CCF) factors β=βD=5% were used acc. to [N3] and [N4].

Reliability Block Diagram (RBD) of Ter-A series safety controller provided by customer (see [D5] - [D7]) is as following:

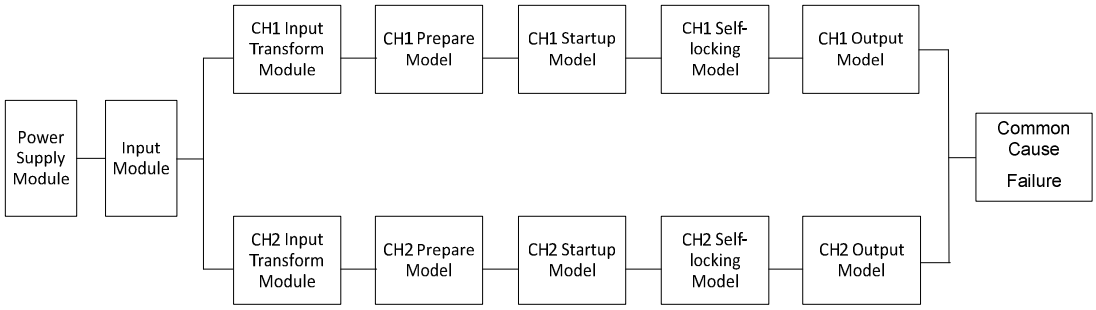

Figure 4-10: Reliability Block Diagram (RBD) of Ter-A series safety controller

The following safety related parameters (see [D6] - [D7]) were calculated by the customer and has been reviewed by the Certification Body (see [T1]):

Safety architecture		1oo1 and 1oo2 mixed
Hardware Fault Tolerance (HFT)	1oo1 part	0
	1oo2 part	1
Hardware Safety Integrity Level (SIL)		SIL 3
Systematic Capability (SC)		SC 3
Performance Level (PL)		PL e
Category		4

Device type	Type A
Safe Failure Fraction (SFF) of each element	> 99%
Mean Time To Repair (MTTR)	0 h
Mean Repair Time (MRT)	0 h
DC_{avg}	> 99% (High)
Common Cause Failure (CCF) total scores acc. to [N3]	> 65
PFH	3.06E-10 (0.31% of SIL 3, at PTI=20 years)
PFDavg	2.66E-05 (2.66% of SIL 3, at PTI=20 years)
MTTFd	188 years (> 30 year, High)

Table 4-1: Safety related parameters of Ter-A series safety controller

DT series safety mat sensor

The calculations of the safety relevant parameters of DT series safety mat sensor were based on the results of endurance tests (see [D17] for details) carried out by the customer according to [N1].

The following safety related parameters (see [D17]) were calculated by the customer and has been reviewed by the Certification Body (see [T1]):

Actuating force	< 300N (Test piece (cylinder) Ø 80 mm)
Response Time	38ms (with Ter-A series safety controller)
Dead Zone (or Inactive Edge)	10mm (side of non-cable exit) 20mm (side of cable exit)
Static load (up to 8 h)	Max. 800 N/cm^2
Number of operations	4,000,000
B10d	30,495,773
Device type	Type A
Hardware Safety Integrity Level (SIL)	SIL 2 (in combination with Ter-A series safety controller)
Systematic Capability (SC)	SC 2 (in combination with Ter-A series safety controller)
Performance Level (PL)	PL d (in combination with Ter-A series safety controller)
Category	3 (in combination with Ter-A series safety controller)
Safe Failure Fraction (SFF) of each element	> 99% (in combination with Ter-A series safety controller)
DC_{avg}	> 99% (High, in combination with GB SR8300 series safety controller)

Table 4-2: Safety related parameters of DT series safety mat sensor

DB series safety edge sensor

The calculations of the safety relevant parameters of DB series safety edge sensor were based on the results of endurance tests (see [D19] for details) carried out by the customer according to [N2].

The following safety related parameters (see [D19]) were calculated by the customer and has been reviewed by the Certification Body (see [T1]):

Mounting orientations	Orientation B (acc. to [N2])
Actuating force	Max. 50N (acc. to [N2], test piece 1, location c3). Max. 80N (acc. to [N2], test piece 2, location c3)
Max. operating speed	250mm/s
Pre-travel at max. operating speed	2.2mm
Overtravel	2.1mm (4.3mm - 2.2mm, at 10.2N) 3.3mm (5.5mm - 2.2mm, at 15.2N)
Working travel	8.9mm (at 50.2N)
Dead surface	15mm
Sensing angle (α)	90°
Detection of fingers	Yes
Number of operations	1,000,000
B10d	4,524,861
Device type	Type A
Hardware Safety Integrity Level (SIL)	SIL 2 (in combination with Ter-A series safety controller)
Systematic Capability (SC)	SC 2 (in combination with Ter-A series safety controller)
Performance Level (PL)	PL d (in combination with Ter-A series safety controller)
Category	3 (in combination with Ter-A series safety controller)
Safe Failure Fraction (SFF) of each element	> 99% (in combination with Ter-A series safety controller)
DC_{avg}	> 99% (High, in combination with Ter-A series safety controller)

Table 4-3: Safety related parameters of DB series safety edge sensor

Result:

The calculation results and method are in accordance with [N1] - [N4] and fulfils the requirements for SIL CL 2 and PL d.

4.2.7. Fault insertion tests and functional test

During the verification activities of the DT series safety mat sensor, DB series safety edge sensor and Ter-A series safety controller, the requirement specifications were not only checked in functional tests (positive tests) but also in negative tests (fault insertion tests).

The functional tests on those safety mat sensors, safety edge sensors and safety controllers were carried out by the manufacturer, and the corresponding test results were documented in [D14] - [D19], which have been reviewed by the Certification Body (see [T1]). The customer has performed the endurance test on DT series safety mat sensor and DB series safety edge sensor according to [N1] and [N2] respectively, and the corresponding test results are documented in [D16] and [D19], which have been reviewed by the Certification Body (see [T1]).

Particularly the implemented diagnostic measures have been verified through fault insertion tests. Some of these tests were carried out in co-operation with the Certification Body in the manufacturer's laboratories during the main approval (see [T2]).

Result:

The functional test results have been passed successfully and are accepted by the Certification Body. The fault insertion tests confirmed the effectiveness of the realized measures to detect and to control faults and shown the correctness of the theoretical analysis of the design. The respective requirements of [N3] - [N4] are fulfilled.

4.2.8. Electrical safety

For GBSR8302 series safety controller, the 24VAC/DC power point shall be energized with a SELV/PELV power supply acc. to the safety manual [U1]. The design of electrical safety was documented in [D9] - [D10]. The clearances and creepage distance between the 24V-circuit and relay output contacts (which are able to switch loads up to 230VAC / 5A) fulfil the requirements for reinforced insulation or double insulation, while the clearances and creepage distance among the relay outputs contacts fulfil the requirements for basic insulation according to [N1], [N2] and IEC 60664-1:2007 under the assumptions of pollution degree 2 and overvoltage category **III**. Pollution degree 2 can only be assumed if the device will be mounted within a cabinet which fulfils the requirements of an IP54 enclosure.

For GBSR8303 series safety controller, the power point shall be energized by an external 220VAC power supply. The design of electrical safety was documented in [D9] - [D10]. The clearances and creepage distance between various power domains (i.e. 24V-circuits, relay outputs contacts and 220VAC-circuits) of the GB8303 series safety controller fulfil the requirements for reinforced insulation or double insulation according to [N1], [N2] and IEC 60664-1:2007 under the assumptions of pollution degree 2 and overvoltage category **II**. Pollution degree 2 can only be assumed if the device will be mounted within a cabinet which fulfils the requirements of an IP54 enclosure.

For both GBSR8302 series and GBSR8303 series safety controller, due to the fact that only basic insulation is fulfilled among the product output contacts, the outputs of the product **MUST NOT** be used in such a way that some output contacts switch 24 V SELV/PELV circuit while others switch 230 VAC circuit, but shall be used in such a way that either all output contacts will switch 24 V SELV/PELV circuit or all output contacts will switch 230 VAC circuit. And a corresponding warning was added to the safety manual [U1].

DT series safety mat can only be powered by SELV / PELV power supply from GB SR8300 series safety controller as required in the safety manual [U2]. Furthermore GB PSM series safety mat consists of only passive components, and the insulation resistance test has been carried out successfully after humidity test acc. to [N1] (see [D17] for details).

DB series safety edge can only be powered by SELV / PELV power supply from GB SR8300 series safety controller as required in the safety manual [U3]. Furthermore the GB - series safety edge consists of only passive components, and the high voltage test has been carried out successfully after humidity test acc. to [N2] (see [D19] for details).

Result:

Respective electrical safety requirements of [N1] - [N2] are fulfilled.

4.2.9. Environmental (ENV) tests

The environmental tests were carried out based on the requirements defined in standards [N1], [N2], IEC 60068-2-1:2007, IEC 60068-2-2:2007, IEC 60068-2-6:2007 and IEC 61298-3:2008. These tests have been performed in manufacturer's own test laboratory, Laboratory of Shanghai Chenzhu Instrument Co., Ltd. and the accredited test laboratory Qingdao Product Quality Supervision and Testing Research Center (QTC). The corresponding test plan and test results were documented in [D14] - [D19], which have been reviewed by the Certification Body (see [T1]).

Result:

All tests have been passed and are accepted by the Certification Body based on the accredited test laboratory Qingdao Product Quality Supervision and Testing Research Center (QTC), and the lab assessment at the manufacturer and Shanghai Chenzhu Instrument Co., Ltd.

4.2.10. Electromagnetic capability (EMC) tests

The EMC tests were carried out based on the requirements defined in standards [N1], [N2], IEC 61326-1:2012 and IEC 61298-3:2008 for normal levels and IEC 61326-3-1:2017 for increased immunity levels. All tests have been performed in Laboratory of Shanghai Chenzhu Instrument Co., Ltd., the accredited test laboratory Shanghai Inspection and Testing Institute of Instruments and Automatic Systems (SITIIAS) and the accredited test laboratory Qingdao Product Quality Supervision and Testing Research Center (QTC). The corresponding test plan and test results were documented in [D14] - [D19], which has been reviewed by the Certification Body (see [T1]).

Result:

All tests have been passed and are accepted by the Certification Body based on the accreditation of the test labs Shanghai Inspection and Testing Institute of Instruments and Automatic Systems (SITIIAS) and Qingdao Product Quality Supervision and Testing Research Center (QTC), and a lab assessment at Shanghai Chenzhu Instrument Co., Ltd.

4.2.11. Enclosure protection degree

Ter-A series safety controller has to be mounted in a cabinet with a protection degree of IP54 as required in the safety manual [U1], to fulfil the electrical safety related requirements. DT series safety mat and DB series safety edge have been subjected to the IP65 protection degree test acc. to IEC 60529:2013 by the accredited test laboratory Qingdao Product Quality Supervision and Testing Research Center (QTC), the corresponding test results are documented in [D13].

Furthermore the safety manuals (see [U1] - [U3]) give detailed information in order to ensure proper mounting and therefore maintaining the protection degree.

Result:

All tests have been passed and are accepted by the Certification Body.

4.2.12. Inspection and review of the documentation for the user

The safety manuals [U1] - [U3] for DT series safety mat sensor, DB series safety edge sensor and Ter-A series safety controller were provided by the manufacturer and have been reviewed by the Certification Body acc. to the applicable requirements of clause 6 of [N1] and [N2], and clause 11 of [N3]. Open items have been discussed and clarified together with the manufacturer (see [T1]).

Result:

The safety manuals cover all relevant aspects for a safe use of the product and are accepted by the Certification Body. All relevant information for identification and safe use is in its appropriate place.

4.2.13. Assessment against the requirements of product standards

4.2.13.1. Requirements according to ISO 13856-1

This standard relates to the pressure sensitive mats and pressure-sensitive floors for functional safety.

In the following table, the relevant requirements are defined. These requirements are applied to the combination of Ter-A series safety controller and DT series safety mat and it is described, if they are applicable and how they are fulfilled:

Clause	Requirements	Result
4.2	Requirements for the safety mat shall respond to the actuating force in accordance with Table 1. - Single sensor	For the combination of Ter-A series safety controller and GB PSM series safety mat, itself these was done during design and verified during integration testing [D17].
	- Combinations of sensors	The combinations of sensors cannot be used. This information has been indicated as a CAUTION in safety manual [U2].
	- Designed to detect persons (e.g. children) weighing more than 20 kg	For the combination of Ter-A series safety controller and GB PSM series safety mat, itself these was done during design and the test piece 4 has been verified during integration testing [D17].
4.3	The response time shall be stated by the manufacturer and shall not exceed 200 ms over the operating temperature range.	For the combination of Ter-A series safety controller and GB PSM series safety mat, the defined response time is no more than 38ms and this requirement was verified during integration testing [D17].
4.4	Requirements for static loading: - After the application of a static force of (2 000 ± 50) N within the effective sensing area through test piece 2 (see Figure 2), for a period of 8 h, the output signal switching device shall change its state within 2 min after the removal of the force. For pressure-sensitive mats, after 1 h the deformation shall not be more than 2 mm in depth at the lowest part of the top surface; for pressure-sensitive floors, there shall not be any permanent deformation.	For the combination of Ter-A series safety controller and GB PSM series safety mat, the requirements of static loading is 800N/cm^2 and this requirements according to chapter 4.4.1 of ISO 13856-1 was verified during integration testing [D17].

Clause	Requirements	Result
	- After the application of a static force of (750 ± 20) N within the effective sensing area through test piece 1 (see Figure 2) at another location to that used in 4.4.1 for a period of 8 h, the output signal switching device shall change its state within 2 min after the removal of the force. For pressure- sensitive mats, after 1 h the deformation shall not be more than 2 mm in depth at the lowest part of the top surface; for pressure-sensitive floors, there shall not be any permanent deformation.	For the combination of Ter-A series safety controller and GB PSM series safety mat, the requirements of static loading is 800N/cm^2 and this requirements according to chapter 4.4.2 of ISO 13856-1 was verified during integration testing [D17].
4.5	Requirements for number of operations - The expected number of operations for the pressure-sensitive mat or pressure-sensitive floor shall be not less than 100 000 operations in each of five locations (500 000 operations in total). If the effective sensing area consists of a combination of sensors, this requirement shall apply to the combination of sensors.	For the combination of Ter-A series safety controller and GB PSM series safety mat, itself these was done during design and verified during integration testing [D17]. More than 300 000 operations in each of five locations have been carried out; the total operations are more than 1500 000.
	- In addition, the expected number of operations for the sensor alone is a further one million operations in one other location.	For the combination of Ter-A series safety controller and GB PSM series safety mat, itself these was done during design and verified during integration testing [D17]. More than 10 000 000 operations in location 8 have been carried out.
	- When the requirements of 4.4 and 4.5.1 have been met, the pressure-sensitive mat or pressure sensitive floor shall still meet the requirements of 4.2 and 4.3.	In integration testing report [D17], the test no.1 (requirements of 4.2) and test no.2 (requirements of 4.3) have been carried out after test no.3 (requirements of 4.4) and test no.4 (requirements of 4.5)
4.6, 4.7	Requirements for output state of sensor and Response of output signal switching device(s) to actuating force	The output state of sensor has been verified during integration test [D17] and complies with the requirements of standard. Refer to test no.5 and test no. 6.
4.8	Access for maintenance	The safety mat has no reserved access channel for maintenance.
4.9	Adjustments	The safety mat do not need adjustment by the end user. However, the function test shall be carried out before any usage as required in the safety manual [U2].

Clause	Requirements	Result
4.10	Requirements for connections - The correct alignment of plug/sockets shall be made clear by either type, shape, marking or designation (or a combination of these).	The connections of Ter-A series safety controller and GB PSM series safety mat are in different colours (Red and Black), the method of connections was defined in safety manual [U2]. The terminals of Ter-A was defined in safety manual [U1] and marked in labels.
	- If a sensor or subsystem is connected by a plug and socket, removal or disconnection of the sensor or subsystem at the plug and socket from or within the control unit shall cause the output signal switching device(s) to go to an OFF state.	For the combination of Ter-A series safety controller and GB PSM series safety mat, itself comply with the idle-current principle, this character has been verified during integration test [D17] and FIT [T2].
4.11	Requirement for Environmental conditions - Temperature - Humidity - Electromagnetic compatibility - Vibration	For the combination of Ter-A series safety controller and GB PSM series safety mat, these performances haven been verified during integration test [D17] and met the requirements according this standard. Further see chapter 4.2.9 of this assessment report.
4.12	Requirement for Power supply - The pressure-sensitive mat or pressure-sensitive floor shall meet the requirements of IEC 60204-1:2005, 4.3.	This test has been carried out during integration test of Ter-A series safety controller [D15] and met the requirements of IEC 60204-1:2016, 4.3.
4.13	Requirement for Electrical equipment - Protection against electric shock - Protection against over-current - Pollution degree - Clearances and creepage distances - Wiring	The requirements of this clause have been validation during integration test [D17], for detail refer to test no.12.

Clause	Requirements	Result
4.14	Requirement for Enclosure - The sensor enclosure shall meet a minimum standard of IP54 in accordance with IEC 60529. - The control unit enclosure shall meet a minimum standard of IP54 in accordance with IEC 60529. Where the control unit is designed for mounting in another control equipment enclosure and this enclosure is to a minimum of IP54 in accordance with IEC 60529, the control unit shall be to a minimum of IP2X in accordance with IEC 60529. The enclosure containing the output signal switching device(s) shall also meet these requirements.	The requirements of this clause has been verified during type test [D13]. The DT series safety mat can reach IP65. In addition, the Ter-A series safety controller should be located in a control cabinet with better than IP54, this requirements was indicated in safety manual [U1]. Further see chapter 4.2.11 of this assessment report.
4.15	Performance levels and categories for SRP/CSs in accordance with ISO 13849-1 - Pressure-sensitive mats and pressure-sensitive floors shall meet at least the requirements of PL = c according to ISO 13849-1.	For the combination of Ter-A series safety controller and GB PSM series safety mat, the performance level can achieve PL d. for details refer to chapters 4.2.4, 4.2.5 and 4.2.6 of this assessment report.
	- The mean number of cycles until 10 % of the components fail to danger (B10d – values for pressure sensitive mats and pressure-sensitive floors) shall be determined according to the test given in 7.7, but at location 8 only.	For the combination of Ter-A series safety controller and GB PSM series safety mat, the test has been carried out during integration test [D17], the value of B10d is 30,495,773.
	- If a pressure-sensitive mat is required to comply with category 3, its architecture may deviate from the designated architecture according to ISO 13849-1:2006, 6.2, provided that the required PL is achieved. Fault exclusions shall be listed and explained in the instructions for use. Fault exclusions which are not tolerable due to a reasonably foreseeable misuse of the pressure-sensitive mat or pressure-sensitive floor shall not be made.	For the combination of Ter-A series safety controller and GB PSM series safety mat, it can achieve category 3. For details refer to chapters 4.2.4, 4.2.5 and 4.2.6 of this assessment report.
4.16, 4.17	- Sensor fittings - Tripping	The accessories of installation is provided by DADI, and the DADI clearly define requirements of installation in safety manual [U2].

Clause	Requirements	Result
4.18	Slip-resistance	The DT series safety mat use rubber antiskid plate to avoid slip.
4.19	Additional coverings of top surfaces of sensor(s)	DT series safety mat is not need to use additional coverings of the top surfaces of sensor in common sense. The installation requirements was defined in safety manual [U2].
4.20	Failure due to blocking or wedging	This requirements was verified during integration test [D17], and the positive result can obtain.
5	Marking - Marking of control unit - Marking of sensor - Marking of other components	The nameplate/markings of control unit and safety mat have been submitted by DADI which covers those requirements.
6	Information for use	The safety manuals [U1] - [U2] of control unit and safety mat have been submitted by DADI which covers those requirements.
7	Testing - The requirement for test environment - Sensor test sample (incl. dimension, location etc.) - Test pieces and test load - Test methods and requirements for the requirements of clause 4.2 - 4.20.	These tests have been carried out, and the corresponding test plan and test results were documented in [D16] and [D17].

Table 4-4: Requirements according to ISO 13856-1

Result:

No contradictions were identified by the assessment in reference with the requirements of the [N1].

The user is responsible for the compliance with all other requirements from the standard including requirements that have an effect on the operation of the safety system. The end-user shall refer to the Safety Manuals [U1] - [U2].

4.2.13.2. Requirements according to ISO 13856-2

This standard relates to the pressure sensitive edges and pressure-sensitive bars for functional safety.

In the following table, the relevant requirements are defined. These requirements are applied to the combination of Ter-A series safety controller and DB series safety edge and it is described, if they are applicable and how they are fulfilled:

Clause	Requirements	Result
4.1	Requirements for Effective sensing - The effective sensing angle of pressure-sensitive protective devices with heights (see Figure 2) X + Z ⩾ 40 mm shall be ⩾ 90° . - The effective sensing angle of pressure-sensitive protective devices with heights X + Z < 40 mm shall be at least 40°. - If the effective sensing angle is less than 90°, a clear warning shall be given in the information for use (see Clause 6).	The effective sensing angle of GB - series safety edge is ⩾ 90° . This design has been verified during integration test [D19].
4.2	Requirements for actuating force for testing: The sensor of the pressure-sensitive edge or pressure-sensitive bar shall generate an output signal sufficient to cause the output signal switching device to change to the OFF state when the specified minimum actuating force(s) is applied. This requirement shall be met when the actuating force(s) is applied perpendicular to the reference axis. The actuating force shall not exceed those specified in Table 2 when applied at the test speeds (from minimum to maximum operating speeds) over the effective sensing surface and over the operating temperature range with the sensor in the mounting orientations which the manufacturer has specified are suitable for use.	The DB series safety edge can only be installed in the orientation B, this design has been verified during integration test [D19]. Furthermore, a corresponding caution was added in safety manual [U3].

Clause	Requirements	Result
4.3, 4.4, 4.5, 4.6	Requirements for Force-travel relationships - The pre-travel shall not be more than that stated by the manufacturer - The working travel shall not be less than that stated by the manufacturer - The overtravel shall not be less than that stated by the manufacturer. - The manufacturer of the pressure-sensitive edge or pressure-sensitive bar shall provide force–travel relationship data for a representative sample in the form of a diagram as shown in Figure 4. This data shall be determined with the force applied through test piece 1 (see Figure 5). The manufacturer shall state the temperature, the operating speed(s), the mounting orientation and the direction of operation at which the data was determined.	The working travel of DB series safety edge is less than 3 mm, this design have been verified during integration test [D19] in test case force-travel relationships. Furthermore, this character has been stated in safety manual [U3].
4.7	Requirements for Minimum operating speed - The minimum operating speed shall not exceed 10 mm · s^{-1}.	The minimum operating speed 10 mm · s^{-1} have been verified during integration test [D19].
4.8	Requirements for Number of operations - single sensors: After 10 000 operations the pressure-sensitive edge or pressure-sensitive bar shall have no defects affecting the safety performance (see 7.8.3). This requirement applies to single sensors used alone or in combination (see 4.8.3). - combination sensors: Where the effective sensing surface comprises of more than one sensor, after a further 1 000 operations at each joint the pressure-sensitive edge or pressure-sensitive bar shall have no defects affecting the safety performance (see 7.8.3).	The number of operations of GB - series safety edge is more than 100 000, this design have been verified during integration test [D19]. However, the usage of combination sensors is not allowed. Furthermore, a corresponding caution of the dead zone has been added in safety manual [U3].

Clause	Requirements	Result
4.9	Requirements for sensor output - The sensor output shall have a value which causes the output signal switching device to change to the OFF state when the actuating force is applied perpendicular to the reference axis to the effective sensing surface.	The requirements were implemented by Ter-A series safety controller, this design have been verified during integration test [D19].
4.10	Requirements for response of output signal switching device to actuating force - Systems, where sensor output remains in OFF state for as long as actuating force is applied - Systems where sensor output does not stay in OFF state when actuating force remains	The requirements were implemented by Ter-A series safety controller, this design have been verified during integration test [D19].
4.11	Requirements for reset function - The reset function of a pressure-sensitive edge or pressure-sensitive bar shall fulfil the general requirements of ISO 13849- 1:2006, 5.2.2 and the functional requirements of Annex A. - When manual reset is provided, it shall function according to Annex A and ISO 13849- 1:2006, 5.2.2.	The requirements were implemented by Ter-A series safety controller, this design have been verified during integration test [D19].
4.12	Requirements for Environmental conditions - Climatic conditions - Electromagnetic compatibility - Vibration - Bump	For the combination of Ter-A series safety controller and GB - series safety edge, these performances has been verified during integration test [D19] and met the requirements of this standard.
4.13	Requirements for power supply variations - Electrical power supply variations the pressure-sensitive edge or pressure-sensitive bar shall meet the requirements of IEC 60204-1:2005, 4.3.	This test has been carried out during integration test of Ter-A series safety controller [D15] and met the requirements of IEC 60204-1:2016, 4.3.
4.14	Requirement for Electrical equipment - Protection against electric shock - Protection against over-current - Pollution degree - Clearances and creepage distances - Wiring	The requirements of this clause has been verified during integration test [D19], for details refer to test no.10.
4.15	Hydraulic equipment - Hydraulic equipment shall meet the relevant requirements of ISO 4413.	These requirements shall be considered by the end-user at application level.

Clause	Requirements	Result
4.16	Pneumatic equipment - Pneumatic equipment shall meet the relevant requirements of ISO 4414.	These requirements shall be considered by the end-user at application level.
4.17	Requirement for Enclosure - The sensor enclosure shall meet a minimum standard of IP54 in accordance with IEC 60529. - The control unit and any external output signal switching device enclosure shall meet the requirements of IP 54 as a minimum. Where the control unit and output signal switching device is designed for mounting in another control equipment enclosure, this enclosure shall meet the requirements of the level of protection relevant to that application. In these circumstances, the control unit and output signal switching device shall meet the requirements of IP 2X as a minimum.	The requirements of this clause has been verified during type test [D13]. The DB series safety edge can reach IP65. In addition, the Ter-A series safety controller shall be located in a control cabinet with better than IP54 as required within safety manual [U1]. Furthermore, refer to chapter 4.2.11 of this assessment report.
4.18	Additional coverings for sensors	DB series safety edge is not need to use additional coverings of the top surfaces of sensor in common sense. The installation requirements was defined in safety manual [U3].
4.19	Access	DB series safety edge has no reserved access channel for maintenance.
4.20	Performance levels and categories for SRP/CSs in accordance with ISO 13849- 1 - Pressure-sensitive edges and pressure-sensitive bars shall meet the requirements of the performance level (PL) and category for which they are specified and marked. The performance levels and categories are specified in ISO 13849- 1. - Pressure-sensitive edges and pressure-sensitive bars shall meet at least the requirements of performance level c according to ISO 13849- 1 as well as the requirements of this part of ISO 13856.	For the combination of Ter-A series safety controller and GB - series safety edge, the performance level can achieve PL d. For details refer to chapters 4.2.4, 4.2.5 and 4.2.6 of this assessment report.

Clause	Requirements	Result
	- B10d values for the sensor shall be determined by means of testing.`	For the combination of Ter-A series safety controller and GB - series safety edge, the test has been carried out during integration test [D19], the value of B10d is 4,524,861.
	- If a pressure-sensitive edge or pressure-sensitive bar complies with category 3, its architecture may deviate from the designated architecture according to ISO 13849- 1:2006, 6.2. - Fault exclusions which are not tolerable due to a reasonably foreseeable misuse of the pressure-sensitive mat or pressure-sensitive floor shall not be made.	For the combination of Ter-A series safety controller and GB - series safety edge, it can achieve category 3. For details refer to chapters 4.2.4, 4.2.5 and 4.2.6 of this assessment report.
4.21	Requirements for Adjustments	The DB series safety edge do not need adjustment by the end user. However, the function test shall be carried out before any usage as required within the safety manual [U3].
4.22	Sensor fixing and mechanical strength - Means shall be provided for all parts of the sensor to be fixed securely in the specified mounting orientation. The fixed sensor shall have sufficient mechanical strength to withstand the maximum forces in the specified directions which are stated by the manufacturer.	The DB series safety edge can withstand the maximum forces 500 N. The test has been carried out during integration test [D19].
4.23	Recovery after deformation - After the effective sensing surface of the sensor has been deformed or displaced by the working travel movement using test piece 1 for 24 h, the effective sensing surface shall recover as shown in Table 3. The working travel in this instance is taken from test No. 4 (see 7.7) with a test speed of 10 mm · s−1 at a force of 250 N.	The test has been carried out during integration test [D19].

Clause	Requirements	Result
4.24	Connections - Where components of different configurations within the pressure-sensitive bar or pressure-sensitive edge are interchangeable by means of plug and socket connections, incorrect placement or exchange of these components shall not cause failure to danger.	The connections of Ter-A series safety controller and GB - series safety edge are in different colours (Red and Black), the method of connections was defined in safety manual [U3]. The terminals of Ter-A was defined in safety manual [U1] and marked in labels.
	- If a sensor is connected by a plug and socket, removal or disconnection of the sensor at the plug and socket from the control unit shall cause the output signal switching device to go to an OFF state.	For the combination of Ter-A series safety controller and GB - series safety edge, itself comply with the idle-current principle, this character has been verified during integration test [D19] and FIT [T2].
4.25	Sharp corners, sharp edges and rough surfaces - Exposed parts of pressure-sensitive edges or pressure-sensitive bars shall not have sharp corners, edges, rough surfaces, etc. which can cause injury to persons who can come into contact with the device(s) (see ISO 12100:2010, 6.2.2.1).	The Ter-A series safety controller and DB series safety edge are smooth. This character has been inspected during integration test [D19].
4.26	Mechanical features - Pressure-sensitive edges and pressure-sensitive bars shall comply with ISO 12100:2010, 6.3.2. For pressure-sensitive bars, see also Annex D.	these requirements has been verified during integration test [D19].
4.27	Inhibition and blocking - The sensors of pressure-sensitive edges or pressure-sensitive bars shall be constructed so that their operation cannot be intentionally inhibited or blocked by simple means. See also D.3.	The DB series safety edge is an enclosed equipment, so their operation cannot be intentionally inhibited or blocked by simple means. This character has been inspected during integration test [D19].
5	Marking - Marking of sensor - Marking of other components - Marking of control unit	The nameplate/markings of control unit and safety edge have been submitted by DADI which covers those requirements.
6	Information for use	The safety manuals [U1] and [U3] of control unit and safety edge have been submitted by DADI which covers those requirements.

Clause	Requirements	Result
7	Testing - The requirement for test environment - Sensor test sample (incl. length, location etc.) - Test pieces - Test methods and requirements for the requirements of clause 4.1 - 4.27.	These tests have been carried out, and the corresponding test plan and test results were documented in [D18] and [D19].

: Requirements according to ISO 13856-2

Result:

No contradictions were identified by the assessment in reference with the requirements of the [N2].

The user is responsible for the compliance with all other requirements from the standard including requirements that have an effect on the operation of the safety system. The end-user shall refer to the Safety Manuals [U1] and [U3].

5. Summary

The DT series safety mat sensor in combination with the Ter-A series safety controller, as specified under chapter 3.1, complies with the requirements of relevant standards (ISO 13856-1, Cat. 3 / PL d acc. to ISO 13849-1, SIL CL 2 acc. to IEC 62061) and can therefore be used in applications up to those safety levels to detect the presence of persons.

The DB series safety edge sensor in combination with the Ter-A series safety controller, as specified under chapter 3.1, complies with the requirements of relevant standards (ISO 13856-2, Cat. 3 / PL d acc. to ISO 13849-1, SIL CL 2 acc. to IEC 62061) and can therefore be used in applications up to those safety levels to detect the parts of body typically where trapping or crushing hazards exist at machinery.

The instructions of Safety Manuals ([U1] - [U3]) have to be considered before any safety related usage. This assessment does not substitute the validation at application level which is mandatory before commissioning a machine.

Beijing, 2019-06-03
TIS/A-FS/Kst. 962 yz-nie

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First technical review:
Date: 2019-06-03

Report released after review:
Date: 2019-06-03

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