DK32 - DK34 - DK37

Supplementary instructions

Variable area flowmeter
Safety manual

KROHNE

1.1 Field of application

Measurement of volume flow rate of liquids, gases and vapours that shall meet the special safety requirements according to IEC 61508.

The measuring device meets the requirements regarding

- Functional safety in accordance with IEC 61508-2:2000
- EMC in accordance to EN 61326-1:2006
- ATEX compliance in accordance to EN 60079-0:2006, EN 60079-11:2007
- PED in accordance to EN 13445-2 and EN 3834-2, AD-2000-Merkblatt Reihe B

For further information please refer to the DK32 - DK34 Declaration of Conformity and DK37 Declaration of conformity at the Downloadcenter of the KROHNE-Website www.krohne.com.

1.2 User benefits

Use for

- Volume flow monitoring up to SIL 2 (acc. to exida FMEDA report Krohne 08/11-46 R009)
- Continuous flow measurement and local analog indication
- Easy commissioning
- Excellent price-performance ratio

1.3 Relevant standards / Literature

[N1] IEC 61508-2:2000 - Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems

[N2] Electrical & Mechanical Component Reliability Handbook, 2nd Edition 2008, exida L.L.C. ISBN 978-0-9727234-6-6

[N3] IEC 60654-1:1993-02 2nd edition, Industrial process measurement and control equipment - Operating conditions - Part 1: Climatic conditions

Terms and definitions

DC_D	Diagnostic Coverage of dangerous failures
FIT	Failure In Time ($1x10^{-9}$ failures per hour)
FMEDA	Failure Modes, Effects and Diagnostic Analysis
HFT	Hardware Fault Tolerance
Low demand mode	Mode, where the frequency of demand for operation made on a safety-related system is not greater than one per year and not greater than twice in the proof test frequency.
PFD_{AVG}	Average Probability of Failure on Demand
SFF	Safe Failure Fraction summarizes the fraction of failure, which lead to a safe state and the fraction of failures which will be detected by diagnostic measures and lead to a defined safety action.
SIF	Safety Instrumented Function
SIL	Safety Integrity Level
Type A component	"Non-complex" subsystem (all failure modes are well defined); for details see 7.4.3.1.2 of IEC 61508-2.
Type B component	"Complex" subsystem (all failure modes are well defined); for details see 7.4.3.1.2 of IEC 61508-2.
T[Proof]	Proof Test Interval

2.1 Description of the considered profiles

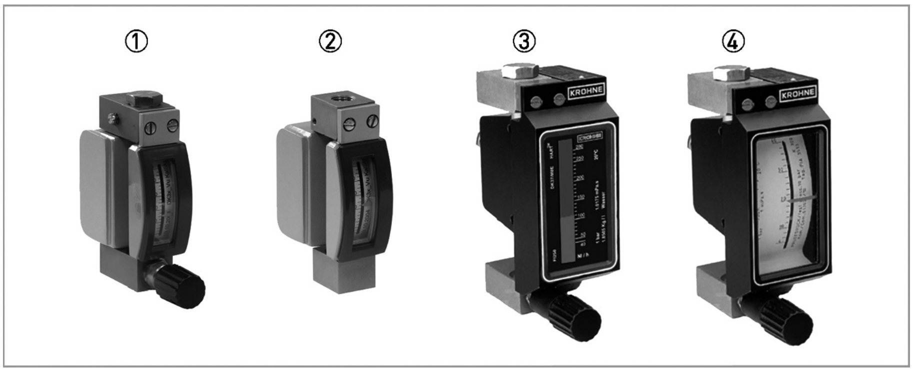
Profile	Profile according to IEC 60654-1	Ambient temperature [°C]		Temperature cycle [°C / 365 days]
		Average (external)	Mean (inside box)	
2	C3	25	30	25
4	D1	25	30	35

Profile 2 (low stress): Mechanical field products with minimal self heating, subject to daily temperature swings.

Profile 4 (high stress): Unprotected mechanical field products with minimal self heating, subject to daily temperature swings and rain or condensation.

3.1 Description of the subsystem

Device versions

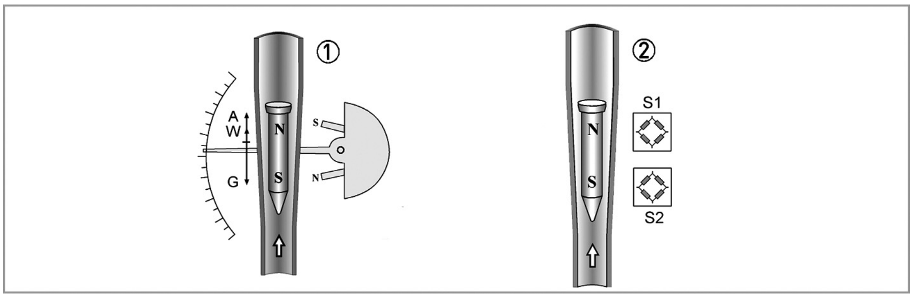


① DK32 with valve - with horizontal connection
② DK34 without valve - with vertical connection
③ DK37/M8E with valve and electronic display
④ DK37/M8M with valve and mechanical display

Versions with regulator

① DK32 with inlet pressure regulator
② DK37 with inlet pressure regulator

3.2 Functional principle



① Magnetic coupling of a pointer at DK32, DK34 and DK37M8M
② Magnetic field sensors at DK37M8E

The flowmeter operates in accordance with the variable area measuring principle.

The DK32, 34, 37 variable area flowmeters feature an upright tapered tube, wider end up, in which a specially shaped float moves freely up and down.

The fluid flows upwards through the tube, causing the float to lift a certain distance and form an annular gap between tube wall and float, until the forces acting on the float are in equilibrium.

At DK32, DK34 and DK37/M8M the position of the float in the measuring tube, representing a certain flowrate, is transmitted by a magnetic coupling and displayed with a pointer on a scale.

At DK37/M8E the position of the float is detected with magnetic field sensors and the flow is indicated on a digital bargraph indicator.

Strong deflecting magnetic fields can lead to deviations in the measured value.

4.1 Description of the failure categories

In order to judge the failure behaviour of the variable-area flowmeters DK3*, the following definitions for the failure of the flowmeter were considered:

Fail - Safe	Failure that causes the subsystem to go to the defined fail-safe state without a demand from process.
Fail Dangerous Undetected	Failure that is dangerous and that is not being diagnosed by internal diagnostics.
Fail Dangerous Detected	Failure that is dangerous but is detected by internal diagnostics (These failures may be converted to the selected fail-safe state)
Fail No Effect	Failure of a component that is part of the safety function but is neither a safe failure nor a dangerous failure and has no effect on the safety function. For the calculation of the SFF it is treated like a safe undetected failure.
Not part	Failures of a component which is not part of the safety function but part of the circuit diagram and is listed for completeness. When calculating the SFF this failure mode is not taken into account. It is also not part of the total failure rate.

DK32, DK34, DK37M8M with inductive limit switch output

Fail-Safe State	The fail-safe state is defined as the output beeing de-energized
Fail Dangerous	Failure that does not respond to a demand from the process (i.e. being unable to go to the defined fail-safe state)

DK37M8E with 4…20mA output

Fail-Safe State	The fail-safe state is defined as the output exceeding the user defined threshold
Fail Dangerous	Failure that does not respond to a demand from the process (i.e. being unable to go to the defined fail-safe state) or that deviates the output current by more than 2.5% of full span.
Fail High	Failure that causes the output signal to go to the maximum output current (>21mA) according NAMUR NE43.
Fail Low	Failure that causes the output signal to go to the minimum output current (< 3.6 mA) according NAMUR NE43.

In IEC 61508 the "No Effect" failures are defined as safe undetected failures even though they will not cause the safety function to go to a safe state. Therefore they need to be considered in the Safe Failure Fraction calculation.

The demand response time of DK32, DK34, DK37 is < 2s.

5.1 Applicable device documentation

[D1] TD DK32/34/37-Rxx-en
Technical datasheet DK32, DK34, DK37 – Variable area flowmeter

[D2] MA DK32/34/37-Rxx-en
Handbook including installation and operating instructions

[D3] exida FMEDA report: KROHNE 08/11-46 R009

5.2 Project planning, behaviour during operation and malfunction

- The stress levels shall be average for an industrial outdoor environment and shall be similar to exida Profile 2 or Profile 4 with temperature limits within the manufacture's rating. Other environmental characteristics are assumed to be within the manufacturer's ratings.
- Under normal conditions the maximum operating time will be 10 years.
- Requirements made in the operating manual have to be kept.
- Repair and inspection intervals have to be based on the safety calculations.
- Follow the KROHNE repair instructions in the printed operating manual.
- Modifications made without specific authorisation of the manufacturer are strictly prohibited.
- Follow the Installation and Operating Instructions.
- The application program in the safety logic solver is configured to detect under-range and over-range failures and does not automatically trip on these failures; therefore these failures have been classified as dangerous detected failures. The failure rates of the safety logic solver are not included in the listed failures rates.
- The parameters given by the FMEDA are considered as planning support. The end user is responsible for the overall functional safety of the application.
- For help to find the correct order text see annex 1.

6.1 Life time

Although a constant failure rate is assumed by the probabilistic estimation method this only applies provided that the useful lifetime of components is not exceeded.
Beyond their useful lifetime, the result of the probabilistic calculation method is meaningless, as the probability of failure significantly increases with time.
The useful lifetime is highly dependent on the component itself and its operating conditions – temperature in particular (for example, electrolyte capacitors can be very sensitive).
This assumption of a constant failure rate is based on the bathtub curve, which shows the typical behaviour for electronic components. Therefore it is obvious that the PFD_{AVG} calculation is only valid for components which have this constant domain and that the validity of the calculation is limited to the useful lifetime of each component.

It is assumed that early failures are detected to a huge percentage during the installation period and therefore the assumption of a constant failure rate during the useful lifetime is valid.

According to section 7.4.7.4 of IEC 61508-2, a useful lifetime, based on experience, should be assumed.
According to section 7.4.7.4 note 3 of IEC 61508-2 experience has shown that the useful lifetime often lies within a range of 8 to 12 years.

KROHNE recommends an operational life time for variable area flowmeters no longer than 10 years in SIL rated applications. However, if the user is monitoring the instruments over their life time demonstrating the required results (e.g. constant failure rate), this can allow safety capability exceeding this period on the user' s own responsibility.

The required cyclic proof test interval can be found in the table chapter 7.2.

6.2 Proof tests

Possible proof tests to detect dangerous undetected faults

Proof test for DK32, DK34, DK37M8M with inductive limit switches

1. Take appropriate action to avoid a false trip
2. Inspect the device for any visible damage, corrosion or contamination
3. Force the variable-area flowmeter DK3* to reach a defined “MAX” threshold value and verify that the inductive limit switch goes into the safe state
4. Force the variable-area flowmeter DK3* to reach a defined “MIN” threshold value and verify that the inductive limit switch goes into the safe state.
5. Restore the loop to full operation
6. Restore normal operation

Proof test for DK37M8E with 4…20mA output

1. Bypass the safety PLC or take other appropiate action to avoid a false trip
2. Perform 5-point calibration verification of the variable are flowmeter DK37M8E
3. Force the variable are flowmeter DK37M8E to go to the high alarm current output and verify that the analog current reaches that value.
4. Force the variable are flowmeter DK37M8E to go to the low alarm current output and verify that the analog current reaches that value.
5. Restore the loop to full operation
6. Remove the bypass from the safety PLC or otherwise restore normal operation

It is assumed that the test will detect approximately 99% of possible dangerous undetected failures.

7.1 Assumptions

The following assumptions have been made during the Failure Modes, Effects and Diagnostic Analysis of the variable-area flowmeter DK32, DK34 and DK37.

- Failure rates are constant, wear out mechanisms are not included.
- Propagation of failures is not relevant.
- Failures resulting from incorrect use of the flowmeters DK3*, in particular humidity entering through incompletely closed housings or inadequate cable feeding through the inlets, are not considered.
- Sufficient tests are performed prior to shipment to verify the absence of vendor and/or manufacturing defects that prevent proper operation of specified functionality to product specifications or cause operation different from the design analyzed.
- The mean time to restoration (MTTR) after safe failure is 24 hours.
- All modules are operated in the low demand mode of operation.
- External power failure rates are not included.
- The HART protocol at DK37M8E is only used for setup, calibration and diagnostics purpose, not during safety operation mode.
- Practical fault insertion test can demonstrate the correctness of the failure effects assumed during FMEDAs.
- The stress levels are average for an industrial outdoor environment and can be compared to exida Profile 2 or Profile 4 with temperature limits within the manufacture's rating. Other environmental characteristics are assumed to be within the manufacturer's ratings.
- The switching contact outputs are connected to a fail-safe NAMUR amplifier. The failure rates of the amplifier are not included in the listed failure rates.
- The application program in the safety logic solver is configured to detect under-range and over-range failures and does not automatically trip on these failures; therefore these failures have been classified as dangerous detected failures. The failure rates of the safety logic solver are not included in the listed failures rates.
- No effect failures are included in the "safe undetected" failure category. Note that these failures on its own will not affect system reliability or safety, and should not be included in spurious trip calculations.

The variable area flowmeter DK32, DK34, DK37M8M with inductive limit switches are classified as Type A subsystems (non-complex subsystem according 7.4.3.1.2. of IEC 61508-2) with hardware fault tolerance HFT=0. For Type A subsystems the SFF has to be > 60% for SIL2 subsystems with a hardware fault tolerance of 0 (table 2 of IEC 61508-2).

The variable area flowmeter DK37M8E with 4…20mA output is classified as Type B subsystem (complex subsystem according 7.4.3.1.3. of IEC 61508-2) with hardware fault tolerance HFT=0. For Type B subsystems the SFF has to be > 60% for SIL1 subsystems with a hardware fault tolerance of 0 (table 3 of IEC 61508-2).

7.2 Specific safety-related characteristics

Under the assumptions described in 7.1 and the definitions given in section 4 the following tables show the failure rates according to IEC 61508:

DK32/K*...-SK with 1 or 2 fail-safe limit switches ①

	Fail safe		Fail dangerous			
	detected	undetected	detected	undetected		
	λ_{SD}	λ_{SU}	λ_{DD}	λ_{DU}	SFF ②	SIL AC ③
Stress profile 2	0 FIT	238 FIT	0 FIT	97 FIT	71.0%	SIL2
Stress profile 4	0 FIT	300 FIT	0 FIT	136 FIT	68.7%	SIL2

T[Proof] ④	1 year	5 years	10 years
PFD_{AVG} ⑤	$4.63*10^{-4}$	$2.15*10^{-3}$	$4.25*10^{-3}$

① The switching contact output is connected to a fail-safe NAMUR amplifier (e.g. Pepperl & Fuchs KF**-SH-Ex1). The failure rates of the amplifier are not included in the listed failure rates.

② The number listed is for reference only. The SFF must be determined for the complete subsystem.

③ SIL AC (architectural constraints) means that the calculated values are within the range for hardware architectural contraints for the corresponding SIL level.

④ It is assumed that proof testing is performed with a proof test coverage of 99%.

⑤ The PFD_{AVG} was calculated for profile 2 using the Markov modelling. The results must be considered in combination with PFD_{AVG} values of other devices of the Safety Instrumented Function (SIF) in order to determine suitability for a specific Safety Integrity Level (SIL)
For SIL1 applications, the PFD_{AVG} value needs to be < 10^{-1}.
For SIL2 applications, the PFD_{AVG} value needs to be < 10^{-2}.

DK32/R*/K*...-SK with 1 or 2 fail-safe limit switches ① and with dp-regulator

	Fail safe		Fail dangerous			
	detected	undetected	detected	undetected		
	λ_{SD}	λ_{SU}	λ_{DD}	λ_{DU}	SFF ②	SIL AC ③
Stress profile 2	0 FIT	371 FIT	0 FIT	185 FIT	66.7%	SIL2
Stress profile 4	0 FIT	519 FIT	0 FIT	252 FIT	67.3%	SIL2

T[Proof] ④	1 year	5 years	10 years
PFD_{AVG} ⑤	$8.83*10^{-4}$	$4.09*10^{-3}$	$8.10*10^{-3}$

① The switching contact output is connected to a fail-safe NAMUR amplifier (e.g. Pepperl & Fuchs KF**-SH-Ex1). The failure rates of the amplifier are not included in the listed failure rates.

② The number listed is for reference only. The SFF must be determined for the complete subsystem.

③ SIL AC (architectural constraints) means that the calculated values are within the range for hardware architectural contraints for the corresponding SIL level.

④ It is assumed that proof testing is performed with a proof test coverage of 99%.

⑤ The PFD_{AVG} was calculated for profile 2 using the Markov modelling. The results must be considered in combination with PFD_{AVG} values of other devices of the Safety Instrumented Function (SIF) in order to determine suitability for a specific Safety Integrity Level (SIL)
For SIL1 applications, the PFD_{AVG} value needs to be < 10^{-1}.
For SIL2 applications, the PFD_{AVG} value needs to be < 10^{-2}.

DK34/K*...-SK with 1 or 2 fail-safe limit switches ①

	Fail safe		Fail dangerous			
	detected	undetected	detected	undetected		
	λ_{SD}	λ_{SU}	λ_{DD}	λ_{DU}	SFF ②	SIL AC ③
Stress profile 2	0 FIT	132 FIT	0 FIT	71 FIT	65.1%	SIL2
Stress profile 4	0 FIT	166 FIT	0 FIT	109 FIT	60.3%	SIL2

T[Proof] ④	1 year	5 years	10 years
PFD_{AVG} ⑤	$3.39*10^{-4}$	$1.57*10^{-3}$	$3.11*10^{-3}$

① The switching contact output is connected to a fail-safe NAMUR amplifier (e.g. Pepperl & Fuchs KF**-SH-Ex1). The failure rates of the amplifier are not included in the listed failure rates.

② The number listed is for reference only. The SFF must be determined for the complete subsystem.

③ SIL AC (architectural constraints) means that the calculated values are within the range for hardware architectural contraints for the corresponding SIL level.

④ It is assumed that proof testing is performed with a proof test coverage of 99%.

⑤ The PFD_{AVG} was calculated for profile 2 using the Markov modelling. The results must be considered in combination with PFD_{AVG} values of other devices of the Safety Instrumented Function (SIF) in order to determine suitability for a specific Safety Integrity Level (SIL)

For SIL1 applications, the PFD_{AVG} value needs to be < 10^{-1}.

For SIL2 applications, the PFD_{AVG} value needs to be < 10^{-2}.

DK37/M8M/K*...-SK with 1 or 2 fail-safe limit switches ①

	Fail safe		Fail dangerous			
	detected	undetected	detected	undetected		
	λ_{SD}	λ_{SU}	λ_{DD}	λ_{DU}	SFF ②	SIL AC ③
Stress profile 2	0 FIT	245 FIT	0 FIT	97 FIT	71.5%	SIL2
Stress profile 4	0 FIT	308 FIT	0 FIT	136 FIT	69.2%	SIL2

T[Proof] ④	1 year	5 years	10 years
PFD_{AVG} ⑤	$4.63*10^{-4}$	$2.15*10^{-3}$	$4.25*10^{-3}$

DK37/M8M/R*/K*...-SK with 1 or 2 fail-safe limit switches ① and with dp-regulator

	Fail safe		Fail dangerous			
	detected	undetected	detected	undetected		
	λ_{SD}	λ_{SU}	λ_{DD}	λ_{DU}	SFF ②	SIL AC ③
Stress profile 2	0 FIT	378 FIT	0 FIT	185 FIT	67.1%	SIL2
Stress profile 4	0 FIT	527 FIT	0 FIT	252 FIT	67.6%	SIL2

T[Proof] ④	1 year	5 years	10 years
PFD_{AVG} ⑤	$8.83*10^{-4}$	$4.09*10^{-3}$	$8.10*10^{-3}$

① The switching contact output is connected to a fail-safe NAMUR amplifier (e.g. Pepperl & Fuchs KF**-SH-Ex1). The failure rates of the amplifier are not included in the listed failure rates.

② The number listed is for reference only. The SFF must be determined for the complete subsystem.

③ SIL AC (architectural constraints) means that the calculated values are within the range for hardware architectural contraints for the corresponding SIL level.

④ It is assumed that proof testing is performed with a proof test coverage of 99%.

⑤ The PFD_{AVG} was calculated for profile 2 using the Markov modelling. The results must be considered in combination with PFD_{AVG} values of other devices of the Safety Instrumented Function (SIF) in order to determine suitability for a specific Safety Integrity Level (SIL)
For SIL1 applications, the PFD_{AVG} value needs to be $< 10^{-1}$.
For SIL2 applications, the PFD_{AVG} value needs to be $< 10^{-2}$.

DK37/M8E...-SE with 4...20mA current output

	Fail safe		Fail dangerous				
	detected	undetected	detected	undetected			
	λ_{SD}	λ_{SU}	λ_{DD}	λ_{DU}	SFF ②	DC_D	SIL AC ③
Stress profile 2	0 FIT	258 FIT	150 FIT	200 FIT	67.1%	43%	SIL1
Stress profile 4	0 FIT	317 FIT	150 FIT	220 FIT	67.9%	41%	SIL1

T[Proof] ④	1 year	5 years	10 years
PFD_{AVG} ⑤	$9.58*10^{-4}$	$4.43*10^{-3}$	$8.76*10^{-3}$

DK37/M8E/R*...-SE with 4...20mA current output and dp-regulator

	Fail safe		Fail dangerous				
	detected	undetected	detected	undetected			
	λ_{SD}	λ_{SU}	λ_{DD}	λ_{DU}	SFF ②	DC_D	SIL AC ③
Stress profile 2	0 FIT	395 FIT	150 FIT	288 FIT	65.3%	34%	SIL1
Stress profile 4	0 FIT	543 FIT	150 FIT	338 FIT	67.2%	31%	SIL1

T[Proof] ④	1 year	5 years	10 years
PFD_{AVG} ⑤	$1.38*10^{-3}$	$6.37*10^{-3}$	$1.26*10^{-2}$

② The number listed is for reference only. The SFF must be determined for the complete subsystem.

③ SIL AC (architectural constraints) means that the calculated values are within the range for hardware architectural contraints for the corresponding SIL level.

④ It is assumed that proof testing is performed with a proof test coverage of 99%.

⑤ The PFD_{AVG} was calculated for profile 2 using the Markov modelling. The results must be considered in combination with PFD_{AVG} values of other devices of the Safety Instrumented Function (SIF) in order to determine suitability for a specific Safety Integrity Level (SIL)

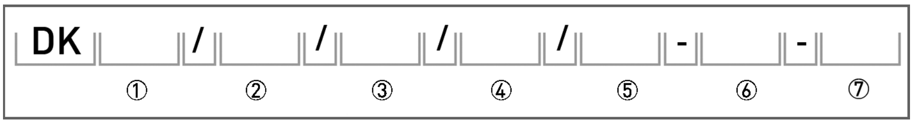
For SIL1 applications, the PFD_{AVG} value needs to be $< 10^{-1}$.

For SIL2 applications, the PFD_{AVG} value needs to be $< 10^{-2}$.

8.1 Annex 1

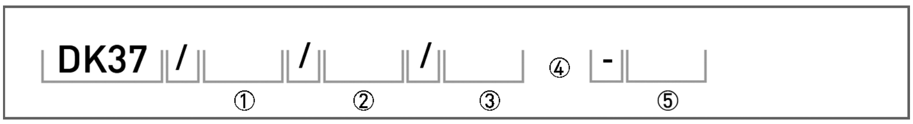
Constricted Description Code for DK3* Functional Safety Equipment acc. to EN 61508

The description code for DK32 and DK34 consists of the following elements ①



① 32 - with needle valve and horizontal connections / 34 without needle valve and vertical connections
② RE - Inlet pressure regulator / RA - Outlet pressure regulator
③ K1 - one limit switch / K2 - two limit switches
④ S - plug connection / L - cable gland incl. 1.5m cable
⑤ A - limit switch EC type-tested
⑥ EX - Explosion-protected equipment
⑦ SK - SIL2 compliance of limit switches acc. to IEC 61508

The description code for DK37 consists of the following elements ①



① M8M - Mechanical display / M8E - Electronic display and signal output 4...20mA
② RE - Inlet pressure regulator / RA - Outlet pressure regulator
③ K1 - one limit switch / K2 - two limit switches
④ Ex is not part of the designation key
⑤ SK - SIL2 compliance of limit switches acc. to IEC 61508
SE - SIL1 compliance of current output acc. to IEC 61508

① Positions which are not used in the type code are not required.

8.2 Annex 2

Fail-safe contact types, used for SIL2 compliant DK32, DK34, DK37/M8M:

SJ2-SN (Pepperl+Fuchs)	2-wire fail-safe inductive NAMUR switch
SJ2-S1N (Pepperl+Fuchs)	2-wire fail-safe inductive NAMUR switch (inverted)

Recommended fail-safe switching amplifiers for the fail-safe NAMUR limit switches

Type code	Manufacturer	Supply voltage	Channel	Output
KFD2-SH-Ex1	Pepperl+Fuchs	20…35 Vdc	1 safe fail	Redundant relay
KHD2-SH-Ex1.T.OP	Pepperl+Fuchs	20…35 Vdc	1 safe fail	Electronic + relay
KHA6-SH-Ex1	Pepperl+Fuchs	85…253 Vac	1 safe fail	Redundant relay

KROHNE product overview

- Electromagnetic flowmeters
- Variable area flowmeters
- Ultrasonic flowmeters
- Mass flowmeters
- Vortex flowmeters
- Flow controllers
- Level meters
- Temperature meters
- Pressure meters
- Analysis products
- Products and systems for the oil & gas industry
- Measuring systems for the marine industry

Head Office KROHNE Messtechnik GmbH
Ludwig-Krohne-Str. 5
47058 Duisburg (Germany)
Tel.:+49 (0)203 301 0
Fax:+49 (0)203 301 10389
info@krohne.de

The current list of all KROHNE contacts and addresses can be found at:
www.krohne.com