USER MANUAL

QG40N Tilt/Acceleration Switch (SIL1 PLc)

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1 Safety Information

1.1 Intended Use

The usage of this device within a machine or system is permissible under the following conditions:

- The user must possess expertise in designing and employing functional safety sensors.
- The user has acquired knowledge of both the Datasheet, the User Manual and the Declaration of Conformity.
- The device should only be used in environmental situations covered by the datasheet.
- The device is mounted correctly as described in the datasheet and user manual.
- Given the accelerometer-based nature of this device, its sensitivity to accelerations/vibrations necessitates application-specific testing to to ascertain its compliance with customer requirements.
- The zeroing function and configuration using the QG40N configuration tool should only be undertaken by authorized personnel, in the correct position. The Manufacturer disclaims responsibility for any damage resulting from customer settings, even when employing manufacturer defaults.
- Bandwidth settings (filtering) are set according to the application requirements.
- Configuration of the Tilt switch device, including changing switch points, filtering, etc., can be done using the optional QG40N configurator. The customer is responsible for ensuring only authorized / trained personnel do this configuration. The manufacturer is not responsible for these configuration changes.
- The proof test interval (mission time) for this sensor is 20 years. After this interval, replacement or assessment by comparing the output to a reference sensor, or checking/recalibrating by the manufacturer is advised. This step aims to identify non-detectable faults and/or degradation. Note that this check/recalibration is not covered within the product's initial purchase price.
- This sensor does not require any maintenance between proof-test intervals.

1.2 Sensor Defective

The sensor is considered “defective” when

- The output of the device is non-conductive, resulting in a ‘low’ state due to the external pull down resistor.
- If two outputs are used, the device will be considered as ‘unsafe’ even if only one output is non-conductive.

If any damage is noticed the device must be replaced by a new one in order to avoid hazard.

By ignoring the safety information the manufacturer cannot be hold responsible for any damage or hazard. For uncertainties, contact the distributor or manufacturer. Unauthorized modifications or usage voids the warranty and manufacturer liability.

2 About This Manual

2.1 Intended Use

This manual is valid for the following safety switch sensors with the specified models:

- QG40N Tilt switch SIL1 / PLc
- QG40N Acceleration switch SIL1 / PLc

2.2 Symbols Used In The Text

h	Subscript for hexadecimal values.
d	Subscript for decimal values.
⚠	Caution that indicates either potential damage to the sensor or explains how to avoid a problem.
	Important information.
→	Cross-reference

2.3 Copyright

2.4 Document Revision Control

Version	Date(y-m-d)	Revision
V0.1		Draft by MvA
V1.0		After review by RM
V1.1		Chapter 4: PLd corrected to PLc
V1.2	2020-02-25	Available measuring ranges updated
V1.3	2020-05-25	Acceleration switch functions added
V1.4	2023-10-13	Safety checks in the firmware added

3 Quick Reference

- One housing type: 40x40mm plastic.
- Two types of Tilt switch:
  1-axis (vertical plane) up to ±170° range, outputs 2x NPN or 2xPNP
  2-axis (horizontal plane) up to ±80° range, outputs 2x NPN or 2xPNP
- Two types of Acceleration switch:
  2-axis (horizontal plane) up to 7g, outputs 2x NPN or 2xPNP
  3-axis (omnidirectional) up to 7g, outputs 2x NPN or 2xPNP
- Available with M12 connector or cable with open ended wires.
- Programmable parameters: switch points, delay times, filtering etc.
- Optional QG40N configurator: support tilt switch only.
- Safety level: SIL CL 1 / PLc
- Output load: withstand 200mA continuous, all outputs simultaneously.
- Zeroing adjustment available via separate input.
- Default bandwidth of Tilt Switch: 0.7Hz, sample rate of MEMS: 3200Hz.
- Bandwidth Acceleration Switch: 1600Hz, sample rate of MEMS: 3200Hz.
- Output filter(only for tilt switch): adjustable 1st order low-pass filter.
- The calculated MTTFd of the sensor is specified in the datasheet.

4 Functional Description

4.1 Safety Switch Explained

The safety function of the switch sensor is to generate the requested switching behaviour based on inclination or acceleration values (caused by gravitation) measured by a MEMS acceleration sensor chip. Based on this switching behaviour (one non-conducting output = unsafe) the safety controller of the application can switch the machine to safe-mode in order to prevent for a dangerous situation.

Example:
A crane-arm is designed with a maximum tilt angle concerning the chassis. When the crane arm exceeds a critical tilt angle, it can pose a safety risk. To prevent this, a Tilt switch can be mounted on the crane arm to measure its angle. The safety controller of the application is responsible for monitoring the Tilt switch outputs. If any of the outputs become non-conductive, the safety controller activates the crane's safe mode promptly. This proactive measure significantly minimizes the risk of hazardous situations.

The Safety Related Fault Response Time (SRFRT) of this device is defined as the maximum time the sensor will report a non-safe situation to the outside world, after detecting an internal safety error. The actual value is specified in the datasheet

4.1.1 Tilt Switch

A tilt switch is a sensor that triggers a change in output (e.g., NPN/PNP signals) based on the changes in angle of tilt or inclination beyond a predefined threshold, typically measured in relation to Earth's gravity..

The device takes both the static component (100%) and the dynamic component (partial, depending on frequency and bandwidth-setting) into account.

4.1.2 Acceleration Switch

An acceleration switch is a sensor that triggers a change in output (e.g., NPN/PNP signals) based on the changes in acceleration beyond a predefined threshold, indicating a specific acceleration event or condition. An Acceleration sensor measures the acceleration in 1, 2 or 3 axes.

Internally the sensor has a 'measuring interval' depending on the measuring mode:

- PEAK (default): The peak acceleration value is calculated over the fixed 40ms measuring interval.
- RMS (optional): The RMS acceleration value is calculated over a factory programmable measuring interval of n*40ms, where n=integer, with a max. of 10 seconds.

4.2 Safety Level

SIL safety level: SIL CL1 (claim limit 1 according to IEC 62061)

PL safety level: PLc (according to EN ISO 13849)

Architecture: HFT=0 (according to IEC 62061) & CAT2 (according to EN ISO 13849)

This is a self-certified safety device.

The firmware of this device is developed according to EN ISO 13849 and meets the SRESW requirements for both 'PL a to d' and 'PL c or d'.

See separate 'Declaration of Conformity' for all safety related parameters.

4.3 Internal Diagnostic Checks

Comprehensive safety checks are performed during both the start-up and operational phases. In case of any diagnostic errors, both sensor outputs are forcefully switched to a "non-conducting" state in a permanent manner to inform the application that an unsafe situation could occur.

4.3.1 MCU EEPROM Error

MCU EEPROM error check involves verifying the integrity of the EEPROM data. The microcontroller's firmware calculates a checksum or uses a cyclic redundancy check (CRC) algorithm on the stored data. This computed value is then compared with a pre-determined reference value. If they match, it indicates that the EEPROM data is valid; if not, an error is detected. This process ensures that data stored in the EEPROM remains accurate and uncorrupted.

4.3.2 MEMS Self-test Error

The MCU briefly activates the MEMS acceleration chip's self-test mode to verify its proper functionality

4.3.3 Output Error

As a component of the required Diagnostic Coverage for achieving SIL1 functional safety, it is necessary to monitor the switching output of the sensor. To facilitate this, the SIL1 tilt switch incorporates a feedback mechanism from its output to the microcontroller. If the logical feedback deviates from expected parameters, the sensor transitions into a permanent critical state until a system reboot is performed. It is crucial to ensure the correct operation of the sensor that no voltage is applied to the NPN or PNP outputs.

4.3.4 MCU Errors

The MCU is a key component that manages the sensor's operation, data processing, communication, and other functions. Therefore we continuously monitor error or fault that occurs within the MCU.

- **Unknown interrupt**
  An MCU might not handle interrupts correctly, leading to missed sensor events or incorrect responses to interrupts.
- **RAM error**

- **FLASH error**
- **Watch Dog error**

4.3.5 MEMS Interrupt Error

The MEMS use the interrupt line to indicate the availability of the output. By implementing robust error-handling mechanisms in the firmware, we can detect and handle interrupt errors. Log error information for debugging purposes.

4.3.6 MEMS Data Format Error

A "Sensor Data Format Error" refers to a situation where the format of the data obtained from MEMS does not match the expected or specified format.

4.3.7 Voltage Error

Voltage errors can occur due to various reasons, such as power supply fluctuations, noise, or issues with the sensor itself. Check for voltage errors is crucial to ensure that the voltage supplied to the sensor falls within acceptable limits for proper and safe operation.

4.4 Signal Processing

The signal processing consist of several aspect, addressed below.

4.4.1 Sample Rate And Averaging

Tilt Switch:

The internal g-sensor chip is sampled every 10ms. Each sample of the element consists of 16 samples for each axis. Resulting in sample rate of 1600 Hz. These samples are input for a 32 tabs FIR input low pass filter. Each 10ms new data is available for the µC.
A decimating filter reduces the refresh rate by 4x, so refresh rate is 40ms.
This decimating filter is averaging the values during the 40ms refresh rate (4 samples averaging)

Acceleration Switch:

The internal g-sensor chip is sampled every 5ms. Each sample of the element consists of 16 samples for each axis. Resulting in sample rate of 3200 Hz. Each sample is checked over the measuring interval. At the end of the measuring interval the acceleration value is compared to the programmed switch points and the switching outputs are set accordingly, refresh rate 40ms.

4.4.2 Output Filter

Tilt Switch:

The output of the sensor can be extra filtered by a 1st order low-pass filter. Default this output filter is disabled. Via the optional ‘QG40N configurator’ a -3dB frequency or RC-time can be configured.
A longer low-pass filter time results is a smaller bandwidth and therefore a more stable output signal (less noise), but also more phase delay.

Acceleration Switch Sensor: Not applicable

4.5 Output Explained

DIS Tilt/Acceleration switch has either **PNP or NPN output**, the connection of the load depends on the output type.

Figure 1 - PNP output

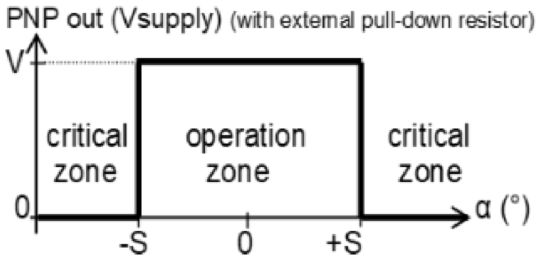
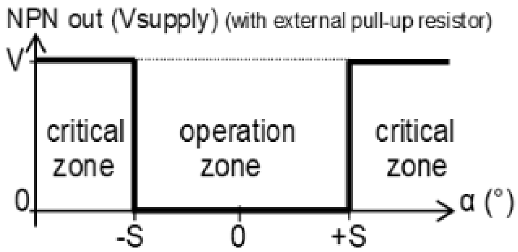


Figure 2 - NPN output



	Definition	PNP	NPN
Operation Zone	Sensor position within ±S Sensor is conducting and can be seen as "On" /switch closed.	The current flows from the Vcc through Sensor(transistor) to the load and finally to the ground. You will measure a voltage about the Vcc.	The current goes from the Vcc through the load to the ground. The output is basically grounded, so you will measure only a few mV, almost 0V.
Critical Zone	Sensor position outside ±S Sensor is non-conducting and can be seen as "Off"/switch is open.	The output pin is grounded, so you will measure almost 0V.	The output pin is connected to the Vcc via the load, so you'll measure a voltage about the same as Vcc.
Load	Resistor 5-10kOhm	Pull-down between Output and GND	Pull-up between Vcc and Output

⚠ In case the sensor is defect, or cable is broken, the sensor is in non-conducting mode, which is "critical".

4.6 Zero Adjustment

To eliminate mechanical offsets, a zero adjustment can be performed during the 1st minute after power up the zeroing input is sensitive for a zeroing action.

Sequence:

1. Left input unconnected during power up for at least 0.5s
2. Switched/connect input to Gnd for at least 0.5s
3. Left unconnected again
4. Result: The sensor will set the current inclination position as 0°. The actual zeroing point is where the input changes from Gnd to unconnected.

The maximum zeroing-range is specified in the datasheet. Horizontal mounting sensors have zeroing-range-limit of ±5°, vertical mounting sensor can be zero-ed over full 360°.

The new 0° value will be stored in non-volatile memory (EEPROM).

4.7 Programmable Parameters (Tilt Switch Only)

Each switching output is pre-programmed to have certain parameters, these parameters can also be changed by the customer with optional QG40N configurator.

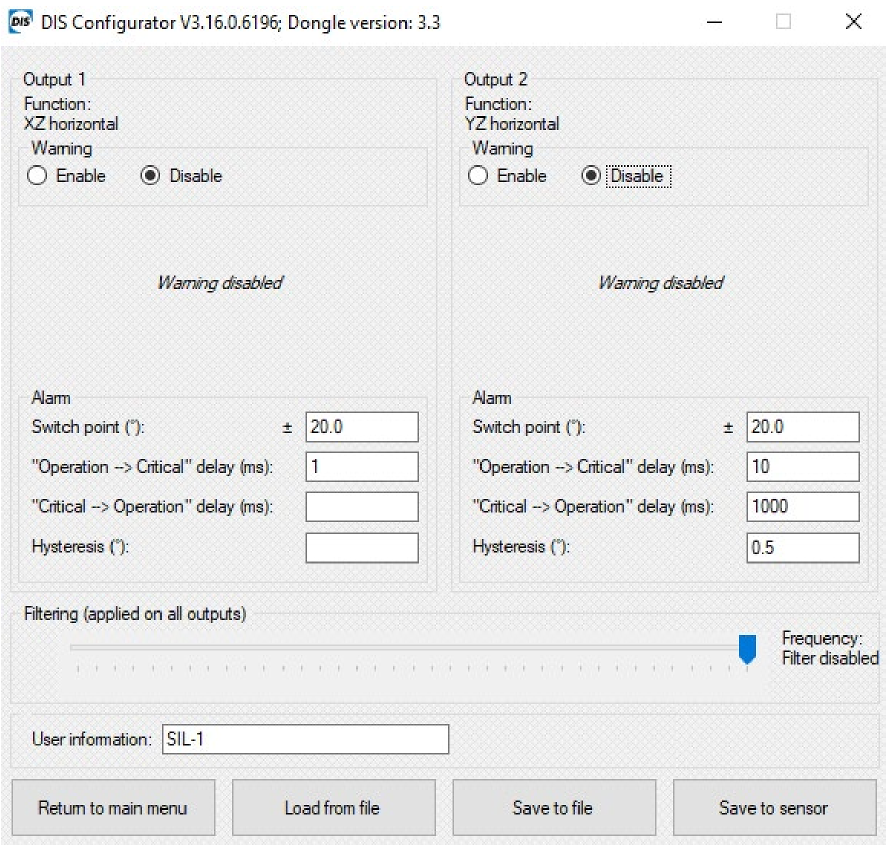


Figure 3 - Configuration panel

4.7.1 Switch Points

Switch points (±S) is a pair of pre-defined angles which set off the operation zone and critical zone (→4.5 Output explained). The S can be set with a unit of 0.1° and in default only symmetrical switch points are allowed, ie. Switch points is always ±3 or ±45°.

Example: Switch point = ±3°

Sensor position at (-3°,+3°), the output will be in the operation zone.

Figure 4 - operation zone

Sensor position at (-3°, -90°) and (+3°, +90°), the output will be in the critical zone.

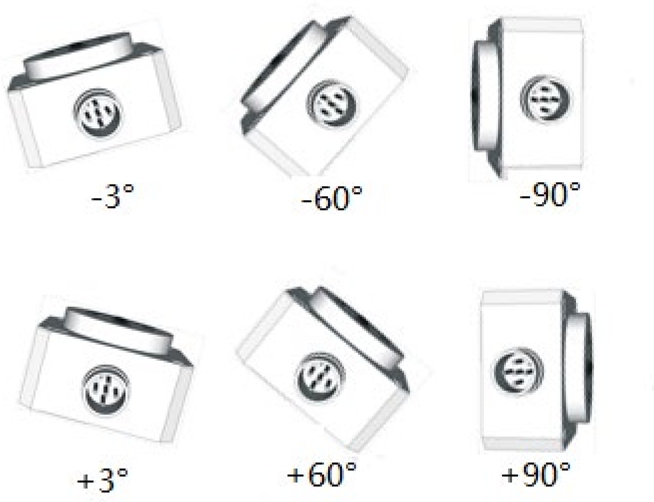


Figure 5 - critical zone

An asymmetrical switch points such as (+2°, +80°) can also be requested with a customized configuration. Contact your local distributor for more information.

4.7.2 Hysteresis

By creating a hysteresis, we can prevent sensor constantly switching at the switch point. The actual switch point from critical to operation zone will be ±S', whose value is the programmed switch point S minus Hysteresis.

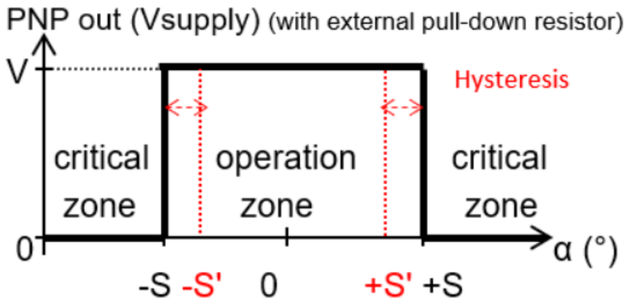


Figure 6 - Hysteresis

Example: Switch point = ±80°, hysteresis = 0.5°

The sensor switches from conducting(operation) to non-conducting(critical) exactly at ±80°, but it switches from non-conducting(critical) back to conducting (operation) at ±79.5° (80° - 0.5°) instead.

4.7.3 Delay Times

- **Operation to Critical delay**
  The switching output changes only when the measured angle is continuously over the switch point ±**S** for more than de delay time. If it's a short vibration, the object often returns to its safe position in the operation zone. In this case, the sensor will then not be switched to non-conducting. The timer will be then reset to the delay time and start to monitor again.

- **Critical to Operation delay**
  when the sensor tilts back to the operation zone, the switching output changes only when the measured angle is continuously below the **S'(not S)** for more than the delay time. Similarly, if it's a short vibration, the sensor moves back to the critical zone immediately, sensor will not be switched and the timer will be reset.

4.8 EMC / CE

See separate 'Declaration of Conformity'

5 Installation Guide

5.1 Mechanical drawing

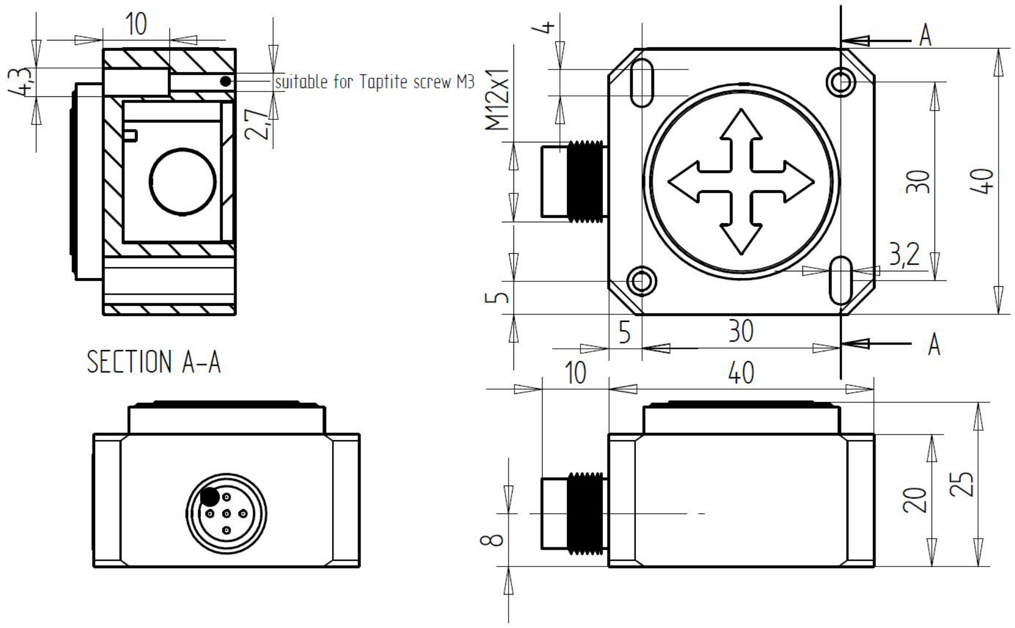


Figure 7 - Mechanical drawing of QG40N with a male M12

5.2 Mounting

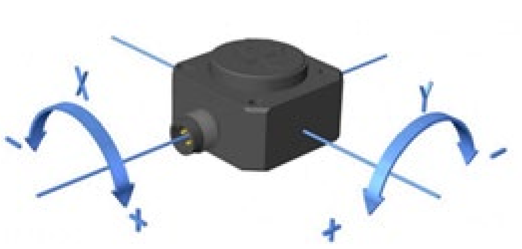


Figure 8 - Horizontal mounting 2-axis

Figure 9 Vertical mounting 1-axis

- The sensor should be mounted on a stable flat surface with at least two screws tightened.
- Never move the sensor by pulling the cable.
- A 1-axis tilt switch must be mounted vertically. The factory default zero position is with the male connector pointing down as shown in Figure 3. The sensor can be zero adjusted at any position within the full range.
- A 2-axis tilt switch must be mounted horizontally. The factory default zero position is shown in Figure 2. After installation, the sensor can be zero adjusted to eliminate the mechanical offsets within a ±5° offset range.

5.3 Connection

The sensor is equipped with

Default: 5-pins M12 connector male (A-coding). See datasheets for details

Optional: Cable with open ended wires. See datasheets for details

Pin	Assignment
Pin 1	+ Supply Voltage
Pin 2	Output2
Pin 3	Gnd
Pin 4	Output1
Pin 5	Zeroing

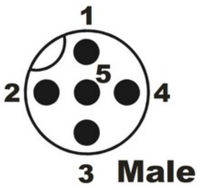
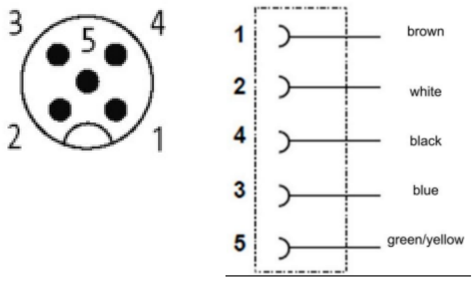


Figure 10 - Pin definition

If connected with an optional PVC cable with 5-pins M12 Female(→ accessory sold by DIS)

Pin	Assignment
Pin 1	Brown
Pin 2	White
Pin 3	Blue
Pin 4	Black
Pin 5	Green/Yellow



- The voltage supply must be dimensioned to prevent exceeding the specified voltage limits.
- The power consumption is about 50mA typical.
- This device must be connected to a class 2 power supply.

⚠ *Customer takes care to only use good quality industrial connectors/cabling to connect the sensor.*

6 Abbreviations and definitions

SIL1	Safety Integrity Level 1
PLd	Performance Level d
HFT	Hardware Fault Tolerance
MTTFd	Mean time to dangerous failure
SRFRT	Safety Related Fault Response Time
CAT2	Category 2
µC	Microcontroller

7 Normative references

EN-IEC 62061	International standards which specifies requirements and makes recommendations for the design, integration and validation of safety-related control systems (SCS) for machines.
EN ISO 13849	provides safety requirements and guidance on the principles for the design and integration of safety-related parts of control systems (SRP/CS)