MH Series
Magnetostrictive linear sensors with SIL 2 specification

Technical Data/Safety Manual

Significant Features:
- Reliable magnetostrictive principle
- Approved MH design intended for IN cylinder assembly
- SIL 2 rated acc. to IEC/ EN 61508
- Operates in machines and safety critical equipment acc. to ISO 13849
- Linear position sensing with internal diagnostic
- Monitoring of operating temperature and stroke range

All specifications are subject to change. Contact MTS for specifications and engineering drawings that are critical to your application. Drawings contained in this document are for reference only. Please visit www.mtssensor.com for the actual support documentation related to your selected model.
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1. Product description and technology

Temposonics® sensors can be used in versatile mobile machines without any restriction and replace contact-based linear sensors like potentiometers. Highly dynamic systems are controlled safely by means of Temposonics® sensors, thus enhancing the productivity, availability and quality of the working process of the machine. Insensitive to vibration, shocks, dust and weathering influence and electro-magnetic disturbances. Temposonics® MH Series sensors are successfully used in front axle and articulated frame steering cylinders, hydraulic jacks and in steering systems for hydraulic units on agricultural and construction machinery.

![Diagram of MH sensor components]

**Simple Mechanics**
The extremely robust sensor consists of the following main parts:

1. The innovative connector system which is easy to install in a few seconds, any soldering or crimping needless, dust- and waterproof up to IP69K.
2. The flange housing with built-in electronics and signal converter.
3. The position magnet as only moving part, which is assembled into the piston bottom. This permanent magnet travels wear-free and contactless along the pressure pipe and measures the actual position.
4. The pressure pipe placed within the drilled piston rod contains the protected magnetostrictive sensing element.

**Magnetostriction**
Temposonics® linear sensors are based on the magnetostrictive technology. By measuring the actual position with a non-contact position magnet the sensor operates 100% wear-free. The absolute operating principle enables reliable readings without any reference point or recalibration. A mechanical strain pulse is triggered by the travelling position magnet. The runtime of this ultrasonic wave is measured precisely and compiled into standard electronic output signals.

**Measuring principle**

- Due to small dimensions MH sensors require only little space
- Suitable for operating pressures up to 350 bar
- Unaffected by surrounding media such as ageing or foaming oil
- Insensitive to shock and vibration
- Designed for all current supply voltages (12/24 VDC)
- Temposonics® sensors offer all common used output signals:
  - Analog: VDC
  - Digital: CANopen Safety
2. Functional safety for linear position sensing

Temposonics® linear displacement sensors “MH Safety” are based on the magnetostrictive technology and designed acc. to the requirements out of IEC/EN 61508 and rated with SIL2 safety level. Developed for use in safety circuits/safety functions for measuring linear position as part of the functional safety of machinery and equipment it is also possible to use them up to PL d acc. to ISO 13849.

Operating with internal diagnostics consisting of evaluation electronics in order to detect a fail function relevant failure status will transmitted to the ECU. Critical safety function is evaluated in the ECU- emergency stop or emergency run will enable a safe operation after detecting the failure. Main areas of application are as linear sensor in safety oriented systems such as steering systems, load torque limitation in truck-mounted cranes (outrigger cylinders) and boom lifting and tilting cylinders in working platforms.

The design is a single architecture (Cat2) PLd acc. to ISO 13849

The user has two alternatives at his disposal:

1. MH Analog Safety
Position sensor with an isolated three-wire analog output. Classified as type B according to IEC 61508. The sensor contains a self-diagnostic circuit. In an event of a detected failure, the sensor sends a defined output of 0 V.

2. MH CANopen Safety
CANopen based position sensor classified as type B according to IEC 61508 sends safety relevant data objects. In an event of a detected failure, the internal diagnostic algorithm sends safety relevant data object (SRDO) which includes the corresponding emergency status information to the ECU. This will ensure to perform the requested functional safety.

see also Safety Manual chapter 2.2
3. Temposonics® connector system M12

MTS presents the innovative connector system for Temposonics® MH Series

The Temposonics® Connector System meets the highest protection requirements important for a harsh environment in mobile hydraulic applications. Protection type IP69K performs water and dust proof. In addition it is even resistive against high pressure water cleaning.

1. The MH sensor is delivered by MTS together with the new connector system:
   The connector insert carrier is already connected to the sensor conductors, i.e. no soldering, any color or connection mistake.

2. The connector insert is taken out of the cylinder through a bore hole. The flange can easily be clicked in position from outside.

3. Four standard screws must be tightened to mount the connector system on the cylinder. In case of using angled type connectors the connector insert can be rotated inside the flange in 45° steps.

4. With a corresponding mating plug the connector system fulfills an IP rating of IP69K.

- Absolutely easy and safe installation.
- No brazing or crimping of connecting leads is required.
### Technical Data

**4. Dimensions**

- **Wire length**: 60…240 mm in 20 mm steps
- **All dimensions in mm**

#### Mechanical configurations

<table>
<thead>
<tr>
<th>Form factor: stainless steel housing</th>
<th>C</th>
<th>Z = 63 mm (s ≤ 2,500 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>Z = 63 mm (s ≤ 2,500 mm), M4 female port</td>
</tr>
<tr>
<td>steel housing</td>
<td>S</td>
<td>Z = 63 mm (s ≤ 2,500 mm)</td>
</tr>
<tr>
<td><strong>Stroke length</strong></td>
<td>s</td>
<td>50…2500 mm</td>
</tr>
<tr>
<td><strong>Wire length</strong></td>
<td>w</td>
<td>60…240 mm</td>
</tr>
</tbody>
</table>

#### Electrical configurations

- **MH Analog**
  - M12 4 pin: 1 = VDC  3 = GND  2 = Sig  4 = n.c.
- **MH Digital**
  - M12 5 pin: 2 = VDC  3 = GND  4 = CAN HI  5 = CAN LO  1 = n.c.
- **MH Analog**
  - V99: 0.50 - 4.50 VDC
- **MH Digital**
  - S01: CANopen Safety

#### Other specifications

- **Baudrate**: 2 500 kbit/sec
- **Node ID**: 40 40 hex

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**Note:** Dimensions are typical without tolerances.
## 5. Electrical installation

### MH Digital (5 pin)

<table>
<thead>
<tr>
<th>PIN assignment Digital 5 pin</th>
<th>F</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PIN 1</td>
<td>n.c.</td>
<td></td>
</tr>
<tr>
<td>PIN 2</td>
<td>VDC</td>
<td></td>
</tr>
<tr>
<td>PIN 3</td>
<td>GND</td>
<td></td>
</tr>
<tr>
<td>PIN 4</td>
<td>CAN HI</td>
<td></td>
</tr>
<tr>
<td>PIN 5</td>
<td>CAN LO</td>
<td></td>
</tr>
</tbody>
</table>

### MH Analog (4 pin)

<table>
<thead>
<tr>
<th>PIN assignment Analog 4 pin</th>
<th>H</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PIN 1</td>
<td>VDC</td>
<td></td>
</tr>
<tr>
<td>PIN 2</td>
<td>signal</td>
<td></td>
</tr>
<tr>
<td>PIN 3</td>
<td>GND</td>
<td></td>
</tr>
<tr>
<td>PIN 4</td>
<td>n.c.</td>
<td></td>
</tr>
</tbody>
</table>

#### Pin assignment (e.g. N10F)

1. n.c.
2. +12/24 VDC
3. GND (0 V)
4. CAN HI
5. CAN LO

#### Pin assignment (e.g. N08H)

1. +12/24 VDC
2. Signal: VDC
3. GND (0 V)
4. n.c.

### M12 connector system

![M12 connector diagram](image-url)

### Connecting schematics on vehicle electronics:

![Connection schematic](image-url)

- **ECU**: Chassis GND, 12/24 VDC, Signal
- **Cable shield**: Signal, GND, VDC
- **Press**: Chassis GND

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Please pay attention to operation manual.

All dimensions in mm.
6. In cylinder assembly

Mechanical installation
The robust Temposonics® MH sensor is designed for direct stroke measurement in hydraulic cylinders. The Temposonics® MH sensor can be installed from the head side or the rod side of the cylinder depending on the cylinder design.

Example

Sensor installation
The method of installation is entirely dependent on the cylinder design. While the most common method of installation is from the rod side of the cylinder, an installation from the head side of the cylinder is also possible. In both installation methods, the hermetic sealing of the cylinder is given by an O-ring with additional back-up ring.

Please pay attention:
- The position magnet shall not touch the pressure pipe.
- The min. bore diameter in the piston rod is 13.5 mm.
- Do not exceed operating pressure.

Flange housing with O-ring and back-up ring

Please pay attention to installation manual!

All dimensions in mm
6.1. Position magnets

<table>
<thead>
<tr>
<th>Part no.: 401 032</th>
<th>Part no.: 400 533</th>
<th>Part no.: 201 542-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>OD 17.4 mm</td>
<td>OD 25.4 mm</td>
<td>OD 33 mm</td>
</tr>
<tr>
<td>ID 13.5 mm</td>
<td>ID 13.5 mm</td>
<td>ID 13.5 mm</td>
</tr>
<tr>
<td>Height 8 mm</td>
<td>Height 8 mm</td>
<td>Height 8 mm</td>
</tr>
<tr>
<td>$P_a^* 10 \text{ N/mm}^2$</td>
<td>$P_a^* 40 \text{ N/mm}^2$</td>
<td>$P_a^* 40 \text{ N/mm}^2$</td>
</tr>
</tbody>
</table>

*max. mechanical burden, e.g. by circlip, lock washers etc.

Fastening torque for screws M4: max 1 Nm

6.2 Position magnet (M) and magnet assembly with spacer (S) in piston

<table>
<thead>
<tr>
<th>Part no.: 401 032</th>
<th>Part no.: 400 533</th>
<th>Part no.: 201 542-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>OD 17.5 mm</td>
<td>25.5 mm</td>
<td>33.1 mm</td>
</tr>
<tr>
<td>d 13.0 mm</td>
<td>13.0 mm</td>
<td>13.0 mm</td>
</tr>
</tbody>
</table>

Non-magnetic (stainless steel)

POM, PU, Aluminum

Magnetic (steel)

S = OD x 5 x 13.5

Please pay attention to installation manual!

All dimensions in mm
7. MH Analog Safety: Technical data / Model configurator

**Input**
- Measured variable: Position
- Stroke range: 50…2500 mm in 5 mm steps

**Output**
- Signal characteristic: Continuously analog output restricted by noise or A/D converter of control unit
- Voltage: 0.5…4.5 VDC with error output < 0.5 VDC
- Resolution: Typ. 0.1 mm
- Power uptime: Typ. 250 ms
- Null zone: 30 mm
- Damping: 63 mm

**Accuracy**
- Linearity: 50…250 mm ≤ ± 0.1 mm
- 255…2000 mm ± 0.04 % full stroke (F.S.)
- 2005…2500 mm ≤ ± 0.8 mm
- Hysteresis: ± 0.1 mm
- Internal sample rate: 2 ms
- Setpoint tolerance: ≤ 1 mm

**Operating conditions**
- Fitting position: Any
- Operating temperature electronics: -40 °C…+100 °C
- Storage temperature: -20 °C…+65 °C
- Fluid temperature: -30 °C…+85 °C
- Dew point, humidity: EN60068-2-30, 90 % rel. humidity, no condensation

**Pressure**
- Operating pressure ratings: Ø 10 mm pressure pipe pressure impulse test acc. to DIN EN ISO 19879
  - PN: 350 bar
  - Pmax: 450 bar
  - Pstatic: 625 bar

**IP rating**
- M12 connector: EN60529 (IP69K), plugged
- Sensor housing: EN60529 (IP67)

**Environmental testing**
- Shock: IEC 60068-2-27, 100 g (11 ms) single shock, 50 g (11 ms) at 1000 shocks per axis
- Vibration: IEC 60068-2-64, 20 g (r.m.s.) Ø 10 mm pressure pipe (10…2000 Hz) - resonance frequencies excluded
- EMC: 2009/64/EG road vehicles (e1 conform)
  2009/19/EG agricultural and forest machines
  ISO 14982 emissions/immunity
  ISO 7637-1/2 transient impulses
  ISO/TR 10605 electrostatic discharge (E.S.D.)

**Materials and dimensions**
- Pressure pipe: Stainless steel 1.4306 / AISI 304L (Ø 10 mm)
- Housing: 1. stainless steel 1.4305 / AISI 303
  2. steel 1.0718 (11SMnPb30) acc. to EN 10087
  Burnished (black oxide) acc. to DIN 50938
  Surface treatment to avoid corrosion during storage, handling and installation
  Flange Ø 48 mm
- Sealing: O-Ring 40.87 x 3.53 mm NBR 80, back-up ring 42.6 x 48 x 1.4 PTFE

**Electrical installation**
- Connector: Connector system M12x1 with O-ring 7 x 1.35 mm NBR 70
- Connecting flange brass nickel-plated with O-Ring 13 x 1.6 NBR 70
- Supply voltage: 12/24 VDC (tolerance range 8…32 VDC)
- Voltage supply ripple: < 1 % s-s
- Power drain: < 1 W
  - 12 VDC typ. < 100 mA
  - 24 VDC typ. < 50 mA
- Electric strength: 500 VDC (DC GND to chassis GND) @ 60 sec
- Insulation Resistance: R ≥ 10 MΩ (DC GND to chassis GND)
- Over voltage protection (GND-VDC): Up to +36 VDC
- Polarity protection (GND-VDC): Up to -36 VDC
- Load: R ≥ 10 kΩ
- Inrush current: Max 4.5 A/2 ms (24 VDC)
  Max 2.5 A/2 ms (12 VDC)
**Sensor model**
MH - Flange housing Ø 48 mm

**Form factor**
C - Stainless steel housing / Pressure pipe Ø 10 mm  
Damping 63 mm
R - Stainless steel housing / Pressure pipe Ø 10 mm  
Damping 63 mm, M4 female port
S - Steel housing / Pressure pipe Ø 10 mm  
Damping 63 mm

**Stroke length**
0050...2500 mm in 5 mm steps

**Connection type**
Single wires with connector system M12
N _ _ H - 4 single wires (20 mm increments), M12 IP69K, 4 pin (pin assignment 1-3-2)
N06H - 60 mm min. wire length
N24H - 240 mm max. wire length

**Supply voltage**
3 - +12/24 VDC

**Output signal**
V99 - 0.5...4.5 VDC

**Scope of delivery**
Position sensor, O-ring, back-up ring
M12 connector system
Please order magnets separately!

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**Accessories (selection)**

<table>
<thead>
<tr>
<th>Part no.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>401 032</td>
<td>OD 17.4 mm Ring magnet</td>
</tr>
<tr>
<td>400 533</td>
<td>OD 25.4 mm Ring magnet</td>
</tr>
<tr>
<td>201 542</td>
<td>OD 33.0 mm Ring magnet</td>
</tr>
</tbody>
</table>

**MH Testkit**

Scope of delivery:
- MH-Series Analog / PWM Tester
- 12 VDC battery charger with adapter
  (adapter main plug EU, adapter main plug UK)
- cable with M12 connector
- cable with pigtailed wires
- carrying case
- CD-Rom with user’s guide

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Serial Product available from Dec 2013
Please consult MTS for prototype request
## 8. MH CANopen Safety: Technical data/Model configurator

### Input
- **Measured variables:** Position and velocity
- **Stroke range (position):** 50…2500 mm in 5 mm steps
- **Measuring range (velocity):** 0…1000 mm/s

### Output
- **Signal characteristic:** EN 50325-5: bus-protocol acc. to CiA DS-304 CANopen Safety, device profile DS-406 V3.1
- **Resolution (position):** 0.1 mm
- **Resolution (velocity):** 1 mm/s
- **Boot up time:** Typ. 400 ms
- **Cycle time:** 25 ms
- **Null zone:** 30 mm
- **Damping:** 63 mm: stroke length ≤ 2500 mm

### Accuracy
- **Linearity:**
  - 50…250 mm ≤ ± 0.1 mm
  - 255…2000 mm ± 0.04 % full stroke
  - 2005…2500 mm ≤ ± 0.8 mm
- **Hysteresis:** ± 0.1 mm
- **Internal sample rate:** 1 ms
- **Setpoint tolerance:** ± 0.2 mm

### Operating conditions
- **Fitting position:** Any
- **Operating temperature electronics:** -40 °C…+100 °C
- **Storage temperature:** -20 °C…+65 °C
- **Fluid temperature:** -30 °C…+85 °C
- **Dew point, humidity:** EN60068-2-30, 90 % rel. humidity, no condensation

### Pressure pipe
- **Operating pressure ratings:** Ø 10 mm pressure pipe pressure pulse test acc. to DIN EN ISO 19879
  - PN: 350 bar
  - Pmax: 450 bar
  - Pstatic: 625 bar

### IP rating
- **M12 connector:** EN60529 (IP69K), plugged
- **Sensor housing:** EN60529 (IP67)

### Environmental testing
- **Shock:** IEC 60068-2-27, 100 g (11 ms) single shock, 50 g (11 ms) at 1000 shocks per axis
- **Vibration:** IEC 60068-2-64, 20 g (r.m.s.) Ø 10 mm pressure pipe (10…2000 Hz)- resonance frequencies excluded
- **EMC:** 2009/64/EG road vehicles (e1 conform)
  - 2009/19/EG agricultural and forest machines
  - ISO 14982 emissions/immunity
  - ISO 7637-1/2 transient impulses
  - ISO/TR 10605 electrostatic discharge (E.S.D.)

### Materials and dimensions
- **Pressure pipe:** Stainless steel 1.4306 / AISI 304L
- **Housing (electronic):**
  - 1. stainless steel 1.4305/AISI 303
  - 2. steel 1.0718 (11SMnPb30) acc. to EN 10087
  - Burnished (black oxide) acc. to DIN 50938
- **Sealing:** O-ring 40.87 x 3.53 mm NBR 80, back-up ring 42.6 x 48 x 1.4 PTFE

### Electrical installation
- **Connector:** Connector system M12x1 with O-Ring 7 x 1.35 mm NBR 70
- **Supply voltage:** 12/24 VDC (tolerance range 8…32 VDC)
- **Voltage supply ripple:** < 1 % s-s
- **Power drain:**
  - 12 VDC typ. < 100 mA
  - 24 VDC typ. < 50 mA
- **Electric strength:** 500 VDC (DC GND to chassis GND) @ 60 sec
- **Insulation Resistance:** R ≥ 10 MΩ (DC GND to chassis GND)
- **Over voltage protection (GND - VDC):** Up to -36 VDC
- **Polarity protection (GND - VDC):** Up to +36 VDC
- **Inrush current:**
  - 1.5 A/2 ms (24 VDC)
  - 1.0 A/2 ms (12 VDC)
**Tempsonics® Model configurator**

**Sensor model**
MH - Flange housing Ø 48 mm

**Form factor**
- C - Stainless steel housing / pressure pipe Ø 10 mm
  Damping 63 mm
- R - Stainless steel housing / pressure pipe Ø 10 mm
  Damping 63 mm, M4 female port
- S - Steel housing / pressure pipe Ø 10 mm
  Damping 63 mm

**Stroke length**
0050…2500 mm in 5 mm steps

**Connection type**
- Single wire with connector system M12
  N … F - 4 single wires (20 mm increments), M12 IP69K, 5 pin
  N06F - 60 mm min. wire length
  N24F - 240 mm max. wire length

**Supply voltage**
3 - +12 / 24 VDC

**Output**
- S01 - CANopen Safety, cycle time 25 ms (default setting)

**Baud rate**
- 0 - 1000 kbit/sec • 1 - 800 kbit/sec • 2 - 500 kbit/sec (default setting) • 3 - 250 kbit/sec • 4 - 125 kbit/sec • 5 - reserved • 6 - 50 kbit/sec • 7 - 20 kbit/sec • 8 - 10 kbit/sec

**Node-ID**
- CANopen Safety: hex 01...40
  - default setting: 40

**Scope of delivery**
- Position sensor, O-ring, back-up ring
- M12 connector system
- Please order magnets separately!

**Accessories (selection)**
- OD 17.4 mm Ring magnet 401 032
- OD 25.4 mm Ring magnet 400 533
- OD 33.0 mm Ring magnet 201 542-2

**MH testkit** 254 267
Scope of delivery:
- MH-Series CANopen / J1939 test software installation CD
- USB CAN-modul kit:
  - USB CAN modul
  - USB CAN mod utility CD (with drives and description)
  - USB connector cable
- Cable with MTS M12 connector and RS232 connector
- Cable with core cable ends and RS232 connector
- Carrying case
- Installation manual on CD
- 12 V charger with adapter

**Order information:**
For complete package please order both part numbers.
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1. Introduction

This manual provides electrical installation and operation guidelines for the Temposonics® MH Safety models with analog and digital outputs in safety related applications to the user. The MH Safety models are SIL (Safety Integrity Level) certified according to IEC61508, they have a performance Level (PL) in accordance with ISO 13849-1, and meet the EN 954-1 standard.

At present the new machine safety standards – the ISO 13849-1 and the IEC 61508 for machines are about to deal with the usage of safety related functions on machines. The purpose of this revision of machine safety standards is obvious: the EN 954-1 has an immediate need to include software components in terms of safety, especially regarding the potential risk of breakdowns caused by software failures. To include these aspects, the standardization committee defines the ISO 13849-1, which is based on the IEC 61508, which comprises programmable products such as safety control units with microcontrollers. MTS Sensors will have a SIL (Safety Integrity Level) category according to the IEC 61508 and a Performance Level (PL) according to the ISO 13849-1 in addition to the existing categories of the EN 954-1.

For manufacturers this means that, independent of which standard their products must meet, MTS products can easily be taken into consideration. Besides the SIL and the PL can be compared easily. The EN 13849 will cover all technologies like mechanical, electrical, pneumatic and hydraulic parts, so this standard would be most important for machine manufacturers. According to the DIN ISO 13849 the following risk graph is necessary to define which PL has to be fulfilled:

2. Risk analysis

2.1 Risk graph

Risk graph according to ISO 13849-1 determining PL for each safety function:

<table>
<thead>
<tr>
<th>Risk parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>S Severity of injury</td>
</tr>
<tr>
<td>S₁ Light (usually reversible injury)</td>
</tr>
<tr>
<td>S₂ Serious (usually irreversible injury including death)</td>
</tr>
<tr>
<td>F Frequency and/or duration of exposure to danger</td>
</tr>
<tr>
<td>F₁ Seldom to less frequent and/or short duration</td>
</tr>
<tr>
<td>F₂ Frequent to long-term and/or long duration</td>
</tr>
<tr>
<td>P Possibility of avoiding risk or limitation of damage</td>
</tr>
<tr>
<td>P₁ Possible under certain conditions</td>
</tr>
<tr>
<td>P₂ Scarcely possible</td>
</tr>
</tbody>
</table>

Within IEC 61508 the safety level (1 to 3) is given in Safety Integrity Level (SIL). Each level explains the possibility of a fail function. A higher level indicates a less risk of a fail function.
2.2 Performance level vs. safety categories

**PL**

| a | Cat. B | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |![](https://example.com/temposonics_mh_safety_safety_manual.png)
2.3 Probability of dangerous failure
SIL (IEC 61508) in relation to PL (ISO 13849)

<table>
<thead>
<tr>
<th>IEC 61508 SIL</th>
<th>MTTF&lt;sub&gt;d&lt;/sub&gt;</th>
<th>High Demand Mode PFH</th>
<th>EN 13849 Performance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>high 30 &lt; 100 years</td>
<td>≥ 10&lt;sup&gt;-8&lt;/sup&gt; to &lt; 10&lt;sup&gt;-7&lt;/sup&gt;</td>
<td>e</td>
</tr>
<tr>
<td>2</td>
<td>med 10 &lt; 30 years</td>
<td>≥ 10&lt;sup&gt;-7&lt;/sup&gt; to &lt; 10&lt;sup&gt;-6&lt;/sup&gt;</td>
<td>d</td>
</tr>
<tr>
<td>1</td>
<td>low 3 &lt; 10 years</td>
<td>≥ 10&lt;sup&gt;-6&lt;/sup&gt; to &lt; 3x10&lt;sup&gt;-6&lt;/sup&gt;</td>
<td>c</td>
</tr>
<tr>
<td>1</td>
<td>low 3 &lt; 10 years</td>
<td>≥ 3x10&lt;sup&gt;-6&lt;/sup&gt; to &lt; 10&lt;sup&gt;-5&lt;/sup&gt;</td>
<td>b</td>
</tr>
<tr>
<td>No special requirements</td>
<td>- x –x –</td>
<td>≥ 10&lt;sup&gt;-5&lt;/sup&gt; to &lt; 10&lt;sup&gt;-4&lt;/sup&gt;</td>
<td>a</td>
</tr>
</tbody>
</table>

Definition of MTTF<sub>d</sub> per channel acc. to parts count method:
All components of each channel have to be considered.

\[
\frac{1}{\text{MTTF}<sub>d</sub>} = \frac{1}{\text{MTTF}<sub>d</sub>} + \frac{1}{\text{MTTF}<sub>d</sub>} + \frac{1}{\text{MTTF}<sub>d</sub>}
\]

System | Sensor | Controller | Actor (Valve) | Weight |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>35 %</td>
<td>15 %</td>
<td>50 %</td>
<td></td>
</tr>
</tbody>
</table>
3. System design
3.1 Redundant design without internal diagnostic

2 Sensors, each with an independent output (reverse output operation) will be put into place. The validation of the function is performed by a cross-comparison where the correct output of 2 signals is:

\[ Z = CH(A) + CH(-B) = 0 \]

If this necessary result is not succeeded, the controller interprets a system fault and runs the system into the emergency stop.

Missing the diagnostic performance of the channels, the system is not able to detect which channel has failed. The controller is busy with the comparison algorithm and its processing capacity will be reduced.
3.2 Redundant design with internal diagnostic

Sensors with internal self-diagnostic capability enable a failure message independent from the controller processing loop. The sensor itself will run into the fail safe state.

The advantage of this architecture is clear: The controller is able to separate the channels and the system can run into a safe operational mode, where the machine is able to perform the function with one channel operation until the failed sensor gets replaced.
3.3 The safety function

The MH Safety sensor will continuously output a position signal proportional to the magnet position, and the internal diagnostic function will check safety relevant parameters within the hardware. In the event of a failure the sensor will output an error signal. The control unit (ECU) receives provided signals. In an event of a failure the ECU must react in an appropriate manner in order to manage the emergency function. The system will shut off or operate in emergency mode.

| MH Analog Safety                      | Voltage output | 0.5 to 4.5 V |
|                                       | Error output   | < 0.5 V      |
| MH CANopen Safety                     | Time delayed shifted data telegrams (bit inverted) |
|                                       | Counter enables unique assignment |
|                                       | Error status message |

Failure types
1. Safe failures ($\lambda_{sd}$ and $\lambda_{su}$) detected and undetected
2. Dangerous failures ($\lambda_{dd}$ and $\lambda_{du}$) detected and undetected

<table>
<thead>
<tr>
<th>Type of failures ($\lambda$) within safety related systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fail state</td>
</tr>
<tr>
<td>Safe fail</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Dangerous fail</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
4. Device specific notes

4.1 Determination and intend to use

The MH Safety model is a magnetostrictive linear-position sensor, which is designed for IN cylinder assembly and dedicated to mobile hydraulic applications. The MH Safety model is certified according to IEC61508 for single input in low and high demand, SIL 2 Safety Instrumented Systems and to ISO 13849 performance level d for single channel architectures. Dual channel architectures are realized by 2 sensors used in 2 cylinder applications “left/right” or “front/rear”. The sensor measures the relative position of a travelling magnet relative to its NULL position. The output signal is transmitted to an external controller (ECU) and processed according to its requirements.

4.2 Mechanical and electrical installation

No special or additional sensor installation requirements exist beyond the standard installation practices documented in the actual MH Series installation manual. Environmental operating specifications are applicable as published in the specifications section in the model MH Safety product specification.

4.3 Operating and OFFLINE PROOF tests

For complete information regarding performance, installation, operation, and specifications of MH Safety models, please refer to our product specification and available manuals. All installation recommendations as documented in the operating manual of MH sensors are applicable. Functional tests of safety relevant circuits will give a reliable statement about all components in use (sensor, controller and acting device). The user is responsible for applying an OFFLINE PROOF test (check interval is 1 year).

4.4 Maintenance and repair

The MH safety sensor is maintenance free. The MH safety models are not field repairable; device repairs must be performed by MTS. The electronic is encapsulated within a protective housing. All terminal faults\(^1\) which are not followed by 10 consecutive startups without terminal faults must be reported. In the event of a failure please contact MTS.

\(^1\) Please look at 4.8 for the description of terminal faults

4.5 Illegal and safety critical operation modes

All operating modes outside given specifications are not allowed. The specific limits are valid and they shall not be exceeded. All valid manuals and specifications need to be considered. Especially the programming manual and the operating manual need to be considered. No firmware changes are permitted nor authorized.

4.6 Common cause failure

The following CCF issues from annex F of the ISO 13849-1 standard have been considered in the design of the MH Safety models and can be used in overall system CCF analysis:

1. Physical separation between signal paths.
2. The sensor is protected against over-voltage, up to max. pressure rating, miswiring (VDC – GND).
3. The FMEDA is available and the results of the FMEDA were taken into account for CCF analysis.
4. The designers of this sensor have been trained to understand the causes and consequences of common cause failure.
5. The sensor has been tested for:
   - EMC (emission and immunity), Mechanical loads (e.g. vibration, temperature, pressure, fluid ingress) and environmental influences like fluid ingress and temperature. The sensor is compatible within these environments and is intended to be used in these conditions while it is sealed against contamination from those environments.
4.7 Measures against foreseeable misuse
The measures that have been taken against the foreseeable misuse of the MH Safety are:
1. Full protection against miswiring of the sensor.
2. Detailed instructions in the installation manual on methods to prevent damage to the sensor during installation.
3. Checking the function of the sensor after installation will mitigate the possibility of damage to the sensor after it has been damaged during the installation process.

4.8 Fault failure action plan
In the event the sensor exhibits a terminal fault response,

Failure Status
- MH Analog Safety: Signal output is less than 0.5 Volts
  A “terminal fault” is defined as the condition in which the sensor outputs a voltage < 0.5 Volts (turns off) due to an unsafe condition being detected. The sensor only recovers when the input voltage is removed and then reconnected to the sensor.
- MH CANopen Safety: The failure status byte within the received SRDO message is incorrect. The machine controller interprets this as an error and reacts in a certain manner.

The sensor must operate without a subsequent terminal fault for 10 consecutive starts following the initial fault response. All terminal faults which are not followed by 10 consecutive startups without terminal faults must be reported. Otherwise, the sensor must be returned to MTS for inspection.

4.9 Product identification
The model number of the sensor will be preceded by relevant string, indicating the output type.

Example: MH Analog Safety: MHC-xxxxM-NyyH-3-V99
MH CANopen Safety: MHC-xxxxM-NyyF-3-S01-2-40
5. MH Analog Safety

5.1 Functional description

The MH Analog safety position sensor is classified according to IEC 61508 type B and ISO 13849. Its design is based on isolated a three wire. The sensor performs self-diagnostics and enters a fail-safe state upon the detection of a failure, indicating the safety function cannot be performed. For the sensor output to be considered valid value must be in the range (0.5 to 4.5 volts) of 10 consecutive milliseconds. If the sensor output value ever lies outside of this range, and therefore in a fault condition, the fault condition shall be considered presently until the output is in the valid range of 10 consecutive milliseconds.

**ONLINE PROOF test:** The conditions that will trigger a fault are
• Missing or damaged position magnet
• Internal hardware failure
• Invalid checksum of parameter memory
• Magnet position is outside the valid measuring range
• Invalid checksum of program memory

5.2 Device parameter

Because of the applied operating mode and its influence on the safety of the complete system, safety critical parameters need to setup within the application. Please make sure that the software within the ECU is protected against non authorized access to the safety relevant parameters.

5.3 OFFLINE PROOF test: Method for checking the safety function in which the sensor must be removed from the cylinder

The OFFLINE PROOF test can be applied in order to check the safety function of the sensor. The safety function of the MH Safety sensor is internally checked but the diagnostic coverage of the sensor can be increased by checking the function of the sensor externally.

The recommended method for checking the function is:

1. Set the sensor to its zero position.
2. Stroke the sensor to its full-span position to confirm full range of motion and continuous output along full range.
3. Return the sensor to its zero position.
4. Perform a 3 point calibration verification of the sensor over the full-span of the sensor.
5. Move the magnet beyond the stroke range (NULL < 20 mm on F.S. > 70 mm) and make sure that the output voltage drops < 0.1 volts.
6. Remove position magnet to see voltage drops < 0.1 volts.

All applied methods and results of the proof test have to be written in a test report. When the functional test is negative, the device and the system need to be shut down. The process has to be kept in a safe mode due to appropriate actions. Please pay attention to the valid technical literature:

*Assembly and installation manual (MTS # 551 289)*
*Operating manual (electrical operation and installation), (MTS # 551 290)*

Please use MH Analog Testkit MTS p/n 280618
5.4 Safety tolerance (analog)
Please review the MH Safety product specification for the operating accuracy of the sensor. The safety accuracy of the MH Analog Safety is 2.5% full stroke. An example of the calculations necessary for determining the maximum safe position of the sensor magnet proceeds:

<table>
<thead>
<tr>
<th>Cylinder electrical stroke</th>
<th>Magnet (piston) speed</th>
<th>Actual magnet (piston) position</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 mm</td>
<td>100 mm/sec</td>
<td>200 mm - 10 mm - 1.0 mm</td>
</tr>
</tbody>
</table>

Safety Tolerance = 400 mm x 2.5% = 10 mm

@safe position = 10 mm

5.5 Certification and failure rate data
The failure rates are considered to the FMEDA acc. to IEC 61805. Calculations based on the failure rates of electronic components acc. to SN29500 and assuming an average temperature of 40 °C. The FMEDA is available for review.

Following assumptions are valid:
- The sensor operates in low and high demand mode
- Failure rates of external power supplies are not considered
- Please refer to FMEDA-report for mentioned SFF and PFDavg values
- The MH Analog Safety will enter a fail-safe state in the event of a failure
- The controller device needs to interpret the failure signal in the correct manner.
- The average operating temperature is typ. 40 °C
- The ambient conditions follow the specifications out of the valid data sheets.
- PFD value is calculated assuming a 1-year OFF LINE PROOF test interval.

MTS MH Sensor with analog safety output (V99)
Model No. MHC-xxxxM-NyyH-3-V99

MTS Sensors hereby confirms as manufacturer that all above mentioned requirements are fulfilled by safety related applications and design acc. to IEC/ EN 61508. Safety relevant parameters approved as follows:

<table>
<thead>
<tr>
<th>MH Analog Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 61508</td>
</tr>
<tr>
<td>Safety Level</td>
</tr>
<tr>
<td>Diagnostic Coverage</td>
</tr>
<tr>
<td>Device type</td>
</tr>
<tr>
<td>MTTF&lt;sub&gt;d&lt;/sub&gt;</td>
</tr>
<tr>
<td>PFD&lt;sub&gt;avg&lt;/sub&gt;</td>
</tr>
<tr>
<td>Diagnostic response time (Fail detection time)</td>
</tr>
<tr>
<td>Safety tolerance</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Device temperature</th>
<th>λ&lt;sub&gt;SD&lt;/sub&gt;</th>
<th>λ&lt;sub&gt;SU&lt;/sub&gt;</th>
<th>λ&lt;sub&gt;SD&lt;/sub&gt;</th>
<th>λ&lt;sub&gt;SU&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>(FIT) 60 °C</td>
<td>129 FIT</td>
<td>78 FIT</td>
<td>193 FIT</td>
<td>2 FIT</td>
</tr>
<tr>
<td>(FIT) 80 °C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6. MH CANopen Safety

6.1 Functional description

The linear position sensor MH CANopen Safety is specified acc. to IEC 61508 classified as type B. It contains self-diagnostics and is programmed to send Safety Relevant Data Objects (SRDO). The sensor is based on a single channel design. In an event of a detected failure, the max. Diagnostic Response Time and the max. Safety Tolerance must be considered.

- CANopen communication profile DS301 V4.02
- Encoder profile DS406 V3.2
- LSS service DS305 V2.1.1
- Framework for safety relevant communication DS304 V1.01
- Time delayed shifted messages (SRDO) will be sent bit inverted to the controller
- Counter for each transmitted CAN message (positive and inverted datas) enables the unique assignment of each position value.
- Error status message

The CAN message consists of the following bytes:
4 bytes (position), 2 bytes (velocity), 1 byte (status) and 1 byte (counter).

ONLINE PROOF test The conditions that will trigger a fault are:
• Missing or damaged position magnet  Emergency message
• Internal hardware failure  Emergency message
• Invalid checksum of parameter memory  SRDO message
• Magnet position is outside of the valid measuring range  SRDO message
• Electronic temperature > 100 °C  SRDO message

6.2 Device parameter

Because of the applied operating mode and its influence on the safety of the complete system, the sensor must be protected against non authorized access to the safety relevant parameters.

6.3 OFFLINE PROOF test: Method for checking the safety function in which the sensor must be removed from the cylinder

The OFFLINE PROOF test can be applied in order to check the safety function of the sensor. Within the OFFLINE test recommended functional tests: Please run the tests with activated password protection to avoid a parameter change by mistake.

The recommended method for checking the safety function is:

1. Set the sensor to its zero position.
2. Stroke the sensor to its full-span position to confirm full range of motion and continuous output along full range.
3. Return the sensor to its zero position.
4. Perform a 3 point calibration verification of the sensor over the full-span of the sensor.
5. Move the magnet beyond the stroke range (NULL < 20 mm on F.S. > 70 mm) and make sure that the error flags in the CAN message will appear.
6. Remove the position magnet and check error flags transmitted within CAN messages.
   The time monitoring of the controller software must give an error message as well.
   This is related to the time shift of complemented and inverted CAN messages.
7. Change safety relevant parameter setting by transmission wrong checksum to the sensor.
   To check if the corresponding failure flag is set within the respond CAN message of the sensor.

All applied methods and results of the proof test have to be written in a test report. When the functional test is negative, the device and the system need to be shut down. The process has to be kept in a safe mode due to appropriate actions. Please pay attention to the valid technical literature:

Assembly and installation manual (MTS # 551 289)
Programming manual (MTS # 901 492)
Operating manual (electrical operation and installation) (MTS # 551 291)

Please use MH Digital Testkit MTS p/n 280618 and MH Digital Testsoftware p/n 551288
6.4 Safety tolerance (digital)

Please review the MH Safety product specification for the operating accuracy of the sensor. The safety accuracy of the MH Analog Safety is 2.5% full stroke. An example of the calculations necessary for determining the maximum safe position of the sensor magnet proceeds:

<table>
<thead>
<tr>
<th>Cylinder electrical stroke</th>
<th>Magnet (piston) speed</th>
<th>Actual magnet (piston) position</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 mm</td>
<td>100 mm/sec</td>
<td>200 mm</td>
</tr>
</tbody>
</table>

Safety Tolerance: 400 mm x 2.5%

- a. 100 mm/sec x 5 msec
- b. 100 mm/sec x 25 msec

<table>
<thead>
<tr>
<th>@safe position</th>
<th>a. 0.5 mm</th>
<th>b. 2.5 mm</th>
<th>a. 189.5 mm</th>
<th>b. 187.5 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>= 10 mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- a. in the event of emergency message
- b. in the event of SRDO message

6.5 Safety relevant characteristics MH CANopen Safety

The failure rates are considered to the FMEDA acc. to IEC 61508. Calculations based on the failure rates of electronic components according to SN29500. Following assumptions are valid:

- The sensor operates in low and high demand mode
- Failure rates of external power supplies are not considered
- Please refer to FMEDA report for mentioned SFF and PFH_{avg} values
- The communication via CANopen Safety protocol will be performed acc. to CiA 304.
  - In an event of a failure the controller software must verify the received CAN messages and set the system into a safe state.
- The controller device needs to interpret this signal in a correct matter.
- The average operating temperature is typ. 80 °C
- The ambient conditions follow the specifications out of the valid data sheets.
- The sensor will be protected against non authorized settings (password protection)
- In addition to check the error flags, the software must implement a time out monitoring of received CAN messages, too.

MTS Sensor with CANopen safety protocol (S01)
Model No. MHC-xxxxM-NyyF-3-S01-2-40

MTS Sensors hereby confirms as manufacturer that all above mentioned requirements fulfilled by safety related applications and design acc. to IEC/ EN 61508. The data protocol follows the guidelines of CiA standard 304.

Safety relevant parameters approved as follows:

<table>
<thead>
<tr>
<th>MH CANopen Safety</th>
<th>EN 13849</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety Level</td>
<td>SIL 2</td>
</tr>
<tr>
<td>Diagnostic Coverage</td>
<td>SFF 98 %</td>
</tr>
<tr>
<td>MTTF_{s} (years)</td>
<td>10.750 years (60 °C)</td>
</tr>
<tr>
<td></td>
<td>4.530 years (80 °C)</td>
</tr>
<tr>
<td>PFH (1/h)</td>
<td>0.108 x 10^{-7} (60 °C)</td>
</tr>
<tr>
<td></td>
<td>0.255 x 10^{-7} (80 °C)</td>
</tr>
<tr>
<td>Diagnostic Response Time</td>
<td></td>
</tr>
<tr>
<td>(Fail Detection Time)</td>
<td>5 msec (emergency message)</td>
</tr>
<tr>
<td></td>
<td>25 msec (SRDO message)</td>
</tr>
<tr>
<td>Safety Tolerance</td>
<td>2.5 % F.S.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Device temperature</th>
<th>( \lambda_{sb} )</th>
<th>( \lambda_{su} )</th>
<th>( \lambda_{dd} )</th>
<th>( \lambda_{du} )</th>
<th>( \lambda_{o} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>(FIT) 60 °C</td>
<td>0</td>
<td>269</td>
<td>365</td>
<td>11</td>
<td>376</td>
</tr>
<tr>
<td>(FIT) 80 °C</td>
<td>0</td>
<td>577</td>
<td>821</td>
<td>25</td>
<td>846</td>
</tr>
</tbody>
</table>
### 7. Terms and abbreviations

<table>
<thead>
<tr>
<th>C</th>
<th>Cat.</th>
<th>Safety category acc. to EN 954-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>E/E/PE</td>
<td>Electrical/Electronic/Programmable Electronic</td>
</tr>
<tr>
<td>F</td>
<td>FIT</td>
<td>Failure in time (1x10⁻⁹ failures per hour)</td>
</tr>
<tr>
<td></td>
<td>FMEDA</td>
<td>Failure Mode, Effects and Diagnostic Analysis</td>
</tr>
<tr>
<td></td>
<td>FSM</td>
<td>Functional Safety Management</td>
</tr>
<tr>
<td>H</td>
<td>HFT</td>
<td>Hardware Fault Tolerance, ( HFT = x ) where ( x ) is the number of faults that the design can tolerate without losing its safety function.</td>
</tr>
<tr>
<td></td>
<td>High demand mode</td>
<td>High demand or continuous mode of operation (PFH)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Probability of a dangerous failure per hour</td>
</tr>
<tr>
<td>L</td>
<td>Low demand mode</td>
<td>Low demand mode of operation ( (PFD_{avg}) )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Average probability of failure to perform its design function on demand)</td>
</tr>
<tr>
<td>P</td>
<td>PFD(_{avg})</td>
<td>Probability of Failure on Demand (Average)</td>
</tr>
<tr>
<td></td>
<td>PFH</td>
<td>Probability of Failure per Hour</td>
</tr>
<tr>
<td></td>
<td>( P_L )</td>
<td>Performance Level according to ISO 13849</td>
</tr>
<tr>
<td>S</td>
<td>SFF</td>
<td>Safe Failure Fraction summarizes the fraction of failures, 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.</td>
</tr>
<tr>
<td></td>
<td>SIF</td>
<td>Safety Instrumented Function</td>
</tr>
<tr>
<td></td>
<td>SIL</td>
<td>Safety Integrity Level according to IEC 61508</td>
</tr>
<tr>
<td></td>
<td>SIS</td>
<td>Safety Instrumented System – Implementation of one or more Safety Instrumented Functions. A SIS is composed of any combination of device(s), logic solver(s), and final element(s).</td>
</tr>
<tr>
<td></td>
<td>SLC</td>
<td>Safety Lifecycle</td>
</tr>
<tr>
<td>T</td>
<td>Type A component</td>
<td>“Non-complex” component (using discrete elements); for details see 7.4.3.1.3 of IEC 61508-2</td>
</tr>
<tr>
<td></td>
<td>Type B component</td>
<td>“Complex” component (using micro controllers or programmable logic); for details see 7.4.3.1.3 of IEC 61508-2</td>
</tr>
<tr>
<td>V</td>
<td>V&amp;V</td>
<td>Verification and Validation</td>
</tr>
<tr>
<td></td>
<td>Verification</td>
<td>The demonstration for each phase of the life-cycle that the (output) deliverables of the phase meet the objectives and requirements specified by the inputs to the phase. The verification is usually executed by analysis and / or testing.</td>
</tr>
<tr>
<td></td>
<td>Validation</td>
<td>The demonstration that the safety-related system(s) or the combination of safety-related system(s) and external risk reduction facilities meet, in all respects, the Safety Integrity Requirements Specification. The validation is usually executed by testing.</td>
</tr>
</tbody>
</table>