Optimisation of and solutions to technical processes by means of sensors, networking and control systems

Training manual

Evaluation systems for pulse and standard signal monitoring
Training manual "Evaluation systems", version 2.0

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This manual was written with the utmost care. Nevertheless, we cannot assume any guarantee for the correctness and completeness of the contents.

Since errors cannot be avoided despite all efforts, we appreciate any comments.

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1 Introduction

1.1 Current situation

In today's industrial production rotational speed and standstill monitoring of drives is required in a large number of applications. The main reason for this is to avoid damage to machines or driven parts and products or to keep it to a minimum. Rotational speed monitoring can be carried out in this context to monitor rotating shafts but also movements of steady oscillation or linear movements.

More and more computer-aided control systems (PLC) are used for this purpose in the field of automation. Complexity and efficiency are constantly increasing. There are higher and higher requirements on planners, programmers and service staff.

A PLC can perform almost any kind of monitoring task of machine parts. The programs only have to be created accordingly. But even the easiest monitoring functions such as overspeed or slip of a clutch sometimes require considerably complex programming. The result is a big and extensive PLC program. It lacks clarity and the cycle time may be too long.

With regard to easier handling it is logical if many standard tasks run independently of the controller and messages are only provided in case of a fault. The monitoring task as such is ensured by independent systems that are easy to handle - evaluation systems such as monitors.

Advantages of decentralised solutions

- Time-critical queries can be implemented in independent devices such as evaluation systems with possibilities of parameter setting and displays for error messages.
- The controller is relieved of the small tasks. The program lengths are reduced so that smaller PLCs could be used.

Evaluation systems are stand-alone systems. Nowadays they provide very complex evaluations and can relieve a PLC considerably.

Typical applications for independent evaluation systems are monitoring:

- rotational movements
- linear movements
- oscillating movements
- transport speed
- slip
- synchronous movement
- direction of rotation
- skew
- rotational speed of engines
- slides, carriages
- vibratory conveyors
- conveyors
- slipping clutches
- hoists, shafts
- pumps, lift systems
- elevators

1.2 Unit families

The following unit families of evaluation systems are distinguished:

- pulse evaluation
- standard signal evaluation
- signal adaptation

1.2.1 Pulse evaluation

Pulse evaluation systems monitor rotating and linear movements as well as all physical quantities which can be converted into pulse sequences.

Units with different functions allow tailor-made monitoring of slow and fast rotational speeds as well as complex slip, synchronous or direction monitoring.
Relay or transistor outputs give a signal when the actual value is above or below the set limit value. Compact units with integrated sensor are a practical alternative to the units for DIN rail mounting.

1.2.2 Standard signal evaluation

Analogue standard signals (0/4 - 20 mA, 0 - 10 V) from sensors or transmitters can be detected, displayed and evaluated. Threshold relays and displays with analogue input show the actual values according to the preset physical units. Switching outputs signal if limit values are reached or exceeded.

1.2.3 Signal adaptation

Pulse dividers or converters adapt the pulse sequences to other systems such as programmable logic controllers. For example, they stretch the short pulse of an inductive sensor so that it is detected by a PLC input.

1.3 Designation of evaluation systems

In the framework of evaluation systems people partly talk about 'monitors' such as speed monitors or slip monitors.

Monitors

Background: These monitoring systems make decisions of binary nature. For example, only the question if the rotational speed has or has not been exceeded is answered. There are no statements such as: ‘a bit too fast’. Evaluation systems are called monitors.

---

1 2-wire DC sensors only providing an analogue current signal of min. 4 mA are called transmitters.
2 System set-up

The system including an evaluation system is usually set up like this:

pulse pick-up - evaluation system - monitor - controller

Illustration 1: System set-up

Instead of a controller there can also be contactor/relay circuits, a display and/or a measuring instrument.

2.1 Evaluation process

1. A pulse pick-up senses the movement of a machine part. The physical conditions e.g. rotational speed are converted into electrical, binary voltage pulses or analogue standard signals and transmitted to the evaluation system. The time distances between the electrical pulses are for example an indication of the speed and the size of the standard signal can be an indication of the system pressure of the plant.
2. The evaluation system converts these values into mathematically usable units and compares them with the set limit and preset values.
3. As a result of the comparison mostly binary switching signals are generated which are transferred to other evaluation options (e.g. PLC).
4. The PLC reacts to the signal of the evaluation system, e.g. by switching off a drive because it is blocked. It could be considerably damaged if it continues to remain under voltage.
5. In addition many evaluation systems can convert the sequence of binary input signals into analogue standard signal values and provide them via a separate signal output.

2.2 Pulse pick-ups

Electronic sensors/proximity switches, encoders and mechanical switches are used to generate the signals for the evaluation system.

2.2.1 Electronic pulse pick-ups

Advantages of electronic solutions with sensors and encoders are for example:

- non-contact detection of the plant parts
- ideal signal shape of the binary signals
- high switching frequencies
- no contact bouncing
Inductive, capacitive, photoelectric and magnetic sensors, for example, have electronic signal outputs. Only the incremental version of encoders can be used as pulse pick-ups for pulse evaluation systems. Electronic sensors can be designed so that they also provide analogue standard signals as current or voltage. In the Annex you can find tips and tricks for the use of inductive sensors on toothed wheels and shafts.

2.2.2 Mechanical pulse pick-ups
Mechanical contacts provide only binary signals. They are considerably resistant electrically and do not need any energy supply. These advantages are not relevant for evaluation systems. No high signal currents are required. And the evaluation systems provide sensors with a 24VDC voltage supply.

The disadvantages of mechanical contacts prevail if used with evaluation systems. These include:

- contact bouncing
- low switching frequency
- wear
- mechanical power required for activation
- limited switching frequency (life cycle)

Due to the disadvantages of mechanical switches mainly electronic sensors and encoders are used as pulse pick-ups.

2.2.3 Targets on the shaft
Non-contact pulse pick-ups such as inductive sensors are damped by metal parts sufficiently protruding from the moving machine part. The teeth of a toothed wheel are another example.
Number of targets
Since the evaluation electronics internally calculates the number of revolutions per minute or second, it has to know the correct number of targets on the shaft. If, for example, the setting on the evaluation electronics is 1 target but in reality there are four targets on the shaft, the evaluation system would calculate with a rotational speed four times as high and display the four-fold speed.

Symmetry
The distribution of the targets on the shaft has a considerable influence on evaluation. There are in general no problems with only one target. If there are several targets, they should be distributed on the shaft symmetrically and at the same distance.

Fluctuations analogue
If analogue signals are generated by the evaluation electronics, an unsymmetrical distribution of the targets will lead to fluctuations of the analogue signal.

2.3 Signal types
In electronics the following signal shapes are distinguished:

- binary signals
- analogue signals
- communication signals from bus systems

Evaluation systems mainly process binary signals. However, they can also evaluate analogue signals; they are not (yet) bus-compatible.

2.3.1 Binary signals
They are voltage pulses that only distinguish two possible states:

- physically 0 V = off = LOW = zero (0) = FALSE
- physically e.g. 24 V = on = HIGH = one (1) = TRUE
Evaluation systems

2.3.2 Analogue signals

There are two signal types:

- current loop 4 - 20 mA (also 0 - 20 mA)
- voltage 0 - 10 VDC

For further information we recommend the training manual "Sensors - signals and connection".
3 Terms

In the context of evaluation systems there are particular features and possibilities of parameter setting. They can be reached via a menu function which is displayed on the monitor. The most important and common ones will be briefly described below. However, not every possible parameter setting described is available for each monitor.

3.1 System and application parameters

Switching function outputs

Function output (in the setting menu: FOx).

- NC and NO function for the conditions:
  - current value below the switch point
  - current value above the switch point
  - within the frequency range
- Window function in connection with the parameter hysteresis.

Hysteresis for switch point

Hysteresis (in the setting menu: HYx).
The hysteresis value determines the difference between the switch-off point and the switch point. It prevents possible chattering of the switching output.

In connection with special switching functions an acceptable range or a fault range can be defined (window technology).

Output function analogue output

Function output (in the setting menu: FO1).
Setting values from 1 to 6.
1 = 4 to 20 mA, 2 = 0 to 20 mA, 3 = 0 to 10 V (1/2/3 = proportional output signals).
4 = 20 to 4 mA, 5 = 20 to 0 mA, 6 = 10 to 0 V (4/5/6 = antiproportional output signals).

Final value of the frequency range

Frequency high (in the setting menu: FHx).
The analogue MIN or MAX values can be indicated (final value of the frequency range).

Initial value of the frequency range

Frequency low (in the setting menu: FLx).
The analogue MIN or MAX values can be indicated (initial value of the frequency range).
Illustration 9: Example of the initial and final values of the frequency range with an analogue output

Averaging Cycles (in the setting menu: CYL).
Averaging of up to 16 measurements. Only influences the frequency-current-conversion and suppresses fluctuations.

Start-up delay Start-up delay time (in the setting menu: STx).
The start-up delay enables suppression of the error messages during start-up of the installation. It starts when the motor receives voltage or when 24VDC are applied to the reset input on the monitor during operation.
When the evaluation system has been switched on, the output for the time set is in the "good" state, i.e. no fault.
The time values can be set from 0.0 s to 1,000 s.
Setting to 0.0 s means: no start-up delay.

Display format Dimension (in the setting menu: DIM).
Indication in Hz or RPM\(^2\) (revolutions per minute).
When a new unit is selected, the monitor converts all existing values into the new unit.

Latch function for the outputs Store output (in the setting menu: SOx).
When this parameter is active, the respective output does not switch back automatically but must be reset (manually).
Setting values: 0 = inactive. 1 = front reset (activate button on the monitor). 2 = front reset and external reset.

Illustration 10: Latch function

Explanation of Illustration 10: SP: switch point; HY: hysteresis; A: overspeed - signal output switches on; B: rotational speed moderate - signal output should switch off, remains switched on, however, because of the latch function; D: switching off the signal output manually (front reset).

Targets - number Number of targets (in the setting menu: NCx).
Number of targets and thus number of pulses being registered per revolution. The monitor uses this value to calculate the rotational speed.

Time delay outputs Delay time (in the setting menu: DTx).

\(^2\) RPM: revolutions per minute
Enables delayed switching of the outputs. The respective output switches only if the current value is above or below the switch point for more than the time set here.

### Fleeting function outputs

**Fleeting time (in the setting menu: FTx).**
When an event occurs, the output changes its state during the set time and then automatically switches back to the initial state.

### Initial analogue value

**Analogue offset (in the setting menu: AOx).**
Current value displayed and provided for an input value of 0 Hz/RPM. Value range 0.0...20 mA (typical setting: 0.0 or 4.0 mA). The preset is 4.0 mA.

### Final analogue value

**Final value analogue (in the setting menu: FAx).**
Input value in Hz or RPM at which the final value 20 mA is displayed and provided. The output signal is limited to 20.5 mA.
Value range 0.1 to 1000.0 Hz or 1 to 60,000 RPM.
3.2 Menu structure for setting and parameter setting

Example for a speed monitor:

![Illustration 11: Possible menu structure of a monitor](image)

Illustration 11: Possible menu structure of a monitor

3.3 Operating elements of the monitor

![Illustration 12: Operating elements](image)

Illustration 12: Operating elements
3.4 Electrical connection, terminal connection of a monitor

Example of a speed monitor

Illustration 13: Possible electrical connection of a monitor (here without NAMUR inputs)

3.5 Connection of binary sensors to a monitor

Illustration 14: Possible connections of sensors to monitors

3.6 Typical input circuit of the monitor

Illustration 15: Input circuit (not for NAMUR³)

³ 2-wire sensors for hazardous areas with intrinsically safe output stage.
4 Operating principles of the evaluation systems

4.1 Measuring principles
The evaluation systems operate to two operating principles:

- pulse counting in a time unit (gate time principle)
- interval measurement (frequency measurement)

4.1.1 Pulse counting in a time unit (gate time principle)
During a certain identical gate time the incoming pulses are counted and compared with a preset value. If the actual value is below the preset value, fewer incoming pulses were detected. A shaft is turning too slowly, for example.

Illustration 16: Pulse counting between $t_s$ and $t_e$

If the actual value is above the preset value, the rotational speed is exceeded, i.e. the shaft rotates too quickly.

Frequencies are indicated in Hertz (Hz) and correspond to the indication for pulses per second (1/s or s⁻¹).

In that case the (input) frequency of the pulses relates to the speed.

4.1.2 Interval measurement (frequency measurement)
The first principle is based on an interval measurement: The time between the rising edges of two consecutive pulses is measured and compared with an adjustable preset value.

For a rotating shaft that means: If the measured time is higher than the preset time, the shaft rotates too slowly; there is underspeed.
If the actual value is smaller than the preset value there is overspeed.
The advantage of interval measurement is the shorter reaction time as compared to
the gate time measurement since the system already reacts from pulse to pulse.
With a measurement via a gate time the message is given after this time has elapsed.

4.1.3 Selection of the operating principle

Which of the two deviations (the actual value is above or below the set value) is to
be signalled depends on the type of application.

- Actual value below a preset value
  If, for example a V-belt is to be monitored, it makes sense to monitor the
  driven shaft for underspeed.
  In the event of slip or breakage of the V-belt the driven shaft becomes slower
  and an error message is signalled.

- Actual value above a preset value
  On a freight elevator an error message could make sense if the actual value is
  above the preset value which could indicate an overload of the system for
  downward travel.
Types of monitoring by means of monitors
Movements of installations and machines can be manifold. The following types of monitoring are in general distinguished according to the various tasks:

- rotational speed monitoring
- standstill monitoring
- slip/synchronous monitoring
- monitoring of the direction of rotation

4.2 Rotational speed monitoring
Rotational speed monitoring is a simple task for an evaluation system and refers both to overspeed, underspeed and monitoring of a rotational speed range (window).

Illustration 18: Not too fast ...

An evaluation system to monitor rotational speed can monitor rotating, linear, vibrating or oscillating movements. Hence everything that has to do with speed, rotational speed or frequency. For example:

- rotational speed monitoring of rotating shafts
- detection of rotating toothed wheels
- monitoring of vibrating conveyor systems
- underspeed on agitators
- checking the belt speed on conveyors

4.2.1 Operating principle of the speed monitor

- picking up the pulses from an external pulse pick-up
- calculating the input frequency/speed
- comparison with the set values
- switching of the outputs
- depending on the version provision of additional analogue values
4.2.2 Parameter setting of the speed monitor

To adapt to the requested monitoring a speed monitor can be set in many different ways. One factor is dependency on the unit design, such as:

- **Switching function**
  - Message in case of overspeed, underspeed or a window function for rotational speed.
- **Hysteresis**
  - Difference between the reset point and the set point - prevents possible ‘chattering’ of the switching output.
- **Start-up delay**
  - Error messages are suppressed for a certain time during start-up of the plant.
- **Delay time**
  - Adjustable time delay for the outputs.
- **Fleeting function**
  - When there is a message, the output changes its state for the set time and then switches back to the initial state.
- **Latch function**
  - Message has to be acknowledged
- **Wire-break monitoring of the pulse pick-ups**
- **Indication of the number of targets**
- **Initial and final value for the analogue output (scaling)**
- **Display with speed or frequency indication**

4.2.3 Monitoring example

Below an example of monitoring for overshoot and the performance of the signal output in conjunction with the different settings:

4.2.3.1 The start-up delay is active

- On power-on and during start-up the output is off (no error message - rotational speed not yet fast enough).
- If the rotational speed exceeds the switch point/set point, the output switches on (error message: ‘too fast’).
- If the rotational speed falls below the value of the set point minus hysteresis, the output switches off again.
4.2.3.2 Start-up delay not active:

- On power-on and during start-up the output is on (start-up delay).
- If the time for the start-up delay has elapsed and the rotational speed does not exceed the switch point, the output switches off.
- If the rotational speed exceeds the switch point when the start-up delay has elapsed, the output remains on.
- If the rotational speed falls below the value of the switch point minus hysteresis, the output switches off again.

4.2.3.3 Delay time (DT) is active

If the rotational speed exceeds the switch point, the output does not switch before the speed is above the switch point for at least the time of the delay time.

4.2.3.4 Fleeting time (FT) is active

If the rotational speed exceeds the switch point, the output switches on for the fleeting time set. Then the output remains off even if the rotational speed is still above the switch point. The rotational speed must have fallen below the switch point before another message is displayed in case of overspeed.

4.2.3.5 Latch function (SO) is active

If the rotational speed exceeds the switch point, the output switches on. It remains on even if the rotational speed falls below the value of the switch point minus hysteresis. The message must be reset/acknowledged on the unit or via remote control.

4.2.3.6 Sequence chart for monitoring overspeed

The switching characteristics of the signal output depending on the parameter setting are shown below.
4.3 Standstill monitoring

It is often the case that system parts have to stand still so that the next operating steps can be introduced. For example, the drill change must not be started before the drill does not 'stand'. Or the train, the bus or the tram must 'stand' before the doors can be opened.

For a human being it is relatively easy to find out if something is 'standing still'. The slower the movement becomes the more difficult it becomes. There is the same problem for the technical implementation of standstill indication. The standstill is determined on the basis of rotational speed measurement. The distance between two consecutive pulses is determined. If there is no more pulse, there must be standstill or almost standstill. But how is technology to know if there is another pulse at another time which would prove that there actually is no standstill?
For this reason the user has to define a min. value as a number of pulses or a frequency from which on the state 'standstill' exists. A minimum value is for example the indication of 3 pulses per minute. In other words, standstill is signalled if there is no more pulse for 20 seconds. Longer waiting times are usually not feasible.

### Illustration 22: Losing speed

<table>
<thead>
<tr>
<th>No. of pulses per minute</th>
<th>Response time in seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>20.0</td>
</tr>
<tr>
<td>4</td>
<td>16.0</td>
</tr>
<tr>
<td>5</td>
<td>12.0</td>
</tr>
<tr>
<td>6</td>
<td>10.0</td>
</tr>
<tr>
<td>10</td>
<td>6.0</td>
</tr>
<tr>
<td>12</td>
<td>5.0</td>
</tr>
<tr>
<td>20</td>
<td>3.0</td>
</tr>
<tr>
<td>60</td>
<td>1.2</td>
</tr>
<tr>
<td>80</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Illustration 23: Response times until standstill is signalled

Technical examples are rotational or other movements and also even strokes on:

- vehicles
- screw conveyors
- agitators and grinding gears
- centrifuges
- vibratory conveyors

#### 4.3.1 Operating principle of the rotational speed monitor for standstill monitoring

- picking up the pulses from an external pulse pick-up
- calculation of the input frequency
- comparison with preset values
- switching of the outputs

Illustration 24: Standstill monitoring principle

#### 4.3.2 Parameter setting of the speed monitor for standstill monitoring

To adapt to the requested monitoring task a standstill monitor has the same different possible settings as a speed monitor - see there. They are for example:
Evaluation systems

- switching function
- hysteresis
- start-up delay
- delay time
- fleeting function
- latch function
- wire-break monitoring of the pulse pick-ups
- number of targets
- display with speed indication

4.3.3 Number of targets

The higher the number of targets on a shaft, the better and more precise the standstill can be determined.

Example:
On a shaft there is one ring with 20 targets and one ring with one target. The standstill monitor is set to "smaller 5 pulses per minute". That corresponds to a max. waiting time of 12 seconds until the standstill is signalled.
For a ring with one target the rotational speed may still be one revolution in 12.1 seconds. However, standstill is already signalled.
For a ring with 20 targets the rotational speed is only one revolution in approx. 242 seconds until the standstill is signalled - thus considerably slower and therefore 'better' standstill.

Note: At high rotational speed and a high number of targets it is possible that the max. input frequency of the monitor is exceeded. 'Standstill' would be indicated since the monitor does not register any input pulses.

4.4 Slip/synchronous monitoring

In drive technology different systems are often coupled. This is usually made via clutches. Or several engines drive one machine part independently and simultaneously.

In the easiest case such a system consists of a drive and a driven part. In this context the drive is also called master. Usually it is a motor (electric motor, air motor, hydraulic motor, etc.)
The driven machine part is called non-drive end or slave.

It is important for a clutch that it does not slip or does not slip too long. While it slips, there is a rotational speed difference between the drive (motor side) and the non-drive end (e.g. gear side).
Evaluation systems

A: drive/master/motor;     B: clutch;     C: non-drive end/slave/gear/machine part

Illustration 26: Drive unit

This rotational speed difference is called slip. In the long run it can destroy the clutch or the production run is disturbed. Slip can be welcome or is permitted to a certain degree. The permitted rotational speed difference is indicated in percent or absolute rotational speed.

Synchronous movement

If a machine part is simultaneously moved by several independent, non-mechanically coupled drives, it is indispensable that the motors run at the same speed.

A: drive/master/motor;     C: non-drive end/slave/gear

Illustration 27: Four independent drive units

There must be synchronous movement between the individual drives so that the transport surface in the above example does not skew.

Solution to the problem

Skew or slip/synchronous monitoring is carried out by the evaluation system by the same name. In a figurative sense that means: If the clutch protects the motor, the slip/synchronous monitor protects the clutch. It can be very complex to replace a clutch.

The differentiation between slip monitoring or synchronous monitoring is smooth. If synchronous movement is monitored and synchronous movement exists, there is no slip. If slip is monitored and there is no slip, there is synchronous movement.

It often happens that a clutch has to have slip during heavy-load start-up. When a certain time has elapsed, synchronous movement is required so that the ‘sliding’ clutch is not damaged due to overheating. You may know this example from your car.

Comparing speeds

In a slip/synchronous monitor basically two speeds/frequencies/pulses are compared and evaluated. The speed on the motor side and the speed on the non-drive end. In between there may be the clutch.

The slip/synchronous monitor monitors for example:
Evaluation systems

- slipping clutches
- mechanically coupled drive motors
- even core feed in a cable machine
- belt conveyors
- spindles on a lifting platform

### 4.4.1 Operating principle of the slip/synchronous monitor

- simultaneous pick-up of the pulses from two external pulse pick-ups
- calculation of the input frequencies and/or counting the pulses
- determination of the difference
- comparison with preset values
- switching of the outputs

![Illustration 28: Slip/synchronous monitoring principle](image)

Elementary difference as compared with the speed/standstill monitor is that the slip/synchronous monitor has two separate pulse inputs and requires two independent pulse sequences for correct operation. It is important that the two speeds to be compared can be determined correctly. With different numbers of targets on the drive and the non-drive end there may easily be parameter setting errors of the monitor.

### 4.4.2 Parameter setting of the slip/synchronous monitor

To adapt to the required monitoring task a slip/synchronous monitor provides many different ways of setting. They are for example:

- **Switching function**  Signalling slip or synchronous movement.
- **Reset time**  Time after which the corresponding differential pulse counter is reset.
- **Start-up delay**  Error messages are suppressed for a certain time; for example during start-up of a plant.
- **Switch points**  Number of the differential pulses which must not be reached within the reset time.
- **Delay time**  Adjustable time delay for the outputs.
- **Fleeting function**  When there is a message, the output changes its state during the set time and then switches back to the initial state.
- **Latch function**  Message has to be acknowledged.
- **Wire monitoring**  of the pulse pick-ups
- **Number of targets**  Can be set separately for each pulse pick-up input.
- **Display with speed indication and slip**
4.4.3 Example of slip monitoring

A motor drives a gear via a clutch. There are two targets on a shaft at the drive end and two on the non-drive end. The drive speed is 1,500 revolutions per minute. During synchronous movement the monitor receives 3,000 pulses per minute on both inputs. That means 50 pulses per second.

Elementary parameters for the monitor:

1. reset time - resetting the differential pulses
2. number of targets
3. max. perm. number of differential pulses (within the reset time).

Illustration 29: Drive unit with pulse detection

To prevent the differential pulses from adding up to the limit value/switch point with frequent uncritical slip for a longer time which would cause a message, they are regularly reset when the adjustable reset time has elapsed. Only in case of critical slip or blocking is the allowed number of differential pulses exceeded within the reset time and the monitor switches.

Differential pulses are generated by:

- blocking maximum rotational speed difference in a very short period
- overload small rotational speed difference over a longer period

The length of the reset time also depends on the allowed rotational speed difference and the data of the clutch. In principle, it can be said:
The monitoring sensitivity increases when the reset time is prolonged for an identical number of differential pulses. With this setting the monitor has more time to add the differential pulses.

4.4.4 Operating states for the example in Illustration 29

**Synchronous movement - no slip:**
The pulse difference is therefore 0 pulses per second. There is no message.

**Blocking the non-drive end:**
The rotational speed of the drive of the motor remains the same with 1,500 revolutions per minute. The rotational speed of the non-drive end is now 0 revolutions per minute, however.
The rotational speed difference is 1,500 revolutions per minute. That means a pulse difference of 3000 pulses per minute (50 differential pulses per second since there are two targets).
Consequence: The monitor immediately gives a message.

**Overload - clutch is slipping:**
The rotational speed of the drive of the motor remains the same with 1,500 revolutions per minute. The rotational speed of the non-drive end is now only 1,440 revolutions per minute, however (the clutch is slightly slipping). Rotational speed difference: 60 revolutions per minute. That is a pulse difference of 120 pulses per minute (2 differential pulses per second).

1. Setting version for slipping clutch:
Max. number of differential pulses: 10 pulses per second (with two targets)
Set reset time: 10 seconds

Result: Slip is indicated since 10 differential pulses occurred within 5 seconds. And that is 10 differential pulses more than defined/permitted. The signal is given after already 5 seconds.

2. Setting version for slipping clutch:
Max. number of differential pulses: 20 pulses per second
Set reset time: 5 seconds

Result: No indication of slip since (only) 10 differential pulses occur within 5 seconds. After 5 seconds the memory of the added differential pulses is reset to zero.

4.5 Monitoring of the direction of rotation

The direction of rotation or sense of rotation indicates the direction in which points relatively move around an axis of rotation. It is distinguished between clockwise and counterclockwise rotation.

Illustration 30: Direction of rotation

Often there are definitions what your relative position is with regard to an axis of rotation to determine the direction of movement. With electric motors, for example, you look from the front at the shaft part protruding from the motor. Within a plant the operator can freely determine the directions of rotation and movement of a machine part. This circumstance has effects on the monitoring part, i.e. the direction of rotation monitor. Within this chain there is a definition when the drive moves into the right direction. It is always important to determine the direction of rotation of a plant part, when
Evaluation systems

- drives constantly have to change the direction of rotation due to operation
- there is the wrong direction of rotation after a motor has been replaced
- the backflow of a medium drives the pump in its opposite pump direction
- the wrong direction of rotation causes damage or even destruction of the machine part
- grinding gears are monitored
- the fixing systems of a freight crane do not grip any more and the load is slowly moving downwards.

4.5.1 Operating principle of the rotational direction monitor

- Picking up the pulses from two pulse pick-ups providing pulses with a time offset due to mechanical displacement.
- Determination which pulse pick-up has the first LOW/HIGH change.
- Switching of the outputs.

Illustration 31: Rotational direction monitor - principle

Pulse sequence not simultaneous

The motor evaluates the time offset of the two input pulses (pulse sequence) to determine the direction of rotation. For this purpose the mechanical arrangement of the two pulse pick-ups has to be as shown below. Or it is for example an incremental encoder always providing two phase-shifted signals.

Illustration 32: Arrangement of the pulse pick-ups

Furthermore it is required for the signal sequence that both input signals have to have a HIGH signal for a min. period of 0.25 ms.
4.5.2 Parameter setting of the direction of rotation monitor

To adapt to the requested monitoring a direction of rotation monitor can be set in many different ways. They are for example:

- **Evaluation mode** "Fast" detection of the direction.
  - The output switches on with the first input pulse.
  - When the sequence changes, the output switches back immediately.
- **Evaluation mode** "Reliable" detection of the direction
  - The output does not switch until the second sensor has also sent a pulse to the respective input. When the sequence changes, the output switches back immediately.
- **Start-up condition** For output 1 or A
- **Switching function** For output 1 or A
  - For output 2 or B
- **Start-up delay** Error messages are suppressed for a certain time; for example during start-up of a plant.
- **Delay time** Adjustable switch-on delay for the outputs.
- **Fleeting function** When there is a message, the output changes its state during the set time and then switches back to the initial state.
- **Reset time** If it is activated, the output switches back when the set time has elapsed, if within the reset time no direction-dependent pulses were detected.
- **Latch function** Message has to be acknowledged
- **Wire-break monitoring of the pulse pick-ups**
5 Standard signal evaluation

Standard signals are the analogue signals

- current DC 0/4 mA to 20 mA
- voltage DC 0 V to 10 V

A threshold relay can evaluate physical units that can be represented as analogue standard signals. There is no evaluation of binary pulses but of variable current or voltage values.

Application examples:

- limit value monitoring of flow, pressure, temperature or level
- monitoring of the difference between inflow and return flow or
- pressure difference monitoring.

5.1.1 Operating principle of the standard signal monitor

- pick-up of the standard signal from an external source
- comparison with the set values
- switching of the outputs

Illustration 34: Standard signal evaluation - principle

5.1.2 Monitoring example

Each time the analogue value exceeds SP, the signal output switches. Only if the analogue value falls below SP-HY, does the output signal drop again.

Illustration 35: Monitoring analogue voltage

5.1.3 Parameter setting of the standard signal monitor

To adapt to the requested monitoring a standard signal monitor can be set in many different ways. They are for example:
Evaluation systems

- Operating mode Comparison of overspeed and underspeed or of two analogue signals.
- Type of input signal
- Switch point
- Hysteresis
- Initial and final value of the measuring range
- Switching function of the outputs
- Latch function Message has to be acknowledged.
- Signal and wire monitoring
- Dimension for the display
- Hysteresis Distance between the reset point and the set point. The hysteresis prevents possible 'chattering' of the switching output.
- Start-up delay Messages are suppressed for a certain time during start-up of the plant.
- Delay time Adjustable time delay for the outputs.
- Wire-break monitoring of the pulse pick-ups
- Number of targets

5.1.4 Connection of analogue sensors to a monitor

A: transmitter;  B: 3-wire sensor;  C: transmitter with external power supply;
D: 3-wire sensor - with external power supply

Illustration 36: Possible connection of analogue sensors to monitors
6 Signal adaptation

Frequency

Binary signal sequences can have high frequencies. Then a binary signal is very short, i.e. shorter than 5 ms.

Pulse length

Pulses or pulse sequences can be so fast or short for control monitors such as PLCs that they cannot be completely/reliably detected. An adaptation of these fast or short signals is then necessary.

For this purpose special units for signal adaptation can be used:

- pulse dividers
- pulse stretchers

6.1 Pulse divider

Pulse dividers convert pulse sequences with a high frequency in pulse sequences with a lower frequency.

A certain number of pulses is converted in a pulse according to a defined division ratio. Assuming a division ratio of 10:1 for example, a frequency of 1.5 kHz becomes a frequency of 150 Hz.

Illustration 37: Pulse divider 1: 10

Besides the fixed pulse dividers (e.g. 10:1) there are also adjustable units. Using these pulse dividers you can select the division ratio between 1:1 and 255:1 and thus adapt it to the requirements.

6.2 Pulse stretcher / pulse converter

A pulse stretcher stretches short binary signals for a certain time duration.

Illustration 38: Pulse stretching

Let us assume a pulse is stretched for 25 ms. Then there should be a longer time between the increasing edges of the input pulses (IN) than 25 ms. The next output pulse (OUT) is prepared with the falling edge of the input pulse (IN).

If the input pulse sequence is shorter than 25 ms, the time for the output starts running again - see Illustration 38. If short pulse sequences are permanently at time intervals shorter than 25 ms, the output signal (OUT) will remain permanently ON.
With a duration of the input pulse (IN) of more than 25 ms the output pulse remains ON for the same period.
7 Evaluation systems from ifm

Below you will get an overview of the different evaluation systems from ifm with some of the most important data.

7.1 Rotational speed and standstill monitoring

The speed monitors from the ifm range of products differ in certain technical data and features. They can also be used as standstill monitor (standstill is in principle a very low speed).

7.1.1 Monitors

They are cabinet units with DIN rail mounting.

Illustration 39: Monitor

Distinctive features:

- Operating voltage: direct voltage and alternating voltage in a large range
- Number of inputs and thus the number of the speeds that can be separately evaluated
- Number of the outputs (one channel or two channels)
- NAMUR inputs (8.2 V). It is also possible to connect sensors that are intrinsically safe. These sensors must, however, not be installed in the hazardous areas.
- Monitoring wire break (NAMUR)

7.1.2 Compact units or compact speed monitor

Pulse pick-up (sensor) and evaluation (monitor) are combined in one sensor housing. Main applications monitor underspeed and blocking.

Illustration 40: Compact speed monitor

For various units of this family the actual signal frequency is another signal output besides the static signal for overspeed or underspeed (type M18 - DGA).
Evaluation systems

Distinctive features:

- Housing types: M18 or M30 metal
- Connections: connector or cable
- Operating voltage: direct voltage and alternating voltage in a large range
- Setting ranges
7.1.3 Data sheets

Illustration 42: Example data sheet - speed monitor
Illustration 43: Example data sheet - compact speed monitor
7.2 Slip/synchronous monitoring

The slip/synchronous monitors in the ifm range of products differ in certain technical data and features. They can be used as slip or synchronous monitor depending on the respective setting and additionally as speed monitor.

7.2.1 Monitors

They are cabinet units with DIN rail mounting.

Illustration 44: Monitor

Distinctive features:

- operating voltage, direct voltage and alternating voltage in a large range
- pulse evaluation system for slip/synchronous monitoring and separately for frequency, rotational speed and speed
- with differential pulses and reset time
- with separate slip signals
- two relay outputs and two transistor outputs
- NAMUR inputs (intrinsically safe; 8.2 V). It is possible to connect sensors that are intrinsically safe. These sensors must, however, not be installed in the hazardous areas.
- monitoring wire break (NAMUR)
7.2.2 Data sheet

Illustration 45: Example data sheet - slip/synchronous monitor

7.3 Direction of rotation monitor

The direction of rotation monitors in the ifm range of products differ in certain technical data and features.

7.3.1 Monitors

They are cabinet units with DIN rail mounting.
Illustration 46: Direction of rotation monitor

Distinctive features:

- operating voltage, direct voltage and alternating voltage in a large range
- pulse evaluation system for direction monitoring and separately for frequency, rotational speed and speed
- two relay outputs and two transistor outputs
- NAMUR inputs (intrinsically safe; 8.2 V). It is possible to connect sensors that are intrinsically safe. These sensors must, however, not be installed in the hazardous areas.
### 7.3.2 Data sheet

**Illustration 47: Example data sheet - direction of rotation monitor**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal voltage [V]</td>
<td>110...240 AC/DC (85...89 Hz) DC (up to 24 DC)</td>
</tr>
<tr>
<td>Voltage tolerance [%]</td>
<td>1...10</td>
</tr>
<tr>
<td>Contact rating</td>
<td>6 A (250 V AC), 500 V, 3000 A</td>
</tr>
<tr>
<td>Power consumption [W]</td>
<td>2 (250)</td>
</tr>
<tr>
<td>Adjustment range</td>
<td>透过/通过, 来自/来自 (24 V)</td>
</tr>
<tr>
<td></td>
<td>加速设置电压: 24 V DC/15 mA, 短路电路保护</td>
</tr>
<tr>
<td></td>
<td>阈值电压: &gt; 1 V DC, &lt; 0 V</td>
</tr>
<tr>
<td></td>
<td>瞬时电压: &gt; 10 V DC, &lt; 6 V</td>
</tr>
<tr>
<td>Input frequency (max)</td>
<td>1 kHz (corresponds to min. pulse length / space 0.1 ms)</td>
</tr>
<tr>
<td>Translator outputs</td>
<td>透过/通过, 端口/端口</td>
</tr>
<tr>
<td></td>
<td>开关电压/开关电压: 24 V DC / max. 15 mA; 短路电路保护</td>
</tr>
<tr>
<td>Measuring error [% of the final value]</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Switching function</td>
<td>1 switching output for indication of direction; 1 switching output for unacceptable speed and acceptable range</td>
</tr>
<tr>
<td>Max. relative air humidity [%]</td>
<td>75 (35°C)</td>
</tr>
<tr>
<td>Ambient temperature [°C]</td>
<td>-20...80</td>
</tr>
<tr>
<td>Storage temperature [°C]</td>
<td>-25...80</td>
</tr>
<tr>
<td>Protection housing / terminals</td>
<td>IP 50 / IP 20</td>
</tr>
<tr>
<td>EMC</td>
<td>EN 61801-1:1992 + A2:1995</td>
</tr>
<tr>
<td></td>
<td>EN 60664:8/1</td>
</tr>
<tr>
<td></td>
<td>EN 61800-9/2</td>
</tr>
<tr>
<td>Housing materials</td>
<td>绝缘/隔离</td>
</tr>
<tr>
<td>Function display</td>
<td>绿色/绿色 (light when the relay is energized / the translator is closed)</td>
</tr>
<tr>
<td></td>
<td>黄色/黄色</td>
</tr>
<tr>
<td>Input pulsar LED</td>
<td>数字显示器, 7位/7位</td>
</tr>
<tr>
<td>Function LED</td>
<td>连接方式/连接方式</td>
</tr>
<tr>
<td></td>
<td>连接方式/连接方式</td>
</tr>
<tr>
<td>Weight [kg]</td>
<td>0.385</td>
</tr>
<tr>
<td>Remarks</td>
<td>过载/超过类别; 角度/角度</td>
</tr>
</tbody>
</table>

- **Wiring**
  1. DC supply voltage (8...)
  2. DC supply voltage (8...)
  3. common transistor output (8...)

- **Evaluation systems from ifm** - **Direction of rotation monitor**
8 Application examples

8.1 Speed monitor

8.1.1 Coolant control on drills

A speed monitor monitors the minimum rotational speed of the drill spindle. Furthermore, coolant is only supplied when the drill spindle is in rotation.

8.1.2 Speed monitoring on wind power stations

Wind power stations can be operated only up to a certain maximum wind speed. A speed monitor can monitor if this speed is exceeded by detecting the rotor shaft.

8.1.3 Speed monitoring on rope winches

An incremental encoder provides pulses in proportion to the winding speed of the rope. The speed monitor monitors the winch in terms of exceeding the maximum speed and switches off the motor.
Additionally, start-up monitoring can be carried out. I.e. that after a defined period of time after power-on the brake must have been released. To avoid an error message in the event of standstill the start-up delay is activated on the reset input by applying a voltage of +24V.

8.1.4 V-belt monitoring

Illustration 51: Long response times with only one target

V-belts are heavily strained components which have to be monitored. The necessary pulses are generated by means of an inductive sensor and targets on the driven disc. The clearance between the targets is an indicator of the response time. The more targets are arranged on the circumference, the faster the standstill monitor can react. When the intervals between the pulses become too long, e.g. due to slip or breakage of a V-belt, the standstill monitor signals a fault.

Illustration 52: Short response times due to a larger number of targets

8.1.5 Speed monitoring on a conveyor belt

Illustration 53: Overload protection on a conveyor belt

In the worst case overload or too heavy stretching of a conveyor belt can lead to its destruction. Here, the rotational speed of the driving roller and deflection roller is monitored by means of a speed monitor and unacceptable differences are detected.
8.1.6 Ventilation monitoring in chemistry

Illustration 54: Two ventilators are monitored by one unit

In chemical processes monitoring of the forced ventilation is often required (e.g. when toxic vapours occur). The fan blades can be detected without contact by means of inductive or capacitive sensors. The generated pulses are independently monitored for underspeed by a speed monitor with two separate evaluation ranges.

8.1.7 Standstill monitoring on grinding gears

Illustration 55: Dust monitoring on a stone mill

In a stone grinding gear there is often blocking caused by boulders. A standstill monitor can detect this error by monitoring the actuator shaft and by switching off the motor.

8.1.8 Monitoring the PLC program cycle

Illustration 56: Monitoring the program cycle on a PLC (watchdog function)

To monitor the processing time of PLC programs the time for one cycle can be measured. To do so, an output is repeatedly set and reset after each program cycle. The time between these two output states is an indicator for one program cycle. If this time is extended due to programming faults or a system crash, the standstill monitor signals this fault.
8.2 Slip/synchronous monitor

8.2.1 Monitoring slip on material conveyors

Illustration 57: Vertical conveyors with slip monitoring (elevators)

Overload protection on continuous conveyors, bucket elevators etc. can be implemented by non-contact slip and speed monitoring by means of inductive sensors and a slip monitor. When the rotational speed of the upper reel is outside the permitted range as compared with the lower reel, there will be a slip signal. A long-lasting overload of the system can be signalled by the additional use of the integrated speed monitoring function.

8.2.2 Monitoring slip on slipping clutches

Illustration 58: Monitoring slip on a slipping clutch

A slipping clutch is monitored by a slip monitor. It is important that the rotational speed difference between drive and non-drive end does not exceed the defined value. A dual-channel slip/synchronous monitor can monitor two preset values. Besides the max. slip (e.g. blocking) in channel 1 minor differences can be detected and evaluated for a longer period of time (channel 2) since otherwise the clutch could be destroyed.
8.2.3 Slip monitoring in cable machines

![Illustration 59: Monitoring slip on a cable machine](image)

The rotational speed of the deflection rollers is converted into pulses by means of inductive sensors and controlled by a slip sensor. When the cores are stretched or torn, a rotational speed difference arises. The slip monitor detects this fault and switches off the machine.

8.2.4 Monitoring elevators

![Illustration 60: Synchronous monitoring on an elevator](image)

Synchronous monitoring is carried out for mechanically coupled drive motors such as elevators, conveyor belts, etc., using a slip/synchronous monitor to avoid damage to the gear or motors. Additionally, a minimum rotational speed can be monitored.

In this example an inductive sensor in the lower area of the elevator generates the pulses for the master side (drive). The other side (slave side) is not illustrated. But here the pulses are generated by an inductive sensor as well. Elevators of this type are used in various applications.

8.2.5 Synchronous monitoring on lifting platforms

![Illustration 61: Lifting platform is monitored for synchronous movement](image)

A lifting platform is driven by two synchronous spindles. If one spindle failed, the lifting platform would tilt and the lifted goods would fall down. The rotational speeds of the two spindles are constantly detected by inductive sensors. The slip/synchronous monitor monitors the permissible difference.
8.2.6 Conveyor system with synchronous monitoring

Wooden panels (e.g. doors) are transported on a belt at high speed (approx. 60 m/min) along machines for edge banding. Solid metal bolts ensure that the panels are always at the same distance. To monitor synchronous movement two inductive sensors and one slip/synchronous monitor are used.

8.3 Direction of rotation monitor

8.3.1 Back-flow monitoring on pumps

Only one pump is necessary for the operation of the system. The second pump is used as reserve. Operation is carried out alternately so that both pumps are equally used.

If, for example, the first circuit runs with pump 1 and valve 1 and the non-return valve V2 is faulty, the medium will be pressed back into the second circuit. That causes pump P2 to run backwards. This fault can be detected by monitoring the direction of rotation of the pumps.
8.3.2 Freight elevator with detection of the direction of rotation

Illustration 64: Detection of direction on a freight elevator

A direction of rotation monitor is used on a freight elevator. The upward or downward movement of the elevator is signalled by the direction monitor. The two inductive sensors are offset so that overlapping, i.e. the simultaneous damping of the sensors for at least 2.5 ms, is possible.
Inductive sensors are frequently used when movements, rotational speed and speed are to be detected. Below you will find some information about the use of inductive sensors for mechanical damping by machine parts such as shafts, pins, slides or toothed wheels.

Before you start you can refresh your knowledge about the inductive sensor (chapter 9.1). Then you will find some brief information about the term ‘pulse/pause ratio’ (chapter 9.2) and then some considerations about the different operating conditions (chapter 9.3).

9.1 Inductive sensor - basics

An inductive sensor detects any metal without contact. It cannot distinguish whether it is your target or its metal installation surroundings.

9.1.1 Sensing range

The sensing range is the mechanical distance activating the signal output with axial approach of sufficiently plane metal.\(^4\)

In this respect we distinguish mainly the nominal sensing range, the real sensing range and the assured operating distance.

- **Nominal sensing range**
  - The nominal sensing range is often abbreviated as \(s_n\), it is a data sheet indication and a mere statistic value of the unit. The nominal sensing range is characteristic of a sensor. E.g. \(s_n = 4\) mm or \(s_n = 15\) mm.

- **Real sensing range**
  - Even with remeasurement according to the standard the nominal sensing range is not met. A tolerance of \(\pm 10\%\) around the nominal sensing range is permitted. That is the real sensing range \(s_r\) at room temperature.

- **Operating distance**
  - The abbreviation of the operating distance is in general \(s_o\) and there may be another deviation of \(\pm 10\%\) from the real sensing range due to temperature influence.
  - Possibly only approx. 80% of the nominal sensing range may be left or there may be 120%.
  - That results in an (assured) operating distance of 0% to 80% of the nominal sensing range.

\(^4\) Here axial means that the target approaches the sensor from the front, the centre and plane-parallel to the sensing face.
Evaluation systems

A: nominal sensing range;  B: real sensing range;  C: operating distance;
D: max. deviation upward.

Illustration 65: Sensing ranges - tolerance ranges

In the worst case the metal of the target must have approached the sensing face of a sensor with $s_n = 20$ mm at a distance of approx. 16 cm so that the output stage of the sensors switches. In theory it is also possible that it already switches at a mechanical distance of approx. 24 mm.

The permitted tolerances apply to both directions from the nominal sensing range

**Tip 1:**

80% rule

To determine the mechanical distance between the target surface and the sensing face of the sensor you should expect 80% of the nominal sensing range. It is assured and guaranteed by the sensor manufacturer.

Examples:
- $s_n = 2$ mm; you use $s_a = 1.6$ mm for your calculation
- $s_n = 5$ mm; you use $s_a = 4$ mm for your calculation
- $s_n = 15$ mm; you use $s_a = 12$ mm for your calculation
- $s_n = 20$ mm; you use $s_a = 16$ mm for your calculation

**9.1.2 Correction factors**

Standard target

The above-mentioned percentages for the sensing range only apply if the standard target is used for their determination.

Their main characteristics are:
- Metal from mild steel (ferromagnetic), square-shaped, even, 1 mm thick, no rounded edges and corners. Their size (edge length) depends on the nominal sensing range of the sensor to be measured.
- In general the following applies: The edge length (‘m’ in Illustration 66) of the standard target is three times the length of the nominal sensing range of the sensor.
- If the sensor to be measured has a nominal sensing range of 10 mm, the edge length of its square-shaped standard target is $3 \times s_n = 3 \times 10$ mm = 30 mm.

Illustration 66: Standard target

Enlarging the target to more than three times the nominal sensing range will not lead to an increase of the sensing range.
Note: If the above calculation results in an edge length below the diameter of the sensing range of the sensor, the edge length of the standard target must be equal to the diameter of the sensing face.

Example: The sensor is an M12x1 thread. The diameter of the sensing face of the sensor is therefore 12 mm. Its nominal sensing range \( (s_n) \) is 2 mm. 

\[ 3 \times s_n = 3 \times 2 \text{ mm} = 6 \text{ mm} \]

edge length of the standard target for this sensor. And therefore it is smaller than the diameter of the sensing face. Therefore: the edge length of the standard target for this sensor is 12 x 12 mm².

Every inductive sensor has a standard target which is adapted to its nominal sensing range with regard to the size.

**Correction factor target surface**

There are no standard targets in industrial installations.

A: standard target - minimum size;     B: 1/2 of the edge length of A;
C: 1/4 of the edge length of A;     D: 1/6 of the edge length of A;

**Illustration 67: Correction factor target surface**

The further the surface of the target is below the calculated value of the standard target, the closer it has to be installed to the sensor.

**Target surface ≥ sensing face sensor**

Remember that the size of the target surface must be at least the same as that of the sensing face of the sensor. Then the losses referred to the sensing range will be limited.

**Correction factor target shape**

If the surface of the target is not even, you will also have to expect losses for the sensing range.

A: ideal;     B: unfavourable;     C: very critical;    D: critical

**Illustration 68: Target shape**

**Correction factor material (Kₘ)**

The type of metal of the target is decisive for the standard sensor. Ferromagnetic metals such as iron and steel are best. They obtain the longest sensing ranges (see standard target).

The less iron the metal contains, the smaller the sensing ranges when the target surface remains the same.

On the basis of iron \( (Kₘ = 1) \) stainless steel has a \( Kₘ \) of approx. 0.7, aluminium of approx. 0.4 and copper of approx. 0.3. That is 100, 70, 40 and 30 percent of the nominal sensing range \( s_n \).
Evaluation systems

A: iron (1.0); B: stainless steel (0.7); C: aluminium (0.4); D: copper (0.3);

Illustration 69: Correction factor material - sensing ranges

Example, at a nominal sensing range $s_n = 20$ mm:
area always the same size ($60 \times 60$ mm$^2$), targets from

- iron ($K_M = 1.0$) $s = 20$ mm (80 % rule: 16 mm)
- stainless steel ($K_M = 0.7$) $s = 14$ mm (80 % rule: 11.2 mm)
- aluminium ($K_M = 0.4$) $s = 8$ mm (80 % rule: 6.4 mm)
- copper ($K_M = 0.3$) $s = 6$ mm (80 % rule: 4.8 mm)

Tip 3:
In case of doubt use inductive sensors without correction factor. These are the $K=1$ units.

9.1.3 Flush and non-flush

The fact if the installation location is metal or not is decisive for the two installations ‘flush’ and ‘non flush’.

Flush-mountable sensors may be flush mounted in metal. They can, however, also be mounted non flush.
Non-flush mountable sensors must be mounted non-flush in metal.
The designations for the installation on the type label are:

'f' = flush and 'nf' = non flush.

The non-flush mountable sensor has a longer sensing range than the flush mountable sensor of the same type. Partly with double the value:
E.g. an M30 sensor: 'f' with $s_n = 10$ mm, 'nf' with $s_n = 15$ mm (plus 50 %); an M12 sensor: 'f' with $s_n = 2$ mm, 'nf' with $s_n = 4$ mm (plus 100 %).

Tip 4:
Flush mounting is universal
In a tight metal installation environment a flush mountable sensor is better suited since due to its shorter sensing range it does not react as sensitively to its installation environment. In addition it is protected by the surrounding metal.
9.1.4 Coverage of the sensing face

Unless the entire sensing face of the sensor is covered by the target, problems may arise.

Illustration 71: Coverage of the sensing face

If the target moves slowly and at a short distance to the sensing face, the sensor will switch in the three examples of Illustration 71.
If the distance to the sensing face of the sensor becomes longer and/or if the travel speed of the target increases, first constellation 'E' and then constellation 'D' will cause problems.

9.1.5 Switch-on curve and travel speed

Axial damping (i.e. from the front in direction of the sensing face of the sensor) is not as frequent in installations as the radial damping direction. The target approaches the sensor from the side at a sufficient distance.

Illustration 72: Radial damping direction - typical of speed monitoring

If the target passes by within the sensing range, the following effect will typically occur:
The farther the target is away from the sensing face of the sensor, the more it must cover the sensing face to trigger the switching operation.
This behaviour is represented in the switch-on curve which is created for each sensor separately.
Evaluation systems

s: sensing range; A: curve; B: sensor, sensing face side view; C: target (blue) - radial movement

Illustration 73: Simplified typical switch-on curve (radial) and degree of coverage\(^5\)

(side view)

With slow travel speed the switching operation of the sensor will be performed in all three cases of Illustration 73.

If the travel speed increases, the target will no longer trigger the sensor to switch at a distance of \(s = 100\%\). With the other two (at \(s = \text{approx. } 60\%\) and \(s = \text{approx. } 10\%\)) the sensor will switch even at high travel speed of the target.

Addition:

It is, of course, of no importance to the behaviour of the sensor at the described conditions, if the target or the sensor is moving.

Tip 5:

The ideal distance for the high travel speeds of the target is 10\% to 50\% of the nominal sensing range (\(s_n\)).

At a distance of 50\% of \(s_n\), between sensing face and standard target the maximum switching frequency (as indicated in the data sheet) will be determined.

9.1.6 Travel speed and switching frequency

The higher the speed at which the target travels passed the sensing face, the shorter its relative dwell time in front of the sensing face. Due to physics the sensor requires a certain time to detect the metal and to transform its presence into a switching signal.

If the travel speed of the target is so fast that it is gone again within the response time, the sensor can no longer detect it.

Therefore it is important to know the switching frequency of the sensor. A standard sensor, for example, can have a switching frequency of 250 Hz. That means that it can detect mechanical damping 250 times per second. That is sufficient for most applications.

However, there are always sensors with a switching frequency of 2,000 Hz or more.

The relative dwell time of the target travelling in front of the sensing face of the sensor depends on its length and the travel speed.

To calculate the length of the target you can proceed as follows:

First determine the speed of the shaft surface with target height. In this respect you need the diameter of the shaft plus target height in millimetres, the figure \(\pi\) and the rotational speed per minute.

Multiply these three values. Divide this result by 60 s/min. Then you have the travel speed in the unit 'mm per second - mm/s'.

Divide this value again by the switching frequency of the sensor.

The result is the minimum length of the target for the maximum switching frequency of this sensor.

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\(^5\) degree of coverage: The entire sensing face is centrically covered by the standard target.
Evaluation systems

A: target;   B: diameter;     C: speed;     D: target surface

Illustration 74: Travel speed - target on shaft

Here you also have to see that it does not become smaller than the size of the sensor's sensing face.
Example:
The shaft's diameter is 400 mm (the dimension B in Illustration 74, including target height) and rotates at 600 revolutions per minute. The sensor has a switching frequency of $f_{\text{sensor}} = 250$ Hz.

Travel speed $C_w = (400 \text{ mm} \times 3.14 \times 600 \text{ min}^{-1}) / 60 = 12,560 \text{ mm/s}$. Minimum target length $D_n = C_w / f_{\text{sensor}} = 12,560 \text{ mm/s} / 250 \text{ s}^{-1} = 50.24 \text{ mm}$.

The target length should therefore be 50 mm.
Distance to the sensor: half the nominal sensing range or smaller.

Tip 6:
The pulse length of the sensor may be too short for the connected electronics (PLC, counter, monitor). Possible remedy:
- extend the target or
- use a smaller sensor or
- connect a pulse stretcher (pulse converter).

You may even have to take several of the above measures.

9.1.7 Free spaces for the sensing face of the sensor

Just like flush or non-flush it is important if the installation environment is metal or non-metal.
In a metal installation environment free space should be left between the sensing face of the sensor and the metal (e.g. stationary machine parts, covers, housings or the like) - see Illustration 75.

The closer the metal of the installation environment comes to the sensing face of the sensor, the more it will be predamped. That means that it has become more sensitive. That can lead to the intended target to cause the sensor to switch; if the target is gone again, the sensor remains on. However, it is ‘trapped’ in its hysteresis.
A similar behaviour of the sensor can show if a non-flush mountable sensor is mounted partially flush or a flush mountable sensor is mounted overflush - see Illustration 76.

Illustration 76: Mounted partially flush (left) or overflush (right)

9.2 Pulse/pause ratio and inductive sensors

A pulse/pause ratio is in general the time or space ratio of the (binary) on/off state of a process.

For the use of inductive sensors there are two terms in the context of pulse/pause ratio that are of interest to us:

- the mechanical pulse/pause ratio
- the electrical pulse/pause ratio

At first glance the mechanical pulse/pause ratio is of interest since the electrical pulse/pause ratio depends on it with certain deviations.

To determine the pulse/pause ratio the time is considered until a (mechanical) process is repeated.

A classic mechanical example is the toothed wheel:
A tooth is followed by a gap of the same size. Then there is again a tooth and a gap (2nd period). This constellation repeats itself constantly until the circumference of the toothed wheel has been moved around once. Then the whole process starts again.

In this case we talk about a mechanical pulse/pause ratio of 1 to 1 (1:1) since the tooth and the gap are of the same size.

If the gap is twice as big, the pulse/pause ratio is 1:2.
If the gap is four times as big, then 1:4.

Vice versa, if the tooth is four times the size of the gap, the mechanical pulse/pause ratio is 4:1.

Illustration 77: Mechanical pulse/pause ratio 1 to 2 (1:2)

For example, if there is only one target on the shaft, the mechanical pulse/pause ratio may be 1:20. That may mean that the target is 40 mm long and the section without target (shaft) is then 800 mm.

The inductive sensor turns the mechanical pulse/pause ratio into an electrical one. Independent of the size of the sensor there are in any case physically caused delays for the switch-on and switch-off moments of its binary output stage.
Evaluation systems

A: damping;  B: oscillator amplitude of the sensor;  C: binary output stage;  
D: switch-on delay;  E: switch-off delay.

Illustration 78: Switch-on and switch-off moments of an inductive sensor

With a mechanical pulse/pause ratio of 1:1 the sensor can provide signals whose distance is large enough (Illustration 79).

A: damping;  B: oscillator amplitude of the sensor;  C: binary output stage;  
D: switch-on delay;  E: switch-off delay.

Illustration 79: Mechanical pulse/pause ratio 1:1

In most cases there will be problems if the mechanical pulse/pause ratio is worse than 1:1. In particular, if the travel speed of the targets is very high or if the disc with the hole is poorly dimensioned.

In the next case the mechanical pulse/pause ratio is no longer 1:1 but e.g. 5:2 (Illustration 80). The pause time is thus considerably shorter than the on-time of the mechanical damping (A).

A: damping;  B: oscillator amplitude of the sensor;  C: output stage

Illustration 80: Mechanical pulse/pause ratio 3:1

The output stage of the sensor can no longer reliably switch off.

Note:
The mechanical pulse/pause ratio must be considered including the sensor surface. The mechanical gap should be at least as big as the sensing face of the sensor.
9.3 Analysis of different applications

Some examples will be discussed below where everything is OK and where problems arise or may arise. Toothed wheels are shown flattened to simply the illustration.

9.3.1 Very reliable application

A: metal target; B: inductive sensor; C: toothed wheel body; l: target length; h: target height; p: pause; v: speed and direction

Illustration 81: Very reliable application

Technical data
Inductive sensor (B): s = 20 mm, flush, sensing face 40 x 40 mm². Distance to the target approx. 10 mm.
Metal target (A): material mild steel, l ≈ 120 mm, h = 60 mm
Pulse/pause ratio (l:p): 1:2
Toothed wheel body (C): metal

Consideration:
Mechanical pulse/pause ratio very good (1:2, l ≈ 120, p ≈ 240 mm).
Target length (l): very good (three times the sensor width -120 mm)
Target height (h): very good (h = 60 mm ≈ 3 x s = 60 mm distance to the toothed wheel body (C)).

Result:
Up to its max. switching frequency the sensor will provide reliable signals.

9.3.2 Still reliable application

A: metal target; B: inductive sensor; C: toothed wheel body; l: target length; h: target height; p: pause; v: speed and direction

Illustration 82: Still reliable application

Technical data
Inductive sensor (B): s = 20 mm, flush, sensing face 40 x 40 mm². Distance to the target approx. 10 mm.
Metal target (A): material mild steel, l ≈ 120 mm, h = 60 mm
Pulse/pause ratio (l:p): 1:2
Toothed wheel body (C): metal
Evaluation systems

Consideration:
Mechanical pulse/pause ratio very good (1:2, \( l \approx 40, p \approx 80 \text{ mm} \)).
Target length: satisfactory (only sensor width - 40 mm).
Target height (h): very good (\( h = 60 \text{ mm} = 3 \times s = 60 \text{ mm distance to the toothed wheel body (C)} \)).

Result:
With high travel speeds (v) it is possible that the sensor does not provide any signals any more.
It is also possible that the switch-on time of the sensor signal is too short.

Remedy:
Use a sensor with a smaller sensing face and a smaller sensing range.
Short sensor signals can be stretched by a pulse converter.

### 9.3.3 Conditionally reliable application - 1st possibility

- A: metal target
- B: inductive sensor
- C: toothed wheel body
- l: target length
- h: target height
- p: pause
- v: speed and direction

Illustration 83: Reasonably reliable application

Technical data
Inductive sensor (B): \( s = 20 \text{ mm}, \) flush, sensing face \( 40 \times 40 \text{ mm}^2 \). Distance to the target approx. 10 mm.
Metal target (A): material mild steel, \( l \approx 40 \text{ mm}, h = 60 \text{ mm} \)
Pulse/pause ratio (l:p): 1:1
Toothed wheel body (C): metal

Consideration:
Mechanical pulse/pause ratio satisfactory (1:1, \( l \approx 40, p \approx 40 \text{ mm} \)).
Target length: satisfactory (only sensor width, 40 mm).
Target height (h): very good (\( h = 60 \text{ mm} = 3 \times s = 60 \text{ mm distance to the toothed wheel body (C)} \)).

Result:
The problems may have been largely caused by the mechanical pulse/pause ratio of 1:1.
The sensor's behaviour at high travel speeds (v) is uncertain. Depending on the mechanical distance between the sensing face of the sensor and the target it is possible that the sensor does not provide any signals any more or remains permanently on.
There should be no problems at very low travel speeds.

Remedy:
Use a sensor with a smaller sensing face and a smaller sensing range.
9.3.4 Conditionally reliable application - 2nd possibility

A: metal target;  B: inductive sensor;  C: toothed wheel body;  l: target length;  h: target height;  p: pause;  v: speed and direction

Illustration 84: Reasonably reliable application

Technical data:
Inductive sensor (B): s = 20 mm, flush, sensing face 40 x 40 mm². Distance to the target approx. 10 mm.
Metal target (A): material mild steel, l = 120 mm, h = 60 mm
Pulse/pause ratio (l:p): 2:1
Toothed wheel body (C): metal

Consideration:
Mechanical pulse/pause ratio unsatisfactory (2:1, l ≈ 120, p ≈ 40 mm).
Target length: good (three times the sensor width -120 mm).
Target height (h): very good (h = 60 mm ≙ 3 x s = 60 mm distance to the toothed wheel body (C)).

Result:
The problems may have been largely caused by the mechanical pulse/pause ratio of 2:1.
The sensor's behaviour at high travel speeds (v) is uncertain. It is probable that the output stage of the sensor is permanently on.
There should be no problems at very low travel speeds.

Remedy:
Use a sensor with a smaller sensing face and a smaller sensing range.

9.3.5 Conditionally unreliable application - 1st possibility

A: metal target;  B: inductive sensor;  C: toothed wheel body;  l: target length;  h: target height;  p: pause;  v: speed and direction

Illustration 85: Unreliable application

Technical data:
Inductive sensor (B): s = 20 mm, flush, sensing face 40 x 40 mm². Distance to the target approx. 10 mm.
Metal target (A): material mild steel, l = 120 mm, h = 25 mm
Pulse/pause ratio (l:p): 1:1
Toothed wheel body (C): metal

Consideration:
Mechanical pulse/pause ratio very good (1:1, l ≈ 120, p ≈ 120 mm).
Target length: very good (three times the sensor width - 120 mm).
Target height: poor (p = 25 mm plus 10 mm between B and A = 25 mm distance to the toothed wheel body (C)).

Result:
The problem may be largely caused by the small height (h) of the target(A).
When the first passing target switches the sensor on once, it is possible that it does not switch off again with the gap to the next target. It is predamped by the metal toothed wheel body (C) to such an extent that it cannot leave its hysteresis.

Remedy:
Increase the sensor distance.

New problem: The sensor may not switch at high travel speeds.
Remedy in the long run:
Use a sensor with a small sensing range and decrease the mechanical distance to the target (s, /2).

9.3.6 Conditionally unreliable application - 2nd possibility

A: metal target; B: inductive sensor; C: toothed wheel body; l: target length; h: target height; p: pause; v: speed and direction

Technological data
Inductive sensor (B): s = 20 mm, flush, sensing face 40 x 40 mm². Distance to the target approx. 10 mm.
Metal target (A): material mild steel, l = 40 mm, h = 25 mm
Pulse/pause ratio (l:p): 1:6
Toothed wheel body (C): metal

Consideration:
Mechanical pulse/pause ratio very good (1:6, l ≈ 40, p ≈ 240 mm).
Target length: satisfactory (only sensor width - 40 mm).
Target height: poor (p = 25 mm plus 10 mm between B and A = 25 mm distance to the toothed wheel body (C)).

Result:
The problems may be largely caused by the small height (h) of the target (A) and the target length (l).
When the first passing target switches the sensor on once, it is possible that it does not switch off again with the gap to the next target. It is predamped by the metal toothed wheel body to such an extent that it cannot leave its hysteresis.

Remedy:
Increase the sensor distance.
New problem: The sensor may not switch at medium and high travel speeds.
Remedy in the long run:
Use sensor with a small sensing range and a smaller sensing area and decrease the mechanical distance to the target (sn /2).

9.3.7 Unreliable application

A: metal target; B: inductive sensor; C: toothed wheel body; l: target length; h: target height; p: pause; v: speed and direction

Illustration 87: Very unreliable application

Technical data:
Inductive sensor (B): s = 20 mm, flush, sensing face 40 x 40 mm². Distance to the target approx. 10 mm.
Metal target (A): material mild steel, l = 25 mm, h = 60 mm.
Pulse/pause ratio (l/p): 1:4
Toothed wheel body (C): metal

Consideration:
Mechanical pulse/pause ratio very good (1:4, l ≈ 25, p ≈ 100 mm).
Target length: unsatisfactory (only 25 mm - much smaller than the sensing face of the sensor).
Target height (h): very good (h = 60 mm ≈ 3 x s = 60 mm distance to the toothed wheel body (C)).

Result:
This problem is caused by the small length (l) of the target.
The sensor will switch at slow travel speeds. Not so at high travel speeds, though.

Remedy:
Use a sensor with a considerably smaller sensing face (≤ 25 mm).

THE END