White paper

Safe Motion

Safe drive technology through sensor-free motion monitoring

Find out more about:

- Safe Motion applications in stationary and mobile machines and plants
- Important safety functions in accordance with EN 61800-5-2
- Innovative methods of sensor-free motion monitoring

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Introduction

The highest possible efficiency and productivity combined with the best possible protection of persons against hazardous drive and axis movement are the fundamental requirements for operating machines and systems economically and safely.

Safe Motion – in other words, electric drive technology designed with safety in mind – combines both of these objectives in the best possible way. This applies both to stationary applications, as in industrial manufacturing, and to mobile applications such as automated guided vehicle systems or mobile robots and platforms. For machine builders, integrators and operators, it is important to guarantee functional safety as specified in the relevant standards, and also to ensure that safety engineering is time- and cost-efficient and can be controlled reliably. Using standardized safety functions in safe controllers contributes to this, as does easy-to-integrate motion monitoring that is independent of the motor and measures directly at the drive.

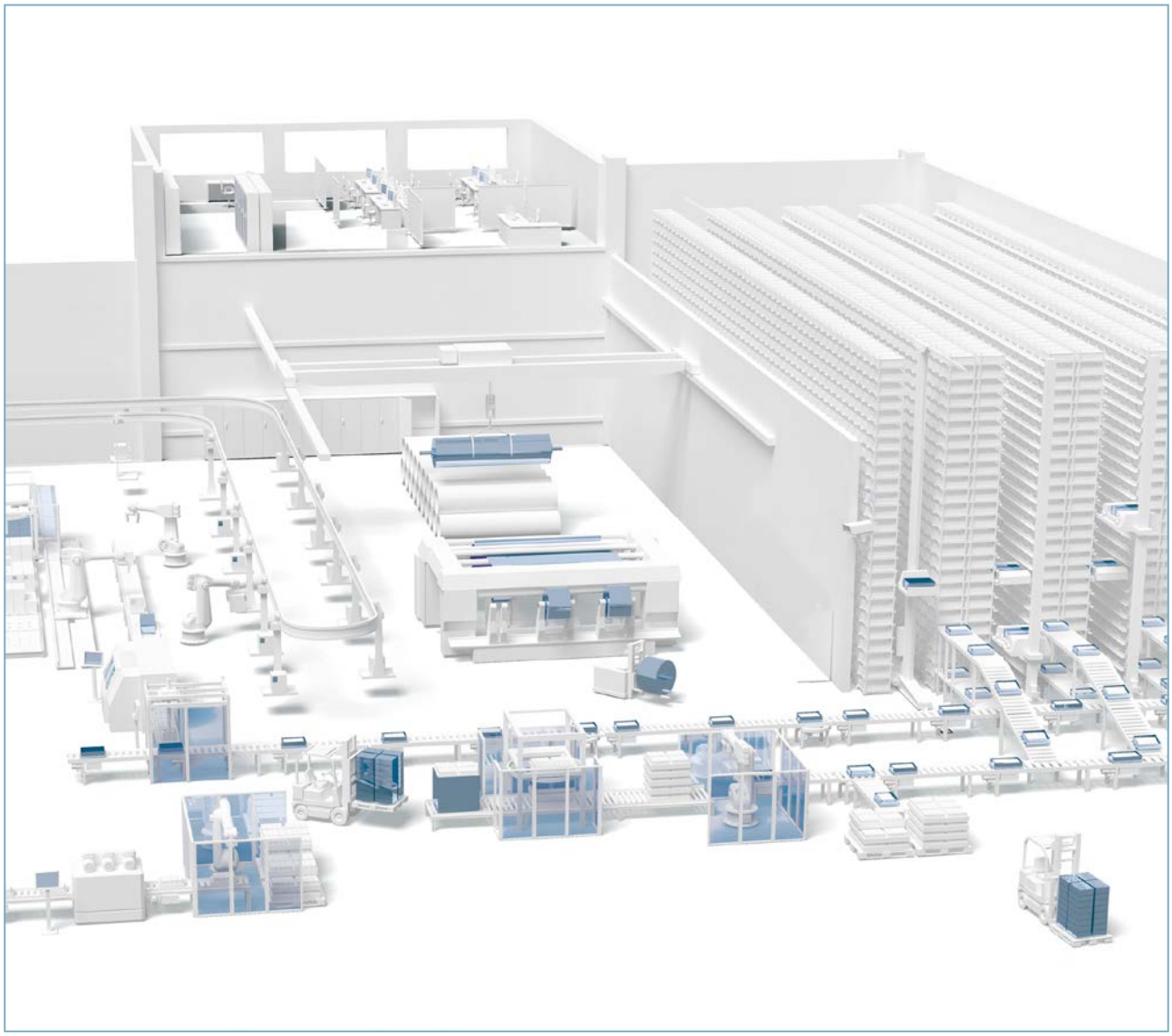
This article introduces the various application scenarios of stationary and mobile machines and systems, explains the important standard-based safety functions in accordance with EN 61800-5-2, presents both sensor-based and innovative, sensor-free methods of safety-related motion monitoring, and explains the advantages of these methods in selected use cases.

Contents

1 Functional safety in electric drive technology

Drives move things. They move machines and machine components, robots, self-driving vehicles, driverless platforms and carts, and much more. Depending on the task, the requirements may call for high torques with enormous forces, high dynamics with ultra-fast accelerations and motion sequences, or high precision for exact positioning.

Regardless of what electric drives are designed for, suitable safety functions must always be integrated in order to protect both people and assets against hazardous movements of machinery.



Industrial building with machines, conveyor belts, and high bay warehouse

Validation scenarios for stationary machines and plants

Machine tools, presses, saws, bending and forming plants, handling portals, woodworking machines, and robots are examples of stationary machines and plants that are integrated into processes and whose setup, operation, maintenance, or repair can cause hazards for persons in the vicinity. The machines operate in a permanent location, and potential hazards can occur both in the machine itself and in the handling, moving, or swiveling area of protruding workpieces that will be machined. Here, the tasks of Safe Motion solutions are to reliably detect all hazardous movements in the machine and its immediate environment and to stop them in case of danger. During setup or service work, the priorities are to reliably detect and limit the minimum and maximum speed of movements and to reliably monitor the zero-speed of drives.

Validation scenarios of mobile machines and plants

Automated guided vehicles, self-driving platforms, and mobile robots and carts are typical examples of mobile machines that often share a common work environment with people and therefore need to be monitored for safety. For one thing, it is necessary to detect possible collision hazards on and off the route while moving, brake soon enough in front of detected obstacles, and then either stop or move around them. During docking for load pickups or load transfers, and during service and maintenance work as well, the task of a Safe Motion solution is to monitor the electric drives of the vehicles for permissible upper and lower travel speed limits and ensure a safe zero-speed.

2 Safety functions for axes and drives in accordance with EN 61800-5-2

The standard "DIN EN 61800-5-2:2017-11 Adjustable speed electrical power drive systems – Part 5-2: Safety requirements – Functional safety" addresses the requirements and recommendations for the design, development, integration, and validation of safety-relevant power drive systems with adjustable speed.
By implementing the specifications of the standard, performance in terms of the functional safety of electric drives can be documented. Depending on the type and scope of safety-related drive monitoring, various safety functions are configured and executed together.
From the large number of drive-relevant safety functions, the following section focuses on the ones that are implemented most frequently in Safe Motion applications.

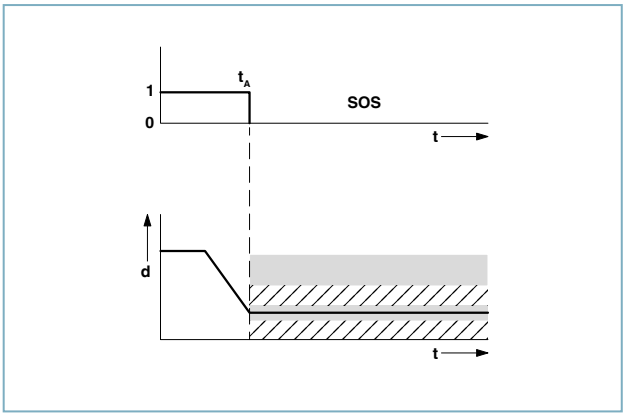
Safe position monitoring: SLP, SLI, and SOS

Safe position monitoring of the SLP (Safety Limited Position) of electric drives ensures that an absolute position or position limit value defined for a motor is not exceeded. If this is not met, for example, by the motor shaft exceeding a specified position limit, the drive is slowed down and stopped safely, taking into account the possible trailing motion of the kinematics.

The safety function SLI (Safely Limited Increment) is used to monitor a permissible angle of rotation or a permissible linear movement with regard to safety. When a motor reaches an approved angle or a defined route length, the drive is stopped safely.

If the limit value is exceeded, the drive is safely set to zero speed, for example, by disconnecting it from the power supply.

SOS (Safe Operating Stop) is a drive monitoring function that safely monitors the zero-speed of the drive in the controlled state – both at a specified absolute position and within a defined position window. If the drive exceeds this position or exits the window, it is switched off safely. Drives can be started automatically by the control function, but restarting the motor after an emergency shutdown must be confirmed – an automatic restart is not allowed.

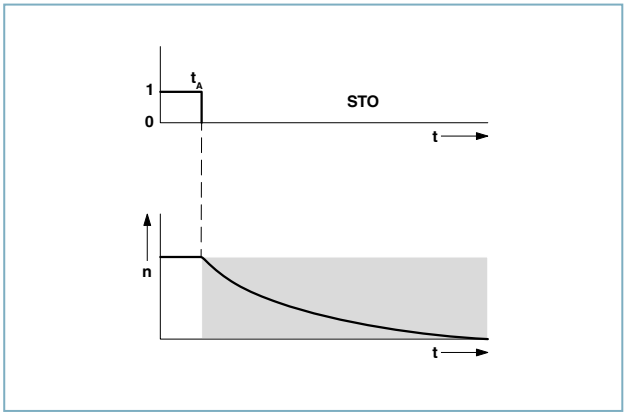


Safe Operating Stop – SOS

Safe stopping: STO, SS1, and SS2

If someone pushes an emergency stop button, mechanically separating safety equipment monitored by safety switches opens, electro-sensitive protective equipment responds, or a sensor-free motor and motion monitoring system detects a fault – these are typical emergency situations in which the drives must be stopped quickly and safely in order to prevent accidents. With the STO (Safe Torque Off) safety function, the drive

and drive controller are stopped immediately by disconnecting them from the supply network. As a result, no more energy is supplied to the kinematics for movement or rotation, and the drive is blocked so that it cannot be started or restarted automatically.



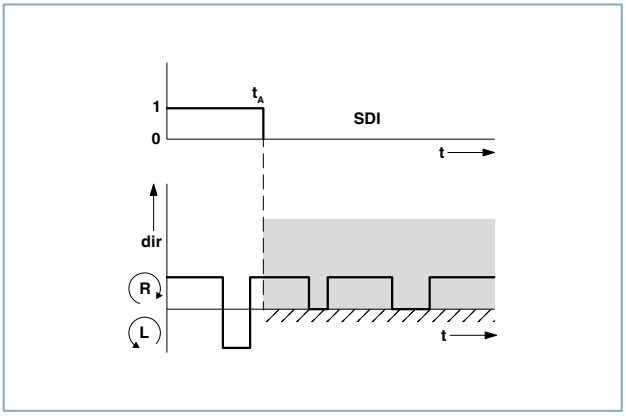
Safe Torque Off – STO

Since this involves stopping the drive without control, its movements can slow down in an uncontrolled manner, depending on the kinematics. This can be prevented with the SS1 (safe stop 1) safety function. Directly in the drive controller, this function monitors the deceleration process specified by a parameterized ramp up to the transition to STO: an uncontrolled stop becomes a controlled stop.

Whereas SS1 switches the drive at zero-speed to STO and thus to an uncontrolled state, safety function SS2 (safe stop 2) keeps the drive in controlled operation. Monitored deceleration down to the zero-speed position follows, which the SOS safety function keeps in the closed-loop control circuit. Unlike STO in conjunction with SS1, the synchronization of axes and motion sequences is also maintained, for example – the drive and machine can restart immediately and automatically.

Safe direction of rotation monitoring: SDI

Particularly when commissioning, servicing, or repairing drives or electrically driven kinematic systems, it is often necessary to ensure that an axis – and thus the drive – can only move in one direction in order to protect against accidents. The SDI (safe direction) safety function performs this task. It either blocks the prohibited direction of movement completely or restricts it to a defined and tolerable reverse route: for example, in order to adjust limit switches and check their function. When work is being done in especially hazardous areas, where it is important to shut down the drive as quickly as possible in case of danger, this safety function is often combined with the SLS safe speed monitoring system.

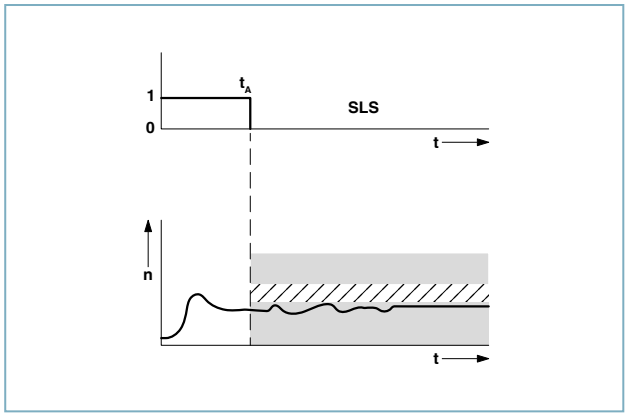


Safe direction – SDI

Safe speed monitoring: SLS, SSM, and SSR

When work is being done on or in a machine, such as during setup or maintenance, the SLS (safe limited speed) safety function in the axis controller reduces the risk of injury. This involves a controlled

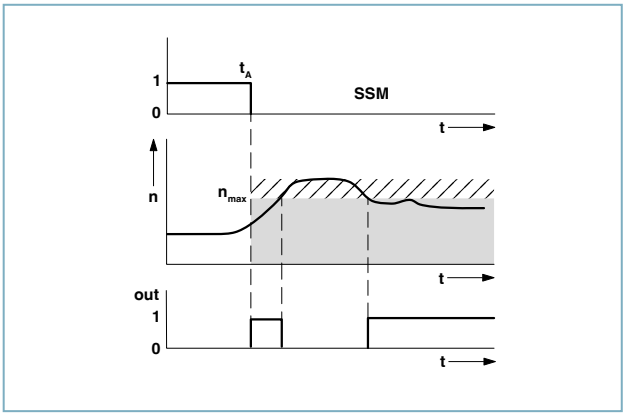
transition from the operating speed to a defined, reduced speed that must be traveled when setting up or maintaining a machine to allow manual intervention in the danger zone. If the setup speed is exceeded, the safety function recognizes this as a fault and switches off the machine drive safely. The big advantage of the SLS safe speed monitoring function is that processes do not necessarily have to be stopped. In addition, it is possible to carry out setup operations more quickly because the machine can be traveled at reduced speed.



Safe limited speed – SLS

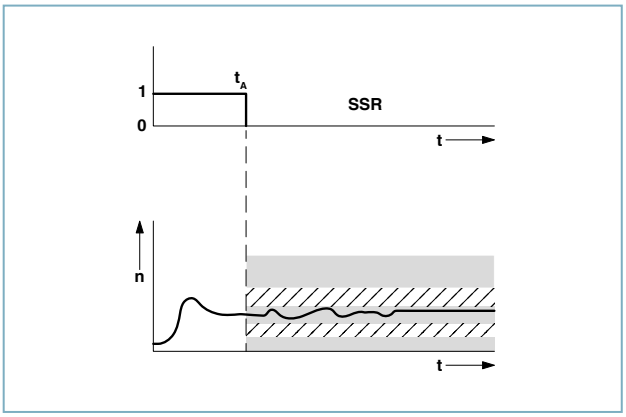
With the SSM (safe speed monitor) safety function, the servo drive controller detects when the speed of a drive falls below a defined limit value. This monitoring function is required, for example, to enable safety doors or hoods to be opened only when the drive no longer exceeds the specified speed.

The SSR (safe speed range) speed monitoring function combines SLS and SSM. This makes it possible to simultaneously monitor whether a drive is maintaining the configured minimum and maximum speeds. If the motor speed exits the specified speed corridor, SSR switches off the drive and shuts it down safely – either via STO or SS1, depending on the Safe Motion configuration.



Safe speed monitor – SSM

Since the safe speed monitoring functions described above, except for STO, run in the closed-loop operation of the drives, the drive power can be used to determine the speeds and speed ranges directly, without sensors by measuring the rotating field or evaluating the residual voltage. The safety relay modules available for this can be integrated easily and compactly on the control side. The modules are also generally more cost-effective than contact-free, rotary, or linear safety sensors – especially since unlike safety relay modules, the sensors do not always meet the high safety requirement levels (SIL3) and performance level (PL e).



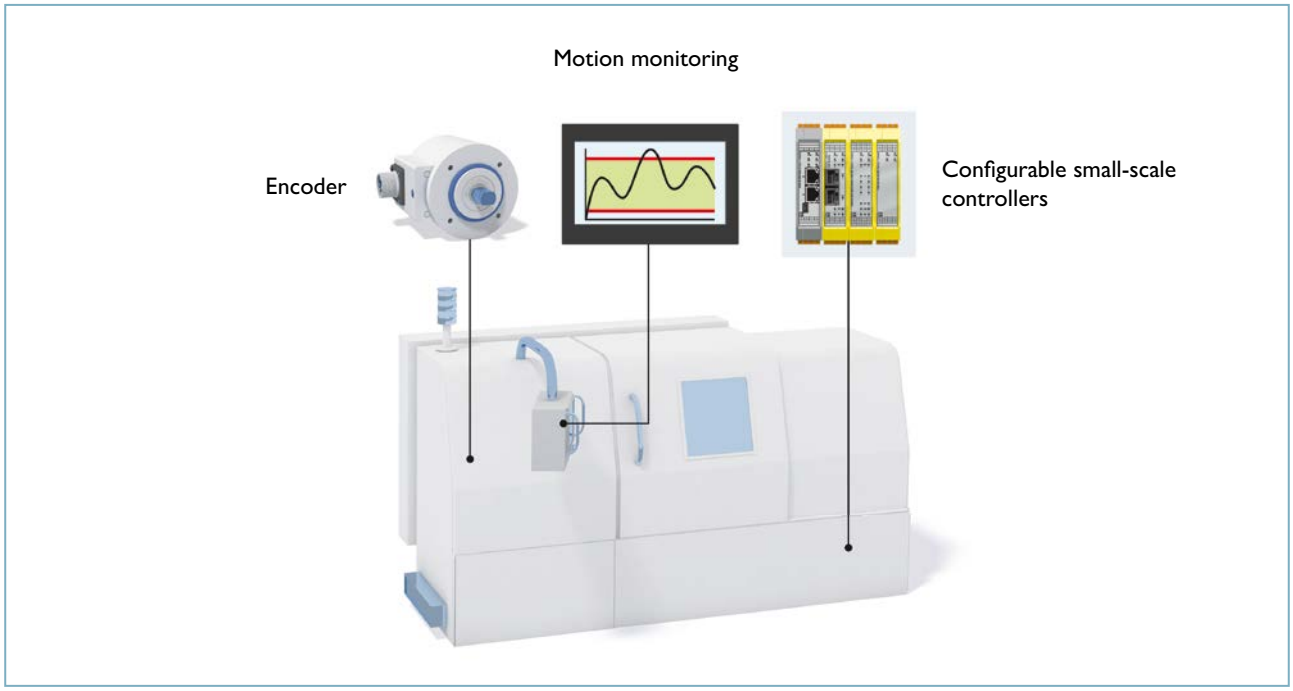
Safe speed range – SSR

3 External options for safety-related motion monitoring

In real-world use, there are several basic validation scenarios for Safe Motion applications. In principle, this also includes using tactile safety equipment such as pressure-sensitive mats, protective hoods, or fences. Protection against access or entry is often monitored by using tactile safety switches or contact-free, secure binary or RFID sensors and switches. This equipment generally does not directly influence the safety functions for axes and drives described in this paper, which are used to safely monitor the movements and zero-speed of drives in automatic mode and during setup or service work. Therefore, they will not be considered further here.

Linear and rotary safety sensors

The direct control and monitoring of the actual kinematics often also requires the use of safe linear and rotary sensors – in other words, safe encoders and safe motor feedback systems. They provide the basic information for detecting, monitoring, and controlling the movements of rotary servo drives and linear direct drives – not only in automatic mode but also during setup or service work. Using linear and rotary sensors in conjunction with contact-free safety sensors and a suitable safety controller involves a great deal of hardware, integration, and costs for implementing Safe Motion solutions, which, for example, are often not required for this form of safe speed monitoring.



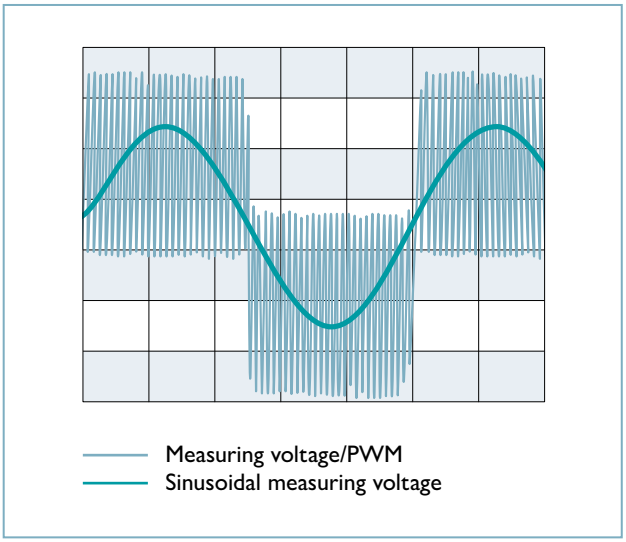
Sensor-based motion monitoring with encoders

Safe sensor-free monitoring

Safe sensor-free monitoring to determine whether electric drives are at a zero-speed or safe speed is increasingly becoming an established alternative to using contact-free, rotary and linear safety sensors. There are many reasons for this, including the ability to directly evaluate motion information from the motors in the corresponding safety relay modules without intermediate sensors, to meet stringent safety requirements, and to configure the system (usually without software). Other advantages are the smaller space requirements for the drive and in the control cabinet, faster commissioning of the Safe Motion solution, and high mechanical robustness and electromagnetic immunity.
The achievable cost savings resulting from all these factors are also a significant argument in favor of using the drive power for safe, sensor-free monitoring. Two operating principles are especially suitable for this: rotating field measurement and evaluation of the residual voltage.

Speed and speed range monitoring with rotating field measurement

When a rotating field is measured, a safety relay module monitors the drive power via two-channel evaluation of the rotating field, which continuously rotates around the axis of rotation of an AC or three-phase motor. This makes it possible to monitor the speeds and speed ranges of the drive without sensors. It is no longer necessary to install and adjust external encoders.

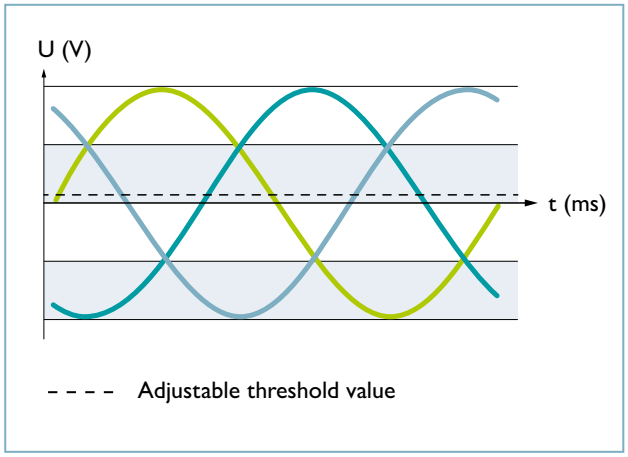


Measurement of the drive rotary field

Rotating field measurement is highly reliable because this method is not affected by external environmental influences and interference such as shock, vibration, or EMC. To protect against hazardous motion, a safety relay module like this can be used to implement Safe Motion safety functions such as STO, SLS, SSM, and SSR. Further, as a 12.5-mm wide DIN rail module, it hardly requires any space in the control cabinet. Direct motion monitoring fulfills high safety categories by meeting SIL3 and PL e. In terms of state-of-the-art operating technology, modern safety relay modules feature front-mounted operating elements and an intuitive configuration interface.

Zero-speed monitoring by evaluating residual voltage

To monitor whether a drive is at zero-speed without using any sensors, innovative safety relay modules are capable of evaluating the residual voltage of AC, AC, and DC motors on two channels.



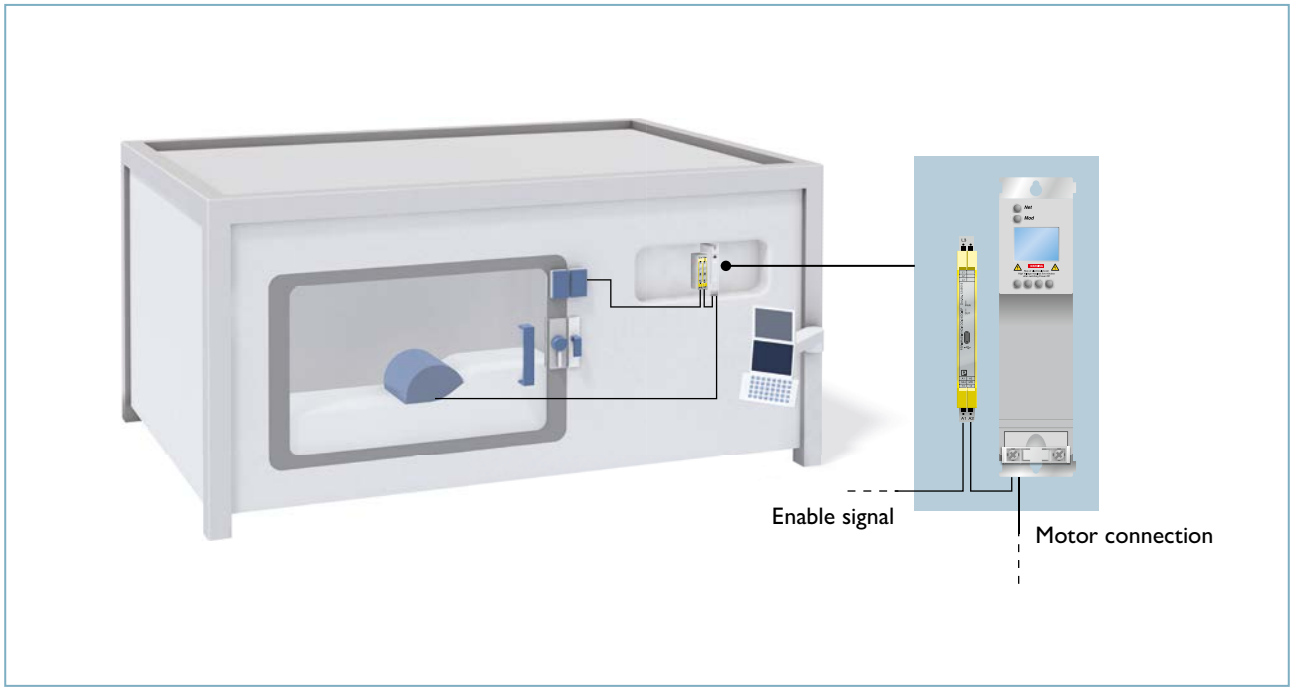
Measurement of the residual voltage of the drive

Consequently, the decisive information for this type of zero-speed safety relay, which is ideal for use in machines with and without frequency converters, is the residual voltage generated by the rotary motion.

Speed and zero-speed monitoring as a functional unit

If the aim is to implement safe speed monitoring and safe zero-speed monitoring together in a Safe Motion solution, suitable safety relay modules up to SIL3 and PL e with integrated over-speed and zero-speed safety relay functionality with two-channel evaluation are available to do this. They feature force-guided relay contacts, configurable signaling outputs, compatible connectivity for proximity switches, and both rotary and linear safety sensors.

For seamless integration into the digitalized drive technology of machines, combined over-speed and zero-speed safety relays also offer the option of online monitoring via suitable, downloadable software tools.



Sensor-free motion monitoring completely without additional sensors

4 Use cases for sensor-free motion monitoring

The safe, sensor-free monitoring of electric drives is used in a variety of industries and applications – especially where it is important to implement Safe Motion cost-effectively, robustly, and in a manner that meets high safety requirements and is easy to integrate.

Turning and grinding machine for metal processing

Machine tools

Machine tools and machining centers are a typical field of application for safe, sensor-free motion monitoring. To protect machine operators, service personnel, and other people in the vicinity of machinery against potential accidents, it is necessary to safely monitor the speed of motion and the stopping of electric drives during workpiece insertion or removal, tool changeover, and maintenance, servicing, and repair work.

Wood processing in a sawmill

Woodworking machines

From saws or milling machines, to drilling, sanding or planing machines, and interlinked conveyor components between stations – it is essential to operate the drives of woodworking machines safely due to the high potential of risks to persons in the vicinity of hazardous movements. The safe, sensor-free motion monitoring system is designed exactly for this harsh operating environment, as it receives the necessary information for safe speed and zero-speed monitoring directly from the drive power of the servo motors instead of sensors in the field.

Drawbridge used for road traffic

Transportation infrastructure

In power-operated bridge systems, speeds and zero-speeds can be monitored without sensors during the lifting and lowering of bridge decks weighing tons. The supports of the roadway, which weigh several tons, are raised or lowered at different speeds depending on their position. After the supports begin to move, the mechanical parts move extremely slowly. The speed increases when a certain angle is reached and then decreases again shortly before arriving at the end position. SSM ensures that the movements do not exceed the specified speeds in the start, normal, and braking phases.

Automated guided vehicle system in production

Automated guided vehicle systems

In most industrial and intralogistics applications, automated guided vehicle systems and other self-driving mobile machines and platforms share their workspace with people. Safe Motion using safe, sensor-free drive monitoring makes it possible to monitor travel speed, docking speed, and safety-related zero-speed in transport operations and during load pickups and transfers in a way that saves space and is easy to integrate and efficient. Further, sensor-free over-speed and zero-speed safety relays offer the option of providing additional redundancy for sensor-based drive monitoring.

Conclusion

Safe, sensor-free drive monitoring for controllable safety engineering

Safe Motion in the form of safe, sensor-free motion monitoring meets essential requirements for the functional safety of electric drives and axes as specified by the relevant standards. Easy-to-integrate, motor-independent motion monitoring that measures directly at the drive plus eliminating the need for external encoders enable machine builders and integrators to implement standardized safety functions in safe controllers in way that saves both time and costs.

Over-speed and zero-speed safety relays, as well as safety relays that integrate both functions, provide controllable safety engineering and ensure that the Safe Motion solution is readily available to operators – thereby enabling excellent machine productivity.

Safe production on the assembly line

Glossary

Relevant standards and links

EN 61800-5-2:2017
Adjustable speed electrical power drive systems – Part 5-2: Safety requirements – Functional safety (IEC 61800-5-2:2016)

IEC 61508
Functional safety of electric/electronic/programmable electronic safety-related systems

EN 62061
Safety of machinery – Functional safety of safety-related electric, electronic and programmable electronic control systems

EN ISO 13849
Safety of machinery – Safety-related parts of control systems

DIN EN 60947-1
Low-voltage switchgear for use in circuits up to 1 kV alternating voltage or 1.5 kV direct voltage

DIN EN 50178
Electronic equipment for use in power installations

Safe Motion: Over-speed and zero-speed safety relays from Phoenix Contact

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