Servomotor press design - Safety recommendations

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NS 340 NOTE SCIENTIFIQUE ET TECHNIQUE

Servomotor press design - Safety recommendations

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Abstract:

Servopresses are innovative machines whose sales are increasing. The evolution of servomotors and the recent arrival on the market of power drive systems including safety functions have contributed to their emergence. For example, servomotors are used to participate in the “safe” stopping of the slide when protective devices are actuated.
There is still no European or international standard for these specific presses, though a draft is scheduled at ISO standardization level.
This document presents an inventory of specific servopress techniques and the results of their detailed study in normal operation and in the case of failure. In particular, it points out that a safety-related power drive system, when affected by a failure, reacts to the latter by initiating a failsafe position which may be different from the initially intended safety function. In the case of servopresses, this can result in the degradation of safety function performances.
Recommendations regarding the safety functions supported by the power drive system are proposed. For example, safe stop “types” have been defined, describing the different steps assigned to servomotors and those that require an additional mechanical brake to stop the slide in the absence of motor torque.
In conclusion, the paper describes the conditions in which the means of protection listed in the standards for the design of "traditional" machines can ensure their function.

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1. Presentation of the problem

Metalworking presses remain particularly hazardous machines and require the implementation of adapted safety measures to avoid serious work accidents.
INRS is focusing on a generation of innovative machines, servomotor presses whose distribution will increase since users are interested in the new functions they provide. For example, the slide movement and force characteristics can be varied in real time, making it possible to perform complex work cycles. As yet, there is no safety standard that takes into account the specific characteristics of this type of press. It is important that these machines that implement new technologies reach a level of safety equivalent to that of conventional presses.

Specific start and stop techniques for the potentially hazardous mobile parts are applied on these new presses. The slide movements depend directly on an electric servomotor[1], and are thus indissociable from its rotation (see Figure 1).

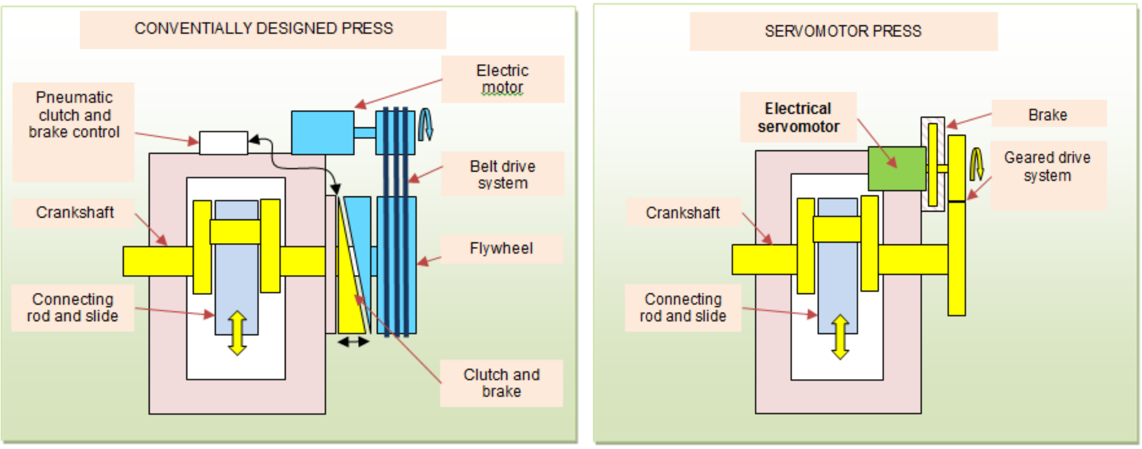

Figure 1: Diagrams of a conventional eccentric drive press and a servomotor press

The evolution of servomotors and the recent arrival on the market of electronic power systems incorporating “predefined” safety functions (IEC 61800-5-2[2]) have contributed to the emergence of this type of press. Energy input based stop functions, never previously used as safety functions on this type of machine, can now be used. It has proven necessary to establish the design principles for safe control systems adapted to the case of servomotor presses using such electronic systems.
This document presents an inventory of techniques specific to servomotor presses, a detailed study of the parts relating to safety and takes stock of the validity of conventional protection devices in view to their use on servomotor presses.

[1] The term “servomotor” in this document concerns the servomotor(s) required to drive the slide

[2] IEC 61800-5-2:2007 - Adjustable speed electrical power drive systems - Part 5-2: Safety requirements – Functional

2. Scope of application of the document

This document deals with presses equipped with a slide that moves vertically and generates tool closing movements when it descends. It is assumed that the upward movement does not present a risk, which is often the case for this type of machine.
The other mobile elements such as die cushions, ejectors, etc., are not taken into account.
The inventory of servomotor presses has permitted identifying many types of press. However, the case of eccentric drive servomotor presses has been dealt with in greater detail since they have the most specific characteristics for which the largest amount of technical information is available.

3. Functionalities and contributions of servomotors

3.1. Traditional presses (without servomotor)

Many machines use electric motors and, if needed, electronic controllers that allow managing:

- starting and stopping,
- changing the direction of motor rotation,
- rotation speed,
- drive torque,
- acceleration and deceleration ramps,
- other functions such as overload, mechanical blocking of the rotor, etc.

Regarding traditional presses, electric motors are used to provide the basic motor energy. When electronic variable speed controllers are used, they are programmed for given characteristics that never change during the same work cycle (raising and lowering of the slide).

The electric motor runs constantly and does not play any role in controlling the movement of the slide, its positioning or holding in stop position. The position of the slide is controlled, via position sensors, by a clutch or hydraulic distributors. The position of the slide is not controlled by the electric motor.

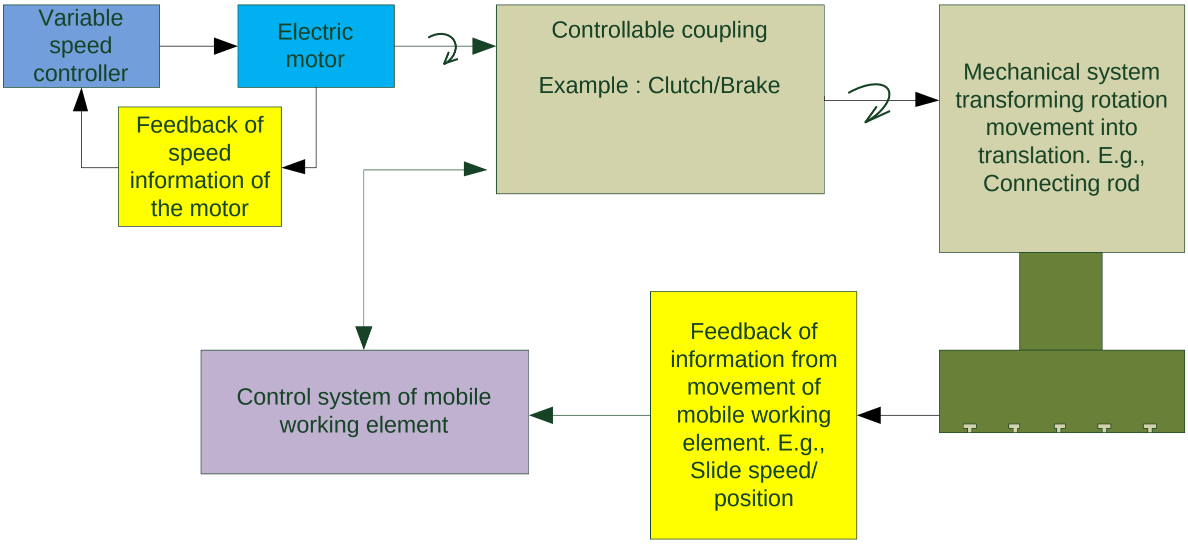

Figure 2: Diagrammatic example of a traditional mechanical eccentric drive press with a variable speed controller

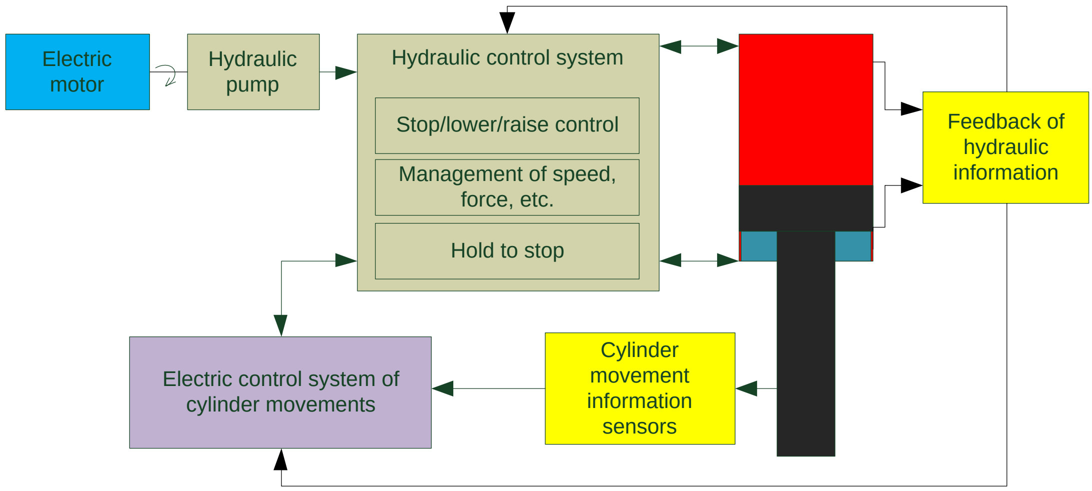

Figure 3: Diagrammatic example of a traditional hydraulic press

3.2. Servomotor presses

Electronic variable speed controllers have evolved, and permit the constant and precise management of the angular position of controlled electric motors, and the management of the braking torque to ensure precise position holding. This holding in stopped position is achieved through the energy supplied to the motor and does not use additional mechanical braking. Great advances have also been made with electric motors, which now accept frequent start/stop and change of rotation direction commands, and provide considerable torques immediately on starting and at low speeds.
This has led to improvements in press kinematics and servomotor presses have appeared on the market.
As with traditional presses, the electric motor is used to provide the basic driving power. However, the slide movements are directly linked to its rotation.

The electric motor performs all the following tasks:

- it rotates only when the slide has to be moved,
- it manages the slide movement speed at every point of the stroke,
- it manages the direction of the slide movements at every point of the stroke,
- it manages the positioning of the slide at programmed points at every point of the stroke,
- it manages holding the slide stopped at every point of the stroke (servo-control as long as power is supplied).

The slide movements are therefore controlled directly via the command of the electric servomotor, hence the names “servomotor press” and “servopress”.

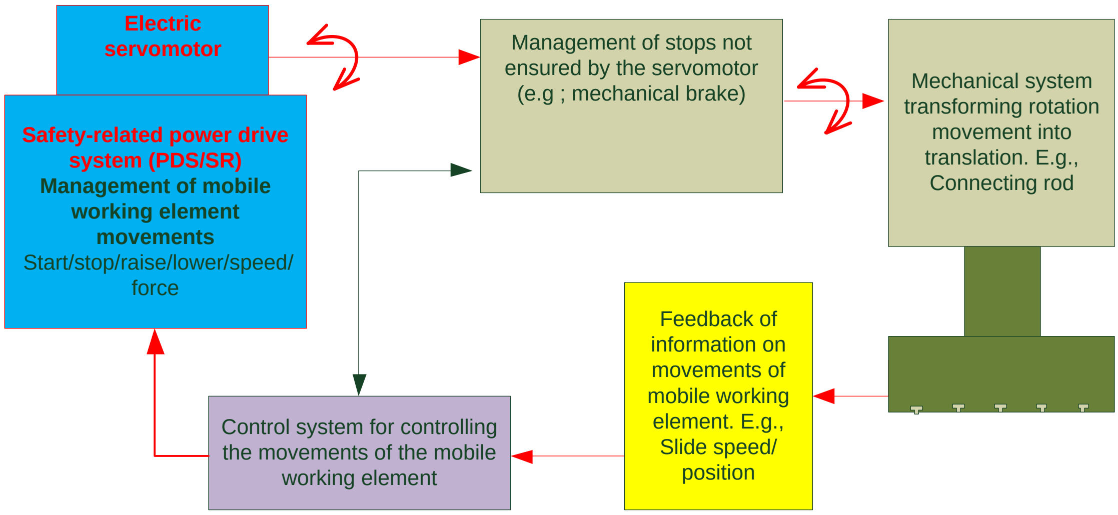

Figure 4: Diagrammatic example of a servomotor controlled eccentric press

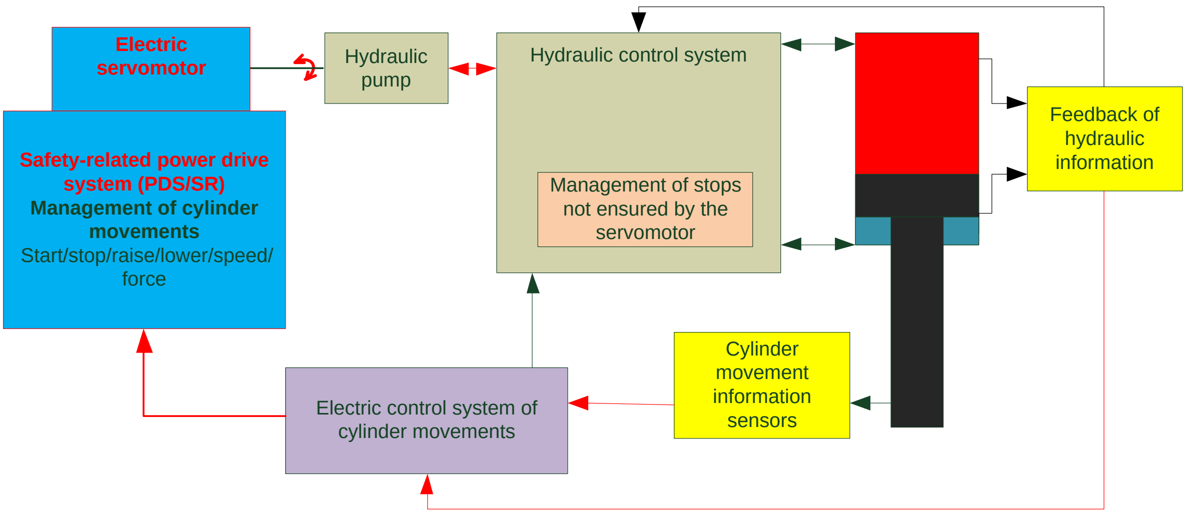

Figure 5: Diagrammatic example of a servomotor controlled hydraulic press

4. Classification of servomotor presses

Two large families of servomotor presses with vertical slide movements have been taken into account:

- presses for general use such as stamping, cutting (or assembly such as fitting, clinching),
- press brakes.

A literature search led to the identification, among the presses on the market, of those whose name refers to the use of servomotors and to the collection of the main and important characteristics of these machines liable to have an impact on the safety of operators. Among these characteristics, note should be taken, for example, of the slide drive mode. Several types of drive have been identified.

Eccentric drive
The movement of the servomotor is transmitted to an eccentric drive that activates a connecting rod, either a toggle, or a “linkdrive” type mechanism (a mechanical system that slows down the speed of the slide during its descent). Several servomotors can be used. The transmission of the servomotor movement to the eccentric drive can be direct or indirect via a belt or gear reduction drive. This type of drive only concerns “mechanical” presses.

Screw drive
The servomotor movement is transmitted to a screw linked to the slide. Several servomotors can be used. The transmission of the servomotor movement to the screw can be direct or indirect via a belt or gear reduction drive.

Hydraulic drive
The servomotor movement is transmitted to a hydraulic pump that drives the cylinder supporting the slide and which directly manages the working parameters of the machine, without additional analogic components such as servo valves, for example. Several associated servomotors and pumps can be used as well as several cylinders.

Belt pulley drive system
This principle is found specifically on press-brakes. The servomotor movement is transmitted to a belt linked to the slide by pulleys. Several servomotors can be used.

An inventory of servomotor press drive techniques available on the market in 2013 led to the synthetic classification of the main solutions used for presses and press brakes. They are presented in the flowchart of Figure 6.

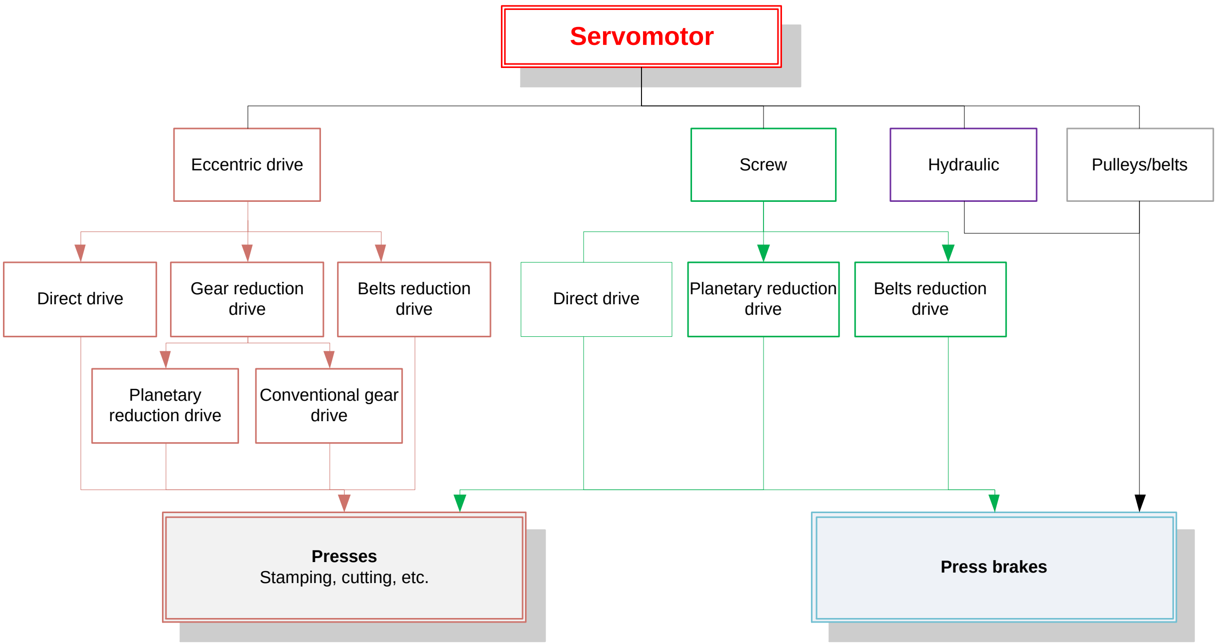

Figure 6: Summary of the different types of press drives concerned

5. Main principles for operating an eccentric drive servomotor press

5.1. Slide stroke control by action on the rotation of the servomotor

5.1.1. Case of a classical stroke

When the servomotor is still rotating in the same direction during the same cycle, the operation of the press is the same as that of a traditional press.

Figure 7 shows the kinematics of a servomotor press whose eccentric drive is always driven in the same direction (shown in the upper part of each drawing) for slide lowering and raising. The servomotor is stopped each time the slide stops, whereas the motor rotates constantly in a traditional press. The stroke of the slide is constant throughout each cycle as it depends directly on the mechanical regulation.

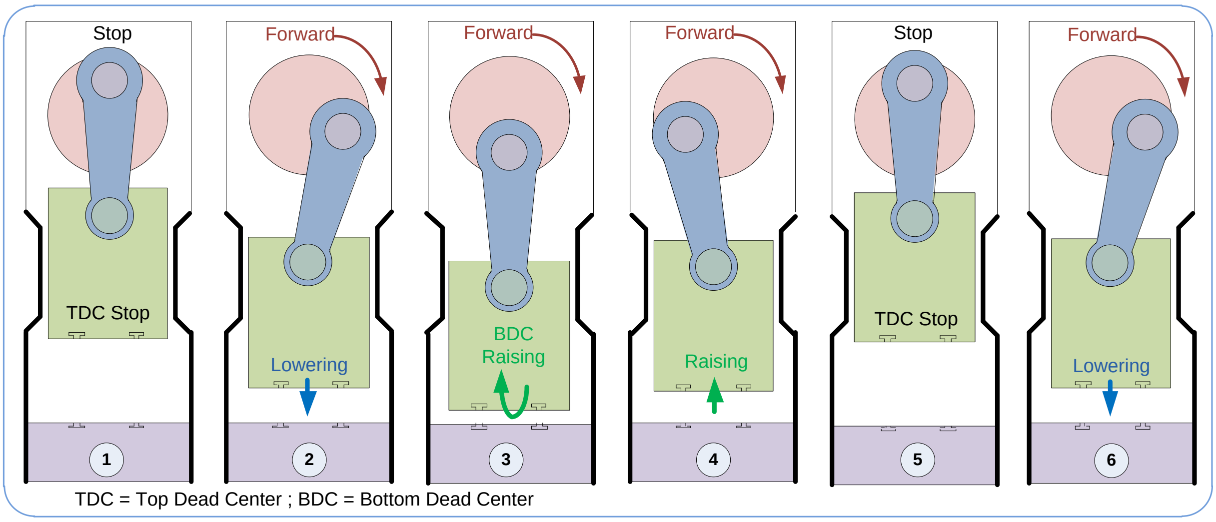

Figure 7: Mechanical press (eccentric drive) with servomotor – Maximum stroke (top and bottom dead centre points) – Single direction rotation of the servomotor

A servomotor press reproduces the displacement curve of a traditional press if the speed of the servomotor is constant (curve on the left of Figure 8), and also varies this curve if the speed is varied (other curves).

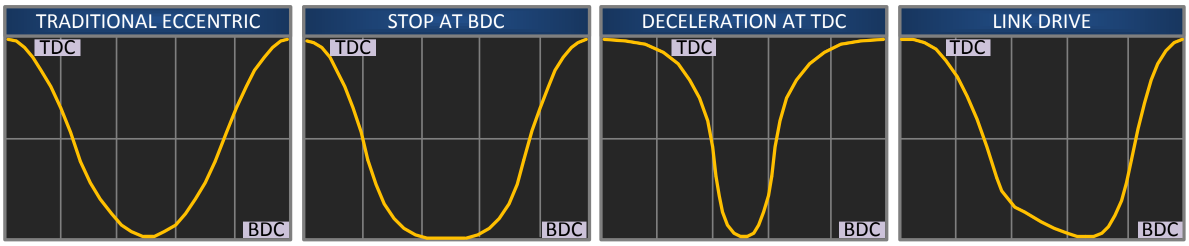

Figure 8: Mechanical press (eccentric drive) with servomotor without mechanical stroke adjustment - Examples of slide displacement curves (position of slide/time)

Servomotor presses provide highly flexible utilisation by making it possible to sequence and vary slide strokes by reversing the direction of the servomotor at the time desired.

In Figure 9 and Figure 11, the stroke of the slide is reduced only by the servomotor, without mechanical adjustment as would be the case for a traditional variable stroke mechanical press. The successive reversals of the rotation direction of the servomotor generate a pendular movement of the eccentric drive and the connecting rod.

5.1.2. Case of reduced stroke with intermediate top point and bottom dead centre point

In this mode of operation, at the end of the cycle, the servomotor is stopped at an intermediate top point located below the top dead centre point. Its rotation is controlled to permit the movement of the slide, which passes systematically via the bottom dead centre point. The direction of rotation of the servomotor (detailed in the upper part of each drawing) is reversed at each departure from the intermediate top point. It remains the same for each full cycle, for raising and lowering the slide. **Thus the slide does not pass via the top dead centre point.**

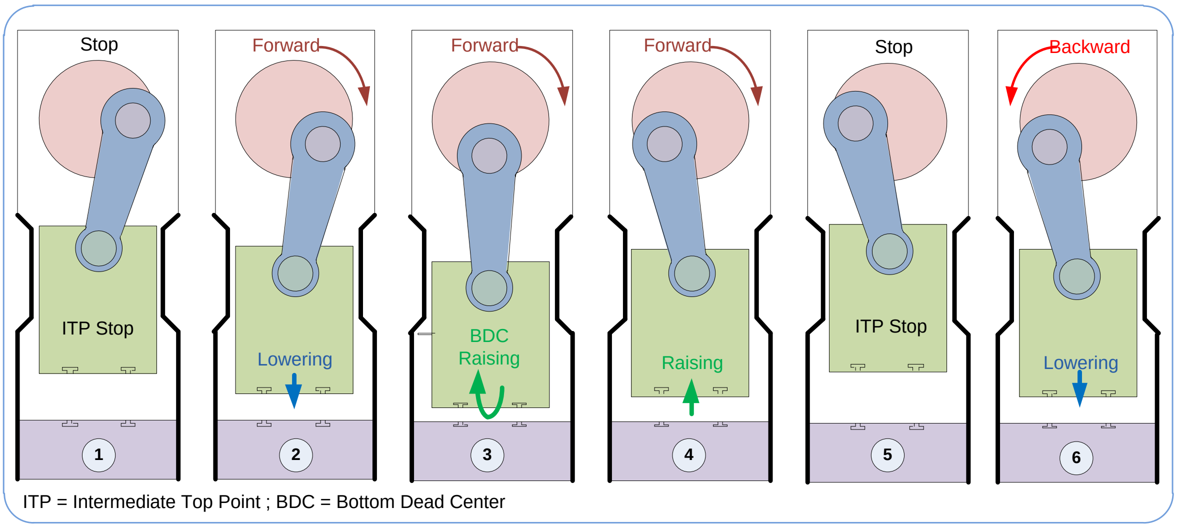

Figure 9: Mechanical press (eccentric drive) with servomotor – Stroke reduced by the servomotor (intermediate top point and bottom dead centre point) - Example of the “pendular” cycle

Figure 10 shows an example of the displacement curve for this type of pendular cycle.

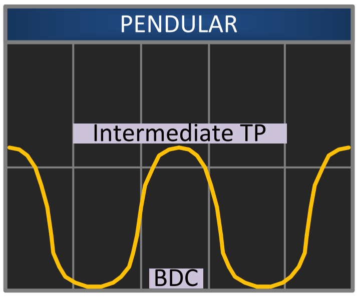

Figure 10: Mechanical press (eccentric drive) with servomotor - Examples of slide displacement curves in a “pendular” cycle with passage via the bottom dead centre point (position of the slide/time)

5.1.3. Case of reduced stroke with intermediate top and bottom points

In this mode of operation, at the end of the cycle, the servomotor is stopped at an intermediate top point, located below the top dead centre point. The servomotor is controlled in a rotation direction to produce the slide lowering movement, then, once the intermediate bottom point is reached, corresponding to the stroke desired, the rotation direction is reversed for the raising phase. **Thus the slide does not pass via the top and bottom dead centre points.**

Each rotation direction of the servomotor (detailed in the upper part of each drawing) corresponds to a direction of the slide movement.

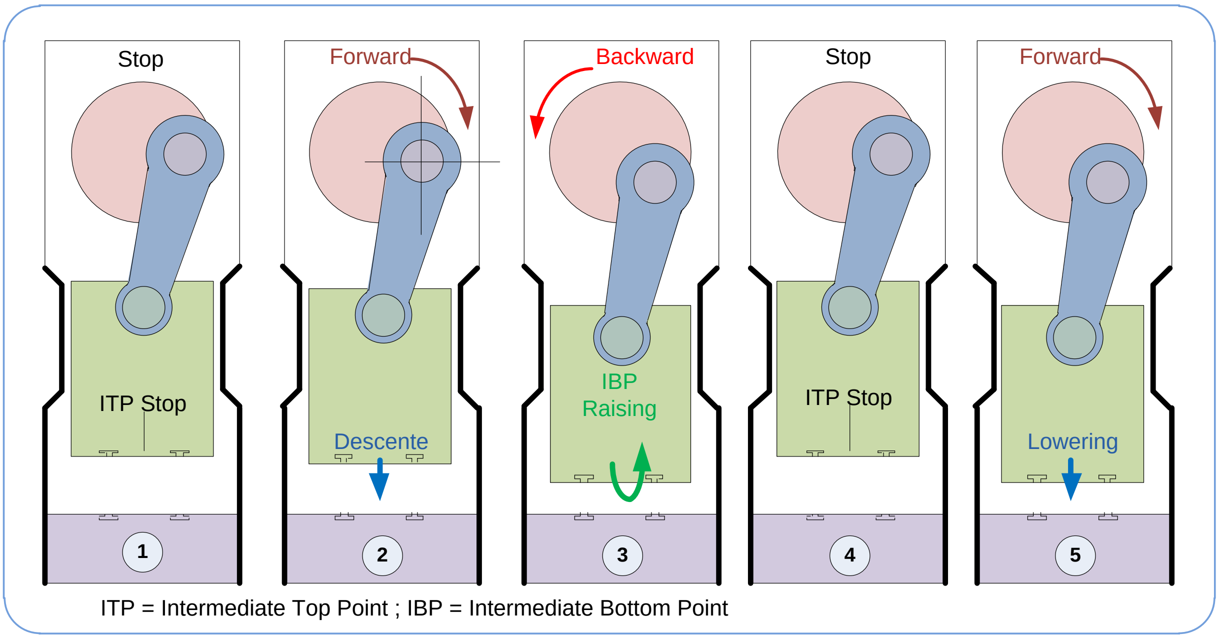

Figure 11: Mechanical press (eccentric drive) with servomotor - Stroke reduced by the servomotor (intermediate top and bottom points)

Figure 12 shows an example of the displacement curve for this type of cycle.

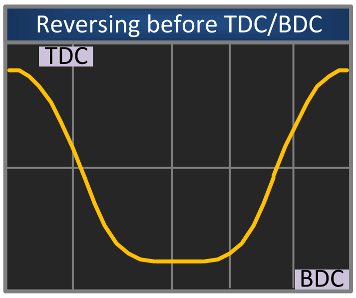

Figure 12: Mechanical press (eccentric drive) with servomotor - Examples of slide displacement curves without passing via the top and bottom dead centre points (position of slide/time)

5.2. Intermediate transmission between a servomotor and an eccentric drive

The eccentric drive is driven by the servomotor via a “non declutchable” transmission. To ensure the correct and precise positioning of the slide, and transfer the full power of the servomotor, the movement of the servomotor must be perfectly in phase with that of the eccentric drive. In most of the cases identified, the link between the latter and the servomotor is ensured by a gear train, out of alignment (conventional, e.g., harness type) or planetary (planetary reduction drive) assembled at the end of the shaft. Some manufacturers use toothed belts. Figure 13, Figure 14 and Figure 15 show how these types of drive are implemented.

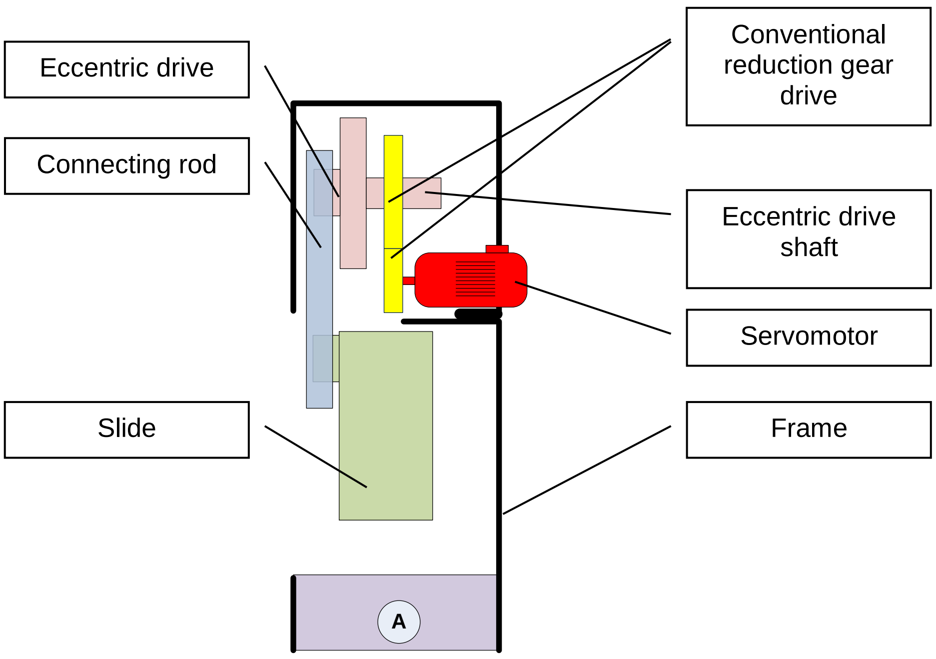

Figure 13: Diagrammatic view of a drive with a conventional reduction gear drive

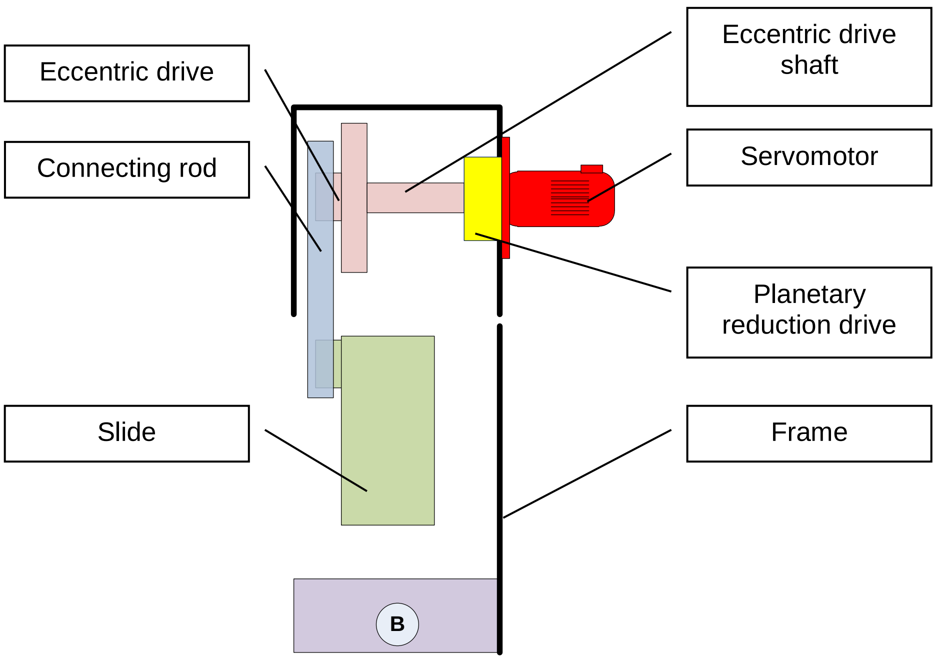

Figure 14: Diagrammatic view of a drive with a planetary reduction drive

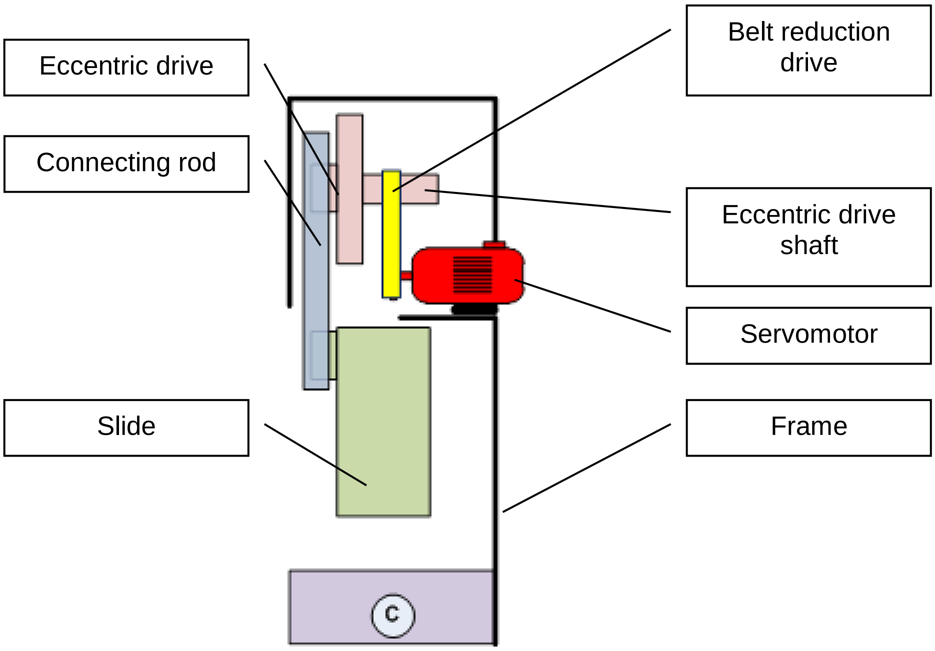

Figure 15: Diagrammatic view of a belt reduction drive

5.3. Slide stops

5.3.1. A reminder on "traditional" mechanical eccentric drive presses

Traditional presses with clutch/brake units are all equipped with a mechanical brake whose minimum safety characteristics are written in standard NF EN 692[3]. This mechanical brake is initiated automatically by the control system each time it is necessary to stop the slide, thus for stops:

- of production to allow, for example, manual loading/unloading of parts (at top dead centre point),
- for safety when an operator safety device is used or in the case of control failure (at any point of the stroke),
- in case of disconnection or a power supply failure (at any point of the stroke).

Each stop is controlled systematically by declutching, cutting off the power supplied to the mechanical brake and by activating springs to apply the brake pads.

5.3.2. Eccentric drive servomotor presses

Different slide stops can be performed with servomotor presses:

Stop due to cutting off power:
A stop similar to that of traditional presses can be performed by cutting off the driving power (cutting off the power supply to the servomotor) and applying a mechanical brake. This stop is not planned for use during production, but can be employed:

- for safety reasons when an operator protection device is used or in the case of failure of the control system (at any point of the stroke),
- if the power is cut off (at any point of the stroke).

[3] NF EN 692:2009 - Machine tools - Mechanical presses - Safety

Stop controlled by the servomotor:
This can be performed for:
- production stops,
- safety stops when an operator protection device is used.

This stop is generated by the electronic regulation system of the servomotor then by a mechanical brake.

Stop and hold to stop phase controlled by the servomotor:
This is provided for stops linked to production, either, for example, for manual loading/unloading of parts, or between two phases of an automatic cycle.
This stop is performed through the characteristics provided by servomotors and their electronic regulation system. The stop holding phase is obtained by maintaining the power to the servomotor so that the slide does not deviate from the intended stop position, for example at the top dead centre point. Thus it is an electronic control system used for control in this position.

5.4. Tool opening movements

For conventional presses, the main motor runs permanently in the same direction of rotation, and the press mechanism ensures the raising and lowering of the slide via the eccentric drive. Generally, the protection devices can be inhibited during the slide raising phase, since this movement is not considered to represent a significant danger.
The motor reverse option is only used for the setting mode.

In the case of servomotor presses, the direction of the servomotor can change during the same cycle, for example, for pendular modes. These directions of movement are generated by the electronic regulation system.

5.5. Slide speed

Some servomotor presses provide the possibility, in setting mode, of controlling movements at reduced speed, with the speed limited to 10 mm/s to reduce risks, with an action held on a control device with three positions. The speed of the servomotor is therefore managed by the electronic regulation system.

5.6. Summary of the main characteristics of a mechanical servomotor press and comparison with a traditional mechanical press

Main characteristics	Traditional eccentric drive press	Eccentric drive servomotor press
Supply of energy needed for work	Electric motor and flywheel to store and restore the energy needed for work.	Electric torque motor and possibly an energy storage system (condensers, etc.) to store (notably during slide deceleration phases) and restore (when pressing sheet steel) the energy required for the task.
Power supply to the drive motor during production	Continuous supply to the motor, even when the slide is stopped.	Continuous supply to the servomotor for movements and maintaining the stop when it is ensured by the servomotor.

Main characteristics	Traditional eccentric drive press	Eccentric drive servomotor press
Rotation of the drive motor	Continuous rotation of the motor, even when the slide is stopped.	The servomotor rotates only when slide movements are required.
Direction of motor rotation	Single direction in production mode and possibly bi-directional when a “reverse setting” mode is intended.	Single or bi-directional as a function of the operating modes used.
Direction of motor rotation for lowering the slide in production mode	“Forward” direction.	“Forward” and “backward” directions according to the operating modes used.
Direction of motor rotation for raising the slide in production mode	“Forward” direction.	“Forward” and “backward” directions according to the operating modes used.
Motor rotation speed during a cycle (lowering and raising)	Fixed	Variable “electronically”.
Mechanical transmission between the motor and the eccentric drive	Via a mechanical clutch between the motor/flywheel assembly and the eccentric drive.	Permanent link between the servomotor and the eccentric drive.
Slide movement speed	Sinusoidal variation for a traditional transmission (eccentric driver/connection rod), that can vary (speed + or – fast at the low dead centre point) according to the design of the transmission used (toggle, link-drive).	Sinusoidal variation for a traditional transmission (eccentric driver/connection rod) at a constant servomotor rotation speed, that can be varied as desired as a function of the servomotor speed during the movement.
Slide stroke	Non adjustable, or adjustable mechanically by varying the eccentricity.	Possibility of adjustment without the mechanical system, by reversing the direction of rotation of the servomotor before the top/bottom dead centre points.
Type of stop during production (e.g., to permit manual loading/unloading of parts)	Mechanical uncoupling of the drive (declutching) and cutting off power to the brake.	Either by cutting off power to the servomotor and mechanical braking, or controlled stop with stop maintained by continuing the power supply to the servomotor.

Table 1: Comparison of the main characteristics between a traditional eccentric drive press and an eccentric drive servomotor press

6. General operating principles of a servomotor screw press

Servomotor screw presses (also called electric presses) for cold metalworking have come on the market quite recently. This is due to the progress made in screw/nut systems whose efficiency (that can now reach 95%), longevity and admissible forces have been improved in particular by satellite or planetary roller screws, and above all the evolution of servomotors and the electronic control systems.
Several motors and screws can be used for the same slide.
Servomotor driven screw presses are intended to perform works usually done by hydraulic and pneumatic presses such as metal cutting and stamping, bending, and assembly by clinching and fitting, for example.

6.1. The different slide drive modes using a screw/nut system

Two cases can be considered:

- the screw is driven in rotation by the servomotor. The nut is linked to or incorporated in the press slide and drives its slide translation movement (raising/lowering),
- the nut is drawn in rotation by the servomotor. The screw is linked to the press slide and drives its translation movement (raising/lowering).

6.2. Management of slide displacement curves by varying servomotor speed

With a screw system, for a constant servomotor drive speed, the speed of the slide is the same throughout the stroke. By varying the servomotor’s parameters, this type of press can provide slide displacement curves comparable to those of a hydraulic press, and thus perform the same types of work, by eliminating the variations of the characteristics generated by variations in the temperature of the hydraulic fluid.

6.3. Management of the slide stroke through action on servomotor rotation

The servomotor also makes it possible to manage the stroke of the slide directly by reversing the direction of rotation at the time desired.
At the end of a cycle, the servomotor is stopped at a programmed intermediate top point, located below the maximum top point. The servomotor is controlled in one direction of rotation to produce the slide lowering movement, then as soon as the programmed intermediate bottom point is reached, it reverses for the slide raising movement.
Each direction of rotation of the servomotor corresponds to one direction of slide movement.

6.4. Intermediate transmission between a servomotor and a screw/nut system

The screw or nut is driven by the servomotor via a “non-declutchable” transmission. To ensure that the press operates correctly and precisely, and that all the power of the servomotor is transmitted, it is necessary for the movement of the servomotor to be in perfect phase with that of the screw/nut system. In most of the cases identified, transmission to the servomotor is done:

- either directly, via a planetary reduction gear (epicyclic) assembled in alignment with the servomotor and the screw,
- or using a toothed belt.

6.5. Slide stops

These stops are the same as those described for the eccentric drive presses (see § 5.3.2).

The lowering of the slide by gravity is a potential cause of risks.
The internal friction coefficients of screw/nut systems, for example, satellite or planetary roller screws, can be very low and permits reaching an efficiency of 95 %. Thus if the nut (or the screw in the second case) is subjected to an axial force (slide mass), the screw (or the nut in

the second case) is subjected to a rotation torque. The system is therefore reversible and the slide lowers by gravity if no additional stop system is provided.

For high power screw presses, the manufacturers mainly use pneumatically or hydraulically controlled brakes.
For low power presses, electromagnetically controlled brakes are usually used.

6.6. Tool opening movement

For the great majority of presses operating in “single cycle” mode (manual loading/unloading), the protection devices can be muted during the tool opening phase (raising of the slide), if this movement does not represent a significant hazard.

In the case of a screw servomotor press, the direction of servomotor rotation changes during the same cycle, either to obtain a lowering movement, or to obtain a raising movement. Thus it is the electronic regulation system of the servomotor that manages these directions of movement.

7. Main principles of operating a servomotor driven hydraulic press

A servomotor drives a hydraulic pump that supplies the cylinder supporting the slide and which directly controls the working parameters of the machine. This assembly replaces the equivalent components usually used, such as servo-distributors, since the control of the hydraulic flow in the cylinder depends directly on the variations of the directions and characteristics of the servomotor. Several associated servomotors and pumps (servo pumps) can be used as well as several cylinders.
This type of press has not been studied in detail since the manufacturers use various techniques for which we have not been able to collect enough technical information, as most of it is subject to patents.

8. General operating principles of a belt and pulley driven servomotor press

Belt and pulley drives can only be found on brake presses with a mobile upper beam mounted on an H-frame.

8.1. Principle of moving the beam

The mobile beam is equipped with two rows of loose pulleys (one row per vertical shaft) located in its upper part. The transversal part (between the two lateral sides forming an H) is also equipped with two rows of loose pulleys (one row per vertical shaft) located in its lower part and two drive pulleys (one per shaft) each driven by a servomotor. The pulleys of the frame and beam are linked together by a belt for each shaft driven by the servomotor.
Each of the shafts is equipped with springs that ensure a force in opposition to the lowering of the mobile beam (tool closing).
During the closing movement, the belts are tightened between a fixed point located on the frame and the drive pulley. This draws the pulleys of the beam closer to those of the frame and compresses the springs.
During the opening movement, the belts are loosened and the springs ensure the raising movement of the slide, controlled by the servomotors.

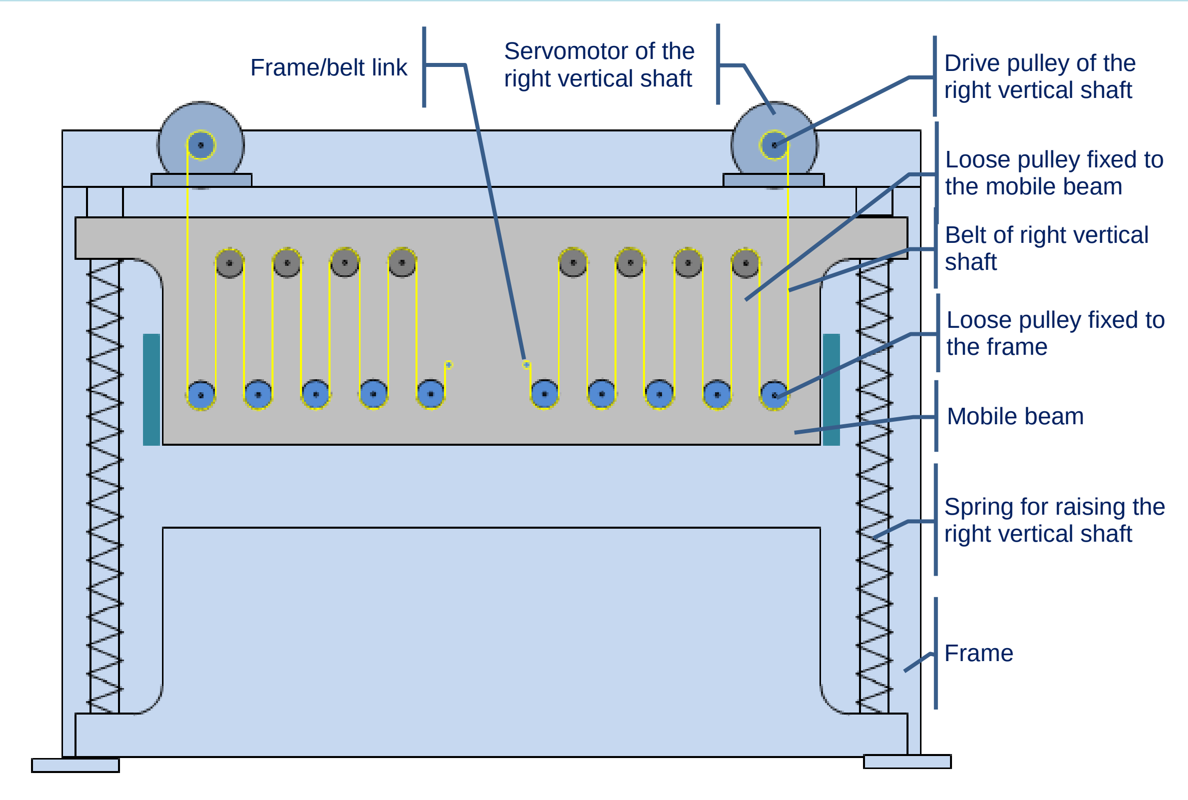

Figure 16: Principle of the pulley/belt drive system

According to the manufacturer and the model of press-brake, the latter can be equipped with two identical pulley/belt drive mechanisms located on either side of the mobile beam. This permits distributing the forces on either side of the beam for high powers.
Likewise for the number and type of springs equipping the vertical shafts. Each of the shafts is equipped with a retention system composed of one or several springs or assemblies of springs assembled in series (end to end). This solution ensures the slide raising function even if a spring breaks.

8.2. Beam stops

The stops can be the same as those described for eccentric drive presses (see § 5.3.2), taking into account that the springs prevent the lowering of the beam by gravity.

9. Safety functions relating to servomotor presses

9.1. Generalities/Introduction

In order to study the influence on safety of the new technologies implemented in servomotor presses, it is first necessary to identify [§ 9.2] and specify [§ 9.3] precisely the safety functions participating in the protection of operators. It is necessary to ensure they are capable of providing the service expected, by taking into account the technologies and principles employed on servomotor presses. For example, the definition of specific and adapted stop functions.

9.2. Identification of functions involved in safety

In conformity with the requirements of the "machinery" directive and in application of the recommendations of standard NF EN ISO 12100[4], the manufacturer of a servomotor press must carry out a risk assessment, and reduce the risks from the design stage.
Presses, including servomotor presses, generally require human actions in the tool zone (slide movement zone). For example, they take place for setting and maintenance operations, and during certain phases of production such as the manual loading and unloading of parts. Safety measures must therefore be taken to ensure that no slide lowering movement can occur as long as the operator is exposed to a risk in this zone.

In the case of presses, the main safety functions are linked to the protection means (movable guards, protective devices, etc.) intended to cover risks relating to mobile working elements (slide, etc.).

- Mention can be made of **stopping and/or hold to stop functions** of potentially hazardous mobile elements that stem, for example, from using a movable guard equipped with an interlocking device, an interlocking device with guard locking or a protective device such as photoelectric barriers or a two-hand control.
- There is also a **speed limitation function** for the hazardous movement when this measure is associated with a **hold to run control** to reduce risk.

Of the other safety functions specific to presses and for which the use of servomotors requires reflection, mention must be made of the function used to **mute** the protection means which is authorised when the movement of the mobile element is not in the hazardous phase of a cycle. This is the case in particular when raising the slide (opening tools) of a press. This muting function can only be triggered when the slide is in a "safe" position and/or direction of movement. When the muting function is used, it must be associated with strict control of the **slide position and its direction of movement**. The latter point is especially important for eccentric drive servomotor presses for which the direction of slide movement is not ensured by the direction of rotation of the servomotor.

9.3. Specification of safety functions

All the safety functions must be specified precisely according to two criteria:

- functional requirements,
- safety integrity requirements (e.g., Performance Level required [PLr]).

The functional requirements must permit specifying, among other things, the conditions for activating the function and the description of the action expected from the sensors to the actuators (e.g., stop or movement limitation). If necessary, the specification must specify the type of stop and/or hold to stop expected with the objectives in terms of time/distance of the stop and/or the position of the mobile element considered. Likewise, the movement and speed limitation values must be defined.

The determination of safety integrity requirements is not dealt with in this document. The level of performance required for the safety function (PLr) can be either determined by applying, for example, the methodology proposed in standard NF EN ISO 13849-1[5], or taken from the press design standard.
In the case of a mechanical servomotor press, Appendix B proposes examples of typical safety function specifications of these presses.

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4 NF EN ISO 12100:2010 - Safety of machinery - General principles for design - Risk assessment and risk reduction

5 NF EN ISO 13849-1:2008 - Safety of machinery - Safety related parts of control systems. Part 1: General principles for design

9.3.1. **Functional requirements relating to stop and safe hold to stop functions**

It is necessary to foresee and treat safe slide stop functions adapted to each of the potentially hazardous situations. Depending on the protection systems provided and the situations in which they are employed, these stop functions can play several roles. They can be assigned to stopping a movement in progress and/or maintaining a static load, while preventing an unintended start. This requires that different characteristics are taken into account and specified precisely.

By way of example, safety function no. 1 “stop by protective device”, specified in appendix B, requires a “protection stop” function which has two objectives:

- prevent slide movements from occurring as long as the photoelectric barrier is interrupted – this is the “safe” hold to stop function of the slide,
- stop slide movements “covered” by the photoelectric barrier while it is interrupted– it is a stop function triggered during the movement for which the maximum time of completion must be controlled.

To start this stop function, it is necessary to consider that:

- ➢ the servomotor and its control system (variable speed control) are integrally involved in the management of stop functions, which is not the case for mechanical presses of traditional design, for which a clutch/brake is used. This assembly can be used actively by adjusting the parameters (torque, speed) for the deceleration phases and also for maintaining the slide stopped;
- ➢ the slide is a dynamic load subject to gravity that cannot be held in position by the servomotor as it is not powered up;
- ➢ a mechanical brake is therefore required to ensure the stop phases not guaranteed by the servomotor.

9.3.2. **Reminder of the stop categories according to standard EN 60204-1**

NF EN 60204-1[6] is the only standard to define the stop categories (see Figure 17) for machines. It deals with equipment designed exclusively on the basis of electric technology. As stated previously, the stop functions of servomotor presses use electric components as well as those with other technologies such as hydraulics.
Additional means using non electric technology are needed for stop functions not covered by this standard, and thus not included in the recommendations relating to stop categories, and they must be dealt with additionally by the designer.

9.2.2 Stop functions

There are three categories of stop functions as follows:

– stop category 0: stopping by immediate removal of power to the machine actuators (i.e. an uncontrolled stop – see 3.56);

– stop category 1: a controlled stop (see 3.11) with power available to the machine actuators to achieve the stop and then removal of power when the stop is achieved;

– stop category 2: a controlled stop with power left available to the machine actuators.

Figure 17: Extract of standard EN 60204-1:2006

[6] EN 60204-1:2006 - Safety of machinery - Electrical equipment of machines - Part 1: General requirements

9.3.3. **The different stop functions of a mechanical servomotor press (eccentric or screw drive)**

To take into account all the requirements specific to servomotor presses, different hold to stop and stop functions have been defined as a basis for specifications for their safety functions.

9.3.3.1. Safe hold to stop without energy

This is provided to ensure **the hold to stop** of the slide by doing the following:

- cutting off the electric energy to the servomotor concerned and simultaneously cutting off the power supply (electric or other) to the device maintaining the slide in stopped position (mechanical restraint device).

Note: Safe hold to stop without energy is the last phase of a type 0 safe stop (§ 9.3.3.3) or type 1 (§ 9.3.3.4).

It can also be used:

- to maintain the stop when initiating a **"normal stop"** (EHSR 1.2.4.1 of directive 2006/42/EC) of a servomotor press whose mobile element was at "safe hold to stop with energy" (§ 9.3.3.2) or "type 2 safe stop" (§ 9.3.3.5),
- to ensure a **hold to stop at end of cycle** (§ 9.3.3.9).

9.3.3.2. Safe hold to stop with energy

This is provided to ensure the **hold to stop** of the slide by maintaining the electric power supply to the servomotor concerned.

Note: Safe hold to stop with energy constitutes the last phase of a type 2 safe stop (§ 9.3.3.6).

It can be used in normal operation to ensure a **hold to stop at end of cycle** (§ 9.3.3.9).

9.3.3.3. Type 0 safe stop

This is provided to ensure the **stop** of the slide and its **hold to stop** by doing the following:

- Immediate cutting off of the electric power supply to the servomotor concerned and immediate cutting off of the energy supply (electric or other) to the mechanical brake.

Note: During normal operation, this type of stop can be used to ensure:

- a "protection stop" (§ 9.3.3.6),
- an "anti-repetition" (§ 9.3.3.7),
- a "stop by control device" (§ 9.3.3.9).

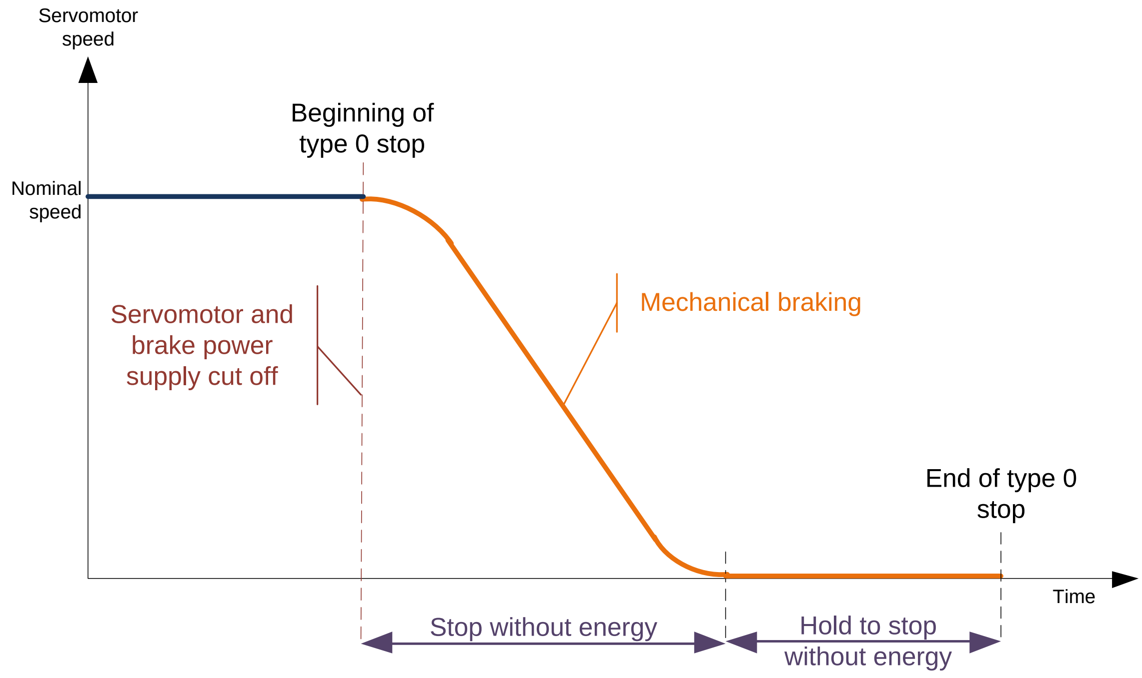

*Figure 18: Chronogram of the principle of a **type 0 safe stop***

9.3.3.4. Type 1 safe stop

This is provided to ensure the **stop** of the slide and its **hold to stop** by doing the following:

- decelerate the servomotor by maintaining the electric power supply until the movement stops,
- then, when the movement stops, cut off the electric power supply to the servomotor and immediately cut off the supply of energy (electric or other) to the mechanical brake.

Note: During normal operation, this type of stop can be used to ensure:

- a “protection stop” (§ 9.3.3.6),
- an “anti-repetition” (§ 9.3.3.7),
- a “stop by control device” (§ 9.3.3.9).

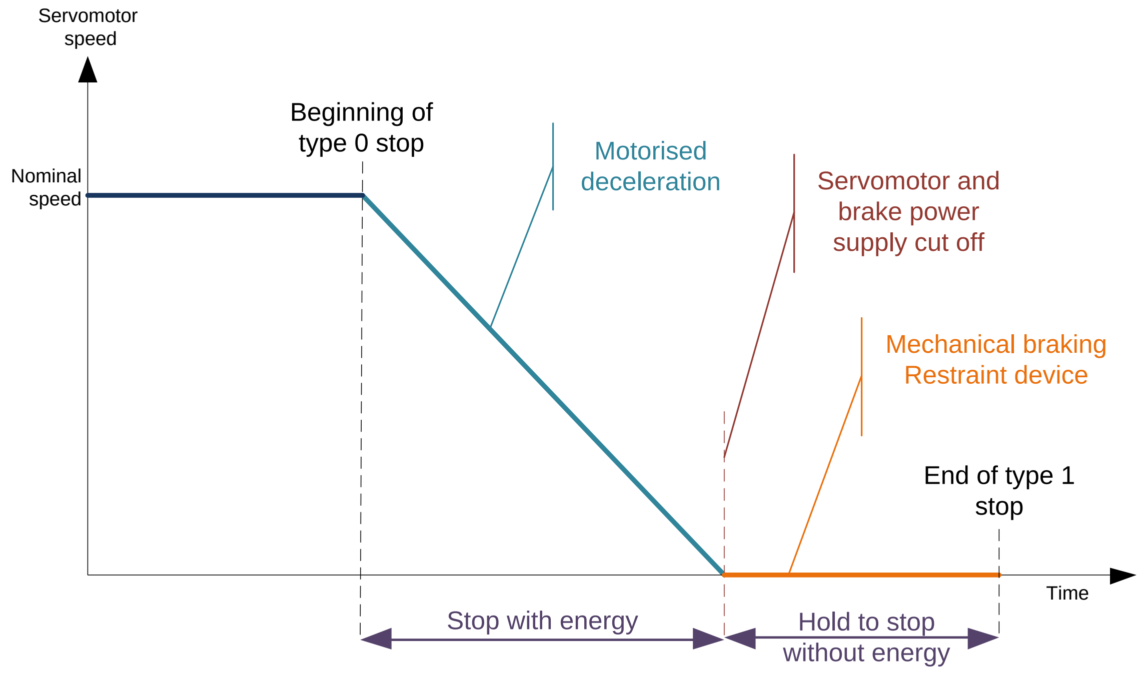

*Figure 19: Chronogram of the principle of a **type 1 safe stop***

9.3.3.5. Type 2 safe stop

This is provided to ensure **the stop** of the slide and its **hold to stop** by doing the following:

- decelerate the servomotor until the movement stops,
- then, when the movement stops, hold to stop.

All this is done while maintaining the electric power supply to the servomotor.

Note: During normal operation, this type of stop can be used to ensure:

- a “anti-repetition” (§ 9.3.3.7),
- a “stop by control device” (§ 9.3.3.9).

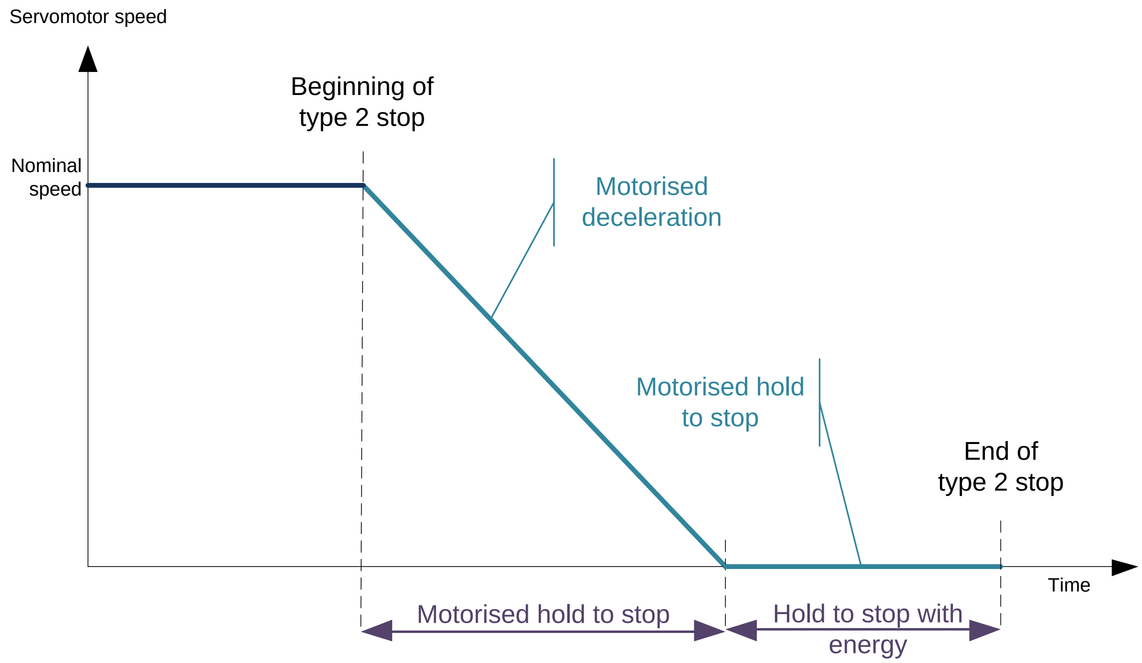

*Figure 20: Chronogram of the principle of a **type 2 safe stop***

9.3.3.6. Protection stop

Stopping and holding to stop of the slide in reaction to the activation of a protection means (movable guards interlocking device, protective devices such as photoelectric barriers, two-hand controls, etc.) during a hazardous movement, and acting in the form of a **type 0 safe stop** (§ 9.3.3.3) or a **type 1 safe stop** (§ 9.3.3.4).

When a stop function (type 0 or 1) is activated in the framework of a protection stop, **the control of the stopping time** must be ensured**,** when the slide is stopped, to guarantee the correct positioning of the protection systems in all situations. **Control of the stop position** must also be ensured during the hold to stop phase to guarantee that the slide does not lower while the operator may be in the hazardous zone.

Note: The notion of the function “Protection stop” ***(in the draft of the ISO standard)***, defined previously stems from the works of the standardisation group ISO/TC 39/SC 10/WG. 1, responsible for works on servomotor presses (draft of standard ISO 16092-2).

9.3.3.7. Anti-repetition

When muting function of a protection is activated on an **eccentric drive servomotor press** during the automatic raising phase, a safety stop must guarantee that the slide is stopped and held to stop at the end of the cycle. This safety function must prevent the cycle from being repeated, leading to a hazardous movement for the operator. This function can be ensured by a **type 0 safe stop** (§ 9.3.3.3), a **type 1 safe stop** (§ 9.3.3.4) and **type 2 safe stop** (§ 9.3.3.5).

When a stop function (type 0, 1 or 2) is implemented in the framework of anti-repetition, **control of the stop position** must be ensured when stopping the slide and holding the stop, to prevent the slide from lowering after passing through the top dead centre point while the operator is located in the hazardous zone.

Note: For screw presses, hydraulic presses and press brakes, whose kinematics do not allow cycle repetitions in the case of failure, a safety function is not necessary to stop the raising of the slide at the end of the cycle, when the protective device is muted.
However, on these machines, when the stop is obtained normally (not by a safety function), a **hold to stop at end of cycle** safety function must be implemented when the inhibition of the protection is active.

9.3.3.8. Hold to stop at end of cycle

This safety function guarantees holding the slide to stop in **production** when the protection device is muted during the planned functional stop, for example, for manual machine loading/unloading operations.

When the protection of a servomotor press (screw, hydraulic or press brake) is ensured by a movable guard without guard locking or protective device, the hold to stop at end of cycle can be ensured by a **safe hold to stop without energy** (§ 9.3.3.1) or a **safe hold to stop with energy** (§ 9.3.3.2).

Note: If necessary, this safety function can be ensured by a **type 0 safe stop**, a **type 1 safe stop** or a **type 2 safe stop** which also comprises a hold to stop phase.

When the protection means of a servopress (whatever technology is used) is ensured by a movable guard with an interlockingand guard locking, the hold to stop at end of cycle can be ensured by a **safe hold to stop without energy** (§ 9.3.3.1). This hold function is required when the guard is unlocked or not closed, to guarantee the stop of the mobile element and prevent its unintended start-up.

A “safe hold to stop with energy” function can also suffice. However, the advantage for a servomotor press of implementing this (interlocking with guard locking) measure, when not imposed by a problem of movement inertia (stopping time of mobile elements too long to employ an interlocking guard without guard locking) is to override a slide stop safety function with the ensuing material consequences (control of slide stopping time and the need for an adapted braking capacity). Furthermore, since the “safe hold to stop with energy” function requires the supply of energy, in the case of an electric power failure or absence of power, the function can no longer be ensured, meaning that it will be necessary to implement a “safe hold to stop without energy”. In this case, the advantage of choosing a guard equipped with guard locking will be lost.

Recommendation:

When a movable guard with guard locking is considered (see also §11, *Analysis of the validity of conventional protection means on servomotor presses*), it is recommended not to ensure that the slide is held in stopped position by a “safe hold to stop with energy” but to privilege a “safe hold to stop without energy”.

When a safe hold to stop function (with or without energy) is implemented in the framework of a hold to end of cycle stop, **the control of the stop position** must be ensured to guarantee that there is no lowering movement of the slide when the operator is in the hazardous zone.

9.3.3.9. Safe stop by control device

This safety stop ensures that the slide stops and is held to stop when a control device is used (release of the 2nd position or actuation of the 3rd position) and when this measure participates in reducing the risk associated with the reduction of the slide speed. This function can be ensured by a **type 0 safe stop** (§ 9.3.3.3), and **type 1 safe stop** (§ 9.3.3.4) or a **type 2 safe stop** (§ 9.3.3.5).

Note: The current draft of the ISO standard on servomotor presses does not yet define whether a **type 2 safe stop** can be accepted to ensure this function.

When a stop function (type 0, 1 or 2) is employed in the framework of a stop by control device, **control of the stop position** must be ensured when holding the slide at stop to ensure that there is no downwards movement of the slide when the operator is in the hazardous zone.

10. Analysis of functions involved in safety

The analysis of the kinematic chain of eccentric drive servomotor presses has led to the identification of the parts (links) involved in the slide downwards movement (hazardous movement), and analyse their functional role. For example, Figure 21 shows the different parts making up the kinematic chain of an eccentric drive servomotor press by highlighting in the green square, the parts that differentiate this type of press from a conventional (clutch/brake) mechanical press.

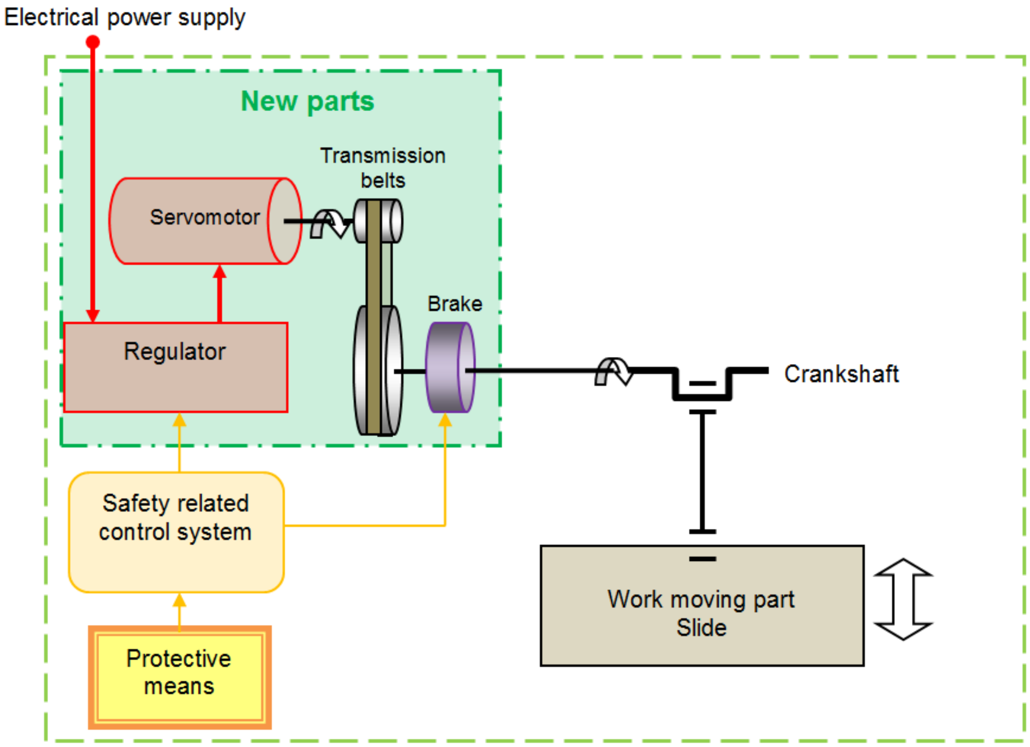

Figure 21: Example of the kinematic chain of an eccentric drive servomotor press

It is necessary to analyse the behaviour of the components contributing to these safety functions to ensure that they correspond to these specifications during normal operation and in the case of failure. A failure mode and effects analysis (FMEA) must therefore be carried out. Measures must be taken right from the design phase to ensure that none of the links of the chain is defective, whether mechanical, electric or otherwise, and that they cannot dangerously affect the performance of safety functions. Great attention must be given to certain safety functions which, in the case of failure, continue to fulfil their function, but with abnormal characteristics such as longer response times.

This analysis must be conducted according to two criteria:

- functional – to verify that these material parts and the techniques used are capable of ensuring the functions expected,
- functional safety – to characterise their behaviour if a fault occurs in view to identifying those that could cause hazardous situations. To do this, the following points must be analysed for each of the links in the chain and for each of the safety functions considered:
    - the type of failure, if necessary the part of the element affected by a potentially hazardous failure and the conditions of its occurrence (type of stop, press cycle phase, etc.),
    - the effect on the behaviour of the safety function,
    - the type of hazard liable to result from this failure,
    - the measures to be implemented to react to the failures and prevent hazardous situations from occurring.

Note: Only the parts that include new features in comparison to what is implemented at present on conventional presses are analysed. Indeed, regarding the latter, design recommendations are already included in the standards of the presses concerned.
These new features concern:

- the power drive system related to safety (PDS/SR for Power Drive System / Safety Related as per IEC 61800-5-2), for the instrumentation and control part [§ 10.1],

- and in particular belts and ball screws for the mechanical parts involved in safety [§ 10.10].

The following parts deal with several important points of these analyses regarding different functions or parts of the safety function such as:

- failure mode and effects analysis of the PDS/SR in the framework of applying a stop function,
- the influence of the servomotor's direction of rotation for eccentric drive presses,
- the management of the servomotor's rotation speed when it contributes to the implementation of a safety function,
- the analysis of certain mechanical elements of the kinematic chain.

10.1. Analysis of the behaviour of the PDS/SR – All servomotor presses

10.1.1. **Generalities**

The power drive system related to safety (PDS/SR) is an essential and unavoidable element of servomotor press control systems and safety functions. It is composed of the servomotor and its control system (including at least an electronic variable speed control and sensors) as shown in Figure 22.

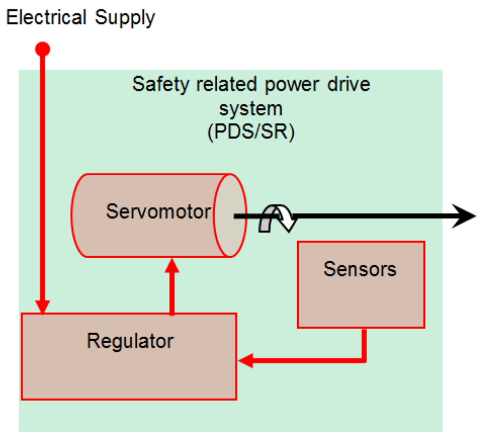

Figure 22: Diagrammatic view of the PDS/SR

The manufacturers of variable speed controllers offer different safety "options" or "modules" to ensure part of the safety functions specified by the press designer. In most cases, these safety "modules" claim conformity with the safety function definitions of standard IEC 61800-5-2 (STO, SS1, SS2, SLS, etc.) which specifies the requirements and gives recommendations for the design, development, integration and validation of the PDS/SR.

The control diagram of a servomotor press incorporating a PDS/SR, can take different forms depending on the level of integration of the safety "modules" offered by the manufacturers and ensuring all or part of the safety functions specified.
Several examples illustrating these different configurations are presented in appendix A.

For certain machines, the PDS/SR can be composed of several servomotors to provide the power required for the slide, or include an energy recovery system. These two specific cases are dealt with in § 10.9.5 to analyse their possible impact on operator safety.

10.1.2. **Level of safety of the PDS/SR and behaviour in the presence of a failure**

A PDS/SR must be capable, through its design, to ensure the parts of the safety functions in which it participates, with a Performance Level in accordance with standard NF EN ISO

13849-1 or SIL according to standard NF EN 62061[7] compatible with the level of risk to be covered.

The manufacturers of variable speed controllers claim safety performance levels for all the “modules” proposed or individually per “module”.

NOTE: Designers of servomotor press control systems must give attention to the fact that these levels of performance are not always easy to find in the manufacturers' documentation. Moreover, it is not always obvious that when a single global level of performance is claimed, it covers all the “modules” proposed.

Of the different functions (modules) offered by the manufacturers, it must be borne in mind that only the STO function (cf. § 10.2) is capable of ensuring behaviour in the presence of a failure in conformity with its nominal behaviour.
The other safety functions ensure monitoring of the function specified whose reaction, in the case of failure or deviation in comparison to the nominal result expected, lead to a safe fall-back position. This is why the safe fall-back position is characterised by an STO function for these different monitoring functions and in most of the cases observed. This behaviour is the same whatever the safety performance level claimed by the manufacturer of the PDS/SR (level PL or SIL). This safety performance level is in fact assigned to the monitoring function. The entire monitoring system, including the acquisition of information from the sensors (coders) must conform to the performance level specified for the function.

Recommendations:

Generally, and in case of failure, whether following a lack of energy, internal failure or a regulation problem, the reaction to the PDS/SR defect must lead to a fall-back position **corresponding to a type 0 safe stop function** (§ 9.3.3.3).
This must correspond to the absence of servomotor torque and therefore a fall-back position corresponding to an STO function. Likewise, possible safety outputs on the PDS/SR intended to cut the brake control (to obtain braking) must be designed and programmed to mirror the STO function in all situations.

In the framework of our analysis of the PDS/SR, it is vital to define the role it can play for each type of safety function specified as well as the programming conditions that must be satisfied. It is also necessary to understand its behaviour in the presence of a failure in order to be capable to define adapted safety recommendations.

Note: Failures taken into account at PDS/SR level are those that lead the loss of the safety function required for servomotor presses.
In the framework of stop functions, they can cause the downwards movement of the slide to accelerate instead of decelerate or an unintended downwards movement instead of holding the stop.
For the other safety functions implemented (e.g., speed limitation, control of rotation direction, etc.), they can cause an unintended increase of the downwards movement of the slide or a reversal of the slide movement (transformation of a non-hazardous upwards movement into a potentially hazardous downwards movement).

10.1.3. Implementation of a PDS/SR for safe stop functions

The stop functions of standard IEC 61800-5-2, which can be used to participate in the functions defined specifically for servomotor presses, are the following:

- STO (Safe Torque Off) – safe absence of torque,
- SS1 (Safe Stop 1),

[7] NF EN 62061:2005 - Safety of machinery - Functional safety of electric, electronic and programmable electronic control systems related to safety

- SS2 (Safe Stop 2),
- SOS (Safe Operating Stop) – holding to safe stop.

The definitions of these functions are available in appendix D.

10.2. "Safe hold to stop without energy" using an STO function

10.2.1. Functional analysis

The description of the function is given below:

Safe hold to stop using the STO function

Cutting off the electric power supply to the servomotor concerned via an STO function obtained by the PDS/SR and simultaneous cutting off of the supply of energy (electric or other) of the hold to stop device (mechanical restraint system).

Reminder: The STO function alone does not hold the slide in stopped position (see NOTE 3 of § 4.2.2.2 of standard IEC 61800-5-2). Thus it must be completed by a mechanical device intended and designed for this purpose.

Recommendations:

Cutting off the supply of energy to the mechanical restraint device must be actuated:

- either independently of the PDS/SR, by the same information as that which commanded to the PDS/SR to cut off the energy to the servomotor,
- or by using output information from the PDS/SR signalling the cutting off of energy to the servomotor.

10.2.2. Effects of a failure

In the case of the energy supply being cut off and affecting the entire PDS/SR, and taking into account the reaction to the expected faults (see § 10.1.2), if the power cut occurs when the safe hold to stop function without energy is active:

- it remains without energy since the servomotor is not supplied with energy due to the STO function,
- it remains without energy since the brake is not powered up.

If the PDS/SR is subject to a failure and taking into account the reaction to faults expected (see § 10.1.2), the reaction of the PDS/SR produces the same effect (a fall-back function in the form of the STO) as the function without failure.

A loss of power supply or a PDS/SR failure does not affect the "safe hold to stop without energy" function.

10.3. Type 0 safe stop function using an STO function

10.3.1. Functional analysis

The description of this function is given below:

Type 0 safe stop using an STO function

Immediate cutting off of the electric power supply to the servomotor concerned via an STO function obtained by the PDS/SR and simultaneous cutting off of the energy (electric or other) to the mechanical brake.

Recommendations:

Cutting the supply of energy to the brake must be actuated:

- either independently of the PDS/SR, by the same information as that commanded to the PDS/SR to cut off energy to the servomotor,
- or by using output information from the PDS/SR corresponding to cutting off the energy to the servomotor.

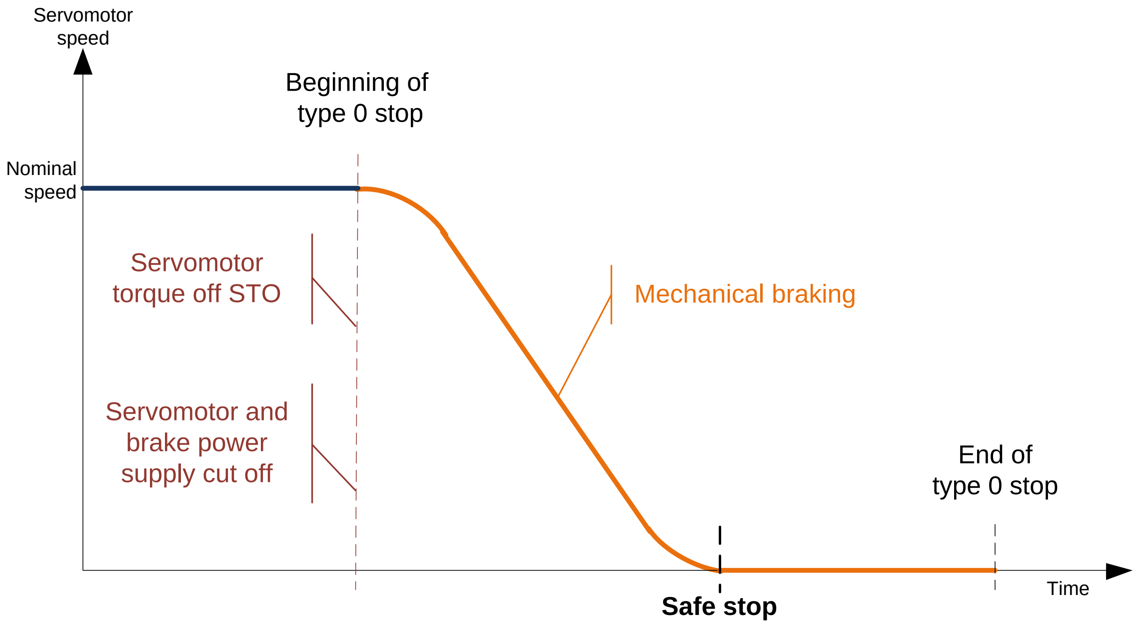

Figure 23: Chronogram of a type 0 safe stop function using an STO function

Observation: The stopping time of the servomotor, and thus the press slide, depends directly on the brake characteristics. The brake must be designed accordingly (see § 10.10.4).

10.3.2. **Effects of a failure**

The analysis and its results are similar to those of the “safe hold to stop without energy” function (see § 10.2.2).

A loss of power supply or a PDS/SR failure does not affect the type 0 safe stop function.

10.4. Type 1 safe stop function using an STO function

In principle, the SS1 function is composed of a motor deceleration phase and a motor de-energising phase ensured by the STO function. It can therefore be suitable (excluding the case of “SS1,a)” as described below) for participating in a **type 1 safe stop** function of a servomotor press.

10.4.1. **Functional analysis of case SS1, a)**

The stop is achieved following a deceleration ramp that is commanded but not monitored. Since the actuation of the motor de-energising phase depends on reaching near zero speed, in the case of failure (e.g., non-deceleration), it will not be commanded. There will be no reaction to the failure and thus loss of the expected safety function. The duration of the stop and the stop position will not be controlled in the case of a failure.

An SS1, a) cannot be used to perform a type 1 safe stop since it is vital to control the duration of the stop and the stop position in all the safety functions in which this type of stop can be performed.

10.4.2. Functional analysis of case SS1, b)

The description of this function is given below:

Type 1 safe stop using function SS1, b)

The PDS/SR actuates and monitors the deceleration of the servomotor within the limits set for stopping it (by maintaining the electric power supply).
When the speed of the servomotor is lower than a given threshold (and close to stopping), it cuts off the electric power supply of the servomotor via an STO function obtained by the PDS/SR and simultaneously cuts off the energy supply (electric or other) to the mechanical brake.

Recommendations:

The threshold of the end of servomotor deceleration must be determined by the press manufacturer so that the speed of the servomotor, thus the slide, is almost zero when commanding the STO function.

Cutting off the energy supply to the brake must be actuated by using output data from the PDS/SR corresponding to cutting off the energy supply to the servomotor.

When the mechanical brake is commanded, the speed of the servomotor is not quite zero, in line with the threshold value of the end of deceleration. The mechanical brake must be designed to ensure the last phase of stopping the slide before fulfilling its role of restraint device.

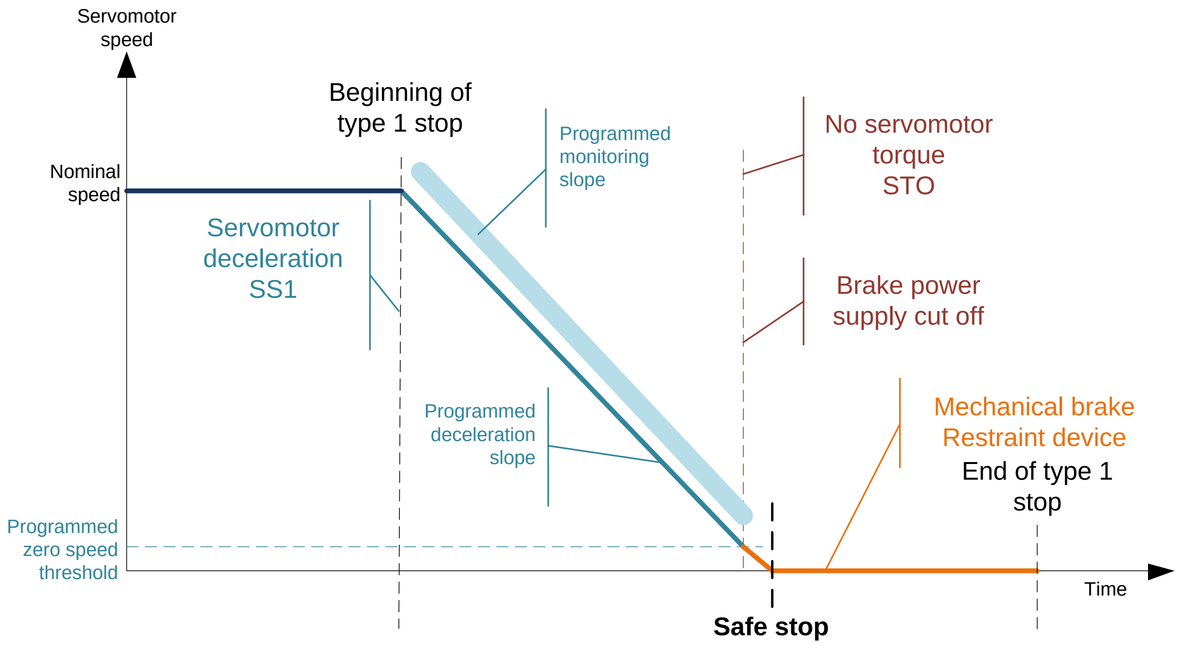

Figure 24: Chronogram of the type 1 safe stop function using an SS1, b) function

Observation: The stopping time of the servomotor, thus the press slide, depends on the ramp programmed in the PDS/SR and on the brake characteristics in the final phase.

10.4.3. **Effects of a failure for case SS1, b)**

The analysis permits showing that:

- a loss of power supply or a PDS/SR failure occurring during the hold to stop without energy (STO) does not affect the type 1 safe stop function;

- when a loss of power or a PDS/SR failure occurs during the deceleration phase, the servomotor temporarily runs in “freewheeling” mode since the PDS/SR no longer supplies energy to slow it down. The stop is therefore ensured only by the mechanical brake. This failure can influence the stop performance (see § 10.11.2) of the slide which will depend on the characteristics of the brake (see § 10.10.4) and the time of reaction to the PDS/SR failure.

Note: The time of reaction to the failure depends on:

- the time needed to detect this fault, conditioned by:
  - the PDS/SR parameters for an internal fault,
  - the **monitoring parameters of the safety function implemented (e.g., the value of the monitoring ramp, the percentage of the nominal speed, etc.) by the press designer**.
- The internal time of the PDS/SR for generating the fall-back position expected.

Figure 25 describes the phases of a **type 1** safe stop for a failure that:

- occurs during a deceleration,
- generates an acceleration of the movement instead of a deceleration,
- is detected when the speed reaches a value of the monitoring ramp, whose effect is to command the fall-back function (STO).

This example shows the case of an increase in the stopping time of the slide and thus the stroke of the stop, in comparison to that of the function expected.

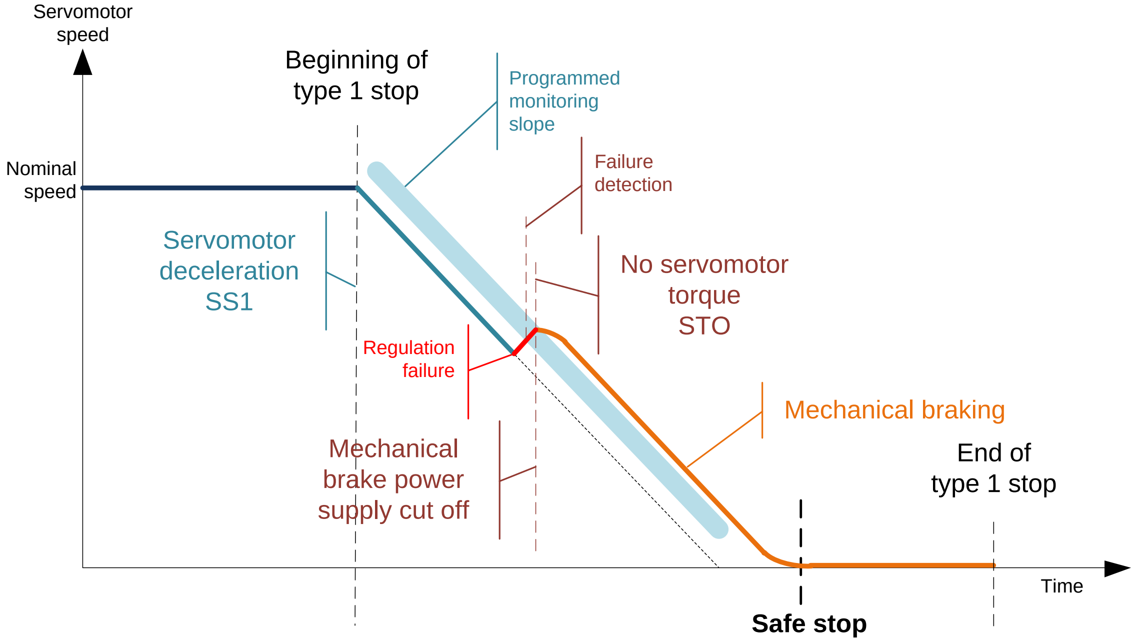

Figure 25: Chronogram of a type 1 safe stop function using an SS1, b) function; and the reaction in the presence of a PDS/SR failure

10.4.4. **Functional analysis of SS1, c) case**

This description of this function is given below:

Type 1 safe stop using function SS1, c)

The PDS/SR actuates the deceleration of the servomotor.
After a time-out specific to the application, it cuts off the energy supply to the servomotor via an STO function obtained by the PDS/SR and simultaneously cuts off the energy (electric or other) to the mechanical brake.

Recommendations:

Since the stop was commanded at the maximum speed of the servomotor, the time-out must be calibrated so that when it ends the speed of the slide must be zero when the STO function is commanded. Some manufacturers propose an alternative by commanding the STO function when the speed is zero, without waiting for the end of the time-out.

Cutting off the energy supply to the brake must be actuated by using output information from the PDS/SR corresponding to cutting off power to the servomotor.

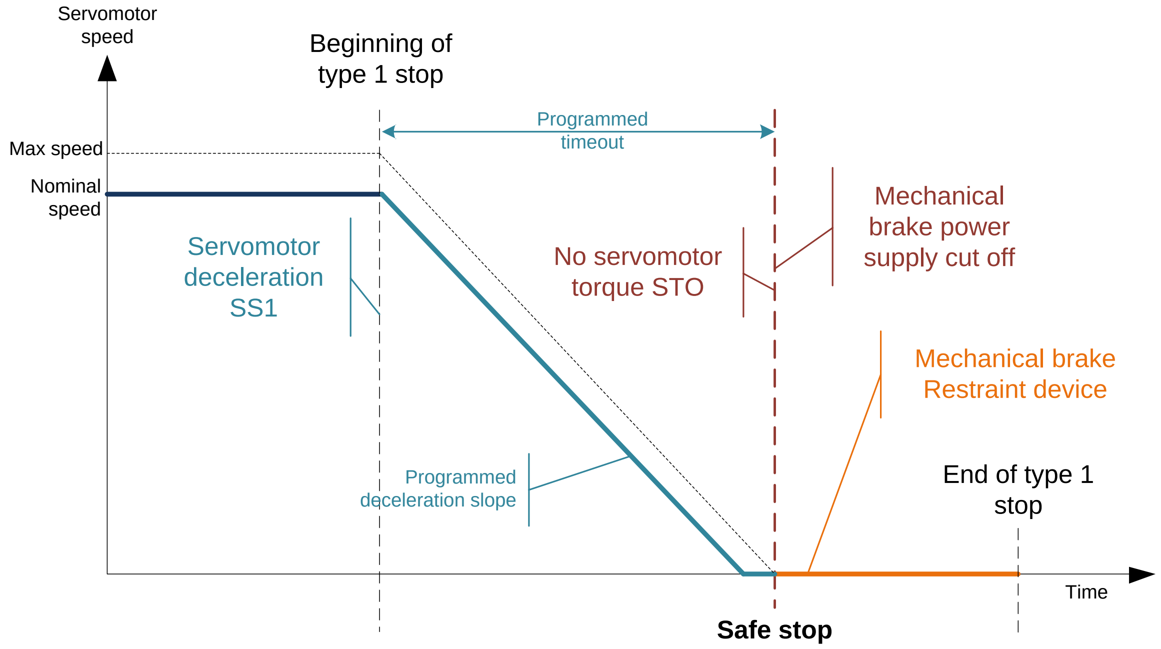

Figure 26: Chronogram of a type 1 safe stop function using an SS1, c) function

Observation: The time for accomplishing the type 1 safe stop mainly depends on the time-out programmed in the PDS/SR.

10.4.5. **Effects of a failure for case SS1, c)**

The analysis permits showing that:

- cutting off the power supply or a PDS/SR failure occurring during the hold to stop without energy phase (STO) does not affect the type 1 safe stop function,
- when a loss of energy supply occurs during the deceleration phase, as the PDS/SR no longer supplies energy to slow down the servomotor, the latter

temporarily runs in “freewheeling” mode. The stop is therefore ensured only by the mechanical brake. This failure can influence the stop performances (see § 10.11.2) of the slide which will depend on the characteristics of the brake (see § 10.10.4),

- a PDS/SR failure linked to regulation that occurs during the deceleration phase is not detected during the duration of the time-out. In this case, the fall-back function of the PDS/SR or the STO function switches off the energy supply to the servomotor so it runs in “freewheeling” mode. The stop is therefore ensured only by the mechanical brake. This failure will influence the stop performances (see § 10.11.2) of the slide which will depend on the time of reaction to the PDS/SR failure and the characteristics of the brake (see § 10.10.4).

Notes: The time of reaction to the failure depends on:

- the time needed to detect the fault conditioned by:
  - the PDS/SR parameters for an internal fault,
  - the **time-out value set by the press designer**, which commands the STO function.
- the internal time of the PDS/SR to generate the expected fall-back position.

When a fault linked to regulation occurs, the stop performances of the slide will be less efficient than those obtained during normal operation since the brake will be applied only at the end of the time-out, with a non-zero speed liable to reach the maximum speed of the servomotor.

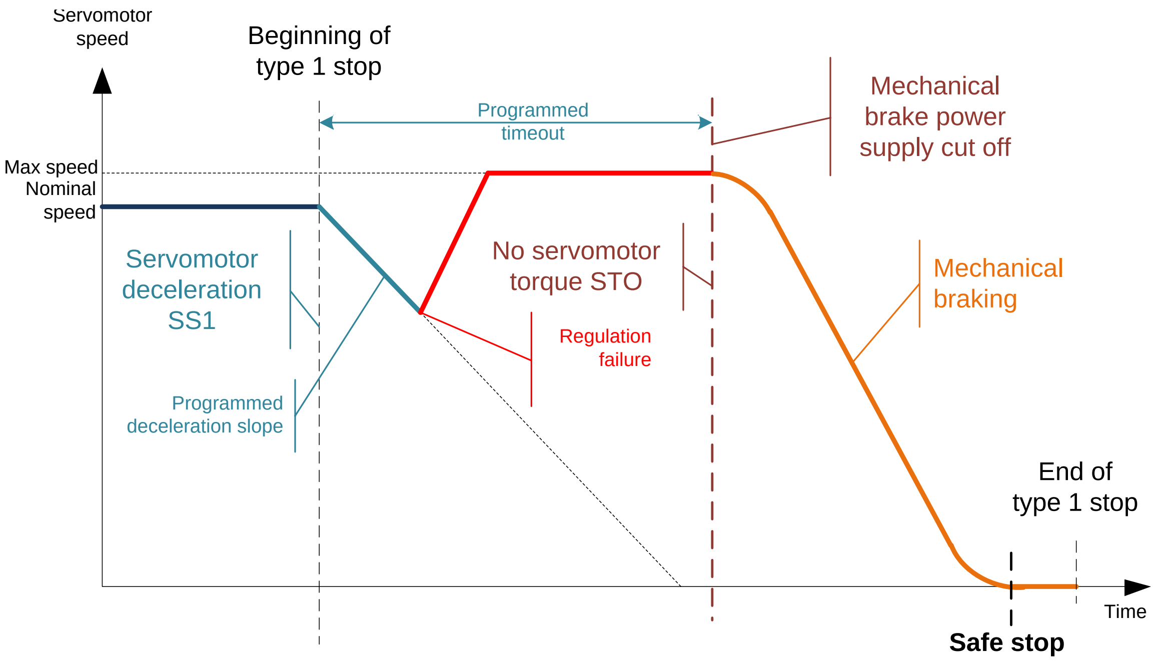

Figure 27: Chronogram of a type 1 safe stop function using an SS1, c) function; and the reaction in the presence of a PDS/SR regulation failure

10.5. Type 2 safe stop function using an SS2 function

In principle, the SS2 function is composed of a motor deceleration and a motor hold to stop in position phase ensured by the SOS function. It can therefore be suitable (excluding the case of the "SS2, a)" as described below) for participating in **a type 2 safe stop function** of a servomotor press.

Note: Some PDS/SR manufacturers offer, by way of an SOS function, a safe hold to stop by maintaining zero speed. The speed regulation permits slow displacement in relation to the desired stop position. This principle does not respond to the definition of § 4.2.3.1 of standard IEC 61800-5-2 which requires holding a stop position.

10.5.1. **Functional analysis of case SS2, a)**

The stop is obtained following a deceleration ramp that is commanded but not monitored. Since the actuation of the hold to stop phase depends on reaching a nearly zero speed, it will not be commanded in the case of a failure (e.g., non-deceleration). There will be no reaction to the failure and thus a loss of the expected safety function.

It is not possible to use an SS2, a) to perform a type 2 safe stop since it is vital to control the stop position in all the safety functions for which this type of stop can be implemented.

10.5.2. **Functional analysis of case SS2, b)**

The description of this function is given below:

Type 2 safe stop using an SS2, b) function

The PDS/SR actuates and monitors the deceleration of the servomotor within the limits set for stopping it.
When the speed of the servomotor is lower than a given threshold (and close to a stop), it triggers a safe hold to stop function in position via the SOS function (with the electric power supply to the servomotor maintained).

<u>Recommendations</u>:

The end of the deceleration threshold of the servomotor must be determined by the press manufacturer so that the speed of the servomotor, and thus the slide, is almost zero when commanding the SOS function.

The limit of the regulation around the stop position defined by the press designer must allow the variable speed controller to perform its function without "pumping" and without exceeding a value presenting a risk to the operator who may be in the hazardous zone under the slide (see § 10.11.2.3).

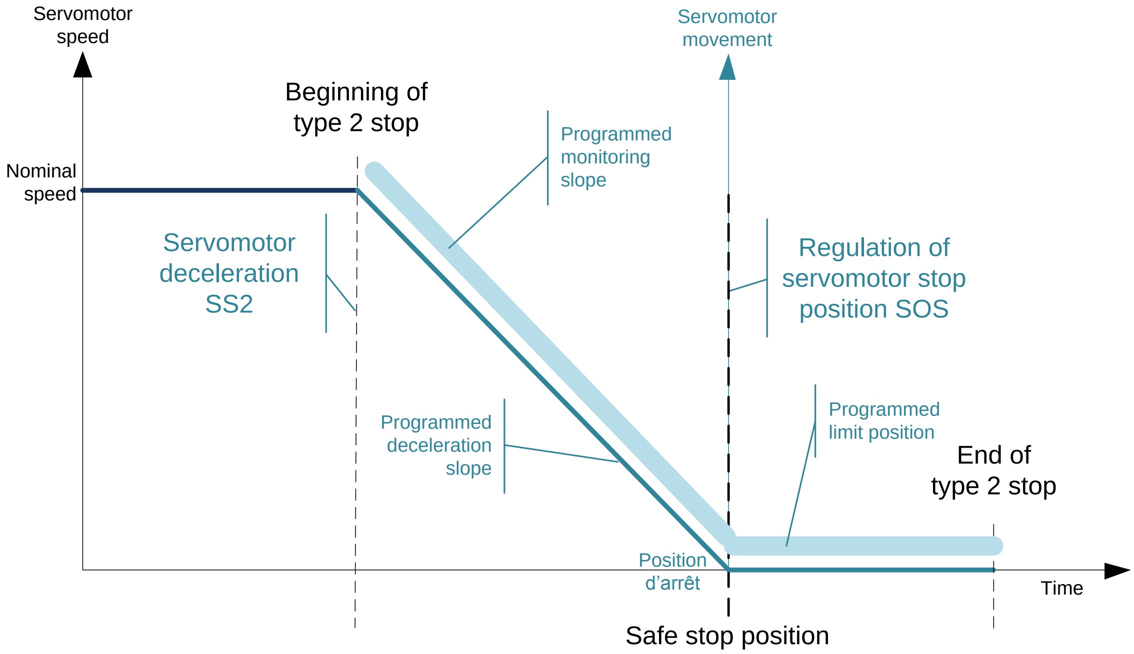

Figure 28: Chronogram of the type 2 safe stop function using an SS2, b) function

NOTE: In the case of implementing an SS2 function, the stop position is considered safe as long as it remains within the limits set by the risk analysis (see § 10.11.2.3).

10.5.3. **Effects of a failure for case SS2, b)**

The analysis permits showing that:

Cutting off the power supply or a PDS/SR failure occurring during a deceleration phase or during the hold to stop in position phase switches the servomotor to "freewheeling" mode and therefore affects the type 2 safe stop function.

Recommendations:

The reaction to the failure must not only generate a fall-back position of the PDS/SR equivalent to the STO function, but also actuate an additional mechanical brake to stop and hold the press slide stopped although this element is not necessarily in normal operating mode. **The global reaction in the case of failure must be equivalent to a type 0 safe stop (§ 9.3.3.3).**
The slide stop performances (see § 10.11.2) in the presence of a failure will depend on the reaction time regarding the failure of the PDS/SR and the characteristics of this brake (see § 10.10.4).

Note: The reaction time relating to the failure depends on:

- the time taken to detect the failure is conditioned by:
  - the PDS/SR parameters for an internal failure,
  - **the monitoring parameters of the safety function implemented (e.g. deceleration ramp, hold in position range, etc.) determined by the press designer**.
- the internal time of the PDS/SR to generate the expected fall-back position.

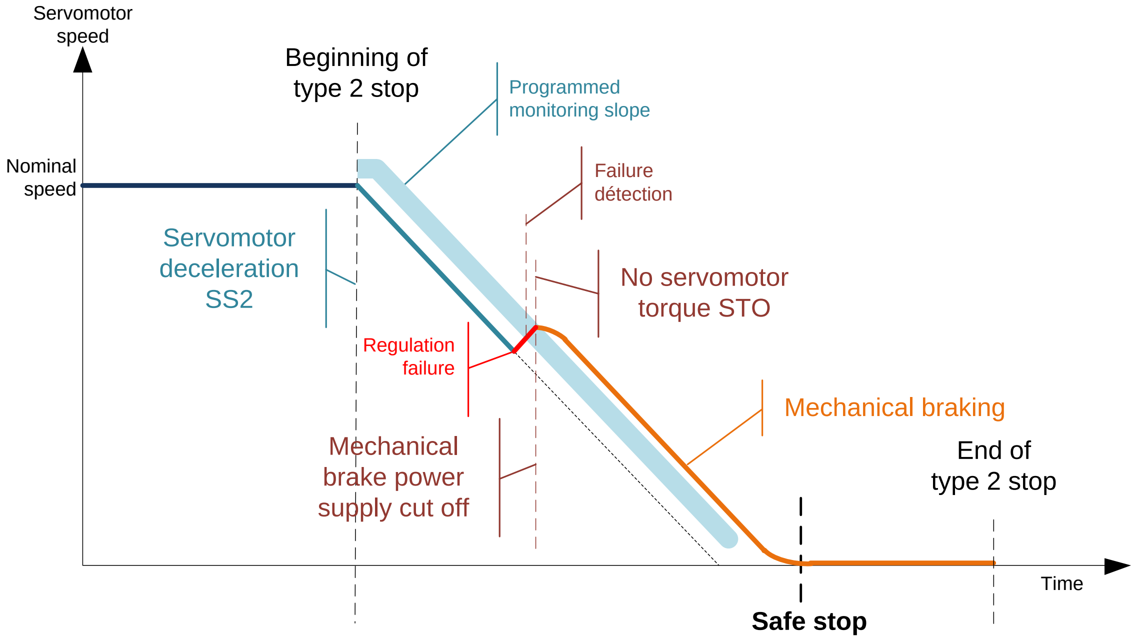

Figure 29: Chronogram of a type 2 safe stop using an SS2, b) function; and reaction in the presence of a PDS/SR regulation failure during the deceleration phase

Observation: When a failure occurs during the deceleration phase, the reaction to the fault for function SS2 b) is the same as that of function SS1 b).

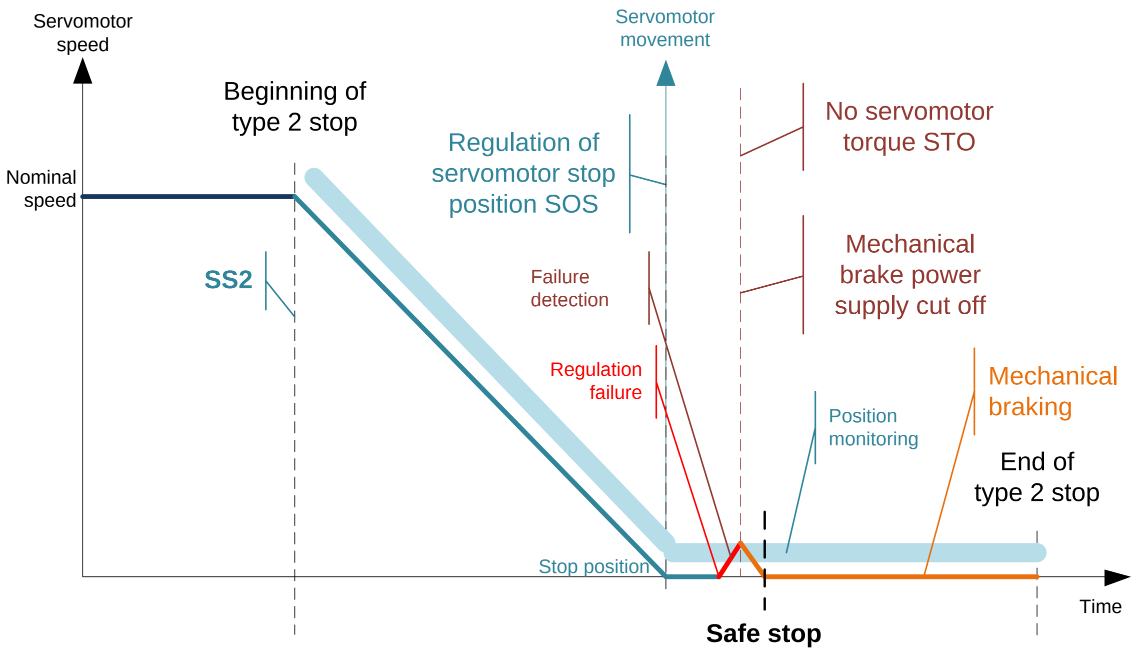

Figure 30: Chronogram of a type 2 safe stop using an SS2, b) function, and reaction in the presence of a PDS/SR regulation failure during the hold to stop phase

10.5.4. **Functional analysis of the case SS2, c)**

The description of this function is given below:

Type 2 safe stop using function SS2, c)

The PDS/SR actuates the deceleration of the servomotor.
After a time-out specific to the application, it triggers a safe hold to stop in position via the SOS function (with the electric power supply to the servomotor maintained).

Recommendations:

Since the stop was commanded at the maximum speed of the servomotor, the time-out must be calibrated so that when it ends the speed of the slide must be zero when the command of the SOS function is made.
Some manufacturers offer an alternative by commanding the SOS function when the speed is zero, without waiting for the end of the time-out.

The limit of the regulation around the stop position defined by the press designer must allow the variable speed control to fulfil its function without "pumping" and without exceeding a value presenting a risk for the operator who may be in the hazardous zone under the slide (see § 10.11.2.3).

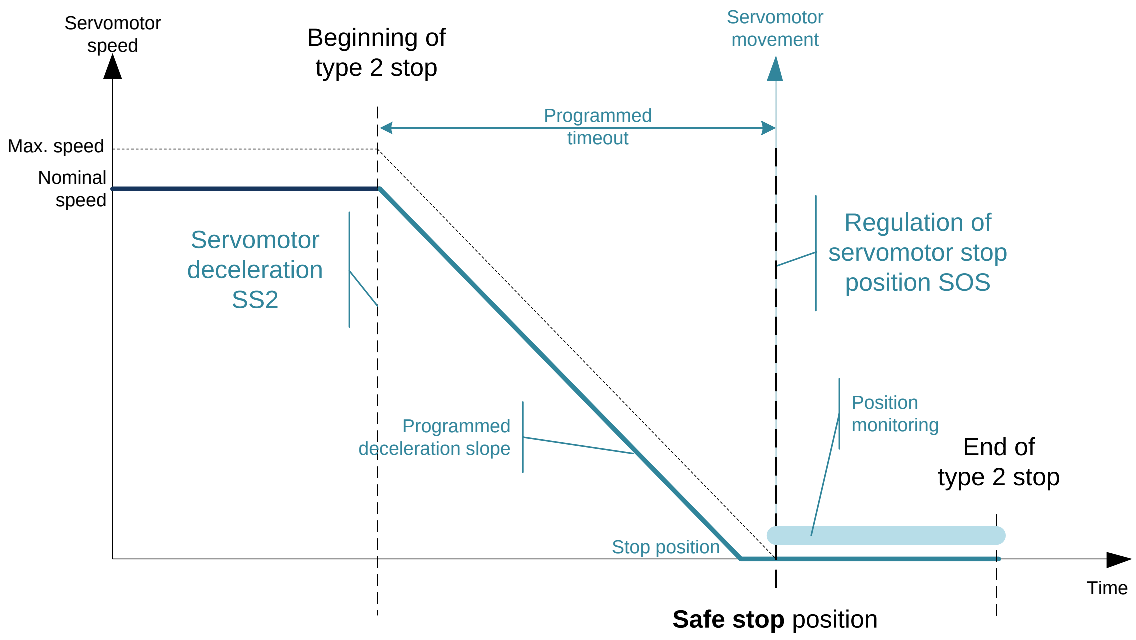

Figure 31: Chronogram of a type 2 safe stop with the implementation of an SS2, c) function

10.5.5. **Effects of a failure for the case SS2, c)**

The analysis allowed showing that:

Cutting off the power supply or a PDS/SR failure that occurs during a deceleration phase or during a hold to stop in position phase switches the servomotor to "freewheeling" mode and thus affects the type 2 safe stop function.

<u>Recommendations</u>:

The reaction to the failure must not only generate a fall-back position of the PDS/SR equivalent to an STO function, but also activate an additional mechanical brake to stop and maintain the press slide stopped, although this element is not necessary during normal operation. **The global reaction in case of failure must be equivalent to a 0 type safe stop (§ 9.3.3.3).**
The stop performances (see § 10.11.2) of the slide in the presence of a failure will depend on the time of reaction to the PDS/SR failure and the characteristics of the brake (see § 10.10.4).

NOTE:

The time of reaction to the failure depends on:

- the time taken to detect the failure which is conditioned by:
    - the PDS/SR parameters for an internal failure,
    - the **monitoring parameters of the safety function implemented (timeout and/or range of hold in position) by the press designer** to command the fall-back position (STO).
- the internal time of the PDS/SR to generate the expected fall-back position.

When a failure linked to regulation occurs, the stop performances of the slide will not be as good as those obtained in normal operation since the additional brake will be applied only at the end of the timeout and after the detection of a non-controlled position, with a non-zero speed liable to reach the maximum speed of the servomotor.

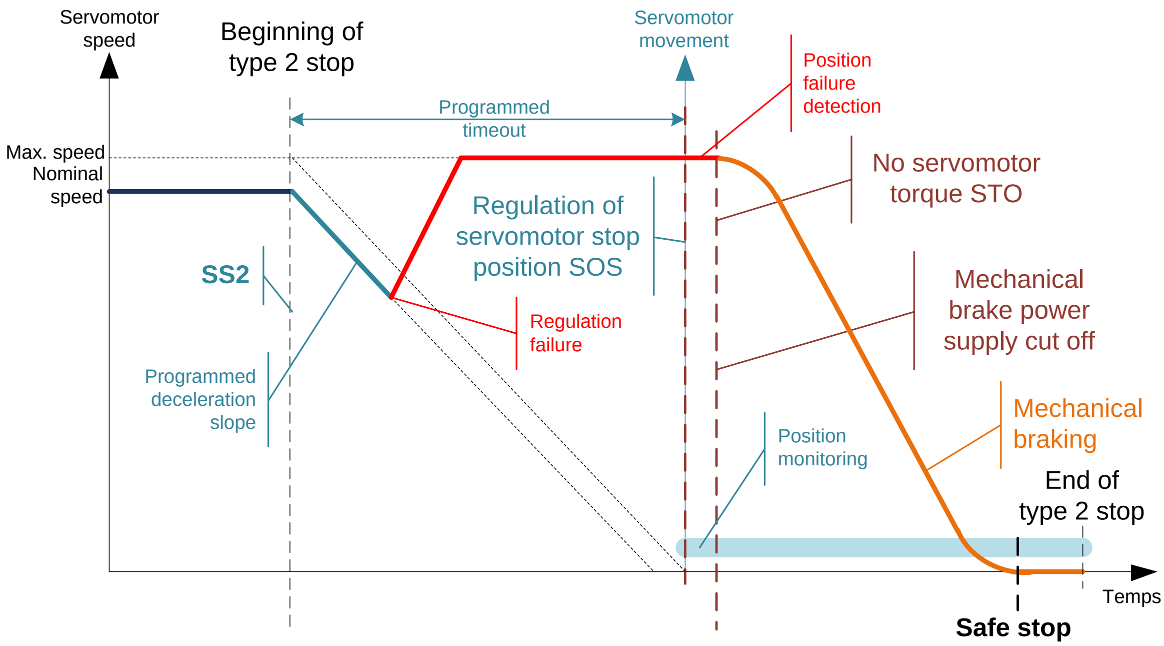

Figure 32: Chronogram of type 2 safe stop function with the implementation of an SS2, c) function; and reaction in the presence of a PDS/SR regulation failure during the deceleration phase

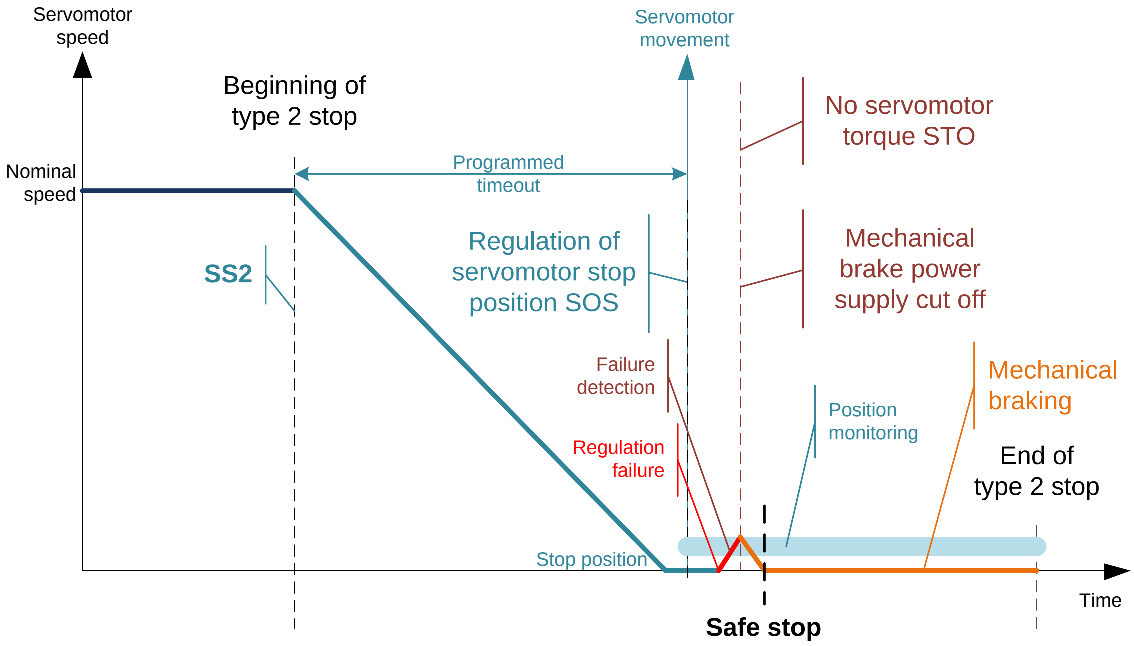

Figure 33: Chronogram of a type 2 safe stop function 2 with the implementation of an SS2, c) function, and reaction in the presence of a PDS/SR regulation failure during the hold to stop phase

Observation: When a failure occurs during the hold to stop phase, the reaction to the fault for function SS2 c) is the same as that of function SS2 b).

10.6. Safe hold to stop function with energy using an SOS function

10.6.1. **Functional analysis**

The SOS function controls the hold to stop in position for the servomotor in the same way as for the second phase of function SS2. In principle and during normal operation, an SOS function is suitable for ensuring a **safe hold to stop with energy** function for a servomotor press.

NOTE: Some PDS/SR manufacturers offer, by way of an SOS function, a safe hold to stop function by maintaining zero speed. The speed regulation permits slow displacement in relation to the desired stop position. This principle does not respond to the definition of § 4.2.3.1 of standard IEC 61800-5-2 which requires maintaining a stop position.

The description of this function is given below:

Safe hold to stop with energy using the SOS function

The PDS/SR prevents the servomotor from diverging by more than a defined quantity from the stop position (the slide is held stopped), by supplying energy to the servomotor to allow it to resist external forces.

<u>Recommendation</u>:

The regulation limit around the stop position defined by the press designer must allow the variable speed control to ensure its function without “pumping” and without exceeding a value liable to present a risk for the operator who may be in the hazardous zone under the slide (see § 10.11.2.3).

10.6.2. Effects of a failure

The analysis showed that:

Cutting off the power supply or a PDS/SR failure occurring during the hold in position phase switches the servomotor to “freewheeling” mode and does not allow restraining the slide. Thus it affects the hold to stop function with energy.

<u>Recommendations</u>:

The reaction to the failure must not only generate a fall-back position of the PDS/SR equivalent to an STO function, but also activate an additional mechanical brake to stop the slide and keep it stopped although this element is not necessary during normal operation. **The global reaction in case of failure must be the same as a 0 type safe stop (§ 9.3.3.3).** The performances of the hold to stop (see § 10.11.2.3) of the slide in the presence of a failure will depend on the time of reaction to the PDS/SR failure and possibly the characteristics of the brake (see § 10.10.4).

Notes:

The time of reaction to the failure depends on:

- The time taken to detect this failure which is conditioned by:
    - the PDS/SR parameters for an internal failure,
    - the **monitoring parameters of the safety function implemented (range of holding in position) by the press designer**.
- the internal time of the PDS/SR to generate the expected fall-back position.

The reaction to the fault for the SOS function is the same as that of the SS2 function when a failure occurs during the hold to stop phase.

10.7. Contribution of the PDS/SR to the command of a restraint device or a brake

As described previously, a restraint device or a brake must be commanded for certain stops, and/or when the PDS/SR is defective and generates a fall-back position (STO) leading to the servomotor being switched to freewheeling mode.
To command the brake, the PDS/SR on the market generally provide a copy-back output of the variable speed controller STO status. Some variable speed controllers provide a specific output intended to control the brake, called SBC (Safe Brake Control), whose operation is defined in standard IEC 61800-5-2.

Extract 1: § 4.2.3.12 of standard IEC 61800-5-2

4.2.3.12 Safe brake control (SBC) *The SBC function provides a safe output signal(s) to control an external brake(s).*

The figures of appendix A show examples of using the copy back signals STO or SBC for an external brake command.

Recommendation:

These safety outputs (copy back signals of STO and SBC) must be designed so that in the case of a power cut or PDS/SR failure, the brake is operated automatically in the framework of a fall-back of the PDS/SR (see § 10.1.2).

10.8. Conclusion on the implementation of a PDS/SR to manage servomotor press stop functions

10.8.1. General remarks

Analysis of the behaviour of a PDS/SR if a failure occurs shows that the conditions for stopping the servomotor can be abnormal in comparison to normal conditions or not be ensured; for example, non-compliance with the deceleration ramp, or acceleration or unintended cutting of the energy to the servomotor.

The PDS/SR can detect these failures. However, it can only ensure one fall-back condition on its own, i.e. guarantee that the servomotor will not supply any torque. This fall-back function is equivalent to the STO function. It is therefore necessary for the PDS/SR fitter to assess the effects of the fall-back position and, if necessary, take additional measures to ensure that it does not lead to a hazardous situation.
Thus the press designer must:

- choose from the options proposed from the control system that permits detection in the presence of a fault and a reaction compatible with the risk analysis of the machine;
- provide in all cases and whatever the type of stop implemented, the automatic application of a brake to compensate the failure of the PDS/SR, even though it is designed to ensure a safety function;
- take into account the stop performances (see § 10.11.2) of the mobile element in the presence of a failure. They can differ from those obtained with the PDS/SR not subject to failure, according to the fault detection time, the time needed to implement the fall-back function and the brake, and the stopping performance of the brake.

10.8.2. Remarks specific to the implementation of functions SS2 and SOS involved in type 2 safe stop functions and safe hold to stop with energy functions

Servomotors allow managing stops and holding to stop by supplying energy. The use of these safety functions is done via the PDS/SR and the utilisation of specific SS2 and SOS functions. In the case of the hold to stop phase ensured in both cases by the SOS function, a failure can generate an unintentional movement of the servomotor and thus the slide which will be detected by the function. This failure can occur while the protection devices are inhibited when the operator is in the potentially hazardous zone to perform press loading and/or unloading operations.
Before the reaction to the failure stops the hazardous movement via the fall-back position implemented (STO + brake), the slide will be displaced, leading to a potential risk for the operator. This situation is not possible when giving priority to the hold to stop without energy phases using an STO function and a brake, which is the case of type 0 safe stops, type 1 safe stops and hold to stop without energy.

Recommendation:

Using functions SS2 et SOS cannot be accepted for use with type 2 safe stop and safe hold to stop functions with energy, unless the potential unintentional movement following a failure does not present a risk for the operator (see § 10.11.2.3).

10.9. Management of slide movements by a PDS/SR

10.9.1. Generalities

In addition to the stop functions described previously, other functions that can be used at PDS/SR level can participate in performing the safety functions specified for the press.
This is the case, for example, when **limiting the speed of the slide**, and thus the speed of the servomotor, participates in reducing the risk.

This is also the case when the aim is to implement a protective device muting function. An example of the specification of this function is given in appendix B, Table 3. To authorise this function, it is necessary to perfectly control the slide movements and know the direction in which the slide is moving at all times to determine whether the movement is potentially hazardous or not. An unintentional reversal of the slide movement can result from a PDS/SR fault such as an unintended reverse servomotor command or power supply command leading to a loss of servomotor torque, causing a reversal of the slide movement during an upward phase under the effect of a driving load. This function can be ensured by a slide **displacement direction control**.
But this measure may not be sufficient, in particular given the options and programmed ranges of detection and the time of reaction to faults. This is why, in the framework of standardisation works linked to servomotor press design, several measures are stipulated to guarantee that the muting function can only be activated when the risk analysis shows that there is no longer any risk for the operator. These measures consist in guaranteeing that in the case of reversal of the slide movement direction, an abnormal reduction of slide speed or a loss of power supply to the PDS/SR, the reaction to the failure leads immediately to eliminating the torque on the servomotor and to applying the brake. These measures therefore require implementing **speed threshold monitoring** in addition to controlling the direction of displacement and the fall-back position adopted in a general way (see § 10.1.2).

Analysis of the behaviour of these different functions, with and without a fault, is dealt with in the following paragraphs.

10.9.2. Behaviour in the presence of a failure of the monitoring functions

Generally, all the slide movement management functions proceed from the supply of energy. The monitoring functions implemented in the framework of the servomotor press safety functions are focused on the operating limits and ranges defined by parameters entered by the machine designer.
In the case of a failure regarding the predefined limits or if they are exceeded, the PDS/SR generates a fall-back position which is generally performed by an STO function.

Note: In certain cases, manufacturers offer the option of also choosing the SS1 and SS2 as the fall-back position. Since the latter can be subject to faults, the ultimate fall-back position will lead to an STO function.

Recommendations:

When implanting these parameter monitoring functions (speed, direction, etc.) on servomotor presses, whose mobile elements are subject to driving loads and given the response times linked to the accumulation of these functions, **it is recommended to always select the STO function as the fall-back function.**

The reaction to the fault must also activate an additional mechanical brake to stop and maintain the press slide, although this element is not necessary during normal operation. **The global reaction in case of failure must be the same as a type 0 safe stop (§ 9.3.3.3).**

10.9.3. **Control of the slide displacement direction**

Standard IEC 61800-5-2 proposes the SDI function (Safe Direction).

Extract 2: § 4.2.3.10 of standard IEC 61800-5-2.

> *4.2.3.10 Safe direction (SDI)*
>
> *The SDI function prevents the motor shaft from moving in the unintended direction.*

This function monitors the direction of servomotor rotation (defined by the application) and generates a fall-back position (STO) in the case of a reversal of the direction whatever the cause.
However, in the case of failure, during the time of detection and reaction to the fault, the direction of slide displacement can reverse and cause a hazardous movement (downwards) for the operator if he is in the tool zone.
This unintended downwards movement must in no way exceed 2 mm.

Recommendations:

When implementing this function, it is necessary to pay attention to the type of press on which it is used.

On presses with a linear mode of transmission (e.g., screw presses), the direction of rotation is constantly representative of the direction of slide displacement. Thus it is easy to determine the direction corresponding to the non-hazardous movement of the slide. The information representing the movement direction will be the same whether it is obtained from the servomotor shaft or from the slide.

On traditional mechanical presses driven by a connecting rod, the direction of motor rotation (unidirectional) only represents the direction of slide movement for half the cycle. This is even less so for mechanical servomotor presses using specific operating modes (e.g., pendular mode). In this case, the movement of the slide is reversed during the cycle by the reversal of the direction of rotation and independently of the press kinematics (e.g., without passing by the high dead centre point).
Thus, in this case it appears difficult to manage the direction of the slide rotation by monitoring the direction of the servomotor, making it necessary to obtain safety information on the reversals of direction linked to the process. It is therefore recommended, for mechanical presses, to use direct information on the direction of the slide displacement.

10.9.4. **Speed management**

To respond to the needs expressed in §10.9.1, standard IEC 61800-5-2 proposes the two following functions:

- Safely limited speed (SLS – Safely Limited Speed),
- safe speed monitoring (SSM – Safe Speed Monitor).

Extract 3: § 4.2.3.4 of standard IEC 61800-5-2.

> *4.2.3.4 Safely-limited speed (SLS)*
>
> *The SLS function prevents the motor from exceeding the specified speed limit.*

This function monitors the rotation speed of the motor and generates a fall-back position (STO) if the limit defined by the application is exceeded for whatever cause.

In our case, this function is used to limit the downward speed of the slide. Thus, if the PDS/SR command system allows, it can be used together with a rotation direction control.
For servomotor presses, when this function participates in reducing risk, the slide speed limit is set at 10 mm/s.

Note: Given the monitoring resources implemented, it may be acceptable for the set point value for normal operation to be exceeded temporarily, in the case of failure, provided that the time of detection and reaction to the fault do not allow the speed to increase dangerously. In the current state of drafting the ISO standard for servomotor presses, no overshooting is accepted even in the presence of a fault.

Extract 4: § 4.2.3.14 of standard IEC 61800-5-2.

> *4.2.3.14 Safe speed monitor (SSM)*
>
> *The SSM function provides a safe output signal to indicate whether the motor speed is below a specified limit.*

This function monitors the speed of rotation of the motor and supplies a signal when it is lower than the value defined by the application for whatever cause.
In our case, this function is used to anticipate a reversal of the slide movement that could become hazardous (upward movement that changes into downward movement) before its occurrence. As with the speed limit, if the PDS/SR command system permits, it can be used together with a rotation direction control. This function must therefore detect a relatively low speed, without disturbing the normal operation of the press. The speed threshold will be determined by the designer as a function of the application.

Recommendations:

When implementing these two functions, it is necessary to pay attention to the type of press on which they are used.

On presses with linear transmission (e.g., screw presses), the servomotor rotation speed is constantly proportional to the slide displacement speed. Thus it is easy to determine a rotation speed threshold corresponding to the slide speed threshold. The information representative of the slide speed could be obtained from the servomotor shaft or from the slide.

On mechanical servomotor presses driven by a connection rod, the motor rotation speed is not representative of the slide displacement speed. For a constant motor speed, the slide speed follows a sinusoidal cycle.
Therefore information representative of the slide displacement speed must be used to manage the slide speed limit (SLS).
Therefore information on the servomotor speed must be used to manage the minimum speed threshold (SSM).

10.9.5. Case of a PDS/SR composed of several servomotors or comprising an energy recovery system

10.9.5.1. Drive by several servomotors

A PDS/SR can be composed of one or more variable speed controller servomotor assemblies to drive a single shaft. This is particularly the case on mechanical eccentric drive presses and screw presses for which high forces are obtained via several servomotors. This choice can be determined by concerns given to standardising equipment (servomotor, variable speed control), to improve the energetic profitability of the servomotors, etc.

Note: This paragraph does not concern, for example, press-brake which comprises two servomotors, but for which a single servomotor is used for each shaft.

The question that arises here is: how will the PDS/SR react if one or all the variable speed control-servomotor assemblies fail?

For failures affecting the entire PDS/SR, such as power failures, the reaction to the failure will be the same as in the case of a single servomotor.

When the failure affects a single servomotor (on an assembly including several servomotors), in the framework of implementing a safety function requiring the supply of energy (e.g., SS1, SS2, SOS, etc.), it is possible that the other servomotors will offset this failure.
What is important is that the performances expected for the safety function(s), in terms of stopping time, stop position, etc. are maintained.

An assembly using several servomotors cannot, whatever the case, dispense with a braking system intended for use in the presence of a failure.

10.9.5.2. Energy recovery system

Some PDS are equipped with an energy recovery system designed to recover energy during slowing phases and to restore it when the PDS demands full power. This system makes it possible to avoid over dimensioning the electric installation for high powers.
This system is designed solely for a functional purpose and cannot be used to compensate an energy supply failure, even if temporary.

10.10. Considerations on the mechanical part of the drive system

10.10.1. **Introduction**

The mechanical parts of the drive system fully participate in the safety functions by providing the link between the servomotor, which controls part of the functions (deceleration during stops, regulation of speed and position, etc.), the braking and hold to stop system (mechanical) and the slide.
Many of these different elements are already present on traditional presses for which design stipulations exist in “press” standards.
In the framework of this consideration, only the mechanical parts involved in safety and which possess novel features (e.g., belts, ball-screw, etc.) have been analysed.

10.10.2. **Belt transmission**

10.10.2.1. Functional analysis

On some eccentric drive presses, screw presses and press brakes, the transmission between the servomotor and the slide can now be ensured by belts that contribute to certain safety functions. For the record, this is not the case on traditional presses, notably mechanical ones. Regarding this new feature, this transmission system must be designed to ensure the expected safety function (stop and hold to stop, speed limit, etc.).

10.10.2.2. Behaviour in the case of failure

Generally, the failures identified for a belt can be breaking, elongation and sliding. The effects can be variable according to whether a single belt is used, and depending on the function it provides. By way of example, mention can be made of:

- unintended descent of the slide (no stop or hold to stop) in case of breaking,
- degradation of stop performances in case of sliding or elongation.

The absence of evaluation criteria for safety performances and the lack of feedback from experience on using a single belt on servomotor presses do not allow neglecting the possibility of failure of this component.
Therefore, when this mode of transmission is used, measures must be taken so that the failure of a belt does not lead to a loss of a safety function.

Recommendations:

The belts that participate in safety functions must be doubled (redundancy), each of them must be calibrated so that they can fulfil the safety function alone. They must be self-monitoring so that the press is stopped in case a belt breaks.
In addition, design measures must be implemented so that belt breaks do not simultaneously cause the detachment of the second belt.

10.10.3. **Transmission by a screw/nut system**

When only the hold to stop function is required [example of implementing an interlocking guard with guard loking (see § 9.3.3.1) or a hold to stop phase of a type 1 safe stop (see § 9.3.3.4)], the designer could ask whether it is necessary to provide, in normal operation, a hold to stop system, or question the capacity of the screw/nut system to hold the slide in stopped position when it is subjected to a driving load.

The advances made in the design of screw-nut systems to improve their efficiency (e.g. ball screw), has also contributed to making them reversible when they are no longer driven by the servomotor. Likewise for more traditional systems where the progressive wear between the screw and nut tends to reduce friction and lead to reversibility.

Therefore, for all screw-nut systems, a slide restraint system (e.g., brake) is required for all situations needing a hold to stop without energy.

Note: This restraint system is not an additional device, it is that provided when implementing a safe hold to stop without energy (see § 9.3.3.1).

10.10.4. **Braking and/or hold to stop system**

10.10.4.1. Reminder

On mechanical servomotor presses (eccentric or screw drive) the presence of a safety braking and/or hold to stop system is vital whatever the types of safety stop considered.

This system can be used:
- to maintain the slide stopped during **a safe hold to stop without energy** (see § 9.3.3.1),
- to stop the slide and hold it stopped during a **type 0 safe stop** (see § 9.3.3.3),
- to end the stop and hold the slide stopped during a **type 1 safe stop** (see § 9.3.3.4),
- to stop the slide and hold it stopped during a **fall-back position** (type 0 safe stop) in reaction to a failure or lack of power to the PDS/SR for all the safety functions in which it participates.

The braking system can be positioned at different points of the transmission chain, from the servomotor to the slide, but all the transmission components located between the brake and the slide must be safe.

10.10.4.2. Design and dimensioning

The braking and/or hold to stop system must be properly dimensioned to ensure the functions in which they participate:

- when they ensure only the hold to stop function, they must be dimensioned to hold the maximum weight of the mobile element (slide, tools, etc.) without inertia;
- when they ensure braking under normal operation or in the presence of a failure, they must be calibrated for the maximum characteristics of the mobile element (speed, weight, etc.) and as a function of the stopping performances expected or desired for positioning the protection means (see § 10.11.2).

Recommendation:

The braking system must be dimensioned to ensure a type 0 safe stop whatever the type of stop implemented (0, 1 or 2).

The design rules for the brakes participating in the safety functions remain the same as those established in particular in standard NF EN 692 for traditional mechanical presses.

Note: When the braking system is not used to ensure a 0 type safe stop at each cycle, the main difference in comparison with the brake of a traditional press (e.g., mechanical clutch-brake press) used for manual loading/unloading is that its rate of use can be quite low (only for stops for protection or fall-back position following a failure).

10.11. Braking and stopping performances

10.11.1. Control of braking performances

Contrary to the brake of an eccentric drive press with a friction clutch that, when in operation for manual loading/unloading, is used and controlled at each cycle, the braking system of a mechanical servomotor press (eccentric or screw drive) may be only rarely or never used under normal operation, depending on the type of stop considered for its use.

It is therefore necessary to control the braking performances:

- for all **screw drive servomotor presses**,
- for all **eccentric drive servomotor presses** except those whose cyclic production stops use the brake for this purpose (type 0 stop). Regarding the latter, the control of stop performances (§ 10.11.2.4), made at each cycle is sufficient to control the brake.

This brake performance control is composed of a static control and a dynamic control.

10.11.1.1. Static control of the brake

This test is intended to control the capacity of the brake to fulfil its function.

Type of test: The test consists in applying a motor torque for one second while the brake is in service and ensuring that the slide remains immobile. This motor torque must at least correspond to 1.5 times the maximum braking torque required to stop the slide under the worst conditions. If the test is not conclusive, the control system must prohibit the press from operating.

Note: This test can be performed without removing the tools assembled. The protection systems must be operational and active during the test.

Periodicity: The periodicity of the test is determined as a function of press use and the frequency at which the operators intervene in the hazardous zone. The higher the frequency (case of manual loading/unloading of the press), the shorter the periodicity (each time the operator starts their shift or every 8 hours). For the others, the periodicity can be reduced to once a day.

10.11.1.2. Dynamic control of the brake

This test is intended to control the operation of the brake under its maximum conditions of use and its wear.

Type of test: The test consists in commanding a type 0 safe stop (§ 9.3.3.3) during the closing stroke of the slide at its maximum speed and ensuring that the stopping time obtained (T_{test}) does not exceed a value corresponding to the maximum accepted wear (δ), and the reference time (the same type of stop under the same conditions) during the calculation of the safety distance ($T_{réf}$). If the test is not conclusive, the control system must prohibit the operation of the press.

$$Ttest \leq Tref + \delta$$

Periodicity: The dynamic test must be performed automatically at least once a year.

Note: The current draft of the ISO standard on servomotor presses specifies that if the dynamic test is performed at least once every three months (during periodic verifications), the static test is not compulsory.

10.11.2. **Control of stopping performances**

Stop and/or hold to stop performance criteria have been provided in the specification of certain safety functions (protection stop, end of cycle stop, etc.).
Stop performance criteria are expressed:

- as **stopping time**, when they are used to calculate the safety distance necessary for positioning certain protection means. This is the case in particular for the protection stop function (§ 9.3.3.6),
- or as **stopping distance**, when the aim is to ensure, in the case of a failure, that the stop position is not exceeded as this may present a risk for the operator. This is the case in particular for anti-repetition functions (§ 9.3.3.7) or a safe stop commanded by a control device (§ 9.3.3.9),
- or in **stop position**, when the aim is to ensure the stop is held in a safe position. This is the case in particular for the hold to stop at end of cycle function (§ 9.3.3.8), and also for the phases of protection stops (§ 9.3.3.6), anti-repetitions (§ 9.3.3.7) and stops commanded by a control device (§ 9.3.3.9) which concern holding to stop.

10.11.2.1. Stopping time

For interlocking guards without guard locking and protective devices, control of the stopping time of the mobile element is crucial. It is necessary to position these protective means correctly in relation to the hazardous zone.

For a “traditional” mechanical clutch-brake press, the system ensuring safe stopping and stopping in the presence of a failure (clutch release and braking) is also used to ensure “normal” stop functions. The use of this safety function generates the same stopping time as the normal stop, which can therefore be measured easily.
For servomotor presses, when implementing a type 2 safe stop under normal operation, using the “stop production” safety function must proceed with a type 0 or 1 safe stop. The performances of the protection stop, which must be taken into account to position the protection devices, can therefore be different.

The implementation of certain stop functions by a PDS/SR can also affect response time according to the choices made [e.g., SS1 b) vs SS1 c)] or in the case of a failure of the system.

The stop time must therefore include several parameters:

- the response time of all the elements composing the stop chain from the event triggering the function (e.g., crossing a photoelectric barrier) to the complete stop of the mobile element concerned, i.e. the slide;
- the stopping time under the worst material conditions of the mobile element (maximum speed and load);
- taking into account the specificities linked to the stop function implemented at the PDS/SR (e.g., SS1) and the options configured for this stop;
- the response time in the presence of a failure of the element with the worst impact on the stop chain, including for certain parts of the function, the time of reaction to the failure to ensure the safety function (case of the type 1 safe stop function).

Notes: For certain elements composing the stop chain, it is possible to determine, or obtain from the manufacturers, the response times under normal operation and in the presence of a failure. When taking into account the different elements composing the stop chain, **only one failure must be considered at a time**.

In the case of using components or a part of a function (e.g., SS1) whose response time increases in the presence of a failure, it is necessary to calculate the global stop time for the failure of the component or the part of the function for which the difference between the time without failure and that with failure is the greater.

Appendix C provides a detailed example of determining the response time for a protection stop function implementing an SS1 b) function.

The response time determined for calculating the safety distance will also be used as the reference during the dynamic control of the brake (§ 10.11.1.2) and the control of stop performances (§ 10.11.2.4).

10.11.2.2. Stopping distance

The stopping distance of the slide is a crucial factor:

- for eccentric drive presses when an anti-repetition function is implemented (§ 9.3.3.7),
- for all presses when the prevention measure is partly ensured by releasing the control device (§ 9.3.3.9).

In the first case and in the case of failure (regulation, brake wear, etc.), the overrun distance accepted in relation to a stopping distance without failure must not exceed a value corresponding to crankshaft rotation angle of 15° (value given in standard NF EN 692).
An automatic control of stop performances (§ 10.11.2.4) must be installed.

<u>Recommendation</u>:

In the second case, the overrun distance accepted in the case of failure must not exceed 2 mm in comparison to the stopping distance without failure.

Note: These results must be obtained by optimising the consequence of a failure on a selected stop function. For example, if a type 1 safe stop function is chosen to ensure the control device release function, it will be advisable to privilege the implementation of an SS1 b) function (§ 10.4) which limits the increase in response time in the case of failure.

10.11.2.3. Stop position

Maintaining the slide of a press in stop position can be ensured:

- either without energy in the case of a safe hold to stop without energy, a type 0 or 1 safe stop;
- or with energy in the case of a safe hold to stop with energy or a type 2 safe stop function.

In the first case, the hold to stop is ensured by a brake or by a mechanical restraint system operating without energy. This element is designed, calibrated and monitored so that the function it ensures is not degraded, even in the presence of a failure.
In the second case, the hold to stop is ensured by the PDS/SR, by maintaining torque on the servomotor. Resources are implemented, particularly with the SOS function (§ 10.6), to control the stop position of the slide. In the case of failure, this function leads to a fall-back position equivalent to a type 0 safe stop. During the time taken to detect the failure and the application of fall-back position, the slide can start a downwards movement potentially hazardous for an operator working in this zone.

Recommendation:

When the hold to stop position function is ensured by a safe hold to stop with energy function (SOS), the maximum accepted difference in position must not present a risk for the operator. This value must not exceed a maximum of 2 mm.

10.11.2.4. Control of the stopping performances of mechanical servomotor presses

Mechanical servomotor presses protected by an interlocking guard without guard lockingor by a protective device muted during automatic upward movement must include a control of their stopping performances.

Note: This test must be implemented independently of the type of stop (0, 1 or 2) chosen to stop the slide at the end of the cycle.

The test consists:

- for eccentric drive presses only: in controlling at the end of each press cycle, that the possible surplus stroke on stopping does not exceed 15° of the crankshaft in comparison to a predetermined stop position. This test also allows controlling the wear of the brake when the end of cycle stop is ensured by a “type 0 safe stop”;
- for all mechanical presses (eccentric drive and screw drive): in controlling for each demand for protection, that the stopping time of the slide does not exceed the time taken into account to calculate the safety distance.

Overshooting the limits set must prevent a new press cycle.

10.11.3. **Synthesis of performance controls to be performed**

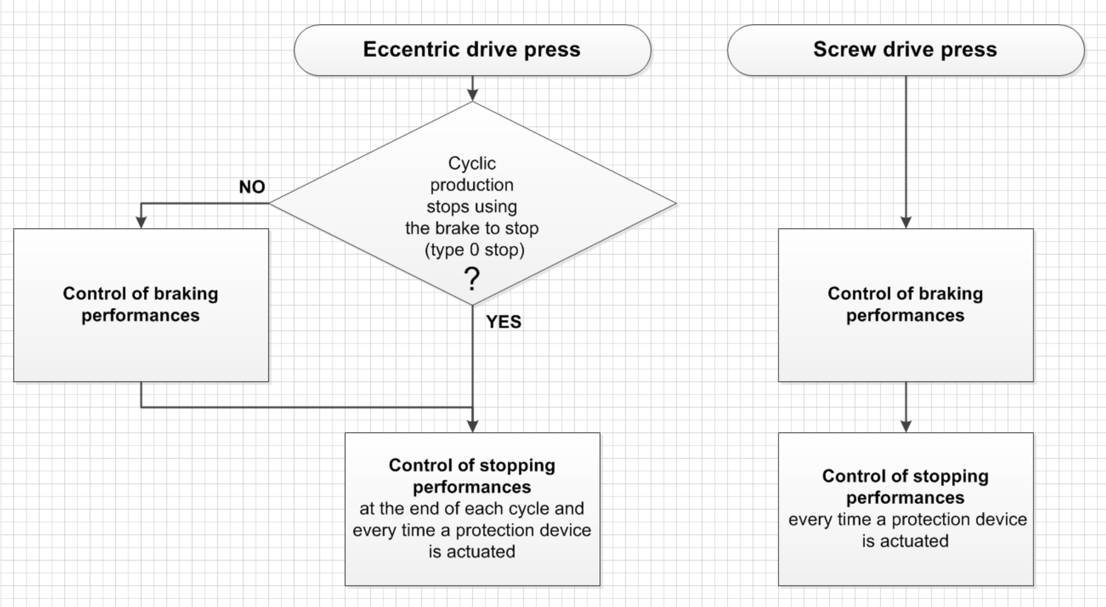

Figure 34: Performance controls to be performed in eccentric and screw drive servomotor presses

11. Analysis of the validity of conventional protection means on servomotor presses

During the design phase of a press, the manufacturer is often led to choosing a protection means (guard, protective device) to cover the risks identified during the assessment. **The implementation of servomotors on presses does not change the appreciation of the risks to which operators are exposed.** The protection means listed in the reference standards relating to “traditional” presses remain valid under certain conditions.

The selection criteria of the protection means best adapted to a given situation greatly depends on:

- the nature of the mechanical risks to be covered (linked only to tools or additional risks of projections),
- the predictable utilisation of the press (single cycle with manual loading/unloading of parts or continuous operation without intervention by the operator for production),
- the frequency of intervention in the potentially hazardous zone (slide, tools),
- the characteristics and stop performances of the mobile elements of these presses.

Although the first three criteria are independent of servomotor presses, the last one can be strongly influenced by this technology, taking account of:

- the particularities of stop functions specific to servomotor presses,
- the behaviour in the presence of a failure of the electronic components used to control these stop functions,
- the performances of the mechanical brakes used,
- the conditions of assessment, calculation and/or measurement of the maximum stopping times.

The analysis of stop characteristics must guide the choice of the best adapted protection systems.

Another criteria not directly linked to the risk analysis can be taken into account to minimise the technological and financial impact that may be incurred by the design of a mechanical servomotor press.

As shown previously, when the protection of the operator is ensured by interlocking guards without guard locking or protective devices, the designer must provide a braking system capable of stopping the slide under the worst conditions, whatever the type of stop planned for production. In other words, even if the production stops at the end of a cycle are ensured exclusively by the servomotor via a type 2 safe stop (§ 9.3.3.5), the designer must provide an additional appropriately dimensioned brake to ensure, or participate in, the protection stop function (§ 9.3.3.6) and ensure the slide stops if the PDS/SR fails. This may lead to a considerable technical and financial investment for a very low probability of use.
When the press is used in continuous operation and the protection device is never muted, the designer can install interlocking guards with guard locking to ensure the operators are protected. With this means of protection, the stopping time of the mobile element no longer has an impact on safety. Only one safe hold to stop function without energy (§ 9.3.3.1) is required when the guard is unlocked or not closed, to guarantee the mobile element being stopped and prevent it from starting unintentionally while the operator is acting in the work zone. This function can be ensured by a restraint device without a braking capacity.
When conceivable, the choice of this protection system can lead to obtaining benefits from the functions of servomotors, by getting round the technical barriers relating to control over stopping time.

12. Discussion and conclusions

Contrary to "traditional" presses, the power drive system on servomotor presses and press-brakes does not only supply the mechanical or hydraulic energy needed to move the slide, it also fully participates in performing the safety functions implemented to cover the risks identified.
The PDS/SR becomes the heart of the control system, permitting the implementation of new modes of operation and ensuring, in part, a large number of safety functions needed to protect the operators (different types of stop, speed and position regulation and limitation, control of rotation direction, etc.).

By virtue of its design (electronic components) and its mode of managing a large number of safety functions (by supplying energy), the PDS/SR can be affected by failures whose consequence is to lower the safety performance of the functions to be carried out.
On the one hand, this degradation can lead to extending the response time, and on the other hand it can make it impossible to carry out alone the function expected in case of an internal failure or the absence of energy at PDS/SR level.
The different systems present on the market all provide a safety fall-back position consisting of the absence of torque on the servomotor. Although this fall-back position is sufficient for some machines, for metal presses where potentially hazardous mobile elements operate vertically and are subject to gravity, it is not enough to ensure the functions expected, especially the stop and hold to stop functions.
If access to the hazardous zone is possible when the slide is moving (when guards without guard locking or protective devices are used), a brake capable of stopping the slide in case of a type 0 safe stop, PDS/SR failure or a loss of electric power supply must be provided. This brake must be dimensioned for the maximum capacity of the machine. The stopping time required for positioning the protection systems must be determined under the worst conditions for the machine (speed, driving load). The worst failure must be considered, in terms of response time and the global control circuit, including the PDS/SR.
If access to the hazardous zone is impossible when the slide is moving (case of guards with guard locking without inhibition), the implementation of a hold to stop system may be sufficient.

Regarding the "new" mechanical elements for servomotor presses, mention can be made of screw/nut drives (electric cylinder) used on presses and screw driven press-brakes. The characteristics of these screws, especially their reversibility, do not exempt manufacturers from implementing a restraint system to prevent an unintented descent due to gravity.

Some drives are ensured by belts which, contrary to traditional presses, can contribute to certain safety functions. Consequently, this drive system must be designed to guarantee these functions (e.g., redundancy and self-monitoring).
The other rigid mechanical drives that have already been used to contribute to safety functions remain acceptable if they have been designed in line with the state of the art and conform to the references concerned.

Regarding the choice of protection system adapted to servomotor presses, all those that were recommended for traditional presses are also recommended for these new presses. Great attention must be paid to determining the stopping time required to calculate the safety distance for positioning certain guards and protective devices.
When it is not essential to impose an inhibition during the upwards phase of the slide movement, it is advisable to study the possibility of using an interlocking guard with guard locking, even if the risk analysis provides the opportunity of using other protection systems. Since the control of slide stopping time is not necessary with an interlocking guard with guard locking, the technical constraints for press design and manufacture will be less severe (no braking system, only a restraint system, limitation of the number of safety functions managed by the PDS/SR, etc.).

An important point relating to type 2 safe stops whose effects have been clearly identified, was emphasised in this document. The question of whether this principle is acceptable on presses and to what extent an unintentional movement does not create a risk remain to be defined in the standardisation works.

Appendix A: Examples of PDS/SR configurations as a function of the level of integration of safety "modules" in the variable speed control

The main safety functions (modules) mentioned are symbolised by abbreviations taken from standard IEC 61800-5-2:

- STO: Safe Torque Off,
- SS1: Safe Stop 1,
- SS2: Safe Stop 2,
- SOS: Safe Operating Stop,
- SBC: Safe Brake Control.

The other abbreviations used are the following:

- OSSD: Output Signal Switching Device,
- Fm: motor brake, fixed to the motor shaft,
- Fex: External brake, generally positioned on the drive line between the motor and the slide,
- Cm: Motor encoder. Fixed to the motor shaft, it indicates the position, direction of rotation and speed of the motor;
- Cex: External encoder (rotational or linear) which indicates the position, direction of movement and speed of the slide.

The first example, Figure 35, shows the design of a PDS/SR with a **standard variable speed controller** (without any safety function) and a monitoring and control system that manages the safety functions linked to the mobile working element with a driving load.

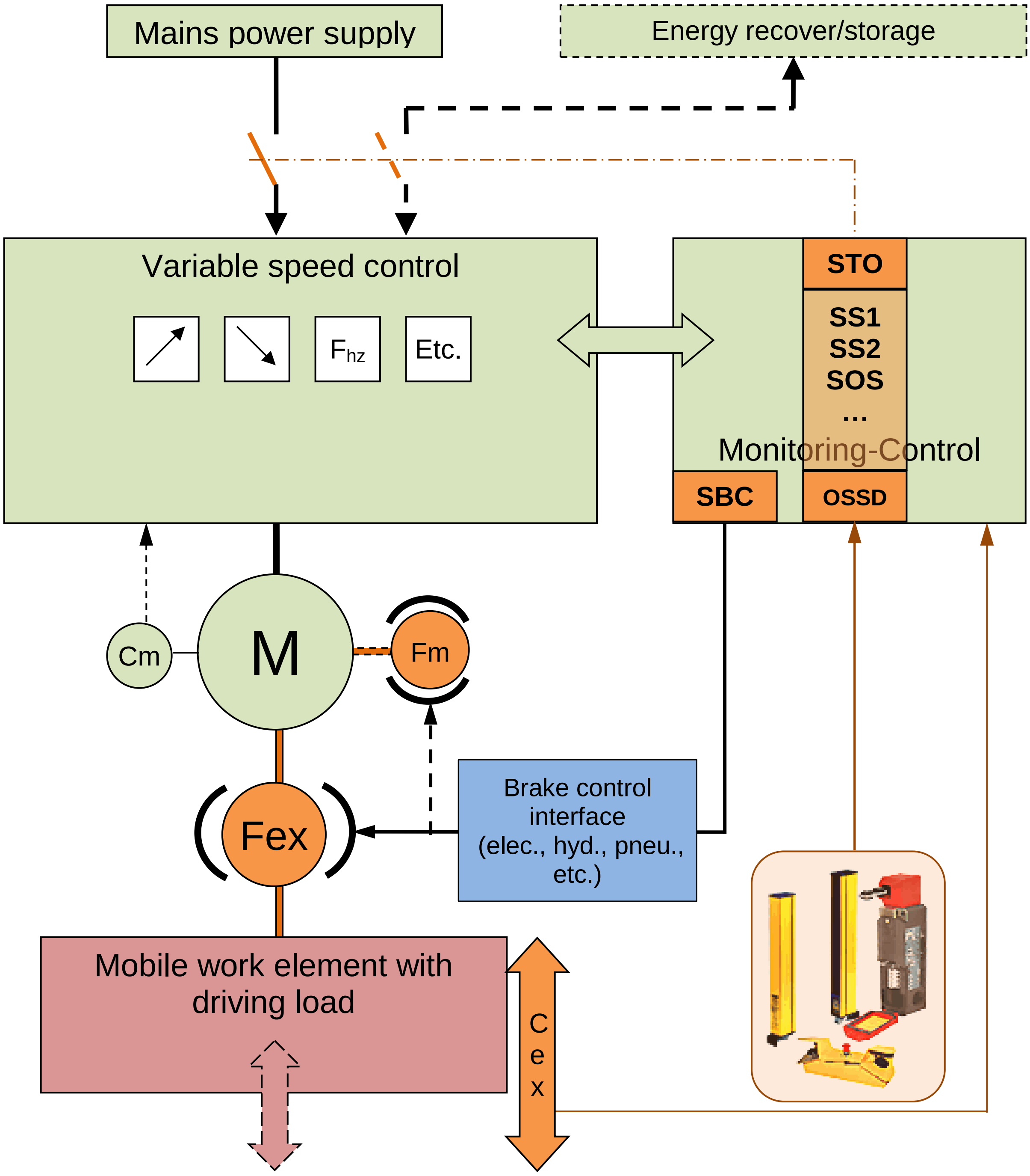

Figure 35: Integration of a PDS/SR in the control circuit of a servomotor press - ***Example 1: Standard variable speed control***

The second example, Figure 36, shows the design of a PDS/SR with a **variable speed control** with only the **STO** safety function and a monitoring-control system managing the safety functions linked to the mobile work element with driving load.

Note: When integrated in the variable speed control, the STO function avoids recourse to an external safety cut-off device (e.g., contactor).
Exchanges of safety information are required between the monitoring-control part and the variable speed control or its safety card.

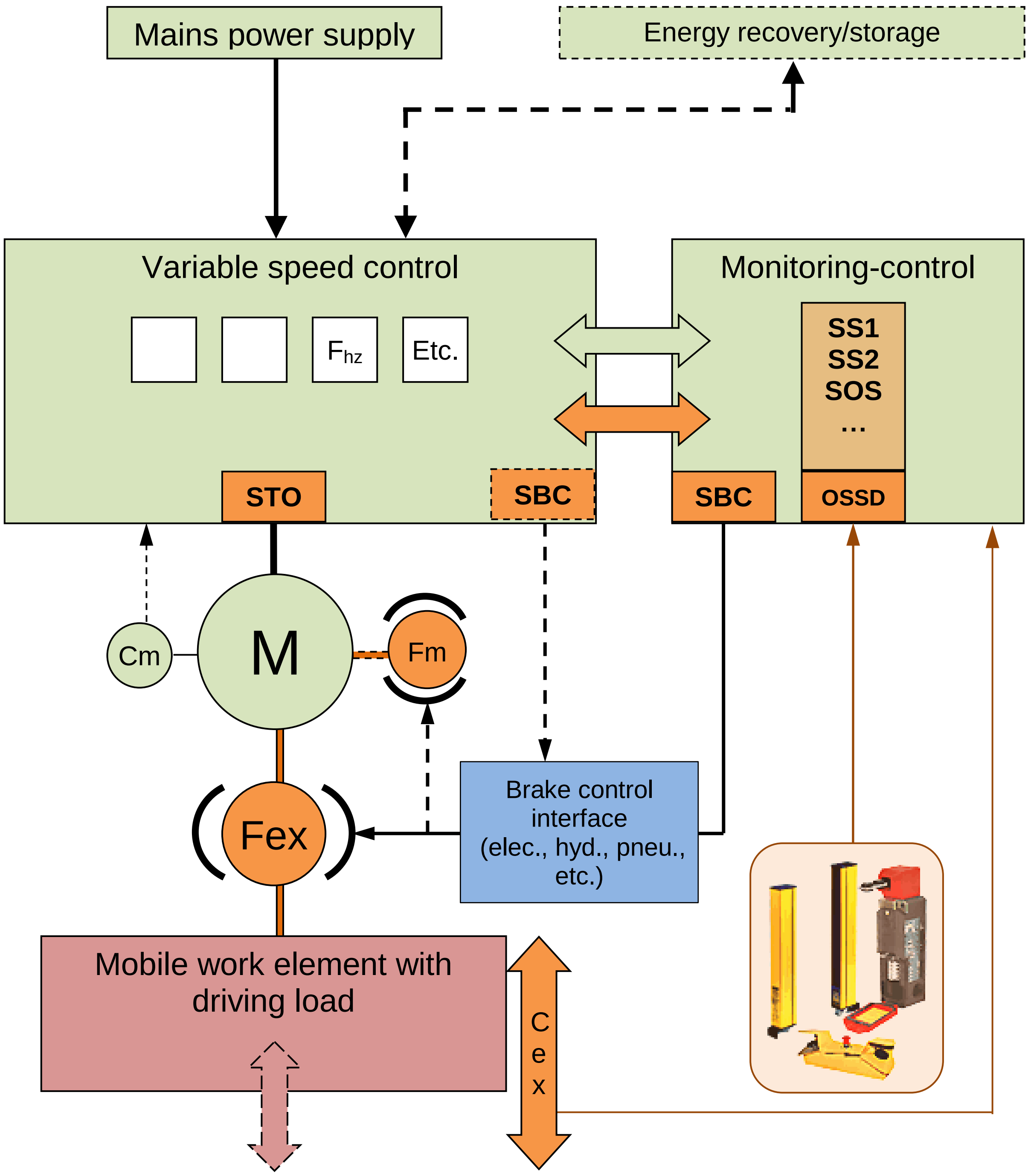

*Figure 36: Integration of a PDS/SR in the control circuit of a servomotor press - **Example 2: Variable speed control with only an STO function***

The third example, Figure 37, shows the design of a PDS/SR with a variable speed control with a series of safety functions (SS1, SS2, SOS, etc.) including the **STO** safety function.

Note: Exchanges of safety information are required between the monitoring-control part and the variable speed control or its safety card.

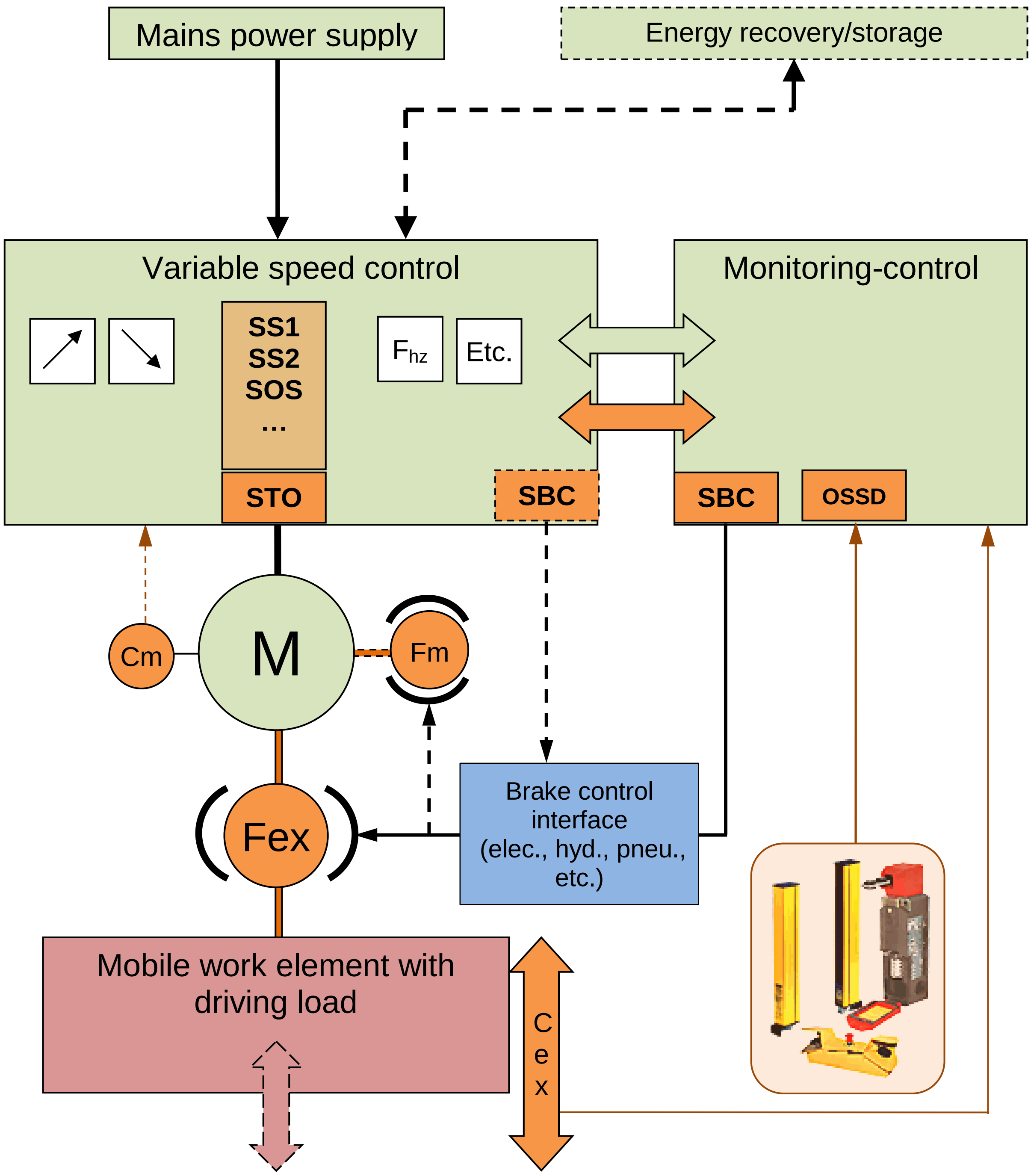

Figure 37: Integration of a PDS/SR in the control circuit of a servomotor press - ***Example 3: Variable speed control ensuring all the safety functions of the PDS/SR***

Appendix B : Examples of specifications of functional requirements of safety functions

This appendix presents examples of **specifications of functional requirements** for the safety functions of a **mechanical eccentric drive servomotor press**. In this case, it is a press intended for manual loading/unloading operations in the work zone. These safety functions result from a safety analysis and the installation of protection systems involving the machine's control circuit, to cover risks linked to slide movements (the main mobile work element). These specifications are used to analyse the behaviour in the presence of failures of the different elements composing the transmission chain from the servomotor to the slide.
The determination of the safety function integrity requirements (level of performance required) is not dealt with in this appendix. These data are available in the current standard for mechanical press design (NF EN 692) and feature in the drafts of ISO standards relating to the design of presses including servopresses.

The following safety functions, which are representative of what can be found on a press, have been taken as examples:

1. **Stop by protective device** – This function ensures the stopping of the slide during production mode of operation when the protection device (e.g., photoelectric barrier) is actuated.
2. **Muting** – This function permits muting the protective device in place for the phases where the slide does not present a hazard for the operator.
3. **Anti-repetition** – This function is necessary on eccentric drive presses, when a muting function is used, in order to prevent a repetition of the cycle while the operator is in the hazardous zone.

Table 2: Specifications of the "stop by protective device function" in the framework of implementing a "stop protection" command by a protective device in the form of a photoelectric barrier.

Specification of functional requirements of the safety function	
FS1	***Name of function*** **Stop by protective device**
Level of performance required (following the risk assessment)	Not dealt with in this appendix.
Conditions of actuating the function	This function is active in Single cycle mode.
Function interfaces	Element triggering the function: - means of protection: protective device (photoelectric barrier). Output of function: - potentially hazardous mobile element: slide.
Description of the function	A "**protection** stop" must: - prevent the slide from moving as long as the photoelectric barrier detects an object in its field, - stop slide movements "covered" by the photoelectric barrier during the period it detects an object in its field. When the field of the photoelectric barrier is no longer interrupted, the slide movements "covered" by the protective device can be performed (freeing the field of the photoelectric barrier does not trigger hazardous slide movements on its own). A function "inhibiting" the "stop by protective device" function can be implemented when certain slide movements are not hazardous. Note: possible resetting conditions of the means of protection are not dealt with.
Other simultaneous functions	Inhibition function (FS2).
Maximum reaction time of function	The maximum reaction time must be taken into account for positioning the protective device in relation to the hazardous zone (see § 10.11.2.1).
Reaction to faults	In the case of a fault (of a component or the power supply), the function must remain ensured, if necessary during the detection of the fault. The reaction to the fault must continue to maintain the function until the elimination of the fault or lead to a fall-back position corresponding to a "**type 0 safe stop**". The time to stop the slide in the presence of a fault must not exceed the reference time for positioning the protective device.

Table 3: Specifications of the "muting" function in the framework of implementing a "protection stop" by a protective device.

Specification of the function requirements of the safety function	
FS2	***Name of the function*** **Muting**
Required level of performance (following a risk assessment)	Not dealt with in this appendix.
Conditions for activating the function	This function is active in Single cycle mode.
Function interfaces	Element triggering the function: - means of muting: direction of slide displacement and slide position/stroke determined by the process. Output of function: - function to be muted: FS1.
Description of the function	When the muting function is in service, the "stop by protective device" function is suspended. The muting of this function can be performed when the slide: - descends (closing of tools) and the remaining stroke no longer presents a risk, - raises (opening of tools), - is stopped automatically at the programmed top dead centre point. The muting must stop at the latest before the slide starts its descent. When the muting function is active on a mechanical eccentric drive press, an "anti-repetition" function must be implemented.
Other simultaneous functions	"Anti-repetition" function (FS3).
Maximum reaction time of function	not relevant
Reaction to faults	If a fault occurs (of a component or the power supply), the function must remain ensured, if necessary during the detection of the fault. The reaction to the fault must continue to maintain the function until the elimination of this fault or lead to a fall-back position corresponding to a **"type 0 safe stop"**. The possible unintended downwards stroke of the slide must not present a risk for the operator, in conformity with the risk analysis specific to this machine.

Table 4: Specifications of the "anti-repetition" function in the framework of implementing an "muting" function

Specification of the functional requirements of the safety function	
FS3	***Name of the function*** **Anti-repetition**
Required level of performance (following the risk assessment)	Not dealt with in this appendix.
Conditions for activating the function	This function is active in Single cycle mode, when the muting of the "stop by protective device" is active.
Function interfaces	<u>Element triggering the function</u>: - command information to obtain an automatic stop at the top dead centre point of the slide. <u>Output of the function</u>: - mobile element: slide.
Description of the function	When the "anti-repetition" function is in service, the control system must command an automatic stop of the slide so that it is stopped and held to stop at the programmed position, by commanding a "**type 1 or 2 safe stop**". The programmed stop position must not exceed the top dead centre point.
Other similar functions	Muting (FS2).
Maximum reaction time of function	Not relevant
Reaction to faults	If a fault occurs (of a component or the power supply), the function must remain ensured, if necessary during the detection of the fault. The reaction to the fault must continue to maintain the function until the elimination of this fault or lead to a fall-back position corresponding to a "**type 0 safe stop**". The possible overrun downward stroke of the slide must not lead to a risk for the operator, in conformity to the risk analysis specific to this machine.

Appendix C: Example of determining the global response time of a protection stop function on a mechanical servomotor press

1. Preamble

The protection stop function dealt with in this example implements a **type 1 safe stop**. This function is initiated following the activation of a protective device (e.g., crossing of a photoelectric barrier) to stop the slide of a mechanical press.
The two options of implementing a type 1 safe stop at the PDS/SR are dealt with: SS1 b) and SS1 c).
The material chain participating in the function proposes two examples of configurations, one which implements cable links between different electric components and the other which implements a fieldbus network dedicated to safety.

2. Hardware control channel of a type 1 safe stop (§ 10.4)

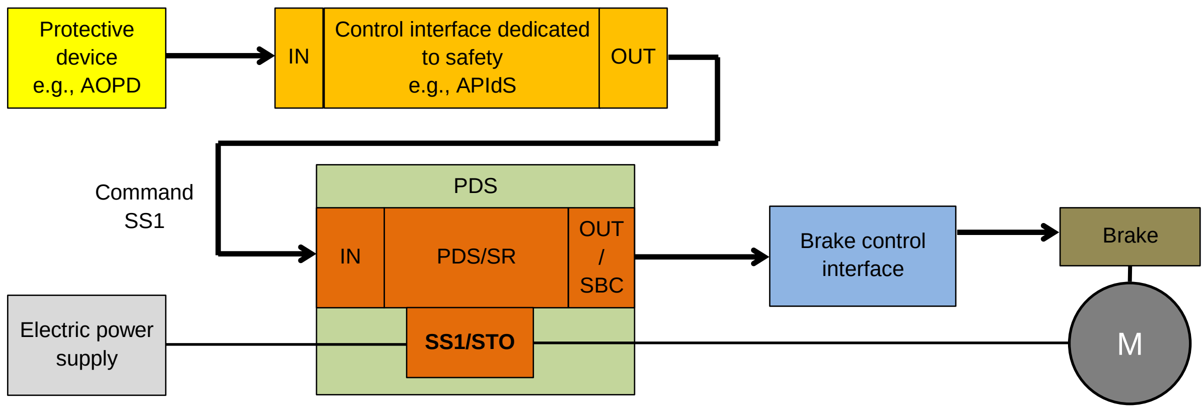

Figure 38: Hardware control channel with servomotor and brake control by the PDS/SR with electric cable links

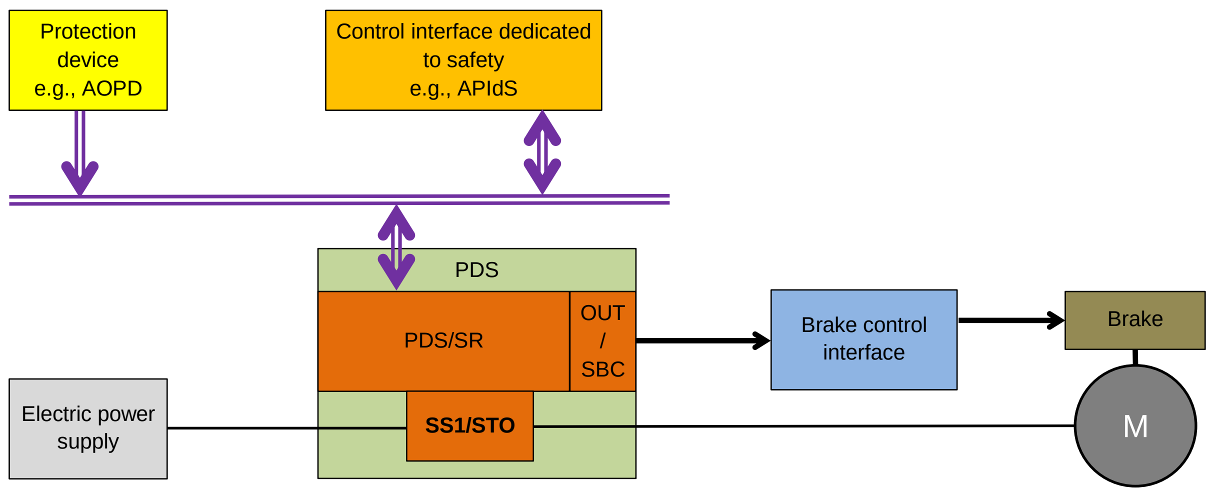

Figure 39: Hardware control channel with servomotor and brake control by the PDS/SR for which certain electric links are ensured by a safety dedicated fieldbus network

Analysis:

Under normal operation**,** the brake is necessarily controlled by the PDS/SR since it is activated after the motor deceleration phase (SS1).
If a fault occurs or in case of a failure of the power supply to the safety dedicated fieldbus network, the status of the OUT output of the safety dedicated fieldbus network changes and controls an SS1. There is no extension of the stop time in comparison to a normal command of the function.
If a fault occurs or if the electric power supply to the variable speed controller is cut off, the fall-back function of the PDS/SR ensures that no torque is exerted on the motor (STO) and switches the output statuses (OUT or SBC) of the brake command.

3. Analysis of the response time of the stop chain

For certain elements composing the stop chain, it is possible to determine, or find from the manufacturers, the response times under normal operation and in the presence of a fault. **When taking into account the different elements composing the stop chain, only one fault should be considered at a time. It is therefore necessary to apply the fault of the the element having the worst consequences in the calculation.**

Note: In the case of using components or part of the function (e.g., SS1) whose response increases if a fault occurs. It is necessary to calculate the global stop time with the fault of the component or the part of the function for which the differential between the time without a fault and the time with a fault is the longest.

3.1. Protective device

T_P: Response time of the protective device

Generally, regarding these components, only one maximum response time value is given by the manufacturer of the protective device (e.g., photoelectric barrier).

Note: When the protective device is composed of a detection device and an associated safety module, this time includes the response time of the detection device + the response time of the processing unit (module).

Example of response time of a photoelectric barrier

Example T_P	Time without a fault	Time with a fault	Differential
Photoelectric barrier	15 ms	15 ms	0
Associated module	None	/	/

3.2. Link between the components of the stop chain

T_C: Communication time

This time is null if a cable link is used.

When certain links (e.g., link between the protective device and the safety dedicated electric control interface) are ensured by a safety dedicated fieldbus network, the response time is determined as per the manufacturer’s data.
The response time if a fault occurs must take into account the maximum detection time if communication is absent or lost (Time OUT).

Example of communication time

Example T_C	Time without failure	Time with failure	Differential
Cable link	0	0	0

3.3. Electric control interface dedicated to safety

T_T: Response time of electric interface

This time can be divided into three parts as a function of the type of hardware implemented:

- **T_{TI}**: Input signal acquisition time (Input),
- **T_{TL}**: Control logic processing time,
- **T_{TO}**: Output signal recovery time (Output).

The input signal acquisition time must take into account the hardware response time (manufacturer’s data) and possible filtering time of inputs programmed by the designer.
The control logic processing time is based on the cycle time of the device processing unit. The calculation method is determined by the manufacturer. Several values can be proposed, specifying the response time with or without internal system failure.
The output signal recovery time must take into account the response time of the hardware (manufacturer’s data).

Example of an electric interface composed of an industrial PLC dedicated to safety (fieldbus network dedicated to safety)

Example T_T	Time without failure	Time with failure	Differential
Fieldbus card **T_{TI}**	2 ms	2 ms	0
Fieldbus cycle time **T_{TL}**	1 ms	4 ms	3 ms
Fieldbus output card **T_{TO}**	0	0	0

3.4. PDS/SR safety dedicated power drive system

T_V: Response time of the variable speed controller for controlling its outputs (STO, SS1, OUT/SBC).

This time can be divided into three parts as a function of the type of hardware implemented:

- **T_{VI}**: Input signal acquisition time,
- **T_{VL}**: Control logic processing time (excluding functions, e.g., SS1),
- **T_{VO}**: >Output signal recovery time.

The input signal acquisition time must take into account the response time of the hardware (manufacturer’s data) and the possible filtering time of inputs programmed by the designer.
The control logic processing time is based on the cycle time of the device processing unit. The calculation time is determined by the manufacturer. Several values can be proposed, specifying the response time with or without the internal system failure (e.g., "typical value" or "worst case"). Likewise, the values proposed can vary according to the safety functions implemented.
The output signal recovery time must take into account the hardware response time (manufacturer’s data).

Note: In our example, response time **T_V** does not take into account the specific parameters linked to the regulation functions implemented by the PDS/SR (e.g., SS1, etc.) which are processed independently.

Example of response time of the safety part of the variable speed controller

Example T_V	Time without failure	Time with failure	Differential
Variable speed controller input card T_{VI}	2 ms	2 ms	0
Variable speed controller cycle time T_{VL}	8 ms	16 ms	8 ms
Variable speed controller output card T_{VO}	0	0	0

3.5. Type 1 safe stop time

This time is between the actuation of function SS1 in the PDS/SR (start of deceleration) and the total arrest of the slide after applying the brake.
This time can be broken down into four phases:

- the for performing the SS1 function,
- the response time of the brake interface (if available),
- the response time of the brake (excluding sliding),
- the sliding time (mechanical braking).

The type 1 safe stop must be considered globally for these four aspects both for normal operation and operation in the presence of a fault since, in the present case, the brake, which is rarely used under normal operation, participates fully in stopping the slide in the case of a fault relating to the SS1 function.

3.5.1. SS1 function

$\mathbf{T_{SS1}}$: Time for performing the SS1 function

This time is between the actuation of the SS1 function in the PDS/SR (start of deceleration) and the control of the absence of torque STO that occurs:

- under normal operation:
  - when the drive motor reaches the “zero speed” parameter if SS1 b) (Figure 40),
  - or at the end of the programmed timeout if SS1 c) (Figure 42).
- in the case of a regulation failure:
  - when the system detects the fault via the programmed monitoring if SS1 b) (Figure 41),
  - or at the end of the programmed timeout if SS1 c) (Figure 43).

If the control of the function is performed by a timeout (SS1 c), the response time to be taken into account for $\mathbf{T_{SS1}}$ is that of the programmed timeout. It is the same under normal operation and in the presence of a fault.

If the control of the function is performed by ramp monitoring (SS1 b):

- under normal operation, the response time will depend on the deceleration ramp, the maximum speed value and the zero speed value, programmed for the application.
- In the case of a regulation failure, the response time will be linked to its detection. It must be determined by considering the following hypotheses:
  - the failure occurs immediately the SS1 function is actuated,
  - the servomotor speed is the same as the maximum speed,
  - the failure consists of an acceleration following the maximum admissible ramp,
  - if any, the timeout before the control programmed for the application must also be taken into account.

3.5.2. Pre-actuator (if any)

$\mathbf{T_E}$: Brake control interface response time

The time between the command and the switching of the pre-actuator.
If the interface is provided by electromechanical components (e.g., relay) the response time to be taken into account is the maximum switching time of the component (contact opening) supplied by the manufacturer. The architecture used must not lead to the extension of the response time in the case of failure.

3.5.3. Actuator (brake)

$\mathbf{T_A}$: Actuator response time

The time between the switching of the pre-actuator and the closing of the brake discs.
Since the component is correctly dimensioned (number of springs and their capacity), there should be no extension of response time in the case of an internal brake fault.

3.5.4. Mechanical braking

$\mathbf{T_G}$: Sliding time

Analysis:
Under normal operation, the brake plays only a secondary role for the deceleration phase (final stop of movement after the deceleration phase ensured by SS1) and a role in holding to stop that does not impact on the stopping time. The sliding time will be very short (Figure 40, Figure 42) since the brake intervenes only when the movement has stopped or almost stopped.

In case of an SS1 function failure during the deceleration phase, it is the brake alone that will stop the movement of the mobile element (Figure 41, Figure 43).
The sliding time of the mobile element depends on its inertia which in turn depends on the speed of the mobile element at the time the brake command is emitted, its weight and the external elements linked to the design and kinematics of the drive system (e.g., friction, driving load, balancing system, etc.).
Its value must be determined by measurement under the worst conditions (maximum speed and load, specific kinematics). If a balancing system is present and its operation cannot be ensured (e.g., control of pneumatic pressure), the measurement must be performed without the balancing system.

Note: Braking is considered with zero torque on the drive motor of the mobile element.

In the case of failure, the sliding time is the same as that obtained for a type 0 safe stop which can occur following a stop command or a fall-back position of the PDS/SR.

Example of performing a type 1 safe stop with the implementation of an SS1 b) function

Example $\mathbf{T_{AT1}}$	Time without failure	Time with failure	Differential
Function SS1 b) $\mathbf{T_{SS1}}$	60 ms	20 ms	/
Pre-actuator $\mathbf{T_E}$	12 ms	12 ms	/
Actuator $\mathbf{T_A}$	14 ms	14 ms	/
Mechanical braking $\mathbf{T_G}$	10 ms	70 ms	/
Global time $\mathbf{T_{AT1}}$	96 ms	116 ms	20 ms

3.6. Determination of response time of the stop chain: T_R

TR: stop chain response time
TR = $T_P + T_C + T_T + T_V + T_{AT1}$

Example of the determination of the global response time of the stop chain

Example	Time without failure	Maximum differential	T_R
T_P	**15** ms	0	/
T_C	**0** ms	0	/
T_T	**3** ms	3 ms	/
T_V	**10** ms	8 ms	/
T_{AT1}	**96** ms	**20** ms	/
Global time	**124** ms	**20** ms	**144** ms

In this example, the response time of 144 ms will be used to calculate the necessary safety distance for positioning the photoelectric barrier. It will also be used as the reference during dynamic braking controls (§ 10.11.1.2) and the control of stop performances (§ 10.11.2.4).

3.6.1. Diagrams of different configurations

Note: The purpose of the following chronograms is to illustrate the determination of response time T_R without taking into account the times specific to each part of the safety function.

3.6.1.1. Protection stop with implementation of an SS1 b) function

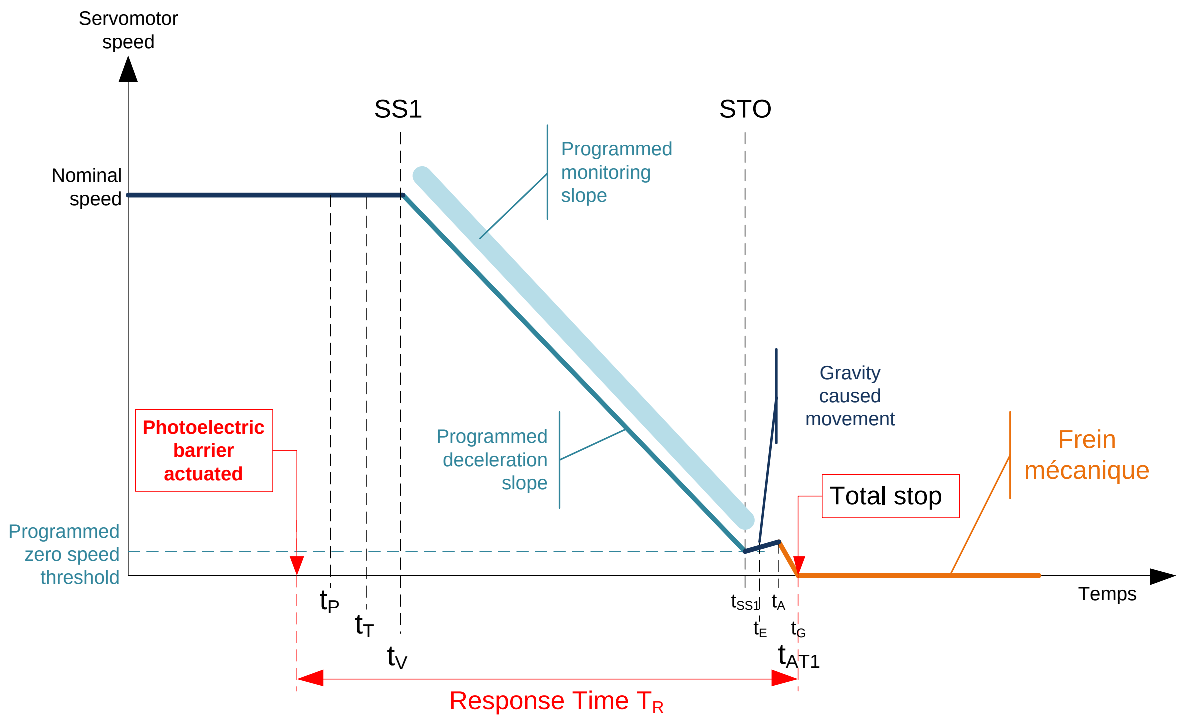

Figure 40: Chronogram of a protection stop with implementation of an SS1, b) function: Normal operation

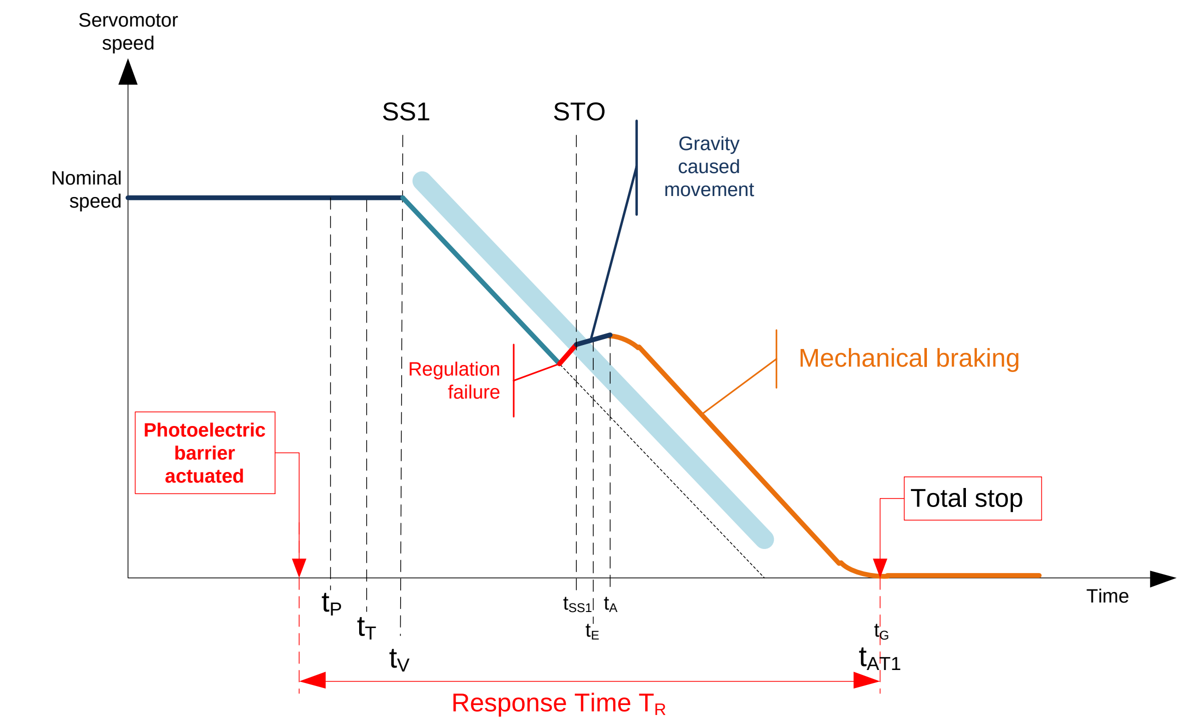

Figure 41: Chronogram of a protection stop with implementation of an SS1, b) function; and reaction in the presence of a PDS/SR regulation failure

3.6.1.2. Protection stop with implementation of an SS1 c) function

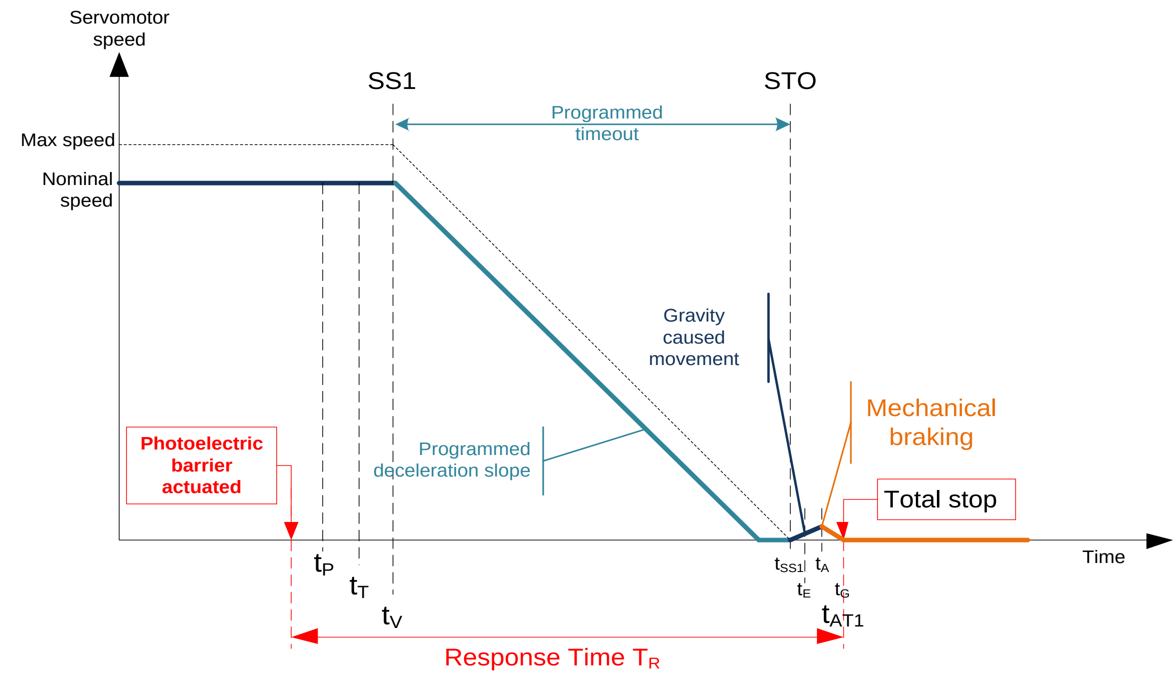

Figure 42: Chronogram of a protection stop with implementation of an SS1, c) function: Normal operation

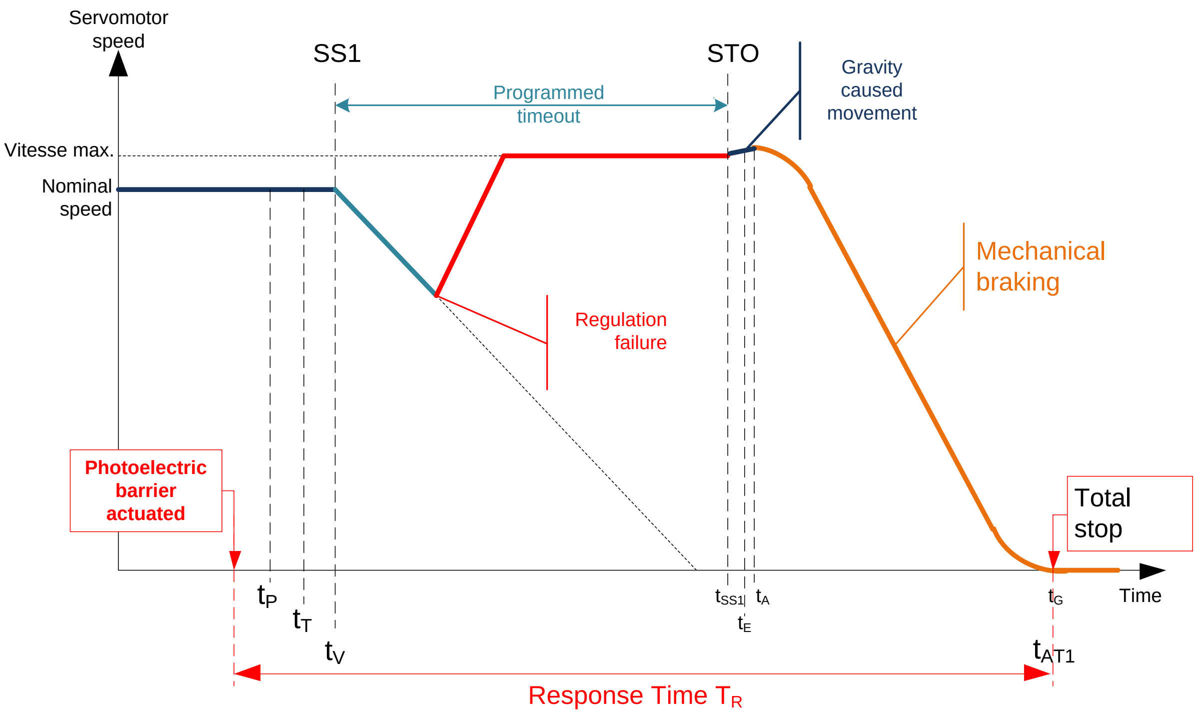

Figure 43: Chronogram of a protection stop with implementation of an SS1, c) function: Reaction in the presence of a PDS/SR regulation failure

Appendix D: Stop functions of standard IEC 61800-5-2

The definitions of the stop functions of standard IEC 61800-5-2, translated by the INRS, are the following:

Extract 5: Translation of § 4.2.2.2 of standard IEC 61800-5-2, defining the STO function

4.2.2.2 Safe torque off (STO)

The power supply, which can cause rotation (or movement in the case of a linear motor), is not applied to the motor. The PDS (SR) does not supply energy to the motor which can generate torque (or force in the case of a linear motor).

***Note 1:** This safety function corresponds to a non controlled stop in conformity with the 0 stop category of IEC 60204-1.*

***Note 2**: This function can be used when the power supply must be cut to avoid an unintentional start of operation.*

***Note 3**: If external impacts (for example, the fall of suspended loads) are present, additional measures (for example, mechanical brakes) may be necessary to prevent any hazard.*

***Note 4**: Electronic devices for cutting off power and contactors are not adapted to protect against electric shocks, and additional insulation measures may be necessary*.

Extract 6: Translation of § 4.2.2.3 of standard IEC 61800-5-2, defining the SS1 function

4.2.2.3 Safe stop 1 (SS1)

The PDS(SR):
a) actuates and controls the motor deceleration ramp within the limits fixed to stop the motor and trigger the STO function (see 4.2.2.2) when the motor speed is lower than a given threshold, or
b) actuates and monitors the motor deceleration ramp within the limits fixed to stop the motor and trigger the STO function when the motor speed is lower than a given threshold, or
c) actuates the deceleration of the motor and triggers the STO function after a timeout specific to the application.

Note: This safety function corresponds to a controlled stop in conformity with the stop 1 category of IEC 60204-1.

Extract 7: Translation of § 4.2.2.4 of standard IEC 61800-5-2, defining the SS2 function

4.2.2.4 Safe stop 2 (SS2)

The PDS(SR):

a) actuates and controls the motor deceleration ramp within the limits fixed to stop the motor and triggers the safe hold to stop function (see 4.2.3.1) when the motor speed is lower than a given threshold; or

b) actuates and monitors the motor deceleration ramp within the limits fixed to stop the motor and triggers the safe hold to stop when the motor speed is lower than a given threshold; or

c) actuates the deceleration of the motor and trigger the safe hold to stop function after a timeout specific to the application.

Note: This safety function corresponds to a controlled stop in conformity with the stop 2 category of IEC 60204-1.

Extract 8: Translation of § 4.2.3.1 of standard IEC 61800-5-2, defining the SOS function

4.2.3.1 Safe hold to stop (SOS)

The SOS function prevents the motor from deviating by more than a defined quantity from the stop position. The PDS(SR) supplies energy to the motor to allow it to resist external forces.

Note: This description of a safe hold to stop is based on the implementation of a PDS(SR) without external brakes (for example, mechanical).