Belt Conveyor Safety

Understanding the hazards

By Laurent Giraud, Serge Massé and Luc Schreiber

BELT CONVEYORS ARE HAZARDOUS machines. Over the last 20 years, 85 serious and fatal accidents have been formally investigated and documented in the U.S. (32 events investigated by OSHA between 1984 and 1996); France (42 incidents investigated by that country's Institut National de Recherche et de Securite); and Quebec, Canada [11 incidents investigated by Quebec's Occupational Health and Safety Commission (CSST)].

Although detailed technical literature exists on conveyor design (CEMA; Mulani) as well as general literature on conveyor safety (Schultz; CEN EN 620; ANSI B20.1; MAQOHSC), no document, in the form of a guide, provides details (with illustrations and dimensions) on how to make such machines safe. This article assesses the accident situation for belt conveyors, then summarizes their components and operation. Conveyor-related hazards and their consequences are described, as are safety requirements that have been proposed for production operations. The authors also draw some conclusions about this work and discuss future developments.

Accidents Involving Belt Conveyors

As Table 1 indicates, investigation of the 85 accidents revealed that more than half—47 accidents—involved the head or tail pulleys as well as the power transmission mechanisms (e.g., drive pulley, reducing gear, motor) (Giraud, et al 15). Idlers or return idlers, although clearly more numerous than pulleys, were the location of only 11 accidents (13 percent).

As Table 2 shows, a large portion of the accidents—26 (31 percent)—occurred during conveyor cleaning or during cleaning around it. Other accidents occurred during maintenance interventions near or on a conveyor with a moving belt (22 accidents or 26 percent). Thirteen accidents (15 percent) were related to a jammed belt, a frozen and icy belt, or a caught article. Accidents that occurred during regular production activities (e.g., sorting, packaging) were less common, accounting for only 10 accidents (12 percent). These statistics highlight the diversity and extent of hazards to which those who work on or near a conveyor are exposed, regardless of the nature of their activity.

Belt Conveyor Design & Operation

Belt conveyors are common in industry and businesses because they move products or materials easily from one point to another (CEMA). They exist in many forms and dimensions, can move up and down, and can be very long. Yet, most are built according to the same principle: They consist of a belt generally supported by idlers and driven by a motor via a drive pulley (CKIT). Construction of various components (e.g., belt, idlers, pulleys, frame) differs for each application depending on factors such as material conveyed and power standards used. The material, in bulk (e.g., sand, chips, ore) or in unit loads (e.g., boxes, unit components, cans) is often loaded at one end of a conveyor and unloaded at the other. For bulk transport, the belt is often trough-shaped (Figure 1) but can also be shaped like a tube or a bag. For transporting unit loads, the belt is flat.

When a conveyor's components are in good condition and well-aligned, and sufficient tension is placed in the belt, it will operate properly. When good contact occurs between the driving pulley and the belt (sufficient arc of contact and coefficient of friction), the driving pulley drives the belt without slipping (Figure 2). The common equation of non-slipping is $T_1/T_2 = e^{\theta f}$ with:

T_1: Tension in the carrying side of the belt;

T_2: Tension in the return side of the belt

θ: arc of contact between the belt and the driving pulley (generally 180 degrees)

f: coefficient of friction between the belt and the driving pulley

Feeder loads center and stabilize material on the belt, which transports the material and unloads it in

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the discharge chute. Belt cleaners remove residues that adhere to the belt, release them into the discharge chute and the cycle begins again. It should be noted that belt cleaners do not always function as desired, however, so other equipment, such as disc return rollers, winged pulleys and tail scrapers, may be incorporated into the design.

Once a component becomes too worn, does not operate properly or becomes misaligned, the belt will shift off center rapidly. This may also occur when new equipment is improperly designed and manufactured. This shift may lead to a spill, which will require an employee to intervene and clean, check, adjust or repair the unit. Consequently, accident risks increase. These risks are again amplified if the conveyor cannot be stopped due to production requirements (for example, if only one conveyor supplies a boiler or a continuous process). In such cases, however, lockout/tagout standards should be applied to protect workers (29 CFR 1910.147; ANSI Z244.1).

Belt Conveyor Safety

The main hazards related to belt conveyors are mechanical. Other hazards are produced by noncompliance with ergonomic principles when workers operate near the conveyor (operation station, control of the process, loading and unloading); failure or malfunction of safety-related control systems; electrical hazards; and thermal phenomena (such as heat, fire or explosion).

The main mechanical hazards are related to:

•mechanical power transmission components (e.g., drive shaft, reducing gears) that can cause damage by entrainment (by a belt or on nip points), crushing or entanglement (human body entangled around a rotating part) on contact with rotating components;

•other moving components (e.g., idlers, pulleys, belt) that can cause damage by entrainment in nip points, abrasion and burns;

•pinching zones (e.g., feeder, skirtboard, skirtboard seal) that can cause damage by shearing and crushing;

•moving loads that can cause damage by shearing and crushing between the load and a fixed component, or an impact;

•moving subassemblies (e.g., ejectors, switches, transfer mechanism) that can cause damage by shearing and crushing.

Safeguards Against Mechanical Hazards

Production activities include starting and stopping the conveyor, loading and unloading, labeling and supervision. They also include moving along the length of the conveyor or passing under it.

Various measures can be used to protect workers against mechanical hazards during these activities. The most effective way to protect workers is to eliminate the hazards (ISO 14121). This can be achieved by inherent design measures when possible. For example, in the case of belt conveyors, eliminating the nip point between the belt and idlers will be difficult. In some cases, however, idlers can be replaced with skids or slider beds. When this is done, the nip point is replaced by a pinch point. This pinch point will reduce the access between the belt and the skid, and will facilitate withdrawal of the involved body part (e.g., fingers).

If inherent prevention is not possible, the risk may be reduced technically in several ways, such as lessening the power or limiting the mechanism's reach. In the case of conveyors, this reduction in risk can be achieved in various ways:

•Modify the type of belt (e.g., from a pocket belt to a chevron-molded belt; however, it should be

Table 1

Accident Frequency: Conveyor Location

Location	Number (%)
Between the drive pulley, head pulley or tail pulley and the belt, inside one of these pulleys or between one of these pulleys and another pulley.	41 (48 percent)
Between an idler or a return idler and the belt.	11 (13 percent)
Other locations (e.g., between electromagnets and other components).	11 (13 percent)
Drum motor transmission mechanism.	6 (7 percent)
Between a take-up pulley and the belt.	4 (5 percent)
Between a caught tool and the belt or the conveyor frame.	2 (2 percent)
Not indicated or uncertain.	10 (12 percent)

Source: Giraud, et al.

Table 2

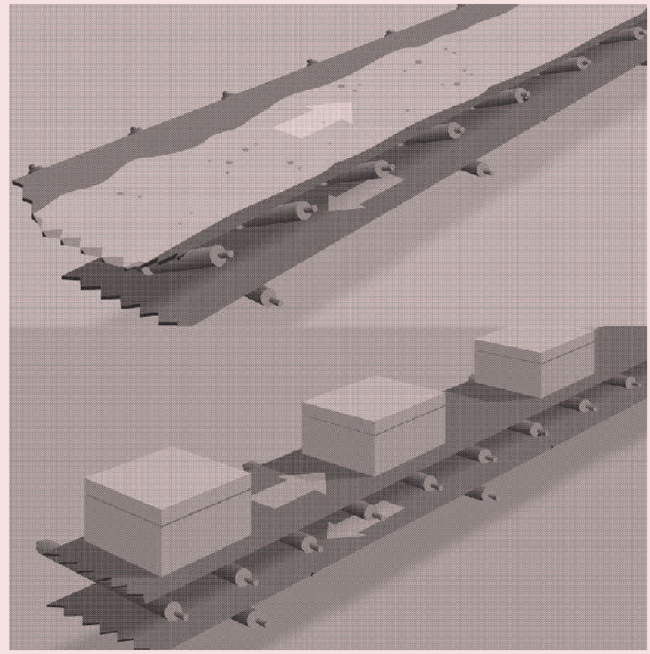
Accident Frequency: Worker Activity

Activity	Number (%)
Cleaning a pulley or applying adhesive on a pulley or cleaning another component of a conveyor (idler or return idler, frame).	20 (24 percent)
Maintenance work (other than cleaning) conducted on a moving conveyor.	17 (20 percent)
Normal work (e.g., sorting, packaging) performed on or near a conveyor.	10 (11 percent)
Recovering an article caught in an unprotected nip point (7 of 8: between a pulley and the belt; 1 of 8: between electromagnet roller and the belt).	8 (9 percent)
Cleaning under or around a conveyor.	6 (7 percent)
Maintenance work (other than cleaning) near a moving conveyor.	5 (6 percent)
Unjamming the conveyor or removing an accumulation of material.	4 (5 percent)
Adjusting the belt tension or alignment.	3 (4 percent)
Other activities (e.g., worker being transported by a conveyor).	3 (4 percent)
De-icing and unjamming a frozen belt.	1 (1 percent)
Not indicated.	8 (9 percent)

Source: Giraud, et al.

Figure 1

Troughed Belt & Flat Belt



Source: Giraud, et al 12.

noted that splicing or repairing such belts requires highly skilled personnel).

•Reduce intervention frequency (e.g., corrective maintenance, machine releasing, repair) on certain mechanical components. This entails application of a preventive maintenance program or regular follow-up on operating parameters.

•Distance workers from the hazard zone (during conveyor design).

If risk reduction does not eliminate all mechanical hazards that threaten worker safety during production activities performed on or near conveyors, guards or impeding devices may be needed. These include:

•fixed guards such as enclosing (prevent access to the hazard zone); distance (prevent access to the hazard zone by keeping workers away); nip-point (i.e., placed next to the nip point);

•impeding devices that limit immediate or involuntary access to the hazard zone side protection plate;

•guardrail.

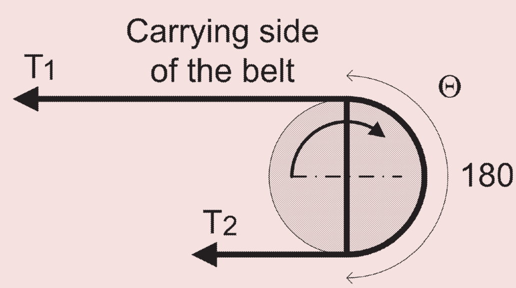
Fixed guards may include openings that must comply, for example, with current standards (e.g., ASME B15.1-2000, CSA Z432). In the case of fixed enclosing guards, the opening necessary for passage of the belt and transported load is such that, in most cases, this guard encloses the hazard zone only partially (CEN EN 620).

Thus, for conveyors with three troughed idlers, in order to prevent access to nip points created by the belt and idlers without completely covering the conveyor (for accessibility related to a workstation or for operation monitoring), a fixed enclosing guard that extends over the belt can be used (Giraud, et al 26). According to CEN EN 349 (a European standard), the distance between the upper end of the guard and the belt must be 100mm to prevent a hand from being caught in it. This distance must be calculated perpendicular to the inclined idler from a point located one third of the length of this idler from the top (Figure 3). In this way, the possible lateral displacement of the belt on the idlers and the operating play necessary for the belt can be taken into account (Mulani 117), allowing only rare direct access from the top of the conveyor to the nip point located just under the belt.

Enclosing guards (Figure 4) must also prevent access to the hazard along the belt by covering 1,000mm of the belt back from the first pinch point. This dimension is applicable regardless of the diameter of the idlers to be protected, which is not the case in CEN EN 620. Finally, enclosing guards must also cover a distance of at least 620mm beyond the last hazard on the side where the belt emerges. This dimension, more restrictive than that in CEN EN 620, is based on possible arm (length without hand) movements around a protective structure (CEN EN 294, Table 3). For the distance-fixed guards, the distance between the guard and the hazard must follow Table E1 of ASME B15.1-2000 or Table 1 of CEN EN 294, which are similar.

Figure 2

Contact Between Driving Pulley & Belt



To adapt safeguards to the existence and importance of various hazards encountered, the conveyor can be divided into several distinct zones:

1) mechanical power transmission components;
2) belt;
3) carrying/return strand idlers in a straight zone;
4) convex curve;
5) transition zone;
6) pulleys;
7) moving loads;
8) moving subassemblies;
9) mobile conveyor (Figure 5).

In general, only hazards (e.g., nip points) located within the 2.5m above a work surface (ground or platform) must be protected. This height is proposed in reference CEN EN 294 for cases where it is unlikely that people will attempt to reach the hazard zone. One or more safeguards (e.g, fixed guard, nip-point guard) are associated with each identified zone (Giraud, et al 36-57). In some cases, when work environment factors impact the conveyor's safety (e.g., access frequency, material, work near the conveyor during regular operation), a risk analysis must be performed (per ISO 14121) to determine the most appropriate safeguards. This analysis will use the hazard, hazardous situation, hazardous event and potential harm to calculate a risk estimation. Tables 3 and 4 present safeguard and hazard information zone by zone.

Mechanical Power Transmission Components

To ensure that they do not introduce new problems during component maintenance, lubricating points for mobile power transmission components must be outside the guard so they are accessible at all times. This also applies to any component that requires regular lubrication (e.g., idlers, screws) (Table 3).

Belts

Belts with pockets, side walls or ribs pose additional risks that must be considered in the analysis as well. The type of splice can also be changed to reduce the risk, if possible (Table 3).

Carrying & Return Strands in a Straight Zone

The risk analysis must also consider a layout in which idlers are supported from above, along a walkway (garland idlers, which are either three-roll or five-roll idlers joined at the ends of their respective shafts by special lugs to form a continuous chain of idlers). This layout leads to additional pinch points between the idler support structure and the belt or its load (Table 3).

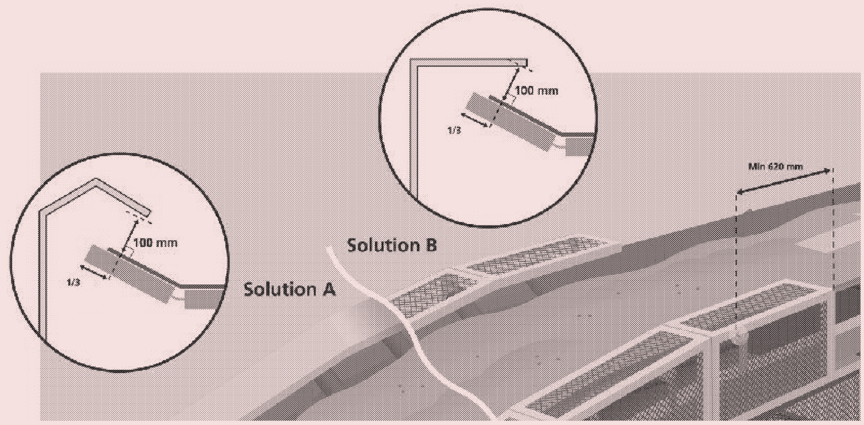
Use of a side protection plate (CEN EN 620) must be reserved for protecting the nip points of the return strand that are located within 70cm of the ground along a walkway (Figure 6). In the latter case, cleaning operations under an operating conveyor are not permitted because the primary objective of the plate is only to impede accidental or careless access when moving along the walkway.

Convex Curve

For a troughed belt, tension in the edges of the belt is greater on convex curves compared to a straight section of the conveyor. This overtension is due to the elongation of the belt edges on the curve. For a flat belt on convex curves, the force applied by the belt to the idlers is also greater than in a straight section. This is why protective devices have not been chosen as a safeguard. The same is true with respect to transition zones. It is important to guard all idlers and pulleys in these zones (Table 4).

Figure 3

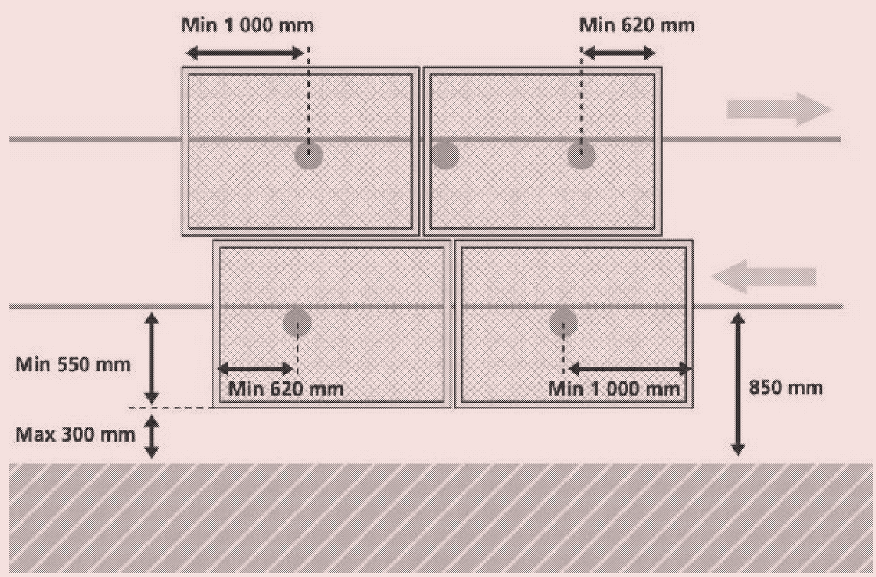
Enclosing Fixed Guard to Limit Access from Above the Conveyor



Source: Giraud, et al 27.

Figure 4

Extension of Fixed Guards



Source: Giraud, et al 28.

Figure 5

Conveyor Zones

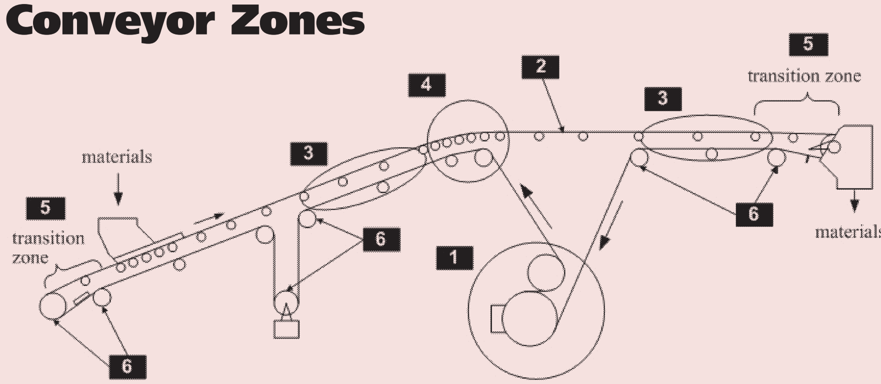


Table 3

Hazards & Safeguards by Zone: Part 1

MECHANICAL POWER TRANSMISSION COMPONENTS

Hazards	Consequences	Safeguards
Motor shaft, shaft end, sprocket wheel, pulley, chain, driving belt, gear or coupling.	Entrainment, crushing, wrench (body part), entanglement or catching of clothing.	Fixed enclosing guard.

BELT

Hazards	Consequences	Safeguards
Belt in good condition. Splice in good condition.	Depending on the speed and characteristics of the belt: burns or abrasions by friction, impact, entrainment.	**Carrying strand** (carrying part of the belt) •*Operation station:* Risk analysis. **Return strand** (noncarrying) •*Operation station:* Risk analysis. •*Walkway parallel to the conveyor:* Risk analysis. •*Walkway passing under the conveyor:* Protection plate for holding the belt should it break.
Deteriorated belt or splice.	Entrainment, burns, punctures, cuts.	Change design or manufacture of the splice; maintain the splice or belt.

CARRYING & RETURN STRANDS: STRAIGHT ZONE

Hazards	Consequences	Safeguards
Nip points created by the carrying strand and idlers under the feeder, carrying strand under the skirtboard or under the skirtboard seal.	Entrainment, wrench, crushing in the nip point. Shearing or burning by the belt.	Fixed enclosing or distance guard.
Nip points created by the carrying strand and idlers in a straight section.	Entrainment, wrench, crushing.	•*Operation station:* Fixed enclosing or nip-point guard (plates between the idlers). •*Walkway:* Risk analysis.
Nip points created by the return strand and the return idlers in a straight section.	Entrainment, wrench, crushing, impacts.	•*Operation station (beside/under conveyor):* Fixed enclosing or nip-point guard and addition of a protection plate if the operation station is located under the return idlers. •*Walkway parallel to the conveyor* •0.7m < nip point < 2.5m: Fixed enclosing, nip-point, distance guard or impeding device. •nip point < 0.7m: Impeding device (guardrail or side plate). •*Walkway passing under the conveyor:* Fixed enclosing, nip-point, distance guard or impeding device (guardrail) and addition of a protection plate.
Return idlers.	Impact, crushing (from falling).	Retaining device for the return idlers, if necessary, based on the results of the risk analysis (the risk can also be reduced by applying a preventive maintenance program).
Belt under the belt cleaner on the return strand.	Pinching or crushing. Abrasion by the belt.	Based on the result of the risk analysis (the protective device for the belt cleaner may also be combined with the one for the pulley).

Pulleys

When the counterweight is always less than 2.5m from the ground, the guard used to prevent access under it must be at least 2.5m high, because the conveyor's normal operation (starting, stopping) can make the height of the counterweight vary rapidly. As well, the take-up pulley and related devices (such as springs and cylinders) must also be protected by taking into account the extreme positions of the pulley. Tension control points must be brought outside the guards so they can be accessed at all times without having to lockout the machine (Table 4).

Moving Loads

The primary objective of protection against hazards due to a unit load and a fixed obstacle is to distance the worker from the crushing zone. The safeguard selected will depend on risk analysis results; it must not create a new hazard (that is, it must not also become a fixed obstacle). The same is true when dealing with moving subassemblies (Table 4).

Table 4

Hazards & Safeguards by Zone: Part 2

CONVEX CURVE

Hazards	Consequences	Safeguards
Nip points created by the belt and idlers in a convex curve.	Entrainment, wrench, crushing.	Fixed enclosing, nip-point or distance guard.

TRANSITION ZONE

Hazards	Consequences	Safeguards
Nip points created by the carrying strand and idlers in a transition zone.	Entrainment, wrench, crushing.	Fixed enclosing or nip-point guard.

PULLEYS

Hazards	Consequences	Safeguards
Nip points created by the belt and pulleys.	Entrainment, wrench, crushing.	Fixed enclosing, nip-point or distance guard.
Suspended counterweight. Nip points created by the belt and pulleys.	Crushing by the moving or falling counterweight. Entrainment, wrench, crushing in the nip point.	Fixed enclosing or distance guard. If the counterweight is always more than 2.5m from the floor or the work platform, an impeding device should be installed to prevent access under the counterweight.
Junction between two conveyors.	Entrainment and pinching if the clearance between the belts is more than 5mm.	Fixed guard (cover plate) or free retractable idler.

MOVING LOADS

Hazards	Consequences	Safeguards
Unit load the length of the skirtboard. Moving unit load.	Pinching, crushing between the unit load and the skirtboard.	•*Operation station:* Limit the space between the skirtboard and belt to a maximum of 5mm. Eliminate the skirtboard. Design a fixed enclosing guard based on the results of the risk analysis. •*Elsewhere:* Risk analysis.
Unit load and fixed obstacle outside the conveyor (post, wall, entry to a tunnel or an enclosed space, etc.).	Pinching, crushing, impact.	Fixed guard or impeding device, based on the result of the risk analysis by respecting the following minimum safety distances (CEN EN 349) between the load and obstacle: •entire body can be entrained: 500mm; •arms can be entrained: 120mm; •legs can be entrained: 180mm.
Unit load or idlers that exceed the width of the belt.	Pinching, crushing, impact.	•*Operation station:* Fixed distance guard or plate between the idlers. •*Elsewhere:* Fixed distance guard, plate between the idlers or impeding device.
Unit load.	Impact, crushing (after the fall).	Protection plate, screen, net or skirts based on the risk analysis.

MOVING SUBASSEMBLIES

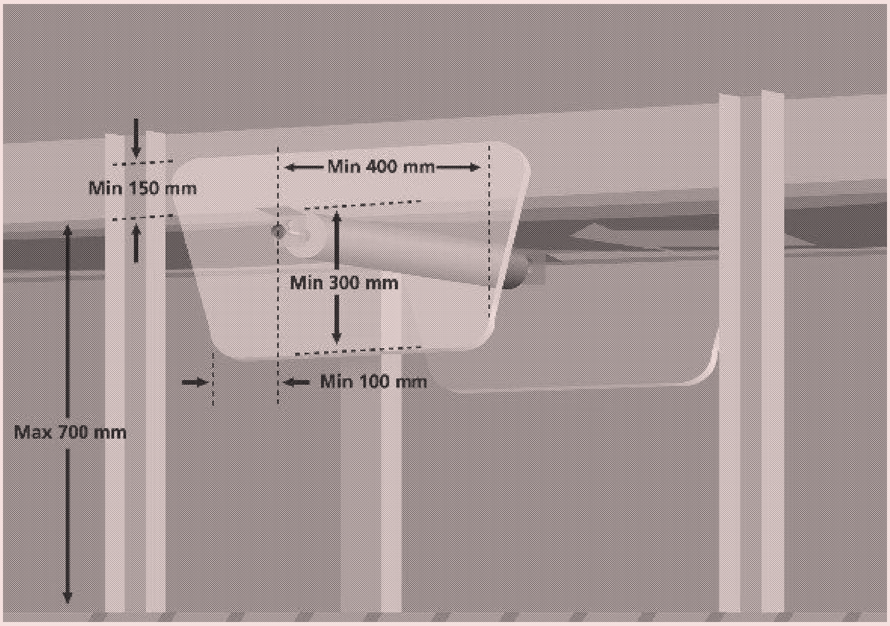
Hazards	Consequences	Safeguards
Pushers, stops, ejectors, switching devices.	Crushing, shearing.	Fixed enclosing or distance guard.

MOBILE CONVEYOR

Hazards	Consequences	Safeguards
Mobile conveyor.	Crushing, entrainment, pinching after it has moved.	Based on risk analysis results: Distance guard, impeding device or marking of the unit's movement zone. Electronic safety devices can also be used.

Figure 6

Impeding Device: Side Protection Plate



Source: Giraud, et al 43.

Mobile Conveyor

In the case of a mobile conveyor, the conveyor's limit positions (minimum and maximum slope, minimum and maximum rotating angle, upper and lower positions, etc.) as well as its states (activated, resting, unenergized) or its operating mode (automatic or not) must be taken considered in the risk analysis (Table 4).

Safeguarding zone by zone allows these measures to be adapted to the hazards present in each zone. Detailed illustrations as well as recommended safety distances are available in Giraud, et al (36-57). The tables also help SH&E professionals match safeguards with possible consequences. For example, for pulleys, impeding devices are not chosen because pulleys are involved in 48 percent of the documented accidents. In some cases, no safeguard can be determined in advance due to the many parameters involved (e.g., environment, intervention frequency). Therefore, a risk analysis is recommended (ISO 14121).

Conclusion

The proposed safeguards cover production-related operations. However, maintenance interventions on conveyors are equally or even more hazardous. The principle selected to define the safeguards for production operations do not apply to maintenance interventions. In fact, a mechanical component can be changed on a pulley, on a return idler or in a coupling; lubrication can be performed in many locations on the conveyor; adjustments can be made to belt cleaners, pulleys, idlers, take-up and other components. Consequently, to specify safeguards for maintenance activities, the type of interventions must be considered instead of the location where they are conducted.

In addition, when production safeguards are implemented, they must be adaptable to maintenance requirements. For example, if a lubrication point is inside a fixed guard, the guard could be moved rather rapidly (to perform the lubrication), but may not be replaced. Therefore, safeguards must be designed by taking maintenance into consideration, such as using hinged guards to minimize handling and avoid their loss.

Eliminating all hazards of belt conveyors in the design stage is idealistic because the very principle of using rotating idlers to support a moving belt is inherently hazardous (creation of nip points). However, it is at this stage that means must be found to reduce the number of interventions needed to clean under the conveyor, unjam the unit or maintain it. To achieve this, designers must receive appropriate indications so they can devise solutions that minimize these risks. These indications could be a list of positive or negative safety effects for all belt conveyor components; or a fault tree that illustrates the relationships between belt conveyor malfunctions and an accident. Such tools will help designers integrate safe solutions into their design, or at the very least to ask themselves—before manufacture—key questions relating to conveyor safety. ■

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