CHAPTER 5.2

Belt Conveyors

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Belt conveyors are widely used in transporting bulk materials. They are relatively inexpensive to install and operate, and they are safe, reliable, and versatile. Although there are several types of belt conveyors, the troughed belt conveyor is by far the most commonly used and thus is treated in detail in this chapter. Other types of conveyors are described briefly, with references provided for further information on their design and operation. Detailed information on the design, operation, and maintenance of belt conveyors is found in two readily available publications. The seventh edition of *Belt Conveyors for Bulk Materials*, published by the Conveyor Equipment Manufacturers Association (CEMA), is referred to hereinafter as the *CEMA Handbook* (CEMA 2014). The fourth edition of *Foundations—The Practical Resource for Cleaner, Safer, More Productive Dust and Material Control* is published by Martin Engineering Company (Swinderman et al. 2009) and is referred to hereinafter as *Foundations*.

CONVENTIONAL TROUGHED CONVEYOR

The troughed belt conveyor comprises a continuous belt, supported on rollers called *idlers* and driven by one or more rotating pulleys. Various other components may be added as needed. The system is loaded at one end, usually called the *tail end*, and discharged at the other, the *head end*. The idlers that support the portion of the belt carrying the load and traveling from the tail to the head are called *carrying idlers*. They are almost always configured to form the belt into a trough across its width, increasing the belt's carrying capacity and minimizing spillage. The return idlers, which support the empty belt from the head to the tail, are usually flat. A typical layout for a simple troughed belt conveyor is shown in Figure 1.

Troughed conveyors are very versatile. They can carry a broad variety of materials and have a wide range of capacities over short or long distances. They can be configured to negotiate inclines and declines of 18 degrees or more, and horizontal curves with radii of a few thousand meters. They can be designed to operate in almost any environment. These belts can also operate as components of a materials process, providing blending, sampling, and metered flow as desired.

Belt conveyors have relatively low capital, operating, and maintenance costs, and components are readily available from many sources all over the world. They are capable of throughputs up to 40,000 t/h (metric tons per hour), and conveying speeds up to 10 m/s. Because they are electrically driven, the only potential air emissions are dust and spillage, both of which can be controlled with proper design.

Although each installation is different, the following rules of thumb may be used in assessing the economics of belt conveyors (CEMA 2014):

1. An overland conveyor will have lower operating costs than truck haulage if the haulage distance exceeds 1 km.
2. Beyond the 1-km haulage distance, the ton-per-kilometer cost of belt transport may be as low as one-tenth that of truck haulage.
3. Operating yearly maintenance costs for a belt conveyor may be estimated at 2% of the purchase cost of the equipment (structure and drive) plus 5% of the cost of the belt.
4. Belt replacement is required at approximately 5-year intervals in hard rock applications and up to 15-year intervals in nonabrasive applications.
5. Well-maintained conveyor systems can have an operational availability of 90% or higher.

DESIGN CHARACTERISTICS OF BULK MATERIALS

Material flow may be characterized by many parameters, including internal and effective friction, cohesive and adhesive strength, flowability, boundary friction and adhesion, angle of repose, surcharge angle, particle size distribution, and bulk density. All of these properties are affected by the moisture content of the material and the manner in which it is handled during its transport. In some applications, material property testing by a qualified organization is advisable.

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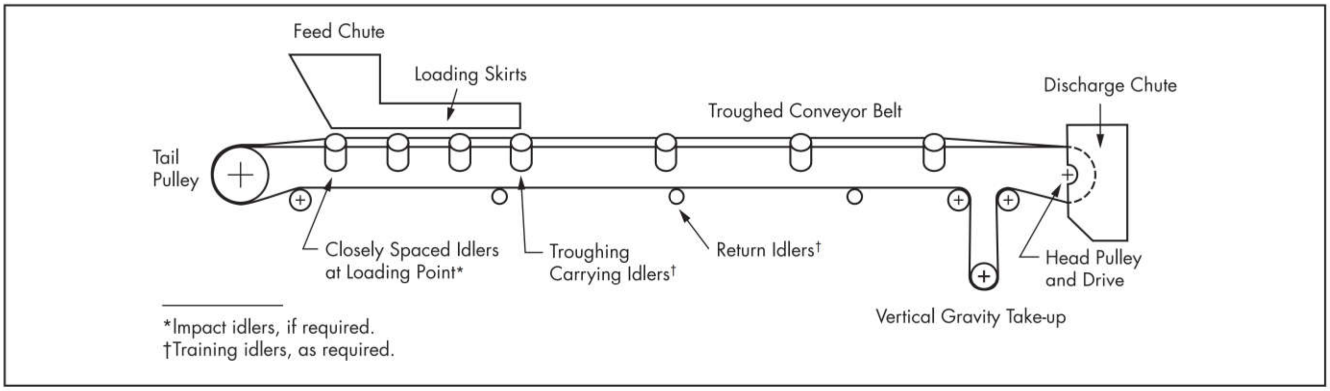


Source: CEMA 2014
Figure 1 Troughed belt conveyor layout

Angles of Repose and Surcharge

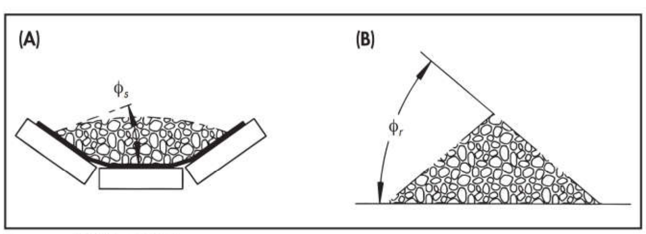
The angle of repose ϕ_r, sometimes called the *angle of friction*, is the maximum angle of the stable slope formed when a granular material is poured onto a horizontal surface and forms a conical pile. It is related to the size distribution, density, surface area, particle shape, and coefficient of friction of the material.

The angle of surcharge ϕ_s is the angle to the horizontal formed by material on a moving conveyor. The surcharge angle defines the surcharge area, which is the area of a segment of a circle that is tangent to the surcharge angles at the two points that represent the load width on the belt. The surcharge area is used in the calculation of conveyor capacity, but the value of the surcharge angle is often only an approximation. The surcharge angle used in conveyor design should be compared with that for other conveyors at the same site moving similar material. The angles of surcharge and repose are illustrated in Figure 2.

The carrying capacity in cubic meters per second (m^3/s) for a conveyor system is a function of the cross-sectional area of the material load on the belt, at steady-state conditions, and the linear velocity of the belt. From a dimensional analysis

$$m^2/s \cdot m/s = m^3/s \qquad \textbf{(EQ 1)}$$

Figure 2 shows that the cross-sectional area of the material load on the belt is determined by the material surcharge angle, the troughing angle of the belt, and the distance from the material load to the edge of the belt. If the surface of the material on the belt is assumed to approximate a circular arc, this area may be calculated as the sum of two areas, a trapezoid and a circular segment, defined by the points at which the edges of the material load contact the belt. The *CEMA Handbook* (2014) also provides convenient tables showing the cross-sectional areas for belt widths from 500 to 3,000 mm for flat belts and belts troughed at 20, 35, and 45 degrees.



Source: CEMA 2014
Figure 2 Angles of (A) surcharge and (B) repose

Other Properties

Although the angles of repose and surcharge, particle size distribution, and bulk density can be determined with relatively simple and easy-to-use equipment, the determination of other properties requires special testing equipment and standard methods developed and promulgated by such organizations as ASTM International.

The specific gravity of a material is the ratio of the density of that material to the density water at 4°C. It may also be described as ratio of the mass of a substance to the mass of water at its densest for the same given volume. Specific gravity is determined for a single particle of a pure material, without any voids, cracks, or similar defects. The bulk density is defined for powdered or granular material and is the mass per unit volume of many particles of the material divided by the total volume they occupy. The total volume includes particle volume, interparticle void volume, and internal pore volume. Bulk density is not an intrinsic material property. It can change depending on how the material is handled. For example, if a powdered material is poured into a container and then tapped or shaken, the powder particles may move and settle closer together, increasing the bulk density of the powder. This may also happen when a material is on a conveyor, as the material is shaken by the movement of the belt.

CEMA has developed a material classification system, as shown in Table 1 (ANSI/CEMA 550). This system considers particle size, flowability and angle of repose, abrasiveness, and miscellaneous characteristics, assigning a letter or number to characterize each property for a given material. Thus, if a material is granular, average flowing, abrasive, very dusty, and degradable, it would be classified as C36LQ. ANSI/CEMA 550 lists many common materials and their characteristics in their material classification system.

COMPONENTS OF BELT CONVEYOR SYSTEMS

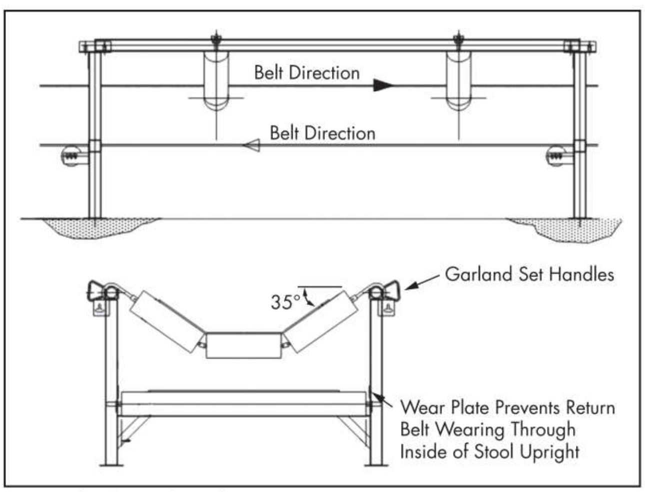
Structure

The structure of a belt conveyor supports all the components associated with the conveyor. The carrying and return run structure, often called the *belt structure*, supports the carrying and return idlers, which in turn support the belt and the material on the belt. Other structures support the head and tail

Table 1 CEMA material classification system

Material Property	Material Characteristics	Code
Size	Very fine—100 mesh and under	A
	Fine—under 3 mm	B
	Granular—under 178 mm	C
	Lumpy—containing lumps under 406 mm	D
	Irregular—stringy, interlocking, mats together	E
Flowability and angle of repose	Very free flowing—angle of repose <19 degrees	1
	Free flowing—angle of repose 20–29 degrees	2
	Average flowing—angle of repose 30–39 degrees	3
	Sluggish—angle of repose >40 degrees	4
Abrasiveness	Nonabrasive	5
	Abrasive	6
	Very abrasive	7
	Very sharp—cuts or gouges belt covers	8
Miscellaneous characteristics (more than one may apply)	Very dusty	L
	Aerates and develops fluid characteristics	M
	Contains explosive dust	N
	Sticky—adheres easily	O
	Contaminable, affecting sale or use	P
	Degradable, affecting sale or use	Q
	Gives off harmful fumes or dust	R
	Highly corrosive	S
	Mildly corrosive	T
	Hygroscopic	U
	Interlocks or mats	V
	Oils or chemicals present—may affect rubber	W
	Packs under pressure	X
	Very light and fluffy—may be windswept	Y
	Elevated temperature	Z

Source: ANSI/CEMA Standard 550 2015



Source: Khodiyar Industrial Corporation 2008
Figure 3 Floor- or ground-mounted basic structure

pulleys, the conveyor drive, and additional components for loading material to and discharging material from the belt.

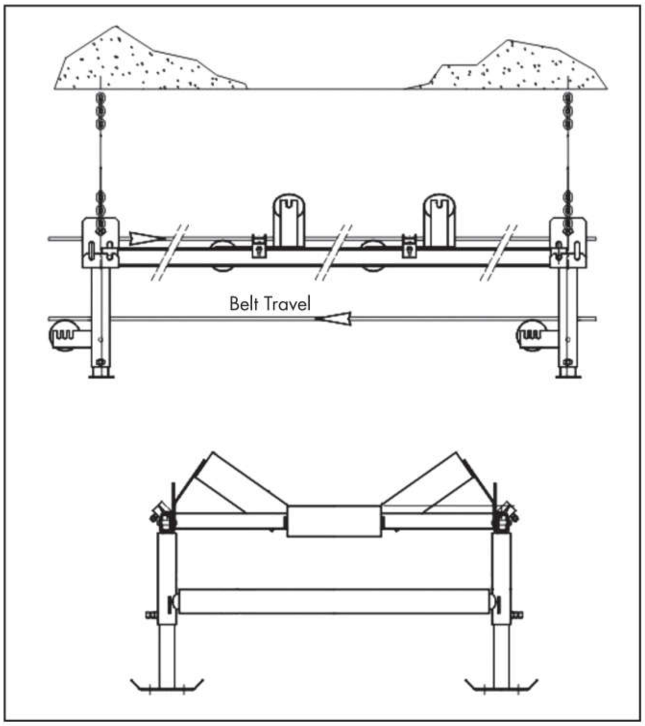
Figure 3 shows a typical layout for belt structure that sits on the floor or the ground; Figure 4 shows a structure that is supported from above. Such structures are usually made of standard structural steel shapes and must be designed to accommodate the idlers, using CEMA 502 or a comparable standard. Most such standards are based on the idler bolt-hole dimension and the clearance dimensions.

Figure 5 shows a belt structure being installed on the surface in a mine. This is a temporary installation, so the structure is installed and leveled on timbers. Figure 6 shows a structure supported from a mine roof.

The structures for the pulleys and drives are sized to support those components and the loads associated with them. ANSI/CEMA B105.1 and CEMA 501.1 provide the standards for many pulley applications.

Conveyors are installed in a wide variety of conditions and configurations, and conveyor structures vary accordingly. The belt structure often includes a walkway to allow visual inspection and maintenance of the belt. It may also include a cover above the belt, to contain dust and prevent contamination of the load, and a catch plate below the belt, to capture spillage. The structure may also be completely enclosed in a tube.

Overland conveyors may operate at some distance above grade, with the structure supported on towers. In permanent belt installations, all structural elements should be supported on foundations designed to support the dead loads and external loads applied to the system. Internal forces, including the



Source: Khodiyar Industrial Corporation 2008
Figure 4 Roof-mounted basic structure schematic

Figure 5 Ground-mounted basic structure

Courtesy of Fenner Dunlop
Figure 6 Roof-mounted structure

belt tension, may be contained within the structure or supported by the foundations, at the discretion of the designer.

Idlers

Idlers are axially mounted cylinders fitted with bearings so they can rotate freely. Belt systems use two types of idlers. Both are shown in Figures 5 and 6. Carrying idlers, on the upper side of the structure, support the belt and the material being conveyed. Return idlers, underneath the carrying idlers, support the empty belt as it returns to the loading point, or tail.

Carrying idlers typically comprise three idler rolls, configured in a shape that will form the belt into a trough. This increases conveying capacity and controls spillage. The troughing angle is the angle to the horizontal formed by the roll on either side of the idlers. Standard troughing angles are 20, 35, and 45 degrees.

Factors in the design of idlers include idler load rating, control of belt sag, and the desired life of the idlers. The idler load rating is determined by an individual idler's share of the weight of the belt and the conveyed material, the belt tension (which will be higher on vertical curves), and the interaction of the belt tension with the vertical misalignment between adjacent idlers. Idler life is determined by the load on the idlers, the idler load rating, and the rotational speed of the idler. Belt sag is determined by the tension in the belt, the idler spacing, the construction of the belt, and the size of the largest lumps of material carried on the belt. Idler design affects the power consumption of the conveyor because energy from the drive is required to overcome the total rolling resistance of all the idlers. Recent developments in idler technology include improved seals and bearings and intrinsic condition monitoring. Motorized idlers are also available, to reduce belt tension and decrease the cost of drives.

Belting

Standard conveyor belts have three components, the carcass, the top cover, and the bottom cover, as shown in Figure 7. The carcass provides the belt its substance and strength; the top and bottom covers respectively protect the carcass. All three components must work together to fulfill the desired function of the belt, providing the required mechanical properties, resistance to wear, abrasion, impact, chemical damage, and extreme temperatures.

Conveyor covers for mining and mineral processing applications are usually made of rubber and rubber-like materials or elastomers, including natural rubber, styrene-butadiene rubber, polybutadiene, acrylonitrile, and various blends. General-purpose covers are used for most heavy industry applications, including mining and mineral processing.

In the United States, elastomers used for conveyor covers are defined by the Association for Rubber Products Manufacturers as either grade I or grade II. Grade I covers are made of natural or synthetic rubber or blends and characterized by high resistance to cutting, gouging, and tearing and very good to excellent resistance to abrasion. These materials are recommended for use with sharp and abrasive materials and for severe impact loading conditions. Grade II covers are made of the same types of materials as those used in grade I.

Adapted from CEMA 2014

Figure 7 Cross section of a multi-ply fabric-reinforced belt

They have good to excellent abrasion resistance but may not have the same resistance to cutting and gouging as grade I covers. Conveyor covers may tested in accordance with ASTM D412, to indicate compliance with standard requirements for tensile strength and elongation at break, and in accordance with ISO 4649 Part 8 for compliance with standard volume loss requirements. Specifications for conveyor covers should include elastomer grade, minimum tensile strength, maximum elongation at break, adhesion between adjacent plies, adhesion between cover and ply, and cover thickness.

The belt carcass carries the load and provides reinforcement for resistance to tear and impact and for mechanical fastener retention. Belt carcasses are usually made of woven fabric, with one or more plies as needed for strength. Belts for high-tension use may have a carcass comprising a single layer of steel cable or specially woven aramid fiber.

The belt carcass for a given application is chosen to satisfy the operating requirements. High-strength synthetic fibers are most common, but multi-ply cotton carcass belts are still used in some applications. Belts tension ratings are given in kilonewtons per meter (kN/m) or pounds per inch width, and range from 13 to 220 kN/m for standard belts with rubber covers. Carcasses are available in many configurations, with various fibers and weaving patterns.

The belt design must consider the loading conditions anticipated in application. The belt loading point is often the location of the highest impact and abrasion on the belt, so loading conditions affect selection of the covers and the carcass.

The first factor in assessing the effects of loading conditions is the frequency factor, which is the amount of time required for the belt to complete one traverse of its length. The frequency factor is given by

$$F_f = 2L/V \quad \textbf{(EQ 2)}$$

where

F_f = frequency factor, min
L = belt length, m
V = belt speed, m/min

When the frequency factor is greater than or equal to 4 minutes, the minimum top cover thickness can be selected based on the loading conditions. As the frequency factor decreases to 0.2 minutes, the top cover thickness should be increased proportionally to twice that use for a frequency of 4 minutes.

Loading conditions that minimize cover wear include the following:

- The direction in which the material feed is traveling is the same as the direction of belt travel.
- The equivalent free fall of material onto the conveyor belt is 1 m or less.
- The loading area of the belt conveyor is horizontal or has a slope of not more than 8 degrees.
- Properly designed chutes and skirtboards are used to form, center, and settle the load on the belt.
- Material temperature is in the range of 0° to 65°C.
- An engineered loading system is used to place the fines on the conveyor belt first, providing a bed for large lumps.

Material transfer and loading onto belts is discussed in a later section of this chapter. When severe loading conditions are anticipated, the belt design may include one or more *breaker* layers. Breaker fabric is usually woven of nylon or polyester, using an open weave to dissipate impact energy and minimize puncturing of the carcass by sharp edges that penetrate the belt cover. Breaker layers are usually between the carcass and the belt cover.

Belt Tension

The motor drive for a conveyor belt provides the power needed to move the belt and the transported material. This power is provided as a torque applied to one or more drive pulleys, which in turn transmit force to the belt by friction. When power is transmitted to the belt, the belt is placed under tension; power is transmitted only when the belt tension entering the drive, T_1, is greater than that when the belt is leaving, T_2. This transmission of power occurs in starting, stopping, and steady-state operation of the belt. The power consumed by the belt, P, at any given time may be calculated as the product of the effective tension, T_e, and the linear velocity of the belt, thus

$$P = T_e \cdot V \quad \textbf{(EQ 3)}$$

where

$T_e = T_1 - T_2$
V = belt velocity

Correct design of the belt drive must account for all operating conditions. In steady-state operation, power is required only to overcome the friction in the system and to raise the loaded material on an inclined belt. The design must also account for the power required for acceleration on start-up, which will include acceleration of the belt and the load, the drive pulley, all the idler pulleys, and the components of the drive itself—motor, gear drive, and so forth. In steeply declined belts, the drive motor may act as a generator, opposing the acceleration of the material load as it descends, or the energy from the accelerating material may be dissipated into a braking system. The design must also account for the energy required to stop the belt, using brakes. It must also prevent unwanted motion when an inclined or declined belt that is loaded stops unexpectedly using backstops.

Designing the drive for a belt begins with a calculation of the power required to overcome the friction in the system. Power is calculated by estimating the effective tension required in the belt, which requires calculating or estimating the following parameters:

- Tension to overcome frictional resistance of the idlers
- Tension to overcome sliding resistance between the belt and idler rolls
- Tension to overcome resistance of the belt and load to flexure as the loaded belt passes over the idlers
- Tension to overcome frictional resistance of nondriven pulleys, including the tail pulley and snubbing pulleys
- Tension to overcome frictional resistance of accessories such as skirtboards, scrapers, slider beds, and plows
- Effect of low temperature on the system

Power to lift the conveyed material up an incline or power generated by travel of the conveyed material down a decline is added to the power required to overcome friction to provide an estimate of the running power required for the motor. The power required to accelerate the entire system, including the belt, idlers, pulleys, motor, gear drive, and coupling, along with the power required to continuously accelerate the material being loaded, are added to the running power to provide an estimate for the total power required.

A formal method using this approach, now referred to as the *CEMA historical method*, was described in detail in the *CEMA Handbook* for each of its first five editions and is still available from CEMA as a separate publication. The CEMA historical method requires the use of two tables to estimate friction factors, and two-way interpolation in the tables is often necessary. Furthermore, the method requires determination of the rolling resistances of idlers and pulleys, either from vendor literature or standard tables published by CEMA. The calculation is not difficult, but it can be long and tedious, and there are many opportunities for errors. For these reasons, several computer programs exist to make calculation using this method simpler and more reliable. The historical method is still used by some individuals and firms.

The sixth edition of the *CEMA Handbook* (2014) recognized that the historical method did not include five factors that add to the required belt tension—viscoelastic belt deformation, idler misalignment, material liftoff and tramping, and belt bending on the pulleys. The sixth edition recognized three types of conveyor belts, and suggested a method of calculating the power required for each type.

The *basic* conveyor has the following characteristics:

- Single flight of less than 250 m long
- Single, free-flowing load point
- Inclined or horizontal but without curves
- Fabric carcass belt
- Flat or equal-roll troughing idlers
- Single drive
- Unidirectional or reversing up to 150 m/min
- A single gravity or fixed take-up
- Maximum belt tension of 53 kN

Effective tension required in a basic conveyor may be estimated by the following equation:

$$T_e \leq W_m H + 1.72(2W_b + W_m)L \quad \textbf{(EQ 4)}$$

where

T_e = effective belt tension, kgf
W_m = weight of the material conveyed per unit length of the conveying distance, kg/m
H = height of the incline or decline of the belt, if any, m
W_b = weight of the belt, kg/m
L = conveying distance or length of the conveyor, m

The *standard* conveyor has the following characteristics:

- Single flight of less than 900 m long
- Single or multiple free-flowing load points
- Inclined, declined, or horizontal with or without vertical curves
- Fabric carcass belt
- Flat or equal-roll troughing idlers
- Unidirectional or reversing at any speed
- Single or multiple drives
- Gravity or automatic take-up
- Maximum belt tension of 7,250 kgf

Effective tension required in a standard conveyor may be estimated by the following equation:

$$T_e = LK_t(K_x + K_y\, W_b + 0.015W_b) + W_m(L\, K_y + H) + T_p + T_{am} + T_{ac} \quad \textbf{(EQ 5)}$$

where

L, H, W_b, and W_m are defined as in Equation 4
K_x = idler resistance factor
K_y = belt resistance factor
K_t = temperature correction factor
T_p = tension from belt flexure around pulleys and pulley bearing resistance
T_{am} = tension from the force to accelerate the material as it is fed onto the belt
T_{ac} = tension from accessories

Equation 5 is a formal explication of the CEMA historical method and requires access to the tables for k_x, k_y, and k_t.

The universal conveyor has the following characteristics:

- Any length
- Single or multiple, free-flowing load points
- Inclined, declined, or horizontal flights with horizontal or vertical curves
- Fabric carcass or steel cord belt
- Any belt profile
- Unidirectional or reversing
- Single or multiple drives
- Gravity or automatic take-ups

To calculate effective tension, the belt must be analyzed in sections or flights, starting a new flight at each point where an incline or decline begins or where a drive pulley is located. The following equation shows the calculation for a given flight, n:

$$\Delta T_n = \Delta\Sigma T_{\text{Energy } n} + \Delta\Sigma T_{\text{Main } n} + \Delta\Sigma T_{\text{Point } n} \quad \textbf{(EQ 6)}$$

where

ΔT_n = total change in belt tension to cause steady belt speed
$\Delta\Sigma T_{\text{Energy } n} = \Delta T_{\text{H}n} + \Delta T_{amn}$
$\Delta\Sigma T_{\text{Main } n} = \Delta T_{ssn} + \Delta T_{isn} + \Delta T_{iWn} + \Delta T_{bin} + \Delta T_{mn} + \Delta T_{sbn} + \Delta T_{sn} + \Delta T_{mzn}$
$\Delta\Sigma T_{\text{Point } n} = \Delta T_{pxn} + \Delta T_{prn} + \Delta T_{bcn}$
ΔT_{Hn} = change in tension to lift or lower the material and belt

ΔT_{amn} = change in tension to continuously accelerate loaded material to belt speed
ΔT_{ssn} = change in tension from the belt sliding on skirtboard seal
ΔT_{isn} = change in tension from idler seal friction
ΔT_{iwn} = change in tension from idler load friction
ΔT_{bin} = change in tension from viscoelastic belt deformation
ΔT_{mn} = change in tension from idler misalignment
ΔT_{sbn} = change in tension from drag in slider beds
ΔT_{sn} = change in tension from sliding of material on skirtboards
ΔT_{mzn} = change in tension material from moving between idlers
ΔT_{pxn} = change in tension from belt bending on the pulley
ΔT_{prn} = change in tension from pulley bearings
ΔT_{bcn} = change in tension from belt cleaners and plows
ΔT_{dpn} = change in tension from discharge plow

The tension along the belt must be continuous, meaning that the tension at the beginning of one flight must equal that of the end of the previous flight. The calculation may require several iterations to achieve continuity. Manual calculation of total tension using this method is possible, but also tedious and time-consuming. It is preferable to do the calculation by computer, and many suppliers of conveyor systems, consultants, and engineering firms have programs designed to do so.

The analysis of belt tension must also include an estimate of the tension required to prevent sag of the belt at any point beyond an acceptable limit. On a fully loaded conveyor, the acceptable sag when running is between 1.5% and 3% of the span between idlers, depending on the troughing angle and the percentage of the load made up of large lumps. Sag on the return side should also be considered. On a level or inclined belt, the minimum tension decreases continually from the head pulley to the tail pulley. If the tension on the belt as it exits the head pulley, T_2, is too low, the belt may sag too much as it approaches the tail pulley.

Belt Specifications

Properties to be considered in specifying belts for a given application include the belt's working strength, number of plies, carcass gauge and weight, carcass fabric type, troughability, and maximum width for empty troughing as a function of the troughing angle and material weight per unit length.

The working strength is often the first factor considered. It is measured in kilonewtons per meter or pounds per inch width. The working strength should be equal to or greater than the maximum tension in the belt divided by the belt width. It is not to be confused with the ultimate tensile strength, which should be greater than the maximum tension experienced by the belt during the most severe operating or start-up conditions.

Conveyor Drives

The drive system includes the motor, the starting mechanism, and the coupling system. In all systems, the motor must be coupled to the drive pulley. The coupling system connects the motor to the drive pulley and must provide the required rotational speed to the drive pulley. It may also provide some isolation between the motor and the moving conveyor to allow controlled acceleration and prevent motor damage under exceptional conditions. Many drive systems also include brakes and backstops. There are many possible combinations of the components in a conveyor drive system. The most common are described here.

Conveyor Motors

Almost all conveyors are driven by electric motors. Criteria for the selection of conveyor drive motors include the following:

- **Required power.** This is based on calculations of belt tension and required acceleration.
- **Operating speed.** An optimum match is provided from the motor to the belt, through the drive system and speed reducer.
- **Voltage.** The plant electrical system must be compatible.
- **Service factor.** The capacity of the motor to operate beyond its rated insulation and winding temperatures for a short period is indicated by the service factor. A service factor of 1.15 is often selected, indicating that the motor can withstand a 15% thermal overload. Higher service factors require coordination with the motor supplier.
- **Torque-speed characteristic.** How the torque is delivered by a motor varies with its rotational speed. Selection under this criterion is primarily made based on the conditions expected when the belt starts. In the United States, motors are rated by the National Electrical Manufacturers Association (NEMA). NEMA designs A–D describe the torque–speed relationships for four types of motors up to 150 kW in size. Designs B and C are most commonly used for conveyors.
- **Operating conditions.** Conditions include operating temperature range; the presence of moisture, washdown water, or precipitation; and the presence of dust or other contaminants.

Coupling Systems

Direct-coupled drive systems include an alternating current (AC) induction motor with a direct coupling and a speed reducer. They are most often used on small belts with moderate speeds and profiles (inclines and declines). Induction motors are widely available and inexpensive, but offer no control over starting torque. These systems require little maintenance, and are capable of absorbing the energy from a descending load, dumping the generated current to other motors in the system. Because the motor experiences high currents during starting and acceleration, the number of starts before failure decreases with increasing motor size.

Direct-coupled drives with reduced-voltage starting systems are the most commonly used for belt conveyors. Control of the terminal voltage to an AC induction motor is used during starting to control the resultant torque. There are many ways to control this voltage, including an autotransformer, a capacitor, or a silicon-controlled rectifier (SCR). The SCR is the most common and most reliable. This system can control starting speed but cannot control speed during operation.

Direct-coupled, variable-frequency control drives provide improved control and increased energy efficiency. Variable-frequency drives (VFDs) control motor speed by electronically modifying the frequency of the voltage applied to the motor. A VFD can start a motor slowly and vary motor speed to optimize energy consumption. VFDs are now relatively small and can be installed in most drive systems, reducing costs and maintenance requirements. VFDs do require additional training for maintenance personnel and the stocking of additional spare parts, but they are now so commonly used that these requirements do not usually result in additional costs. Not all VFDs can function regeneratively. If a belt profile will result in the need for regenerative capacity, the VFD specification must include that capability.

Fluid couplings may be used to provide a gradual transfer of torque from the motor to the belt system. There are two types of fluid couplings—fixed fill and variable fill. Fluid couplings are installed between the motor and the speed reducer and allow the motor to be started at full voltage without putting full torque on the belt system instantaneously, providing soft acceleration. The behavior of a fixed-fill fluid coupling, unlike that of a VFD, cannot be varied. The torque–speed curve of a variable-fill fluid coupling can be varied by changing the fill level in the coupling. Fluid couplings are not normally a good choice for downhill, regenerative conveyors. Fixed-fill fluid couplings are simple and easy to maintain, while variable-fill couplings are much more complex and require careful maintenance. The oil in the fluid coupling gets hot during start-up and operation, and this may limit the number of starts in a given time period.

Speed-reducer mechanisms include V-belts and sheaves, roller chains and sprockets, and many varieties of gear-speed reducers or gear motors. Speed reducers are selected based on cost, power requirements, available space, and user preference. Reducers that use V-belts or roller chains are simple and easy to maintain but usually require more frequent maintenance. All speed reducers use energy, as expressed by their efficiencies. For example, a reducer with V-belts and sheaves has an approximate efficiency of 94%, while that of double-reduction helical gear, shaft-mounted reducer is 97%, and that of a high-ratio worm-gear reducer is 50%.

Installation of belt drive systems requires proper support and alignment of all components—motor, couplings, speed reducer, and drive pulley. An alignment-free drive, containing the couplings and gear-type speed reducer, can reduce installation expenses.

Where local conditions may result in the formation of ice on the conveyor belt, the installation of a creeper drive is advised. The creeper drive uses a small auxiliary motor and associated drive that can be mechanically switched to drive the empty belt at a slow speed.

Brakes and Backstops

Brakes are used to stop or slow down a moving belt. They are required on sloped belts or belts that develop high momentum. After being stopped, almost all inclined or declined belts require the positive holding force of a backstop to keep them from further movement.

Mechanical brakes used on belt conveyors are usually operated electrically. The braking surfaces are engaged by spring action, and disengage by either hydraulic pressure or magnetic action. Such brakes are interlocked with the conveyor motor so that if the motor is shut off after the brake is set, the actuating coil on the brake is also de-energized. Brakes that operate in this way are considered fail-safe. Brakes can be installed on either the high- or low-speed end of the drive train. Low-speed brakes are typically used for downhill conveyors where increased safety and large thermal capacity is required. Eddy-current brakes employ a metallic disk or drum that rotates in a magnetic field. As the drum or disk rotates, eddy currents are generated on its surface and the interactions of these currents with the poles of the magnetic field induce a braking force on the drum. The torque generated by the brake is directly proportional to the field current delivered to the magnet and can be adjusted by a control system. However, eddy-current brakes have no holding action when there is a power failure, so an auxiliary mechanical brake should also be provided.

Braking action can also be provided by the drive motor, in three ways. First, the motor may be *plugged* by reversing the motor current to generate a counter torque on the drive pulley, with the resulting energy being dissipated as heat. When the belt speed reaches zero, the motor must be stopped, or the motor will begin to accelerate the belt in the opposite direction. At zero speed, there is no holding effect. When plugging a motor, energy losses are high, and there is a risk of a belt fire from the heat generated by the reverse motion of the drive pulley against the belt.

In dynamic braking, the motor functions as a generator, with the kinetic energy of the moving belt and load providing the driving force. Use of dynamic braking requires the installation of additional controls, so that when the conveyor is stopped, the AC connection to the motor is disconnected and a direct-current excitation current is connected to the motor primary. Braking force at first increases rapidly as the motor slows down, but then decreases and disappears as the motor comes to a stop. At this point, there is no holding effect.

Finally, when a squirrel-cage motor is used, regenerative braking may be employed. When such a motor is operated above its synchronous speed, power generated by the motor will flow back into the power system. The system must be capable of absorbing this power. Regenerative braking is useful for declined conveyors that drive the motor at its synchronous speed.

Backstops are designed to hold an inclined or declined belt in place when the motor stops, while continuing to allow travel in forward direction. When the force required to lift a load vertically on an incline is greater than the sum of the forces required to move the belt horizontally, a backstop is required. On a long belt, with several inclined or declined sections, each possible condition under which the belt may stop must be considered. For example, if a belt has a short incline followed by a longer decline, it might be thought that a backstop is required only on the declined portion. However, if the belt is stopped after the inclined portion is loaded but before the load progresses to the decline, a backstop may be required on the inclined portion.

High-speed backstops are designed to act quickly. They are mounted on one of the shafts of the gearbox or speed reducer and provide relatively low torque. A high-speed backstop is less expensive than its low-speed counterpart, but because it does not act directly on the drive pulley, a failure in the gearbox or speed reducer will nullify its effect on the motion of the belt. Low-speed backstops are fitted directly to the shaft of the drive pulley shaft. There are several types of backstops, all of which are mechanical so that the absence of electrical power will not affect their proper operation.

Brakes and backstops are usually used in combination. Table 2, adapted from the *CEMA Handbook*, summarizes recommended applications of brake and backstop combinations.

Table 2 Brake and backstop combinations

Type of Conveyor	Backstop	Brake	Forces To Be Controlled
Horizontal	Not required	Required when coasting of the belt and load is not allowable or must be controlled	Decelerating force minus resisting friction forces
Inclined	Required if required lift power is ≥ power to overcome system friction	Not usually required unless preferred over a backstop	In-line load tension minus restricting friction forces
Declined	Not required	Required in every case	Decelerating forces plus incline load tension minus resisting friction

Adapted from CEMA 2014

Pulleys

Pulleys are cylinders that rotate around an axis. In conveyor systems, they provide power input to the belt, change the direction of the belt travel, or modify the tension in the belt as it travels. The carrying and return idlers previously discussed are pulleys, but were considered separately because of their particular function.

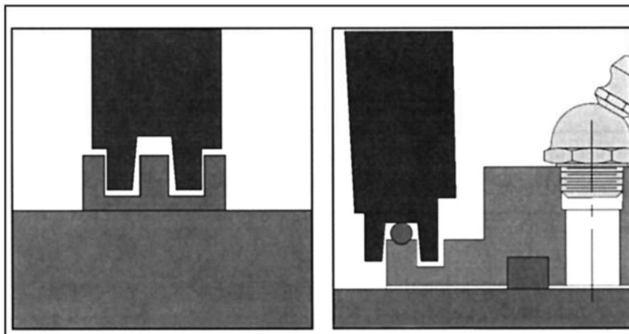
Most conveyor pulleys are made of steel, with a continuous, cylindrical surface and two end disks fitted with compression-type hubs. The pulley drum rotates around the shaft, supported by bearings of various designs. The bearings may be protected by the installation of special seals to prevent exposure to conveyed materials, water, and other contaminants. Pulleys used at the tail ends of conveyors are sometimes of the self-cleaning wing type, with open vanes instead of a drum-type surface. These vanes minimize the buildup of material on the pulley face. In the United States, ANSI/CEMA B105.1 and CEMA 501.1 apply to standard drum and wing pulleys, respectively.

Standard-sized pulleys are also available in mine-duty construction and engineering construction. Mine-duty pulleys are designed for heavy use in applications where severe conditions and high installation costs justify a more conservative and costly design. They are often used where conveyors start and stop frequently or where overloads exceed 1.5 times the running tension. The material thicknesses are greater, bearings may be rated for longer wear, and special seals may be included. There are no CEMA standards for mine-duty pulleys; rather, they are designed as specified by the user. Engineered pulleys are custom designed for a particular conveyor and are often used in overland conveyors, high-tonnage mining conveyors, coal power plants, concentrators, and high-capital construction projects.

Conveyor pulleys are often covered with a lagging of rubber, ceramic, urethane, or other material. On drive pulleys, lagging increases the coefficient of friction between the belt and the pulley for more efficient transfer of energy from the drive to the belt. Lagging can also reduce wear and decrease material buildup on the pulley surface. In some cases, lagging material may be selected for specific environmental conditions, for example, to withstand corrosion.

Many types of bearings and seals are available, and their design and selection is best left to experienced individuals. In mines and mills, labyrinth and taconite-duty seals are often used to protect the bearings from dust and water. Diagrams of labyrinth and taconite-duty seals are shown in Figure 8.

As the name implies, labyrinth seals include a complex maze that is usually filled with grease, which blocks passage of contaminants to the bearing or lubricant out of the bearing. Taconite-duty seals were designed for the conditions encountered in the mining and processing of iron ore. They include three separate elements—an inner seal to keep the lubricant in the bearing, an outer seal to keep contaminants out of the bearing, and a chamber between the two seals that can be filled with grease to trap any contaminants that penetrate the outer seal.



Source: CEMA 2014
Figure 8 Special shaft seals

Material Transfer

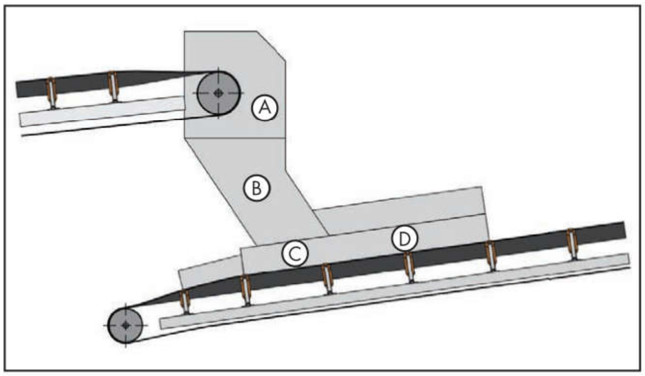
In all belt systems, material must be loaded onto and discharged from the belt. In many systems, material must also be transferred from one belt to another. All of these functions are accomplished with transfer systems, at locations called *transfer points*.

All transfer points should be designed with consideration of the following goals:

- Maximize material throughput.
- Contain material adequately.
- Minimize impact, wear, spillage, dusting, and material degradation.
- Match material flow direction and speed across the transfer point.
- Collect and return to flow the belt scrapings.
- Accommodate all anticipated operating conditions.

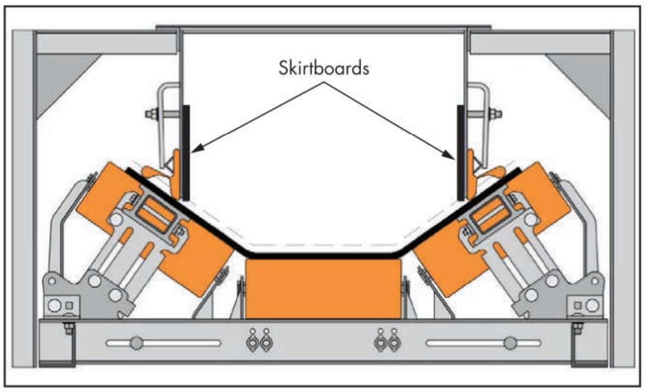
Transfers are usually made through a chute system, designed to accommodate the material flow and direct it properly, while avoiding plugging and minimizing impact on the receiving belt. Figure 9 shows a standard or conventional transfer chute. The parts of the chute as shown in the figure have the following functions:

- The head chute (A) encloses the head pulley of the feeding conveyor, to ensure that all the discharged material enters the transfer, and to limit release of dust.
- The drop chute (B) transfers the material in free fall.



Source: Swinderman et al. 2009

Figure 9 Conventional transfer chute



Source: Swinderman et al. 2009

Figure 10 Skirtboards on a conveyor belt

- The loading chute (C) is where the material enters the receiving belt.
- The loading zone (D) is an extension of the loading chute, which may be installed to contain dust as it settles after dropping onto the receiving belt.

The conventional transfer chute design is often modified to achieve the preceding goals. For example, the loading zone may include skirtboards, as shown in Figure 10, and the skirtboards may extend beyond the loading zone portion of the transfer chute. Skirtboards help to center the loaded material on the belt and limit spillage as the material moves away from the transfer point. In transfer points where there is an excessive drop, the loading chute may be modified to decrease the energy of the falling material. At other times, the loading chute may discharge to a curved spoon, which directs the falling material in the direction of the receiving belt; and in other cases, an intermediate belt may be used to accelerate the material as it enters the receiving belt.

It is important to provide extra support for the receiving belt at a transfer point. Rubber-cushioned impact idlers can be installed closely together, but there are drawbacks to their use. First, each idler supports the belt only at the top of each roller, so the belt will deflect under the load and may oscillate or sway. Second, impact idlers are subject to impact damage, especially from unusually large lumps. Third, idlers that are installed closely together are more difficult to service or replace.

Courtesy of Martin Engineering

Figure 11 Belt-support cradle

Belt-support cradles, also called *impact cradles* or *slider beds*, provide an improved method of belt support at transfer points. Belt-support cradles use low-friction, impact-absorbing bars supported by a steel framework. As shown in Figure 11, the bars are parallel to the direction of belt travel. Because an impact cradle supports the belt continuously, the skirtboards or other devices that contain dust discharge downstream from the transfer point will seal much more effectively. CEMA 575-2013 gives a rating system for impact cradles. It is important the impact cradle is aligned correctly on installation and that the alignment is regularly checked and adjusted.

Open discharge from a conveyor into a bin or onto a stockpile must take into account the discharge trajectory of the flowing material. This trajectory may be calculated using the linear velocity of the material at discharge, the point at which the material leaves the belt, and the effect of gravity on the falling material. The calculation is simple in concept, but the parameters vary considerably with the rotational speed of the pulley, the inclination of the belt, and the material characteristics. The *CEMA Handbook* (2014) gives detailed procedures for calculating the discharge trajectory under various conditions.

Design of transfer points requires careful consideration of all the pertinent data, including material characteristics (which may require laboratory testing of samples), all data for both belts, layout and installation details, method of impact reduction, chute lining materials, and customer preferences. Special care is required when retrofitting equipment at transfer points. Applicable regulations pertaining to noise, dust emission, and spillage must also be considered. The design of the transfer system is often greatly improved by the use of discrete element simulation, as described in the "Developing Technology" section. Most suppliers now offer such simulations in the design of conveyor systems.

Take-Ups

A take-up in a conveyor system is a device that provides the minimum tension on the return side of the belt to prevent slipping of the belt on the drive pulley, compensates for changes in belt length resulting from stretch, and provides extra belt for splicing. All conveyor belts experience stretch, which may be permanent or temporary. Temporary stretch may occur when belt tension changes quickly, as the result of starting, braking, or sudden temperature change. Permanent stretch occurs when the components of the belt elongate or otherwise deform.

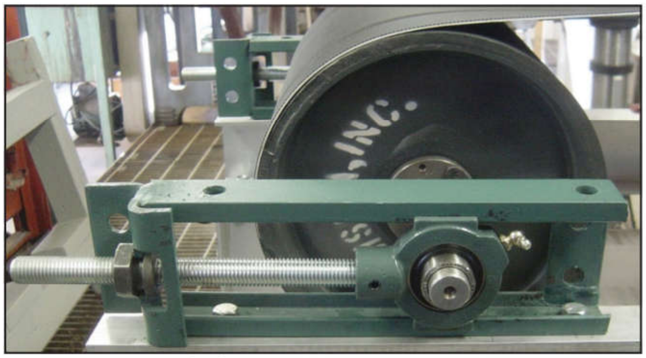


Figure 12 Manual take-up

Where space is constrained, or on short, light-duty conveyors, manual take-ups are used. A manual take-up often consists of two simple, screw-adjusted mechanisms, one on each side of the tail pulley. Use of a manual take-up requires frequent observation of the belt tension and sag to determine when adjustment is needed, and careful adjustment to ensure that the belt tracks properly. When a manual take-up is used, proper guarding must be installed, and adjustments to the take-up must not be made while the belt is running. Figure 12 shows a manual take-up on the tail pulley of a belt designed for laboratory use.

Passive automatic take-ups are actuated by gravity, while active take-ups may be driven electrically, hydraulically, or pneumatically. Some take-ups include spring compression take-ups to accommodate transient loading that occurs during start-up or braking.

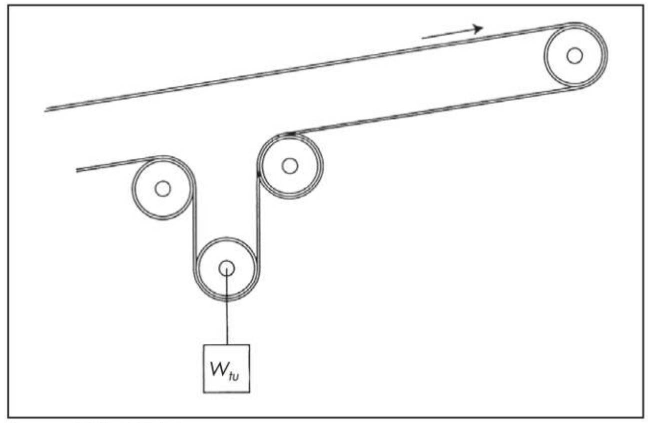
Figure 13 shows a vertical gravity take-up. The tension added to the belt by this take-up is equal to half the take-up weight, $W_{tu}/2$. As shown, such a take-up requires three guide pulleys. In some gravity take-ups, the take-up weight may be varied, to account for changing conditions. Because a gravity take-up uses a large, suspended counterweight suspended on a cable, precautions must be taken to allow for failure of the cable or the belt. To prevent damage to the counterweight in a cable failure, an energy-absorbing weight arrestor may be installed.

Design and installation of active, powered take-ups is usually done by specialists. Powered take-ups use stored energy, and often incorporate wire rope, which may be under considerable tension. To ensure proper operation and safety, powered take-ups should be well maintained and have proper guarding installed.

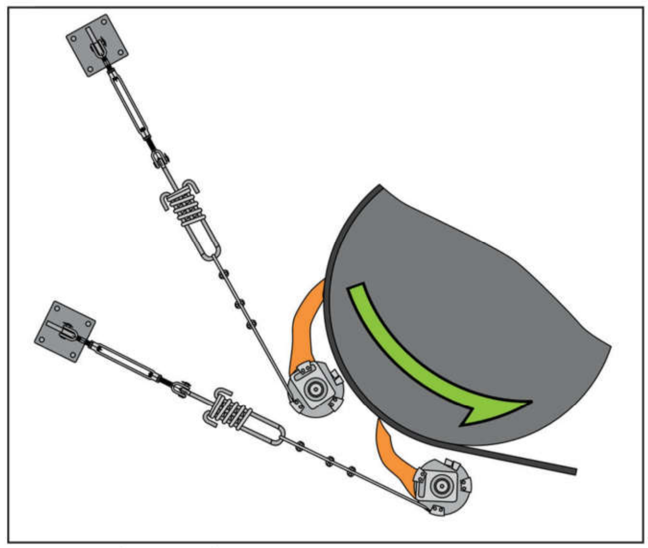
Belt Cleaners

Some of the material carried on a conveyor belt may adhere to the belt after the discharge point. This material, called *carryback*, is usually fine and may be wet or sticky. As the belt travels to its tail end, the carryback is on the underside of the belt, and thus in contact with the return idlers. Carryback results in excessive belt wear, buildup on return idlers, and loss of overall efficiency in the system. It may also lead to misalignment of the belt.

Carryback is removed by belt cleaners. Selection of belt cleaners is usually made by estimating how much material must be removed from the return run of the belt to avoid excessive wear. CEMA 576, *Classification of Application for Bulk Material Conveyor Belt Cleaning*, provides a systematic method for making this estimate, by considering the belt



Source: CEMA 2014
Figure 13 Vertical gravity take-up



Source: Swinderman et al. 2009
Figure 14 Installation of two primary scrapers

width, belt speed, type of splices used, abrasiveness of the material, moisture content or stickiness of the material, and the location of the scrapers.

On standard, smooth-surfaced conveyor belts, scrapers or blades are usually used for cleaning. Typically two scrapers are installed near the discharge end of the belt. Installation in this location usually makes it possible to capture the material removed by the scraper into the main discharge from the belt.

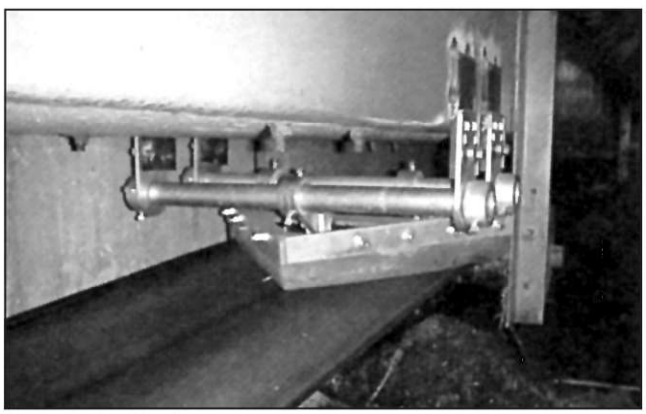
The first scraper should remove most of the carryback material. It is usually made of rubber or urethane and inclined into the direction of belt travel (a positive rake angle) with moderate tension. The second scraper removes finer, stickier material. It may be made of metal or elastomer and have a positive or zero rake angle. Figure 14 shows how two scrapers would be installed on a belt.

Scrapers are fitted with springs and an adjustment mechanism, so that the tension against the belt can be adjusted. Scrapers and plows must be maintained, adjusted, installed, and removed when the conveyor is not in operation and the system is correctly isolated.

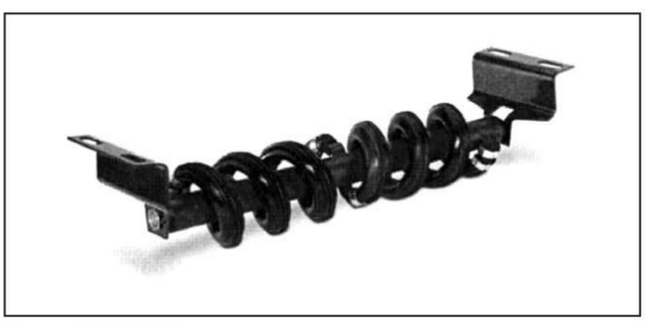
Scrapers may also be used on the return run, to remove material that falls onto the belt from the carrying side. These scrapers are typically a single blade, angled to the width of the belt, or a V-plow, as shown in Figure 15. They are almost always installed at a zero rake angle—perpendicular to the belt surface. Notice the accumulation of material under the cleaner in Figure 15. If a return run cleaner is removing a large amount of material from the belt, the handling of the material may pose a problem. The conveyor should be analyzed to reduce the amount of material that is falling onto the return run.

In some cases, rotary cleaners may be preferred to scrapers. Rotary cleaners can be driven by the motion of the belt or by an electric motor. Spiral cleaners, as shown in Figure 16, provide several continually changing points of contact with the belt surface, resulting in a scrubbing action. They are not affected by mechanical splices and do not affect belt tracking. Brush and finger cleaners are often used on belts that have cleats or some other surface pattern. A motor-driven brush cleaner is shown in Figure 17. A finger cleaner is similar but has flexible fingers—usually made of elastomer—on its surface. Brush and finger cleaners are often used in combination with water sprays

In the selection and installation of belt cleaners, each discharge point should be designed to accept at least one cleaning device. The cleaner should be as close as possible to the discharge point, and the discharge chute should be designed to receive the carryback removed by the cleaner. The discharge area should be designed to allow good access to the chute and the cleaners. If the cleaner is not near the discharge point, special chutes may be needed to direct the cleaner discharge to a point where it can be easily collected and removed.



Source: CEMA 2014
Figure 15 V-plow on a conveyor return run



Source: CEMA 2014
Figure 16 Rotary spiral cleaner

Source: Swinderman et al. 2009
Figure 17 Rotary brush cleaner

It is particularly important that installation, maintenance, and adjustment of all belt cleaning devices be done only after the belt is correctly isolated and locked out.

Instruments and Controls

Instruments and controls for conveyor belt systems vary widely in complexity. The simplest systems have controls for routine starting and stopping and for emergency stopping of a single belt. The most complex provide automatic control of a system of several belts, bins, and stockpiles, with starting, stopping, and individual belt speeds controlled automatically, and detection of many operating parameters.

Starting and Stopping

Belts may be started locally or remotely. In simple systems, individual belts are started with locally mounted start and stop switches or push buttons. When two or more belts that operate in sequence are manually controlled, care must be taken to start and stop the belts in the correct order. The last belt in the sequence should be started first, and the first belt in the sequence should be stopped first, with an adequate amount of time allowed between the stopping and starting of succeeding belts. This will prevent overloading of belts on stopping and starting. Many locally controlled belts are also equipped with a *jog* control that allows an individual belt to be briefly energized and then stop. This function may be useful in clearing overloaded belts, in testing the operation of a recently maintained belt, or other situations.

Safe operation requires that every belt have an emergency stop mechanism that can be actuated from anywhere along the length of the belt where personnel may be present. If a belt is accessible from both sides, an emergency stop must be present on both sides. The most common type of emergency stop comprises lengths of cord or cable installed along the edges of the belt, with each end of each cable attached to a switch that cuts the power to the belt drive. When any one of the lengths of cable is pulled, the belt stops. Figure 18 shows such an emergency stop.

Source: Swinderman et al. 2009

Figure 18 Emergency stop, pull-cord type

In complex systems with several conveyor belts, stopping and starting should be automated so the system can be started and stopped with one action, such as an electrical switch or a command through a computer-based control system. The single command will initiate a start or stop sequence, with appropriate timing throughout. The controls for a complex system may be located in a central control room or at an appropriate location in the mine or plant. Although these systems can be started and stopped by the control system, individual belts should still have manual, local start/stop/jog controls to allow troubleshooting of belt functions and clearing of material for maintenance and cleaning.

In systems that handle large amounts of material or operate under other extreme conditions, belt starting and stopping should be controlled so that starts and stops are gradual. This can save energy and avoid overstressing of large or heavily loaded belts. Such starting and stopping may be controlled by gradually actuating motors or brakes in a fixed manner or using more complex systems that apply starting or stopping force based on measurement of system operating parameters, such as current draw in motors, torque on drive pulleys, or belt speeds.

Instrumentation

Instruments are installed in conveyor systems to measure system parameters, for use in control of the system, and for monitoring the conditions of system components. A single instrument often serves more than one of these functions. In the control system, the output from an instrument may be used to control the speed of the belt or the operation of another system component or simply to shut down the system or a system component if an adverse condition is detected.

Individual instruments are regularly used to monitor the following parameters in conveyor belt systems: belt alignment, belt overload, belt slip, take-up overtravel, bin level, chute blockage, belt wear and damage, and splice condition. Instruments also function in important subsystems. Dust suppression systems usually include ambient or atmospheric dust sensors, and fire suppression systems include sensors that measure belt temperature, smoke, combustion gases, and other early indicators of combustion.

Several vendors also provide integrated systems for monitoring the condition of the belt. Such systems are justified when a given belt is very long, difficult to inspect visually, or key to the continuing operation of the plant. Typical belt condition monitoring systems include instruments to monitor belt misalignment, wear, belt tearing or rip, belt speed, and splice condition. They may incorporate high-speed photo or video cameras, with image analysis and pattern detection (Kellis 2000; Nave 2000; Zhu et al. 2011).

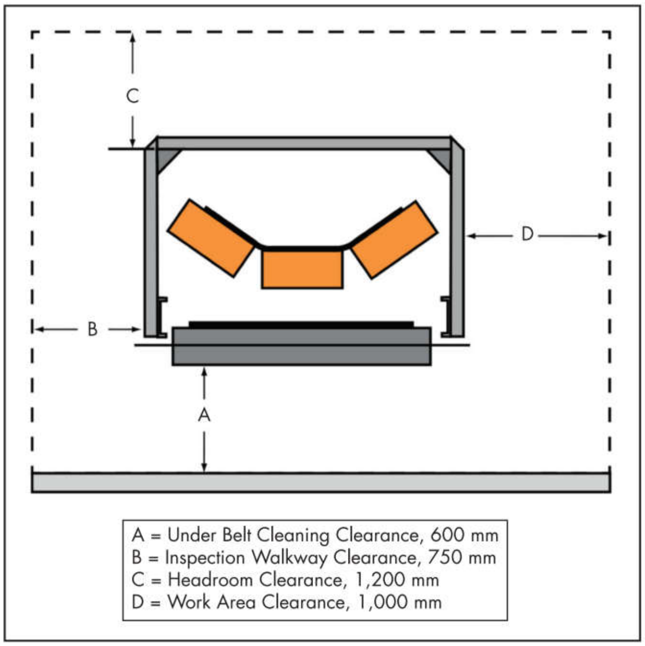
Conveyor drives should have instruments and controls typical of large electromechanical systems. This will include monitoring of the electrical power, including current, voltage, and power factor for all systems, and phase imbalance for three-phase systems. Temperature and vibration should be monitored in drives, couplings, and speed reducers.

INSTALLATION

Each conveyor belt is a complex system, with many parts that must work together. Installation must be done carefully by experienced individuals. The *CEMA Handbook* provides detailed installation specifications, based on the following guidelines:

- Conveyor support structures must be parallel, straight, square, and level. If support structures are properly installed, correct alignment of the idlers will follow.
- Pulleys and shafts must be level and square. Alignment should be measured on the shaft, not the pulley.
- Motor and reducer bases can be concrete or steel. Concrete foundations are usually more rigid and secure. Both types of base must be near level and, if not flat, must allow for shimming to level the motor and reducer.
- Motors, speed reducers, and flexible couplings must be installed with proper alignment—angular, parallel, and axial. These alignments should be verified with dial indicators, machine test levels, or other standard means. When shimming of components is required, oily commercial shim stock should be used.
- Idlers must be square, in-line to the conveyor centerline, and parallel to one another. Alignment must be maintained with reference to a squared and leveled terminal pulley. Use of a laser alignment system is recommended, but a tight wire on the conveyor centerline can also be employed, referenced to the squared starting pulley. Typically, a 30-m tight wire is used. After idlers have been installed over a span of about 15 m, the tight wire should be advanced, with a 15-m overlap on the previous position.

Foundations (Swinderman et al. 2009) offers useful guidelines on installing conveyors with proper accessibility. For ease of operation and maintenance, belts and accessories should be easy to see, easy to reach, and easy to replace. Walkways and work spaces around the belt should conform to the minimum distances shown in Figure 19. For belt repair and replacement, an area for the use of vulcanizing equipment on the exposed belt is required. This should be at least 1,000 mm plus the belt width on each side of the conveyor and a distance of at least 3 m along the belt.



Source: Swinderman et al. 2009

Figure 19 Recommended clearances around a belt conveyor

START-UP

After the support structure, drive and other pulleys, motor and drive system, and idlers are installed, the drive system should be tested for proper rotation. Often the drive motor is bumped—started and then stopped—before it is run for a longer time. During the test of the drive system, experienced individuals should observe the motor and drive system and check the monitoring instruments that are in place, to ensure that no component is vibrating excessively or heating up.

After the belt is installed, it must be aligned or trained. This process is also called *run-in*. Training the belt involves adjusting the idlers and the drive to ensure that the belt does not run to one side or the other. Belt training may require more than one shift and should be done by one individual or crew to ensure that adjustments are made consistently.

The belt is first run empty. It is moved ahead slowly, with careful observation of alignment and other operating parameters. When one or more sections of the belt runs off all along the conveyor, a problem with the belt itself or with a splice is indicated. When the entire belt runs off along a given section of the conveyor, the belt can be centered by moving ahead one side of each of the carrying idlers in that section, and for some distance preceding the region of trouble. The side of the idlers to which the belt runs is moved slightly ahead, but never by more than 6 mm. Belt training usually begins at the head end of the belt and proceeds to the tail pulley, so that the belt can be properly centered on the tail pulley.

If the empty run-in is unsuccessful, the belt may be cambered, or there may be a non-square splice in the belt. Camber occurs when unbalanced warp tensions exist in a conveyor belt, causing the belt to assume a crescent or banana shape when laid flat on a horizontal surface. Slight camber can be instilled into a belt in manufacture, if one of the slitting knives is dull. Camber can also be instilled into a belt during improper storage. Both types of camber can usually be pulled out when the belt is properly tensioned and tracked, but the only correction for a non-square splice is replacement of the splice.

Successful empty run-in is followed by full load run-in. The belt is loaded, and its operation and alignment carefully observed for at least eight hours. If the belt edges remain within the width of the drive pulley face, it is considered properly aligned. If extra-wide pulleys are used, the belt should run within the normal width of the carrying or return idlers.

Again, it is advisable for have one person or crew responsible for training belts. That person should supervise all adjustments. The conveyor should be regularly checked to ensure that it is level. An out-of-level belt may result in misalignment for no other apparent reason. After the belt is run in under full load, the electric power use in the drive should be checked and recorded. These data serve as a reference during future operation, with increased power consumption indicating excessive belt drag because of misalignment or frozen idlers.

When run-in is completed, all belt accessories, including skirtboards, scrapers, shrouds, and transfer point components, should be checked for proper installation and clearance.

OPERATION

A conveyor system that is properly designed, installed, and maintained requires relatively little attention from operators. In a large installation, one or two operators will often suffice for routine operation, inspection, and maintenance. Current systems have extensive monitoring and control systems, incorporating measuring instruments and video-monitoring cameras. Nonetheless, for almost all conveyor systems, the most important operating procedure is the routine inspection and monitoring of the system by the operators.

MAINTENANCE

Because conveyors are often integral to continuing operation, they should be maintained by preventive or predictive maintenance programs, or a combination thereof. Preventive maintenance programs employ regularly scheduled service and rebuilding of major components; predictive maintenance programs rely on inspections and instrument readings to determine when maintenance is required to avoid breakdown.

Correct lubrication of all components is important. This includes idlers and pulleys, the drive system, and moving parts at loading, transfer, and discharge points. A large conveyor will have thousands of idler rolls, all of which have seals and bearings. It is preferable to use sealed bearings, which do not require routine lubrication. When lubrication is required, the manufacturer's recommendations should be thoroughly reviewed. The operating conditions, including operating speed, idler loading, type and size of material being conveyed, and number of operating hours per year should be carefully considered. The operating environment is also important and includes such factors as temperature, dust, material abrasiveness, washdown techniques, and frequency, all of which affect the lubrication and the bearings.

Inspection and monitoring are especially important for the belt itself. The belt is often the most expensive component of the conveyor system. The composition and structure of the belt make it particularly subject to wear and damage, and in modern, high-speed systems, severe damage may occur quickly. Consider a belt with a 300-m conveying distance, and a linear velocity of 3 m/s. If a sharp piece of scrap metal carried in the conveyed material becomes trapped or wedged

Table 3 Regular shift walk-through

Component or System to Be Examined	Notes and Observations
Tail pulley Impact idlers and beds Loading chute Belt Splices Skirtboard seals Belt center loading Carrying idlers Belt tracking and tracking devices Monitoring devices and sensors Guards and covers Safety devices Discharge and dribble chute Head pulley and lagging Belt cleaners Drive Snub bend pulleys Return run idlers Take-up Auxiliary and accessory equipment General housekeeping	Conveyors often give early warning of significant problems in the form of changes in the normal noise patterns of the conveyor, accumulations of fugitive materials, or belt tracking. Every shift an experienced and trained person should inspect the conveyor. The purpose of this inspection is to look for symptoms or early indicators of problems so that they can be dealt with proactively. Each component should be observed, and some minor adjustment or cleaning may be part of the inspection if it can be done safely. Inspection equipment needed is minimal but should always include a flashlight and means of communicating with the operator or control room. A written report, often in the form of a checklist, should be completed and symptoms of major problems addressed as soon as possible. The inspection should take between 30 minutes and 1 hour per shift and is intended as a walk-through only. If problems require urgent attention, they should be dealt with by shutting down the conveyor or immediately scheduling repairs. Perform an inspection of general condition. Test safety features for proper operation. Complete checklist if required.

Source: CEMA 2014

against the belt, the entire belt length of more than 600 m can be damaged or cut in little more than three minutes.

Systematic programs for regular inspection of conveyors are also referred to as *walk-throughs* or *belt surveys*. The *CEMA Handbook* (2014) provides schedules for inspections on per-shift, weekly, monthly, semiannual, and annual bases. Those schedules are shown in Tables 3–9. Tables 3–8 are typical maintenance schedules. Specific procedures should be developed for each site, with reference to information provided by equipment suppliers and experienced personnel in the area.

CONVEYOR SAFETY

Safety incidents associated with conveyors are usually the result of human error, improper maintenance, lack of effective training, or lack of awareness of possible hazards. Padgett (2001) analyzed conveyor-related accidents in non-coal mines in the United States from 1996 to 2000. He identified the following activities related to those accidents:

- Working under or next to poorly guarded equipment
- Using hands or tools to remove material from moving rolls
- Trying to free stalled rolls while the conveyor is moving
- Attempting to remove or install guards on an operating conveyor
- Attempting to remove material at head or tail pulleys while the belt is in operation
- Wearing loose clothing around moving belt conveyors
- Not blocking stalled conveyor belts prior to unplugging, whether flat or inclined, as energy is stored in a stalled conveyor belt
- Reaching behind the guard to pull the V-belt to start the conveyor belt

Padgett's analysis of 459 accidents found that 22 were disabling and 13 were fatal, and that 192 (42%) of the reported injuries, including 10 fatalities, occurred while the injured worker was performing maintenance, lubricating, or checking the conveyor; 179 (39%), including 3 fatalities, occurred while the subject was cleaning and shoveling around belt conveyors.

Kecojevic et al. (2008) analyzed historical fatality data associated with conveyors from 1995 through 2006. Data on belt conveyor–related fatalities from the investigation reports of the U.S. Department of Labor's Mine Safety and Health Administration (MSHA) showed that 49 belt-related fatalities occurred during this period. The authors assigned each accident to one of six risk categories. Fatal incidents that occurred during the belt conveyor cleaning, repair, assembling, or dismantling were classified either as "failure to provide adequate maintenance procedure" or "failure to follow adequate maintenance procedure." The hazard associated with failure of the management to build a crossing facility over the belt conveyor was classified as "failure to provide safe crossing facility," whereas the failure of workers to use such crossing facility or to make shortcuts was classified as "failure to use safe crossing facility." The single fatality caused by roof failure was designated as the hazard "adverse site/geological conditions," and the single fatality caused by the collapse of mechanical structure of belt conveyor was classified as "failure of mechanical components." Table 9 shows the number of fatalities associated with each hazard. The hazards "failure to provide adequate maintenance procedure" and "failure to follow adequate maintenance procedure" contributed to almost 90% of all belt conveyor–related fatalities.

Many countries and organizations issue standards relating to conveyor safety. The following are some of the most widely used:

- ASME B20.l from the American Society of Mechanical Engineers
- ANSI B11.3 from the American National Standards Institute
- AS 1755-2000 from the Council of Standards Australia
- BS EN 619:2002+A1:2010 from the British Standards Institution
- ISO 7149 from the International Organization for Standardization

Table 4 Weekly belt inspection

Component or System	Activity	Time Required per Conveyor, minutes*
Bend pulleys	Ensure that belt is centered on pulley	10
Carrying idlers	Ensure that all rolls are turning†	10
	Ensure that all idler rolls are free of material buildup†	10
	Ensure that belt touches all three rolls both in loaded and unloaded states†	5
Conveyor belting	Check for belt damage or abuse:	10
	Check for belt cupping	10
	Check for belt camber	10
	Check for impact damage	15
	Check for impingement damage	15
	Check for chemical damage	10
	Check for rips or tears	15
	Check for junction-joint failure	5
	Check for top cover cracking	5
Conveyor drive	Check reducer oil level	10
	Check reducer for oil leaks	5
	Inspect drive coupling	10
	Check oil level in backstop and inspect for leaks	10
	Ensure that all safety guards for drive are in place and in good condition	10
Conveyor structure	Check for rusted, bent, broken, or missing structural parts	20
	Check handrails and toeplates to ensure good condition	20
	Check walkways for material spillage or buildup	10
	Check safety gates to ensure good working order	10
Gravity take-up	Check take-up carriage for free and straight operation† Ensure that belt is centered on pulley* Ensure that all safety guards are in place and in good	10
	Ensure that belt is centered on pulley†	10
	Ensure that all safety guards are in place and in good condition	10
Guards	Check for damage and proper installation	10
Head pulley	Inspect belt cleaners for worn or missing blades	20
	Inspect belt cleaners for cleanliness of frames and blades	20
	Check belt-cleaner tension according to supplier's specification	10
	Ensure that belt is centered on pulley	5
Loading zone	Inspect impact idlers for wear	10
	Inspect impact bars for top cover wear	10
	Inspect seal-support cradles for wear	10
	Inspect and adjust dust seals	10
	Inspect dust suppression nozzles†	10
Return rolls	Ensure that rolls are turning freely	10
	Inspect rolls for material buildup	10
	Inspect mounting brackets for wear from belt tracking problems	10
Safety switches	Inspect cables for correct tension	10
	Ensure that flags are free from material buildup	10
Snub pulley	Ensure that belt is centered on pulley	5
	Inspect pulley for material buildup	5
Splices	Mechanical: Check splice and bolts for wear	10
	Vulcanized: Check splice for separation	10
Tail pulley	Ensure that belt is centered on pulley	10
	Check return plow blade for wear, if installed	5
	Check return plow mounting, if installed	5
	Check return plow tension, if installed	5
Tracking idlers	Check for free pivoting of frame†	5
	Ensure that all rolls are turning†	5
	Check rolls for material buildup	5

Adapted from CEMA 2014
* Some activities may be done simultaneously.
† May require the belt to be running.

Table 5 Monthly belt inspection

Component or System	Activity	Approximate Time Required per Conveyor
Bend pulleys	Check bushings for evidence of movement on shaft	20 minutes
	Check bearing condition and locking collars for tightness	20 minutes
	Check for cracks and wear at face and hub ends	20 minutes
	Check lubrication in shaft bearings	10 minutes
Gravity take-up	Check bushing for evidence of movement on shaft	20 minutes
	Check bearing condition and locking collars for tightness	20 minutes
	Check for cracks and wear at face and hub ends	20 minutes
	Check lubrication in shaft bearings	20 minutes
Head pulley	Check bushing for evidence of movement on shaft	20 minutes
	Check bearing condition and locking collars for tightness	20 minutes
	Inspect pulley lagging for wear and secure to head pulley	20 minutes
	Check for cracks and wear at face and hub ends	20 minutes
	Check lubrication in shaft bearings	20 minutes
Snubbing pulleys	Check bushing for evidence of movement on shaft	20 minutes
	Check bearing condition and locking collars for tightness	20 minutes
	Check for cracks and wear at face and hub ends	20 minutes
	Check lubrication in shaft bearings	20 minutes
Tail pulley	Check bushing for evidence of movement on shaft	20 minutes
	Adjust mechanical take-up for correct belt tension	20 minutes
	Check for cracks and wear at face and hub ends	20 minutes
	Check lubrication in shaft bearings	20 minutes
	Check lubrication in mechanical take-up adjusters	20 minutes
	Check bearing condition and locking collars for tightness	20 minutes
Carrying idlers	Check lubrication of bearings in rolls	20 minutes
Conveyor drive	Check lubrication in backstop bearings	30 minutes
	Check lubrication in shaft bearings	20 minutes
	Inspect drive belts for wear and correct tension	20 minutes
Loading zone	Inspect chutes and chute walls for leaks*	10 minutes
	Inspect entry seals	10 minutes
	Inspect exit seals	10 minutes
	Inspect dust-collection pickups for leaks*	20 minutes
Return rolls	Check lubrication in bearings in rolls	20 minutes
Safety horns and lights	Test to ensure it is working properly prior to conveyor start	20 minutes
Safety switches	Test emergency stop switches	1 hour
Tracking idlers	Check lubrication in rolls and pivot	20 minutes

Adapted from CEMA 2014
* May require the belt to be running.

Table 6 Semiannual belt inspection

Component or System	Activity	Approximate Time Required per Conveyor
Brakes and backstops	Test for proper operation under full load*	60 minutes
Conveyor structure	Check foundations for settling	30 minutes
	Check for corrosion	30 minutes
	Check for structure damage	30 minutes
	Check walkways, handrails, steps, and gates	30 minutes
Loading zone	Inspect wear liners for wear	30 minutes
Safety switches	Test operation for conveyor shutdown*	30 minutes
Warning devices and signs	Test for operation and audible/visual or readable functionally*	30 minutes
	Check traffic control signs for visibility and changes in traffic patterns	30 minutes
Seasonal activities	Winterizing or dry season preparation	8 hours
	Summer or wet season preparation	8 hours

Adapted from CEMA 2014
* May require the belt to be running.

Table 7 Annual belt inspection

Component or System	Activity	Approximate Hours Required per Conveyor
Electrical system	Check for open wiring, damaged conduit, overloads, and system grounds	1
Interlocks	Test to ensure proper interlocking of conveyors*	1
Safety switches	Test conveyor start with flags pulled	1
Documentation	Update maintenance documentation and records	40

Adapted from CEMA 2014
* May require the belt to be running.

Table 8 Routine housekeeping activities

Component or System	Activity	Approximate Time Required per Conveyor
Belt cleaners	Flushing of blades	Daily, 30 minutes
Return plows	Flushing of blades	Weekly, 30 minutes
Magnetic separators	Emptying of bin	Weekly, 1 hour
Central dust collectors	Emptying of bin	As required, 8 hours
Spillage and carryback	Cleaning spillage and carryback	Manually, 1 t/h; Mobile equipment, 4 t/h
Dust	Washdown	Manually, 2 hours per conveyor
Pollution control equipment	Cleaning filters and ductwork	Weekly, 1–4 hours per conveyor
Water treatment systems	Cleaning screens	Weekly, 30 minutes

Adapted from CEMA 2014

Table 9 Conveyor-related fatalities reported by MSHA, 1995–2006

Hazard	Number of Associated Fatalities	Total Fatalities, %
Failure to provide adequate maintenance procedure	28	57
Failure to follow adequate maintenance procedure	16	33
Failure to provide safe crossing facility	2	4
Failure to provide use crossing facility	1	2
Adverse site/geological conditions	1	2
Failure of mechanical components	1	2
Total	49	100

Source: Kecojevic et al. 2008

- *MSHA's Guide to Equipment Guarding* (2000)
- Title 30 in the U.S. Code of Federal Regulations, which covers mineral resources in Parts 1 through 199, especially Parts 56 and 57 (MSHA 1979a, 1979b)
- Title 29 in the U.S. Code of Federal Regulations, regarding the Occupational Health and Safety Administration, especially Parts 1910 and 1926 (OSHA 2004a, 2004b)

CEMA offers general guidelines for conveyor safety. In addition to the detailed requirements given in the preceding standards, the following are useful for workplace discussions and general reflection and are reproduced here in full (CEMA 2014):

- A formal safety training program for operations, maintenance, and supervisory personnel will go a long way toward establishing and maintaining the highest standards of safety in the work place.
- Concurrent with completion of the installation and the trial runs of all belt conveyors and associated equipment, a Safety Checkup is recommended. The checkup should include all mechanical and electrical operating equipment, plus the structures, walkways, ladders, stairs, headroom, and access ways. It is at this time that a detailed physical inspection of the facility and the installed conveyor equipment will often reveal the need for additional guarding, safety devices and warning signs.
- At no time should the conveyors be used to handle material other than that originally specified. Capacity and belt speed design ratings should not be exceeded.
- Only trained personnel should be allowed to operate the conveyor system. They should have complete knowledge of conveyor operation, electrical controls, safety and warning devices, and the capacity and performance limitations of the system.
- The location and operation of all emergency control and safety devices should be made known to all personnel. Surrounding areas should be kept free of obstructions or materials that could impede ready access and a clear view of such safety equipment at all times.
- A program should be established to provide frequent inspections of all equipment. Guards, safe devices, and warning signs should be maintained in their proper positions and in good working order. Only competent and properly trained and authorized persons should adjust or work on safety devices.
- A walking inspection of a belt conveyor system is a good means by which well-trained maintenance personnel can often detect potential problems from any unusual sounds made by such components as idlers, pulleys, shafts, bearings, drives, belts, and belt splices.

- Hands and feet should never come in contact with any operating conveyor component, and no one should be allowed to ride on a moving or operable conveyor. Poking at or prodding material on the belt or any component of a moving conveyor should be prohibited. Contact with, or work on, a conveyor must occur only while the equipment is stopped, following the proper lock out, tag out and test out procedures unless the equipment is specifically design to be safely inspected or serviced and the worker specifically trained and aware of the hazards with the belt in operation.
- No person should be allowed to ride on, step on, or cross over a moving conveyor, nor to walk or climb on conveyor structures, without using the walkways, stairs, ladders, and crossovers or cross unders provided. CEMA R SBP-001: Design and Safe Application of Conveyor Crossovers, which is available for free download at the CEMA website's Safety Page.
- Good housekeeping is a prerequisite for safe conditions. All areas around a conveyor, and particularly those surrounding drives, walkways, safety devices, and control stations, should be kept free of spillage, debris and obstacles, including inactive or unused equipment, components, wiring, and obsolete or non-applicable warning signs or posted instructions. Any conveyor found to be in an unsafe condition for operation or one that does not have all guards and safety devices in excellent condition, should not be used unless adequate supplementary safety devices are installed.
- All persons should be barred by appropriate means from entering an area where falling material may present a hazard. Warning signs and barricades can be used.
- First-class maintenance is a prerequisite for the safest operation of conveyors. Maintenance, including lubrications, should be performed with the conveyor stopped and locked out. Special lubricating equipment, lube extensions, pipes, and the like can be installed so as to permit lubrication of an operating conveyor without any foreseeable hazards.
- Good lighting contributes to a safe working environment.
- During the life of a belt conveyor system, its operational conditions and environment may require changes. There should be a continuing effort to detect and treat promptly any new possible safety hazards associated with these changes. If such a hazard cannot be readily eliminated, warning signs, barricades, or posted instructions should be installed.

Before operation of a conveyor and the associated accessories, safety markings, guards, and warnings must be in place in accordance with governmental regulations and site-specific requirements. The CEMA Safety Committee developed the CEMA *Brochure No. 201: Safety Label Brochure* (2017) to provide advice for the selection and application of safety labels for use on conveyors and related material handling equipment to assist in accident prevention.

Many incidents occur during cleanup operations around conveyors. Most conveyors operate at speeds of 1.5 to more than 5 m/s. Typical reaction time for an average human is 0.75 seconds, so if a person's hand or clothing is caught in a conveyor running at 4 m/s, the belt will move 3 m before a person can react, and the arm or clothing will be pulled into the conveyor. Incidents in which a person is pulled into a conveyor are unfortunately too common. Because of this ongoing hazard, proper conveyor guarding must be used to protect personnel from the injury that may result from contact with conveyor equipment during operation. The regulations and enforcement actions are vary with jurisdiction, so it is important to conform the requirements for guarding specific to each location and type of operation.

Guards and basic safety devices are normally included with major equipment such as drives and as part of the original conveyor construction such as safety shutoff pull-cord switches. Conveyors have other potential hazards associated with the moving belt and conveyor components or accessories that must be accessed by the end user, and may need additional guarding. The most common hazard that must be addressed locally is pinch or nip points, which result from the specific layout and location of the conveyor.

Conveyor guards may be constructed from expanded metal, plastic, or other materials that normally have openings small enough to prevent contact with the hazard being guarded, but allow fines and other materials to pass through and permit inspection of conveyor components during normal operation. The distance around the guard should be maintained so that no one may reasonably reach around the guard into the danger zone. The safe distance around the hazard must also be considered when the guard cannot completely contain the hazard. Although standards vary, a 1-m distance around the hazard is usually protected to prevent reaching around the guard. The guard should be painted to be highly visible, according to the color code for the site. Red is generally reserved for firefighting equipment, e-stops, and similar equipment, so safety orange or safety yellow is frequently used for guards.

Three types of guarding are used to protect personnel from the moving parts of a conveyor. Point guarding isolates the specific moving part that poses the hazard; area or perimeter guarding restricts access to a specific, wider area; location guarding functions when the hazard is a safe distance from normal access points. Each of these is discussed in detail in the applicable standards, in the *CEMA Handbook*, and in *Foundations*.

BELT CONVEYOR SYSTEM CALCULATIONS

Belt Width and Speed

Conveyors are often sized to carry a certain tonnage of a given material, but may be oversized in anticipation of increased production. For this example, consider an application in which an existing conveyor belt is 1,000 mm wide with a trough angle of 35 degrees and a belt speed of 150 m/min. The conveyor has been carrying 2,000 t/h of lead-zinc concentrate. The concentrate has a bulk density (not specific gravity) of 3.5 t/m^3, and its angle of surcharge on the moving belt is 20 degrees. The company wishes to increase concentrate production to 2,500 t/h. Can the existing conveyor carry the additional material?

First, convert the required carrying capacity from t/h (mass/time) to m^3/min (volume/time), thus

$$(2{,}500\ t/h)/(3.5\ t/m^3 \cdot 60\ min/h) = 11.9\ m^3/min \quad \textbf{(EQ 7)}$$

The required volume-carrying capacity is then divided by the belt speed to give the required cross-sectional area of the belt:

$$(11.9\ m^3/min)/(150\ m/min) = 0.079\ m^2 \quad \textbf{(EQ 8)}$$

The cross-sectional area of the material on a fully loaded existing belt (1,000 m wide with a 35-degree trough and a 20-degree surcharge angle on the load) is 0.091 m^2. This may be calculated from the geometry of the belt and load or determined from tables in a standard reference book, such as the *CEMA Handbook*. This cross section is greater than that required to carry the increased load, indicating that the existing belt is large enough to do the job. In fact, under these conditions, the belt could carry 2,880 t/h.

Idler Selection

Calculate the load on the carrying idlers for a conveyor belt that will operate under the following conditions:

- Material: crushed limestone
- Bulk density: 1.36 t/m^3
- Capacity: 1,200 t/h
- Belt width: 1,200 mm
- Belt speed: 150 m/min
- Belt weight: 15 kg/m
- Belt tension: 5,000 kgf, carrying side; 2,000 kgf, return side
- Idler spacing: 1.2 m
- Misalignment: 6 mm maximum
- Lump size: 150 mm maximum

The total load on each idler is given by Equation 4:

$$L_{it} = [(W_b + (W_m K_1)]S_i + L_{im} \quad \textbf{(EQ 9)}$$

where

L_{it} = total idler load, kg
W_b = weight of the belt, kg/m
W_m = weight of the material load, kg/m
K_1 = lump adjustment factor
S_i = idler spacing, m
L_{im} = idler misalignment load, kg

Idler misalignment load is given by

$$L_{im} = 2 \cdot [(dT)/S_i] \quad \textbf{(EQ 10)}$$

where

d = maximum vertical misalignment between adjacent idlers, m
T = belt tension, kgf
S_i = idler spacing, m

The value of the lump adjustment factor, K_1, is found from Table 10 to be 1.0.

$$W_m = (1{,}000\ kgf/t)[(1{,}200\ t/h)/(60\ min/h)]/(150\ m/min) = 133\ kgf/m \quad \textbf{(EQ 11)}$$

The idler misalignment load is

$$L_{im} = 2 \cdot [(dT)/S_i] = 2 \cdot [(0.006 \cdot 5{,}000)/1.2] = 50\ kgf \quad \textbf{(EQ 12)}$$

Table 10 Lump adjustment factor, K_1

Maximum Lump Size, mm	Material Specific Weight, kg/m³						
	800	1,200	1,600	2,000	2,400	2,800	3,200
100	1.0	1.0	1.0	1.0	1.1	1.1	1.1
150	1.0	1.0	1.0	1.1	1.1	1.1	1.1
200	1.0	1.0	1.1	1.1	1.2	1.2	1.2
250	1.0	1.1	1.1	1.1	1.2	1.2	1.2
300	1.0	1.1	1.1	1.1	1.2	1.2	1.2
350	1.1	1.1	1.1	1.2	1.2	1.3	1.3
400	1.1	1.1	1.2	1.2	1.3	1.3	1.3
450	1.1	1.1	1.2	1.2	1.3	1.3	1.4

Adapted from CEMA 2014

Thus total load per idler is

$$L_{it} = [(15 + (133 \cdot 1)]1.2 + L_{im} = (15 + 133)1.2 + 50 = 227.6\ kgf \quad \textbf{(EQ 13)}$$

The load on the return idlers is calculated by the same method, but the weight of the material load, W_m, is obviously eliminated, and the return-side tension is used, thus

$$L_{im} = 2 \cdot [(dT)/S_i] = 2 \cdot [(0.006 \cdot 2{,}000)/1.2] = 20\ kgf \quad \textbf{(EQ 14)}$$

$$L_{it} = W_b S_i + L_{im} = (15)1.2 + 20 = 32.5\ kgf \quad \textbf{(EQ 15)}$$

These values can be used to select the appropriate idlers for the application from the tables in the *CEMA Handbook* or from manufacturers' literature. The correct selection of idlers is also affected by the operating conditions, the belt speed, and the desired lifetime, or mean time to failure.

Belt Tension and Power

Find the effective tension required in an inclined conveyor and estimate the power required for steady-state operation. The conveyor operates under the following conditions:

- Conveying distance: 200 m
- Vertical lift: 20 m
- Material Weight: 200 kgf/m
- Belt weight: 5 kgf/m
- Belt velocity: 150 m/min or 2.5 m/s

This belt satisfies the criteria for a basic conveyor. Thus Equation 4 is used to calculate the effective tension, T_e. Using 200 m for W_m, 20 m for H, 5 kg/m for W_b, and 200 m for L, T_e can be solved:

$$T_e \leq 200 \cdot 20 + 0.04(2 \cdot 5 + 20)200 = 5{,}680\ kgf$$

The power required to maintain this tension in steady-state operation is given by Equation 3:

$$P = T_e \cdot V \quad \textbf{(EQ 3)}$$

where

T_e = effective tension
V = belt velocity

Note that 1 W is equivalent to 1 N-m/s or 1 kgf-m/s, so belt velocity (V) must be expressed in meters per second, and the effective tension (T_e) must be multiplied by the acceleration caused by gravity (g) to convert kilogram-force meters per second to watts, thus

$$P = 5{,}680 \text{ kgf} \cdot 9.8 \text{ m/s}^2 \cdot 2.5 \text{ m/s} = 139.2 \text{ kW} \quad \textbf{(EQ 16)}$$

It is important to remember that the calculated power is only that required to raise the conveyed material and overcome the friction in the system. In an actual conveyor, additional power in would be required to accelerate the system when it is started. Furthermore, the nameplate power on the motor would have to be larger than the increased amount, to account for the efficiency of the motor and the drive system, which will always be less than 1.

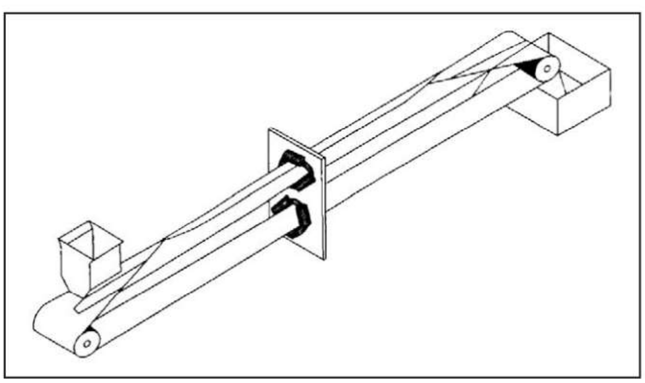
SPECIAL BELT CONVEYOR SYSTEMS

In addition to the conventional conveyor belt, supported by troughed idlers, there are also special conveyor systems that are useful in particular circumstances. *Foundations* identifies three reasons for considering a special conveyor system. The first is improved environmental control, in which dust, spills, and contamination of the conveyed material must be reduced or eliminated; the second is reduction of labor and capital costs, particularly regarding the footprint of the system and the construction costs; the third is a reduction in the number of transfer points, which is, of course, closely related to the first two considerations. This section offers a brief description of five of the most common special conveyors. All of these systems use flexible belts, but have different methods of supporting and driving the belt. For detailed design and operation of these systems, the reader is referred to the technical literature and to the suppliers of such systems.

Pipe Conveyors

Pipe conveyors are similar to conventional troughed conveyors but have the advantage of enclosing the transported material (Wiedenroth 2010). The components of both systems are similar, but rather than forming a trough, the belt is formed into a pipe using a special transition section after the loading point and opened up through a reverse process before the discharge point, as shown in Figure 20. A photo of a transition section is shown in Figure 21. During transit, the piped belt is supported by assemblies of three or more idlers, as shown in Figure 22.

A pipe conveyor has obvious benefits where dust from the material may a problem or where the material needs to be protected. These conveyor systems can also handle steeper inclines and tighter horizontal curves than conventional belts.



Adapted from CEMA 2014

Figure 20 Operation of a pipe conveyor

Figure 21 Transition at the entrance to a pipe conveyor

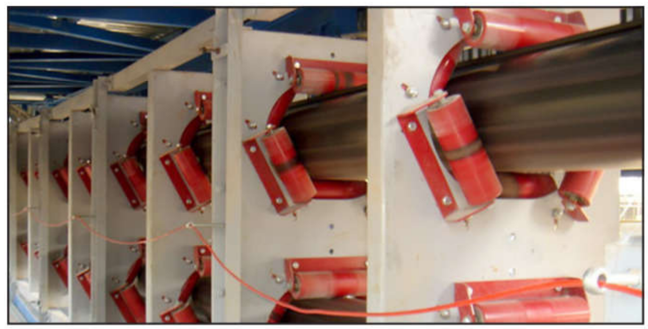


Figure 22 Idlers supporting a pipe conveyor

The disadvantages of this system are the lower tonnages and smaller lump sizes that can be accommodated.

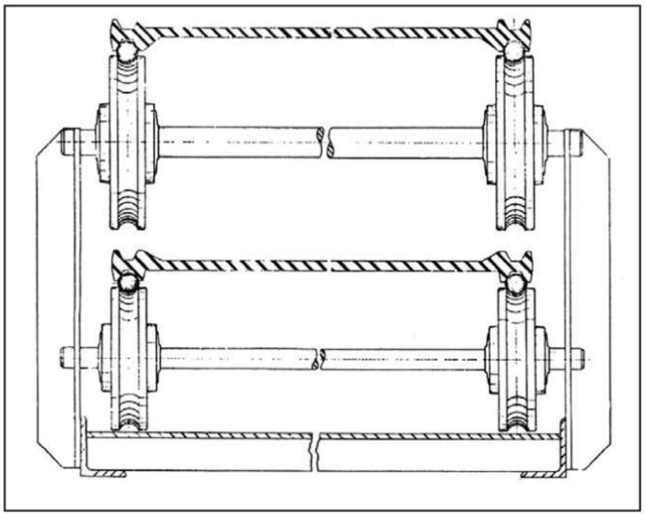
Cable Belts

Cable belt systems use two steel cables to provide the driving force of the system, as shown in Figure 23. The belt has specially molded tracks (sometimes called *shoeforms*) on both sides near its outer edges, so it can be directly supported by the cable, which in turn rides on grooved wheels (Hewett 1957; Anderson and Wilson 1965; Brost and Scanlon 1984). The belt must be more rigid across its width than a conventional belt, so it can support its own weight and the weight of the conveyed material. Figure 24 shows a cable belt with inclined rollers, and Figure 25 is a photo of an operating cable belt.

In long-distance cable belt systems, intermediate drives can be used without the need for transferring material because the driving force is delivered through the cables. Cable belts can also negotiate tighter horizontal curves than conventional systems. A disadvantage is the specialized components that are required.

Air-Supported Conveyors

The air-supported conveyor is constructed with trough-shaped plates that have orifices through which a pressurized airflow provides support for the belt, as shown in Figure 26. The return belt may be supported by air or by conventional return idlers. The belt is covered to contain the escaping airflow, so contamination, spillage, and dust are minimized (Morrell et al. 1984; Hashimoto 1984; Overland Conveyor Company 2017).



Source: Anderson and Wilson 1965
Figure 23 Cable belt system

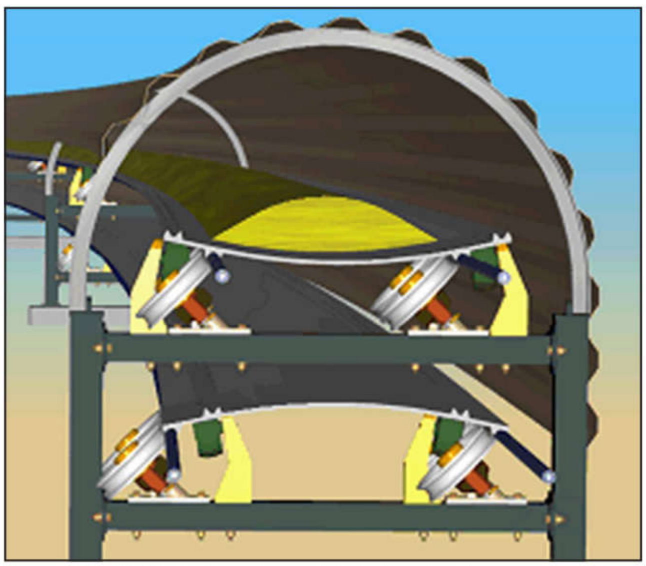


Figure 24 Cable belt system with inclined rollers

The main advantage of air-supported conveyors is the elimination of carrying idlers. In addition, the belt is uniformly supported and experiences less wear from sag and flexure between idlers. The enclosed design improves dust control and reduces spillages, and there are fewer moving parts. Figure 27 shows an air-supported conveyor with one cover section removed.

The disadvantages of this system are that it requires closer fabrication tolerances and better belt cleaning to ensure smooth, consistent operation. Also, interruption of the air-supported conveyor may be required for belt scales and other accessories. Finally, this type of system cannot accommodate horizontal curves.

RopeCon Conveyors

RopeCon conveyors are manufactured by Doppelmayr Transport Technology (2018). They are similar to conventional conveyors but use flat belts with corrugated side walls,

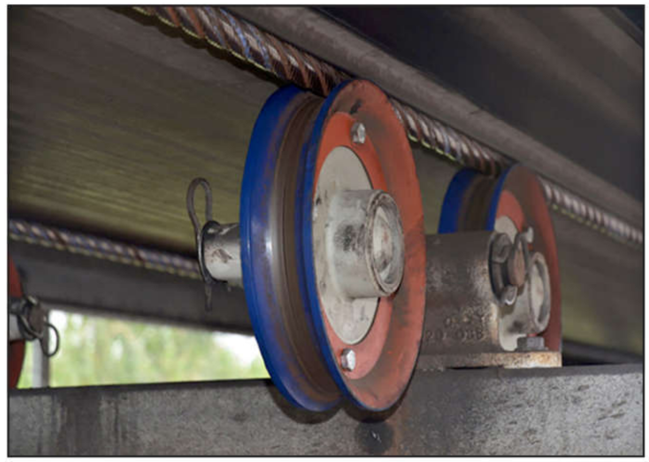
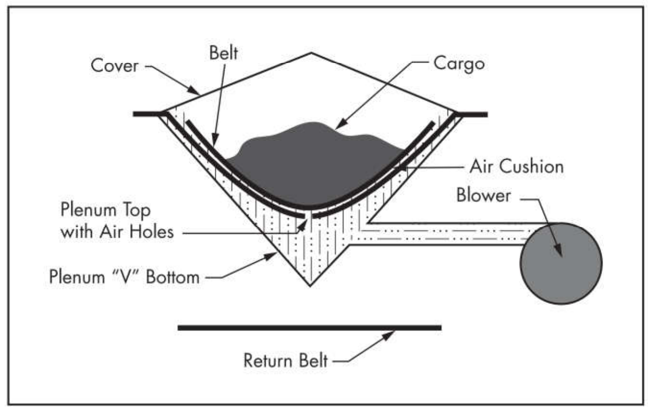


Figure 25 Operating cable belt



Source: Grisley 2002
Figure 26 Air-supported conveyor

as illustrated in Figure 28. The belt is fixed to axles spaced at regular intervals. Wheels on the axles run on fixed ropes spanning between towers. Towers can be spaced hundreds of meters apart, which allows the conveyor to bridge across valleys or other obstructions. Figure 29 shows a portion of a long overland RopeCon conveyor. The major disadvantage of this system is the specialized components that are required and its higher capital cost.

Steep Angle Conveyor Systems

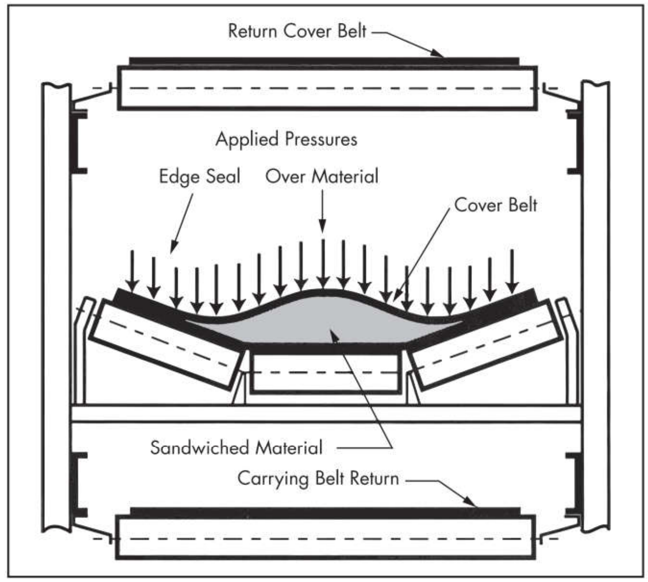
Steep angle conveyor systems are applicable for inclines exceeding 18 degrees and can operate vertically. Many systems are capable of conveying material up steep inclines (Richmond et al. 1991). One method is to enclose the conveyed material in a pipe conveyor, as described earlier, or in a sandwich belt (Dos Santos 2000), as shown in Figure 30.

Another is to retain the material with molded cleats or chevrons that extend across the width of the belt, as shown in Figure 31, or with cleats and flexible walls as shown in Figure 32. (These flexible walls are similar to those on the RopeCon conveyor.) Some disadvantages of these systems are the specialized components required and the lower tonnages and smaller lump sizes that can be accommodated. Table 11 summarizes the advantages and disadvantages of the special conveyor systems discussed here.

Figure 27 Air-supported conveyor with one cover section removed

Courtesy of Doppelmayr Transport Technology
Figure 28 RopeCon system

Courtesy of Doppelmayr Transport Technology
Figure 29 Section of a large overland RopeCon system



Source: CEMA 2014
Figure 30 Sandwich belt conveyor cross section

Source: CEMA 2014
Figure 31 Molded cleats on a conveyor

DEVELOPING TECHNOLOGY

New conveyor technology for conveyor belts continues to develop in two primary areas. The first is new software for the design of conveyors and conveyor systems; the second is new components for such systems. Examples of each are given here, and references are provided so that the interested reader may easily obtain more information.

Computer Modeling

Belt tension and drive requirement for basic conveyors can be more accurately designed using computer modeling.

Belt Tension and Drive

Belt tension and drive requirements may be estimated for a basic conveyor, with a simple calculation as described earlier. A basic conveyor comprises a single flight, a gravity take-up, a single drive, and a single free-flowing loading point. It is less than 250 m long and may inclined but has neither horizontal nor vertical curves. Its speed is less than 150 m/min, and its maximum tension is 5,400 kgf.

Many modern conveyor systems do not meet the basic conveyor criteria. Although these systems may be designed using manual or spreadsheet calculations, design by a computer program is more accurate and takes into account more of the variables in a complex system.

Such programs can select the radius for vertical curves, to ensure that the belting will not lift out of the idlers on a concave curve or exceed the rating of the belting or idlers on convex curves. The calculation takes into account the mass of the belting; how the belt tensions vary with material loading, especially partially loaded conditions; and how the running forces of the system may vary with temperature and operating conditions. These programs can also calculate the minimum radius for a horizontal curve, balancing the gravitational forces and the weight of the belt and material with the tension forces trying to pull the belt into the curve. To balance these forces, the idlers for the system are angled opposite to the direction of the curve. As in the design of a vertical curve, this calculation must account for varying load conditions and the effects of temperature and operating conditions.

Source: CEMA 2014

Figure 32 Lumps being conveyed vertically on a belt with cleats and sidewalls

In some conditions, dynamic analysis is recommended, simulating the changing tensions and velocities that occur during starting, stopping, and load variations of the system. These calculations are essential in designing long, complicated belt conveyors but are not typically required for standard, straight belt conveyors. For a given conveyor system, these programs can give good estimates for drive torque requirements, test starting control options, identify peak tensions for vertical and horizontal curve calculations, evaluate braking and stopping functions, determine take-up requirements, and identify potential tension problems arising during starting and stopping (Zhang and Steven 2012; Kruse 2002; Lodewijks and Nuttall 2008).

Dynamic analysis may also include design of belt networks, in which several belts receive and deliver material from or to different locations. Such systems are usually analyzed with a network analysis, similar to that used in the modeling of pipeline and electrical distribution systems (Tarshizi et al. 2014; Kumar and Yingling 1994; Yingling et al. 1993).

Some suppliers of belt design software are Conveyor Dynamics, Advanced Conveyor Technologies, Professional Designers and Engineers, and Overland Conveyor Company. Many others may be located by searching online.

Discrete Element Modeling

The discrete element method (DEM) simulates the bulk flow of granular materials and has been widely applied to analysis of the handling and processing of bulk materials. DEM was first used to analyze the flow of materials in chutes and bins, and as computer processing capacity and speed increased, it

Table 11 Special belt conveyor systems key-features comparison chart

Conveyor Type	Tonnage	Lump Size	Parts/ Components	Horizontal Curves	Advantages	Disadvantages
Conventional troughed	High	Large	Readily available	Yes	Up to 18-degree inclines; up to 20,000 t/h	—
Pipe	Low	Small	Readily available	Yes	Enclosed transported material; steep inclines; tight horizontal curves	Small lump size may require more crushing
Cable belt	Low	Small	Specialized	Yes	Some technical advantages for long-distance systems and tight horizontals	—
Air-supported	—	—	Specialized	No	Cleaner and safer because of enclosed design and fewer moving parts	Closer fabrication tolerances and better belt cleaning required
RopeCon	High	Large	Specialized	No	Reduced structural footprint; useful in otherwise impassable terrain	—
Steep angle	Low	Small	Specialized	No	Capable of high inclines, up to vertical	—

was applied to design of conveyor transfer points (Moore et al. 2013; Kruse 2000; Hustrulid and Mustoe 1996; Grima et al. 2013; Fioroni et al. 2007).

DEM analysis can address many problem areas in the design of conveyor transfer points, including uncontrolled flow regions, blockage, off-centered loading, unsteady flow rated, high-impact velocities, particle segregation, spillage, and excessive wear. It can also help optimize the locations of wear surfaces and determine reasonable operational capacities.

Before conducting a DEM analysis, it is important to correctly characterize the material whose movement is being simulated. This characterization should include accurate descriptions of particle shape and size, material friction and cohesion, specific gravity, bulk density, and moisture content. Determination of these properties requires laboratory testing. In some cases, dynamic testing of a material sample is justified.

Recent Developments

In addition to the improvements in the special conveyors described earlier (pipe, cable belts, air-supported, steep angle, and RopeCon), there have been recent innovations in drive technology and idler maintenance.

Gearless Drives

Larger mines and processing plants and the remote locations of many operations have led to the use of longer and higher-capacity conveyor systems wherever possible. In many cases, the entire production process is dependent on the availability, reliability, and cost efficiency of the overland conveyor system. The need for larger-capacity overland conveyor systems places greater demands on the performance characteristics of the conveyor drive train. In almost all cases, electrical drive systems that allow soft starting and stopping are preferred. Such systems protect the conveyor belt from high torque and can extend the life cycle of the conveyor system.

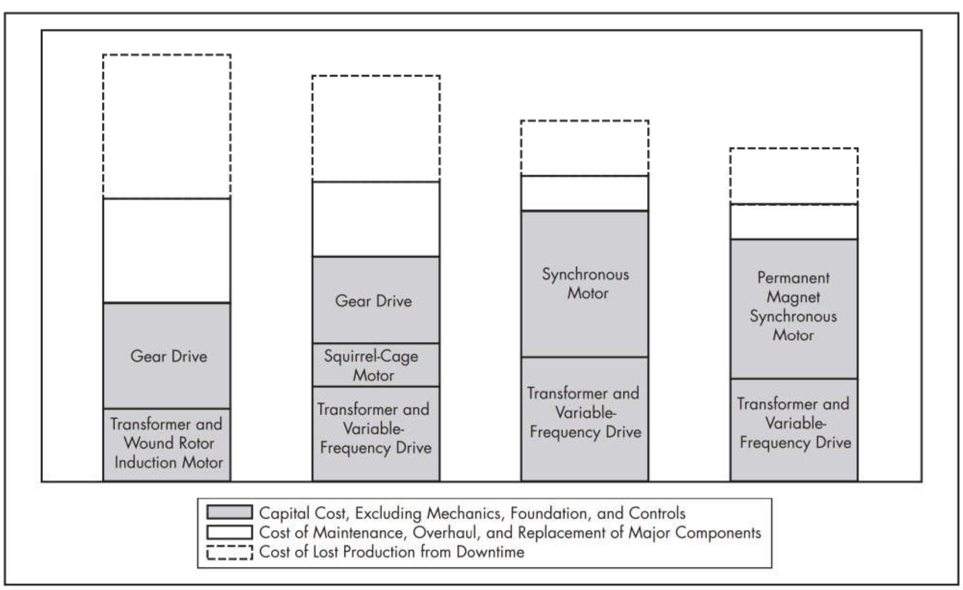
As previously discussed, conveyor drive systems usually comprise an electric motor with a gear reducer and mechanical or fluid coupling. Some of the disadvantages of starting a conveyor with such a drive system include high-tension peaks in the belt at start-up, high starting currents in the network, and higher system and load-sharing losses. All of these conditions can increase maintenance costs and production losses. In particular, gear reducers for longer and higher-capacity conveyors are large and inefficient and require extensive maintenance. The mean time between failures for a gear reducer and associated components is three to four years. The bearings have an operating life of 8–10 years and, when replaced, necessitate a major system overhaul. Finally, the operating life—about 10 years—is often less than half that of the conveyor system.

Gearless drives can reduce or eliminate these problems. The technology for gearless conveyor drives is the same as that used for mine hoist drives. When a bearingless motor is used in the gearless drive system, further advantages accrue. A low-speed, 6-MW gearless and bearingless motor can reduce capital and operating costs by as much as 7% over a 20-year period, compared to a high-speed system with twin gear drives. Gearless drives are more specialized than conventional drives and are offered by only a few vendors. Furthermore, gearless drive installations require additional training for operators and maintenance personnel, and maintenance procedures may require more time.

Gearless drives are offered by several major suppliers of electrical drive systems. Richter (2015) describes gearless drives and provides a detailed case study for the replacement of an existing conveyor drive on a high-capacity mining machine, in which each of the two gearless-drive design options considered gave a weight reduction of about 30%. Richter also provides an economic comparison of four conveyor drive systems, as shown in Figure 33.

Richter (2015) concludes that the major advantages of gearless conveyor drives compared to geared drives are

- Elimination of the main drives gearboxes;
- Higher reliability and availability;
- Lower downtime for maintenance and breakdowns;



Adapted from Richter 2015

Figure 33 Comparison of costs for four conveyor drive systems

- Higher annual production with the same conveyor;
- Decreased revenue losses;
- Lean drive with lower part count and fewer sensors and spare parts;
- Higher energy efficiency, lower energy cost;
- Elimination of vibration issues caused by parts rotating at high speeds; and
- Much lower noise emission (<75 db).

Richter (2015) also states that gearless drives are especially beneficial in the following types of installations:

- The planned life cycle is longer than about 10 years.
- High availability is required.
- No redundant production lines exist.
- Material buffers such as surge bins and stockpiles are small or nonexistent.
- Maintenance parts are expensive or difficult to procure.
- Maintenance work is hard to perform, for example, at high altitude or extreme temperatures.
- Ambient conditions are harsh.

Idler Maintenance

Maintenance of idlers is an ongoing task on all conveyors. Most conveyors have a set of carrying idlers every 1–2 m. These idlers, of course, rotate rapidly whenever the belt is operating and are thus subject to wear and failure. In addition, replacement of failed idlers normally requires shutting down the belt, following a safe lock out/tagout procedure. Thus idler inspection, maintenance, and replacement are ongoing tasks that can be time-consuming and expensive. Mechanized systems for monitoring or changing idlers are offered by at least two companies. Both systems are relatively new but show great promise.

Scott Technology of New Zealand offers the Robotic Idler Predict (ABHR 2013). It is a six-axis robot arm installed on a track-mounted vehicle that travels alongside a conveyor. The robot arm carries a system that uses thermal, vibration, and acoustic monitoring to detect idler wear. The system can also remove debris from under the conveyor.

Lewis Australia (2017) offers the Spidler, a system mounted on light rail installed on either side of the belt. The Spidler is self-propelled, with a diesel motor that provides power to electrical and hydraulic systems. It travels above the belt to the location of a faulty idler, then lifts a length of the belt off the carrying idlers. A robotic manipulator then removes the faulty idler and installs a new idler in its place.

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