You operate a conveyor with turns.
So this article reveals the rules of the art!

Technology of horizontal curves or turns: design, calculation, on-site mastery.

Terminology/description:

Precise terminology is required to describe the subject.

In common language, “horizontal curve” is used for conveyors with a “sinuous” long profile in aerial view X**Z** coordinates; they are also known as “curvilinear conveyors”. By comparison, a conveyor with horizontal, ascending and descending straight sections, with convex (centre of curve below conveyor) and concave (centre of curve above conveyor) curves, has a perfectly "straight" profile. in an aerial visual representation; the representation of such a conveyor, in the usual way, is the X**Y** coordinate, to be perfectly descriptive.

Here, the difficulty lies in the diversity of the so-called horizontal curves; rather, it would be necessary to speak of a curve in the "horizontal plane" of **XZ** coordinates. But if this horizontal plane is inclined, how can we understand the definition of «horizontal curve». To clarify this point, ***C3 Expert*** uses the term “turn” as an analogy to road turns that can have a simple and constant or complicated profile by combining of under-sections of different of slope (inclination) in the same turn.

*Straight conveyors or with one or more convex and/or concave curves have a long profile (in elevation) perfectly visible on a plane of **XY** coordinates.*
*When the conveyor has simple and constant **turns**, these are visible in an **XZ** coordinate plane*
*When curves have concave and/or convex curves, a **3D** representation is required to distinguish the subtleties of the plot.*

Calculation constraints of "turns"

For the calculation of a turn, it is necessary to know the different parameters and their characteristic value.
In the case of a conveyor project, the calculation has the freedom to propose different solutions; but it may have to comply with certain constraints, for example, a trace that imposes a radius of curve in a given geographic template.
In the case of an existing conveyor, the calculation is constrained by the imposed value of many parameters; for example, radius of each turn, model and pitch of roller supports, location of drive pulleys, reference and speed of belt, etc.

Profiles of "turns"

1) Simple turn, with regular parameters
    a. In a horizontal, ascending, descending plane
    b. With a unique center and radius.

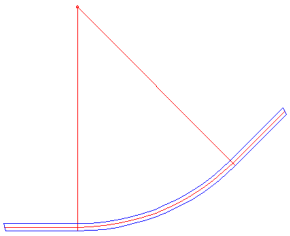
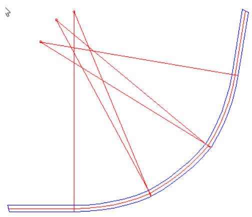


Fig.1: 1 center, 1 radius

2) Simple turn, with variable parameters
    a. In a horizontal, ascending, descending plane
    b. The curved section has several different centers and/or radii.



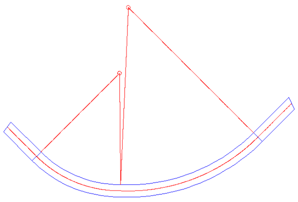


Fig.2.1: 3 centers, 1 radius Fig.2.2: 2 centers, 2 radii

3) Complex curve combining one or more curves in the vertical plane (concave, convex) with the same center and radius of curve or with several centers and/or radii of curve
    a. This type of profile is most complicated to calculate because it depends on the large variations of belt tension throughout the turn depending on whether the mass of the product being handled represents a resistant or driving force. For this type of turn, it is necessary to calculate in advance the minimum and maximum tensions of all the sections of the turn.

4) Sequence of alternating steering turns, without intermediate straight section or with very short intermediate straight section (e.g., length equal to 1 step between 2 consecutive supports).

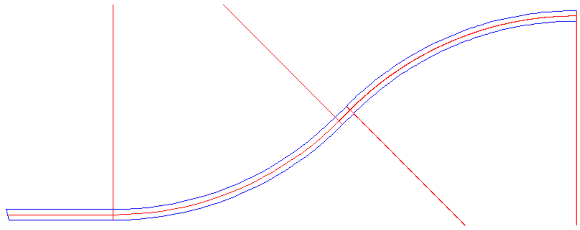


Fig.4: 2 successive reverse turns

Location of carry and return sides

The directions of the turn, carrier and return side, are:

1) Parallel and Superimposed
    a. The radii of the 2 sections, carrier and return side, are equal;

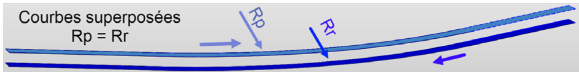


Fig.5.1: The turns are // and superimposed

2) Parallel and side by side
    a. The radius of return side is increased or decreased by the distance that separates it from the longitudinal axes of the 2 sides, depending on the direction of the turn considered (right, left).

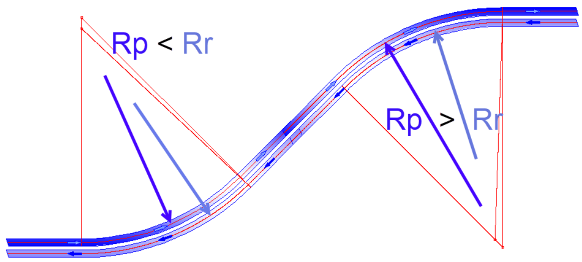


Fig.5.2: The turns are // and side by side

3) Nonparallel
    a. Here, these are 2 distinct paths.

4) "Without" a return side.
    a. This case could exist in the absolute and would be assimilated to a 'ring' or a loop. The interest of such a route is unlikely, but is not impossible.

Belt supports / Design

There are a wide variety of belt supports in turns; they are distinguished according to 3 operating principles:

1) The bracket is **fixed**, in the sense that, once adjusted, it has no movement, movement automatic or drived to make vary the inclination and/or orientation of these angles.

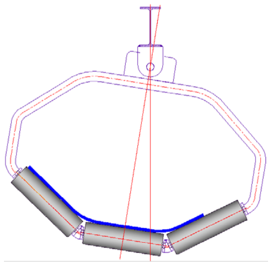
2) The support is «**pendular**» (proofer), single or double (carrier, carrier and return rollers). The principle lies in its inclination under the belt thrust, whose trajectory tends towards the geometric chord of curve, due to its tension forces. Thus, the belt presses on the rollers and the support it tilts, by pivoting on an axis above the proofer, up to a limit value defined by an end-stop.

a. This model manages the variable idler inclination. The orientation angle is fixed, but sensitive to the functional clearance of the articulation, in a new state, then worn;

b. This model allows a shorter turning radius than the fixed model for all other identical characteristics of turn (flow, other factors);

c. The limit inclination is defined by the repose angle of product handled, in dynamic phase, its flow rate, etc.;

d. The performance of this model can be interesting if we compare the cost of manufacturing the proofers and the structure of the conveyor with the efficiency of controlling the belt trajectory in the turn:
   - Tilt efficiency is defined by calculation and must be combined with the possible but fixed orientation angle of the brackets (0° to 3°).



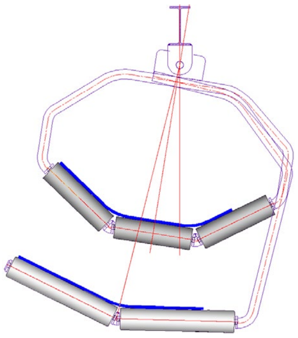


Fig.6.1: Single proofer Fig.6.2: Double proofer

3) The bracket is "**variable orientation**" and is part of n suites of n supports in the turn. The automatic orientation depends on the trend of the path of the belt at the time ***t***, towards the inside or the outside of the curve.

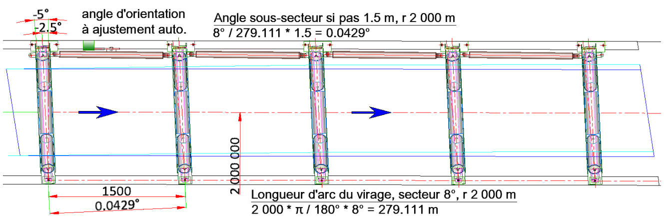


Fig.7: Drive device for variable orientation angle of belt supports

a. This model favors the steering force of the rollers, which is considered as the 1st factor for controlling the belt's trajectory. According to the calculation its performance is completed by a fixed angle of inclination;

b. This model has a good performance since the orientation angle of each series of n supports automatically adjusts to counter the belt offset, depending on its load and its tension, etc., in the turn subsection considered;

c. Under these conditions, a very large belt load variation and/or belt tension is managed by the system. This allows a shorter turn radius compared to the fixed support model;

d. For this variable orientation system, it is recommended to have a series of n supports compatible with the load variation so that the belt does not have time to go out of its calibrated trajectory when there is a sudden change of load and/or tension (empty, full load, empty);

e. The number of supports of the suite is also defined by the force to be used to maneuver easily their orientation;

f. This system can also be satisfied with a small number of supports, which in itself contributes to savings in supplies and energy consumption; this point is to be considered in the economic balance sheet.

Roller supports / Orientation angle

In the article above, the proofer support model, which favors the angle of inclination, is presented before the variable orientation *model*, because it is more common, but in terms of efficiency, it is the angle of orientation that takes precedence, with a tilting supplement if necessary (ditto paper industry).

<u>Angle of orientation (of direction)</u>:
In all the turn section, an angle of orientation can be given to each roller support from its geometric position of reference perfectly perpendicular to the axis of the conveyor;

- This initial and reference position of the bracket coincides with the turn radius, passing through the axis of the bracket rollers (= 0°). In the event that the steering forces, generated by the rollers, would be insufficient to control the belt trajectory, including the maximum allowable drifting, then this angle of orientation must be increased, without exceeding 3°.

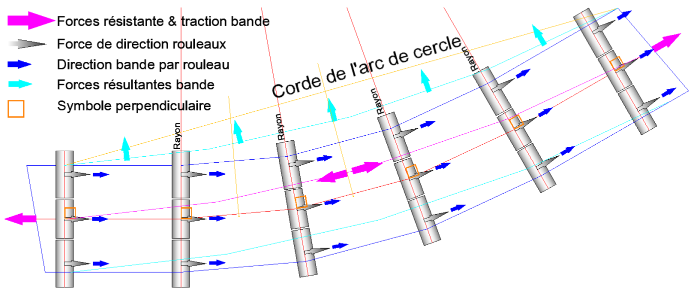


Fig.8.1: Supports aligned with each turn radius

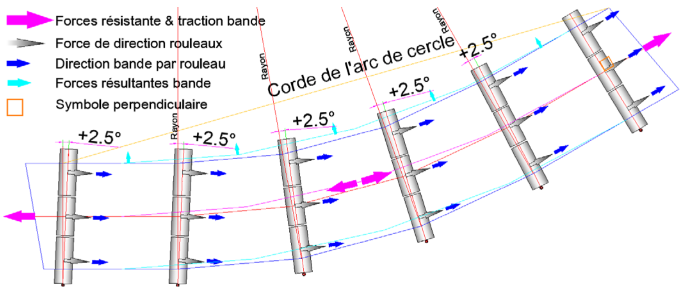


Fig.8.2: Supports facing +2.5° (e.g.), if the 0.0° orientation angle is insufficient to limit the belt drift amplitude

- If the curve has several centers, each series of supports, linked to a turn subsection (same center and radius), defines an initial reference position of supports at 0° and passing by the roller's axis of support, then an orientation angle > 0°, if necessary.
- If the curve has a complicated profile, including concave and/or convex curves, in a general horizontal, ascending and descending variable profile, the orientation angle of the supports may be different from one another, for the same curve radius of the subsection. For a given curve radius, it is the variation of belt tension and the belt load (belt, belt+product), in each curve subsection, that defines the orientation angle of supports, step by step, depending on whether the product being handled generates a driving force or a resistant force applied to the belt.

<u>Principle of the orientation angle (direction)</u>:
In a straight section of the conveyor:

- The tensile and resistant forces must be parallel to the conveyor axis and symmetrical in values, so as not to create a force torque that would drift the belt.
    - In turn sections, this balance of forces in the belt (right & left tension ≠) does not exist. This tension delta increases in proportion with the belt-width, to the other identical data.
- The rollers, in contact with the belt, must generate a steering force perfectly parallel to the conveyor axis, so as not to deviate from its belt-trajectory. This implies supports perfectly perpendicular to the conveyor axis.

In a 'bend' section:

- The tensile and resistant forces in the belt tend to bring its trajectory, in relation to the built curve (the structure in circle arc), towards the chord of this arc, disregarding the friction forces belt/rollers.
- Consequently, forces must be generated, applied to the belt, which oppose the natural tendency of its trajectory to align with this arc chord (see. fig.8.2).
    - <u>Forces «in» the belt</u>: this approach consists in reducing to the maximum the tensile and the resistant forces, in the curve to be calculated, but also on all the other sections of the conveyor, of carrier and return sides. This 1st phase involves a thorough review of all conveyor parameters, such as:
        - The belt speed;
        - The **true maximum flow rate** to be ensured (to be managed upstream),
        - The **actual nominal flow rate**, that is, the constant flow rate regularly achieved by the operator, which is often lower than the nominal flow rate of the initial specifications;
        - The mass of all components, such as pulleys and rollers, by reducing their number (those that are useless); for possible gains of 30%, 50% and more.
        - The mass of the belt by a lighter architecture, such as the thickness of the rubber coatings, the weight of the carcass with an aramid or polyester warp, against a steel;
        - Optimal distribution of drive pulleys, sometimes with the addition of a 'booster' (long conveyor whose length lengthens, e.g., behind a tunnelling machine) and 'retro-booster' with generators in the case of a large downwards section in order to regulate the tension of the belt before the turn.
    - <u>Forces "**on**" the belt</u>: here it is the steering forces generated by the rollers of turn in contact with the rolling face of the belt; thus, we should say "under" the belt:
        - <u>Reminder</u>: if, in the turn, each roller support is perpendicular to conveyor axis, because aligned with the curve radius passing by the roller-axis of support, for the short cross-section between 2 supports (½ step forward, ½ step after the support in question), so the steering forces, which they generate, help to contain the belt trajectory.

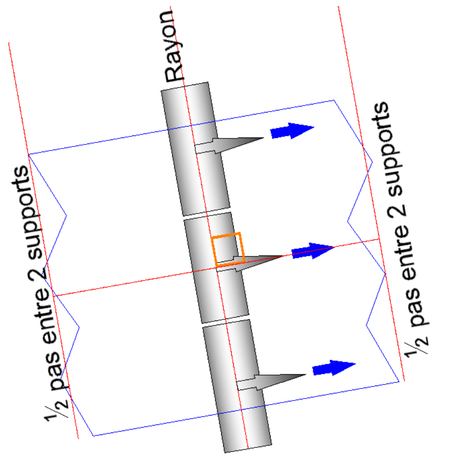


Fig.9: Curved section between 2 supports almost straight
e.g.: [48.14°/1680]= 0.028° or 1680 = nbr supports in curve

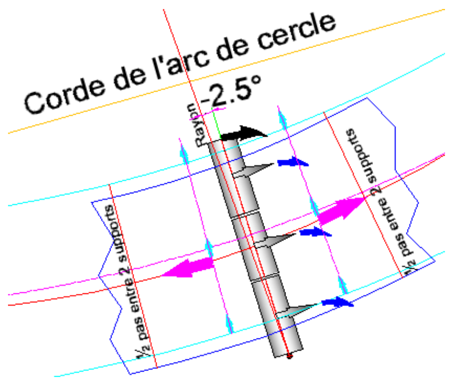


Fig.10: e.g. support orientation to contain the belt trajectory in the turn

- To generate an additional directional force on the belt, **if needed**, that opposes the tensions that drive it toward the chord, each support must be given an identical orientation so that it generates a force of opposite direction that drives the belt toward the outside of the curve.
- The calculation must define an angle of orientation that is compatible with all the operating phases of the conveyor, taking into account the variations in load and tension applied to the belt, at the beginning and end of the calculated bend... Without losing sight of the fact that the tensions in the belt, upstream and downstream of the turn, also influence the calculation results in the turn.
- Because of the fragility of the balance of the belt's trajectory, resulting from the different parameters that operate on this trajectory, it can be interesting to have a design that allows an offset amplitude greater than the standardized value; for example, for an 800 mm wide belt, allow an offset of 100 mm instead of the standardized 40 mm.

This large difference in load and tension applied to the belt is in favor of the variable orientation supports since the orientation angle adapts to the load and tension (see. fig. 7). The control of the orientation angle of rollers allows to reduce the amplitude of the belt drift compared to the fixed orientation model. This means that the weight of the side rollers can be reduced, since this system can be satisfied with rollers of standard length (same length as the middle roller of the support).

The orientation angle of the brackets is always opposite to that of the turn.

Similar to the setting of the roller(s) supports of straight sections, it seems that it is more efficient to prefer a small angle of orientation. Here, the **interaction** between the orientation and tilt angles of the supports must be taken into account, with **sudden breaks in equilibrium** depending on the values chosen (according to our calculations).
Nevertheless, in practice, an orientation angle > 0.0° would be safer (e.g.: 0.5° to 1.5°) given the difficulty of guaranteeing an orientation angle on site under a real adjustment tolerance that is too large and that could result in a negative orientation angle.

Roller supports / Pinch angle

With the exception of the 1 roller model (flat profile), all roller supports for turns can be manufactured with pinching angle as defined in ISO 1537. If the model without pinching angle is mechanically sound, the calculations must be able to take into account the case with a pinch, even if this model is counterproductive in several respects (higher resistant force, ...). Depending on the model of the supports with pinch, this can be neutralized by an appropriate wedge under the base of the support.

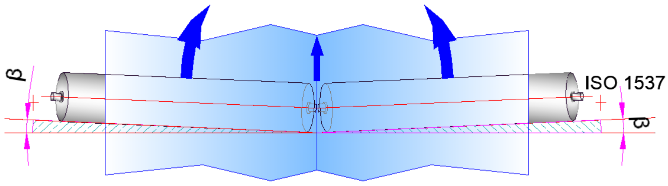


Fig.11.1: Pinch angle (top view)
Support in two sectors,

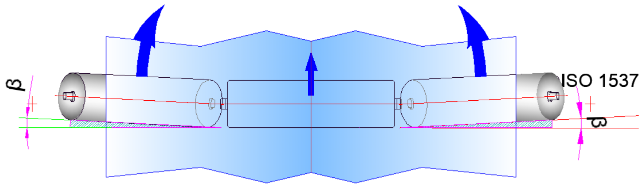


Fig.11.2: Pinch angle (top view)
Support in 3 sectors

A plausible explanation for the use of roller supports with a pinch angle in turns is the pseudo-efficiency of re-centring the belt with this type of support in use in straight sections. The principle of pinch is due to the orientation of the side rollers, in contact with the belt, which results in a convergent force at the conveyor axis, from right to left for the right-side roller, and vice versa for the opposite roller. When the belt moves to one side of the conveyor, the surface of the side roller covered by the belt increases and the steering force generated by this contact increases proportionally, while for the opposite roller it decreases inversely. As for the middle roller, it is neutral and without effect because it is supposed to be perpendicular to the conveyor axis. For straight sections, the point of rotation of the support is its middle, which coincides with the conveyor axis. This is also true for 2-roller V-shaped supports.

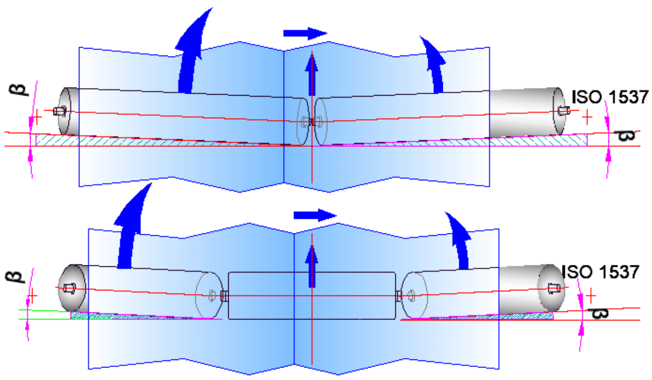


Fig.12: Belt drift for some reason
The Δ of the "steering force" tends to recenter the belt

In the case of sections at turn, in a practical (operational) way, the rotation point or reference pivot is transposed, by convention, to one end of the support (pivot = fixing bolt on the conveyor frame), on the right or left side of the conveyor (most comfortable side for metrology).

In this context, it is the support, as a block, that is adjusted according to the calculated orientation angle. Another pivot point can be taken as a reference, but this would complicate the transposition of the calculation results to the conveyor. In practice, in the **C3 Expert metrology system**, the calculated orientation angle is converted into different vector lengths (calibrated length tubes) to build a triangulation, starting from the director side, chosen on the conveyor.

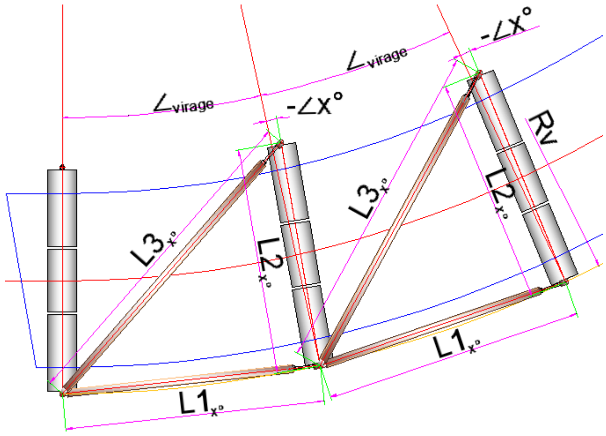


Fig.13: Angle of orientation converted into vectors

Roller supports / Tilt angle

Mini & max tilt angle / Extreme values:

The analysis of the extreme inclinations helps to understand the working principle of support inclination. In reality, the solution will be an intermediate value, which depends on a balance between several antagonistic parameters.

- Bracket extreme tilt angle = 0°:
  Support with 1 roller: in this case, only the belt/roller friction forces oppose the tension forces in the belt to prevent it from following a trajectory that tends towards the geometric-chord, independently of the orientation forces given by the supports.
  Support with a number of rollers >1(V-shaped, 3-sector trough, etc.) only the roller(s) on the inner side of the turn have a force that opposes the tension in the belt that drives it towards the chord. The effectiveness of this roller(s) depends on its trough angle.
- Bracket extreme tilt angle = 90°:
  Like a wall, a stop, the rollers of the supports, in a vertical position, oppose 100% of the tension forces in the belt to prevent it from following a trajectory that tends towards the chord of the arc. Such an arrangement requires that **the orientation angle** of the supports be 0°, since a different angle would cause the belt to rise or down in this vertical plane.
  Obviously, such an inclination reduces the permissible throughput of the belt to 0 t/h, the belt carrier side. It could be considered for the return side, if it is always empty, but in this case the difficulty would be to maintain the belt at a constant altitude throughout the turn; that is to say, many complications for little advantage..

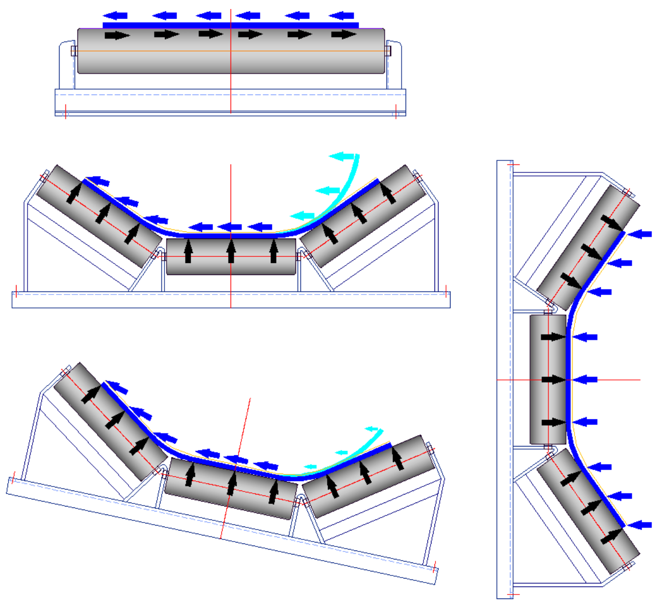


Fig.14: Belt/roller forces in the turn
Fig.14.1&2: Tilt angle 0°, flat, trough
Fig.14.3: Tilt angle 12°
Fig.14.4: Tilt angle 90°

Tilting angle of the brackets, 'loaded' strand:

The loaded belt side is usually the carrying strand; sometimes the return strand can also be loaded simultaneously and/or in different operating sequences.

The maximum permissible inclination of the supports of the loaded belt section depends on the cross-sectional profile of the belt (see # below) and on the product handled, depending on:

- Output,
- Density,
- The grain size
  - the shape of the largest grains (rather flat or spherical),
- The internal product friction, characterized by its slope angle in dynamic phase,
- The belt filling coefficient, considering a product:
  - spread to the limit set by ISO 5048 #7 ($L_{produit}$ = [(Belt width*09)-50 mm])
  - concentrated on the middle of the belt width.

Ultimately, the inclination of the support must not cause the belt to overflow with the ejection of the material being handled.

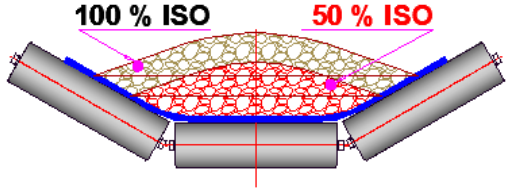


Fig.15.1: Product spread/belt width ratio

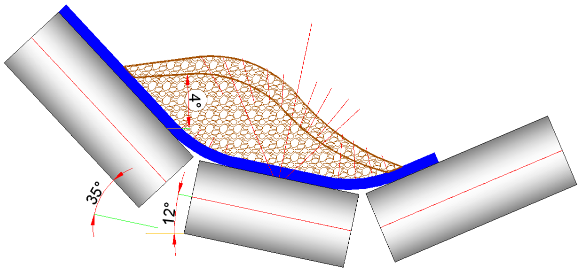


Fig.15.2: Support tilt angles, Product slide angle

The transverse stiffness of the belt is a characteristic that influences the stability of the belt in turns and defines the permissible trough angle in relation to the belt width. This stiffness should be low for good trough ability of the belt, especially for deep troughs. Conversely, there is a risk that about one third of the belt width, on the outside of the curve, will reduce its roller radial pressure on that side, or take off the roller contact at of this range to towards the opposite side (towards the curve inside). This phenomenon may not appear until several years after the belt has been put into service, with to the origin of errors on: trough transitions, convex curves, belt reversals device, inverted supports on the return strand. All these causes weaken the stiffness of the belt carcass through fatigue or deformation. This phenomenon of lifting or folding of one side of the belt in turns also depends on a higher tension on the outside of the curve for short curve radii, due to a higher Δ of belt-tension between the inside and outside edges of the belt in the curve, all other parameters being equal.

Fig.16.1: Carcass too rigid for a deep trough.
Rule: Contact belt/rollers mini = 70% belt width

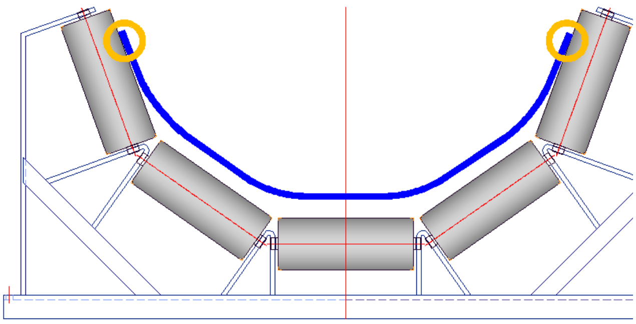


Fig.16.2: Carcass too rigid. The belt trajectory will be unstable, but it resists well to the constraints of turns.

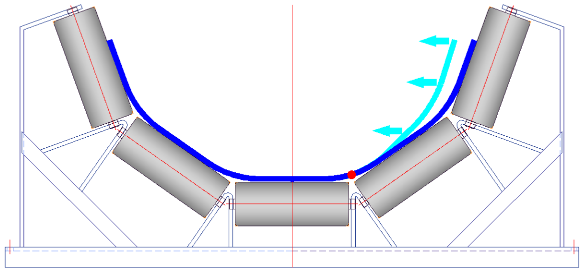


Fig.16.3: Carcass with a good trough ability, but sensitive to folding in turns

Roller supports / Transverse profile

There is a wide variety of transverse profiles for the turn supports, with, to more, the particularity feature that the length of the side rollers is sometimes greater than that of the middle roller of the support in order to allow a greater amplitude of belt drift than that permitted by ISO 15236-1 # 7.10; for example, for an 800 mm wide belt, the maximum standardized belt offset is 40 mm. The number of sectors in the carrier ranges from 1 to 5 or more. Supports with 1 (flat profile) or 2 V-shaped rollers are generally used for the return side, but in some cases the return side can be made up with a higher number of rollers (3, 4, 5, ...).

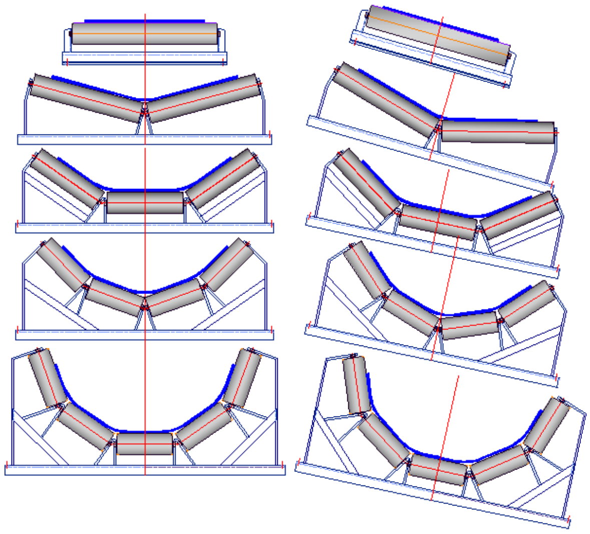


Fig.17.1: 5 usual profiles

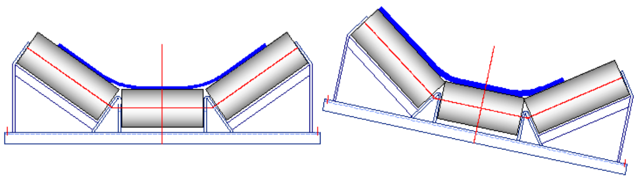


Fig.17.2: Support with longer side rollers

If, at first sight, a deep trough support, for example with 5 sectors (5 rollers), seems more efficient to control the belt trajectory in the turns, since it combines 2 types of forces, this remains relative and depends on the trough ability of the belt, which is a quality antagonistic to its resistance not to "fold" on itself, a quality that requires a sufficiently stiff weft (see. fig. 16.1 &16.2).

For example, one third of the belt width, on the outside of the turn, will have its radial support (belt/roller) on the outside of the turn, until it's lifted of the roller. In this case, the steering force of the side roller, outside the bend, drops to 0 N. This phenomenon can be observed several months after the belt has been put into service, especially on conveyors with errors in trough transitions, convex curve radii, belt reversal devices. This is the problem.

There is another pitfall in the use of deep trough supports with 5 or more rollers is when the belt drift to such an extent that the belt no longer covers the last trough roller; then, when the forces that caused this large drifting disappear, the belt can no longer re-centre itself because the belt heel comes up against the edge of the last trough roller.

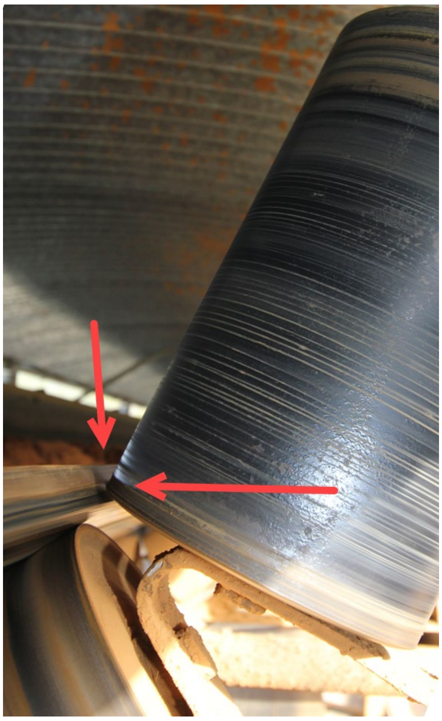


Fig.18: 5-Support with 5 rollers: the belt heel comes up against on roller edge

Roller supports / Step between supports

The turns of the conveyors, with the trough supports, are long sections that involve a large number of rollers, which means a large inertia. Good turn design should aim to reduce the number so as to reduce these inertias, which influence the belt tension and, consequently, the orientation and inclination angles of the supports.

The step, i.e. the distance, between the supports of a turn takes into account many factors, some of which are conflicting. A long step between the roller supports of the carrier strand increases the treading forces of the product, especially in the case of a product concentrated in the middle of the belt width.

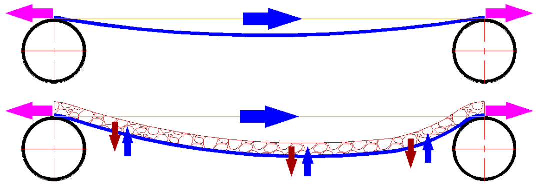


Fig.19.1: Empty: low treading force
Fig.19.2: full, significant treading force
Σ of: the load, the tension, the support steps

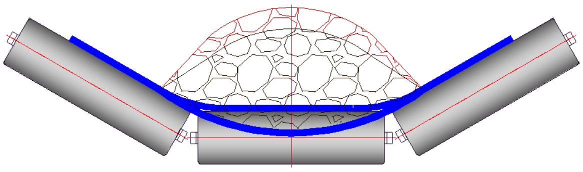
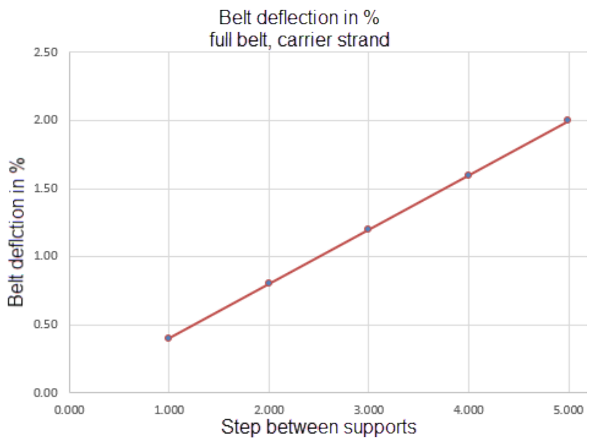


Fig.19.3: Accentuated treading when the concentrated product

A long step implies a radial force and a roll/belt arc proportionally larger than a standard short step, for a given weight and tension. A long step can be more favorable due to the reduction of the longitudinal rigidity of the belt, to perpetuate the efficiency of the steering force from the rollers.

The calculations show that a short or long pitch has little or no influence on the length of the curve radius required to guarantee the trajectory of the belt in the turn, for the same angle of orientation and/or inclination of the support. When step between supports double, radial pressure and arc of winding belt/roll double and ditto for triple pitch, etc.



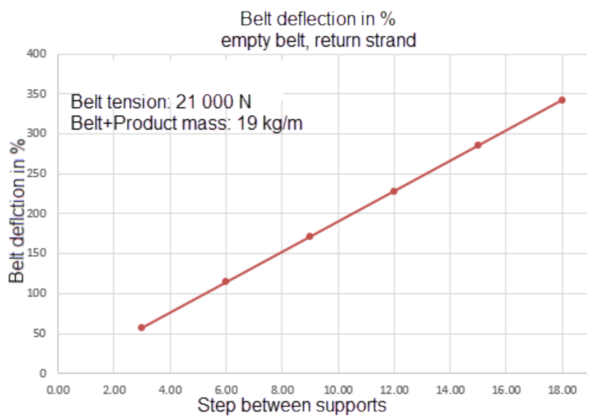


Fig.20.1, 20.2: The deflection of the belt, in %, is proportional to the step between supports and the winding arc and the belt radial force on the roller is proportional and the pressure in mm² is constant. QED

What changes in favor of a long step:

The “long step” design*:*
- Promotes good belt troughing ability; this is more true with an empty belt.
  - This allows for a stiffer belt carcass in the weft (weft reinforcement, breaker) with advantages on this architecture, including:
    - A better resistance to the phenomenon of "folding" of the belt
- Is less sensitive to the risk of belt offloading or partial (reduced radial pressure) shedding of the belt/sidewall roller contact on the outside of the turn.
  - This point includes the case of a weak web/roll contact, with a Δ of speeds between the belt and the roller peripheral speed.
    - This case is "vicious" because, on site, it is difficult to detect with the naked eye; this leads to a wrong interpretation in case of belt drifts.
- Is less sensitive to variations in the belt/roller interface between dry and wet states.
- Reduces the "longitudinal stiffness" of the belt, which improves its sensitivity to the steering forces of the rollers. This point is decisive.

Roller(s) / Without or with coated

If the standard roller design is a steel shell, it can be coated with various materials with a higher belt/roller friction coefficient, which is favorable for the steering effect of the rollers. These coatings are made of rubber, polyurethane or resin with corundum grains (e.g.: Belzona product ref. 1821).

These coatings with a higher coefficient of friction are nevertheless to be used with caution, since their wear and/or the wear of the tread liner must be taken into account, because there is always a slip of the belt. The economic approach must be taken into account and discussed in relation to the gain on the radius of the planned or built turn (existing conveyor).

The calculation must seek the best compromise between the angle of orientation, favoring a low angle of orientation, in order to reduce the wear of the cylinder shell and the stresses on their bearings (axial force) which are not calibrated for this.

The belt

In the context of a conveyor with of turns, the belt is an important element in the calculation of the different characteristics of each turn, starting with the radius of the curve, the step, the orientation and inclination angles of the supports.

In order to satisfy a handling, in relation to a product and its flow rate, density, repose angle, the belt can be studied in different widths, trough profiles and speeds. Because conveyors with turns are often very long, the choice between these 3 criteria is decisive and difficult to reverse later for the first 2 (width, cross-profile).

Belt weight:
It plays an important role in the calculations under 2 antagonistic aspects:

- Significant belt weight (kg/m):
  It is favorable for reducing the delta of the empty/loaded belt weights, especially when a high belt speed is chosen in view of the throughput to be handled with a low belt fill factor (< 50% of ISO 5048 # 7).
  In this case, the difference between the steering forces generated by the turn rollers between empty and loaded belt is relatively small. This small deviation is even more true for the side rollers in the case of handling with a product concentrated in the middle of the belt width, i.e. an almost constant contact.

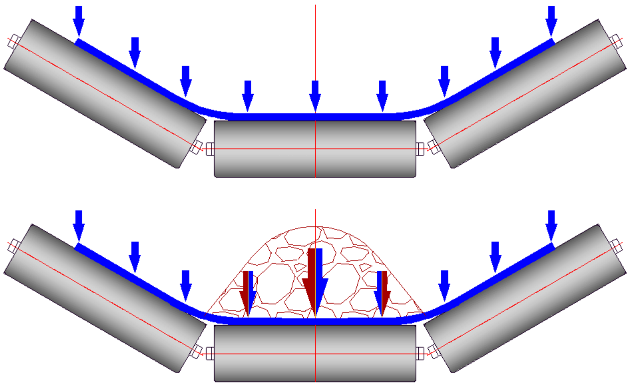


Fig.21.1: Belt radial pressure on the rollers
Fig.21.2: belt pressure on the rollers with product concentrated on the middle of the belt

In this same context, with a high belt weight for a low product weight (kg/m), there is a reduced delta of "belt tension" between empty and full belt.
This high weight of the belt has the disadvantage of penalizing all the other sections of the conveyor that are not in turn and has an unfavorable impact on the final balance of the resisting forces, the total power absorbed by the conveyor and the energy consumed.

The heavy weight of the belt is an aggravating factor when the conveyor has a large descending section. It contributes to lowering the tension of the belt at the low point of the descent and can create festoons of the belt between the supports; this tension can be close to 0 N, or even negative… **This makes the situation prohibitive**.

- Relatively low weight (kg/m):
  We find the same arguments as above but in reverse.

  Attention:
  The weight of the belt does not have a proportional relationship with its breaking strength, since its weight depends on the weight of the carcass material (steel, aramid, polyester), the presence or absence of weft reinforcements, and the thickness and quality of its rubber covers.

Trough ability:
As for the weight criterion, the troughing ability of the belt (ISO 703-1) must satisfy two antagonistic aspects.

- High troughing ability ensures that the belt will have good contact on all the trough rollers (ideally at least 70% of its width). Troughing ability will necessarily be higher for a deep trough. This high troughing ability makes the belt more sensitive to the detachment of the side rollers on the outside of the curve; a detachment (shedding of the contact) makes these rollers inoperative in terms of steering force applied to the belt (see. fig. 16.3).
- Conversely, a poor ability to be lowered into a trough (significant transverse stiffness) strikes the belt/roller contact to the point that the belt can have an unstable trajectory, especially empty, even in straight sections, because its support is limited to its 2 edges or heels. The effect of such stiffness can be mitigated by an increase in pitch between supports. This transverse stiffness makes the belt less sensitive to a detachment of the lateral rollers, the outer side of the curve, which guarantees the directional effect of these rollers (see: fig.16.1 & 16.2)... To do so, there must be a contact belt/roller (70%)!
  A new belt may have good troughing ability for a given width and cross-profile, but as it ages it may become stiffer and have an unmanageable trajectory. This is more true for thick coating rubber with a rubber quality that hardens over time (aggravating factors: sun, heat, ozone), especially when this hardening is stronger on the carrier side than on the running side. This state corresponds to a loss of elasticity. This accelerated ageing of the rubber, from 60-63 Shore A to > 75 Shore A, can be caused by hoods that cover the entire conveyor and whose design creates a confined space between belt and hood. An outer face of the cover without solar radiation treatment can raise the temperature under the cover to ≈85°C... Or the skill and style to do cook the cover rubber of the belt.

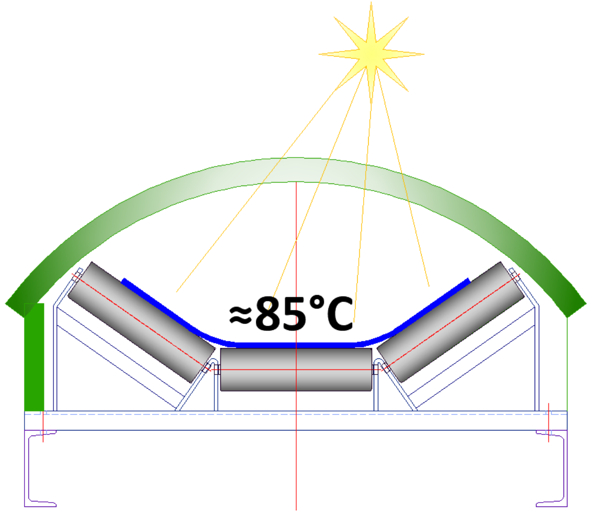


Fig.22: Confined space/ Temperature under the hood

Attention:
For the same belt architecture, its width influences its troughing ability. A good troughing ability can be seen with a width of 1000 mm and too much stiffness with a width of 800 mm. The same belt, with a width of 800 mm, can have a good troughing ability for a shallow trough (e.g.: 30° instead of 40°)

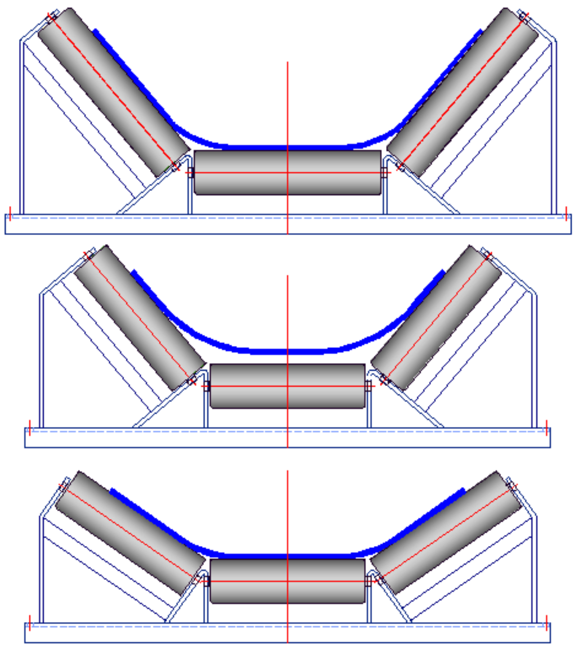


Fig.23.1: 1000 mm wide belt, 45° trough: OK
Fig.23.2: 800 mm wide belt, 45° trough: No
Fig.23.3: 800 mm wide belt, 30° trough: OK

Attention:
For conveyors with long curved sections, it is expensive and sometimes difficult to replace the original supports with supports with a profile better suited to the belt.

Coating thickness and weft reinforcement(s):
These two criteria that define the belt are described in the previous paragraphs. They mainly contribute to the weight of the belt and its suitability for troughing and/or its transverse stiffness. The Weft

reinforcements or breaker(s) give of the transverse stiffness and weight. These elements also add improved stapling strength, which can be considered a significant advantage in the event of a breakdown.

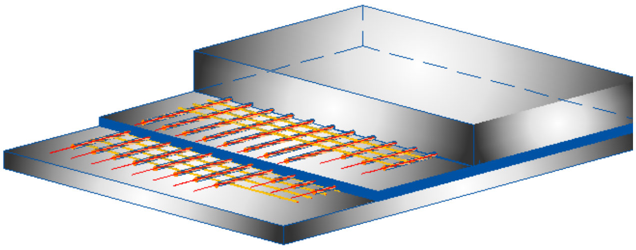


Fig.24.1: 2 ply polyester 'straight warp' + 2 wefts

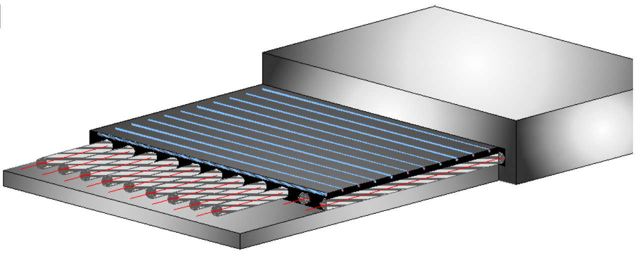


Fig.24.2: Steel cord' + 1 steel weft

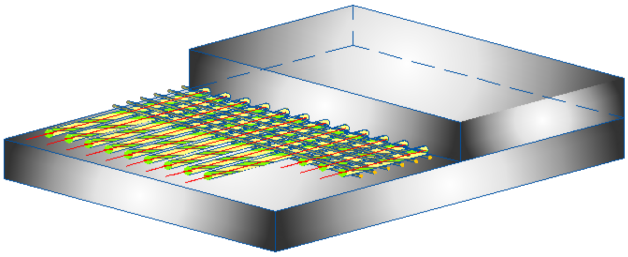


Fig.24.3: Aramid warp + 1 breaker

The carcass:
Usually, the overland conveyors with large lengths are equipped of belt with steel cord carcass. It is mainly in this range of conveyors that configurations with turns are found. However, it is worth remembering that a steel cord carcass can be advantageously replaced by a polyester straight warp(s), for lengths up to 1500 - 2000 m or more (to be calculated), depending on the overall configuration, and an aramid carcass beyond that. Although aramid is expensive, in today's tight market, the technical and economic study can show significant advantages. The low weight of the aramid carcass is an incentive to redesign the entire conveyor and check if a lower breaking strength of the belt can be considered (e.g.: 1st calculation: St 2500 N/mm in steel, 2nd calculation: D 1600 N/mm in aramid) for a lower elastic elongation in favor of aramid and a lower purchase cost compared to an aramid belt of 2500 N/mm.

Other advantages of the aramid carcass concern a more global approach to the calculation of the conveyor by reducing the inertia, the tensions in the belt. This is very relevant in the case of a conveyor with a large descending section.

The width:
The overland conveyors have the particularity of being designed with a narrow belt width associated with a high speed, so as to require the lowest possible breaking strength (reduced product load in kg/m) and thus control the construction costs of the conveyor... but beware of the operating costs (energy cost consumed, ...). When these long conveyors have curves, some designers increase the width of the belt so that the product handled is contained in the middle third of its width and so that the side sections, right and left, are always empty, for thus maintaining a constant belt/side roller radial pressure ≈ (see. fig.20.1 & 20.2).

The width of the belt meets several constraints such as those developed in the preceding paragraphs.

Once the belt width is set, it is almost impossible to change the belt width later.

The product being handled

In the context of a conveyor with of turns, special attention should be paid to the product to be handled, as it has a major influence on the parameters of the turn.

The product flow rate:
This particular attention is first of all focused on the real flow rate(s) to be handled.

From experience, we know that, very often, the specifications mention peak flow rates or extravagant dimensioning flow rates, because these will never be reached and by far.

It should be remembered that the person who calculates the conveyor is obliged to do so with the values in the specifications. A maximum flow rate, whether peak or design, that is 20% higher than the nominal flow rate should draw the attention of the project partners to do everything possible to limit and regulate this maximum flow rate, upstream of the conveyor to be calculated and, quite simply, to define realistic values.

Sometimes, from the beginning of the project, the operator knows that the flow rate will change over time, in 5-10 years or more. In this case, it is relevant to make several simulations with these flow evolutions. The easiest way is to increase the speed of the band over time. Other solutions consist in adding boosters and retro-boosters + generators at particular points of the conveyor to maintain constant tensions in the belt, without increasing its speed (= energy saving).

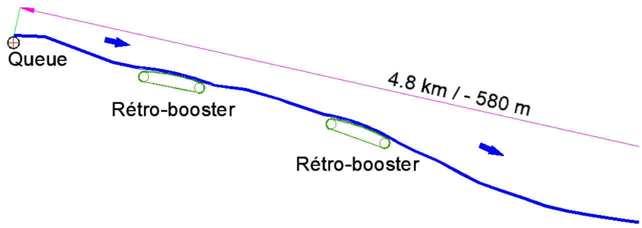


Fig.25.1: Long down section with 2 retro-boosters and 8 self-driving generators

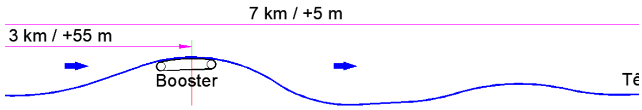


Fig.25.2: Long rolling centre distance with 1 booster

The boosters and retro-boosters can be used on conveyors that lengthen over time, e.g. a conveyor serving a tunnel boring machine, for a mine with an expanding mining field.

The influence of the conveyor flow rate is not limited to the turn itself, but also concerns its influence upstream and downstream of the turn. For example, in the case of a large downhill section before the bend, or included in the bend, the product handled generates a driving force that accelerates the speed of the belt, through its elastic elongation, so that at the bottom of the descent its tension is close to 0 N or even negative.

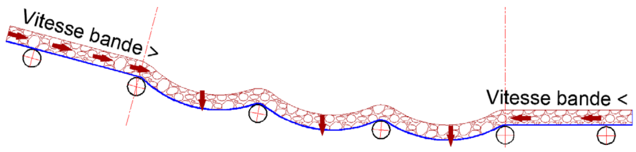


Fig.26: V_{belt}↗ ,T_{belt}↘ = Festons at the bottom of the descent

A reduced flow rate, in compliance with the need, will reduce the phenomenon of overspeed of the belt that causes festoons at the bottom of the run. The need for retro-boosters can only be verified by calculation. Furthermore, an ascending section, upstream of the bend, implies a significant resistive force, and therefore tension, in the belt, which strongly influences the parameters of the bend, particularly when the upstream section is full and the bend is empty. Only calculations can verify the need to install boosters.

In short, the flow rate has a greater or lesser influence on the parameters of the turn depending on the load of the product on the belt upstream, in and downstream of the bend.

<u>The product angle of repose</u>:
The product angle of repose, in the dynamic phase, determines the trough angle of the side roller of the support, the carrier strand, of the turns. This angle of repose limits the angle of inclination of the supports, so as not to risk a spillover of the product out of the belt (see. fig.15.2).

It is also necessary to take into account the presence of blocks in the product that could be placed on the pile (in the middle or at the edge). This mainly concerns spherical blocks, as they are easy to roll. As above, the angle of inclination of the supports should be such that spherical blocks are not thrown off the belt.

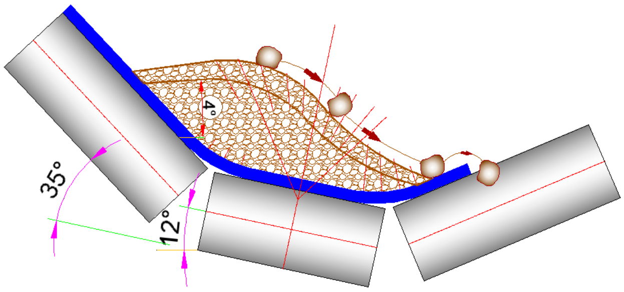


Fig.27.1: Blocks that roll and are ejected from the belt

There are products of the thixotropic type, characterized by a very high static angle of repose and a dynamic angle of repose close to 0°; this zero angle considerably limits the admissible angle of inclination of the supports.

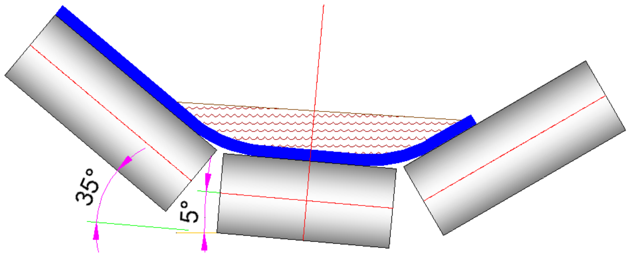


Fig.27.2: Thixotropic product: 0° dynamic slope angle

<u>Other product characteristics</u>:
The other characteristics of the product handled have little or no influence on the turn parameters.

The calculation of turns

From a calculation point of view, a conveyor turn is always considered as 2 distinct turns (the one of the carrying strand, the one of the return strand), even if they have the same radius (see # parallel and superimposed bends); the treatment must be completed by the coupled calculation of these 2 bends to define a common radius.

The first essential action, for a rational and efficient approach to the calculation of the turns of a conveyor, after the revision of the specifications, in particular on the value of the flow rates, **consists in optimizing the design of the conveyor in its entirety**, for all its components, including the belt, **so as to reduce the resisting forces as much as possible**. This approach is explained in detail in our various articles already published. Obviously, it is easier to reach a very high level of optimization with a conveyor in project, than for an existing conveyor which imposes many constraints and high modification costs.

In concrete terms, to achieve this first objective of the best optimization, **C3 Expert** offers training adapted to the subject and a license for its C3v22® software, or the study and calculation services necessary to carry out this first phase.

The 2nd action, always in the case of long conveyors, consists of studying various solutions for the layout of the drive pulley(s), so as to **control the tensions** in the belt with **the lowest possible values in the turns**, so as to be able to admit small curve radii. Conversely, the higher the maximum potential belt tension, the larger the turn radius. Here, both the carrying and return strand must be considered equally, and the largest calculated radius which is proof.

For example, a long conveyor of several kilometers, with a long and very steep first downhill section, equipped with a single drive pulley at the tail (the usual concept), means that the stresses and tensions in the belt will be more difficult to manage on the return side than on the carrying side. In other words, such a conveyor may require a larger turn radius for the return side than the one corresponding to the carrying side.

Since they are always very long conveyors, it may be interesting to provide one or more boosters, type of cassette with convex profile, installed gradually, carrier strand and/or return strand, in order to lower the tension of the belt in the bends for a better control of its trajectory with possibly shorter spokes (see: fig.24.2).

In the same way, in the case of a very large downhill section with a high gradient, it is interesting to install one or more retro-boosters with their generators so as to brake the belt and control its tension at the bottom of the descent to eliminate the risk of festoons (see: Fig. 24.1).

Here again C3 Expert offers you its training and calculation resources. For example, our calculations and engineering have enabled us to reduce the moving masses of one conveyor from 833 t to 425 t! In the same way and on the basis of Newton's law $E=1/2\ m^*V^2$, the calculation allowed us to reduce the initial speed of the belt from 3.6 m/s to 2.0 m/s, for, in the end, a good control of the bends and a strong energy saving in perspective. Who can say better?

After these two preliminaries, the minimum and maximum tensions at the beginning and end of the turns should be extracted from the general calculation of the conveyor.

- For a constant turn profile, it can be considered that the tension evolution in the belt is linear throughout the curve section.
- In the case of a turn with a varied and by definition complicated profile, it is necessary to develop intermediate calculations to establish the minimum and maximum tensions for each homogeneous subsection of the turn.

All these belt tension values are then fed into our specific C3HC software for the calculation of all each turn parameters. Through various iterations, the C3HC software harmonizes the results in such a way that the belt trajectory controlled, both for the carrying and return strands, for parallel superimposed (see Fig. 5.1) or parallel side-by-side (see Fig. 5.2).

Transposition of in situ calculation results

The best calculation or drawing will not give a reliable result if the implementation on the conveyor is not carried out with adequate procedure and means, knowing that the adjustments of the turn roller supports require tolerances of +/- 0.3° - 0.2° or even less.

If the conveyor frame with its turn radius, from a few hundred meters to several kilometres, is built under the supervision of the surveyor, during its construction, the adjustment of the initial neutral position of each turn roller support, (in coincidence with the radius of the curve passing through the axis of the rollers of each support), and then of their orientation, according to the calculated angle, is less easy to master. The difficulties in making these adjustments are all the more true for an existing conveyor, because of the hoods and other obstacles that have been added over time (conveyor components, various constructions, trees and brush, etc.), to which are added the difficulties of access along the conveyor.

To meet this essential need, C3 Expert has developed a rigorous procedure associated with a metrology tool, which can be adapted to the conveyor as it is (with the hoods in place) as long as the roller supports are accessible. Our metrology system requires simple training, the enclosed instructions being sufficiently explicit for the operators to be autonomous; nevertheless this adjustment work requires rigour.

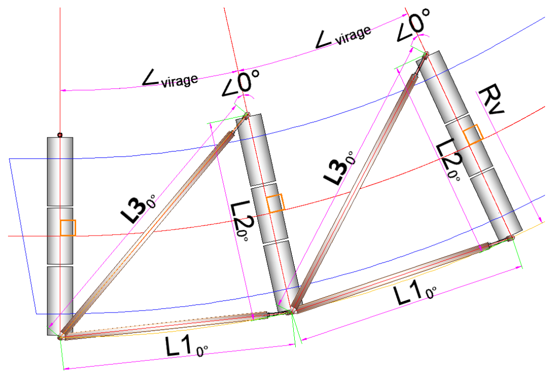


Fig.28.1: adjustment supports on radius of turn

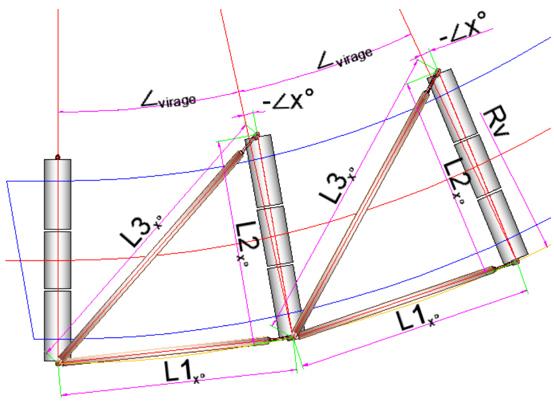


Fig.28.1: added calculated angle of orientation

CONCLUSION

Calculating and controlling the belt trajectory of conveyors with turns is probably the most complex subject in the field of material handling.

The success of a project, whether it is a new construction or the refurbishment of an existing machine, requires a thorough knowledge of conveyor and belt technology. This means taking into account the constraints of the project and being able to negotiate with the customer those that can be revised in the interest of the project, such as flow rates.

Once the project is established in detail, it will be difficult and costly to change the characteristics later.

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NB: *We look forward to your comments on this text. Its publication establishes the state of the art.*