## You operate a conveyor with a large descending section which is affected by different disorders!

# Belt mastery at the low point of a large descending section of overland conveyor

## <u>Description et disorders</u> :



Whether the conveyor is a few hundred meters or several kilometres long (10 - 20 kms, ...), whose longitudinal profile contains a large descending section, with a significant difference in level, followed by more or less horizontal and/or ascending sections, which generate a significant resisting force, it appears that **this type of conveyor is often affected by disorders, at the low point of the descent**, which disturb their operation.

These disorders are the **ejection of the handling product** and/or the formation of **belt scalloped**[(1)] between idlers of the carrier side which blocks production ; there is also a **belt loop** in **front of the head pulley**, cause of damages.

Because there is seldom a separating plate between the carrier and the return side, the web of the carrier strand, during the formation of the scallopeds, pinches the web of the return strand, which blocks it instantly. When this separating plate exists, the idlers lie down, are torn off, over a more or less important distance, under the push of the belt scallopeds formed in front of each idler.

The **first response** of the operators of this type of conveyor **consists in reducing the handled flow** in proportions that are often very important; for example, by loading the belt at **less than 50%** of its nominal flow.

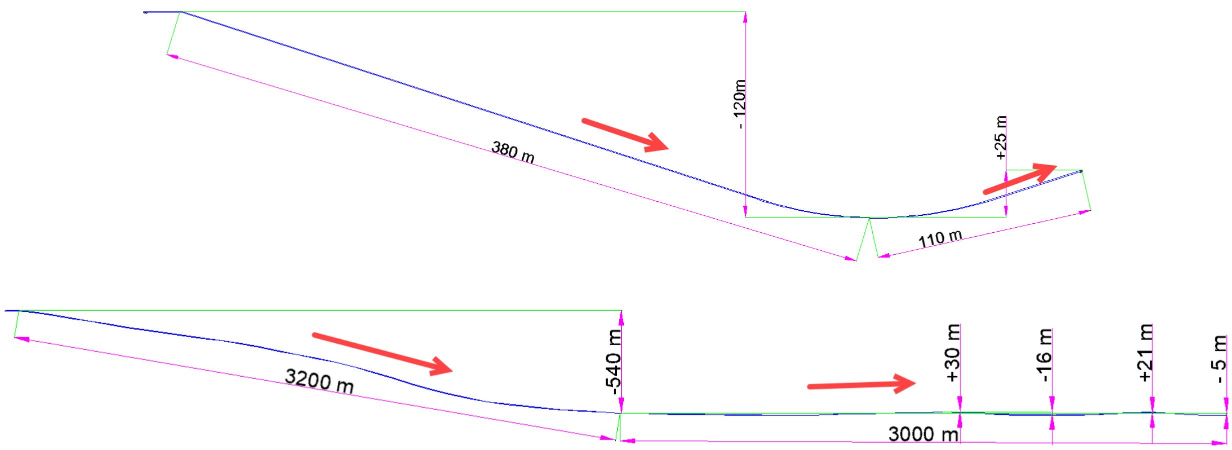


**Fig.1.1 & 1.2** : Longitudinal profile of a conveyor with a steep downhill section

*What must be remembered from this typical case is that the **belt is affected by a maximum "excess length"** at the **low point of the long descent**, originating from its **strong elongation** at the beginning of the descending section, and this **excess length cannot be instantly absorbed** by a **higher speed of the sections following** this low point.*

## Examples in the world

__Scallopeds__ between idlers, at the descent **__low point__**:

| | center distance | vertical drop |
|---|---|---|
| • Algéria 1 : | **490 m**, | **-120 m** |
| • Algérie 2 : | **450 m**, | **-125 m** |
| • Ghana : | **7.2 km**, | **-1 520 m** |
| • New-Caledonia: | **7 km**, d | **-415 m** |
| • New-Caledonia: | **11 km**, | **-550 m** |

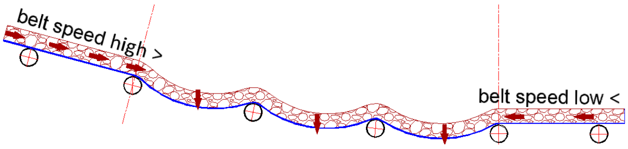


**Fig.2.1** : Formation of **scallopeds** at the low point of the descent

The 2 conveyors *Algeria 1* and *Algeria 2* have a parallel longitudinal profile, with a difference in altitude of their head pulley of ≈ 10 m which seems minimal, but which. is sufficient to show a difference in the quantity of products ejected at the low point of the descent.

**__Loop in front of the head pulley__**:

- France / quarry: center distance 603 m, vertical drop – 80 m ; la boucle se forme au freinage ;
- France / underground mine: center distance 1.5 km, vertical drop –200 m; the loop is almost permanent.

The case with a **belt "loop"** in **front of the head pulley**, corresponds to a constantly descending longitudinal profile, with sometimes short horizontal or ascending sections which generate resistant forces too weak to hold back the belt in descending sections.

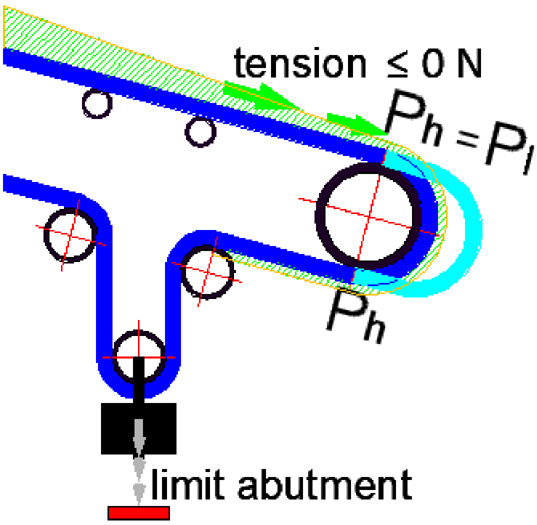


**Fig.2.2** : Formation of a loop in front of the head pulley
The tensioning pulley is at the limit abutment

There are other similar cases characterised by the formation of scallopeds in the concave curve that precedes an ascending conveyor section. This case concerns storage conveyors with a pouring trolley. This case does not apply to this article.

## Belt mechanics

__The context__

The belt starts at a point $P_t$, at the tail pulley at the top of the descent, passes through a point $P_l$ at the bottom of the descent (which may also be the head pulley), at point $P_l$ to the head pulley at an altitude often lower than $P_l$, but not necessarily, to return, via the return strand, to point $P_t$ via point $P_l$. This description shows that the belt is a single entity; it is an endless bel.

__The mechanical reality according to the configuration__

Regardless of the belt carcass architecture, its elongation is proportional to the forces applied to it, all other things being equal. The analysis must distinguish, section by section, whether the elongation originates from the traction of a mechanical component (drive pulley, booster) or from the gravity forces generated by the product handled in the descending section.

Red zone = taut strand, pulled by drive pulley
Green zone = slack strand, pushed by drive pulley or product
$P_t$: tail pulley; **$P_l$**: low point; **$P_h$** : head pulley

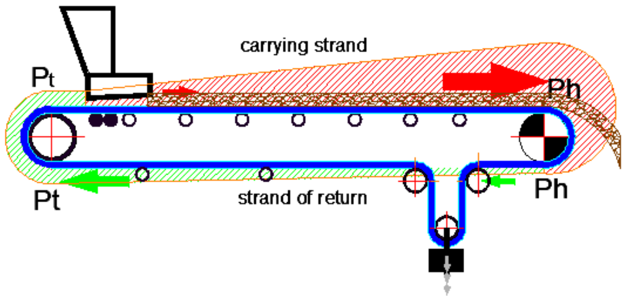


**Fig.3.1** : Common horizontal conveyor
The belt tension increases from tail to head
The carrier strand is taut, the return strand is slack

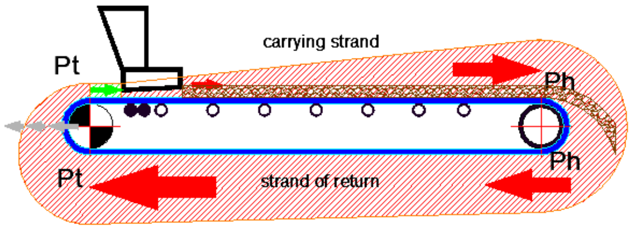


**Fig.3.2** : idem 3.1 with drive pulley in tail
The belt tension increases from the tail to the head and it increases even more from the head to the tail in return strand
From the feeding to the tail pulley via the head, the belt is always taut.

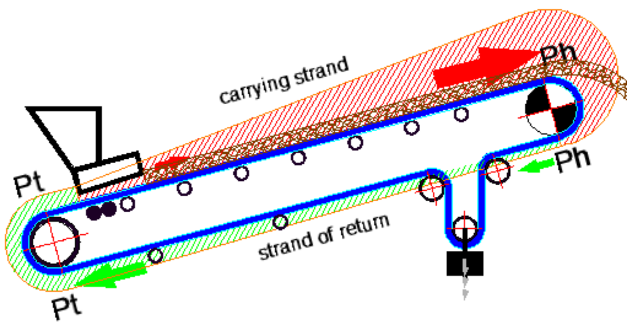


**Fig.3.3** : Common ascending conveyor
The belt tension in increases from tail to head
The carrying strand is taut, the return strand is slack

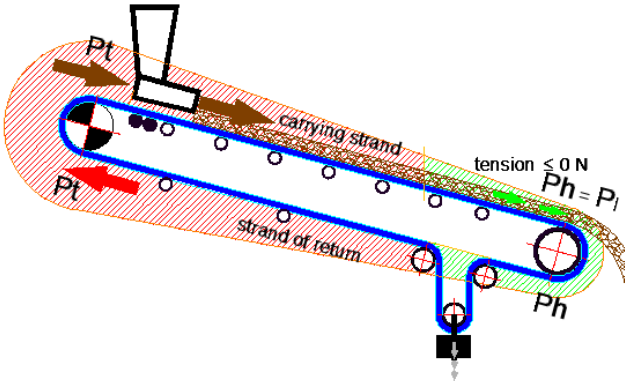


**Fig.3.4** : Common downward conveyor with drive pulley at the tail. The **product pushes** the belt towards the bottom of the conveyor. At the top, the belt tension tends to 0 N

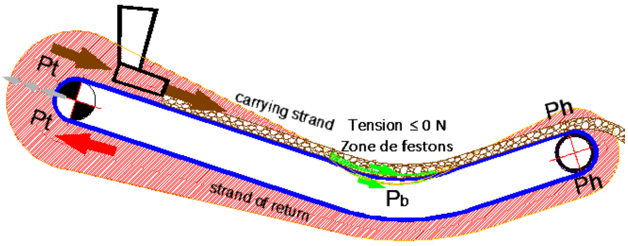


**Fig.3.5** : Conveyor with a steep downhill section followed by an uphill section.
In the descending section **the product pushes** the belt; in the ascending section the **drive pulley pulls** the belt.

Accuracy:

- figures 3.1 to 3.3 : the handled product generates a **resisting force;**
- figure 3.4 : the handled product generates a **driving force;**
- figure 3.5 : the handled **product generates a driving force** in the **descending section** and **a resisting force** in the **ascending section**.

**When the product pushes the belt, beware of scallopeds!**
Preventing "*scallopeds*" and "*loop*" consists in mastering the belt elongation in the downstream section.

What makes the belt lengthen?

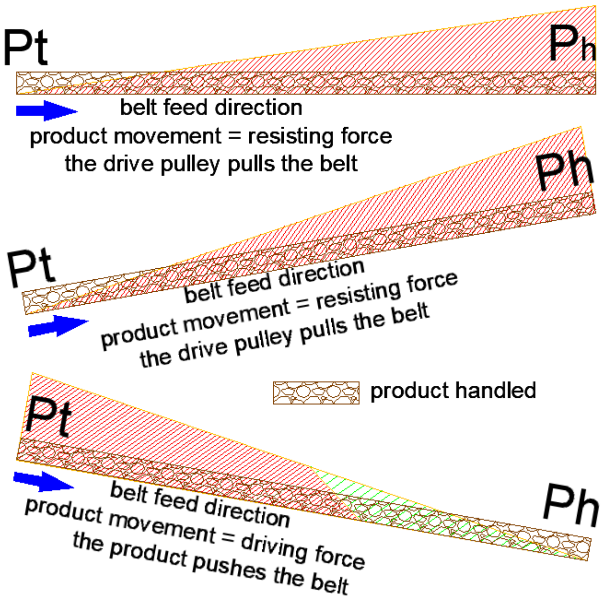


**Fig.3.6** : Distinction between "resisting" and "driving" force generated by the product
Green zone: the belt tension tends towards 0 N

The belt is an apparently monolithic entity. In reality, in the dynamic phase, the length of each belt section varies more or less than its static length[(2)]. It is necessary to "mark out" each section, carrier strand and return strand, according to the belt forces applied and its RMBT[(3)]. It comes to:

- forces generated by the displacement of the product of the different sections (resisting or driving);
- of tensile forces generated by the drive pulley(s) or auxiliary driving equipment;
- of all resisting forces (rollers, belt/idler, etc):

Then the **belt elongations** in relation to its initial length (statically) in the descending section must be calculated[(4)] according to the **elasticity**[(5)] of the **warp ropes**[(6)]. in particular, between the different operating phases which depends, essentially, on:

- the mass of product handled:
  - when empty, at x% and 100% of the nominal flow rate, at peak and design flow rate (contractual value);
- the height of the vertical drop;
- the length of the descending section;
- the belt mass;
- the belt speed;
- the RMBT, depending on the selected flow rate and the pre-tension[(7)] actually applied.
- ... minus belt/idler and internal roller friction, for downhill sections.

## Belt scallopeds and belt loop conditions

The formation of scallopeds, at the low point of a descending section or a loop, in front of the head pulley of a descending section, is subject to the same mechanical constraints characterised by:

- a strong belt elongation in the descending section;
- a belt elongation or "excess-length" of the belt that accumulates at the low point of the descent (concave curve, head pulley);
- an excess-length that cannot be instantly absorbed by the belt moving:
  - of the following sections, carrying strand, for scallopeds:
    - Installing a booster[(8.1)] immediately after the low point of the descent, to absorb them, only moves the scallopeds formation area immediately after the booster;
  - the following sections, return strand, for the loop in front of the head pulley
    - the excess-length of the web should not be expected to be absorbed by moving the tensioning pulley, which at this point is still at the limit abutment... because the calculations did not foresee such a large elongation.

## Excess-length, belt tension and scallopeds

For a given distance between 2 supports corresponds a precise belt length of catenary profile[9], according to its deflection which depends on the parameters of the formula, i.e. d = [(P²*m*g) / (8 * T)], where **P** = pitch between supports, **m** = belt+product mass, **g** = 9.81, **8** = formula, **T** = belt tension.

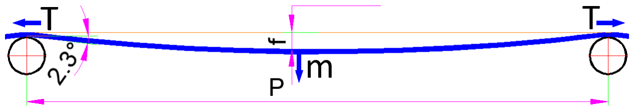


**Fig.4** : Catenary profile of the belt
Representation with a deflection of 2 % of the pitch

If the length of the belt increases between 2 supports, its deflection increases and, simultaneously, its tension decreases. Beyond a deflection of 2% of the pitch, the scallopeds begin..

## RMBT, elongation, elasticity, tension

The RMBT at the point of observation determines the absolute elongation as a function of the elasticity of the belt carcass warp, characterised by its % elongation under reference load.
The absolute elongation of a steel cord, at 0.23% elastic elongation, and a polyester fabric (E) at 0.9% elastic, for a given RMBT of 100%, are

- steel cord = [1,000*0.23%] = 0.0023 m = 2.3 mm/m
- E-mesh = [1.000*0.90%] = 0.0090 m = 9.0 mm/m

This elongation, metre by metre, second by second, accumulates at the bottom of the descent. This excess-length causes the tension in the belt to drop.

Let us not lose sight of the fact that at the beginning of the descent and the upstream sections the RMBT in the belt is very high (often ≥ 200 %) and then it decreases and tends towards 0 at the bottom of the descent. These elongations of the upstream sections are "pushed" to the bottom of the descent.

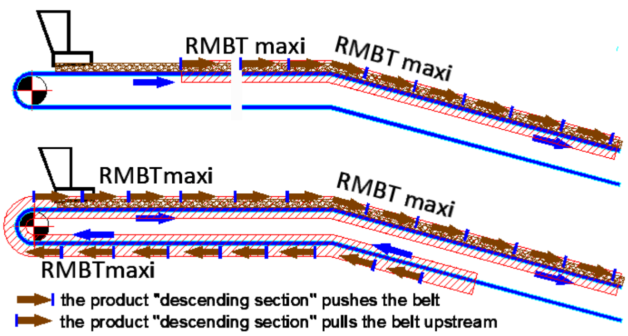


**Fig.5.1 & 5.2** : influence d'une RMBT très élevée sur une distance plus ou moins importante en amont du début de la descente

## Aggravating factor at the scallopeds formation

At the low point of the descending section, a decreasing tension in the belt, with all other parameters constant, implies an increase in the fulling forces which further slowdown the belt's advance in this area of the conveyor. These different factors combine to initiate the sudden, instantaneous formation of the scallopeds that lead to the complete blockage of the belt.

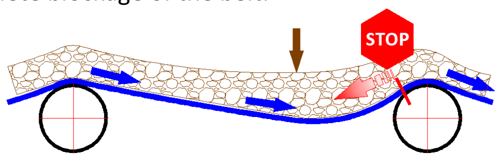


**Fig.6** : the fulling force opposes the belt's advance

## Kinetics[10] of the belt

Understand the formation of belt scallopeds at the bottom of a descending section, by analysing its kinetics:

- Consider a conveyor frame with its roller supports, with a longitudinal profile similar to figure 3.5, on which a loaded conveyor belt (such as 1 fluid) moves easily;
- gravity causes the loaded belt to move naturally down the descending section (fig. 3.6.3), without the need for any additional driving element, as soon as the resistant forces of the rollers and belt/roller friction are exceeded by the force of gravity due to the product alone:

**due to the product alone! Why? Because**:

- the "driving" force, due to gravity, generated by the belt alone (empty), carrying strand, in the downhill direction, balances with the "resisting" ones (in the opposite direction) of the return strand, opposite, in the uphill direction, with more resistance due to a greater number of rollers;

- We deduce that at the bottom of the descent, there is an "energy" due to the product handled; in other words, an available force that should "push" the belt sections of the downstream sections and prevent the formation of festoons:

**Well, no! Why?**

- Because the belt is flexible in the longitudinal direction (it is warp on small Ø drums). This flexibility does not allow the downstream belt sections to be pushed with a resistant force... as would a rigid beam.
  - In fact, the belt section, at the low point of the descent, bends in front of the section immediately downstream to form the famous scallopeds:
    - ✓ downwards, if the pitch of the idlers is large
    - ✓ upwards, if the pitch of the supports is very short (packed tight rollers).

4

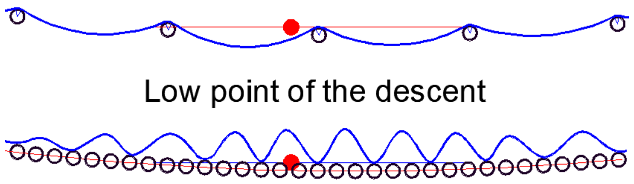


**Fig.7.1** : Common pitch between idlers = scallopeds downwards;
**Fig. 7.2** : short pitch between idlers = scallopeds up

**But the demonstration is missing some elements!**
**... for the scallopeds to form.**
**You need a "delta of speed"!**

In fact, a higher belt speed is needed at the bottom point of the descent than in the next section, both for the scallopeds and for the belt loop at the head pulley.

The speeds:

- After start-up, at the end of the acceleration phase, the belt reaches its nominal speed, with **minute variations** along the conveyor, which are difficult to measure, but very real.
  - These speed variations are due to the elongation of the belt, depending on its elasticity and the load applied at point P, at time T. The belt is pulled by the drive pulley or pushed by the product in the downstream section.
- Because these variations are very small, **a constant belt speed is assumed**, which is derived from the speed of the drive pulley. These speed variations are difficult to measure.

**except that**:

- in the downhill section, the product mass pushes the belt giving it a specific speed which is decorrelate to the reference speed of the conveyor...

Under the push of the product, the belt speed:

- **would theoretically be lower** than the reference speed: **no scallopeds or** loops will be formed.
- **is actually higher** than the **speed of the section following** the low point of the descent: **scallopeds or looped material is formed** at the head pulley.

The overspeed, how and where?

- The **greatest forces** are found at the **beginning of the downhill section**, depending on the amount of product on the belt.
  - the force from the product weight handled is the sum of this product weight, metre by metre, counted from the bottom of the downhill section to the beginning of this section.
    - This is why a loop can be seen at the bottom point of the run, front of the head pulley, even if this area at the end of the run is empty... if those upstream are full.

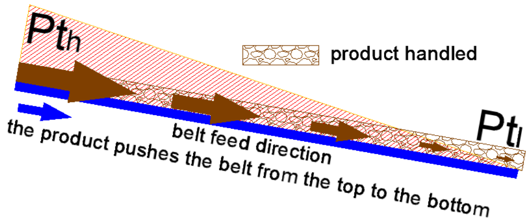


**Fig.8** :

Belt elongations and tensions

Pt$_h$ (high point) : area of higher tension = greater elongation
Pt$_b$ (low point) : area of lower tension and accumulation of elongation from the upper area

- This great force, at the beginning of the descent, decreases towards the bottom of the descent. In the same logic, the belt lengthening is more important for this section, extended to the previous sections (see. Figs.5.1 & 5.2), then in a more and more reduced amplitude which tends towards "0" while approaching the bottom of the descent.
- This belt **excess-length**, which is very important at the beginning of the descent, **propagates towards the bottom** of the descent (law of gravity), "**pushing**" the belt downstream sections, but only in the descent.
- This **excess-length creates the belt overspeed**; it is greater at the bottom point of the descent.
  - In fact, throughout the downhill section, each tiny excess-length, metre by metre of belt, creates a tiny overspeed, which adds up to the low point, because the belt is free to move downhill, until it reaches a significant overspeed compared to the speed of the next belt section;
  - this **overspeed** and the corresponding belt **excess-length** at the low point **dissipate in scallopeds, since the belt is not a rigid beam**
    - This belt **excess-length** at the low point causes it to be "**under-tensioning**", resulting in a significant deflection (see Figs. 9.1 & 9.2) corresponding to the **scalloped field**.

The same principle applies when forming a belt loop in front of the head pulley in relation to the next section of the return strand.

Example:

- overspeed of 0.01 m/s
- belt excess-length after:
  - 1 s : [0.01 * 1] = 0.01 m = 10 mm
  - 10 s : [0.01 * 10] = 0.01 m = 100 mm
  - 20 s : [0.01 * 20] = 0.01 m = 200 mm

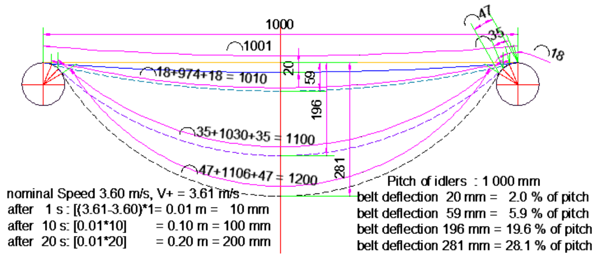


**Fig.9.1** : belt deflection, with 1.0 m pitch between idlers belt deflection at 2% of pitch, i.e. the maximum permissible (ISO 5048#5.3.3), then with an excess-length of 10, 100, 200 mm, i.e. a deflection of **5.9**, **19.6**, **28.1**% of pitch respectively.

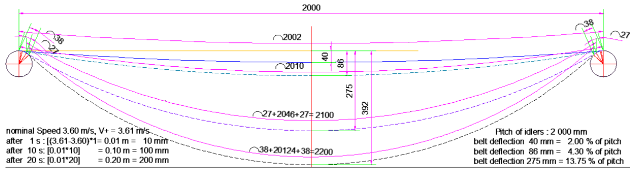


**Fig.9.2** : idem fig.9.1, with a pitch of 2 m between idlers, i.e. a deflection: **4.3**, **13.7**, **19.6** % of the pitch respectively.

Nota : **Figure 9.2** seems more favourable, but by increasing the pitch between idlers, for the same load (belt+product) and the same deflection in % of pitch, the tension in the belt must be increased. The solution is to be calculated.

## Measures to belt control

In order to prevent scalloped or looped, the belt should be controlled and the relevant parameters should be measured.

Speed measurement

The speed of the belt should be measured at the low point of the descent and at the beginning of the next section, where the probability of a speed delta is highest, with :

- tachometers with a sensitivity of the order of 0.001 m/s
  - If such tachometers exist, the uncertainties and hazards of on-site measurement must be taken into account, which must be extremely small.
  - The real problem that makes this type of measurement fail is the "steering method" of the belt and the "time delta" between the moment of the observation of an overspeed, the reaction, even instantaneous, of the mechanical steering system (control pulley, brake, etc.) and the propagation of the corrective effect at the low point of the descent, several hundred or thousands of metres away.
    - Placing a driving device just after the low point of the descent only moves the scallopeds a few metres in after of the device.

Belt deflection measurement

Since scallopeds are characterised by a belt deflection, between 2 idlers, that is greater than the maximum allowed by ISO 5048 # 5.3.3; then this deflection could be measured at the low point of the descent, top side, with:

- an ultrasonic sensor
  - for a good sensitivity and to reduce uncertainties, it is necessary to have a "long" pitch between idlers (at least 8-10 m), which is incompatible in this context where it would be better to shorten the pitch between idlers in the concave curve at the bottom of the descent
  - idem for the "speed measurement": what about the steering of the belt deflection reduction system.

Belt elongation measurement

I do not know of a simple and relevant solution for this measurement; moreover, where and how to measure the reference length to establish the elongation?

Belt tensioning measurement

Since a belt scalloped or belt loop is caused by insufficient tension in the belt at the bottom of the descent, it can be measured with two integrated weighing-scales placed on the descending section. The first one in a perfectly straight section, the second one in an existing or new convex curve. At the programmable logic controller (PLC), the time deltas between the 2 weighing-scales and the low point of the descent must be calculated, in order to be able to calculate the probable belt tension at this low point and to pilot the belt tension regulation system.

- The 1st weighing-scale measures a mass (belt + product) continuously, with a significant uncertainty in a strongly inclined section (15° - 18°);
- The 2nd weighing-scale measures a mass and a parasitic parameter (belt tension) which appears because the weighing area is convex.
  - o The difference between these two measurements, taking into account the time delta, gives the belt tension.
  - o Even if this tension measurement system seems more relevant, its efficiency still depends on the reaction time of the system (idem to "speed measurement").

Flow measurement at the feeder

**This flow measurement** is not used to regulate the amount of product delivered on the belt, to prevent scallopeds or loop, as the operator expects handling at the maximum specification flow rate; **it is only used to know the flow rate at time T**.

This measurement of flow rate and belt speed can be carried out by means of a conventional weight-scale or other systems. It informs the PLC of the quantity of product handled at each moment. Based on a calculated pattern, the PLC activates the clutch of one or more **generators** of **retrobooster(s)**[(8.2)], with the time offset specific to the location of each retrobooster. At this moment, the retroboosters brake the belt, proportionally to the quantity of product handled, in their reference section, to keep its elongation at a sufficiently low value so that a minimum tension remains in the belt at the low point of the descent (see fig.13).

The fact of being able to engage a number of generators in relation to the real quantity of product on the belt allows the conveyor to be operated at empty without having to overcome the resistant forces of the generators and to produce, in full load, energy that is returned to the electrical network.

6

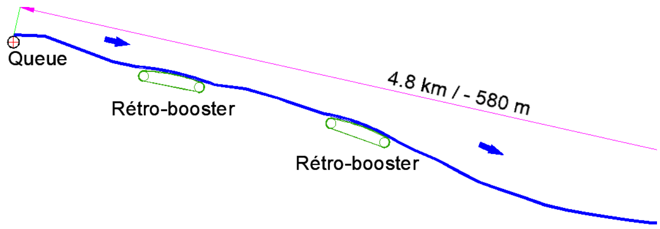


**Fig.10.1** : Long descending section with 2 retroboosters and 8 auto-piloted generators

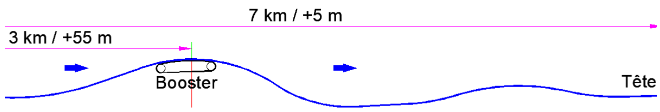


**Fig.10.2** : Long hilly section with 1 booster

## Mastering of the belt stretch

**Mastering** or **more precisely reducing the belt elongation** in the downhill section **is "THE" solution to eliminate scallopeds**, at the low point of the descent, or the **loop** in front of the head pulley.

The **belt elongation** is a function of the **elasticity of the warp cords** in its carcass and the forces applied to it. These forces depend on the law: "**$E=1/2m*v^2$**". To eliminate scallopeds, the factors "m" and "v" must be worked on.

Flow reduction

As stated in the introduction to this article, **reducing the flow rate**, i.e. reducing the mass of product in motion, is a solution, since this reduction lowers the "**m**" value in the equation.

Compared to the nominal flow rate in the specification, this reduction is often significant, in the order of **50% of the nominal** or even less.

*Which truck operator is willing to run his trucks at 50% of their capacity?*
*But this solution does not seem to bother the conveyor operators!*

In their defence, the scalloped problem concerns overland conveyors that are part of a complex industrial device and, often, the needs of the first years of operation mean that the conveyors run at half load. Later, when production reaches its nominal level, the problems on the conveyors appear. To cope with this, the throughput is limited and the operator is forced to increase the working hours of the conveyor; however, he does not file a claim under the performance guarantee, as the time limits have passed... except that a claim under "**latent defect**" is admissible long after the first commissioning.

Reduction of the vertical drop

Although this solution is relevant in theory, it is almost impossible to apply in the sense that the height difference is an imposed datum. On the other hand, replacing a overland-conveyor with n shorter conveyors is an aberration.

Increasing the belt's strenght

The belt elongation can be reduced by increasing its breaking strength, keeping all other parameters constant. This elongation depends on :

- the material of the warp ropes (steel, aramid, polyester) ;
- the way they are implementational (rope, straight, woven);
- their breaking strength;
- the load applied to them (flow rate/.../speed).

For example, if a belt with a breaking strength of **2000 N/mm** is changed to a belt with a breaking strength of **2500 N/mm**, the gain is : [100/2000*2500]-100 = **+25 %**.

Thus the overall elongation of the belt would be reduced.

In reality, the belt's load capacity of +25% must be reduced since the weight of the belt's carcass increases proportionally, all other characteristics being equal (thickness and quality of the covers, weft reinforcements, breaker).

Example
- St 2000 belt, width 1000 mm, 80 ropes, Ø 5.6 mm, net carcass weight: **19.8 kg/m**
- belt St 2500, width 1000 mm, 63 ropes, Ø 7.2 mm, net carcass weight: **25.7 kg/m**

This additional weight of **5.9 kg/m** has an unfavourable influence on the "**m**" factor of the equation in the descending section, from the point of view of the scallopeds, and is detrimental to all other sections of the conveyor.

Example

- belt speed: 3.6 m/s
- belt Δ mass: 5.9 kg/m
- length of the downhill section: 3 200 m
- vertical drop: 550 m
    - résultant: 3 339 m

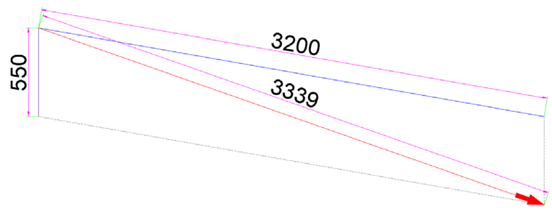


**Fig.11** : representation of the force resultant
$E = ½ m*V^2 = 0.5*(5.9*3339)*3.6^2 =$ **+ 127.7 kJ**[11]

The solution of increasing the breaking strength of the belt is to be considered from a global approach of the conveyor, from the technical and purchasing points of view.

Note:
Often, at the beginning of the downhill section, the product being handled applies forces that cause the RMBT to rise to 200% or more. This excess rarely appears in the calculation notes.

... / ...

The common error in the calculations is that the "negative[12]" forces (belt pushed by the product) in the descent are deducted from the tensile forces of the other sections. This results in a more favourable overall balance. The trap is that these negative forces cannot be integrated into the balance of the tensions in the belt, since they do not allow the belt sections to be pushed beyond the low point of the descending section.

However, these negative forces can be converted into "*energy returned*" by means of generators associated with the retroboosters.

Reduced belt mass with 1 aramid carcass

The same development above applies to the belt aramid carcass, with an elastic elongation similar to steel. Given a belt type of 2500 N/mm and an aramid carcass weight of **3.1 kg/m²**, instead of the **25.7 kg/m²** of the steel equivalent, the mass reduction is [100-(100/25.7 * 3.1)] = **-88%**.

This ideal technical solution has the major disadvantage of the high cost of aramid and a very problematic supply, which makes the solution industrially risky.

However, part of the purchase cost can be compensated by purchasing a belt with a lower breaking strength, e.g. 1800 - 1600 N/mm, as the overall calculation of the conveyor will show a lower belt strength requirement due to its lower weight and a more favourable energy efficiency due to further optimisations.

Reduction in component mass (excluding product)

**This solution, which should be systematic**, concerns the belt, the rollers and the pulleys. It brings significant advantages at all levels in terms of technology, energy, purchasing, reliability and safety. It is rarely used, due to design habits.

**Belt weight** (2nd approach):

On overland-conveyors, belts with thick rubber covers are often used, under the pretext of protecting the belt carcass from abrasion and punching, which seems commendable. Nevertheless, the risks of carcass degradation are very limited, since abrasion and punching wear occurs at the conveyor feed point and at the passage of the scraper to the head pulley; moreover, a well feed chute[13] will considerably reduce the abrasion and punching factor; as for scraper wear, it will decrease proportionally with the reduction of the belt speed.

Example
Compared to a St 2500/1 **5.5**+**5.5** belt, where 5.5 is the thickness in mm of the carry- and running surface coverings, one can opt for **4**+**3** mm coverings.
This **4 mm** delta gives a belt weight reduction of : [1.2*4*1] = **4.8 kg/m²** (1.2 = rubber density). This is good for purchasing and technical purposes.

**Roller weight**:

On overland-conveyors the weight reduction of the rollers over the entire length of the conveyor, carrying and return strands, with a reserve on the concave curve sections, can be considerable. A reduction in weight of 50% or more is entirely achievable.

To achieve this, the pitch between idlers of each conveyor section, carry and return strands, should be recalculated on the basis of article 5.3.3 of ISO 5048 v.1989; including curves, to aim at a belt deflection of 2% of the pitch, depending on the product handled (thixotropic product excluded).

- For the carry strand, the usual pitch of 1 to 2 m can be reached without any counter-indication to a pitch of 4 to 6 m and more... subject to calculation.
- return strand, with a usual pitch of 3 m, a pitch of 15 m can be reached without counter-indication, or even 24 to 30 m in the case of a drive pulley in tail; still, it is necessary that the design of the frame allows it, which is not always possible without important modifications; but for a conveyor project: do not hesitate! Do the math!

If you combine this drastic weight loss down with a reduction in belt speed, you will hit the jackpot!

Example
Calculation of a overland-conveyor in its original design, then optimised in roller mass:
- original: usual pitch between idlers
  - roller mass: 226 102 kg
  - belt speed: 3.6 m/s
    - E= ½ 226102*3.6²= **1 465.1 kJ**
- optimised: long pitch between idlers
  - roll mass : 115 367 kg
  - belt speed: 2.0 m/s
    - E= ½ 115367*2.0²= **230.7 kJ**

**Weight of the pulleys**

This point does not directly concern the downhill section, but the complete conveyor calculation.
A reduction in the weight of the pulleys requires the removal of all unnecessary pulleys, a process which is often neglected, but in terms of energy savings the gain is modest; nevertheless, there is a real gain in the reliability and safety of the conveyor.

**Product weight per linear metre**

For a given flow rate, reducing the weight of the product per linear metre necessarily involves increasing the belt speed. This solution may be correct at first glance in terms of no scalloped formation, but in the end it may be counterproductive.

It is important to make a complete calculation of conveyor and many detailed calculations to arrive at the best choice of belt speed. Here it is important to remember that these overland-conveyors, with a large downhill section with a steep gradient, often have turns, the presence of which complicates the calculations. This reduced amount of product per metre is the choice of many manufacturers for conveyors with turns. To decide on this choice, the calculations must be analysed.

Conversely, **our engineering recommends increasing the product weight per metre by reducing the belt speed**.

**Why?**
Because speed is squared in the equation!

Example
**Calculation of the energy produced** by moving the product, at a constant flow rate in t/h, in the downstream section of a overland-conveyor at **original and optimised speeds**:

- origin:
  - belt speed: **3.6 m/s**
  - output: 600 t/h
  - product weight/m: [600 000/3600/3.6] = 46.3 kg/m
  - resultant descending section: 3 339 m
  - mass: [46.3*3339]= 154 596 kg
    - E= ½ 154596*$3.6^2$= **1 001.8 kJ**
- optimised:
  - belt speed: **2.0 m/s**
  - throughput: 600 t/h
  - product weight/m: [600 000/3600/2.0]= 83.3 kg/m
  - resultant descending section: 3 339 m
  - mass: [83.3*3339]= 278 250 kg
    - E= ½ 278250*$2.0^2$= **556.5 kJ**

It can be seen that the reduction in belt speed, which proportionally increases the mass of product per linear metre, results in less energy, i.e. less stress on the belt and therefore less elongation.

Conclusion on belt elongation control

The Controlling the belt elongation in the descending section is the first step in a well-conducted engineering to reduce the risk of scalloped formation at the low point of the descent or the loop at the head pulley.

The various solutions listed above are the first to be implemented in combination and systematically validated by the complete calculation of the conveyor, including the detail calculations, in order not to get lost in a counterproductive solution.

However, if the **belt tension**, due to its extra length at the bottom of the descent, is too low to **guarantee** a **belt deflection of less than 2% of the pitch between idlers** under all circumstances (ISO 5048 #5.3.3), then **solutions** must be put in place to "**brake**" it.

## Solution for braking the belt

All the previous solutions are intended, in good mechanical logic, to reduce the stress on the belt. If these solutions are not sufficient to prevent the scalloped risk or loop in head pulley, the following additional solutions should be applied:

Pinch angle of idlers

All the previous solutions are intended, in good mechanical logic, to reduce the stress on the belt. If these solutions are not sufficient to prevent the scalloped risk or loop in head pulley, the following additional solutions should be applied:

Pinch angle of idlers

This angle follows the ISO 1537 standard and its maximum value is limited to 3°. This toe-in generates a resisting force that opposes the belt's advance. The belt must remain in good condition "**for life**" and its **contact with the side rollers must be at least 70% of their length**. This angle of 3° has been set to limit wear on the rollers and the belt's running face. There is no reason why this pinch angle cannot be increased to increase the resisting forces... at the risk and peril of the conveyor operator in relation to roller and belt wear.

The physical principle of "pinching" consists of converting belt/roller friction into heat... at pure loss, for modest belt braking performance. In the end, this solution goes against the objectives of environmental responsibility.

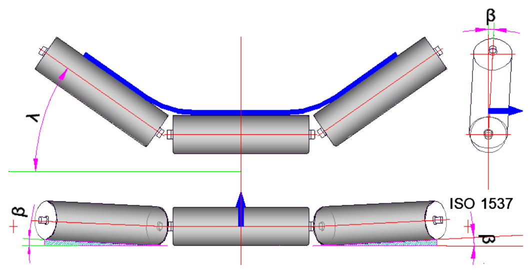


**Fig.12** : top and side views with pinch angle ''β''

Brake rollers

As with the pinch angle, the physical principle of the brake cartridge, internal to the roller, is to convert friction into heat... in pure loss. The belt/roller contact must be sufficient to prevent slippage between the two elements. Unlike the pinch angle, there is no wear on the belt running face. Brake rollers are not suitable for overland-conveyors with high loads; their speed is limited to 0.55 m/s, for a load of 1200 kg, for a slope of <4%. Their application concerns the handling of unit loads.
In the end, this solution is not applicable and would be contrary to the environmental objectives.

Installation of rétroboosters with generators

According to **C3 Expert, the only relevant solution is to install one or more "cassette" type retroboosters, with 4 generators with controlled clutches**. The fact of having 4 generators makes it possible to modulate the braking force, by controlling the number of active generators of each retrobooster, at the moment T according to the flow handled, by activating its clutch. The energy produced is reinjected into the electrical network, with an efficiency of ≈ 0.8.

In the end, this "retroboosters and generators" solution

- In the end, this "retroboosters and generators" solution
- covers the technical need by eliminating any risk of scalloped at the low point of the descent or loop in front of the head pulley, by braking the belt, gradually (several installation points);
- allows the acquisition of a lower breaking strength belt, with a better level of safety, at a reduced cost;
- the delta on the purchase price of the belt finances all or part the retroboosters (and boosters on the other sections); this financial aspect is all the more true as the belt is longer;
- the cassette type allows for easy addition of retroboosters (and boosters) in the case of conveyors whose centre distance increases over time or that the operator increases the conveyor's flow rate;
- the interchangeability of this device facilitates maintenance
- the annual energy balance of the conveyor allows for a quick return on investment, and then operational savings. These savings depend on the price of the kilowatt-hour of the operating site... sometimes very high!

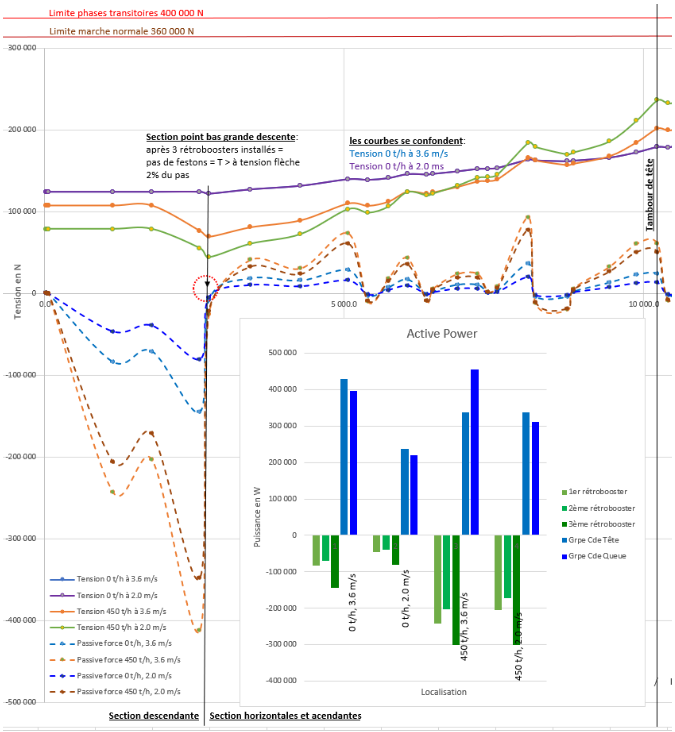


**Fig.13** : Belt tension graphs with 3 retroboosters installed on the large descending section. The belt tension at the low point of the descent is > the minimum tension required to limit its deflection to 2% of the pitch between idlers.

Passive force

This is the resistance to rolling and of product elevation, etc. It is positive when there is resistance and negative when there is driving by the product.

Active force

This is the active resistance of the retroboosters (in the descent) and the active by the drive pulley at the head and/or tail, or at an intermediate location. It is positive when there is drive and negative when there is resistance.

The belt tension is a combination of active and passive forces (starting from the pre-tension value).

## Engineering of descending section profile

In the previous paragraphs, solutions to control the elongation of the belt and how to brake it profitably by recovering the energy produced were described.

Based on the above solutions, the performance of a conveyor project can be improved by working on the longitudinal profile of the descending section by approaching a "cycloid" profile in order to increase the energy returned by the retroboosters.

Source of Illustrations :
https://fr.wikipedia.org/wiki/Cyclo%C3%AFde

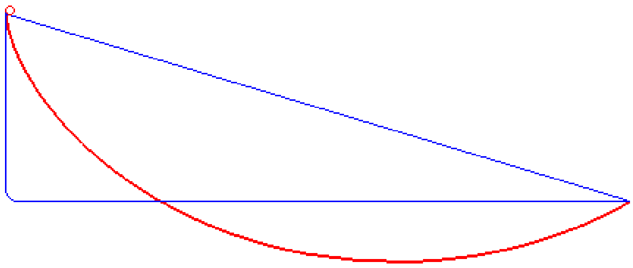

**Fig.14.1** : the cycloid is a brachistochronous curve *

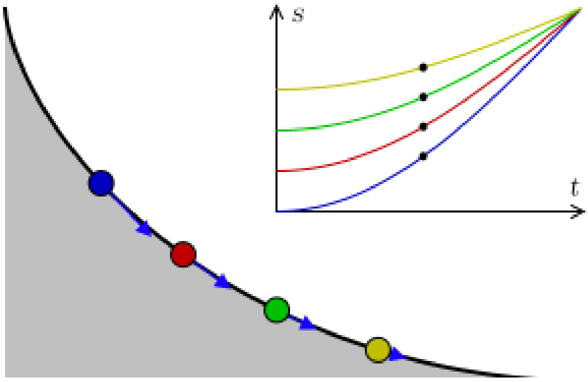


**Fig.14.2?** : the ½ arch of the cycloid is a tautochronous curve

## CONCLUSION

To eliminate the risk of scallopeds or loop, it is necessary to control the belt elongation upstream of the low point of the large descending section. This can be achieved by reducing all stresses that influence the "m" and "V" factors of the energy equation and then, if necessary, installing one or more retroboosters with generators to brake the belt in the descending section.

This approach can be applied to existing conveyors and to projects, with significant benefits.

**Marc des Rieux, Expert**
🖂 marc.desrieux@c3-expert.com
🌍 www.c3-expert.com

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

## Glossary

(1) scalloped: the belt forms a loop between 2 idlers, with a significant depth.

(2) static length: total belt "endless" length after a stop without load and depending on the force applied by the pre-tensioning system.

(3) RMBT: **R**esistance **M**aximum (Allowable) **B**elt **T**ension; this is the belt tension in relation to its breaking strength. An RMBT of 100% is 10% of it's breake value.

(4) calculation: our C3® software and a tool adapted to this type of calculation

(5) Elasticity: "Non-permanent" elongation of warp ropes, when a tensile force is applied and the rope returns to its original length when the force is reduced to 0 N. If the elastic limit is exceeded the belt will undergo permanent elongation which will add up day by day.

(6) warp ropes: the belt carcass, the main component of the belt, is formed by a layer of ropes in the direction of its length. The warp ropes bear all the tensions.

(7) pre-tension: the force applied to the tensioning pulley before the conveyor is put into operation. It must ensure that the drive pulley does not slip, that the belt is not deflected beyond its limits at any point on the conveyor, and that the belt runs directional stability at the pulley with the lowest belt tension.

(8.1) booster : auxiliary drive unit, consisting of 1 to 4 motors, installed under the main belt, carrying side, return side, as required. The cassette type has a very short belt that drives the main belt by contact.

(8.2) rétrobooster : same as booster with generators instead of motors.

(9) catenary: belt profile in the form of a parabolic arc between 2 idlers

(10) kinetics: study of the movement and the forces involved. kinematics: study of the movement without taking into account the forces that cause it

(11) Joule to kWh : 1 kJ = 0.00027 kWh ; 1 kWh = 3 600 kJ

(12) négative force : to say that the force produced by the displacement of the product in the descent is "negative" is a convenience in calculations.

(13) a good feeder chute: this means favouring a mass feed and having a chute with diverging edges.