How to optimize the design, usage and maintenance of belt conveyors

Regulatory references to calculate and optimize belt conveyors

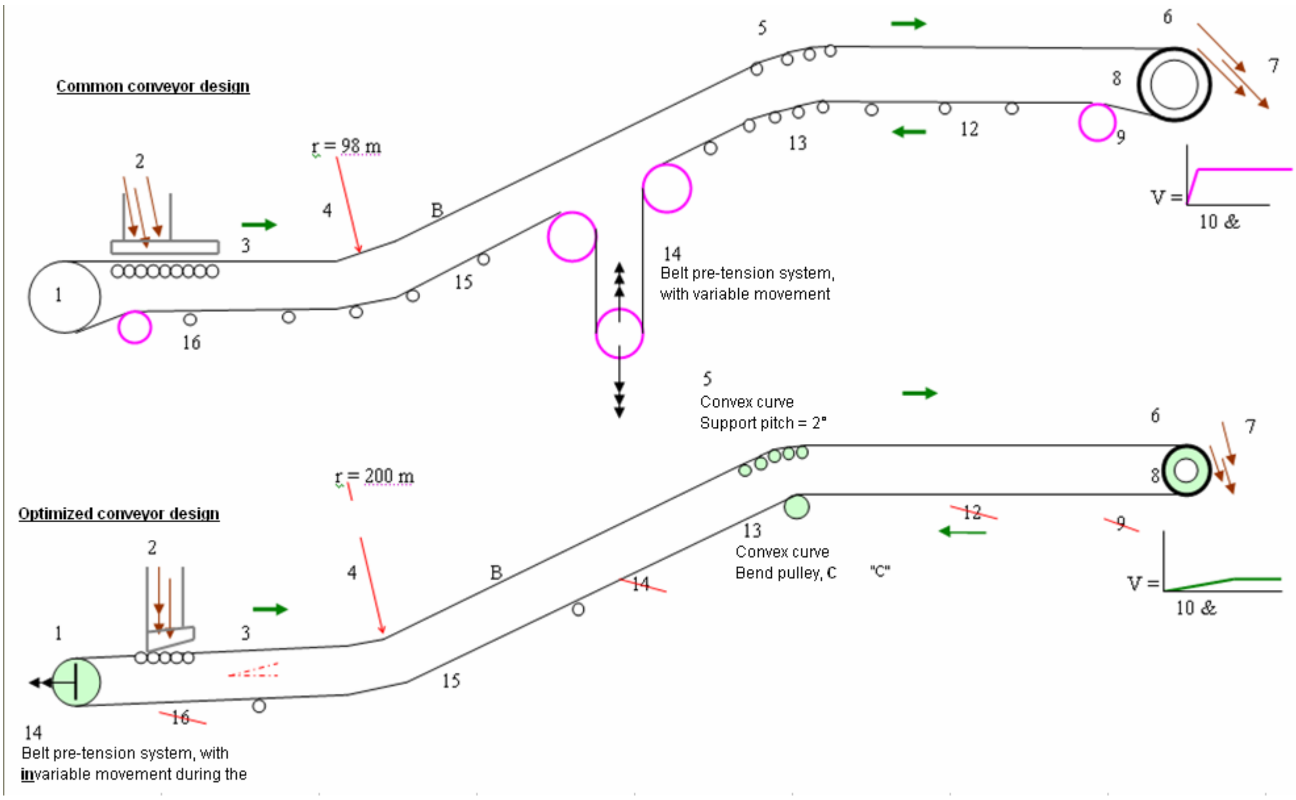
Like many inventions, belt conveyors have developed through time as users and manufacturers raised questions and found new answers. In the early 80', the French Government began to look more seriously into the issue of safety of machines and particularly of conveyors, resulting in a common approach of European States from 1989 through the Machine Directive 89/392 CEE.

For their proper application, the Directives are explained by numerous standards called "***mandated***" that enable us to consider that a machine is presumed to be compliant if its design respects the prescriptions of the standards, subject to an application with good judgment.

We note that for France, European Law is included in French Law by the texts of the Labour Law, particularly the articles L230 and following.

In parallel to the safety standards, the normative library is rich with numerous technical standards.

It is the proper usage of safety and technical standards that allow for a marked development in the design of conveyors, characterized by a greater simplification of this type of machine.



- The standard **EN ISO 12100-1*** is the first useful safety standard; it is the basis of the "***new approach"***.
    - **Its article 5** clearly specifies the hierarchy of actions to undertake for a good design, according to the following paragraphs:

> - ***Specify the limits and the normal use of the machine (see § 5.2);***
> - ***Identify the dangerous phenomena and the dangerous situations which are bound to them (see § 4 and 5.3);***
> - ***Estimate the risk for each of the dangerous phenomena and the dangerous situations identified (to see * 5.3);***
> - ***Estimate the risk and make decisions as for the necessity of reducing it (to see * 5.3);***
> - ***Delete the dangerous phenomenon, or reduce the risk which is associated to it, by taking measures of prevention (to see * 5.4 and 5.5).***

- The standard **ISO 5048** of September 1989 is the main technical reference; it describes the method to calculate the conveyors.
    - **The article 5.3.3** "*limitation due to the deflection of the belt"* acquires a major importance in our simplification approach.

> ***5.3.3 Limitation due to the belt deflection***
>
> ***The minimal tension which has to exercise in the belt to limit the belt deflection between two supports, obtains from the equation (11a) or the equation (11b), as the case may be***
>
> ***- For the carrying belt:*** ***parabola equation "11a"***
>
> $$F_{min} > \frac{a_o (q_B + q_G)\, g}{8\,(h/a)_{adm}}$$
>
> ***- For the return belt:*** ***parabola equation "11b"***
>
> $$F_{min} > \frac{a_u\, q_B\, g}{8\,(h/a)_{adm}}$$
>
> ***These values not have to be lower, in no place of the conveyor. The acceptable value of the belt deflection is generally fixed in 0.005à 0.02.***
>
> *Read: acceptable deflection = 0.5 % a 2.0 % of the step between 2 supports.*

NOTE :
If in the 1st editions (70') this article was completed with examples of **"pitch"** between the idlers, or:
- *Carrying belt, a common value of* ***1.00 m*** *to* ***1.50 m*** *;*
- *Return belt,* *a common value of* ***2.50 m*** *to* ***3.00 m***.

The following versions do not mention anymore those example lengths.
Unfortunately, today those values have become "***immutable***" references since they represent almost 100% of all designs.

*: the standard *EN ISO 12100-1*, of international impact, replaces since 2003 the ratified European standard EN 292-1.

Idler supports
Return side

By using my software **C3v9**® it is very easy to determine the ideal pitch between all the supports of the conveyor.

The 1st time I adopted a "**long**" pitch between supports goes back to 1986 at Lafarge Cements, Teil Plant, on a Hasler doser. The 1st "long" pitch on a long conveyor goes back to 1988 at Lafarge Cements, Val d'Azergue Plant on the quarry link conveyor.

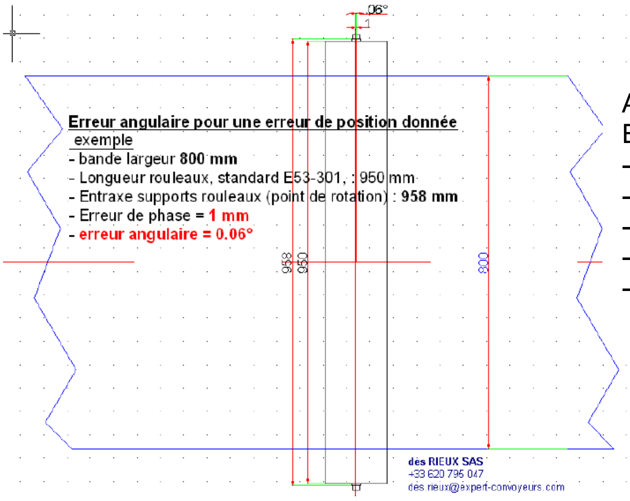
In practice and from a statistical viewpoint, it emerges that the "standard" pitch between supports of a return side is **12 m**, for pulled belts (head drive pulley), or "4 times less" idlers compared to usual designs. For the anecdote, the longest pitch presently in service stands at 56 m with sag of the belt at 350 mm.

Based on this value, we understand that "short" conveyors with a length of 12 m or more, for example 20 m, must be designed with "**ZERO return idlers**", which means "**ZERO Risk**". Such a design is in full compliance with the requirements of the ***Directives Machines, New Approach!!!***

In asserting "zero risk", we are referring to the risks of being caught in the conveyor; when we analyze the risks (standard EN 13857) on traditional machines, we note that they also present risks of ejection of parts (idlers), risks of fall of people due to polluted floor resulting from the loss of material stuck on the return side of the belt and coming out when passing over the idlers. The "zero idler" design eliminates such risks aforementioned.

For long conveyors, the number of risks will be reduced in a 12/3 ratio (or rather 15/3) as compared to common designs with a pitch of 3 m. The pollution of floors will be limited to the first idlers by the effect of wringing of the belt when coming in contact with the idlers due to an increase in its vertical force that increases with the same ratio as previously indicated.

With a "long pitch" design between the return idlers, we reduce various risks thanks to the great stability of the trajectory of the belt. This clear improvement in the trajectory of the belt depends on its support on the idlers and on the decrease of its "***longitudinal rigidity***". In contrast, a common pitch of 3 m between supports makes the belt skid like a rigid wooden plank. In the case of a long pitch, there is a proportionality of amplitude in the swerve of the belt depending on the angular error in the direction of the idlers, while indicating that such proportionality only exists for angular error < at 1°.



Angular error for an error of position of the support:
Example:
- Belt width = 800 mm;
- Roller length, in the standard E53301 = 950 mm;
- Roller support length (point of support rotation) = 958 mm
- Error of phase = 1 mm;
- Angular error = 0.06 °

Fortified by this rule, I have established a method to adjust the idlers called "by comparison" that is very simple and accessible to most people. It helps us to obtain an adjustment tolerance of about 0.03°, thus giving the belt a great stability increased by the greater pressure on the idlers.

The list of risks eliminated includes:

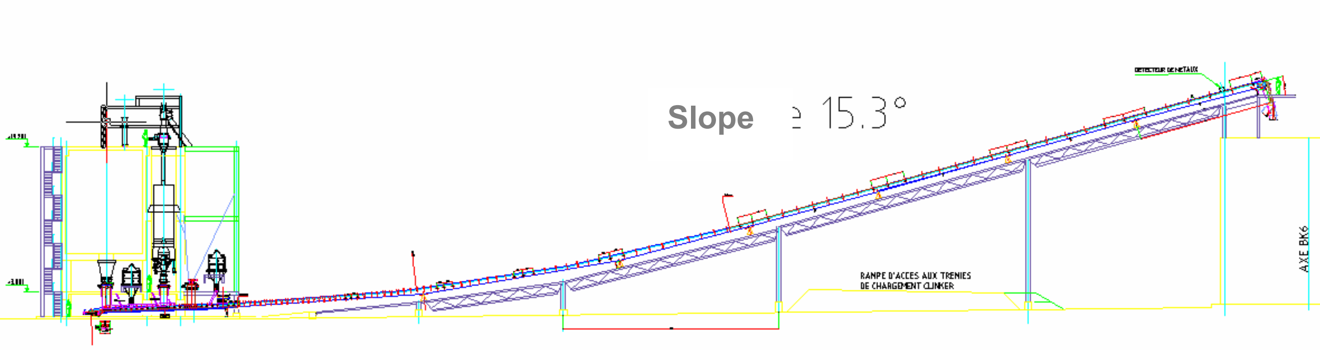
- The removal of "**counter-support**" idlers, placed above the return belt, in the concave curves, and of course, all the "self-tracking" idlers of any model knowing that some of them like the "inversed supports" are:
  - Either inefficient while presenting serious risks of being caught up by the conveyor.
  - Or harmful for the belt and hardly efficient, with the same risks.
- The removal of the conveyors with scrapper chain called "crumb collector", placed under the head section of the conveyor and measuring a few meters long. Indeed, those auxiliary machines have no reason to be used since the 1st idler on the return side is located at least 12 m from the head and that in most cases, the conveyor will be without any snub pulley (see # snub pulley).

Remark:
Often, the return idlers separated by a pitch of 3 m, are loaded with between 5% and 20% of the acceptable load; consequently, when we increase the pitch by a 1 to 4 or 1 to 5 ratio, we are still within the acceptable load.

Carrying side

With regards to idlers, it is important to calculate the pitch between the supports of the carrying side. Depending on the profile of the conveyor, the pitch between supports may vary greatly between the tail and the head section.

For example, on an ascending conveyor, with a first straight section with a 3° gradient, followed by a concave curve, then by a long incline section with an important difference in altitude, the pitch between idlers has increased from **600 mm to 2500 mm**. Here, we need to well manage the pre-tension of the belt to obtain the smallest concave curve radius as possible. If the conveyor was straight, the pitch between the supports would vary within a ratio of 1 to 3 with a starting distance of 1200 mm.



Attention, In the case of a conveyor with a "two-direction" belt, the designer must reduce the pitch between supports and aim at a sag of the belt of around 0.5% of the pitch between supports. This solution opposite to the preceding one, limits to a maximum the pressing force of the belt particularly on the lateral idlers of the troughs, in order to limit the negative effect of the uncertainties of manufacturing and adjustment of the idlers.

The pulleys:

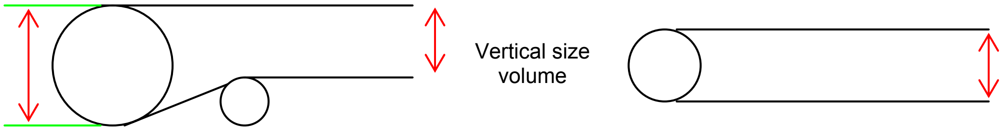
On the issue of "**pulleys**", huge efforts need to be undertaken on the common design of conveyors to follow the philosophy of the ***new approach***.

For this chapter as for the information above, the first rule I recommend to reach a high level of safety and a better technical quality, is to "***remove"*** all the components of the conveyor that have no technical justification; such a justification is based on calculation.

In term of pulleys, such removal of unnecessary components, starting from the most obvious, include:

Snub pulley, associated to a free tail pulley:

- Historical background :
  In the 60' and 70', the belts with multi-ply cotton carcasses were particularly thick and required pulleys with a large diameter. For the tail pulley (return), this large diameter represented a problem of vertical obstruction of the frame. To reduce this obstruction, people added a snub pulley.



  When the requirements of the carcass of the belt enabled us to reduce the diameter of the pulley, the snub pulleys stayed in place under the pretext that a wrapping angle **>** 180° of the belt around the tail pulley increased the stability of the trajectory of the belt in the tail area.

- Technique
  This explanation could have been relevant if the **conditions of tolerance in the shape and position** of the drums had been taken into account. We must understand here that the tolerance value acceptable for 1 active element is divided by 2 in the presence of 2 active elements.

  By ignoring the rules on tolerances, the results on the site always had expensive consequences. Indeed, if at first the stability of the trajectory is significantly ensured, with time, it deteriorates to the point of having to replace the belt after a short period of use. The lifespan is also reduced due to the important distortion of the carcass of the belt when passing over the dirty snub pulley due to the punching effect repeated for each revolution around the dirty pulley on the whole length of the belt.

- Conclusion :
  The snub pulley associated to the "free" tail pulley, is a place of risks, particularly risks of being caught up by the belt, and **must not exist**.

- **Note** :
  On an existing conveyor, in the case where we remove a snub pulley in the tail section, without changing the diameter of the tail pulley, the last idler becomes a "**snub pulley**" and the radial forces applied to it will be all the more important as the pitch (the distance) to the tail pulley is short and the wrapping arc of the belt is large. In such a case, we have only displaced the problem by increasing risks of breaking for the pulley. The solution, **whether we change or not** the diameter of the tail pulley, is to adopt a **long pitch** between the last return idlers and the tail pulley, for example a pitch of 12 m. In this way, the radial force resulting from the tension of the belt depending on the force component defined by the wrapping arc of the belt on the idler will be decreased to a value acceptable for the idler (subject to verification).

Snub pulley associated to a drive pulley:

- Basis :
  In order to justify the use of a snub pulley associated to a drive pulley, we need to carry out a calculation based on the standard ISO 50448.

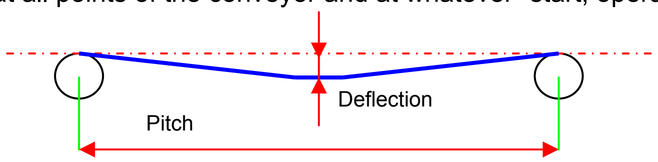
- Hypothesis on the use:

  It seems that from a certain size of conveyor, which varies from one manufacturer to the next, it has become a habit to design the drive unit "**inclusive**" of a snub pulley. After reading the calculation results of such a design, everyone can see that they are compliant at least with regards to the safety ratio of the belt, which is enough to validate the design. The problem is that by taking the same calculation parameters, except for the wrapping arc of the belt on the drive pulley which is 180°, that is a design **without snub pulley**, very often **the results remain perfectly acceptable** and in compliance with the professional practices.

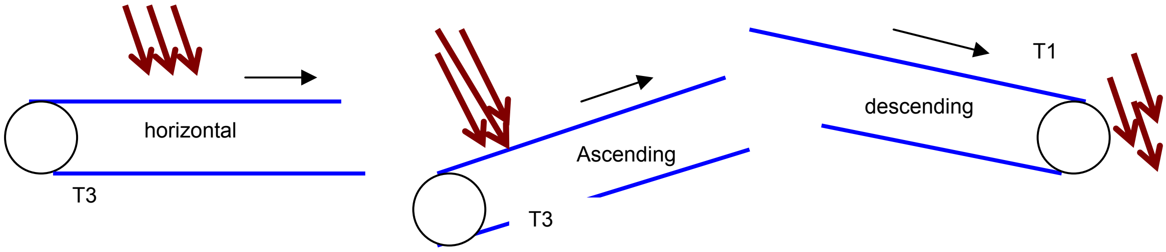
- Technique
  Elements of calculation:

  If all the conveyor calculations firstly determine the ***drive factor*** of the belt by the drive pulley, characterized in result by the force F2 (**T2***), it is rare that this 1st calculation is corroborated by:

  - The calculation of the required pre-tension of the belt to limit its **arrow deflection** between **2 supports**, at all points of the conveyor and at whatever "start, operation, stop" operation phase.



  - The calculation of the required pre-tension of the belt to **guarantee its trajectory stability** at the tail pulley (T3) for horizontal and ascending conveyors, and at the head pulley (T1) for descending conveyors. This pre-tension is estimated in most cases at 2% of the rupture value of the belt normally calculated.



Be reintegrating the **deltas** of the pre-tension forces "***limit sag***" and "***mini pre-tension***" in the initial calculation, we often notice that the new force T2 calculated is higher than the value T2 required under a design "**without**" snub pulley. To properly understand this approach, we need to remember that for a same conveyor, T2 with a snub pulley is inferior to T2 without a snub pulley.

… **consequently, the calculation proves that the snub pulley has no justification**.

*: *pre-tension of the belt after the drive pulley.*

Other arguments:

Here above, the demonstration covers one same conveyor with or without a snub pulley associated to a drive pulley. The calculation results can be even more favourable by comparing a design with a wrapping arc **>180°** and its drive pulley with a **bare metallic contact surface** or covered with a smooth rubber coating (same ratio if the belt/pulley interface is dirty), compared with a design with an arc **<180°** and a pulley covered by **rubber with small diamond-shape** grooves.

In addition to the high level of safety gained by the removal of the snub pulley when its presence is unjustified from the viewpoint of drive, we also need to consider the removal of many nuisances and mess that are sources of material and human risks, after the removal of the snub pulley.

Practical aspect:
Statistically, any conveyor equipped with a snub pulley, associated to a drive pulley that involves a wrapping arc of the belt **≤ 200°** on the drive pulley, can have its snub pulley **removed** without any risk of mechanical disorder; provided that the elements of that section have been adapted, such as the position of the scrapper, the face of the chute under this pulley, the distance to the 1st return idler (for ex. 12 m).

- Conclusion :
  The snub pulley associated to the drive pulley, source of risks, particularly risks of being caught up in the conveyor, **must not exist**, when the demonstration is made by a proper and exhaustive calculation.

Tension system with variable run in operation:

- Definition :
  In order to avoid any confusion between the technical reality and everyday language, I have divided the pre-tension systems of conveyor belts in 2 types:

  - The systems with "**variable run in operation** », depending on the jolts of loads carried by the belt and whatever the operation phases of the conveyor. In this type of system, there are subsections with **counter-weights** where during the operation we notice a real amplitude in the movement of the snub pulley;
  - The systems with "***in*****variable run in operation**", depending on the jolts of loads carried by the belt and whatever the operation phases of the conveyor. In this type of system, there are designs using screws to move the snub pulley. The subsections with counter-weights for which we do not see any amplitude in the movement of the snub pulley or reduced amplitude, come under the definition of "**in**variable" pre-tension.

- Historical background:
  Since the early days of conveyors, it has been accepted that a good conveyor design requires a pre-tension system of the belt of the "variable in operation" type, from 42 m pitch; some manufacturers set that pitch at 30 m, others at 42.5 m, and still others at 50 m. As for the standard, they are often vague and indicate:

  ISO 5048-1989-09 # 5.3.4
  In all the complex cases, the variations of tension applied to the belt must be carefully calculated by a specialist. !!!

To this day, my calculations with the help of my software ***C3***® as well as tests carried out show that a pre-tension system with "***invariable run in operation***" is perfectly operational for designs with the following parameters:

- Pitch : **1 100 m** ;
- Difference in altitude : **+ 30 m** ;
- Output : **600 t/h** with peaks at **700 t/h** ;
- Belt:
  - Width : **800 mm** ;
  - Type : **E1000*/2 6+4** ;
  - Elongation under 10 % rupture load : **1.00 %** ;
  - Weight : **14.7 Kg/m** ;
  - Speed : **1.7 m/s** ;
- Power installed : **160 KW** ;
- Type of start : **progressive** by variation of frequency
- Pulley coating : **sprocket ceramic**
- Wrapping arc on pulley : **180°** ;
- Upper support / pitch : **trough 30° / 2.00 m** ;
- Lower support / pitch : **straight / 12.0 m** ;
- **Pre-tension system / run** : **invariable / 4.50 m**.

** : E = polyester, 1000 = 1000 N/mm resistance to rupture on elongation.*

To apply this technology to much larger conveyors, I intend to launch a research on the characteristization of belt carcasses and to model the results afterwards.

The importance of such an approach is justified by a more economical and safer design in term of operation reliability as well as safety of people.

This ***Infovrac 2009*** conference is the occasion to call upon manufacturers concerned by this topic to take part in my research and development activities.

- Technique :

How to calculate a conveyor from the point of view of pre-tension system

For several years, my R&D team and I have come to understand that the current mathematical models to calculate conveyors from the point of view of pre-tension type, are incorrect.

In June 2008, we were able to show that:

A conveyor must **always be calculated** with a pre-tension system "**with a variable run in operation**".

In the case of a system "***with invariable run in operation***", the difference between the recommended calculation model (variable in operation) and the physical design of the conveyor, with an invariable system, comes only from the method of setting up the pre-tension of the belt on site.

For a design with invariable run in operation, we need to measure in operation, in all circumstances, the sag of the belt at the striking points, particularly in T2 and T3 and adapt its pre-tension depending on the sag calculated at those points. When the belt to be controlled is new, the readjustment of the pre-tension will require several interventions in the early period of operation only*. If later, we notice a drift of the sag of the belt, we will have to consider that such a drift is due to an anomaly to be identified and dealt with accordingly (same if the design is with a variable system). This procedure ensures the long life of the belt and of the components of the conveyor.

*: *Until the belt has reached its permanent elongation.*

Since 2002, on a long conveyor, we measure continuously the value of the tension in the belt at T2 and T3 by means of ultrasound sensors. For another conveyor (5 km long), we in addition measure the tension of the belt at T1. The analysis of the signal by a robot enables us to manage an alarm threshold and a stop threshold of the equipment. This very efficient device makes the rotation detectors that are generally sources of serious accident, obsolete.

In the case of conveyors smaller than the ones described above, a simple soft template (straps cut in any belt offcut) enables us to ensure visually (no contact = no risk) the pre-tension condition of the belt.

- Comments:

  Very often, there exists confusion between the type of pre-tension (variable or invariable) and the length of the run of pre-tension. In the case of an “invariable” system, nothing prevents us from having a pre-tension run as long as it would have been with a “variable” system. Aiming at such a solution is to fight the wrong battle since the objective is the reduction of risks by way of reducing the risks by **eliminating** the components presenting a risk. We aim at removing unnecessary pulleys and other related components in the system that entail risks.

  It is worth noting that the design of a conveyor with a long pitch between the supports of the return side gives a greater pre-tension sensibility of the belt to the variations of loads applied, than a system with conventional variable run such as sub-sections with a counterweight.

Convex curve, carrying side, in the head or tail sections:

- Definition :
  Whatever the conveyor, whenever there is a convex curve on the carrying side, it is made up of idlers, whether the transversal profile of the belt is flat or in trough. This acknowledgment must not make us lose sight of the fact that **convex curves** must be assimilated to **“a sector of pulley”** with a large diameter.

  It is here necessary to explain the difference between a pulley and an idler.
  - **Pulley**: the rotating element is a **pulley** when the **pressure of the belt increases** on the surface of the ferrule whenever the tension of the belt increases.
    - **Safety**: In all circumstances, a pulley presents risks.
  - **Idler**: the rotating element is an **idler** when the **pressure of the belt decreases** on the surface of the ferrule whenever the tension of the belt increases.
    - **Safety**: in the presence of an idler, there are risks when:
      - The speed of the belt ≥ 3 m/s ;
      - The belt has no clearing (presence of capacity flanks);
      - The belt has no clearing due to the high pressure of the belt on the idler. Here, we must assimilate the idler to a pulley as in the case of trough transition zones, convex curves of the carrying side and of the return side. “Inversed” supports are included in the double definition of “trough transition” or “transition and convex curve”; the same applies for counter-support idlers (concave curve of return side). .

- Particular design:

  Some manufacturers and mining companies formerly, design head or tail section of conveyors by including a convex curve that ends on the transition support in the best case or on the pulley in the worst case.

Such a design was validated by the mining companies in the 70' when they incurred very important losses due to the drifting of the belt in the head section. Convex curves were introduced as the solution since the belt under high constraint could not drift with important amplitude. Unfortunately, the "cure" was worse than the disease. After some time of operation, the trajectory of the belt became unmanageable over the whole length of the conveyor.

Another reason for the presence of convex curves in the tail section is due to the trajectory of the products in the chute. Here again, it is an unfounded reason in the light of the calculation of the parabola of the fall. The difference between the discharge length with and without convex curve at the tail is lost in the calculation uncertainties.

- New approach to safety / Conclusion :

  Fortified by the comments above, the design of a conveyor with a head convex curve must not exist anymore. To justify the presence of a head convex curve or in the tail section, we need to provide solid, objective and relevant technical arguments at the risk of having the project rejected for failing to abide by the Labour Law.

Convex curve, return side:

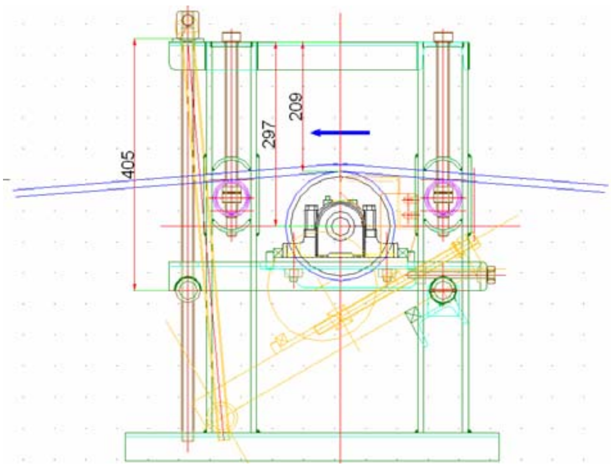
- Ordinary design:
  In most cases I have assessed or during ordinary visits, I have noticed that convex curves on the return side are made up of a "**series of idlers**".

- Increased risks:
  If we accept that the return idlers present a certain number of risks, in the case of idlers in convex curves, those risks are increased in addition to risks related to maintenance which becomes more difficult.

- Reduction of risks:

  Here the requirements of the ***new approach*** become particularly important. Concretely, we need to get rid of the series of idlers in the convex curve in exchange of one sole bend pulley (category C). This pulley must be assembled on an "**ergonomic**" and "**secure**" support that protects from exposures to:

  - Risks of being caught up, by means of an integrated protection;
  - Risks related to maintenance operations;
    - By way of design that allows for the support of the belt when changing idlers;
    - By way of a system to adjust the pulley outside dangerous zones.



Capacity skirting / feeding section:

- Length of capacity skirting:
  Some conveyor designs use capacity skirting with an excessive and unnecessary length under the risk analysis approach.

  Indeed, when a belt does not have the freedom of rising due to the presence of capacity skirting, there exist risks of being caught up and risks related to maintenance when changing idlers.
- Reduction of risks:
  Concretely, we need to remove a maximum of risks by shortening the length of capacity skirting to an optimal length. Such a length is defined based on an optimized design of the feeding chute.

Adjustment of the conveyors when off:

We cannot close this presentation on the design of conveyor by the application of the main rules of safety of the “new approach” without mentioning the adjustment of all types of belt conveyors when “off”. This method of adjustment complies perfectly with the requirements of the Labour Law and more generally with the Machine Directives.

The fact of simplifying the design of conveyor greatly facilitates the work of adjustment on site and reduces the time devoted to that task.

I hope that the information presented here will be of help with regard to the efficiency, the safety and the technology of conveyors, while respecting the Law and following the best practices.

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Convoyeur de conception usuelle Pré-tension à course variable en service Convoyeur de conception « optimisée » Courbe convexe Pas entre supports = 2^o Pré-tension à course **invariable** en service Courbe convexe Tambour d'inflexion	Conveyor with common design Pre-tension with variable run in operation Conveyor with "optimized" design Convex curve Pitch between supports = 2^o Pre-tension with **invariable** run in operation Convex curve Bend pulley

- Specify the limits and the normal usage of the machine (see 5.2) ;
- Identify the dangerous phenomena and the dangerous situation related to them (see the Article 4 and 5.3);
- Assess the risks for each dangerous phenomenon and identified dangerous situations (see 5.3);
- Assess the risks and take appropriate decisions to reduce them (see 5.3);
- Remove the dangerous phenomenon, or reduce the risk associated to it by taking prevention measures (see 5.4 and 5.5).

5.3.3 Limitation due to the sag of the belt

The minimal tension, *F min* that must be applied on the belt to limit the sag of the belt between two sets of carrying idlers is obtained from the equation (11a) or from the equation (11b), depending on the case:

- For the upper side

- For the lower side

We must not go below those values at any point of the equipment. The acceptable value of the sag of the belt (h/a)adm is generally fixed at 0.005 to 0.02.