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Belt Conveyor Transition Geometry

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Summary

This paper has been prepared to provide some practical formulae for selecting minimum transition lengths in belt conveyors and the geometry of the intermediate transition idlers.

The geometry of any type of three roll idler is investigated for transitions where the pulley is (a) mounted at the belt line or (b) where it is raised above the belt line, so that there will be equal stress in the edge and centre sections of the belt.

The theory is based on the basic assumptions that; there will be areas of low tension and areas of high tension within the transition; the average belt stress prior to the transition will be equal to the average tension within the transition.

The minimum transition length is given as a function of idler geometry, the elastic modulus of the belt and the high and low belt tensions within the transition.

By stipulating high and low tension limits as a function of the ultimate belt strength and by accepting that the elastic modulus can be expressed as a function of the ultimate belt strength, the derived formulae can be simplified and graphs of transition length versus belt tension can be produced.

1. Introduction

At the head and tail ends of the conveyor there is a transition where the belt profile changes from the flat to troughed form. The distance over which this change takes place is known as the transition length. Within the transition the stress in some sections of the belt will increase and in other sections it will decrease. The transition length must therefore be adequate to keep the high and low stresses within acceptable limits.

The importance of correct design of the belt transition is often overlooked by engineers and many transitions are either too short, causing distress to the belt, or the belt is incorrectly supported by the transition idlers, so that the belt is bent around only one idler. Photographs 1 and 2 show transitions on two conveyors which illustrate these problems.

Photo 1: Head end transition on German coal conveyor $L_t \simeq 2.5\,w$. Note lines where belt is being bent around the idlers

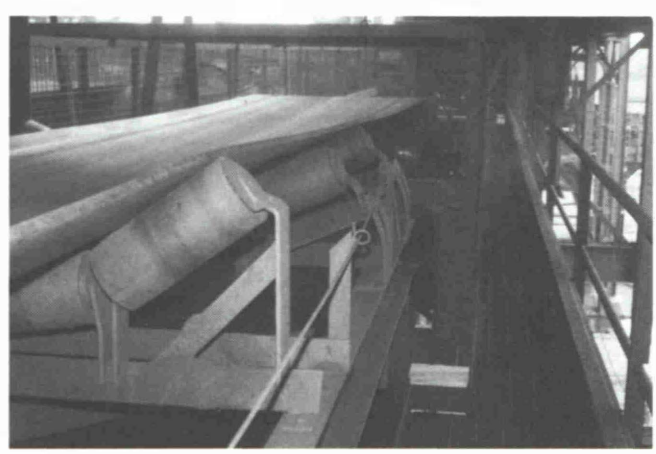


Photo 2: Tail end transition on an iron ore conveyor. Note poor belt support

Information relating to the minimum transition length varies considerably between manufacturers manuals and other text books. There is also an International Standard ISO 5293 1981 (E) which gives formulae for the transition length on three equal length idlers. This ISO Standard and most of the information in manuals and text books appears to be based on incorrect assumptions regarding the belt stresses in the transition area. There is therefore a need for some general formulae which reflect the actual stress conditions and these formulae should also be applicable to idlers which do not necessarily have three equal length rollers.

This document has been prepared to give engineers and draftsmen an understanding of both the theory of transition geometry and some practical formulae which will assist the designer in selecting the correct transition length and the form of the intermediate transition idlers.

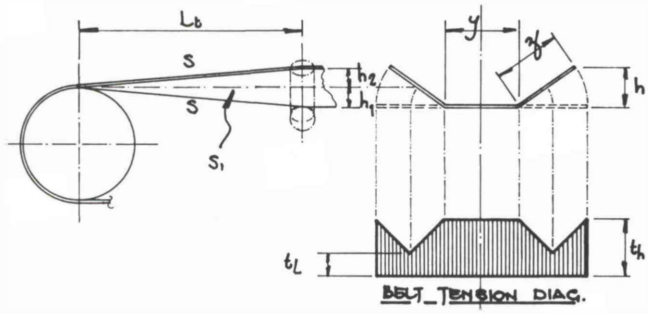


Fig. 3: Pulley mounted at optimum height

2. Transition Geometry — General

The transition from flat to troughed form can be achieved by installing the terminal pulley at the belt line or by raising the pulley to an optimum position, where the stress in the edge of the belt equals the stress at the centre. Figs. 1 and 3 show these two transition arrangements together with corresponding diagrams of the stress variation across the belt. Figs. 2 and 4 show the corresponding geometry of the section of belt on the wing idler.

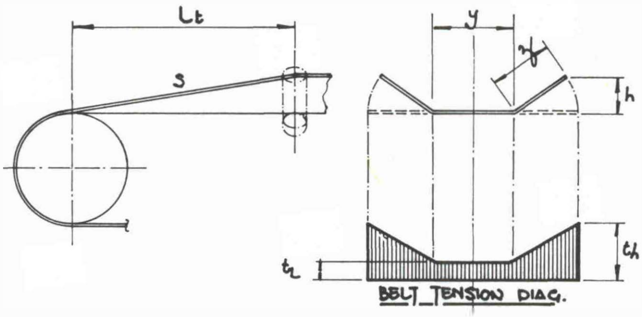


Fig. 1: Pulley mounted at belt line

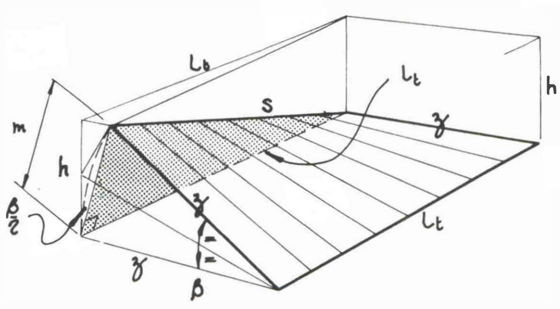


Fig. 2: Wing geometry

With the pulley mounted at the belt line the belt stress diagram shows two peaks of high tension and a wide area of low tension. Conversely, the stress diagram for a transition with the pulley mounted at the optimum height shows two peaks of low tension and a wide area of high tension. The difference in the two stress diagrams has a significant effect on the required transition length particularly when considering belts operating at high tension. It will be shown in Section 8 that for a belt operating at its rated tension with 35° three roll idlers, the transition length for a pulley mounted at the belt line will have to be 2.6 times longer than if the pulley is mounted at the optimum height.

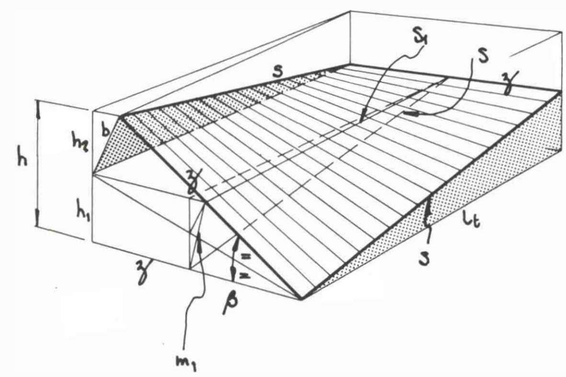


Fig. 4: Wing geometry

However, when the belt tension at the transition is only 20% of the rated tension, the ratio of the required transition lengths will be only 1.3 : 1.

We can therefore say that there is a significant advantage in mounting high tension terminal pulleys at the optimum height, while this advantage in low tension areas is minimal. For these reasons it is generally recommended that head pulleys be mounted at the optimum height, as this will give the shortest safe transition length. An exception to this rule is where the belt is running at relatively low tensions and is carrying large lumps. In this case the head pulley should be mounted at the belt line, as this will reduce the chance of belt injury being caused by the impact of lumps against the pulley.

At tail pulleys the belt tensions are usually low and it is recommended that the pulley be mounted at the belt line. This has the advantage that rain water or wash down water can drain off a horizontal conveyor.

3. Symbols

The following symbols are used in the standard transition formulae.

E	Modulus of elasticity of belt	N/mm
h	Troughed belt height	mm
h_1	Optimum height of pulley	mm
L_t	Minimum transition length	mm
L	Selected transition length	mm
R	Radius used in transition geometry	mm
S	Length of belt at line of maximum stress	mm
S_1	Length of belt at line of minimum stress	mm

t_h	Highest belt tension in transition	N/mm
t_l	Lowest belt tension in transition	N/mm
t_r	Rated belt tension	N/mm
t_t	Average belt tension at transition	N/mm
t_u	Ultimate tensile strength of belt	N/mm
w	Belt Width	mm
x_1, x_2	Pack heights	mm
y	Portion of belt on centre roller	mm
z	Portion of belt on wing roller	mm
β	Trough angle	degrees
β_1, β_2	Trough angle of intermediate transition idlers	degrees

4. General Formulae for Minimum Transition Length

4.1 Transition with Pulley at Belt Line

With reference to Figs. 1 and 2 the following assumptions have been made.

1. The area of the belt tension diagram is equal to the average belt tension just prior to the transition multiplied by the belt width, i. e.,

$$w \cdot t_t = y \cdot t_l + z\,(t_h + t_l)$$

2. By the Pythagorean theorem:

$$S^2 = L_t^2 + m^2$$

3. $$S - L_t = \Delta_s$$

4. From the stress/strain relationship, the tension that produces the extension Δ_s is equal to t.

therefore $$t_h - t_l = t$$

and $$t = \frac{E \cdot \Delta_s}{L_t}$$

By combining and simplifying these expressions the following formulae have been derived:

(a) Transition Length when considering Maximum Tensions.

$$L_t = \frac{h}{\cos\frac{\beta}{2}} \left[\frac{E}{2\left[t_h - \frac{(w \cdot t_t - z \cdot t_h)}{(y + z)}\right]} \right]^{1/2}$$

(b) Transition Length when considering Minimum Tensions.

$$L_t = \frac{h}{\cos\frac{\beta}{2}} \left[\frac{E}{2\left[\frac{[w \cdot t_t - z \cdot t_l]}{(y + z)]} - t_l\right]} \right]^{1/2}$$

4.2 Transition with Pulley at Optimum Height

With reference to Figs. 3 and 4 the following assumptions have been made.

1. The tension at the belt edge is equal to the tension at the centre of the belt.
2. The area of the belt tension diagram is equal to the average belt tension just prior to the transition multiplied by the belt width, i. e.,

$$w \cdot t_t = y \cdot t_h + z\,(t_h + t_l)$$

3. By the Pythagorean theorem:

$$S^2 = S_1^2 + m_1^2$$

4. $$S - S_1 = \Delta_s$$

5. From the stress/strain relationship, the tension that produces the extension Δ_s is equal to t.

therefore $$t_h - t_l = t$$

and $$t = \frac{E \cdot \Delta_s}{S_1}$$

6. The optimum height of the pulley to satisfy condition 1, can be calculated as follows:

$$h_1 = z \cdot \tan\frac{\beta}{2}$$

By combining and simplifying these expressions the following formulae have been derived.

(a) Transition Length when considering Maximum Tensions

$$L_t = \frac{h_1}{\cos\frac{\beta}{2}} \left[\frac{E}{2\left[t_h - \frac{[w \cdot t_t - t_h\,(y + z)]}{z}\right]} \right]^{1/2}$$

(b) Transition Length when considering Minimum Tensions

$$L_t = \frac{h_1}{\cos\frac{\beta}{2}} \left[\frac{E}{2\left[\frac{(w \cdot t_t - z \cdot t_l)}{(y + z)} - t_l\right]} \right]^{1/2}$$

5. Simplified Formulae for Three Equal Roll Idlers

A study of three equal roll idlers has shown that when the belt thickness and the belt radius between centre and wing rollers are taken into consideration, the portion of belt on the wing roller will be approximately equal to $^1/_3$ of the belt width. If lengths y and z are replaced by $^1/_3\,w$, the formulae for minimum transition length can be reduced to the following simplified form.

Transition Type	High Tension Limitations	Low Tension Limitations
Pulley at belt line	$L_t = \frac{h}{\cos \frac{\beta}{2}} \left[\frac{E}{3\,(t_h - t_t)} \right]^{1/2}$	$L_t = \frac{h}{\cos \frac{\beta}{2}} \left[\frac{E}{6\,(t_t - t_l)} \right]^{1/2}$
Pulley at optimum height	$L_t = \frac{h_1}{\cos \frac{\beta}{2}} \left[\frac{E}{6\,(t_h - t_t)} \right]^{1/2}$	$L_t = \frac{h_1}{\cos \frac{\beta}{2}} \left[\frac{E}{3\,(t_t - t_l)} \right]^{1/2}$

The following table gives values for h and h_1 for three equal roll idlers.

Troughing Angle β	20°	35°	45°	60°
h	0.114 w	0.191 w	0.236 w	0.289 w
h_1	0.059w	0.105 w	0.138 w	0.192 w
$h/\cos \frac{\beta}{2}$	0.116 w	0.200 w	0.255 w	0.333 w
$h_1/\cos \frac{\beta}{2}$	0.060 w	0.110 w	0.149 w	0.222 w
h_1/h	0.52	0.55	0.59	0.67

6. Belt Tension Limitations

In order to solve the formulae in Section 4 or 5 it will be necessary to know the average belt tension at the transition under consideration and also the maximum and minimum tensions that will be acceptable.

In other areas of belt conveyor engineering such as vertical curve geometry, the maximum stress in the curve is usually limited to 1.05 t_r and the low limit to 0.05 t_r or even zero. In the case of transitions these values seem reasonable, although the introduction of a radius into the edge of the belt will increase the maximum stress level to somewhere between 1.05 t_r to 1.10 t_r.

The recommended basic stress limitations are therefore as follows:

(a) Maximum tension t_h = 1.05 t_r
(b) Minimum tension t_l = zero.

7. Modulus of Elasticity and Rated Tension

In conveyor engineering the modulus of elasticity and the rated tensions are generally taken as being proportional to the ultimate tensile strength of the belting. The following table gives values for E and t_r for four common belt types. These values are based on information supplied by Dunlop and may vary slightly for different manufacturers.

Belt Type	Designation	Modulus E	Rated Tension t_r
Steelcord	SR	65 t_u	0.15 t_u
Nylon	NN	3.5 t_u	0.08 t_u
Polyester/Nylon	PN	7.6 t_u	0.10 t_u
Kuralon/Nylon	KN	8.0 t_u	0.10 t_u

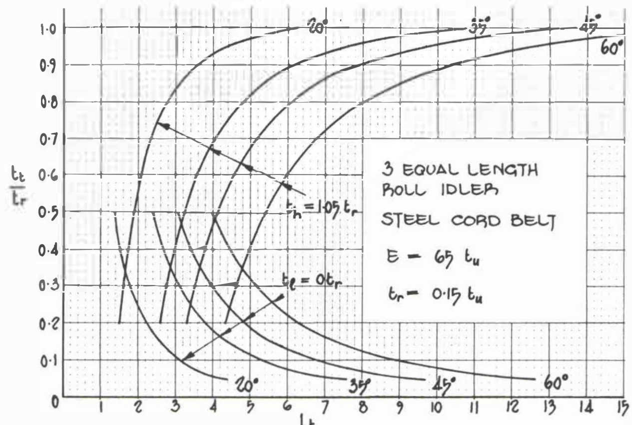
8. Rationalised Transition Lengths for 3 Equal Length Roll Idlers

If the values of E and t_r given in Section 7 and the limiting tension values in Section 6 are introduced into the simplified formulae in Section 5, graphs of t_t/t_r versus L_t/w can be produced for the different belt types.

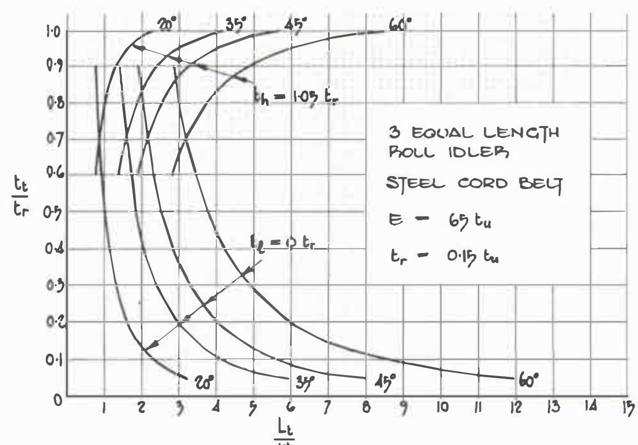
Graphs 1 and 2 show these values for steel cord belting. To obtain values for other types; the value given for L_t/w should be multiplied by the following factors:

NN Belt 0.32, PN Belt 0.42, KN Belt 0.43.

In the design of a large bulk materials handling plant it would be preferable if the transition geometry for any one belt width was a standard throughout the plant. As a result of belt rationalisation conveyors with the same belt type will probably have different tensions at their transition. However, if the maximum value of t_t at a head pulley is taken as t_r and the minimum value of t_t at the tail pulley is taken as 0.2 t_r, then the following rationalised transition lengths could be used for 3 equal roll idlers and steel cord belt.



Graph 1: Pulley at belt line



Graph 2: Pulley at optimum height

Transition Type	Troughing Angle			
	20°	35°	45°	60°
Tail pulley at belt line $t_t \geqslant 0.2\, t_r$	2.2 w	3.8 w	4.9 w	6.4 w
Head pulley at optimum height $t_t \leqslant t_r$	2.3 w	4.2 w	5.7 w	8.4 w

For fabric belts these values could be reduced by the previously quoted factors. However, it is very common to find steel cord belting being used on conveyors that were originally designed for fabric belts. When this occurs, it is usually the case that the original short transition is retained and the new steel cord belt is immediately exposed to possible overstressing. Unless the designer is confident that steel cord belting will not be used in the future, it is recommended that all transition lengths be at least equal to the values in the preceding table.

9. Pack Heights and Trough Angles for Intermediate Transition Idlers

The calculated minimum transition length L_t should be rounded up to suit the standard idler pitch. If the transition is more than one idler pitch long, the use of equal idler pitches will simplify the calculation of pack heights and wing roll angles for the intermediate transition idlers.

If the transition is of the form shown in Fig. 1, the change in direction of the belt edge at the first full trough idler will increase the load on the wing roller bearings. With high tension conveyors the transition will extend over several idlers and in order to reduce the load on the wing roller bearings it is recommended that a radius be introduced into the belt edge. The force arising from the change in direction at the belt edge will then be shared by all the transition idlers.

With the belt mounted at the optimum height a similar situation exists and in addition to the edge radius a centre radius should also be introduced so that the balance between the areas of maximum stress is maintained.

It is acknowledged that the introduction of this radius will increase the areas of high stress above the value of t_h = 1.05 t_r. However, this fact was taken into consideration when the limiting tension values were selected.

9.1 Transition with Pulley at the Belt Line

With reference to Fig. 5, the wing angle of the intermediate transition idlers can be found as follows:

1st Idler $\beta 1 = 2 \sin^{-1}\left[\sin\frac{\beta}{2}\left[1-\left(\frac{P_1}{L}\right)^2\right]\right]$

2nd Idler $\beta 2 = 2 \sin^{-1}\left[\sin\frac{\beta}{2}\left[1-\left(\frac{P_2}{L}\right)^2\right]\right]$ etc.

nth Idler $\beta_n = 2 \sin^{-1}\left[\sin\frac{\beta}{2}\left[1-\left(\frac{P_n}{L}\right)^2\right]\right]$

9.2 Transition with Pulley at the Optimum Height

With reference to Fig. 6, the pack heights and wing angles of the intermediate idlers can be found as follows:

1st Idler x_1 =

$h_1 \left(\frac{P_1}{L}\right)^2$ and $\beta_1 = 2 \tan^{-1}\left[\sin\frac{\beta}{2}\left[1-\left(\frac{P_1}{L}\right)^2\right]\right]$

2nd Idler x_2 =

$h_1 \left(\frac{P_2}{L}\right)^2$ and $\beta_2 = 2 \tan^{-1}\left[\sin\frac{\beta}{2}\left[1-\left(\frac{P_2}{L}\right)^2\right]\right]$

nth Idler x_n =

$h_1 \left(\frac{P_n}{L}\right)^2$ and $\beta_n = 2 \tan^{-1}\left[\sin\frac{\beta}{2}\left[1-\left(\frac{P_n}{L}\right)^2\right]\right]$

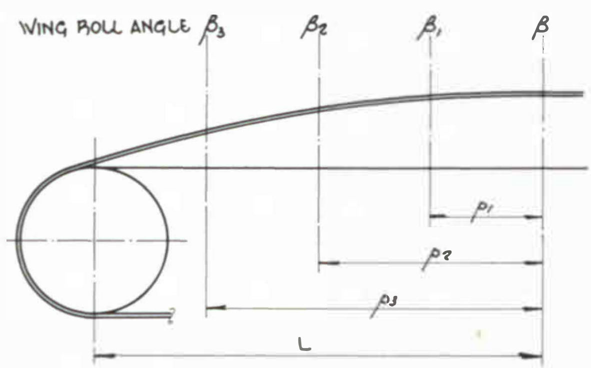


Fig. 5: Pulley mounted at belt line

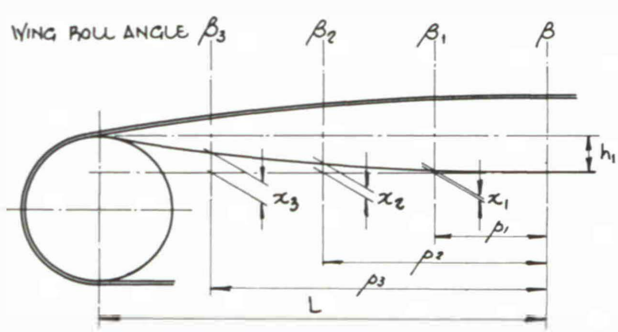


Fig. 6: Pulley mounted at optimum height

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