UNIVERSITY OF LJUBLJANA

Faculty of Mechanical Engineering

Design of a Belt Conveyor for iron ore

A Master's thesis of the second-cycle master's study programme in
MECHANICAL ENGINEERING – a research and development programme

Pelayo López García

Ljubljana, June 2016

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Advisor: ass. dr. Boris Jerman

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Abstract (in English)

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Serial No.: MAG II/286 E

Design of a Belt Conveyor for iron ore transportation at the Faculty of Mechanical Engineering

Pelayo López

Keywords: Belt conveyors
Idlers
Design by analytical approach
Standard equations
Dissipative effects
Driving motor selection

This finals thesis deals with the design of a belt conveyor, this it's done by analytical approach. This means that parts like belt, idlers, pulleys and so on have been calculated by analytical expressions. In the document it is shown all the calculations step by step and the results of them, after all the calculations are done a result it's successfully found.

Povzetek (in Sloven)

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Serial No.: MAG II/ 286 E

Načrtovanje tračnega transporterja za železovo rudo

Pelayo López García

Keywords: tračni transporterji
podporni valji
konstruiranje s pomočjo analitičnega pristopa
standardne enačbe
disipativni učinki
izbor pogonskega motorja

V magistrski nalogi je obravnavano načrtovanje tračnega transporterja za transport železove rude z nižje ležečega predela na višje ležečo ploščad. Najprej so predstavljeni splošni podatki o tračnih transporterjih in njihova zgodovina. Predstavljene so tudi vrste tračnih transporterjev ter njihove prednosti in slabosti. Podrobno so predstavljeni tudi osnovni sestavni deli, kot so nosilno ogrodje, pogonski valj, končni valj, napenjalni valj, podporni valjčki v delovni in povratni veji, čistilni valjčki, valjčki za absorpcijo sunkov, strgalo in njihov namen. Posebna pozornost je namenjena tudi tekočemu traku ter pogonski verigi z elektromotorjem, reduktorjem in sklopkami.
V nadaljevanju so predstavljeni vhodni projektni podatki in zahteve, ki vključujejo tudi zahtevano kapaciteto tračnega transporterja in konfiguracijo terena, skupaj z zahtevano višino dviga. Izdelana je začetna zasnova transporterja, ki vključuje tudi preliminarno izbiro sestavnih delov kot so tekoči trak v skupni dolžini 605 m, podporni valji, kolesa in drugo. Izbran je tudi prečni presek tekočega traku, ki je podprt z osrednjim vodoravnim podpornim valjčkom ter dvema stranskima valjčkoma, nameščenima pod 45°. Izbrana je tudi železovi rudi ustrezna kvaliteta in debelina tekočega traku, s poudarkom na obrabni odpornosti. Izbrana je tudi razmeram ustrezna hitrost transportiranja.
Zasnova tračnega transporterja je preverjena s pomočjo analitičnih standardnih metod. Določen je pričakovan presek na tekoči trak nasute rude ter preverjena dosežena kapaciteta. Izračunane so pričakovane izgube ter natezne sile v tekočem traku. Upoštevaje

te podatke, podatke o energiji, potrebni za dvigovanje rude na višji nivo ter podatke o izkoristkih reduktorja in drugih elementov pogona je določena tudi potrebna nazivna moč pogonskega elektromotorja. Iz katalogov je nato izbran ustrezen standardni elektromotor. Na osnovi nazivne vrtilne hitrosti elektromotorja ter predvidene hitrosti gibanja tekočega traku je določena tudi potrebna prestava reduktorja. Za prenos energije od elektromotorja do pogonskega valja tračnega transporterja so izbrane tudi hidravlična sklopka ter ustrezne elastične sklopke.

Obravnavani tračni transporter vsebuje dva vodoravna odseka in vmesni poševni osek. Zaradi tega je vsebovana tudi po ena konkavna in po ena konveksna sprememba smeri gibanja tekočega traku. Za izvedbo je še posebej zahtevna konkavna sprememba med nižje ležečim vodoravnim delom ter začetkom vzpona traku, kjer je ustrezna lega polnega transporterja zagotovljena kar z lastno težo transportirane rude, medtem ko je pri obratovanju praznega transporterja kot ustrezna rešitev izbran par ozkih usmerjevalnih koles.

S pomočjo izvedenih analitičnih izračunov je ustreznost zasnove in izbranih standardnih elementov tračnega transporterja uspešno dokazana . V dokumentu so prikazani vsi potrebni izračuni, skupaj s potrebnimi tabelami ter pripadajočimi rezultati in končno obliko tračnega transporterja.

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Symbol	Unit	Meaning
A	m^2	surface area
A_1	m^2	top area of the cross sectional area of the load stream
A_2	m^2	low area of the cross sectional area of the load stream
A_c	mm^2	effective contact area between belt and scraper
b	m	usable belt width
B	mm, m	belt width
C	/	belt length factor for peripheral force
C_B	/	belt width factor
C_L	/	belt length factor for power calculation
C_R	/	friction factor
C_{Tr}	/	value of the warp material carcase i.e. belt type
C_v	/	breaking strength loss at join factor
d	mm	thickness of the belt carcase
d_w	mm	shaft diameter of bearing seating
D_R	mm	idlers diameter
D_{Tr}	mm	drive pulley diameter
f	/	friction factor
F_{Gb}	N	belt bending resistance
F_{Gr}	N	friction force between belt and scraper
Fs	N	additional forces
F_{Tr}	N	pulley bearing resistance
F_u	N	peripheral force
F_v	N	take-up tension
G_T	N	pulley weight bearing force
G_v	kg	take up weight
H	m	elevation height
h_{rel}	/	relative belt sag
k	$N\ mm^{-1}$	braking strength
k_f	/	working conditions factor
k_N	$N\ mm^{-1}$	nominal braking strength
k_R	$N\ m^{-1}$	frictional resistance
l	m	length of the middle carrying idler
L	m	belt conveyor length
l_1	m	loading width of outer idlers
L_c	m	length of the curve
l_o	m	distance between carrying idlers
L_R	mm	idler length
l_u	m	distance between return idlers
m'_G	$kg\ m^{-1}$	mass of the belt
m'_L	$kg\ m^{-1}$	mass of the load
m'_R	$kg\ m^{-1}$	mass of the rollers
N_{idlers}	/	number of idlers
p	MPa	pressure between the belt and the cleaner

P_1	kW	power for empty conveyor and load over horizontal distance
P_2	kW	power for lift
P_3	kW	sum of additional powers
P_T	kW	power at the drive pulley
P_M	kW	power of the motor
Q_m	$t\ h^{-1}$	mass transportation capacity
Q_v	$m^3\ h^{-1}$	volumetric transportation capacity
R_a	m	concave curve
R_e	m	convex radius
R_o	kg	carrying side resistance
R_u	kg	return side resistance
S	/	security factor
s	mm	portion of the belt in contact with the idlers
T_1	N	maximum tension at the head
T_2	N	minimum tension at the head
T_3	N	tension at the return side of the tail
T_4	N	tension at the carrying side of the tail
T_m	N	average belt tension
v	$m\ s^{-1}$	belt velocity
x	/	carcase factor
x_a	m	horizontal coordinates of the concave curve
y_a	m	vertical coordinates of the concave curve
α	°	deviation per idler
β	°	surcharge angle
δ	°	belt slope angle
μ	/	friction factor between pulley and belt
μ_c	/	friction factor between belt and cleaner
φ	°	wrap angle
λ	°	troughing angle
ρ	$kg\ m^{-3}$	density of the material

1 Introduction

1.1 Background

Belt conveyors are transport equipment, which is also nowadays widely used in various industries. Most of conveyors are designed to transport bulk materials, but they are often used also for non-bulk goods. In the cases of larger mines or larger material deposits the long belt conveyors are implemented. In some cases the slope of the belt is changing along its length.

In this thesis the premises are to design a belt conveyor from some requirements that will be explained later, from these requirements a reliable design as most optimized as possible has to be find.

1.2 Introduction to conveyor belts

Conveyor belts have been used for decades to transport bulk material and unit loads, the have proved their worth everywhere because belt conveyor installations can be adapted to meet nearly all local conditions. They are work-safe and economical.

The demand for ever increasing capacities and even longer conveying lengths has accelerated the development of the belt conveyor technique, new materials are being developed, new conveying systems are being planned and tested especially those having regard to the environment. [1]

The conveyor belt plays the major part in the whole system and has to overcome the many and varied stresses. In addition to this, every conveying problem is different and needs careful planning and selection of the right elements in order to achieve the optimum conveying capacity in an economical way.

There are a number of practical rules, values and experiences which can be useful during the planning stage. These rules, values and experiences are always followed on the designing of a belt conveyor, all of them provided from manuals, standards etc. that designers can use.

There is already a lot of use of computer calculation and dimensioning of belt conveyor through finite elements for example using software like Matlab or ANSYS.

Anyway all new standards DIN, EN, or ISO, have been taken into consideration since all the manuals and guides used on this thesis follow these standards.

1.3 Conveyor belts through history

Until the middle of the 1970's conveyor belt development and technology was concentrated on the search for appropriate materials for the belt and the solving of drive problems. In the first instance transmission of traction played a part. As the demand grew up for conveyors of larger capacity and longer length, additional requirements effecting the belt had to be considered and researched such as grater work load, elongation, slit resistance and endless splice jointing.

Evolution through time [1].
From 1870: trials with plain cotton belts
Up to 1914: first rubber conveyor belts developed from drive belts.
1921: founding of the Enerka factory. Manufacture of drive belts and later conveyor belts.
1923/1924: first belts with underground, not a success due to drive problems.
1926: first belts with robust Balata reinforced covers.
From 1928: use of belts with Maco cotton plies
From1933: development of Rayon/cotton belts and pure rayon belts. Transition from natural rubber to synthetic rubber for protection of carcase.
From 1939: increased use if synthetic rubber.
1941/1942: use PVC belts above ground.
1942: steel cord belts used for the first time for major long haul installations in the united states.
From 1945: further development of high tensile strength belts e.g. plies from rayon, polyamide and polyester. Cover rubbers with various surface designs. Steep incline belting with profiles and cleats.
From 1955: development and use of steel cord belting in Europe.
From 1970: use of Aramide as reinforcing material for the carcase.
From 1980 development of new conveyor systems e.g. the tube conveyor, hammock conveyor.

This brief history illustrates the more important stages in conveyor belt development. The search for new materials became necessary because of the diameters, vertical and horizontal curves etc. and the demands of new conveying systems.

1.4 Conveyor Belts now a days

1.4.1 General description

A belt conveyor is a continuous transport system basically formed by a belt that moves between two pulleys, carrying on the top side the material, returning empty on the low part.

Belts exists for heavy and light use. The belt is pulled through a friction force by one or more pulleys, that at the same time are driven by motors. This friction force is the result of a tension given to the belt, usually by a take-up weight system. One pulley is driven with a motor and the other rolls free, its function is to return the belt. The belt is supported by several idlers or idlers between those two pulleys.

Due to the movement of the belt the material on it is normally transported to the driven pulley, where the bel rolls on turns the way around. At this zone the material on the belt drops over out of the belt due gravity action and the inertia of the transportation caused by its velocity.

As it was said before conveyor belts are mainly used to transport bulk materials like cereals, coal, ores etc. although they can be used to transport for example persons in closed areas like hospitals.

Often they used to charge cargo ships or trucks. To transport material across inclined land the slope angle barely exceed 18º. There are a big variety of belt conveyors, that are different in the operation mode, way and transport direction, and also idler conveyors, that are use several idlers to transport boxes or pallets.

Light belt conveyors are usually used to transport components for assembling processes, tools for manufacturing processes and helping to transport some loads. At the same time they can be used for automatic distribution and storage.

Combined with computerized equipment for pallet management (often transported by idlers), allow an efficient distribution, saving expenses from human worker salaries and transport of big amounts quickly, what makes a factory to save from costs and storage.

The longest conveyor belt in the world is in Occidental Sahara, it’s 100 km long as we can see from the figure 1.1.

Figure 1.1: Longest belt conveyor in the world, 100 km [2]

Figure 1.1 is a view from satellite where it's possible to see this belt conveyor because of its material losses, the spillages caused by the wind show a white way of the conveyor.

1.4.2 Advantages of belt conveyors

As a consecuence of the different energetic crisis, continuous by belts started to get popular in every kind of installations of material transportation, like open mines.

The principal advantages of belt conveyors are the named below.

1. Low cost of operation and maintenance
2. Electric controlled
3. Good energetic efficiency
4. Big transportation capacity
5. Conveyors are not so affected by climate
6. Easy automation

In the other hand there are some inconveniences that are written bellow.

1. Big initial investments
2. Difficulty to adapt to changes and new requirements of transportation
3. A consequence of its way of operation they can't make important direction changes as big slopes or important curves. This makes necessary to use several conveyors what increase the costs and failures can appear easier.

In case of extraction or mineral transport installations, it can be said that conveyor belts are the right solution when the required capacity is over 100 t/h and the distances of transportation are over a kilometre, or also when the goal is to automate the process.

In other kind of installations, they are recommended when the goal is to automate the transportation and the distribution of bulk materials, decreasing the exploitation costs at the expense of bigger initial investment.

1.4.3 Types of belt conveyors

Conveyor belts can be clasified according to their capacity of movility as fixed, rippable and movable.

1.4.3.1 Fixed belt conveyors

They are the most popular, as it name says, its frame can't move (figure 1.2). An special case are those which have a tripper, tha can move by wheels on the frame of the conveyor and can modify the discharge position (figure 1.3).

Figure 1.2: Fixed conveyor belt [4]

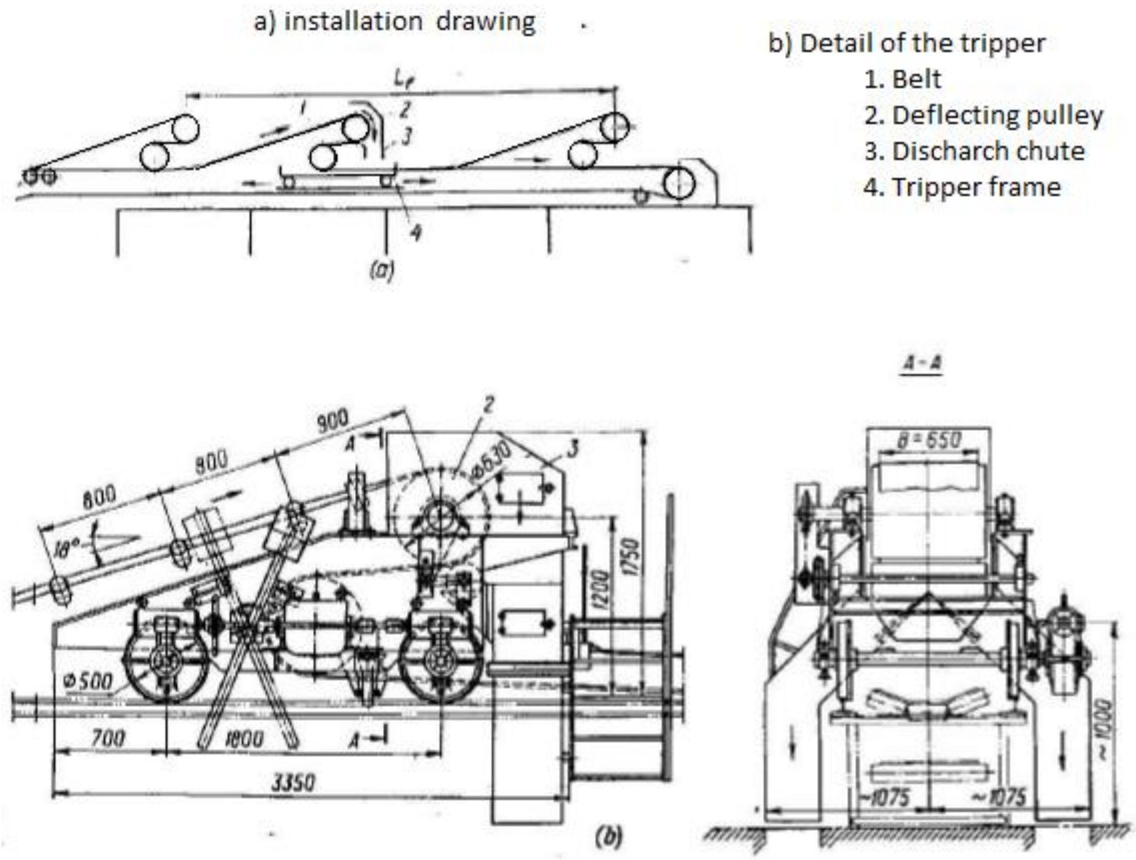


Figure 1.3: Tripper [2]

1.4.3.2 Movable conveyor Belt

They are located on movible frames. They are specially used in mineral extraction operations or discharge of it, in open fields, where it's necessary to move at the same time that the extraction goes(figure 1.4).

Figure 1.4: Movable conveyor belt [2]

1.4.3.3 Portable belt conveyors

They have a frame made of a metallic structure not completely rigid, which can be transported by wheels (figure 1.5) or other kind of guiding (figure 1.6).

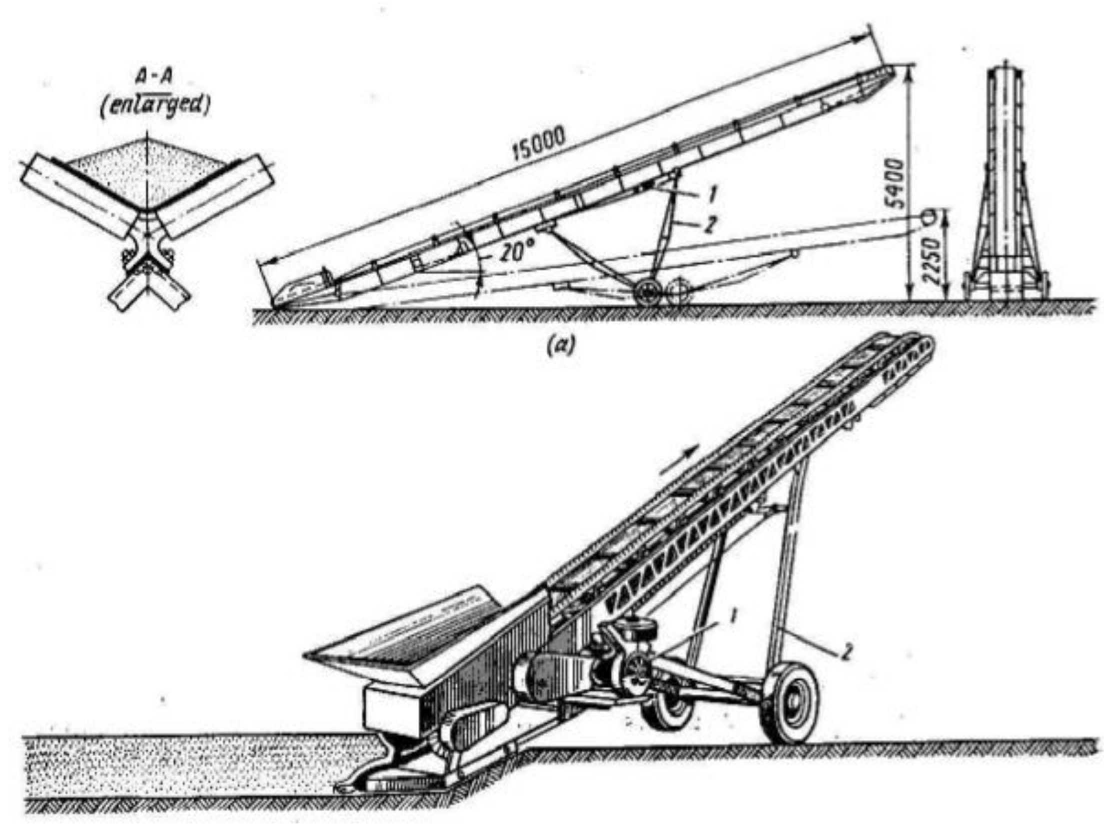


Figure 1.5: Conveyor belt on wheels [2]

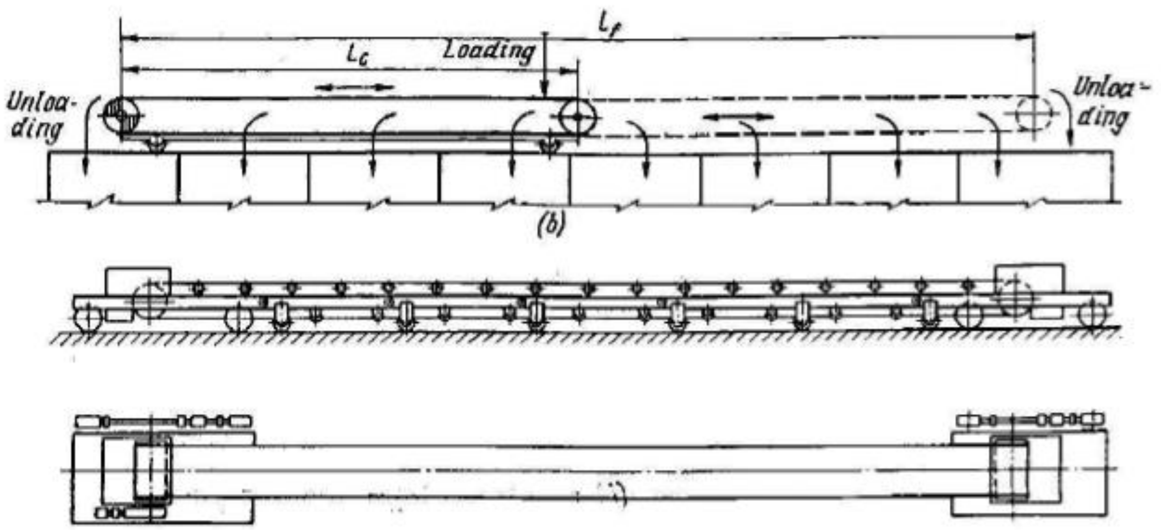


Figure 1.6: Belt conveyor on rails [2]

1.4.4 Principal parts and components of conveyor belts

From figure 1.7 It’s possible to distinguish all the main elements of a belt conveyor.

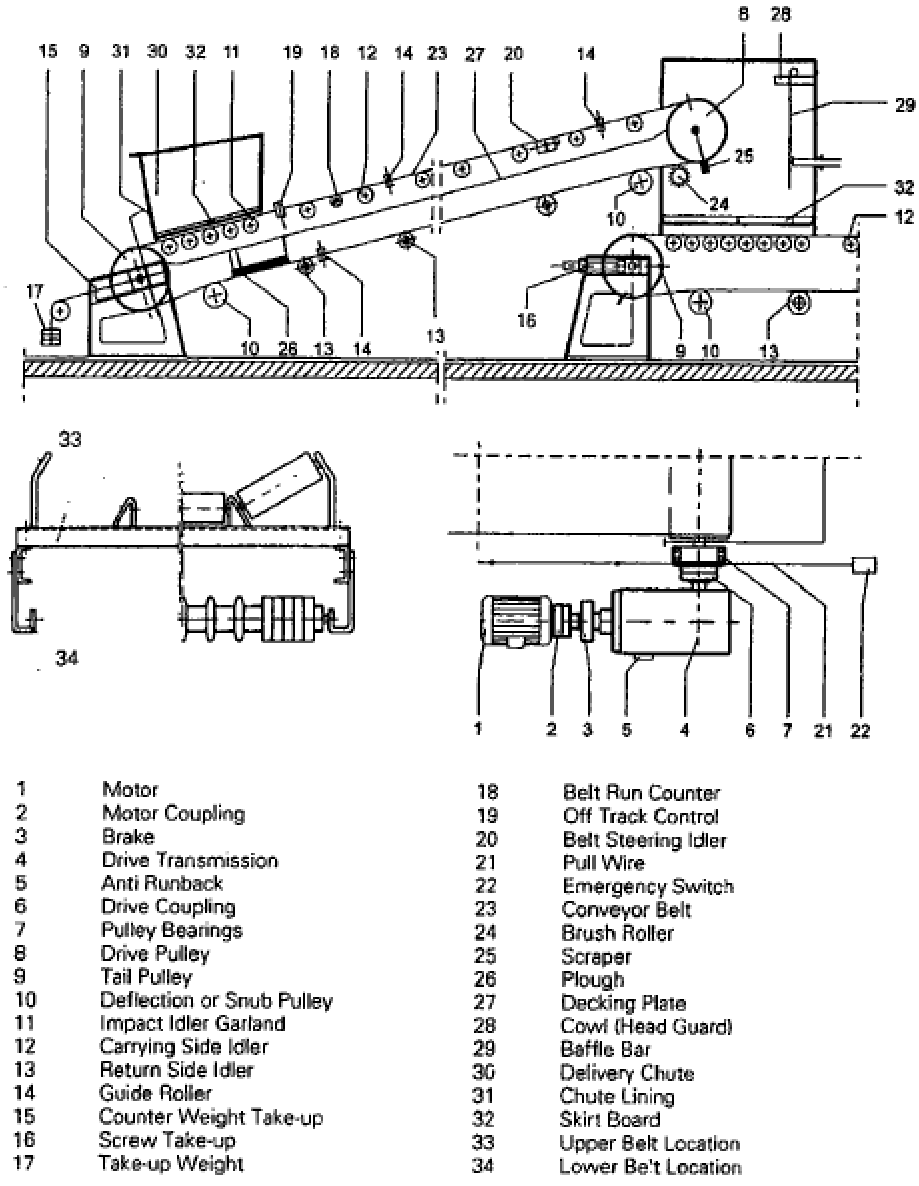


Figure 1.7: Main parts of a belt conveyor [1]

In the chapters below the main parts will be explained.

1.4.4.1 Frame

It supports the belt and it has to be rigid. Usually they are made of UPN profile welded or screwed in easy transporting modules (figure 1.8).

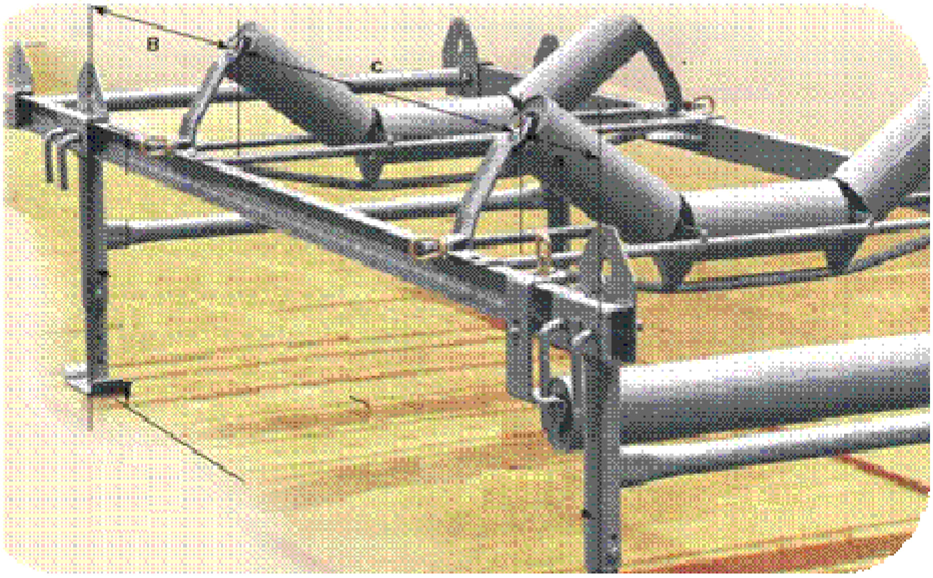


Figure 1.8: Frame with idlers [2]

1.4.4.2 Driving and discharge pulley

It gives the movement to the belt, in order to do that it’s covered by rubber due to have more adherence between its surface and belt’s (figure 1.9).

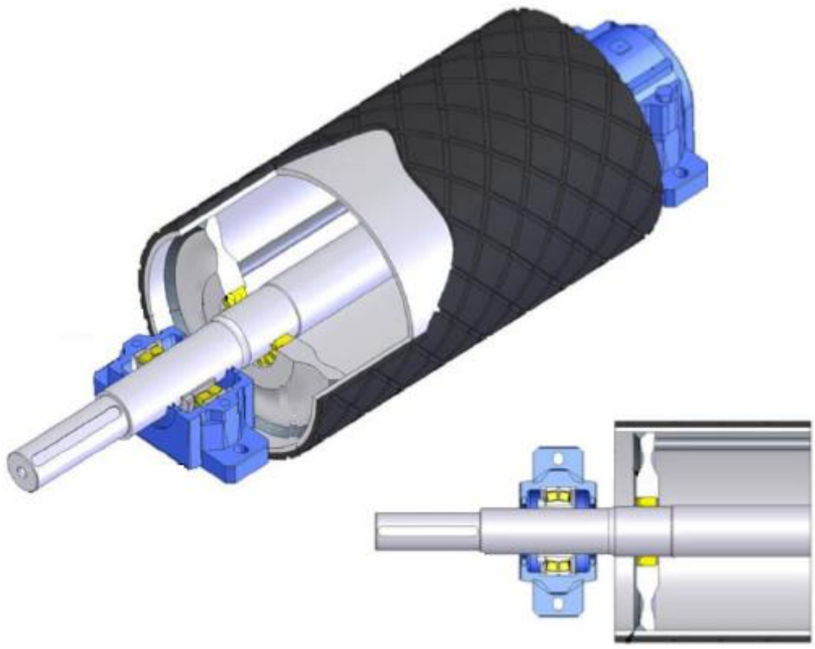


Figure 1.9: Driving pulley [2]

As we can see it has a shaft, through it the power will be transmitted.

1.4.4.3 Returning or tail pulley

This pulley rolls free, allowing the belt to complete is way. In short belts, less than 30 m long, there is a tension system by spindle in this pulleys (figure 1.10).

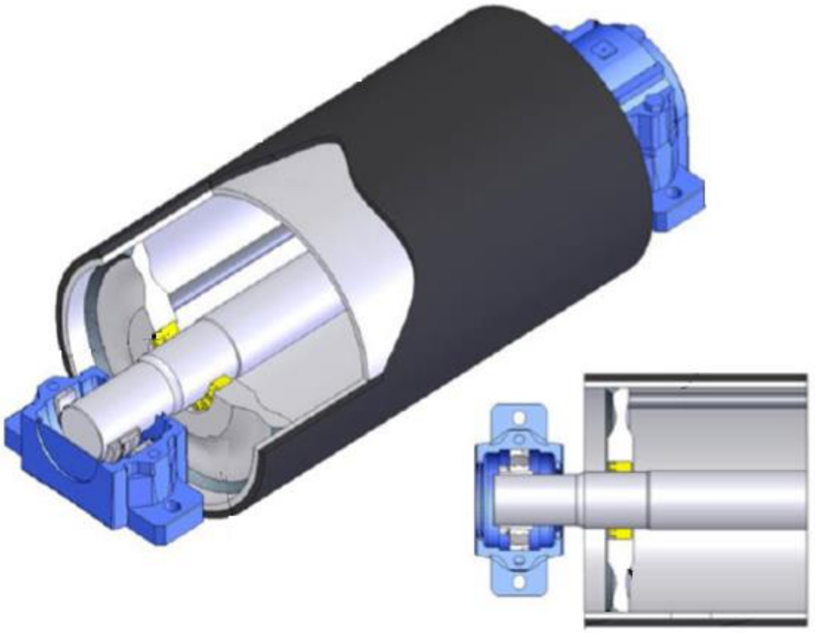


Figure 1.10: Return pulley [2]

As we can see I the figure 1.10 this pulley is not driven, there is not a shaft where the power can be transmitted.

1.4.4.4 Take up pulley

This pulley connects the take up system with the belt, transmitting tension to the belt. (figure 1.11).

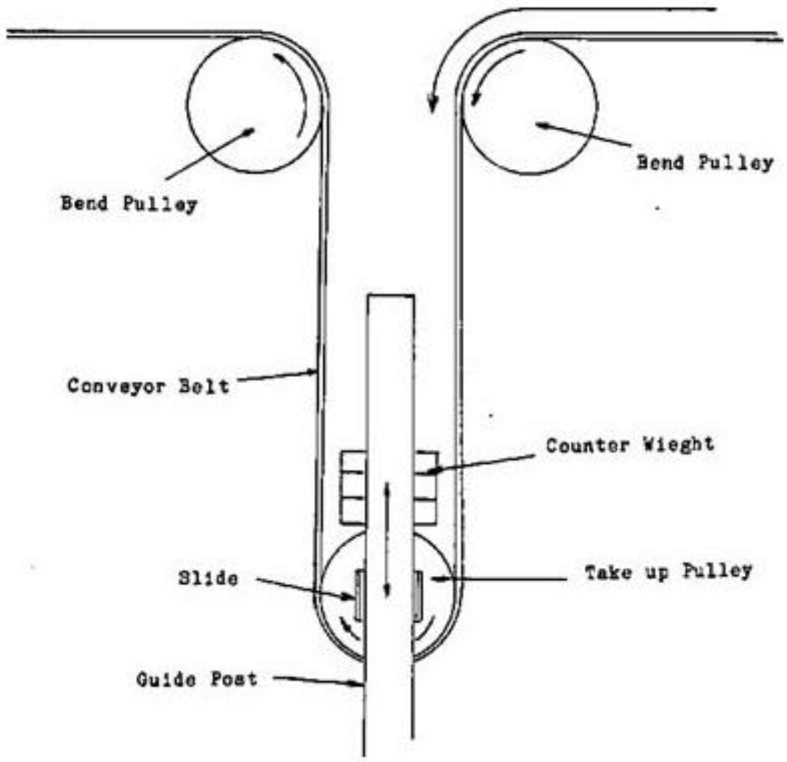


Figure 1.11: Take up pulley [5]

1.4.4.5 Guiding pulleys

They are necessary to guide the belt without damaging it so it can be adapted to the transporting way. They keep the belt in the right way.

1.4.4.6 Deflection or snub pulley

They allow to have a bigger wrap angle between the drive pulley and the belt, so the transmission of the force is better. See figure 1.12 with all kind of pulleys.

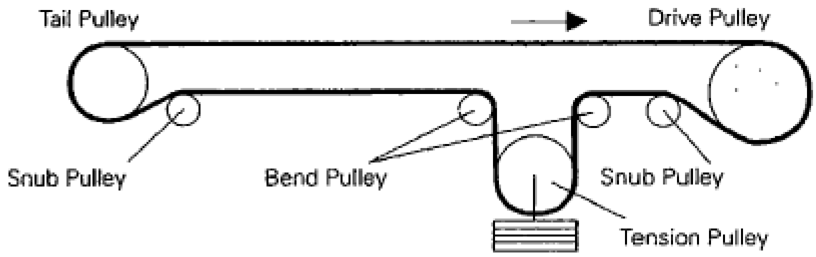


Figure 1.12: Pulleys sketch [1]

1.4.4.7 Take up system

It's a cage with masses which is hanging from the belt. The system is embedded in rails with shock-absorbing system at the bottom to support an impact from the masses if the belt breaks. See figure 1.13.

Figure 1.13: Take up system [2]

1.4.4.8 Upper idlers

These elements are formed by one, two, three or even more idlers which have to support the carrying side of the belt, and at the same time they are being supported by a metallic structure called station, which are on the frame. When there are 3 idlers it's called trough disposition. See figure 1.14.

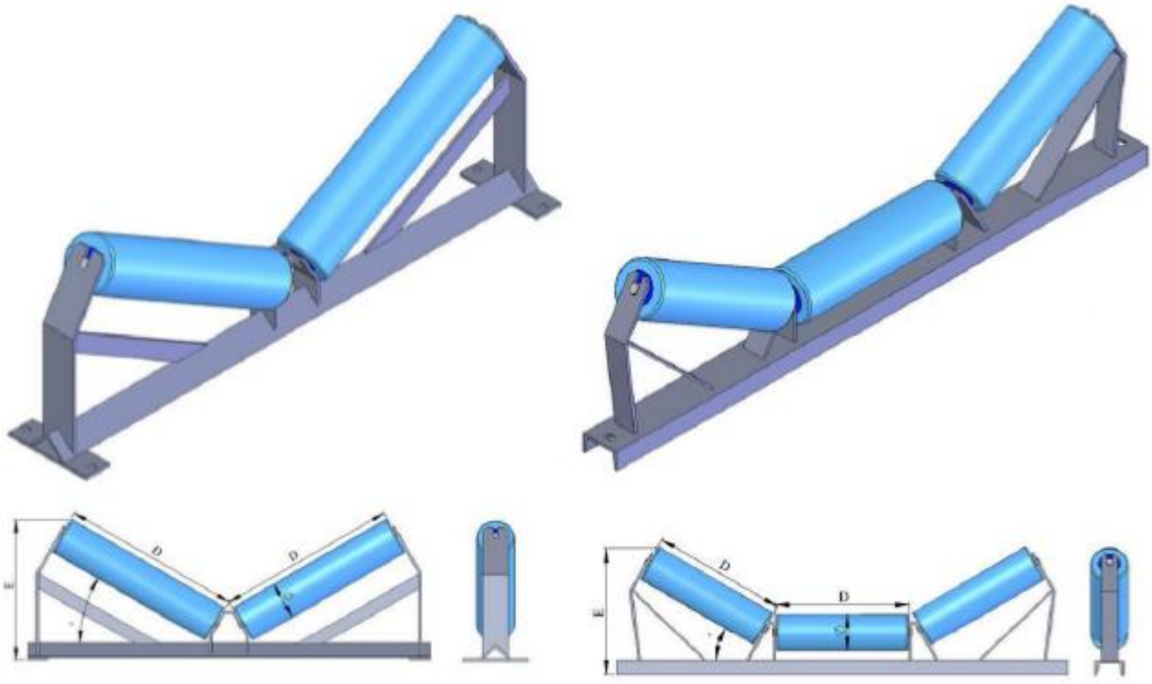


Figure 1.14: Upper idlers [2]

As it’s shown in the picture these idlers are supported by a structure called stations see figure 1.15.

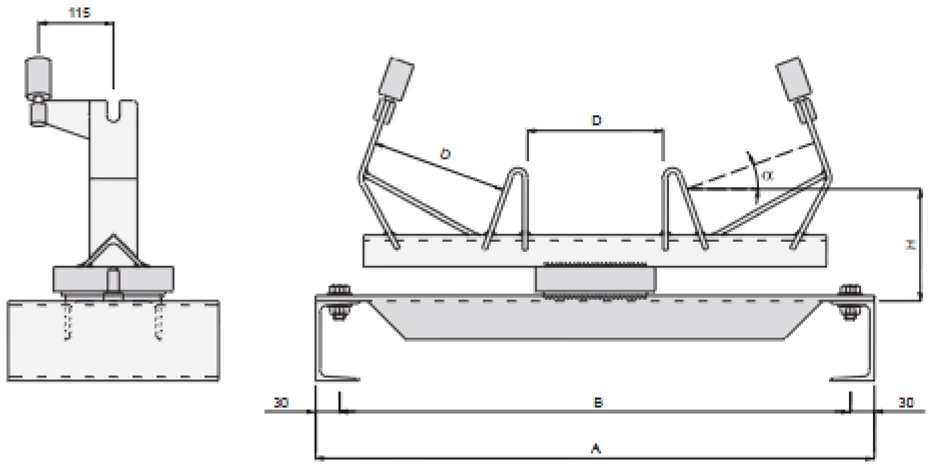


Figure 1.15: carrying idlers station with troughing angle [7]

1.4.4.9 Under idlers

These elements are formed by one or two idlers which have to support the return side of the belt conveyor on its dirty face, these idlers are supported by a metallic structure called under stations which supported by the frame of the belt conveyor. See figure 1.16.

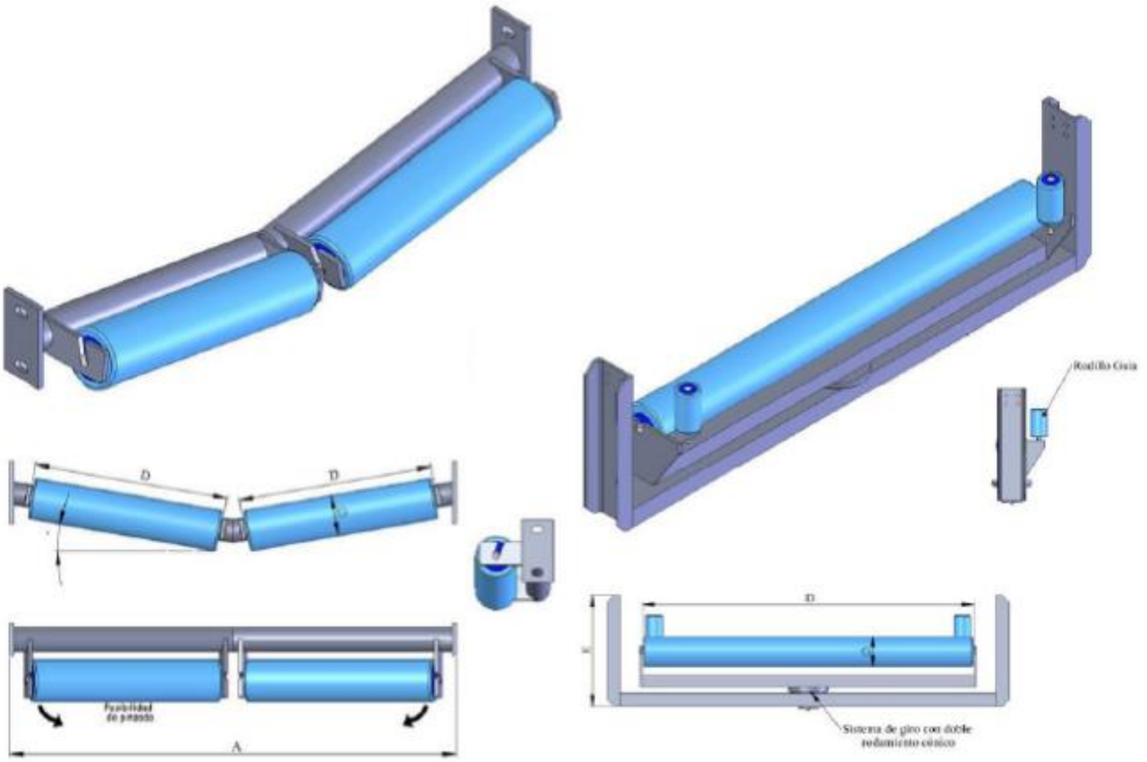


Figure 1.16: Under idlers [2]

There are also specific stations for return idlers see figure 1.17.

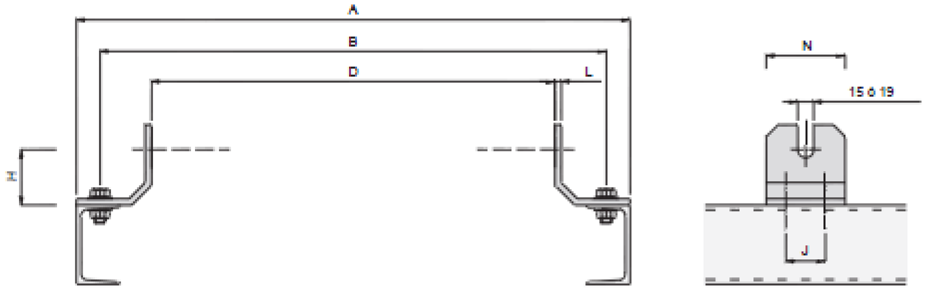


Figure 1.17: Return idlers station [7]

1.4.4.10 Cleaner idlers

There is a kind of idlers that its mission is to clean the dirty side of the belt so the returning idlers don't get damage with the time after so much bulk material crashes it, there are so many kind of cleaner idlers, even with brushes. In the figure 1.18 some cleaner idlers are shown.

Figure 1.18: Cleaner idlers [2]

1.4.4.11 Shock-absorbing idlers

Their mission is to absorb the impact of the material when it's been charging to the belt so the belt doesn't get damage and it can last longer in service. The use to be located in shorter distance between each other than carrying idlers to avoid some spillages of the material and absorb better the impact on belt. See figure 1.19.

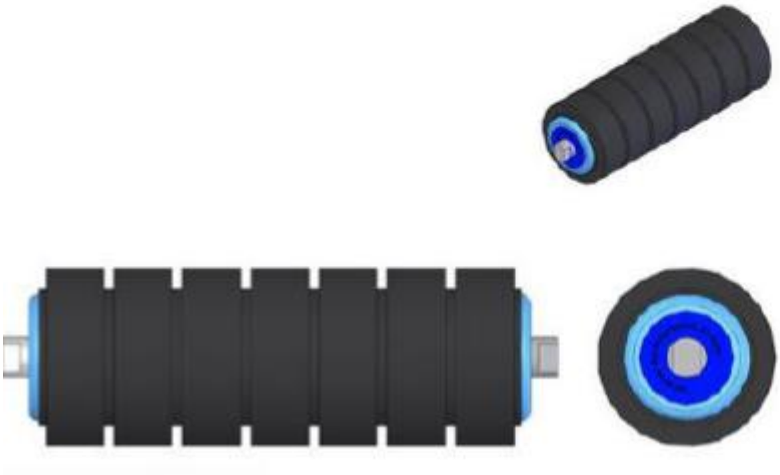


Figure 1.19: Shock-absorbing idlers [2]

1.4.4.12 The belt

The belt is one of the principal elements of the conveyor. It's made of layers that can made of polyester or metallic, and they are covered by rubber in both sides, to give the belt resistance and rigidity needed to commit its double mission, which are to support all the transversal efforts due to the material load and to adapt in the troughing angle and also it has to resist longitudinal efforts due to the transportation. In the figure 1.20 it can be distinguished the polyester and the metallic belt.

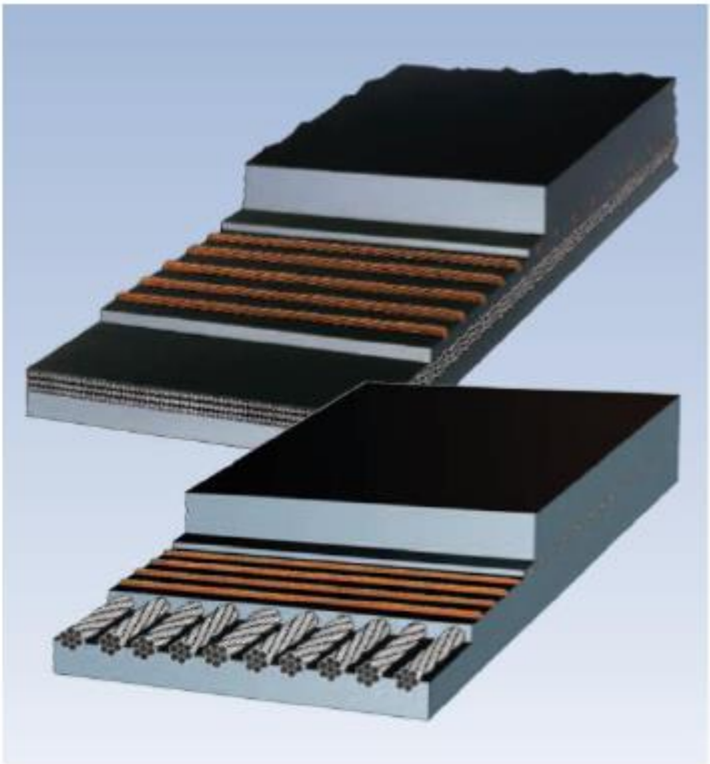


Figure 1.20: Polyester and metallic belts [2]

1.4.4.13 Driving system

The driving system is formed by the electric motor, a break, a coupling (hydraulic normally) and a gear box, its mission is to transmit the force to the pulley needed to make the transportation of the material happen under any circumstances.

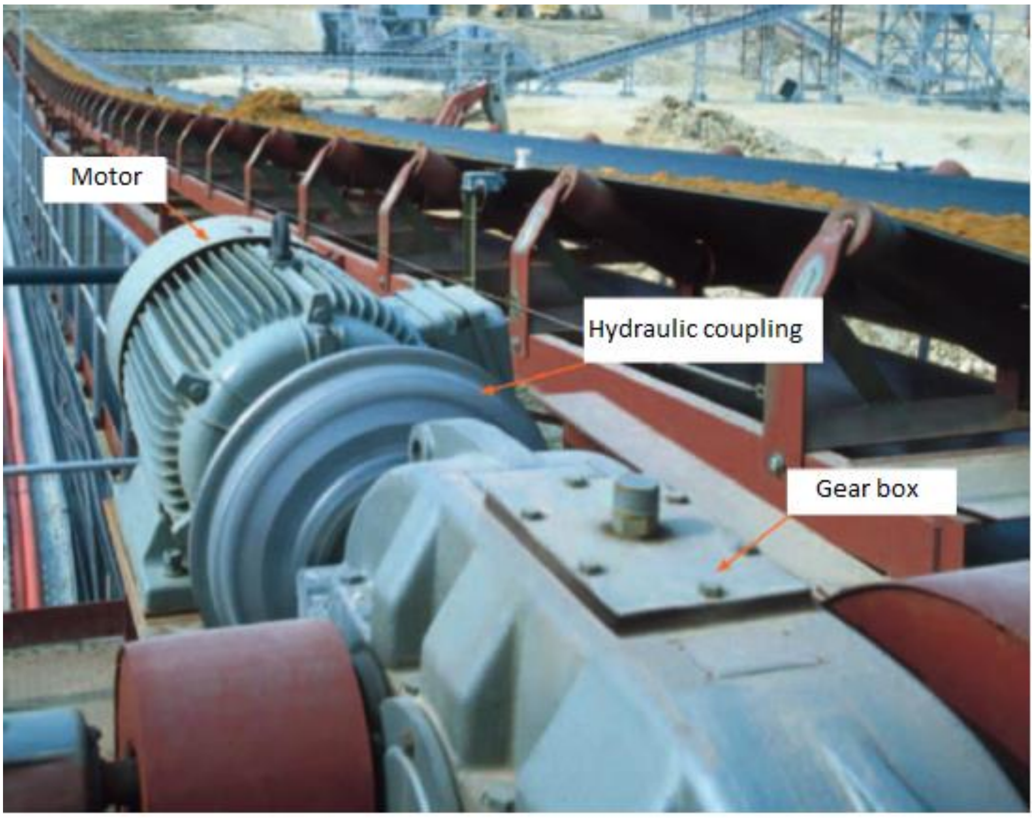


Figure 1.21: Drive system [2]

1.4.4.14 Charging chute

It must guide the material to the centre of the belt to avoid transversal movements that can produce material losses or to make the band go out of its truck. See figure 1.22.

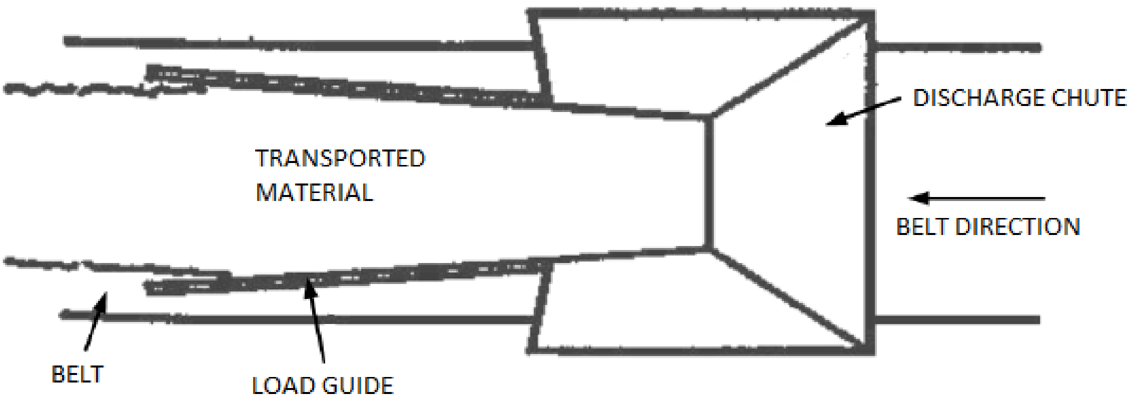


Figure 1.22: Belt charging point [2]

1.4.4.15 Load guide

It's a metallic element with rubber pieces at the lowest part, that guides the bulk material in the carrying side, keeping centred and giving it a better shape to adapt it to the troughing angle, avoiding spillages at the discharge of the chute. See figure 2.23.

1.4.4.16 Chute carcase

It's a metallic element that has a deflection plate to guide the falling of the material to other element, it could be a belt, container, etc. See figure 1.23.

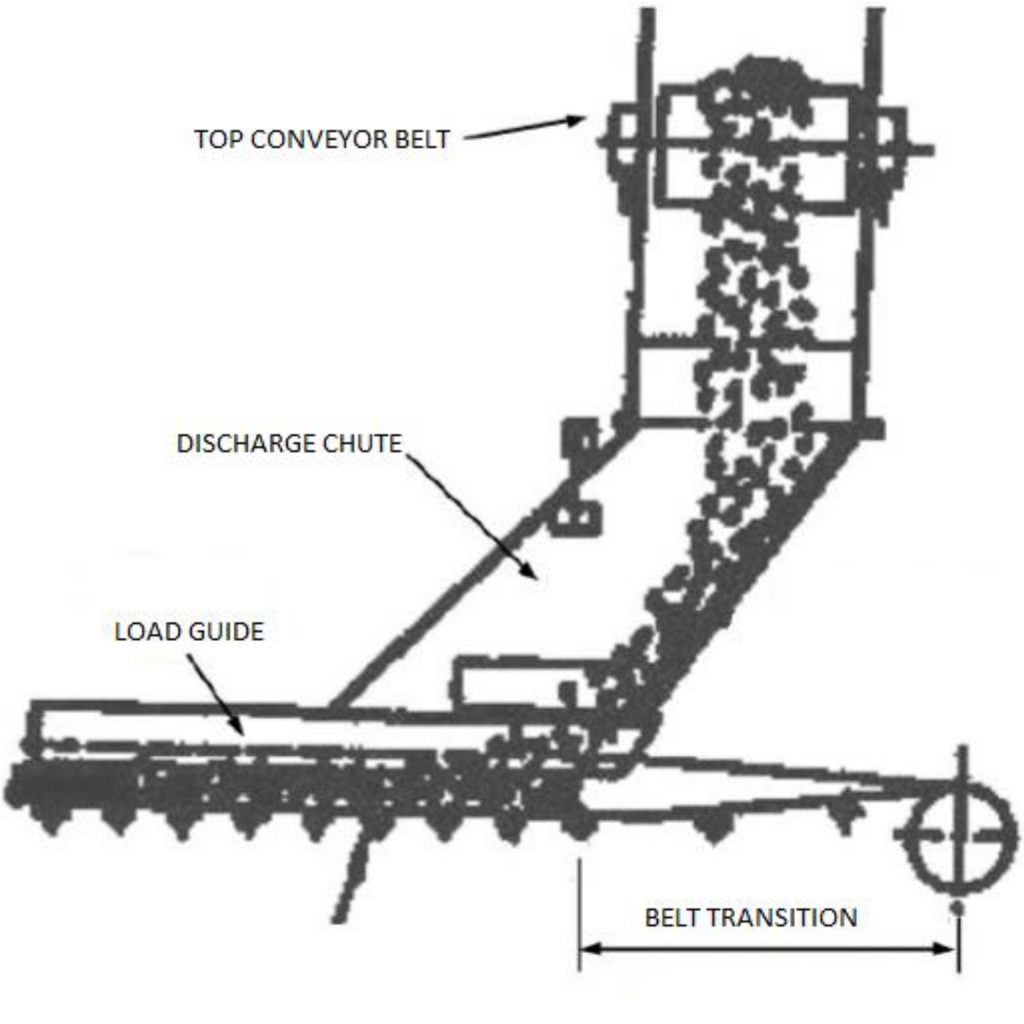


Figure 1.23: Product transfer between two belt conveyors [2]

1.4.4.17 Belt scraper

Formed by a metallic or ceramic plate which scrapes the returning belt before it contacts other pulleys or idlers in order to remove particles coming from the bulk material transported. These particles can damage the belt and the idlers because when they contact there can be friction with cutting edges.

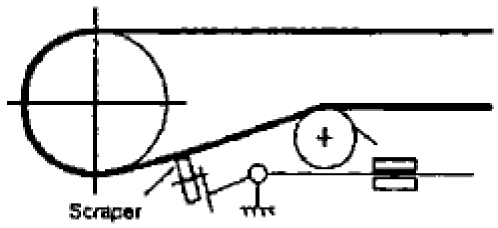


Figure 1.24: Belt scraper [1]

1.5 Objective

The purpose of the project is to design a conveyor belt for transporting iron ore from lower location to the higher location, where the first part of the belt has a horizontal direction and the second part of the belt is inclined along of the slope of the terrene. To this end, the task set the following objectives.

- Definition of detailed requirements for belt conveyor;
- Determination of the forces in the conveyor belt;
- Definition of the configuration of the support idlers;
- Calculation of friction and other dissipative effects;
- Selection of the drive motor;
- The design of the tilting structure scraper.

2 Theoretical background and overview of literature

2.1 Theoretical background

The law of operation of belt conveyors will be explaiened in this chapter.

The transmission of the power from the driver pulley to the belt conveyor obey to the friction expression from Eytelwein-Euler. this theory says that the tension of a belt increases along the surface contact with the perimeter of the driving pulley, according to a logarithmic function, from an initial value T_2 to a final value T_1, this is a consequence of the peripheral force Fu. The difference between the two tensions is this peripheral force (figure 2.2).

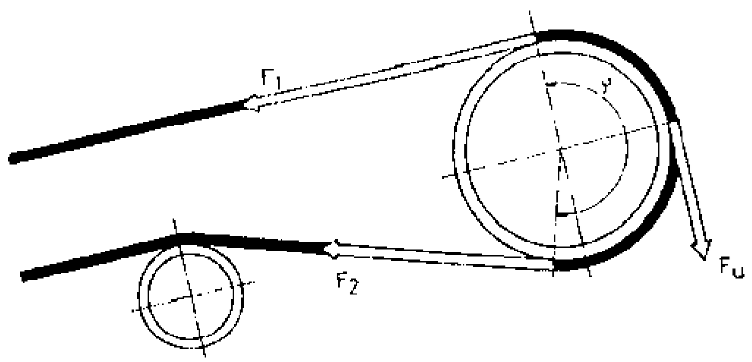


Figure 2.1: Law operation sketch [2]

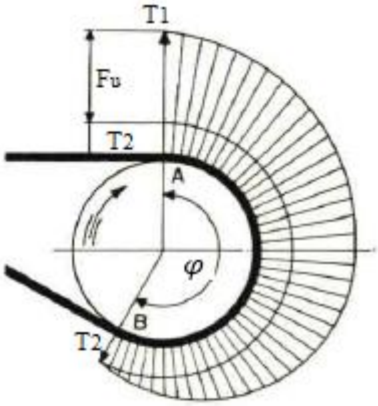


Figure 2.2: Tension and force value representation [3]

Therefore, according to this theory, the belt conveyor shall have a minimum tension as T_2. Otherwise, the transmission of the movement between the pulley and the belt can't exist, both surfaces would slide.

$$\frac{T_1}{T_2} \leq e^{\mu\varphi} \tag{2.1}$$

Where

$$F_u = T_1 - T_2 \tag{2.2}$$

$$T_1 = F_u \cdot \left(\frac{1}{1-\frac{1}{e^{\mu\varphi}}}\right) \tag{2.3}$$

$$F_2 = F_u \cdot \frac{1}{e^{\mu\varphi}-1} \tag{2.4}$$

Therefore, for the correct operation of the belt conveyor, these expressions shall be verified.

2.2 Literature

The thesis will follow the guide from Dunlop referenced as [1]. The guide is also following standards like ISO, DIN etc. because in these standards there is everything about analytical calculation of belt conveyors, and this guide compiles the procedure necessary to the calculation and design of belt conveyors.

This analytical approach in this case is formed by mathematical expressions and tables from where factors from the characteristics of the problem and standard values from the results are chosen.

3 Designing calculations

In this chapter all the process about conveyor belt designing will be shown, fulfilling all the requirements that will be shown in the 3.1 subchapter, then the results will be given at every step of the process and they will be conveniently explained in order to have a clear solution.

3.1 Definition of the problem

It is required to transport at least two tones per hour of iron ore from poin A to point B (see figure 3.1).

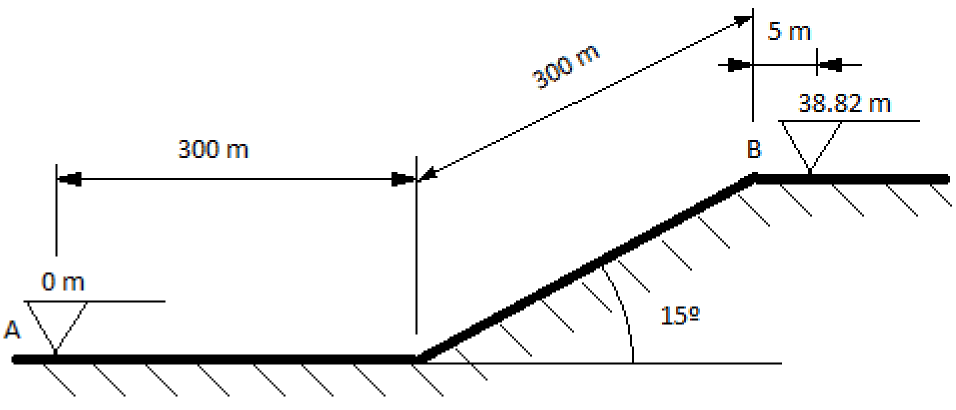


Figure 3.1: Sketch of the profile of the land

So as it's shown in the figure 3.1 there is between point A and point B a horizontal part 300 m, there is a also a 300 m long part of the land where there is a 15 degrees slope, and finally before the discharge point there is 5 metres of horizontal land. There is a height between the point A and the point B due to the slope that is 38.82 metres. There are not horizontal curves that the conveyor has to do.

3.2 Initial designing idea

The idea of the designing analysing the profile of the land where the conveyor will be ubicated it's to follow this profile, therfore the conveyor will have 300 metres of horizontal way, 300 metres of 15 degrees inclination part and a last part horizontal 5 metres long.

In the transportation in belt conveyors usually the carrying side of the belt has a shape, in order to have more capacity, in this case three idlers will be used forming a troughing angle as it's shown in figure 3.2.

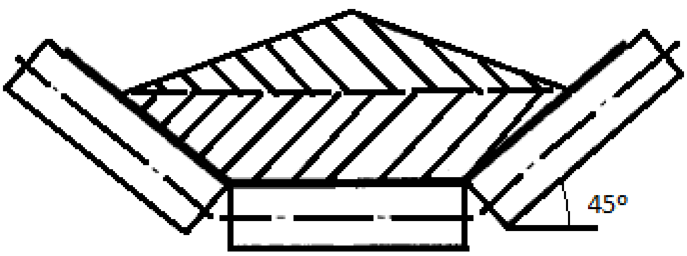


Figure 3.2: Sketch of the cross sectional area.

As it's shown in the figure 3.2 this troughing angle is 45 degrees, this is a typical angle for this kind of transportation, like this the material will be more protected from the wind also. The material, iron ore, has it characteristics as density, grain size, etc. this values will be taken from appendix Q of [1]. Therefor the characteristics from which all the parameters are calculated are:

Belt:

$$L = 605\ m$$

$$\mathrm{H} = 38.82\ \mathrm{m}$$

$$\lambda = 45º$$

$$Q_{min} = 2\ ton/hour$$

Material:

$$Lump\ size = unsized\ 500\ mm$$

$$\rho = 2000 - 4500 \frac{kg}{m^3}$$

$$\beta = 15º$$

3.3 Determination of some belt characteristics

3.3.1 Cover surface type

The application and the maximum angle of inclination of the conveyor will stablish the cover surface type as we can see in the table below.

Table 3.1: Cover surface type [1]

Cover Surface	Belt Type	Max. Gradient	Application
Smooth	Normal	18° - 20°	Unit and bulk loads all types
Profiled	Fishbone Rufftop	up to 35°	Piece and bulk loads
Steep conveyor profile	Steep conveyor CHEVRON HIGH-CHEVRON Multiprof	up to 40°	Bulk loads (non-sticky) Piece loads (sacks)
T-cleats with or without corrugated edges	Belts with corrugated side walls, with or without T-Cleats	up to 90°	Piece and bulk loads
With Steel or rubber buckets attached	Elevator belts	80° - 90°	Bulk loads all types

As it's possible to see at the table 3.1, the slope of the belt will be less than the necessary to choose another type of belt different to smooth, also the application is bulk materials all types, then the belt will be smooth.

3.3.2 Belt cover quality

Next step is to find a quality level for our belt, in this case, the characteristics of the problem will provide us in the table below a quality level. Mainly the material transported determines the quality of the belt.

Table 3.2: Dunlop-Enerka Cover Qualities [1]

Dunlop-Enerka Quality	Quality		Temperature (°C)			Basic base	Characteristics Application
	DIN	ISO.	min.	duration	max.		
RA	Y (N)		-30°	80°	100°	SBR	Abrasion resistant, for normal service conditions encountered in carrying bulk and aggregate materials.
RE	X (M)	H	-40°	80°	90°	NR	Extra abrasion resistant and cut resistant for heavy duty service conditions (sharp materials and adverse loading conditions).
RS	W	D	-30°	80°	90°	NR/SBR	Super abrasion resistant, for heaviest service conditions, abrasive materials with a large proportion of fines.
BETA-HETE	T		-20°	150°	170°	SBR	Heat resistant, for materials at moderate temperatures.
STAR-HETE	T		-20°	180°	220°	IIR	Very heat resistant, for materials with controlled high temperatures
DELTA-HETE	T		-20°	200°	400°	EPDM	Very heat resisant, for heavy duty service conditions including abrasive materials, at temperatures up to 400°C (or more) at times, e.g. some isolated burning materials or red-hot cores, such as embers, sinter, coke etc.
ROS	G		-20°	80°	120°	NBR	Oil and grease resistant, for oily materials on mineral oil base.
ROM	G		-30°	80°	90°	SBR/NBR	Oil and grease resistant, for vegetable oils and animal greases.
MORS	G		-20°	80°	90°	SBR/NBR	Oil and grease resistant, for vegetable oils and animal greases, and for heavy service conditions of the cover.
BV	S/K		-30°	80°	90°	CR/SBR	Fire resistant for conveyance of materials with fire and explosion danger, such as fertilizer
BVO	S/G		-20°	80°	90°	CR/NBR	Fire and oil resistant for conveyance of oily materials (vegetable oils and animal greases), e.g. fertilizer, cereals, derivates etc.

In appendix Q of the Dunlop guide [1] it is said that a recommended Dunlop quality is RS or RAS, for this case RS quality will be taken.

From this table it's also obtained the rubber type, which is NR/SBR.

Table 3.3: rubber type of the cover [1]

Code	Rubber type
NR	Natural Rubber
SBR	Styrene-Butadiene Rubber
NBR	Nitrile Rubber
IIR	Butyl Rubber
EPDM	Ethylene-Propylene-Diene Rubber
CR	Chloroprene Rubber

NR will be chosen, table 3.3 clears up that it means Natural Rubber, that is what the cover will be made off.

3.3.3 Belt thickness

Depending of the material the cover thickness required will be different, from table 3.4 a thickness is taken.

Table 3.4: Cover thickness [1]

Conveyor Load/Duty	Cover Thickness (mm)	
	Carrying Side	Pulley Side
Light package Conveying	2	2
Gravel, Earth, Potash etc.	2 - 4	2 - 3
Ore, Ballast, Coal	4 - 8	2 - 3
Slag	4 - 8	2 - 3
Coarse ballast, coarse Ore	8 - 12	3 - 5
large lump Coal	8 - 12	3 - 5

Then for the material is transported, ore, the carrying side needs a cover of 4-8 mm and the pulley side 2-3 mm, when the belt is chosen bellow the thickness is specified.

3.4 Belt standar velocity range

One of the most important factor of the belt conveyor is the velocity, many characteristics of the design depend of this value. Therefor the velocity of the Belt conveyor must be specified, also more data it’s calculated bellow.

To find the right Velocity value it’s necessary to use one standard value from the next table 3.5.

Table 3.5: Standard velocity values [1]

Standard Velocity values(m/s)
0.42 - 0.52 - 0.66 - 0.84 - 1.05 - 1.31 - 1.68
2.09 - 2.62 - 3.35 - 4.19 - 5.20 - 6.60 - 8.40

There is a range of velocity values to choose a velocity depending of the application of the belt conveyor as we can see in the table 3.6 below.

Table 3.6: Range of velocity [1]

Duty	v (m/s)
Unit Loads, Assembly Lines	≤ 1.68
Mobile Conveyors	0.52 - 1.68
Very dusty loads such as Flour, Cement	≤ 1.31
Ash and Refuse	≤ 1.68
Grain, Crushed Limestone Gravel, Sand Readymix	1.05 - 2.09
Ores, Bituminous Coal, Sinter Storage and transhipment, Power Stations	1.31 - 3.35
Long distance conveying, overburden Brown coal	2.62 - 6.60
Thrower belts	≥ 8.40
Steep gradient belts Type CHEVRON and HIGH CHEVRON	0.84 - 2.62

In the table 3.6 is shown that for the duty of the belt conveyor the velocity value must be in between 1.32 and 3.35 m/s. To be able to reach our capacity to transport necessary in the requirements of the belt conveyor the velocity value will be decided in the following chapters.

3.5 Determination of the belt width, standard idlers and pulleys

Following the guide [1] standard values will be obtained for the belt width, the radius and the length of the idlers and the pulleys.

3.5.1 Belt width

It is given the standard belt width values in the table 3.7, from where a value of our belt will be chosen through the characteristics of the material to be transported.

The lump size of the material determines the belt width, in particular for belt conveyors with low capacity.

Following the standard DIN 22101, in the table 3.7 it is shown the lump size recommended for every belt width.

The belt width that appear in the table 3.7 correspond to the ISO standard.

Table 3.7: Standard belt Width values [1].

300 - 400 - 500 - 650 - 800 - 1000
1200 - 1400 - 1600 - 1800 - 2000 - 2200

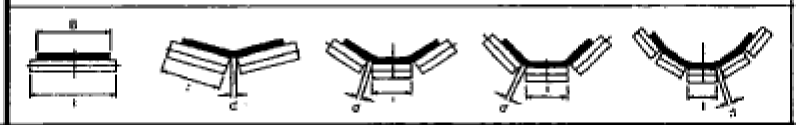
Min. Width (mm)	Lump Size K	
	Sized	Unsized
400	50	100
500	80	150
650	130	200
800	200	300
1000	250	400
1200	350	500
1400	400	600
1600	450	650
1800	550	700
2000	600	800

For the material transported, iron ore unsized 500 mm, the width value of the belt chosen from the standard values is 1.2 m. In the case that the belt width is not big enough to fulfil the capacity a wider can be selected.

3.5.2 Standard Idlers

The idler length it’s related to the belt width and the position of the idlers, for our application throughing type 3 roll will be chosen as a typical shape for this application as it was explained in chapter 3.2.

Table 3.8: Standard idler length [1]

Belt Width B (mm)	Troughing Type Flat	2 roll	3 roll	Deeptrough	Garland
					
300	380	200	-	-	-
400	500	250	160	-	-
500	600	315	200	-	-
600	700	340	250	-	-
650	750	380	250	-	-
800	950	465	315	200	165
1000	1150	600	380	250	205
1200	1400	700	→ 465	315	250
1400	1600	800	530	380	290
1600	1800	900	600	465	340
1800	2000	1000	670	530	380
2000	2200	1100	750	600	420
2200	2500	1250	800	640	460

In the table we can see that for the position of the idlers and the width of the belt the idler's length shall be 465 mm.

As the manual [1] says, the rotation of the idlers shall not exceed 650 min^{-1}, thus from equation 3.1 it is possible to obtain the minimum diameter needed, then one from the standard idler diameter will be chosen.

$$n_R = \frac{60 * v}{\pi * D_R} \quad (3.1)$$

$$D_R = 77\ mm$$

Table 3.9: Standard idler diameters [1]

Carrying Idlers	51	63.5	88.9	108	133	159	193.7	219
Impact Idlers				156	180	215	250	290
Return Run Support Discs		120	138	150	180	215	250	290

As it was obtained from equation a diameter bigger than 77 mm shall be taken from the table 3.9.

Table 3.10: Recommended idler diameter [2]

Belt width (mm)	Recommended idler diameter															
	51	51	70	70	89	89	108	108	133	133	159	159	191	191	216	216
	p	a	p	a	p	a	p	a	p	a	p	a	p	a	p	a
300	1,6	2,4	2,7	4,1												
400	1,9	2,7	3,2	4,6												
500	2,2	3,0	3,7	5,1												
650			4,4	5,8	6,5	9,1										
800			5,4	6,8	7,8	10,4	11,4	16								
1000					9,1	11,7	13,3	17,9	17,5	23,5						
1200							15,7	20,3	20,7	26,7	28,3	36,9				
1400									23,2	29,2	31,7	40,3				
1600									25,8	31,8	35,2	43,8				
1800											38,7	47,2	55,5	70,5		
2000											42,2	50,8	60,3	75,3		
2200													65,1	80,1	84,7	105

As it is shown in table 3.10 the smallest recommended value for the diameter of the idlers for a 1200 mm width belt is 108 mm and that is bigger than 77m, so this value is chosen as the diameter of the idlers.

As it is checked in equation 3.1 the value is correct.

$$n_R = \frac{60*v}{\pi*D_R} = \frac{60*2.62}{\pi*0.108} = 463.32\ min^{-1}$$

The Length of the idlers were calculated previously so the idlers will be:

$$L_R = 465\ mm$$

$$D_R = 108\ mm$$

3.6 Determination of the conveying capacity.

The capacity of a belt conveyor depends of:
1. belt width
2. belt velocity
3. cross sectional area of the load stream
4. the characteristics of the material

First of all, to calculate the capacity of the conveyor, we have to calculate the cross sectional area, this can be obtained by mathematic expressions or by tables, in this case it was calculated by mathematical expressions.

$$A = A1 + A2 \tag{3.3}$$

$$A_1 = 0.25 \cdot \tan(\beta) \cdot (l + (b-1)\cos\lambda)^2 \tag{3.4}$$

$$A_2 = l_1 \cdot \sin\lambda \cdot (l + l_1 \cdot \cos\lambda) \tag{3.5}$$

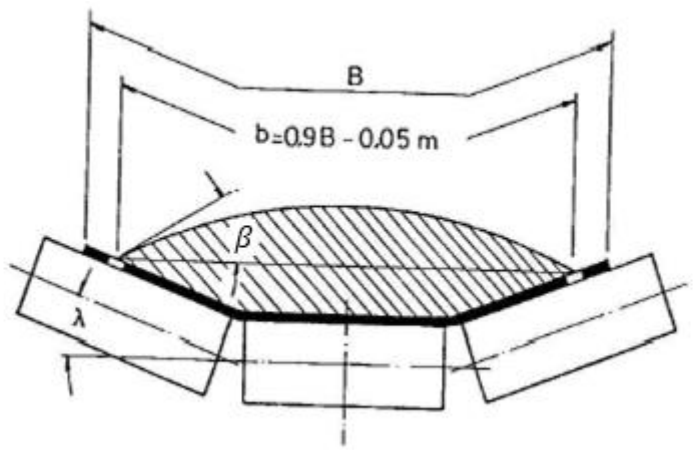


Figure 3.3: transporting material cross section area [3]

$$b = 0.9 \cdot B - 0.05 \quad for\ belts \leq 2000mm \tag{3.5}$$

$$l_1 = 0.5 \cdot (b-1) \tag{3.6}$$

From equations 3.3 to 3.6, it is obtained:

$$b = 0.9 \cdot 1.2 - 0.05 = 1.03\ m$$

$$A1 = 0.25 \cdot \tan 15 \cdot (0.465 + (1.03 - 0.465) \cdot \cos 45)^2 = \ 0.05\ m^2$$

$$L1 = 0.5 \cdot (1.03 - 0.465) = 0.2825\, m$$

$$A2 = 0.2825 \cdot sin45(0.465 + 0.2825 \cdot \cos 45)^2 = 0.0883\, m^2$$

$$A = 0.14\, m^2$$

Thus following the conveyor Belt Technique book, the cross sectional area of the material is calculated as 0.14 m^2.

The capacity of the conveyor is related to the conditions and the maximum slope angle of transportation.
The degree of filling is dependent upon the characteristics of the load, like the lump size, the surcharge angle and the working conditions like the tracking and the reserved capacity.

$$\varphi = \varphi_1 \cdot \varphi_2 \qquad (3.7)$$

Do not confuse with the wrap angle.

For normal working conditions φ_1=1

The reduce factor φ_2 takes into consideration the reduction in part cross sectional area A_1 as a result of the conveying gradient.

Table 3.11: value of φ_2 [1]

Gradient	2°	4°	6°	8°	10°	12°	14°	16°	18°	20°	22°
φ_2	1.0	0.99	0.98	0.97	0.95	0.93	0.91	0.89	0.85	0.81	0.76

This conveyor will have the maximum angle of slope 15º, then from the table 3.11 it's determined that φ_2 = 0.9 thus the factor φ according to equation 3.7 is:

$$\varphi = 0.9$$

Then we have all it's necessary for the calculation of the capacity of the conveyor.

$$Q_v = A \cdot v \cdot 3600 \cdot \varphi \qquad (3.8)$$

In a previous chapter the velocity was not specifically determined, thus for a start the capacity will be calculated for the minimum velocity necessary using the equation 3.8.

$$Q_v = 0.14 \cdot 1.31 \cdot 3600 \cdot 0.9 = 594.216\, m^3/h$$

Iron ore's density is generally in between 2 and 4,5 tons per cubic meter, then capacity will be calculated for the lightest density to be in the safe side, so it's sure the 2000 tons/hour required are transported.

$$Q_m = Q_v \cdot \rho \tag{3.9}$$

Using equation 3.9:

$$Q_m = 594.216 * 2 = 1188.43\ t/h$$

As it is checked the velocity of the conveyor is not enough to assure the required capacity.

To be completely sure the transportation capacity is bigger than the required the velocity will be 2.62 m/s which is a standard velocity in between the application's velocity range, thus the capacity of the belt conveyor using equations 3.8 and 3.9 will be:

$$Q_v = 1174{,}33\ m^3/h$$

$$Q_m = 2348.66\ T/h$$

3.7 Determination of the belt strength

There is a way to calculate approximately the value of the power is necessary to operate the belt conveyor, then with this power it will be possible to determine the strength that is needed for the belt so it is possible to choose one type of belt, that will be useful because in the following chapter 3.8 the weight of the belt will be needed to calculate forces.

Power at the drive pulley:

$$P_T = P_1 + P_2 + P_3 \tag{3.10}$$

Power for empty conveyor and load over the horizontal distance:

$$P_1 = \frac{C_B \cdot v + Q_m}{C_L \cdot k_f} \tag{3.11}$$

Power lift:

$$P_2 = \frac{H \cdot Q_m}{367} \tag{3.12}$$

At this point of roughly calculations it is possible to say that P_3 is completely useless, it makes reference to some dissipative forces that usually they are so small that they are not calculated unless special situations.

Table 3.12: C_B selection [1]

Duty	Bulk Density ρ (t/m3)	Belt Width B (mm)											
		300	400	500	650	800	1000	1200	1400	1600	1800	2000	2200
Light	Up to Ca.1.0	31	54	67	81	108	133	194	227	291			
Medium	1.0 to 2.0	36	59	76	92	126	187	277	320	468	554	691	745
Heavy	Over 2.0		65	86	103	144	241	360	414	644	727	957	1033

From the table 3.12 a value of 360 for C_B is obtained.

Table 3.13: C_L value [1]

L (m)	3	4	5	6	8	10	12.5	16	20
C_L	667	625	555	526	454	417	370	323	286
L (m)	25	32	40	50	63	80	90	100	150
C_L	250	222	192	167	145	119	109	103	77
L (m)	200	250	300	350	400	450	500	550	600
C_L	63	53	47	41	37	33	31	28	26
L (m)	700	800	900	1000	1500	2000			
C_L	23	20	18	17	12	9			

L (m) Conveying Length

From the table 3.13 value of 26 is obtained for C_L.

Table 3.14: k_f value [1]

Working Conditions	k_f
Favourable, good alignment, slow speed	1.17
Normal (Standard Conditions)	1
Unfavourable, dusty, low temperature, overloading, high speed	0.87 - 0.74
Extremely low temperature	0.57

It's reasonable to say that the belt conveyor will operate in standard conditions in this case, but it could be possible to choose another option. Then the value of k_f is 1.

From equations 3.10, 3.11 and 3.12 is determined the power.

$$P_1 = 126.61\ kW$$

$$P_2 = 248.45\ kW$$

$$P_T = 375.06\ kW$$

Now that the approximate value of the power necessary to operate with the conveyor has been determined it is possible to determine the belt strength from where a belt type will be chosen.

$$k = \frac{C_R}{C_V} \cdot \frac{P_T}{v} \tag{3.13}$$

In the equation 3.13 It is shown how to obtain the belt breaking strength through some values that are necessary to obtain from tables.

Table 3.15: Friction factor C_R value [1]

Drive Pulley Surface	Friction Value μ	Belt Width B (mm) 300	400	500	650	800	1000	1200	1400	1600	1800	2000	2200
bare, wet	0.15	98	74	59	45	37	30	25	21	18	16	15	14
rubber lagged, wet	0.25	69	52	41	32	26	21	17	15	13	12	10	9
and dirty	0.30	62	46	37	28	23	18	15	13	12	10	9	8
bare, dry, lagged, wet	0.35	57	43	34	26	21	17	14	12	11	9	8	8
rubber lagged, dry	0.40	53	40	32	25	20	16	13	11	10	9	8	7

It will be assumed that the conveyor will operate in a bare dry situation where μ will be 0.35 and the value of C_R is then 14.

Table 3.16: Breaking strength loss at join factor C_v [1]

DUNLOP Belt Type	Splice Type Ply Rating	Factor c_v
DUNLOFLEX	2 ply overlap 100% 1 ply overlap 50%	1.00 0.50
TRIOFLEX	3 ply overlap 100% 2 ply overlap 67%	1.00 0.67
SUPERFORT	Number of plies 1 2 3 4 5 6	0.70 0.50 0.67 0.75 0.80 0.83
FERROFLEX	Zig-Zag Splice Joint	0.90
DUNLOPLAST	Finger Splice Joint	0.90
Steel Cord Belts	Splice 1 and 2 step 3 step 4 step	1.00 0.95 0.90

A value of 1 will be taken from the table 3.16 for the factor C_v because our belt type is Steel Cord Belt.

Now all the data required to determine the breaking strength of the belt was obtained so it's possible to calculate its value from equation 3.13.

$$k = 2004.15\ N/mm$$

So from the table 3.17 the belt type will be obtained

Table 3.17: Belt type for steel cord belts [1]

Belt Type	Cord Diameter (mm)	Belt Weight m'G (kg/m²) Sum of Carrying and Pulleyside Covers (mm)							
		10	11	12	13	14	15	16	20
ST 500	2.7	16.4	17.5	18.6	19.8	20.9	22.0	23.1	27.6
ST 630	2.7	16.9	18.0	19.2	20.3	21.4	22.5	23.6	28.1
ST 800	3.1	18.4	19.5	20.6	21.7	22.9	24.0	25.1	29.6
ST 900	3.6	19.4	20.5	21.6	22.8	23.9	25.0	26.1	30.6
ST 1000	3.6	19 8	20.9	22.0	23.2	24.3	25.4	26.5	31.0
ST 1150	4.1	20.5	21.6	22.7	23.8	24.9	26.1	27.2	31.7
ST 1250	4.1	21.0	22.1	23.2	24.3	25.5	26.6	27.7	32.2
ST 1400	4.4	22.2	23.3	24.4	25.5	26.6	27.8	28.9	33.4
ST 1600	5.0	23.5	24.6	25.7	26.8	28.0	29.1	30.2	34.7
ST 1800	5.0	24.0	25.1	26.3	27.4	28.5	29.6	30.7	35.2
ST 2000	5.0	24.6	25.8	26.9	28.0	29.1	30.2	31.4	35.8
ST 2250	5.9	28.0	29.1	30.2	31.3	32.5	33.6	34.7	39.2
ST 2500	6.3	29.4	30.5	31.6	32.7	33.9	35.0	36.1	40.6
ST 2750	6.9	30.1	31.2	32.3	33.4	34.5	35.7	36.8	41.3
ST 3150	7.4	32 6	33.7	34.8	35.9	37.1	38.2	39.3	43.8
ST 3500	7.6	34.6	35.7	36.8	37.9	39.1	40.2	41.3	45.8
ST 3750	8.2	36.7	37.8	38.9	40.0	41.1	42.3	43.4	47.9
ST 4000	8.6	38.1	39.3	40.4	41.5	42.6	43.7	44 9	49.3
ST 4250	8.8	39.8	40.9	42.0	43.2	44.3	45.4	46.5	51.0
ST 4500	9.6	41.7	42.8	43.9	45.0	46.2	47.3	48.4	52.9
ST 4750	9.6	43.3	44.5	45.6	46.7	47.8	48.9	50.1	54 5
ST 5000	10.7	45 1	46.2	47.4	48.5	49.6	50.7	51.8	56.3

From this table a bigger value than k must be chosen for k_N, then this value will be 2250 therefore it can be said that the belt will be:

605 m 1200 mm ST 2250 5+5 RS

This definition includes length, width, type of belt, break strength, cover, quality of cover.

3.8 Determination of the forces

Peripheral force steady state working is the sum of the resistances to motion at the drive pulley as it was defined in chapter 2.1, this force is defined by the equation bellow.

$$F_u = C \cdot f \cdot L \cdot g(m'_R + (2 \cdot m'_G + m'_L) \cdot \cos\delta) + H \cdot g \cdot m'_L + F_s \qquad (3.14)$$

C is the length factor, through the table 3.18 the value of it will be obtained.

Table 3.18: C value [1]

L (m)	3	4	5	6	8	10	13	16	20
C	9.0	7.6	6.6	5.9	5.1	4.5	4.0	3.6	3.0
L (m)	25	32	40	50	63	80	90	100	120
C	2.9	2.6	2.4	2.2	2.0	1.92	1.86	1.78	1.70
L (m)	140	160	180	200	250	300	350	400	450
C	1.63	1.56	1.50	1.45	1.38	1.31	1.27	1.25	1.20
L (m)	500	550	600	700	800	900	1000	1500	2000
C	1.20	1.18	1.17	1.14	1.12	1.10	1.09	1.06	1.00

The friction factor f is used for the calculations of resistances motion. It provides an estimate of resistance to rotation of the idlers, the belt resistance and the material impression resistance. Values for the f factor are dependent upon working conditions and construction characteristics of the installation.

Table 3.19: f factor estimation [1]

Horizontal, inclined or slightly declined installations - Motor driven	
Favourable working conditions, easily rotating idlers, material with low internal friction and good tracking, good maintenance	0.017
Normal installation, normal material	0.020
Unfavourable conditions, low temperature, material with high internal friction, subject to overload, poor maintenance	0.023 - 0.027
Installations with steep declines creating regenerative conditions	0.012 - 0.016

So the f value for normal installation can be assumed, which is 0.02 but this estimation is for a conveying velocity of 5 m/s, in this case with the correction value from the table 3.20 will be:

Table 3.20: Correction factor for f [1]

v (m/s)	2	3	4	5	6
Factor c	0.80	0.85	0.90	1.00	1.10

$$f = c \cdot f_{5m/s} \quad (3.15)$$

The correction facto taken is 0.85, then from equation 3.15:

$$f = 0.017$$

To determinate m'$_R$ it's necessary to use the next table:

Table 3.21: m'$_R$ mass (kg) [1].

Belt width B (mm)	Idler Rollers	Idler Roller Diameter 51	63.5	88.9	108	133	159	193.7	219.1
300	flat	1.6	2.2	3.2					
	2 part	2.3	3.4	4.1					
400	flat	2.0	2.7	3.9	5.6				
	2 part	2.6	3.7	4.7	6.6				
	3 part	2.9	4.4	5.4	7.3				
500	flat	2.2	3.2	4.5	6.6				
	2 part	2.8	4.1	5.5	7.8				
	3 part	3.2	4.6	6.1	8.4				
650	flat		4.0	5.5	8.0	10.8			
	2 part		4.7	6.3	9.0	12.1			
	3 part		5.4	7.0	9.8	13.1			
800	flat		4.7	6.7	9.8	13.3			
	2 part		5.6	7.4	10.6	14.2			
	3 part		6.5	8.3	11.6	15.6			
	5 part			9.0	12.4	16.3			
1000	flat			9.4	11.7	15.9	21.9		
	2 part			11.3	13.2	17.8	24.7		
	3 part			13.0	13.6	18.2	26.3		
	5 part			13.8	14.2	18.9	28.0		
1200	flat →				14.2	19.3	26.1		
	2 part				15.0	20.5	28.0		
	3 part →				16.3	22.3	24.5		
	5 part				17.2	21.7	31.9		
1400	flat					21.8	29.3		
	2 part					23.3	31.6		
	3 part					25.0	35.5		
	5 part					24.3	35.0		
1600	flat					25.1	33.4		
	2 part					26.5	35.0		
	3 part					28.0	38.7		
	5 part					28.5	39.3		
1800	flat					27.6	37.8		
	2 part					29.1	39.5		
	3 part					30.7	42.4		
	5 part					31.5	42.5		
2000	flat					30.2	40.2	69.1	
	2 part					31.8	43.3	76.4	
	3 part					33.3	47.0	80.1	
	5 part					33.8	46.5	89.5	
2200	flat						46.5	77.8	88.0
	2 part						49.0	82.6	97.1
	3 part						50.1	93.2	111.0
	5 part						51.0	95.5	111.8

Here it's obtained the value of the mass of the idlers for the carrying side and the return side as 16.3 and 14.2 kg/m.

Another datum that is needed is the distance between idlers.

According to the book [1] it's possible to use l_o= 1.2 m as a distance between the carrying idlers in normal installations and l_u= (2-3)·l_o as a distance between return idlers, so this values will be taken as an approach but probably this values are so small and if necessary they will be recalculated:

$$l_o = 1.2\ m$$

$$l_u = 3 \cdot \mathrm{l_o}$$

(3.16)

Then with 3.15:

$$l_u = 3.6$$

Then,

$$m'_R = \frac{m_{Ro}}{l_o} + \frac{m_{Ru}}{l_u} \quad (3.17)$$

Adding all the data to equation 3.17, it's obtained that:

$$\mathrm{m'_R} = 17.53\ kg/\mathrm{m}$$

For m'$_G$, which is related to the mass of the belt, in the appendix C of the book [1] or table 3.17 it's determined that for ST2250 and 10 mm of cover:

$$m_G = 28\ kg/m^2$$

$$m'_G = \mathrm{m_G} \cdot \mathrm{l_o} \quad (3.18)$$

For equation 3.18:

$$m'_G = 33.6\ kg/m$$

m'$_L$ is related to the load of the conveyor:

$$m'_L = \frac{Q_m}{3.6 * v} \quad (3.19)$$

Then from equation 3.19:

$$\mathrm{m'_L} = 249.01\ kg/m$$

Then we can calculate F_u from equation 3.14:

$F_u = 123.51\ kN$

Also it's possible to obtain the resistance of the carrying side and the return side. From reference [3] the equations are:

$$R_o = C \cdot f \cdot L \cdot (m_{Ro} + m'_G + m'_L) + (m'_G + m'_L) \cdot H \qquad [kg] \qquad (3.20)$$

$$R_u = C \cdot f \cdot L \cdot (m_{Ru} + m'_G) - m'_G \cdot H \qquad [kg] \qquad (3.21)$$

The obtained results from equations 3.20 and 3.21 are then:

$R_o = 13676.85\ kg$

$R_u = -871.86\ kg$

3.9 Tensions in the Belt

As we commented in the introduction of belt conveyors the tensions are what defined the operation of the conveyor belt, first of all it is necessary to define a friction between belt and pulley surface and a wrap angle, both will be relevant in the definition of the tensions.

Table 3.22: friction value [1]

Operating Condition	Pulley Surface			
	Plain Steel (smooth)	Polyurethane lagging (grooved)	Rubber lagging (grooved)	Ceramic lagging (porous)
Dry	0.35 to 0.4	0.35 to 0.4	0.4 to 0.45	0.4 to 0.45
Wet (Clean)	0.1	0.35	0.35	0.35 to 0.4
Wet (dirty mud, clay)	0 05 to 0.1	0.2	0.25 - 0.3	0.35

The pulley's surface is planned to be Plain Steel material which in normal conditions will operate with a 0,35-0,4 fiction value, for this case 0,35 will be chosen to be in the confident side.

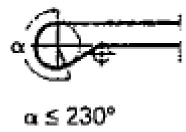


Figure 3.3: Wrap angle [1]

As the Figure 3.3 shows the maximum wrap angle is 230º, for the case of study 210º will be chosen as a wrap angle so it's not that close to the limit, then the tensions will be calculated.

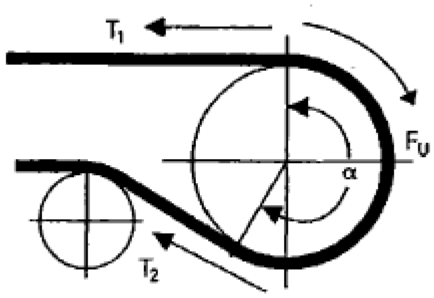


Figure 3.10: Tensions distribution [1].

The tension values from equations 2.3 and 2.4 are:

$$T_1 = 170.89 \text{ kN}$$

$$T_2 = 47.38 \text{ kN}$$

The belt must have an important tension, this tension must be big enough so the belt sag between idler idlers is never more than 0.5% - 1.5% for loaded idlers and between 2-3 % for returning idlers, in the figure 3.11 it will be shown. As it was chosen before the distance between carrying idlers is 1.2 m, and between returning idlers is 3.6 m, through the expression bellow it will be calculated the minimum necessary distance:

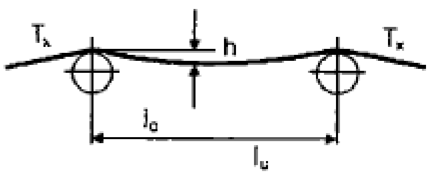


Figure 3.4: Distance between carrying idlers [1]

The distance necessary between idlers is defined by the next expressions:

$$l_o = \frac{T_1 \cdot 8 \cdot h_{rel}}{(m'_L + m'_G) \cdot g} \tag{3.22}$$

$$l_u = \frac{(T_2 \cdot 8 \cdot h_{rel})}{m'_L \cdot g} \qquad (3.23)$$

Taken the biggest restriction for the sags as 0.005 for the carrying idlers and 0.02 for the return idlers, necessary distances are calculated from equations:

$$l_o = 2.47\ m$$

$$l_u = 23\ \text{m}$$

This means that the distance chosen between idlers is really small comparing to the minimum distance necessary between idlers, this happens because the tension is really big compering to the necessary tension that would be needed to have a distance between idlers as it was chosen before. This could be an important opportunity to decrease the cost of the conveyor by using less idlers.

Tensions in at the tail will also be calculated by the next expressions:

$$T_4 = T_1 - R_o \cdot \text{g} \qquad (3.21)$$

$$\text{T}_3 = T_2 - R_u \cdot \text{g} \qquad (3.22)$$

then,

$$T_3 = 38.83\ \text{kN}$$

$$T_4 = 36.72\ kN$$

As it was expected this tensions are quite similar as usually, this is because the tail pulley doesn't drive or give power to the belt.

From all the results obtained it's possible to obtain the value of the security factor.

$$S = \frac{k_N \cdot C_v \cdot B}{T_x} \qquad (2.23)$$

Normally the value of this factor should not be lower than 8, it is around 9. This factor will be calculated for the biggest tension T_1 so we can be sure the value of the result is in the most pessimistic situation:

$$S = 15.8$$

It's possible to say that this result is so big, probably the belt conveyor is a little bit oversized but it's sure that is very safe, what means that it will be really difficult that the belt breaks suddenly what is very dangerous.

3.10 Determination of the standard pulleys

Pulleys as idlers are very important elements in belt conveyors. There are 3 kind of pulleys as it's shown in figure 3.5 and every type has its own function, as drive, return, snub… all of them have to be taken in account.

A) Drive pulley
B) Tail pulley
C) Snub pulley

GROUP	APPLICATION	
A	Pulleys in the areas of high belt stress.	Drive Pulleys
B	Pulleys in areas of low belt stress.	Tail Pulleys
C	Pulleys with an angle of wrap $\alpha \leq 90°$,	Deflection or snub Pulleys

Figure 3.5: Different kind of pulleys [1]

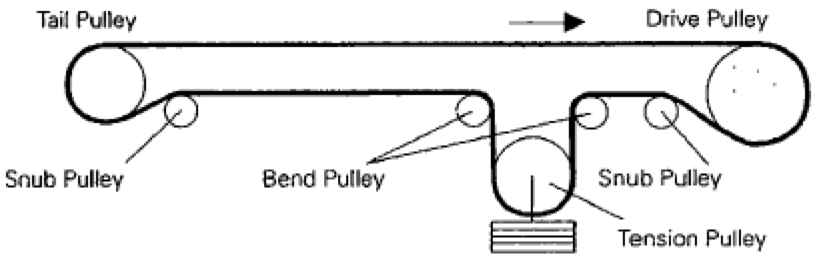


Figure 3.6: Different kind of Pulleys [1]

The mathematical expression that determines the diameter of the drive pulley is:

$$D_{Tr} = C_{Tr} \cdot d \tag{3.24}$$

C_{Tr}	Material of Carcase in Warp or Belt Type	
90	Polyamide (P)	
80	DUNLOFLEX	2 ply Belt
95	TRIOFLEX	3 ply Belt
108	SUPERFORT	Multiply Belt (EP)
138	FERROFLEX	Steel Weave Type
145	SILVERCORD	Steel Cord Belt
100	DUNLOPLAST	Monoply Belt

Figure 3.7: Materia carcase in warp factor [1]

The value of C_{Tr} is 145 due to the belt type, which is SILVERCORD and the thickness of the carcase of the belt is 10 mm, then

$$D_{Tr} = 145 \cdot 10 = 1.45\, m$$

From the standard diameter from the table (3.23) bellow.

Table 3.23: Standard diameters of pulleys

100	125	160	200	250	315	400	500
630	800	1000	1250	1400	1600	1800	2000

The diameter chosen of the drive pulley is:

$$D_{Tr} = 1600\, mm$$

Then, from the value of the diameter of the driver it will be possible to obtain the value of the other pulley through the table 3.24.

Table 3.24: Diameters of the pulleys

Pulley Diameter D_{Tr} (mm)	Diameter Of Pulley Groups (mm)		
	A	B	C
100	100	-	-
125	125	100	-
160	160	125	100
200	200	160	125
250	250	200	160
315	315	250	200
400	400	315	250
500	500	400	315
630	630	500	400
800	800	630	500
1000	1000	800	630
1250	1250	1000	800
1400	1400	1250	1000
1600	1600	1250	1000
1800	1800	1400	1250
2000	2000	1600	1250

Then from here we obtain the diameter on the tail pulley as 1250 mm and the snub pulley 1000 mm.

3.11 Idlers distribution

In this chapter the idler distribution will be calculated and completely explained so they get to be completely defined.

3.11.1 Charge position Idlers

Usually at the possition where the conveyor is charged is necessary to use shock absorbing idlers, normal idlers wouldn't stand to be continuously shocked by the material falling down to the belt, it would damage them in a short amount time.

Figure 3.8: shock absorbing idlers [2]

As the figure 3. shows the material of this idlers is rubber instead of metal, that's because this material can absorb the shock of the material falling constantly on the belt. Then the charge position will be made of a station of 3 shock absorbing idlers.

3.11.2 Carrying Idlers

As it was stablished before the carrying idlers will be formed by stations of three idlers with a troughing angle as its possible to see on the figure 3.9.

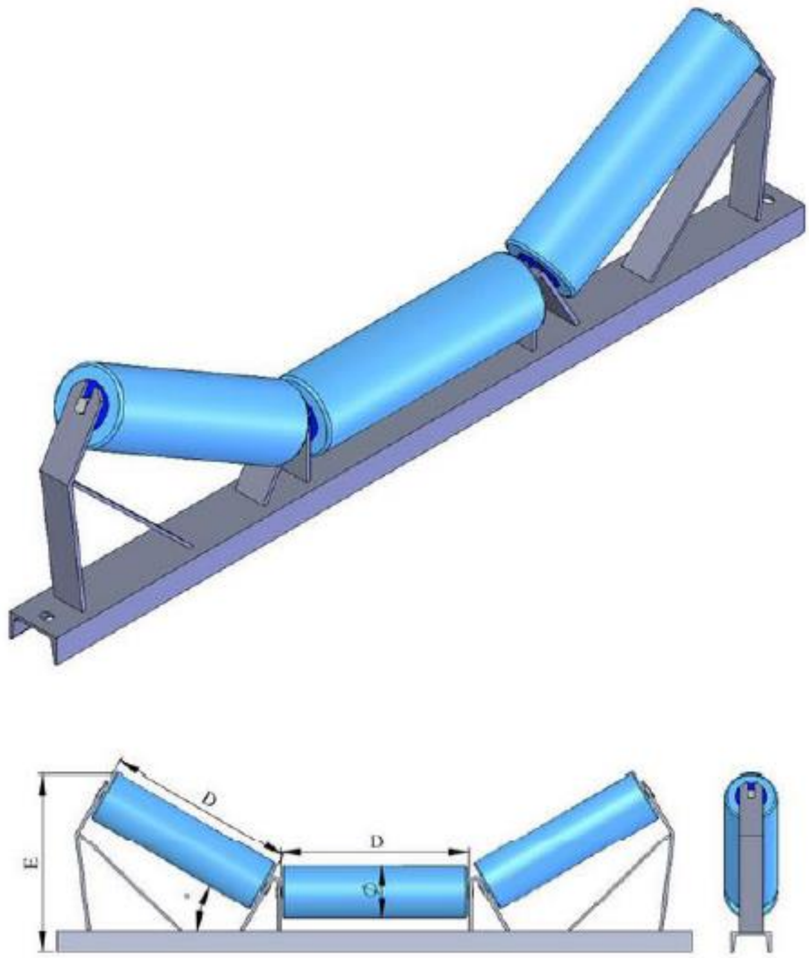


Figure 3.9: Three idlers with troughing angle [2]

This station formed by three idlers is where the carrying part of the belt is supported, at the same time they are being supported by the metallic structure that it's shown un the figure 3.9, this structure is fixed on the frame of the belt conveyor.

As it was calculated before the necessary distance between carrying idlers is 2.47 m, also the belt length is 605 m.

$$N_{idlers} = \frac{605}{2.47} = 245\ idlers \quad (3.25)$$

In the equation (3.25) is obtained the minimum number of idlers that are necessary, the right answer would be 245 idlers.

$$l_o = \frac{605}{245} = 2.47\ m \quad (3.26)$$

In the equation (3.26) it’s possible to see that the carrying idlers will be placed every 2.47 m, then there will be 245 stations of 3 idlers at the carrying side.

3.11.3 Return idlers

The return idlers will be formed by groups of one plane idlers.

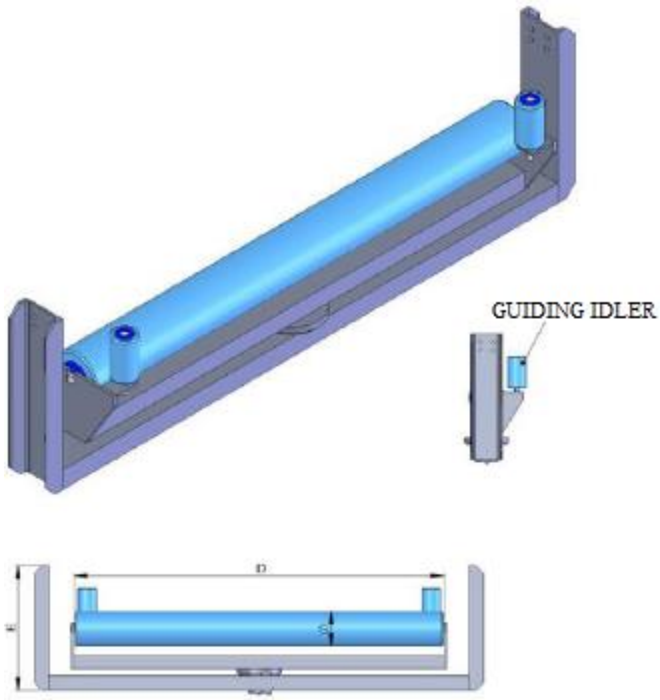


Figure 3.10: Plane idler [2]

These elements are formed by 1 idler which supports the belt returning without load, there are also small guiding idlers that keep the belt always on the roll. These idlers are supported by a metallic structure as is shown in the figure 3.10, this structure will be fixed to the frame of the conveyor which will support them. Finally, it’s necessary to determinate how many idlers are necessary in this conveyor, as it was calculated before the maximum distance between idlers of the return side must be 23 m.

$$N_{idlers} = \frac{605}{23} = 26.3\ idlers \quad (3.27)$$

It means that 7 idlers will be necessary for the returning way, this is a very small number so to be cautious it would be a good option to more idlers. Usually it’s calculated that de necessary distance for returning idlers is 3 times comparing to carrying idlers, what means the third part of idlers will be in the returning way.

$$N_{idlers_{return}} = \frac{245}{3} \approx 82 \; idlers \tag{3.27}$$

The equation (3.27) shows the amount of return idlers are necessary.

$$l_u = \frac{605}{82} = 7.28 \; m \tag{3.28}$$

The equation (3.28) determinates the distance between returning idlers.

3.12 Take up weigh

The take up weigh is a system that keeps the belt in tension, it's necessary so it's sure the belt doen't loose tension and goes out of it's way. This is very important for the start up of the motor so it doesn't slide with the driving pulley. The system is formed by a cage filled with big mass elements, normally heavy wasted materials from construction process.

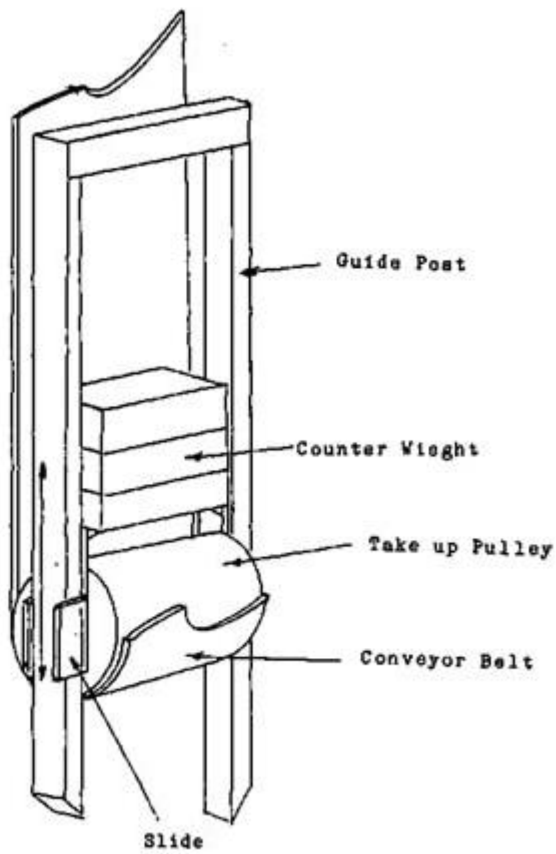


Figure 3.11: Take up weight system [5]

It's important to have a safety system in case the belt breaks, then the system goes through rails that can aborbe and stop the mass falling.

To define the take up tension there is the expression below:

$$F_V = T_3 + T_4 \quad (3.29)$$

or

$$F_V = 2 \cdot T_2 \quad (3.30)$$

To define the take up weight the expression below will be used:

$$G_V = F_V/g \quad (3.31)$$

The equations 3.29, 3.30 and 3.31 show how to obtain the necessary mass for this system. As we can see, it's possible to put this mass at the head or at the tail of the conveyor. It would be economically better to put this mass at the tail, that is because mass necessary would be less due to the tensions. Anyway in this case the mass will be hanging from the head because it's in a higher position, it's complicated in this situation to hang it from the tail.

Then from the equation 3.29 the take up tension is obtained:

$$F_V = 2 \cdot 47379.68 = 94759.36\ N$$

Therefor the take up weight from equation 3.31 is:

$$G_V = \frac{94759.36}{9.81} = 9.66\ t \quad (3.32)$$

Then as the equation (3.32) shows 9.66 t will be needed to hang from the head of the conveyor.

3.13 Curves of the Belt

When the conveyor gets some inclination there is a risk of load loosing or that the belt lifts off the carrying idlers at this inclination changing position.this can lead to a reduction of the tension of the belt. In some situations it can be tolerated but there is a posibility that the belt starts to loose some material, that's why it's necessary to decide a proper angle that makes the situation safe so there is not loss of material.

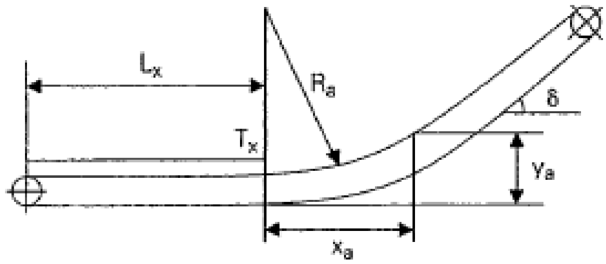


Figure 3.12: concave radius of

the belt [1]

The concave radius shall be:

$$R_a = \frac{T_x}{m'_G \cdot \cos\delta \cdot g} \quad (3.33)$$

And then the horizontal distance and the vertical distance of the belt are:

$$x_a = R_a \cdot \tan\delta \quad (3.34)$$

$$y_a = 0.5 \cdot R_a \cdot \tan^2\delta \quad (3.35)$$

Tension in the tail will be used as it's the correct one according to the figure 3.12.

$$T_4 = 36718.49\ N$$

Then from the equation 3.33a radius is obtained:

$$R_a = \frac{36718.49}{33.6 \cdot \cos(20º) \cdot 9.81} = 115.33\ m$$

Therefor the horizontal distance of the curve is:

$$x_a = 115.33 \cdot \tan(15) = 30.9\ m$$

And the vertical distance of the curve is:

$$y_a = 0.5 \cdot 115.33 \cdot \tan^2(15) = 4.14\ m$$

After calculating the cocave curve, the convex curve will be calculated:

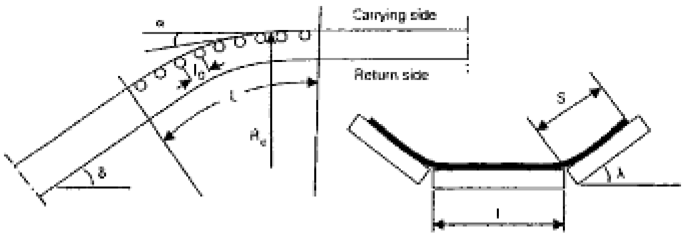


Figure 3.13: Convex curve [1]

The mathematical expression to calculate the radius is:

$$R_e = x \cdot s \cdot \sin \lambda \tag{3.36}$$

Where x shall be 400 for steel cord belts.
The length of the curve is:

$$L_c = \pi \cdot \delta \cdot R_e / 180 \tag{3.37}$$

Number of idlers in the curve:

$$N_{idlers} = \delta / \alpha \tag{3.38}$$

Distance between idlers in the curve:

$$l_o = L / z \tag{3.39}$$

Therefor s is calculated:

$$s = L_R - \frac{3 \cdot L_R - B}{2} = 465 - \frac{3 \cdot 465 - 1200}{2} = 367.5\ mm$$

Then using equation 3.36 the radius of the concave curve is obtained.

$$R_e = 400 \cdot 367.5 \cdot 10^{-3} \cdot \sin(45º) = 103.94\ m$$

The radius of the curve have been optained with the equation (3.36).

The curve length it's (3.37):

$$L = \frac{\pi \cdot 15 \cdot 103.94}{180} = 27.21\ m$$

The number of idlers in the curve it's (3.38):

$$N_{idlers} = \frac{15}{2} = 8\ Idlers$$

What means that in the curve there will be a distance between idlers (3.39):

$$l_o = \frac{36.28}{10} = 3.63\ m$$

These Radiuses were calculated to have a safe change of slope, normally, even if those radiuses where calculate, they were calculated for a tension, this tension doesn't have to be the same always, it's possible that the belt conveyor operates empty or half loaded for example, that's why it's common the use of deviation wheels as we can see at the figure 3.14.

Figure 3.14: Deviation wheels

This wheels are designed to guide the belt when there are some inclination changes, the belt otherwise can bend or even lose its path, so this would be a good solution to this problem.

3.14 Disipative forces

There are several forces that make resistance against the movement of the convenyor, this forces are called secundary resistances. This forces normally are really small comparing to the other forces that oparate in the conveyor so they are determined only in special situations, in this case of study they are not important as usually but they will be determined anyway.

3.14.1 Friction resistant due to the scraper

One friction resistance is created by the scraper that cleans the belt, there is a big contact between the scraper and the belt that crate a friction force against the movement of the belt.

The force friction shall be calculated with the expression below:

$$F_{Gr} = \mu_c \cdot p \cdot A_c \quad (3.40)$$

or

$$F_{Gr} = k_R \cdot B \quad (3.41)$$

Table 3.25: k_R value [1]

Scraper Thickness (mm)	Pressure (N/mm²) normale 15	20	élevée 20	25	30
k_R	340	450	1500	1875	2250

The values of the factors that will be used in the equations are:

$\mu_c = 0.75$

$p = 0.1\ MPa$

$A_c = 1200 \cdot 15 = 18000\ mm^2$

Therefor from equation 3.40 the force is:

$F_{Gr} = 0.75 \cdot 0.1 \cdot 18000 = 1350\ N$

Using equation 3.41 with k_R = 340 from the table3.25 the force obtained is:

$F_{Gr} = 340 \cdot 1.2 = 408$ N

It can be assumed that the most real one is the second result because for the first one the values where assumed and no so exact.

As we can see the value of this resistance is very small, it would not be necessary to be calculated for the designing of the belt conveyor.

3.14.2 Belt bending resistance

The belt makes some resistance to be bended at the pulleys, this resisting force will be calculated. The analytical expression to determine this force is:

$$F_{Gb} = c \cdot B \cdot \left(k + \frac{T_m}{B}\right) \cdot \frac{d}{D_{Tr}} \quad (3.42)$$

To determine this resistance at the head of the conveyor with the equation 3.42 is:

$$F_{Gb} = 0.12 \cdot 1200 \cdot \left(20 + \frac{\frac{T_1+T_2}{2}}{1200}\right) \cdot \frac{10}{1600} = 99.85\ N$$

This force is still small comparing to the main resistance forces of the belt.

3.14.3 Pulley Bearing resistance

This resistance happens in non-driving pulleys, it's also so small that it would be necessary to be calculated as it will be seen bellow.

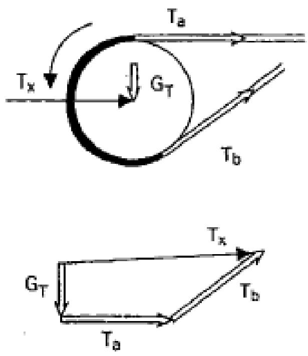


Figure 3.15: Pulley bearing resistance [1]

The analytical expression to determine this force is:

$$F_{Tr} = 0.005 \cdot T \cdot \frac{d_W}{D} \tag{3.42}$$

To obtain the value of T:

$$T = \sqrt{(T_a + T_b)^2 + G_T^2} \tag{3.43}$$

$$T_a = T_4 = 38826.73\ \text{N}$$

$$T_b = T_3 = 36718.49\ N$$

G_T is the mass of the pulley, from the catalogue Martin [6] it's assumed that the mass of the pulley is around 3800 kg.

Then for the equation 3.43 it obtained that the tension is:

$$T = \sqrt{38826.73^2 + 36718.49^2 + (3800 \cdot 9.81)^2} = 65156.82\ \text{N}$$

The value of d_w is approximately 10 smaller than the width, so it can be assumed that from the equation 3.42:

$$F_{Tr} = 0.005 \cdot 253691.13 \cdot \frac{120}{1600} = 95.13\ N$$

Again it's proven that this force is really small so is not necessary to calculate it for the design of a belt conveyor.

3.15 Driver power and motor selection

It's possible to calculate the power at the driver pulley:

$$P_T = \frac{F \cdot v}{1000 \cdot} = \frac{123.5 \cdot 10^3 \cdot 2.62}{1000} = 323.59\ kW\ [1] \qquad (3.44)$$

This is the total power required to move the belt conveyor. To know the real power is requested from a motor we have to count on the efficiency. A Siemens catalogue [8] have been checked, the we can see that the efficiency goes around 90%, using that it is obtained that the necessary power of the motor is:

$$P_M = \frac{323.59}{0.9} \approx 360\ kW \qquad (3.45)$$

Table 3.26: Standard electric motors [kW] [1]

1.5	2.2	3	4	5.5	7.5	11
15	18.5	22	30	37	45	55
75	90	110	132	160	200	250
315	400	500	630			

The idea is to find a real motor from a catalogue, but it's required to use a gear box because it's really approvable that velocity of the shaft of the motor is exactly the one is necessary to move the drive pulley, therefor, the first thing that shall be done is calculate this shaft velocity, for that the mathematical expression is:

$$n_t = \frac{v \cdot 60}{\pi \cdot D_{Tr}} \qquad (3.46)$$

The value of the shaft velocity at the drive pulley is:

$$n_t = \frac{2.62 \cdot 60}{\pi \cdot 1.45} = 34.5\ min^{-1}$$

Then following the standards a 400 kW motor is obtained, choosing from [8] a motor is selected.

SIEMENS High efficiency 1PS4 4 pole 50 Hz 400 kW

The output of this motor is 1500 min^{-1} than the reduction of the gear box must be:

$$i = \frac{1500}{34.5} = 43.47$$

3.16 Coupling

A coupling will not be design but it's necessary to clear up that there is needed of a coupling to transmit the power to the drive pulley.

There are several types of couplings, in this case it's ofter that there are misalignments as radial, longitudinal, angular…

There is a special kind of coupling that it can adapt itself to this kind of problems, it is called flexible coupling

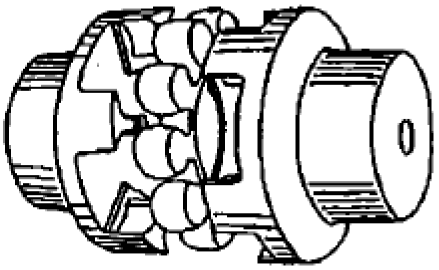


Figure 3.16: Flexible coupling

This coupling will be used for the transmission of the power from the gear box to the driving pulley.

Although another coupling is necessary for the transmission of power from the motor to the gear box, it’s a usual thing to use hydraulic couplings for this application, they permit a load free acceleration of the motor and consequently with increasing oil fill, provide a gentle quasi steady state start-up of the belt conveyor. The maximum torque occurring during the start-up process is restricted to lowest possible level. The splice joints are relieved and conserved.

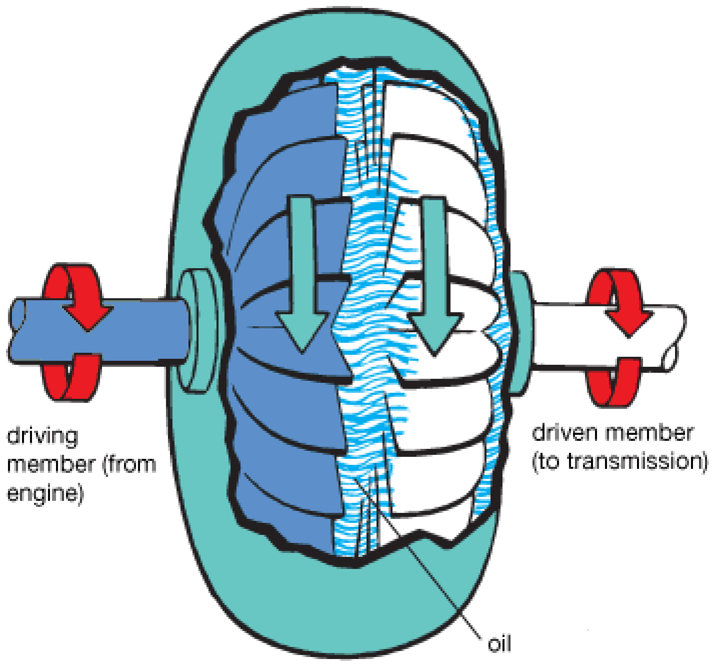


Figure 3.17: Hydraulic coupling [9]

3.17 Scrapper structure

Some materials usually get stuck on the belt's surface and this situation makes important the installation of cleaning devices to belt conveyors

It's recommended to prevent the introduction of material particles to the returning way, this could deteriorate and block the return idlers, thus it is important to add a scrapper that can erase frome the belt the partidules and drop them to the floor, so the idlers don get damaged. The best results are got locating right under the discharge pulley a brush, this cleans the Belt before the particles get to the idlers. Better results are obtained if rolling brusher are used.

With intention to find a good option there is the posibility to add a different kind of scrapper which it can make pressure to the belt so its efficiancy will be better. This scrapper will be formed by ceramic plates that scrape and clean the belt from the particles that could still be on the belt from the material that is transported, this will prevent the idlers and the belt to get damaged. In the figure bellow it will be possible to see the parts of this scrapper structure.

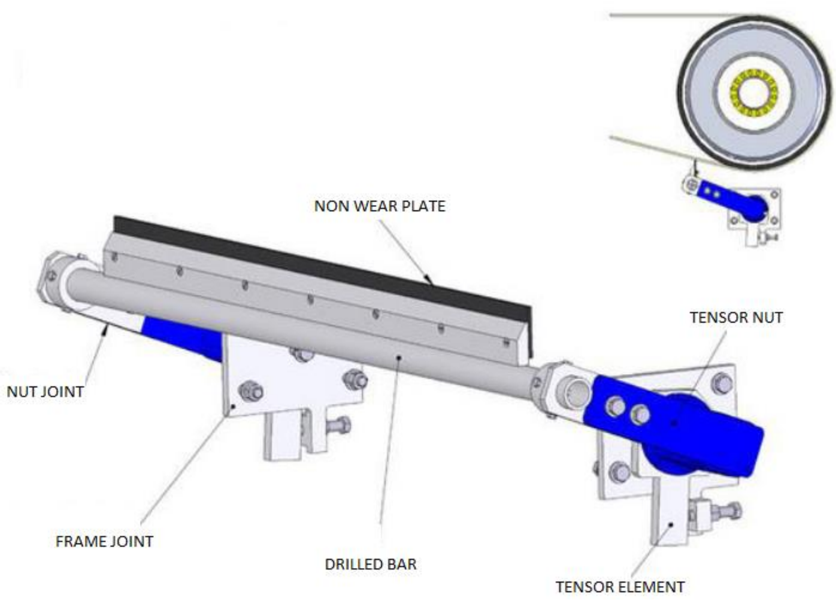


Figure 3.18: Scrapper structure [2]

4 Discussion

The belt conveyor has been calculated, and it’s shown step by step, although there are so many ideas that could be added to the design as cover completely the belt conveyor so the climate circumstances don’t affect to the normal operating of it.

Also it was my choice to have just one snub pulley or one only motor at the head, with more snub pulleys and drive pulleys the wrap angle could be bigger and then the efficiency of the system would increase at the same time the installation would be more complex though. Also as more complex is the solution bigger is the initial investment, the maintenance costs and times and the construction and assembling of the installation.

Then this solution is simple but effective at the same time, but in many ways it can be changed.

Also, when the security factor was calculated the result was quite big, it means that the belt has a big break strength comparing to the necessary, this is not a problem at all but a weaker one was chosen that would mean saving some money, also it would be lighter and the tensions would decrease.

These calculations were made by analytical approach, but as it’s known nowadays, with the strong computer technology it is possible to calculate al the tensions through finite elements, this would have more exact results with the proper software.

5 Conclusions

At the end a result has been obtained following this analytical approach but also the personal ideas.

This was all calculated by the analytical approach guided the conveyor belt technique book that at the same time follows the international standards as ISO, DIN and so on.

As a result of the task, the designing is a bel conveyor, 300 m of horizontal path, 300 m of 15 degrees slope and 5 m of horizontal path following the profile of the land showed in figure 3.1. The belt for this conveyor was selected, 605 m 1200 mm ST 2250 5+5 RS, 605m long, 1200 mm of belt width that was selected mainly according to the lump size of the material, belt strength was determined by the power calculation and also the cover thickness and quality is defined. This belt is determined to move 2.62 m/s to fulfil the required capacity of 2 t/h.

Then belt forces and tensions were calculated with the characteristics of the belt, track, mainly distance, height and angle, and the characteristics of the idlers that are also defined.

Then the idler stations are defined, number, distances between them, diameters, length, type and so on. Therefor 245 stations of three troughing idlers for the carrying side and 82 stations of plane idlers for the return side are needed.

Also secondary systems where determined, as the take up weight, dissipative forces produced by frictions, bending resistance of the belt and bearing resistance of the pulley, even though this forces are not really relevant.

Then there was a problem with the belt at the slope changing points due to some tension loses that where solved calculating the radius necessary at every curve, making the change of slope softer, a consequence of this 8 idlers will have to be added at the carrying side.

Finally, with all the results obtained the power necessary to move the belt at the required velocity is determined, and that value allow us to choose the appropriated motor SIEMENS High efficiency 1PS4 4 pole 50 Hz 400 kW. To keep the velocity required at the pulley a gear box is needed with the reduction factor of 43.49.

This driving system needs special couplings that are also explained at the chapter 3.16, therefor hydraulic and flexible coupling are chosen for the motor shaft and the pulley shaft.

At the last point a scrapper structure for this application was explained and chosen.

The result of this thesis then is entirely explained and it fulfils the requirements of the problem successfully.

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