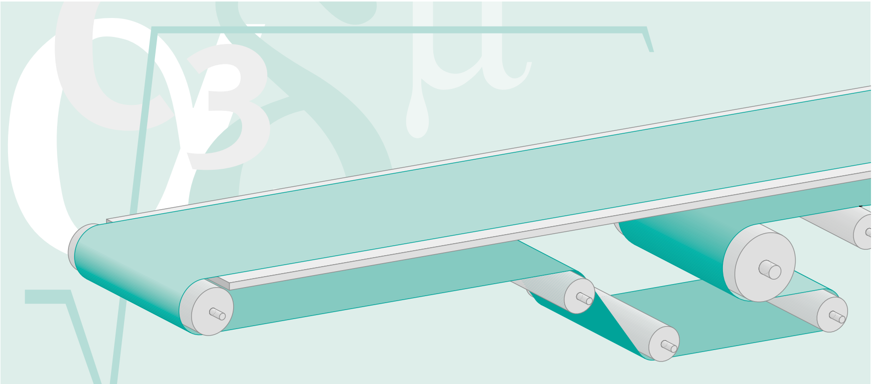
Calculation methods – conveyor belts



The formulae, figures and recommendations in this brochure are state of the art and a result of our years of experience. The calculation results can however differ from our calculation programme B_Rex (free download on the internet under www.siegling.com).

These differences are a result of the basically different approaches: whereas B_Rex is based on empirical measurements and requires a detailed description of the machine, the calculation methods here are based on general, simple physical formulae and derivations backed up by factors (c_2) that include a safety margin. In the majority of cases the safety margin used for calculation in this brochure will be larger than for the corresponding B_Rex calculation.

Content

Further information on machine design can be found in our brochure no. 305 “Recommendations for machine design”.

Terminology

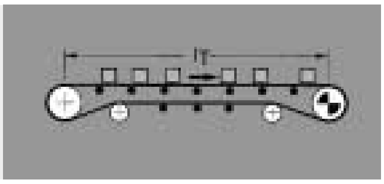
Designation	Symbol	Unit
Force on each belt strand	F	N
Maximum belt pull (at drive drum)	F_1	N
Minimum belt pull (at drive drum)	F_2	N
Effective belt pull	F_U	N
Shaft load at drive drum	F_{WA}	N
Shaft load at end drum	F_{WU}	N
Motor power	P_M	kW
Calculated power at drive drum	P_A	kW
Belt pull at 1% elongation per unit of width	SD	N/mm
Drum/roller width	b	mm
Belt width	b_0	mm
Geometric belt length	Lg	mm
Calculation constants	c..	–
Drum/roller diameter	d	mm
Drive drum diameter	d_A	mm
Rolling resistance of support rollers	f	–
Difference in drum radii	h	mm
Coefficient of friction with support rollers	μ_R	–
Coefficient of friction with accumulated goods	μ_{ST}	–
Coefficient of friction with skid plate	μ_T	–
Acceleration due to gravity	g	$9{,}81 m/s^2$
Production tolerance	Tol	%
Upper support roller pitch	l_o	mm
Lower support roller pitch	l_u	mm
Transition length	l_s	mm
Mass of material conveyed over whole conveying length (total load)	m	kg
Mass of belt	m_B	kg
Mass of all rotating drum/rollers, except drive drum	m_R	kg
Mass of conveyed goods on upper side (total load)	m_1	kg
Mass of conveyed goods on return side (total load)	m_2	kg
Mass of conveyed goods per m of conveying length on upper side Line load	m'_o	kg/m
Mass of conveyed goods per m of conveying length on return side Line load	m'_u	kg/m
Tension take-up range	Z	mm
Total tension take-up range	X	mm
Height of lift	h_T	m
Conveyor length	l_T	β
Belt speed	v	m/s
Belt sag	y_B	mm
Drum deflection	y_{Tr}	mm
Arc of contact at drive drum and idler	β	°
Opening angle at drive drum	γ	°
Incline (+) or decline (–) angle of conveyor	α, δ	°
Elongation at fitting	ε	%
Drive efficiency	η	–
Density of material conveyed	ρ_s	kg/m^3

Unit goods conveying systems

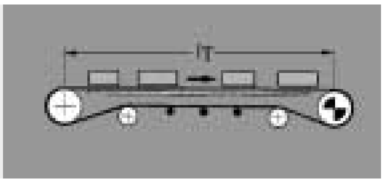
Loading examples to determine the effective pull F_U [N]

$m = l_T \cdot$ mass of conveyed material per m

$F_U = \mu_R \cdot g \cdot (m + m_B + m_R)$ [N]

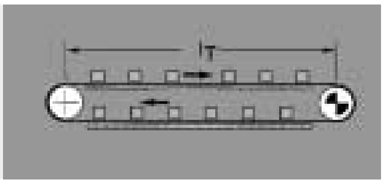


$F_U = \mu_T \cdot g \cdot (m + \frac{m_B}{2}) + \mu_R \cdot g\,(\frac{m_B}{2} + m_R)$ [N]



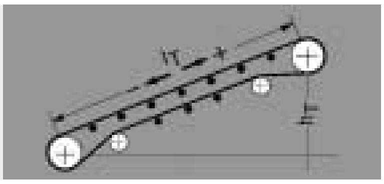
$F_U = \mu_T \cdot g \cdot (m_1 + m_2 + m_B)$ [N]

Coefficient of friction
of end drum was ignored



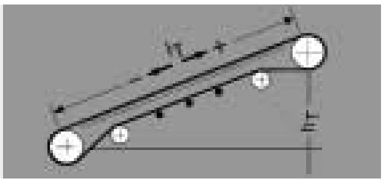
$F_U = \mu_R \cdot g\,(m + m_B + m_R) \overset{(-)}{+} g \cdot m \cdot \sin\alpha$ [N]

(–) increasing
(+) decreasing

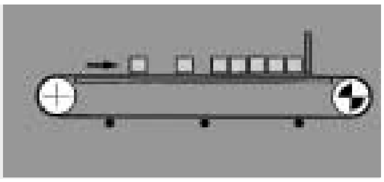


$F_U = \mu_T \cdot g\,(m + \frac{m_B}{2}) + \mu_R \cdot g\,(\frac{m_B}{2} + m_R) \overset{(-)}{+} g \cdot m \cdot \sin\alpha$

[N]

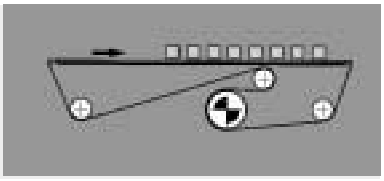


$F_U = \mu_T \cdot g\,(m + \frac{m_B}{2}) + \mu_R \cdot g\,(\frac{m_B}{2} + m_R) + \mu_{ST} \cdot g \cdot m$ [N]

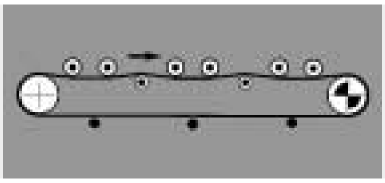


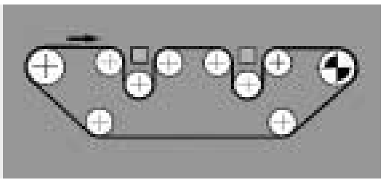
F_U = please inquire

$F_{Uges} = F_{U1} + F_{U2} + F_{U3}$ [N]



F_U =please inquire [N]





Coefficients of friction μS (guidelines)

	0, A0, E0, T, U0, P	NOVO	U1, V1, VH	UH, V2H, U2H, V5H, V10H
μT (skid plate)	0.33	0.33	0.5	0.5
μR (rollers)	0.033	0.033	0.033	0.033
μST (*)	0.33	0.33	0.5	0.5

* accumulated goods

Maximum belt pull F_1

$$F_1 = F_U \cdot c_1 \quad [N]$$

With calculable effective pull F_U.

$$F_1 = \frac{P_M \cdot \eta \cdot c_1 \cdot 1000}{v} \quad [N]$$

If effective belt pull F_U cannot be calculated, maximum belt pull F_1 can be determined from the installed motor power P_M as per the given formula and used to select a belt type.

c_1 constant (is valid for drive drum)

Transilon with underside of	V3, V5, U2, A5, E3			V1, U1, UH, U2H V2H, V5H			0, U0, NOVO, T, P		
Arc of contact β	**180°**	**210°**	**240°**	**180°**	**210°**	**240°**	**180°**	**210°**	**240°**
smooth steel drum									
dry	1.5	1.4	1.3	1.8	1.6	1.5	2.1	1.9	1.7
wet	3.7	3.2	2.9	5.0	4.0	3.0	not recommendable		
lagged drum									
dry	1.4	1.3	1.2	1.6	1.5	1.4	1.5	1.4	1.3
wet	1.8	1.6	1.5	3.7	3.2	2.9	2.1	1.9	1.7

c_2 constant
Counter-checking the type selection

$$\frac{F_1}{b_0} \leq c_2$$

If the value $\frac{F_1}{b_0} > c_2$,
the next stronger type must be used.

Transilon Type	E 2/1	E 3/2	E 2/2 E 3/1 E 4/1	E 4/2 E 5/2	E 6/1	NOVO E 8/2 E10/M	E12/3 E12/2 E15/M	E18/3	E20/M	E30/3	E44/3
Constant c_2	2	10	5	8	8	15	25	35	40	60	70

Note: With perforated belts the number of holes reducing the cross-section must be deducted from b_0. In the case of extreme temperatures c_2 constants change. Please enquire.

Minimum drive drum diameter d_A

$$d_A = \frac{F_U \cdot c_3 \cdot 180}{b_0 \cdot \beta} \quad [mm]$$

c_3 constant (is valid for drive drum)

Transilon with underside of	V3, V5, U2, A5, E3	V1, U1, UH	0, U0, NOVO, T, P
smooth steel drum			
dry	25	50	80
wet	50	not recommendable	not recommendable
lagged drum			
dry	25	30	30
wet	30	40	50

Power P_A at drive drum

$$P_A = \frac{F_U \cdot v}{1000} \quad [kW]$$

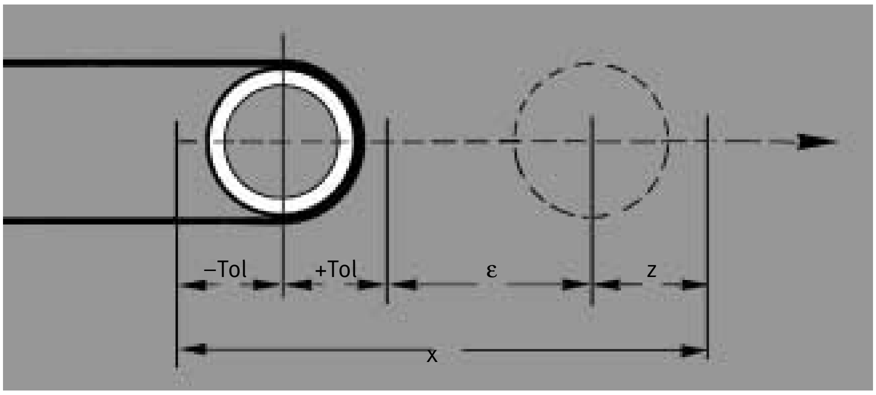
Motor power P_M required

$$P_M = \frac{P_A}{\eta} \text{ [kW]}$$ = next largest standard motor is chosen

Take-up range for screw-operated take-up systems

The following factors must be taken into account when determining the tension take-up range:

1. The approximate amount of elongation ε of the belt resulting from belt load. For determination of ε see pages 7 and 8.
2. The production length tolerances of the belt (Tol).
3. Possible external influences, e.g. temperature, stop-and-go operation, which may necessitate a higher elongation (tension) than normal or justify the allowance of a tension take-up reserve.



Generally, depending on the load, an elongation at fitting in the range of approx. 0.1 – 1% is adequate; a tension take-up range x of 1% of the belt length is therefore sufficient.

Guidelines for shaft load at rest with force F

When assessing shaft loads please take into account the differing belt pulls in stationary and operational modes.

Conveyor at rest

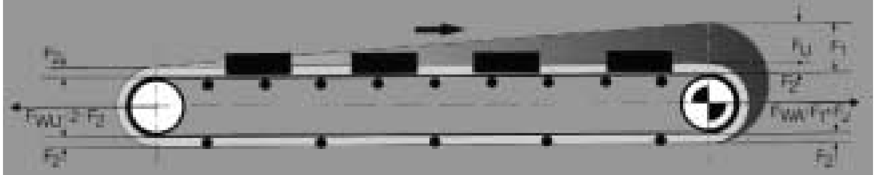
$F_{W1} = F_{W2} = 2 \cdot F \qquad F \approx \varepsilon\% \cdot SD \cdot b_0$ [N]

Guidelines for elongation at fitting ε with head drives

The minimum operational elongation at the fitting for a head drive is

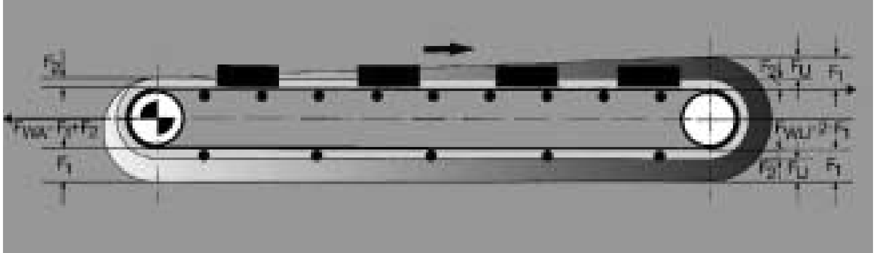
$$\varepsilon \approx \frac{F_U/2 + 2 \cdot F_2}{2 \cdot SD \cdot b_0} \quad [\%]$$

Head drive in operation



$F_2 = F_1 - F_U \qquad F_{WA} = F_1 + F_2$

Tail drive in operation

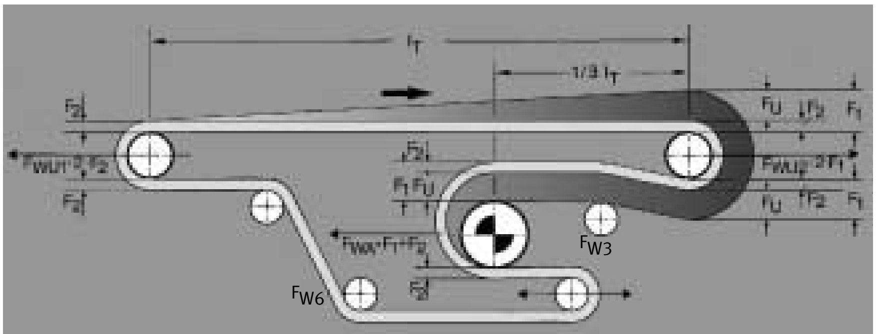


$F_2 = F_1 - F_U$

Guidelines for elongation at fitting ε with tail drives

The operational elongation at fitting for a head drive is

$$\varepsilon \approx \frac{F_U/2 + 2 \cdot F_2 + F_U}{2 \cdot SD \cdot b_0} \quad [\%]$$

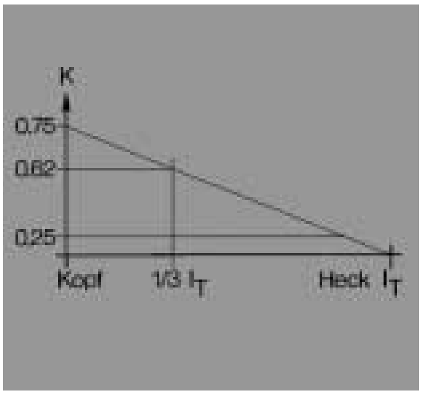


Return side drive in operation

Guidelines for elongation at fitting ε with return-side drives

The operational elongation at fitting for a return-side drive is

$$\varepsilon \approx \frac{F_U\,(c_1 - K)}{SD \cdot b_0} \quad [\%]$$



K with head drive = 0.75
K with return-side drive = 0.62
K with trail drive = 0.25

Guidelines for operational shaft load

Example drive drum β = 180°

$F_{WA} = F_1 + F_2$

Example snub roller β = 15°

$F_{W3} = \sqrt{2 \cdot F_1^2 - 2 \cdot F_1^2 \cdot \cos\beta}$ [N]

Example snub roller β = 25°

$F_{W6} = \sqrt{2 \cdot F_2^2 - 2 \cdot F_2^2 \cdot \cos\beta}$ [N]

Take-up range for load-dependent take-up systems

Determination of F_R

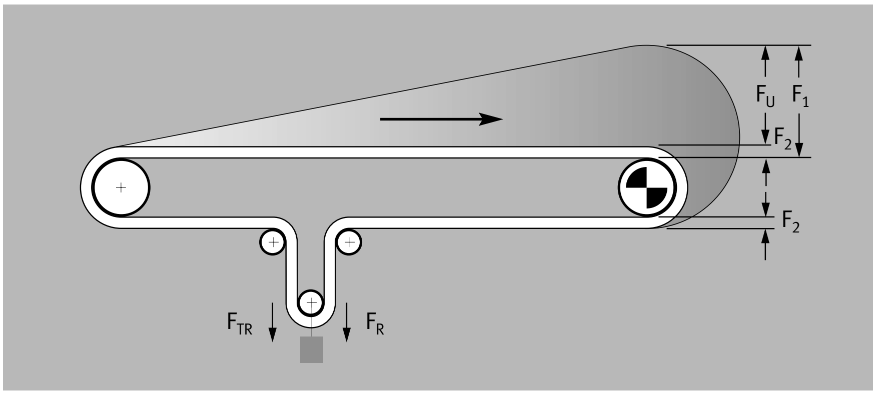
With gravity-operated take-up systems the tensioning weight must generate the force F_2 in order to achieve satisfactory grip by the belt on the drive drum (spring-loaded, pneumatic and hydraulic take-up devices operate in similar fashion).

The tensioning weight must be capable of moving freely. The take-up unit can only be installed after the drive unit. Such a design cannot be used with a reversible conveyor.

The take-up range is a function of the effective pull, the required force F_2, the belt length L_g, its delivery tolerance Tol, the tension reserve Z and the belt type.

$$F_R = 2 \cdot F_2 - F_{TR} \quad [N]$$

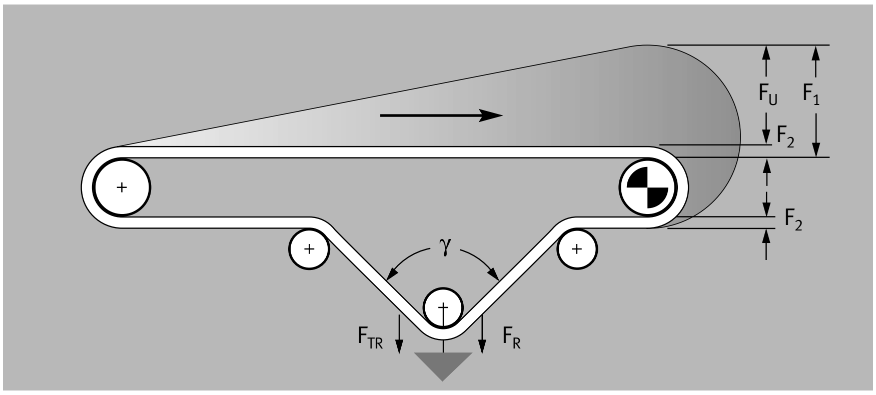
Example for determining the tensioning weight F_R [N] with a 180° arc of contact.



$$F_R = 2 \cdot F_2 \cdot \cos \frac{\gamma}{2} - F_{TR} \quad [N]$$

Example for determining the tensioning weight F_R [N] with an angle γ as shown below.

F_{TR} = weight of tension roller [N]



Bulk goods conveying systems

Longitudinal angle of incline δ

Guidelines for maximum incline angles δ for various bulk goods.

The values are determined by the particle shape, size and mechanical properties of the material conveyed, irrespective of the surface material of the belt.

Bulk goods	δ (ca.°)
Ash, dry	16
Ash, wet	18
Earth, moist	18 – 20
Grain, except oats	14
Lime, lumps	15
Potatoes	12
Gypsum, pulverized	23
Gypsum, broken	18
Wood, chips	22 – 24
Fertilizer, artificial	12 – 15
Flour	15 – 18

Bulk goods	δ (ca.°)
Salt, fine	15 – 18
Salt, rock	18 – 20
Loam, moist	18 – 20
Sand, dry, wet	16 – 22
Peat	16
Sugar, refined	20
Sugar, raw	15
Cement	15 – 20

Density ρ of certain bulk goods

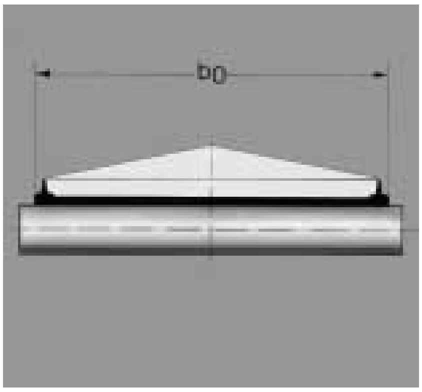
Goods	Bulk density ρ [10^3 kg/m³]
Ash, cold, dry	0.7
Earth, moist	1.5 – 1.9
Grain, except oats	0.7 – 0.85
Wood, hard	0.6 – 1.2
Wood, soft	0.4 – 0.6
Wood, chips	0.35
Charcoal	0.2
Pulses	0.85
Lime, lumps	1.0 – 1.4
Fertilizer, artificial	0.9 – 1.2
Potatoes	0.75
Salt, fine	1.2 – 1.3
Salt, rock	2.1
Gypsum, pulverized	0.95 – 1.0

Goods	Bulk density ρ [10^3 kg/m³]
Gypsum, broken	1.35
Flour	0.5 – 0.6
Clinker	1.2 – 1.5
Loam, dry	1.5 – 1.6
Loam, moist	1.8 – 2.0
Sand, dry	1.3 –1.4
Sand, wet	1.4 – 1.9
Soap, flakes	0.15 – 0.35
Slurry	1.0
Peat	0.4 – 0.6
Sugar, refined	0.8 – 0.9
Sugar, raw	0.9 – 1.1
Sugarcane	0.2 – 0.3

Volume flow for flat conveyors

The table shows the hourly volume flow (m³/h) at a belt speed of v = 1 m/s for a flat, horizontal conveyor belt with 20 mm high T20 longitudinal profiles welded along both edges of the top face.

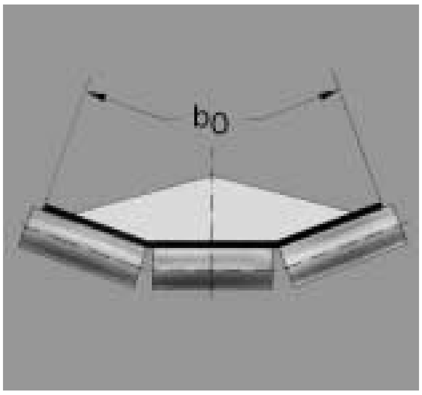
b_0 mm	400	500	650	800	1000	1200	1400
Angle of surcharge 0°	25	32	42	52	66	80	94
Angle of surcharge 10°	40	57	88	123	181	248	326



Volume flow for troughed conveyors

Note: In practical operations the theoretical value established for the volume flow is seldom obtained since it applies only to belts running horizontally and loaded evenly. Uneven distribution of the goods plus changes in the nature of the goods may reduce the volume carried by as much as 30 %.

b_0 mm	400	500	650	800	1000	1200	1400
20° troughed							
Angle of surcharge 0°	21	36	67	105	173	253	355
Angle of surcharge 10°	36	60	110	172	281	412	572
30° troughed							
Angle of surcharge 0°	30	51	95	149	246	360	504
Angle of surcharge 10°	44	74	135	211	345	505	703



c_6 constant

For belts on inclined conveyors the theoretical quantity carried has to be reduced by the c_6 constant depending on the angle of inclination δ.

Angle of inclination δ [°]	2	4	6	8	10	12
c_6 constant	1.0	0.99	0.98	0.97	0.95	0.93
Angle of inclination δ [°]	**14**	**16**	**18**	**20**	**22**	
c_6 constant	0.91	0.89	0.85	0.81	0.76	

Determination of the effective pull F_U

(–) increasing
(+) decreasing

$$F_U = g \cdot c_4 \cdot f\,(m + m_B + m_R) \pm g \cdot m \cdot \sin\alpha \quad [N]$$

plus peripheral forces from scrapers and cleaning devices

c_4 constant

l_T [m]	25	50	75	100	150	200
c_4	2	1.9	1.8	1.7	1.5	1.3

Coefficient of rolling resistance f for support rollers

f = 0.025 for roller bearings
f = 0.050 for plain bearings

For other calculations please refer to unit goods

Support roller pitch

Support roller pitch is a function of the belt's effective pull and the combined masses of belt and goods. It is calculated according to the following equation

$$l_o = \sqrt{\frac{y_B \cdot 800 \cdot F}{m'_o + m'_B}} \quad \text{[mm]}$$

If a max. belt sag of 1% is permitted, i.e. if $y_B = 0.01\ l_o$ is used, then

$$l_o = \frac{8 \cdot F}{m'_o + m'_B} \quad \text{[mm]}$$

Recommendations $l_o \max \leq 2b_0$
$l_u \approx 2 - 3\ l_o \max$

l_o = upper support roller pitch in mm
y_B = max. belt sag in mm
F = effective pull at appropriate point in N
$m'_o + m'_B$ = weight of conveyed goods plus belt in kg/m

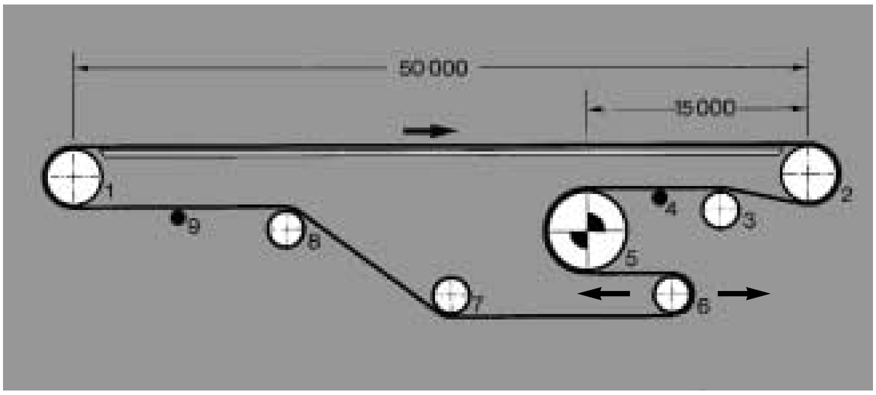
Unit goods conveying systems

Conveyor belts are loaded with a wide variety of goods (objects, containers) which are then sent to the distribution centre.

Horizontal configuration, skid plate support, return side drive as shown above, drive drum lagged, tension take-up, 14 support rollers.

Proposed belt type:

Transilon E8/2 U0/V5H black



End drums 1, 2, 6
Snub rollers 3, 7, 8
Drive drums 5
Support rollers 4, 9, et al.
Tension roller 6.

Conveying length	l_T = 50 m
Geom. belt length	L_g = 105000 mm
Belt width	b_0 = 600 mm
Total load	m = 1200 kg
Arc of contact	β = 180°
v = ca. 0.8 m/s	g = 9.81 m/s²
Mass rollers	m_R = 570 kg (all drums except drum 5)

Effective pull F_U [N]

$$F_U = \mu_T \cdot g \left(m + \frac{m_B}{2}\right) + \mu_R \cdot g \left(\frac{m_B}{2} + m_R\right)$$

$$F_U = 0.33 \cdot 9.81 \left(1200 + \frac{157.5}{2}\right) + 0.033 \cdot 9.81 \left(\frac{157.5}{2} + 570\right)$$

$$F_U \approx 4340 \text{ N}$$

m = 1200 kg
μ_R = 0.033
μ_T = 0.33
m_B = 157.5 kg (from 2.5 kg/m² · 105 · 0.6)

Maximum belt pull F_1 [N]

F_U = 4350 N
c_1 = 1.6

$$F_1 = F_U \cdot c_1$$

$$F_1 = 4350 \cdot 1.6$$

$$F_1 \approx 6960 \text{ N}$$

Counter-checking the type selection

F_1 = 6960 N
b_0 = 600 mm

$$c_2 = \frac{F_1}{b_0}$$

$$c_2 = \frac{6960}{600}$$

$$c_2 = 11.6 \text{ N/mm} \leq 15 \text{ N/mm for E 8/2}$$

The selected belt type is correct.

Minimum drive drum diameter

F_U = 4340 N
c_3 = 30
b = 180°
b_0 = 600 mm

$$d_A = \frac{F_U \cdot c_3 \cdot 180°}{b_0 \cdot \beta} \quad [mm]$$

$$d_A = \frac{4340 \cdot 30 \cdot 180°}{600 \cdot 180°} \quad [mm]$$

d_A = 218 mm

d_A 250 mm selected

Power P_A at the drive drum

F_U = 4350 N
ν = 0.8 m/s

$$P_A = \frac{F_U \cdot \nu}{1000} \quad [kW]$$

$$P_A = \frac{4350 \cdot 0.8}{1000}$$

$P_A \approx 3.5$ kW

Motor power P_M required

P_A = 3.5 kW
η = 0.8 (assumed)

$$P_M = \frac{P_A}{\eta} \quad [kW]$$

$$P_M = \frac{3.5}{0.8} \quad [kW]$$

$P_M \approx 4.4$ kW

P_M 5.5 kW and higher

Minimum elongation at fitting for return-side drive

F_U = 4350 N
c_1 = 1.6
K = 0.62
SD = 8 N/mm for E 8/2
b_0 = 600 mm

$$\varepsilon = \frac{F_U (c_1 - K)}{SD \cdot b_0} \quad [\%]$$

$$\varepsilon = \frac{4350\,(1.6 - 0.62)}{8 \cdot 600} \quad [\%]$$

$\varepsilon \approx 0.9$ %

Shaft load (in operation)
Drum 2 (end drum)

Simplified calculation
assuming $\beta = 180°$

$F_1 = 6960$ N

$F_{W2} = 2 \cdot F_1$

$F_{W2} = 2 \cdot 6960$ N

$F_{W2} \approx 13920$ N

Shaft load (in operation)
Drum 1 (end drum)

$F_2 = F_1 - F_U$
$F_2 = 6960 - 4350$
$F_2 = 2610$ N

$F_{W1} = 2 \cdot F_2$

$F_{W1} = 2 \cdot 2610$ N

$F_{W1} \approx 5220$ N

Shaft load (in operation)
Drum 5 (drive drum)

$F_1 = 6960$ N
$F_2 = F_1 - F_U$
$F_2 = 6960 - 4350$
$F_2 = 2610$ N

$F_{W5} = F_1 + F_2$

$F_{W5} = 6960 + 2610$

$F_{W5} \approx 9570$ N

Shaft load (in operation)
Drum 3 (snub roller)

The calculation of F_{W3} influenced by belt pull F_1, proceeds as given in the equation on page 7.

When the conveyor is at rest, the forces in the upper and return strands are determined solely by the elongation at fitting ε. The force F in each strand is given by

$$F = \varepsilon\,[\%] \cdot SD \cdot b_0 \qquad [N]$$

Example for a drum where the arc of contact β = 180°

(This force acts on drums 1, 5 and 6 because of their 180° arc of contact.)

$$F_W = 2 \cdot F$$
$$F_W = 2 \cdot 0.9 \cdot 8 \cdot 600$$
$$F_W \approx 8640\ N$$

Where β ≠ 180° the following applies in determining F_W

(where $F_1 = F_2$ can be used when the conveyor is at rest.)

$$F_W = \sqrt{F_1^2 + F_2^2 - 2 \cdot F_1 \cdot F_2 \cdot \cos\beta}$$

$$F_W = [N]$$

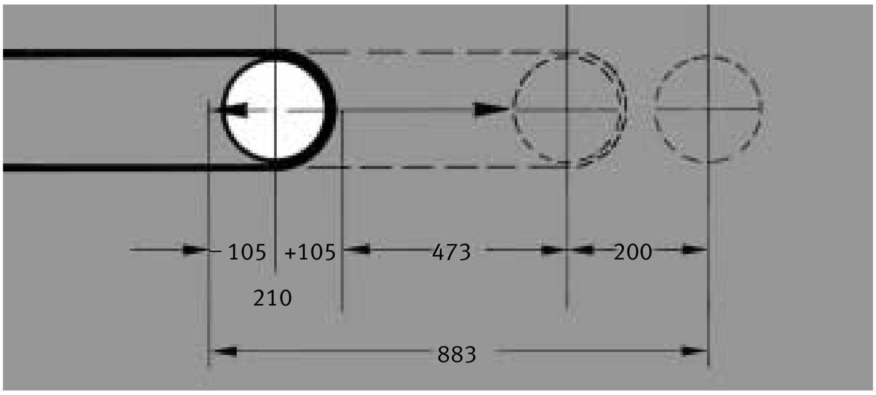
Shaft load at rest

In order to compare the differences between the stationary and operational modes, please look at the variations in shaft load at drum 1.

F_{W1} at rest = 8640 N
F_{W1} operational = 5220 N

Note: Both modes must be taken into account when designing the conveyor.

Tension take-up range



Tol = ± 0.2 %
ε = 0.9 %
L_g = 105000 mm
z = 200 mm

$$X = \frac{\dfrac{2 \cdot Tol \cdot Lg}{100} + \dfrac{\varepsilon \cdot Lg}{100}}{2} + z \qquad [mm]$$

$$X = \frac{\dfrac{2 \cdot 0{,}2 \cdot 105000}{100} + \dfrac{0{,}9 \cdot 105000}{100}}{2} + 200 \qquad [mm]$$

$$X = 210 + 473 + 200 \qquad [mm]$$

$$X \approx 883\ mm$$

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Conveyor and processing belts

Because our products are used in so many applications and because of the individual factors involved, our operating instructions, details and information on the suitability and use of the products are only general guidelines and do not absolve the ordering party from carrying out checks and tests themselves. When we provide technical support on the application, the ordering party bears the risk of the machinery functioning properly.

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