

## Does it Really Save Energy? Speed Control on Belt Conveyors

Dipl.-Ing. Hans Lauhoff is a publicly certified and sworn expert  
for the field of materials handling, in particular continuous conveyors,  
Engineering Office Hans Lauhoff, Beckum, Germany

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# Speed Control on Belt Conveyors - Does it Really Save Energy?

## Summary

In recent years, there have been repeated recommendations - mainly in German technical publications - to control the belt speed of conveyor systems. The level of filling  $\varphi$  of the belt trough with 100 % should serve as a basis for the control procedure. This means that high utilization of the average transport capacity should always be aimed for, at an adapted, reduced belt speed. This type of operation is said to reduce energy consumption and hence operating cost. This essay looks critically at this recommendation. On the basis that DIN 22101 applies to the design of belt conveyors and not to establishing the fictitious resistance coefficient at different belt speeds or filling levels, the limiting quantities on the motion resistance of belt conveyors are described. Based on the dependencies of individual resistances researched in relevant literature, simulation calculations for a fictitious belt conveyor are used to demonstrate that the fictitious resistance coefficient of belt conveyors largely depends on the filling level  $\varphi$  and only to a small degree on the belt speed. By means of the characteristic quantity "specific energy requirement" it is demonstrated that speed control for the purpose of energy savings is inappropriate at traditional filling levels in the range between 60 % and 100 %.

## 1 Introduction

Belt conveyors have proven themselves to be an excellent solution for the transport of raw mineral materials and soil. Today, they are in most cases the most cost-effective solution for handling bulk material mass flows over short and medium conveying distances. Despite the already advantageous costs for belt conveyor operation, there is still a desire to reduce these costs even further.

Publication sources state that, in order to balance the filling level, the belt speed should be controlled in accordance with the load. As a result, energy consumption should decrease. Publications give the impression that a reduction of the

energy consumption by up to 30 % is possible, if, by controlling the conveying speed with the nominal volume flow as a leading quantity, that is a filling level of 100 %, the belt conveyor can also be operated if the volume flow is subject to fluctuations. In this context, publication sources mention center distances of more than 1400 m. In its summary, publication sources also suggest that more an economical operation is achieved if variable-speed drives are used for belt conveyors. In some publication sources, DIN 22101 is used as a basis for these statements.

Against this background, the author of this paper has been asked by Voith Turbo to provide an expert's opinion whether - universally applicable - the energy consumption of belt conveyors is reduced and hence allows more economical operation, if the filling level  $\varphi$  of the belt trough is utilized to 100 %.

## 2 Principle Calculation Methods to Determine the Motion Resistance of Belt Conveyors

The energy consumption of long, horizontal belt conveyor systems in stationary operating conditions is determined by the motion resistance in the loaded section of the belt and the return belt. This resistance consists of the running resistance of the rolls supporting the belt, as well as the flexure resistance of the bulk material and the belt when running across the supporting rolls. The energy required to overcome these resistances is determined by a number of operative and constructive characteristic properties. Compared to the other resistances, overcoming differences in height requires a high amount of energy. Lifting masses to a different level here primarily determines the amount of energy required, and can therefore not be influenced. Motion resistances are all forces acting on the belt along the direction of transport, which have to be overcome during the operation of the belt conveyor.

### 2.1 Calculation Method per DIN 22101 - Overview

Following DIN 22101 motion resistances  $F_W$  are divided into:

- Primary resistances  $F_H$
- Secondary resistances  $F_N$
- Gradient resistances  $F_{St}$



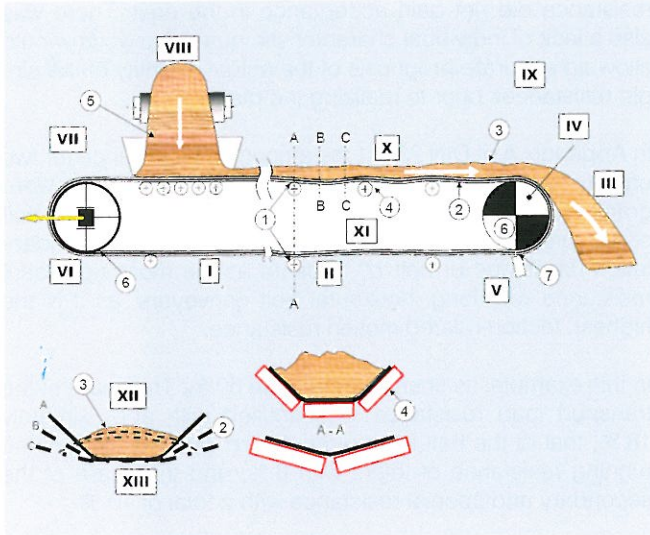


Fig. 1: Belt conveyor with existing motion resistances [9]

- Special resistances  $F_S$

It is thus:

$$F_W = F_H + F_N + F_{St} + F_S$$

**Primary resistances  $F_H$**

Primary resistances are all friction-related resistances along the belt conveyor, with the exception of special resistances. The primary resistances  $F_{Hi}$  on the individual section are, as a matter of simplification and under assumption of a linear relation between resistances and the conveyed load for each individual section  $i$ , determined separately.

$$F_{H,i} = l_i \cdot f_i \cdot g \cdot [m'_{R,i} + (m'_G + m'_{L,i}) \cdot \cos \delta]$$

The sum of all individual sections forms the entire primary resistance.

$$F_H = \sum_{i=1}^n F_{H,i}$$

**Secondary resistances  $F_N$**

Secondary resistances are friction and inertia resistances which occur only at certain parts of the belt conveyor. These include:

- Feeder resistance to goods to be transported  $F_{auf}$  [see Fig. 1, VIII, 5]
- Friction resistance between transport goods and chute  $F_{Schb}$  [see Fig. 1, VII, 5]
- Friction resistance of belt cleaners  $F_{Gr}$  [see Fig. 1, V, 7)]
- Deflection resistance of belt at drums [see Fig. 1, V and VI, (6)]

The secondary resistances are independent of the length of the belt conveyor and are constant. With long center distances, their significance declines compared to motion resistances distributed across the conveying track - the primary

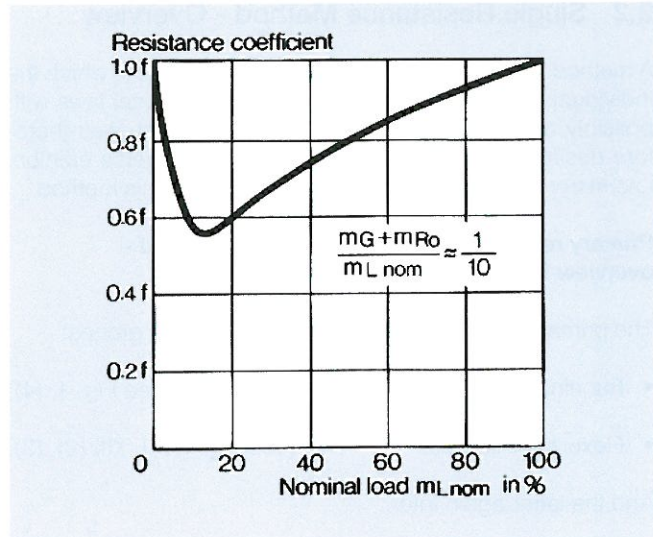


Fig. 2: Resistance coefficient  $f$  depending on load situations according to ALLES [6]

resistances. If the proportion of secondary resistances within the total number of resistances is low, a general assumption is permissible. The total sum of the secondary resistances is taken into consideration by the coefficient  $C$ .

$$F_N = (C - 1) \cdot F_H$$

For conveyors with a length of more than 1 000 m it is  $C \leq 1.09$ .

**Special resistances  $F_S$**

Special resistances are resistances which do not occur at all belt conveyors. These are especially the vertical resistance of idlers, friction resistances outside feeder stations and resistances of the equipment used for feeding the bulk material outside if this happens along the conveying track.

**Application area of DIN 22101**

The norm DIN 22101 covers the fundamentals for the calculation and the design of belt conveyors for bulk materials. For the determination of the primary resistances, a mathematical basis in accordance with COULOMB'S law of friction is used.

The force of the added weights of the moved masses of bulk material, belt and idlers, multiplied by the fictitious resistance coefficient  $f$  results in the primary resistance  $F_H$ . The selection of the fictitious resistance coefficient  $f_i$  is of overriding importance for the quantity of the primary resistances, especially if the gradient resistances tend to be low. According to the norm, a range of values for the fictitious resistance coefficient is stated for different operating and plant parameters. For this, usually several marginal conditions are mentioned, from which these values derive.

Parameters, such as fictitious resistance coefficient and load distribution of bulk materials, are assumed to be constant values for the calculation of the primary resistances.

However, Alles already describes that, above all, the fictitious resistance coefficient is not constant. Therefore, DIN 22101 should not and cannot be used as an immediate calculation basis for fluctuating operating conditions (Fig. 2).



## 2.2 Single Resistance Method - Overview

A method for calculating the primary resistances, in which the individual share of resistances, based on physical laws with possibly all limiting quantities, are incorporated, was therefore desirable for the establishment of this expert's opinion. LACHMANN and VIERLING were the first to set up this method.

### Primary resistance in single resistance method - overview from literature

The primary resistances  $F_H$  are divided into two groups:

- Running resistance of idlers  $U'$  [see Fig. 1, (4)]
- Flexure resistances  $U''$  [see Fig. 1, XII, XIII (2), (3)]

And the latter again into:

- Indentation resistance of belt  $U''_E$  [see Fig. 1, (1)]
- Belt flexure resistance  $U''_G$  [see Fig. 1, XII (2)]
- Transport load flexure resistance  $U''_L$  [see Fig. 1, XIII (3)]

The motion resistances  $F_W$  are therefore established as mentioned in the paper.

$$F_W = F_H + F_N + F_{St} + F_S$$

$$F_W = \sum [U' + (U''_E + U''_G + U''_L)] + F_N + F_{St} + F_S$$

During the last decades, numerous scientific works dealt with this differentiation when calculating single resistances. Due to the complicated influence of constructive, technological and operating characteristics affecting the flexure resistance, the single resistance method for establishing the primary

resistance did not gain acceptance in the past. There was also a lack of individual characteristic quantities which would allow an accurate prognosis of the actual quantity of the single resistances prior to realizing the plant.

In Appendix A of DIN 22101 the amounts of resistance for two equally long belt conveyors, however, with different upward gradients, are shown, Fig. 3. The data applies to long belt conveyors (center distance in excess of 1000 m). The indentation resistance of belt  $U''_E$  appears as the most significant resistance with long, horizontal belt conveyors, as it is the highest, friction-related motion resistance.

In this example, its share is more than 60 %. The share of the transport load resistance is quantified with approximately 18 %, that of the belt flexure resistance with 5 %, and the share of the running resistance of idlers with 6 %, and the share of the secondary and special resistance with a total of 10 %.

In the following, a number of proven methods for calculating the individual share of the primary resistance, as well as the characteristic quantities which are decisive in this context, are shown:

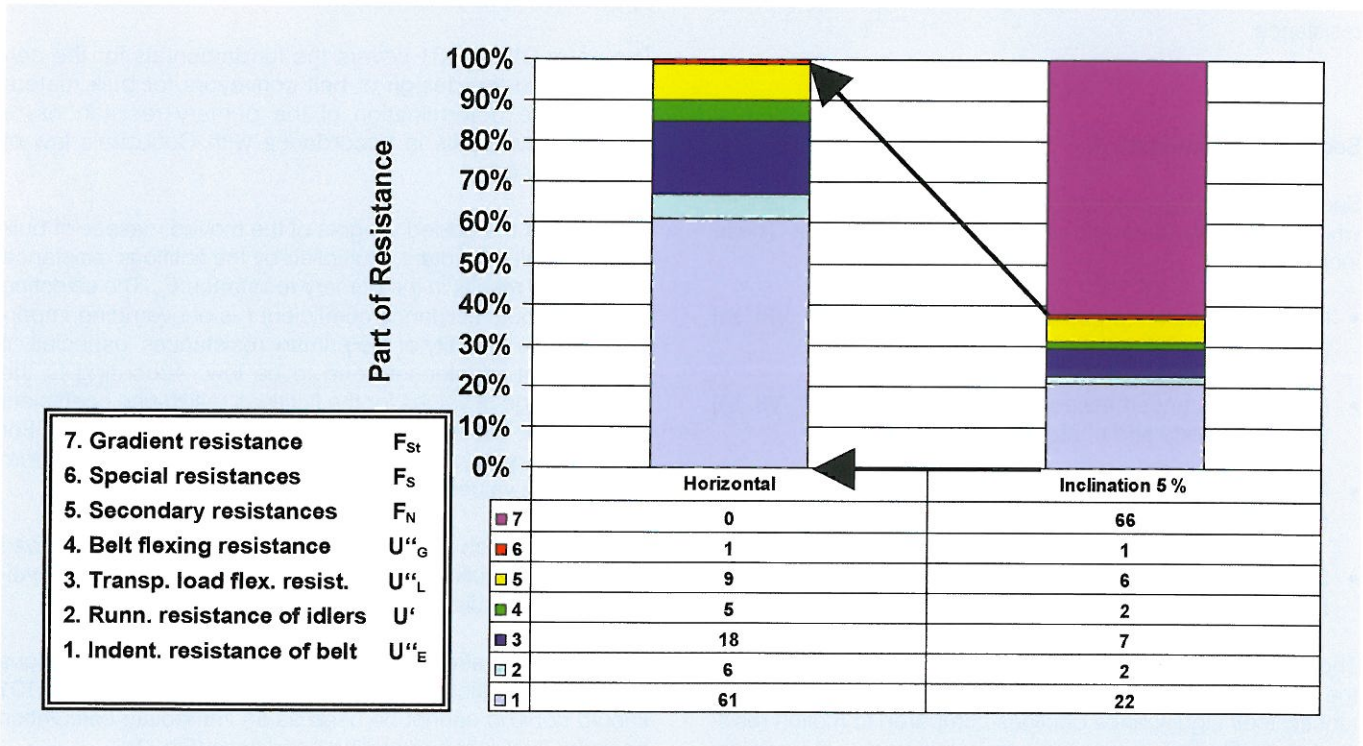
- Conveying speed  $v$ , and
- Dependence on filling level  $\varphi$

## 3 Characteristic Quantities with Single Resistances

### 3.1 Running Resistance of Idlers $U'$

The running resistance of idlers of the carrier rolls supporting the belt is defined as a force in the circumference of the rolls which has to overcome the friction torque from bearing and

Fig. 3: Comparison of resistance share of two equally long belt conveyors (identical design), but different upward gradients [5]





sealing friction under a given load on the rolls  $F_{NR}$  at a certain conveying speed  $v$ , Fig. 4. It is transferred from the belt to the idlers by a friction connection. A high number of idlers is installed across the entire conveying track.

There is no generally applicable formula for a simple calculation of the running resistance of idlers. It was, however, established that the running resistance of idlers is essentially determined by the type and the amount of grease used in the labyrinths and roller bearings. It was also established that temperatures can have a considerable influence. In order to make a highly accurate prognosis of the running resistance of idlers, literature recommends measurements at a test stand. Within the framework of this expert's opinion, the mentioned formula was used as a basis.

$$U = a + b \cdot v + c \cdot F_{NR}$$

The mentioned parameters were assumed as a constant for all evaluations.

The conveying speed  $v$  or the load on the idlers  $F_{NR}$  were varied accordingly.

In order to establish the running resistance of idlers of an entire idler station, the load on individual rolls in dependence on the load condition must be taken into consideration.

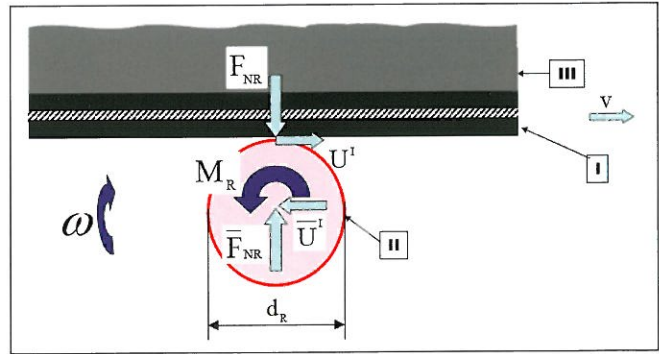


Fig. 4: Idealized illustration of force and motion conditions for defining the running resistance of the idlers [13]

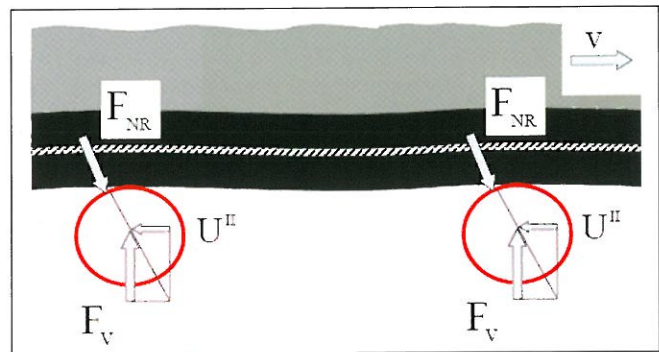


Fig. 5: Idealization of forces due to flexure resistance [9]

### 3.2 Flexure Resistance $U''$

The flexure resistance (with its individual components  $U_E^I$ ,  $U_L^I$  and  $U_Q^I$ ) is of overriding importance for long, horizontal belt conveyors. In this context, the flexure resistance force which acts from the idler on the belt in opposite direction, corresponds to the horizontal share of the normal force  $F_{NR}$  (Fig. 5) of the belt on the idler. An increase of the flexure resistance becomes noticeable by a change in the contact arch in the zone between idler and belt.

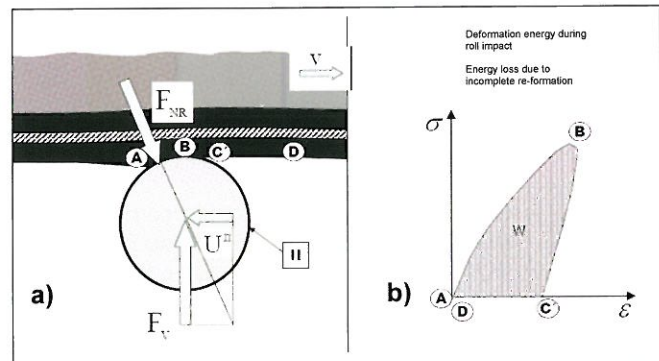


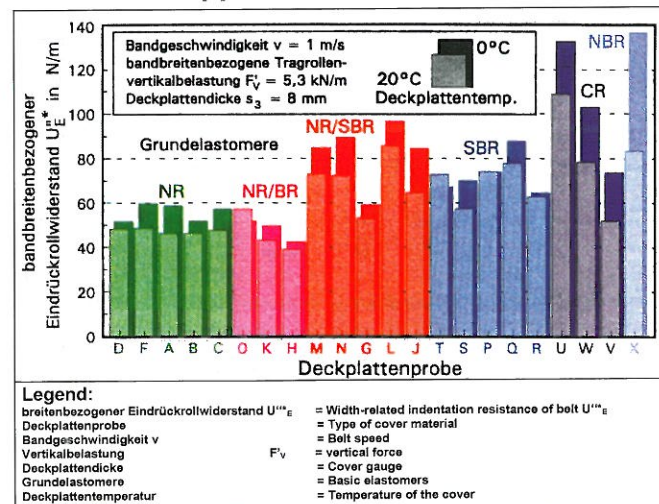
Fig. 6: a) Idealized illustration of forces and deformation, b) Deformation energy due to indentation resistance of belt [9]

#### 3.2.1 Indentation Resistance of the Belt $U_E^I$

The indentation resistance of belt is generated by the rolling off of the idler on the contact side of the belt cover of the belt (Fig. 6a). The deformation work expended by the cover plate cannot be fully regained (Fig. 6b). This hysteresis loss is caused by the visco-elastic characteristics of the rubber. GREUNE already established that the natural forces per 1 m plant length on the idlers, as well as the contact lengths between belt and idlers, decrease with increasing belt speed, as a result of which the roll deformation declines over-proportionally. He also established that, with a constant mass flow at increasing belt speed, there is merely a degressive rise in the output requirement of the product from indentation resistance of belt and belt speed.

Fig. 7: Measurements of indentation resistance of belt with different belt covers [9]

In mentioned literature the calculation bases for the indentation resistance of belt are stated. During his research, HINTZ has examined a high number of different belt cover materials. (Fig. 7).



The indentation resistance  $U_E^I$  of the belt at an idler station can be calculated from the distributed load along the individual idlers. As a special case, the mentioned formula applies to a flat belt which is impacted by an idler, without curvature



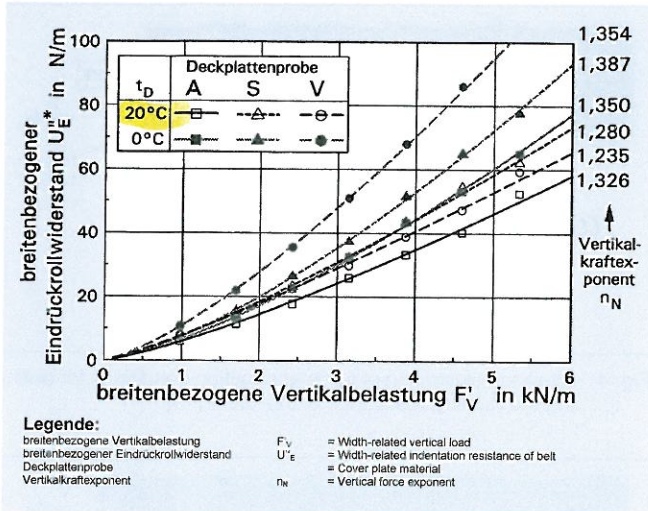


Fig. 8: Indentation resistance of belt dependent on vertical load according to HINTZ [9]

and a constant load for the indentation resistance of belt across the belt width.

$$U_E'' = c_E \cdot d^{-2/3} \cdot F_V^{4/3} \cdot b_R^{-1/3}$$

where:

- $c_E$  cover plate-specific constant
- $d$  idler diameter
- $F_V$  vertical load on idlers
- $b_R$  contact length between idler and belt

Analog to the fictitious friction coefficient according to DIN 22101, the indentation resistance of belt divided by vertical load of idlers is equal to the fictitious friction coefficient  $f_E$  of the indentation resistance of belt.

$$f_E = \frac{U_E''}{F_V}$$

Fig. 8 shows the influence of the width-related vertical load on the width-related indentation resistance of belt.

All curves start at the base and rise progressively. A regression analysis carried out by HINTZ for the altogether six functions, under consideration of a potential equation, resulted in the mentioned formula:

$$U_E'' = a \cdot (F_V')^{n_N}$$

As a mean value, the vertical force exponent can be stated with  $n_N = 1.322$ . The progressive rise of the curves confirms that the effects of reducing the indentation resistance of belt with heavy systems, that means systems with high load distribution and load on the idlers, are more noticeable than with lighter systems. During his investigations, HINTZ established a rise in indentation resistance of belt of only 4 % after doubling the conveying speed.

The simulation calculations in this expert's opinion are based on these findings. Additionally, a simplified formula was applied for the load distribution of the side and central roll.

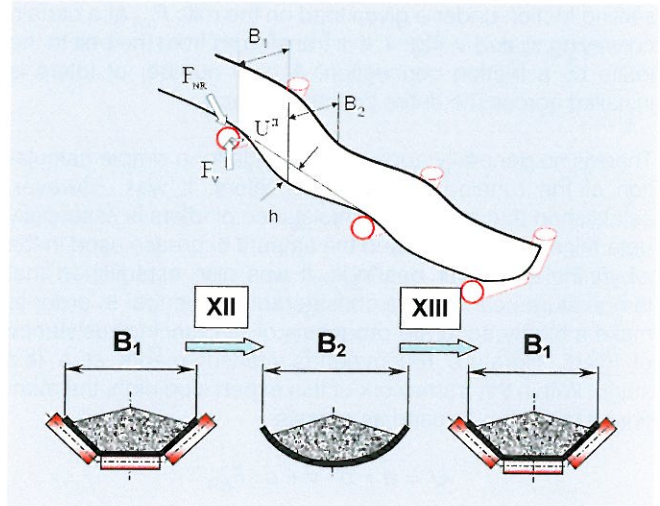


Fig. 9: Schematic illustration of loss-related changes of the belt and material profile between idler stations

### 3.2.2 Transport Load Flexure Resistance $U_L''$

The transport load flexure resistance  $U_L''$  is generated by internal friction losses in the bulk material and external friction losses between material and belt, which occur if the belt profile is changed in longitudinal and transverse direction (Fig. 9).

Literature shows similar calculatory approaches for determining the transport load flexure resistance. In summary, it can be established that the flexure resistance depends on

- the material characteristics,
- the load on the idlers,
- the distance between idlers, and
- the belt pulling force.

The transport load flexure resistance increases dramatically with increasing load [14].

### 3.2.3 Belt Flexure Resistance $U_G''$

The belt flexure resistance is the flexure loss of the conveyor belt, that means internal friction in the traction carriers and the rubber cover plates with any change of the belt profile (see Figs. 1 and 9).

As with the transport load flexure resistance, literature agrees widely that there is a high dependency of the belt flexure resistance on the distance between idlers and the belt pulling force. A wider distance between idlers leads to an increase, while a higher belt pulling force leads to a decrease of the belt flexure resistance.

An expert evaluation of the belt flexure resistance and the material idler resistance was carried out using the following equation:

$$U_L'' + U_G'' = k_{LG} \cdot [(m_G' + m_L') \cdot g \cdot l]^2 \cdot T^{-1}$$

The mentioned constant, the belt pulling force and the length-related belt mass were all used in identical quantities. Depending on the simulated observation, the length-related belt load or the belt speed was varied.



#### 4 Evaluation of Literature - Assessment Using a Calculation Example by Means of the Specific Energy Consumption

In order to provide a satisfactory answers to the issues discussed in this expert's opinion, it was not primarily a matter of making exact statements on the actual primary resistance.

Instead, it was perfectly sufficient, deriving from a fictitious nominal mass flow of a fictitious belt conveyor with a filling level of 100 % and a belt speed of  $v_{nenn}$  to

- (fictitiously) reduce the mass flow in such a way, and
- assume it of being the same size,

that on the one hand:

**Case A:** the filling level  $\phi$  reduces and the conveying speed  $v_{nenn}$  remains constant,

and on the other hand,

**Case B:** the filling level  $\phi$  remains constant at 100 % and the conveying speed  $v$  reduces.

As a result, the quantities and parameters from literary sources which are independent from the belt speed or the filling level of the belt, could be chosen on the grounds of practical application, identically applied in all simulations. For the simulation calculations the parameters shown in Table 1 were used. Additionally, the single resistances were separately established, divided into loaded belt and return belt. For this, some of the calculatory equations on the assumed three-part idler station had to be increased for the loaded belt and standardized to the length of the unit.

#### 4.1 Evaluation of the Single Resistances by Means of the Specific Energy Requirement $W_{spez}$

The power requirement  $P_W$  of a belt conveyor is normally calculated from the product of the motion resistances  $F_W$  and the conveying speed.

$$P_W = F_W \cdot v$$

From a dimensional point of view, the result is expressed in Watt or Kilowatt (W or kW). The amount of money to be paid to the energy suppliers is, however, for the amount of energy used over a certain period, that mean, the actual work. The dimension is Kilowatt hour (kWh). In order to compare and evaluate the simulation results, it was therefore more practical,

Table 1: Parameters of a fictitious belt conveyor for simulation calculations

No.	Formula quantity	Symbol	Unit	Value
1.	(nominal) Degree of fill	$\phi_{nenn}$		1
2.	Belt width	$B$	mm	1000
3.	Belt weight	$m'_G$	kg/m	28,4
4.	(nominal) Mass flow of material	$I_{m\ nenn}$	kg/s	776
5.	(nominal) Capacity per hour		t/h	2794
6.	Bulk density	$\rho$	kg/m <sup>3</sup>	1600
7.	(nominal) Load mass	$m'_L$	kg/m	194,03
8.	(nominal) Belt speed	$v_{nenn}$	m/s	4,00
9.	Conveying length	$L$	m	1.000
10.	Upper conveyor			
11.	3-part troughing angle	$\lambda$	°	40
12.	Idler spacing	$l_O$	mm	1.200
13.	Diameter of the idler	$d_{RO}$	mm	133,00
14.	Idler weight	$m_{RO}$	kg	17,80
15.	Idler tube length	$l$	mm	380,00
16.	Filling cross-section area	$A$	m <sup>2</sup>	0,1212
17.	Lower conveyor			
18.	Flat			
19.	Idler spacing	$l_U$	mm	3.000
20.	Diameter of the idler	$d_{RU}$	mm	133,00
21.	Idler weight	$m_{RU}$	kg	17,80



Calculation simulation with: $v = \text{constant} = v_{\text{nenn}}$ ; Filling level $\varphi$ is reduced									
No.				H.1	H.2	H.3	H.4	H.5	H.6
1.1	Load stage:	$\varphi_{\text{fiktiv}}$		0,6	0,7	0,8	0,9	1	1,1
1.2	"Conveying output" at above load stage		t/h	1676	1956	2235	2515	2794	3073
1.3	Mass flow at above load stage	$I_m$	kg/s	466	543	621	699	776	854
1.4	Filling level for calculation stage: $\varphi_{\text{fiktiv}} = \varphi_{\text{sim}}$	$\varphi_{\text{sim}}$		0,6	0,7	0,8	0,9	1	1,1
1.5	Load distribution due to bulk material type	$m'_{\text{Lsim}}$	kg/m	116,42	135,82	155,22	174,63	194,03	213,43
1.6	Volume flow at above filling level	$I_v$	m <sup>3</sup> /s	0,291	0,340	0,388	0,437	0,485	0,534
1.7	Conveying speed	$v_{\text{nenn}}$	m/s	4,00	4,00	4,00	4,00	4,00	4,00
1.8	Power requirement per DIN 22101: $P_W = F_W \cdot v$	(DIN) $P_W$	kW	178	196	215	233	251	269
1.9	Specific energy consumption (DIN 22101 -conditions)	(DIN) $W_{\text{spez}}$	Ws/kg m	0,348	0,328	0,314	0,303	0,294	0,287
1.10	Specific energy consumption (single resistance method)	$W_{\text{spez}}$	Ws/kg m	0,285	0,283	0,284	0,289	0,294	0,298

Table 2: Case A - Evaluation of speed  $v = \text{constant} = v_{\text{nenn}}$

Table 3: Case B - Evaluation of filling level  $\varphi = \text{constant} = \varphi_{\text{nenn}}$

Calculation simulation with: $\varphi = \text{constant} = \varphi_{\text{nenn}}$ ; Conveying speed $v$ is reduced									
No.				H.1	H.2	H.3	H.4	H.5	H.6
2.1	Load stage:	$\varphi_{\text{fiktiv}}$		0,6	0,7	0,8	0,9	1	1,1
2.2	"Conveying output" at above load stage		t/h	1676	1956	2235	2515	2794	3073
2.3	Mass flow at above load stage	$I_m$	kg/s	466	543	621	699	776	854
2.4	Filling level of calculation stage	$\varphi_{\text{sim}}$		1	1	1	1	1	1
2.5	Load distribution due to bulk material type	$m'_{\text{Lsim}}$	kg/m	194	194	194	194	194	194
2.6	Volume flow at above filling level	$I_v$	m <sup>3</sup> /s	0,291	0,340	0,388	0,437	0,485	0,534
2.7	Conveying speed with: $v = I_v \cdot \varphi_{\text{fiktiv}} / A$	$v_{\text{sim}}$	m/s	2,40	2,80	3,20	3,60	4,00	4,40
2.8	Power requirement per DIN 22101: $P_W = F_W \cdot v$	(DIN) $P_W$	kW	151	176	201	226	251	276
2.9	Specific energy consumption (DIN 22101 -conditions)	(DIN) $W_{\text{spez}}$	Ws/kg m	0,294	0,294	0,294	0,294	0,294	0,294
2.10	Specific energy consumption (single resistance method)	$W_{\text{spez}}$	Ws/kg m	0,291	0,292	0,293	0,293	0,294	0,295



to relate the expended drive power  $P_W$  for the belt conveyor with its differing loads to the time-related mass flow and the conveyor system length  $L$ . The result is defined as the specific energy requirement  $W_{spez}$ :

$$W_{spez} = \frac{P_W}{\dot{m} \cdot L} = \frac{P_W}{m'_L \cdot v \cdot L} = \frac{F_W \cdot v}{m'_L \cdot v \cdot L} \quad \left[ \frac{W}{\frac{kg}{s} \cdot m} = \frac{W \cdot s}{kg \cdot m} \right]$$

**Case A:** Conveying speed  $v = \text{constant} = v_{nenn}$

During the evaluation of  $v = \text{constant} = v_{nenn}$  the conveying speed  $v$  was kept constant. In order to vary the operating conditions, the filling level  $\phi$ , that means the load on the idlers, was changed at stages from 0.6 to 1.1 and hence reduced. For further details refer to Table 2.

**Case B:** Filling level  $\phi = \text{constant} = \phi_{nenn}$

For the evaluation  $\phi = \text{constant}$ , the filling level  $\phi$ , that means the load on the idlers, has been maintained. In order to vary the operating conditions, the conveying speed was adapted at stages from 2.4 m/s to 4.4 m/s. Depending on the simulation (columns H1 to H6 of Tables 2 and 3) the same mass flow was used as a basis (lines 1.3 and 2.3 of Tables 2 and 3).

### 4.2 Comparison of Simulation Results

A summary of the results simulated by calculations is shown in the graph in Fig. 10.

The comparison regarding the specific energy consumption  $W_{spez}$ , established on the basis of the single resistance method (lines 1.10 with 2.10 of Tables 2 and 3) shows, that for the fictitious belt conveyor in

- **Case A** the specific energy requirements  $W_{spez}$  is smaller at a constant conveying speed  $v_{nenn}$  and simultaneously decreasing filling level  $\phi$ , and
- **Case B** controlling the conveying speed  $v$  reduces these requirements while the filling level  $\phi_{nenn}$  is maintained.

At the load stage with a filling level of  $\phi = 1.1$  (see column H6 in Tables 2 and 3), an increase of the conveying speed  $v$  would, however, have a more favorable effect on the specific energy requirement compared with the load increase at a constant conveying speed.

The progression of the curve, with  $v = \text{constant}$ , to the specific energy consumption, is characterized by falling to an absolute minimum, starting from the nominal operating point ( $\phi = \phi_{nenn} = 100\%$ ). At

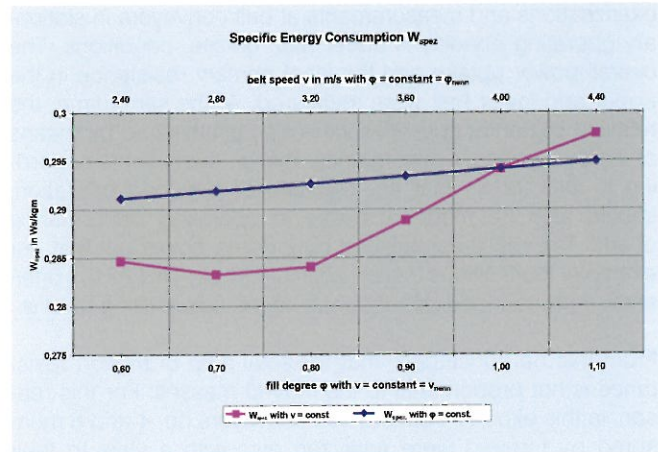


Fig. 10: Graphic illustration of the results regarding specific energy consumption of a fictitious belt conveyor

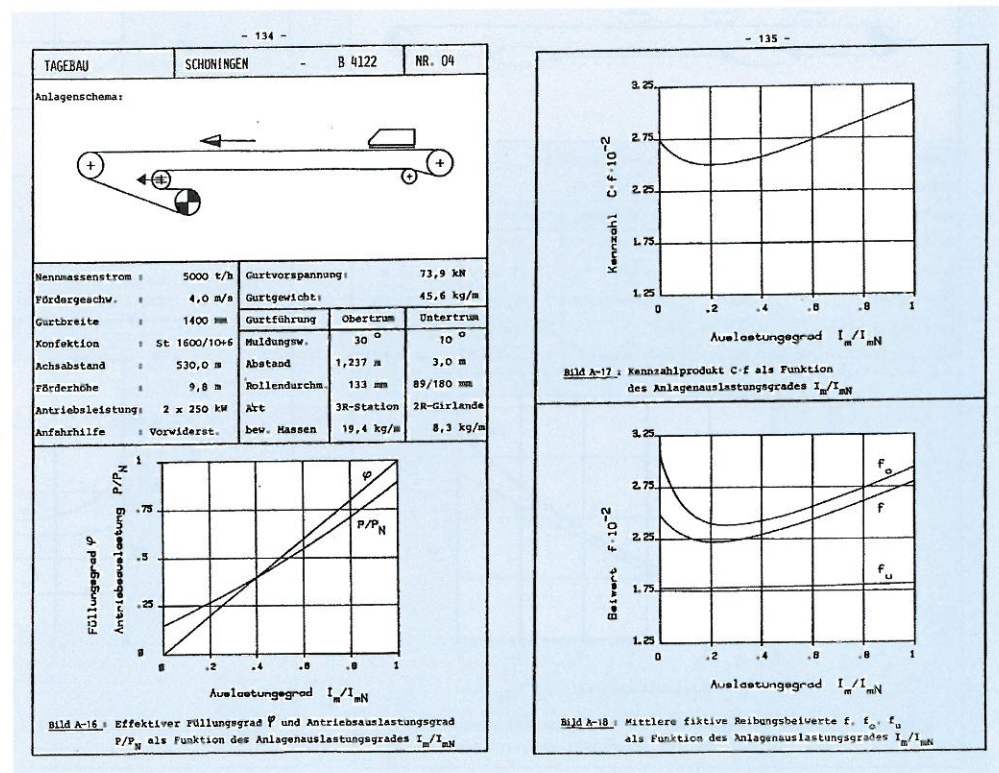
the selected simulation parameters, this minimum is at load stage  $\phi$  which is 70%. Afterwards, the specific energy requirement rises again. By comparison, the curve with  $\phi = \text{constant}$  does not fall as drastically - essentially in proportion to the lower conveying speed. This result is related to the characteristics of the indentation resistance of belt. The latter has, as explained above,

- a major share in the motion resistances with vertical conveyor tracks, and
- rises progressively in dependence on the load on the idlers.

### 5 Evaluation of the LIMBERG Thesis [21]

The result just presented is also confirmed in literature as far as its qualitative contents are concerned. LIMBERG describes

Fig. 11: Data sheet of belt conveyor no. 4 from LIMBERG [21]





examinations and measurements at belt conveyors in stationary operating conditions under real, on-site, conditions. The overall power uptake and the local primary resistance in the upper and lower belt were measured. At the same time, the relevant influence quantities were also established by means of load variations. Consequently, friction coefficients according to DIN 22101 that are relevant for part-load operation, should also be made available in operating performance charts. The result established by LIMBERG points out that, for example, the fictitious friction coefficients per DIN 22101 often show a pronounced dependence on the actual filling level  $\varphi$ .

From this he concluded, that the total sum of motion resistance is not proportional to the moved masses. For this reason, in this expert's opinion, belt conveyors no. 4 and 6 measured by LIMBERG were analyzed also with a view to their specific energy consumption  $W_{spez}$ . Measured belt conveyors no. 4 and 6 in LIMBERG's literature source were chosen, because they contain merely small or no misrepresentations as a result of gradient resistances. Further data for these belt conveyors can be seen in Fig. 11 for belt conveyor no. 4 and Fig. 17 for belt conveyor no. 6.

In performance charts, LIMBERG talks about fictitious friction coefficients per DIN 22101 for part-load areas (filling level  $\varphi$  lower than 100 %) for each of these belt conveyors (Figs. 11 and 13). For this expert statement, the aforementioned load-dependent friction coefficients have been taken from the performance charts and incorporated into the calculations of the specific energy requirement.

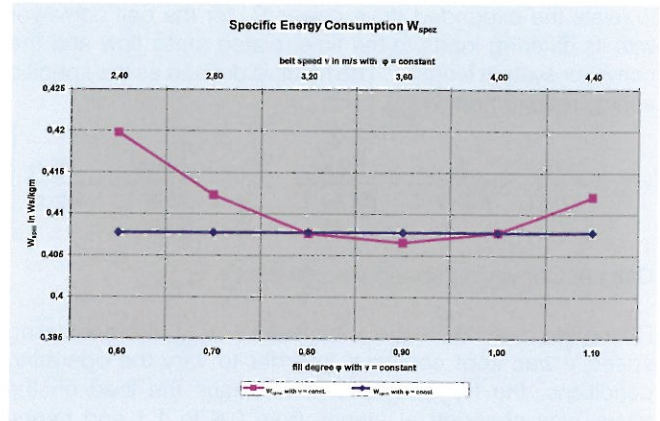
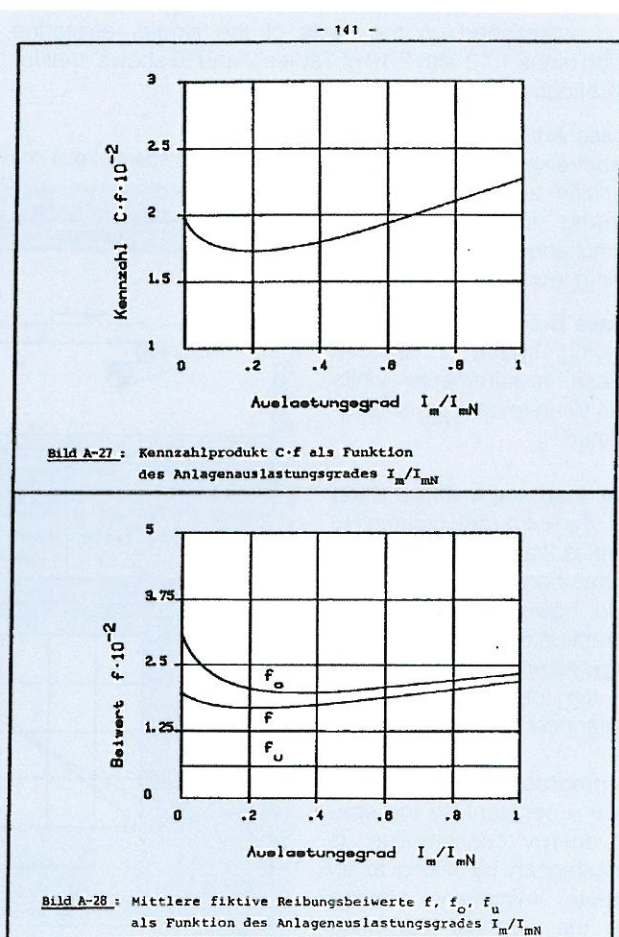
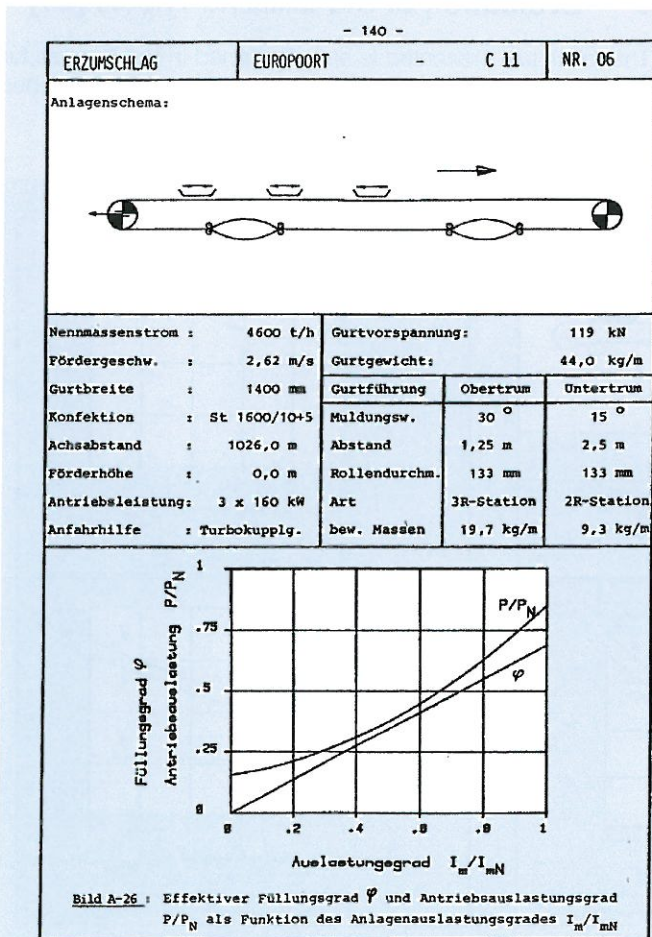


Fig. 12: Result of analysis regarding the specific energy consumption of belt conveyor no. 4 from measurements by LIMBERG [21]

The results are shown in Figs. 12 and 14. Statements that, with an assumed constant conveying speed, the specific energy requirement initially drops to a minimum in part-load areas, are also significant in this context. If the filling level decreases further, the specific energy requirement increases again.

It should also be pointed out that the specific energy requirement of belt conveyor no. 4 is noticeably higher than the specific energy requirement of belt conveyor no. 6. According to the findings of HINTZ, this result is, however, not particularly surprising. Different rubber materials for the respective cover plates can be the sole reason for this considerable difference.

Fig. 13: Data sheet of belt conveyor no. 6 from LIMBERG [21]





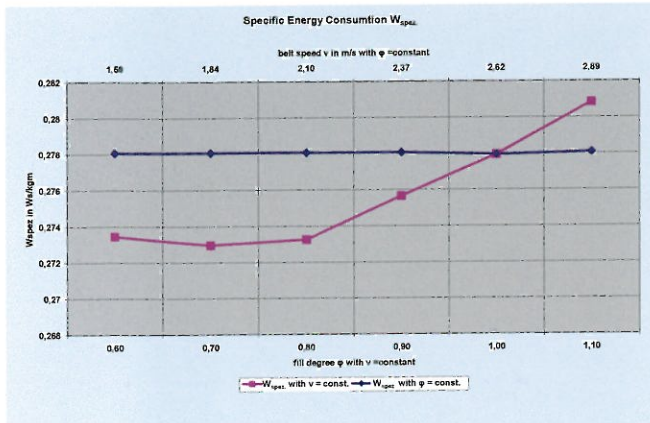


Fig. 14: Result of analysis regarding the specific energy consumption of belt conveyor no. 6 from measurements by LIMBERG [21]

All these analyzes have, however, one thing in common: with a constant conveying speed  $v$ , that means with a decreasing filling level ( $\phi$  gets smaller), the specific energy requirement reduces, while, by reducing the conveying speed  $v$ , that means controlling the conveying speed, the belt load ( $\phi = \text{constant}$ ) is maintained.

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Voith Turbo GmbH & Co. KG  
Startup Components  
Voithstraße 1  
74564 Crailsheim, Germany  
Tel. +49 79 51 32-409  
Fax +49 79 51 32-213  
[startup.components@voith.com](mailto:startup.components@voith.com)  
[voith.com/fluid-couplings](http://voith.com/fluid-couplings)

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