DOES CONTROLLING THE BELT SPEED IN ORDER TO ACHIEVE A HIGH FILLING LEVEL REALLY RESULT IN FREQUENTLY PROMISED ENERGY SAVINGS WITH BELT CONVEYORS?

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SUMMARY

In recent years, there have been repeated recommendations – mainly in German technical literature – to control the belt speed of conveyor systems /1, 2, 3/. The level of filling φ of the belt trough with φ =1 (= 100 %) shall 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 22 101 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 at a fictitious belt conveyor are used to demonstrate that the fictitious resistance coefficient of belt conveyors largely depends on the filling level φ 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 inapt in the traditional filling level ranges (0,6 ≤ φ ≤ 1,0).

1. INTRODUCTION

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

Literature source /1/ states 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 /2, 3/ 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, i. a. a filling level of φ = 1 (= 100%), the belt conveyor can also be operated if the volume flow is subject to fluctuations. In this context, literary sources /2, 3/ mention distances between axes of more than 1400 m. In its summary, literature source /4/ also suggests that more economical operation is achieved, if variable-speed drives are used for belt conveyors. In literature source /2, 3/, DIN 22 101 /5/ (draft) is used as a basis for these statements. Publications /1, 4/ do not name sources for these statements.

Against this background, I have been asked by Voith Turbo, Crailsheim, Germany, 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 φ of the belt trough is utilized with φ = 1.

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 (idlers), as well as the belt flexing 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 quantities. 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

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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 22 101 - OVERVIEW

Per DIN 22 101 /5/ motion resistances $\mathbf{F_W}$ are divided into

- Primary resistances F_H
- Secondary resistances F_N
- Gradient resistances F_{St}
- Special resistances F_S

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

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 connection** between resistances and moved load for each individual section i, determined separately in terms of **(Fig. 1)**.

$$F_{Hi} = l_i * f_i * g * [m'_{R,i} + (m'_G + m'_{L,i})]$$

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

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

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, very low) [see Fig. 1, V and VI, (6)]

The secondary resistances are independent of the length of the belt conveyor and are constant /5/. With long distances between axes, their significance declines compared to motion resistances distributed across the

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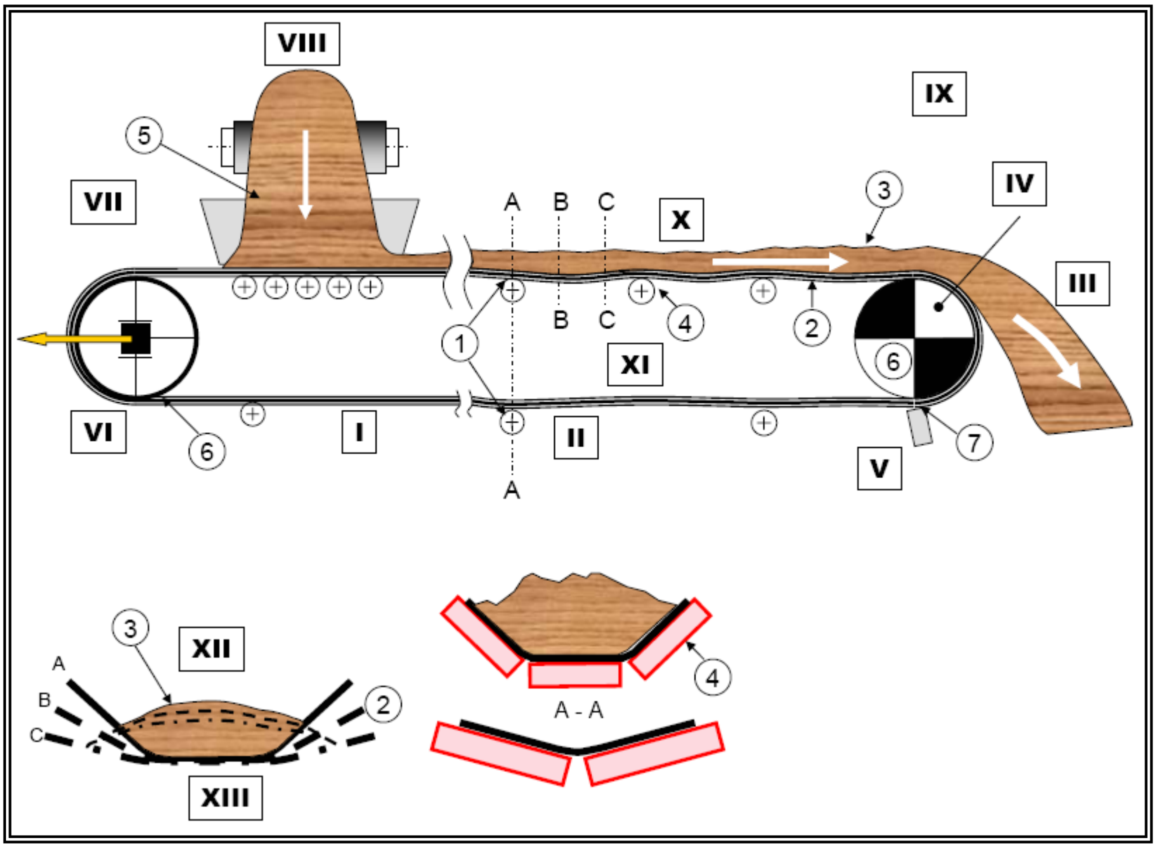

Fig. 1: Belt conveyor with existing motion resistances /9/

conveying track – the primary 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 /5/.

$$F_N = (C - 1) * F_H$$

Guide value for coefficient C with a length ≥ 1000 m: C = 1.09.

Special resistances F_S

Special resistances are resistances which do not occur with 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 materials.

Application area of der DIN 22 101

The norm DIN 22 101 covers the fundamentals for the calculation and the design of belt conveyors and 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.** Normally, for f_i, values of 0.012 to 0.035 are stated for different operating and plant parameters. For this, usually several marginal conditions are mentioned, from which these values derive.

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When carefully considering the limiting quantities and experience values, the advantage of DIN 22 101 manifests itself in a fast configuration of belt conveyor systems for adequately accurate results, i. e. it allows to establish the basic demands on important components in dependence of the existing conveying task and describes a way for **the design** of the belt conveyor. On the other hand, there is also a danger of incorrect estimations caused by a lack of definite facts regarding the operating conditions. Different belt characteristics, especially the behaviour dependent on the transport load, are not taken into consideration.

Parameters, such as fictitious **resistance coefficient f_i** und **load distribution of bulk materials m'_L,** are **assumed to be constant values** for the calculation of **the primary resistances /5/.**
However, literature source /6/ already describes that, above all, the resistance coefficient f_i is not constant. (**Fig. 2**).

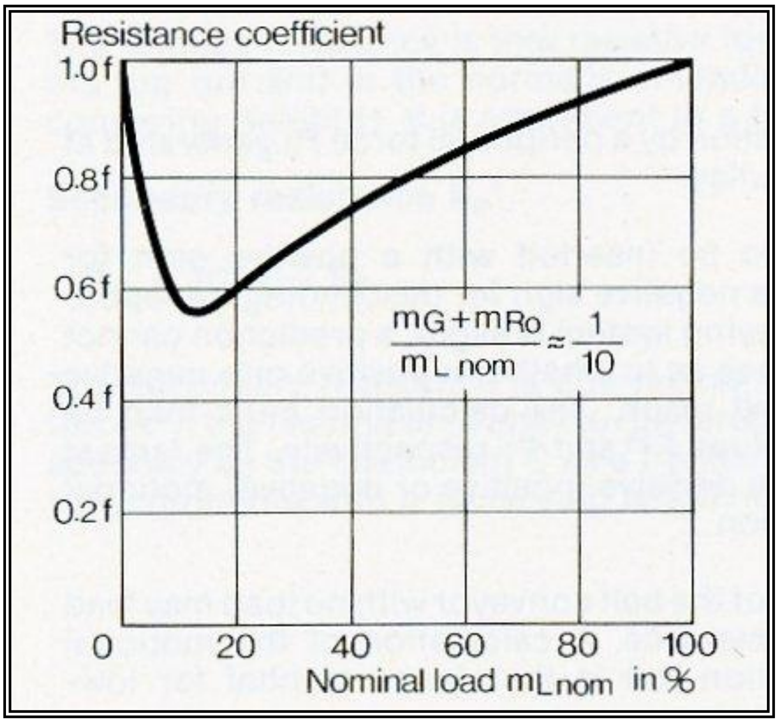

Fig. 2: Resistance coefficient f depending on load situations according to Alles /6/

Therefore, DIN 22 101 should not and cannot be used as an immediate calculation basis for fluctuating operating conditions.

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 /7/ and Vierling /8/9/ were the first to realize this method.

Primary resistance in single resistance method – overview from literature

The primary resistances F_H are divided into two groups:

U': Idler resistance of idlers [see Fig. 1, (4)]
U'': Belt flexing resistances [see Fig. 1, XII, XIII (2), (3)]

And the latter again into:

U''_E: Roll deformation resistance [see Fig. 1, (1)]

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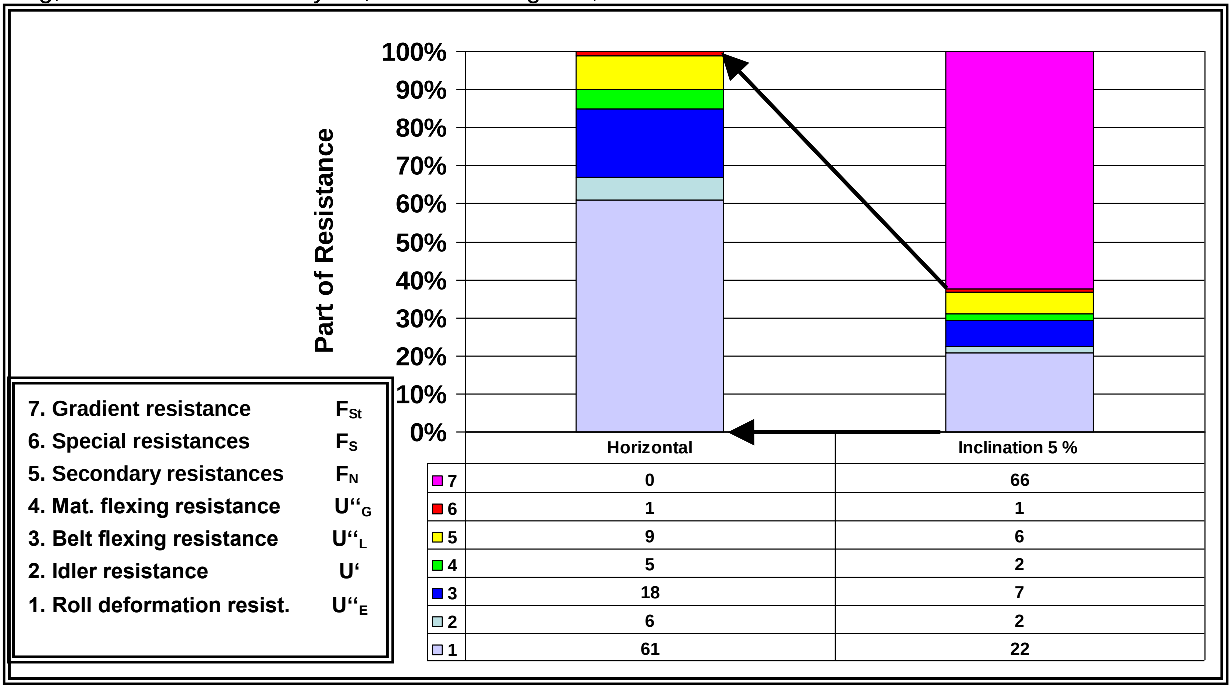
U''_G: Material flexing resistance (of belt) [see Fig. 1, XII (2)]
U''_L: Belt flexing resistance (of transport load) [see Fig. 1, XIII (3)]

The motion resistances $\mathbf{F_W}$ are therefore established as follows:

$$
\begin{aligned}
F_W = \; & F_H + F_N + F_{St} + F_S = \\
& [U' + U''] + F_N + F_{St} + F_S = \\
& [U' + (U''_E + U''_G + U''_L)] + F_N + F_{St} + F_S =
\end{aligned}
$$

During the last decades, numerous scientific works, e. g. Lachmann /7/, Schwarz /10/, Thormann /11/, Behrens /12/, Hintz /9/, Greune /13/, Geesmann /14/ have looked at this differentiation when calculating single resistances. Due to the complicated influence of constructive, technological and operating characteristics affecting the belt flexing resistance, the single resistance method for establishing the primary resistance did not gain acceptance in the past /13/. 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 22 101 /5/ (**Fig. 3**), the amounts of resistance for two equally long belt conveyors, however with different upward gradients, are shown. The data applies to long belt conveyors (axis distance in excess of 100m) /5/. The roll deformation resistance U''_E appears as the most significant resistance with long, horizontal belt conveyors, as it is the highest, friction-related motion resistance.



	Horizontal	Inclination 5 %
7	0	66
6	1	1
5	9	6
4	5	2
3	18	7
2	6	2
1	61	22

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

In this example, its share is more than 60%. The share of the material belt flexing resistance is quantified with approximately 18%, that of the material flexing resistance with 5%, that of the idler resistance 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

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- **Load dependence (= Dependence on filling level φ)**

3. Characteristic quantities with single resistances

3.1 Idler resistance U'

The idler resistance 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 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.

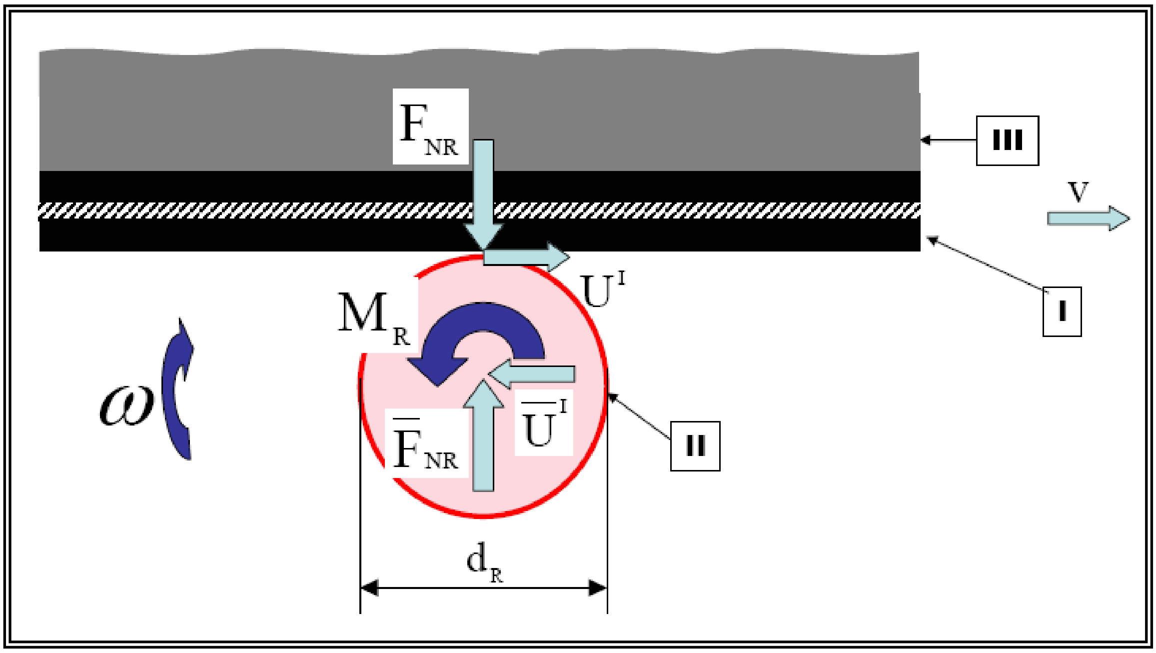

Fig. 4: Idealized illustration of force and motion conditions for defining the running resistance of the idlers /13/

There is no generally applicable formula for a simple calculation of the idler resistance. It was, however, established that the idler resistance 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 /14/. In order to make a highly accurate prognosis of the idler resistance, literature recommends measurements at the test stand. Within the framework of this expert's opinion, the formula

$$U' = a + b * v + c * F_{NR}$$

was used as a basis.

The parameters a, b and c were assumed as a constant for all evaluations and, depending on the conveying speed b and/or the load on the idlers F_{NR}, varied accordingly.
In order to establish the idler resistance of an entire idler station, the load on individual rolls in dependence on the load condition must be taken into consideration.

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3.2 BELT FLEXING RESISTANCE U''

The belt flexing resistance (with its individual components U''_E, U''_L und U''_G) is of overriding importance for long, horizontal belt conveyors. In this context, force U" which acts from the idler on the belt in opposite direction, i. e. the belt flexing resistance, corresponds to the horizontal share of the normal force F_{NR}. (**Fig. 5**) of the belt on the idler. An increase of the belt flexing resistance becomes noticeable by a change in the contact arch in the zone between idler and belt.

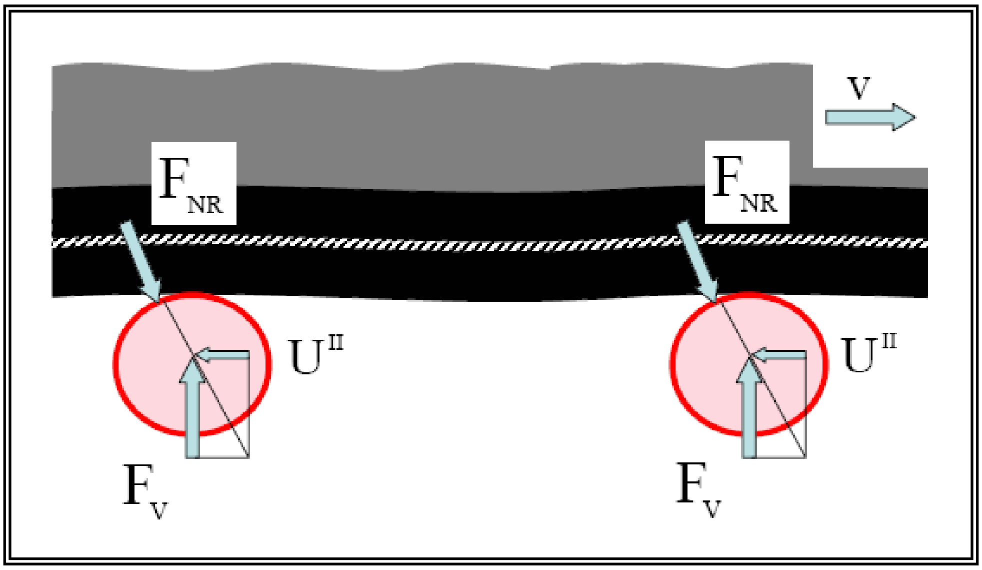

Fig. 5: Idealization of forces due to belt flexing resistance /9/

3.2.1 ROLL DEFORMATION RESISTANCE U''_E

The roll deformation resistance U''_E is generated by the rolling off of the idler on the contact side of the cover plate 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 /9/. Greune /13/ already established that the natural forces per 1m 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 roll deformation resistance and belt speed.

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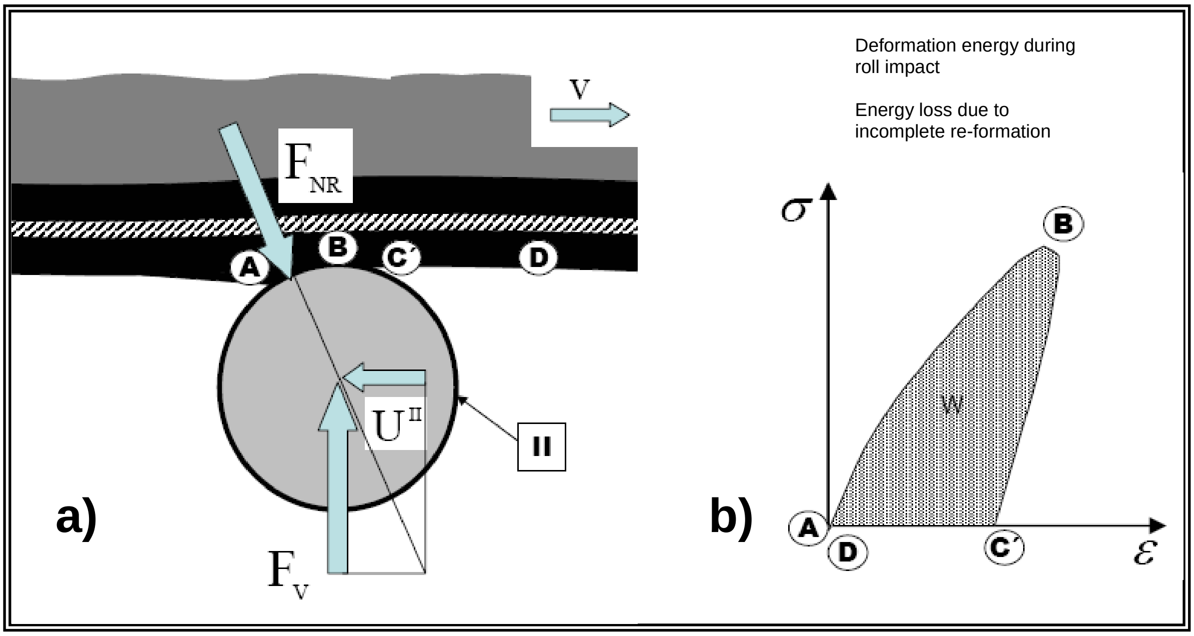

Fig. 6a and 6b: a) Idealized illustration of forces and deformation, as well as b) the deformation energy due to belt flexing resistance /9/

In literature /9/ the calculation bases for the roll deformation resistance are stated. During his research, Hintz has examined a high number of different cover plate materials. (**Fig. 7**).

The roll deformation resistance U''_E at an idler station can be calculated from the distributed load along the individual idlers. As a special case, the following formula applies to a flat belt which is impacted by an idler, without curvature and a constant load for the roll deformation resistance across the belt width:

$$U''_E = c_E * d^{-\frac{2}{3}} * F_V^{\frac{4}{3}} * b_R^{-\frac{1}{3}}$$

where

c_E : Cover plate-specific constant
d : Idler diameter
F_V : Vertical load on idlers
b_R : Contact length between idler and belt

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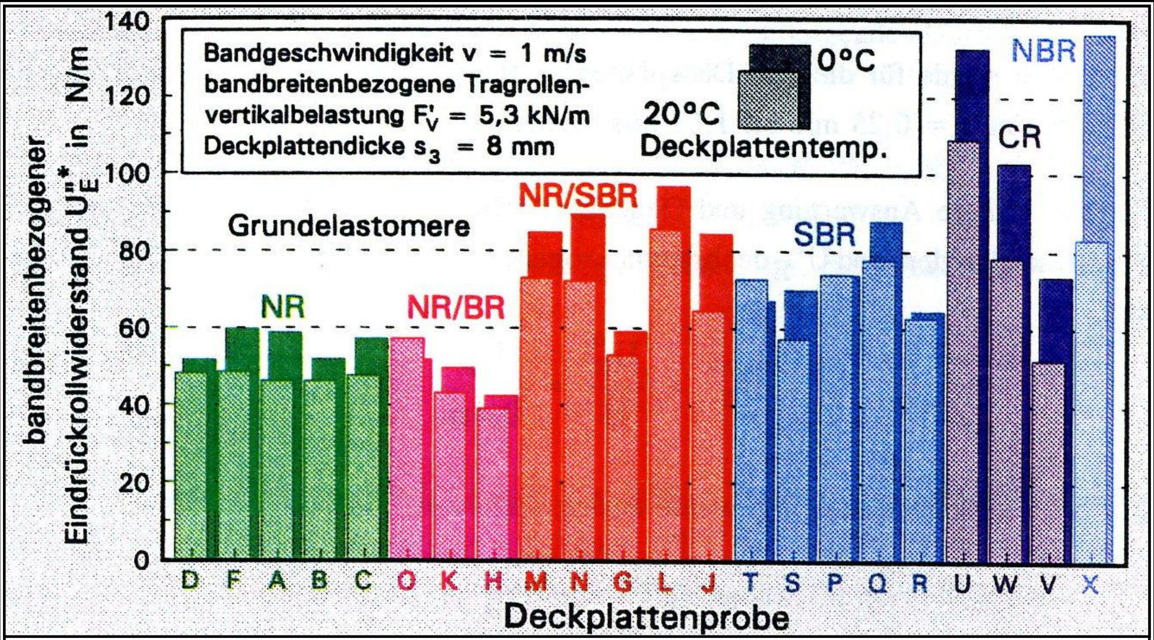

Legend:

breitenbezogener Eindrückrollwiderstand U‘‘*$_E$ = **Width-related roll deformation resistance U‘‘*$_E$**
Deckplattenprobe = **Type of cover material**
Bandgeschwindigkeit v = **Belt speed**
Vertikalbelastung F’$_V$ = **vertical force**
Deckplattendicke = **Cover gauge**
Grundelastomere = **Basic elastomers**
Deckplattentemperatur = **Temperature of the cover**

Fig. 7: Measurements of roll deformation resistance with different belt covers /9/

Analog to the fictitious friction coefficient per DIN 22 101, the formula

$$f_E = \frac{U''_E}{F_V}$$

can be regarded as a fictitious friction coefficient f_E of the roll deformation resistance /9/.
Fig. 8 shows the influence of the width-related vertical load on the width-related roll deformation resistance.

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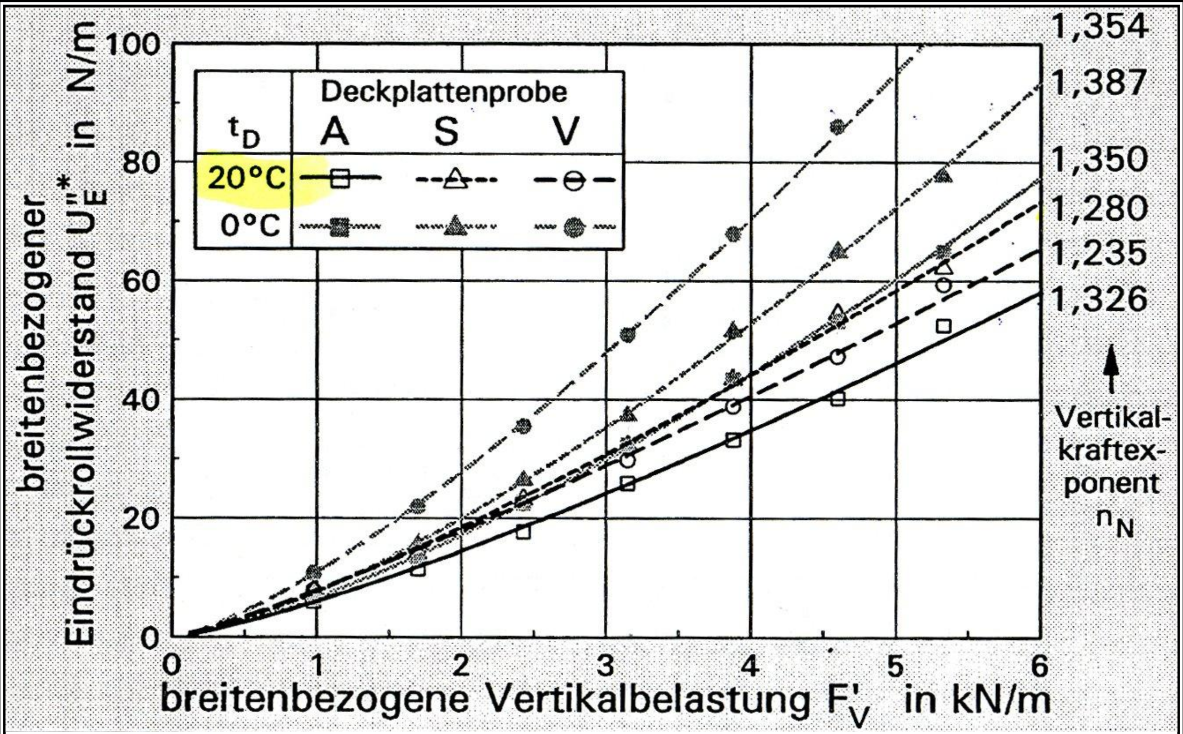

Legende:

breitenbezogene Vertikalbelastung	F'_V	= Width-related vertical load
breitenbezogener Eindrückrollwiderstand	U''_E	= Width-related roll deformation resistance
Deckplattenprobe		= Cover plate material
Vertikalkraftexponent	n_N	= Vertical force exponent

Fig. 8: Roll deformation resistance dependent on vertical load according to Hintz /9/

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:

$$U''^{*}_{E} = a * \left(F'_V\right)^{n_N}$$

for a values from 0.76 10^{-3} to 1.80 10^{-3} and for the exponent n_N values from 1.235 to 1.387. 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 roll deformation resistance with heavy systems, i. e. systems with high load distribution and load on the idlers, are more noticeable than with lighter systems /9/. During his investigations, Hintz established a rise in roll deformation resistance 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. As a permissible simplification, the load across the length of the central idler can be assumed as constant, while it is assumed as triangular across the side rolls /15/ (**Fig. 9**). In connection with the writings of Grimmer /16/, the hence identifiable natural forces of the idlers which have previously been used as a basis especially for the design of horizontal, curved belt conveyors (see Lauhoff /17, 18 and 19/) have been taken into consideration.

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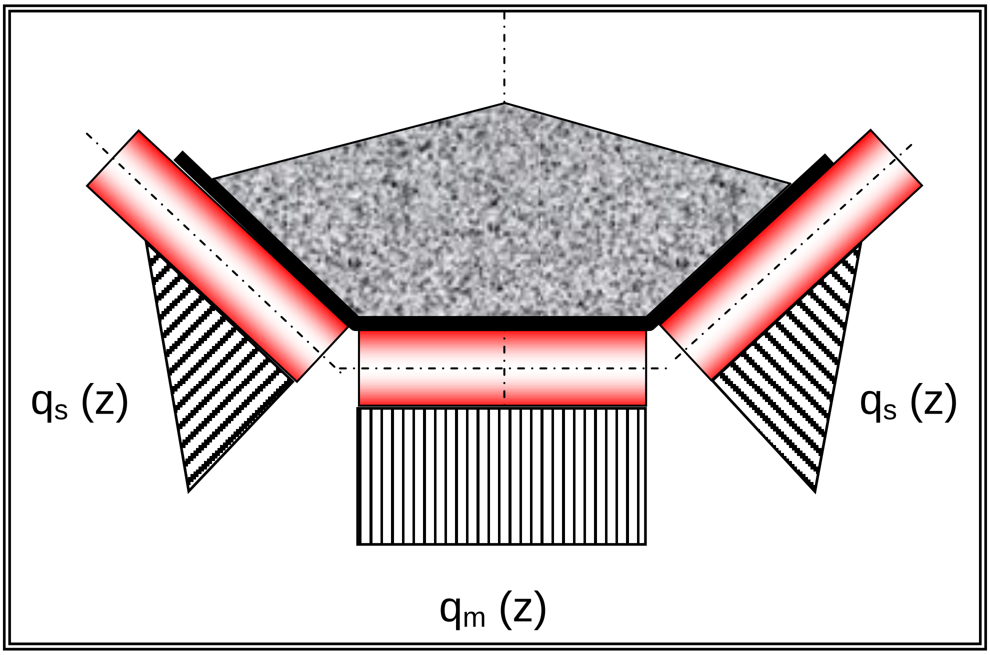

Fig. 9: Load distribution of a three-part idler station when simplified /15/

3.2.2 Material idler resistance U''_L

The material idler 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. 10**).

Literature shows similar calculatory approaches for determining the material idler resistance /13, 14/. In summary, it can be established that the material idler resistance depends on

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

The material idler resistance increases dramatically with increasing load /14/.

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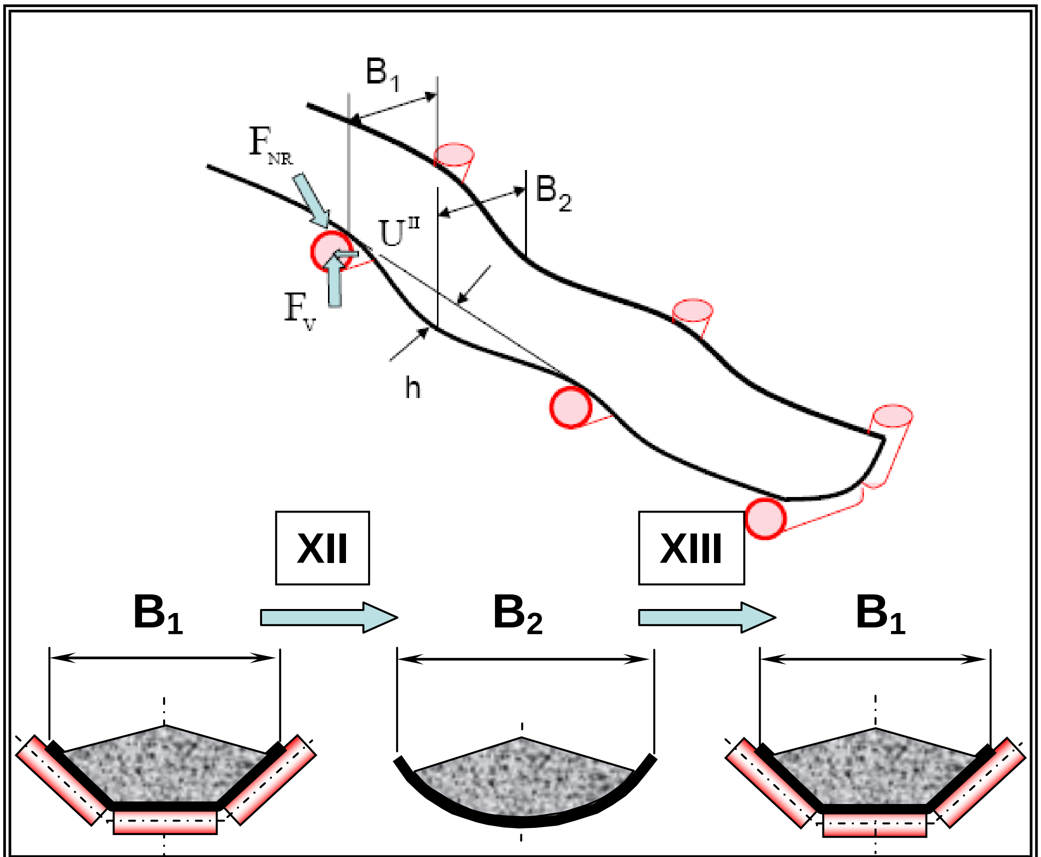

Fig. 10: Schematic illustration of loss-related changes of the belt and material profile between idler stations

3.2.3 Material flexing resistance U''_G

The material flexing resistance is the flexing loss of the conveyor belt, i. e. internal friction in the traction carriers (Zugtraeger ??) and the rubber cover plates with any change of the belt profile (see Fig. 1, 10).

A with the material idler resistance, literature agrees widely that there is a high dependency of the material flexing 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 material flexing resistance /14/. The influence of the conveying speed is regarded as low or even neglected. There are significant differences between St-belts and woven belts.

An expert evaluation of the material flexing resistance and the material idler resistance was carried out with the following equation:

$$U''_L + U''_G = k_{LG} \left(m'_G + m'_L \right) * g * l^2 * T^{-1}$$

The constant k_{LG}, the belt pulling force T and the length-related belt mass m'_G were all used in identical quantities. Depending on the simulated observation, the length-related belt load g m'_L was varied.

4.0 EVALUATION OF LITERATURE – ASSESSMENT USING A CALCULATION EXAMPLE BY MEANS OF THE SPECIFIC ENERGY CONSUMPTION

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In order to provide 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.

No.	Formula quantity	Symbol	Unit	Value
1.	(nominal) Degree of fill	φ_{nenn}		1
2.	Belt with	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	ρ	kg/m³	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	λ	°	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	m²	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

Fig. 11: Parameters of a fictitious belt conveyor for simulation calculations

Instead, it was perfectly sufficient, deriving from a fictitious nominal mass flow of a fictitious belt conveyor with a filling level of von φ_{nenn} = 1 and a belt speed of v = v_{nenn} ,

- to (fictitiously) reduce the material flow (mass flow) in such a way

and

- to assume it of being the same size, that on the one hand

Case A:

- the filling level φ reduces and the conveying speed v v_{nenn} = constant

and on the other hand

Case B:

- the filling level φ = constant = 1 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; the applied identically in all simulations. For the simulation calculations the parameters shown in **Fig. 11** 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.

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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 v as:

$$P_W = F_W * v \qquad \text{in} \qquad W \text{bzw.} kW$$

From a dimensional point of view, the result is expressed in Watt or Kilowatt (W or kW) aus. The amount of money to be paid to the energy suppliers is, however, for the amount of energy used over a certain period, i. e. the actual work. The dimension is kW h. In order to compare and evaluate the simulation results, it was therefore more practical, to relate the expended drive power P_W for the belt conveyor with its differing loads to the time-related mass flow $\dot{m}$ and the conveyor system length L. The result is defined as the specific energy requirement W_{spez} /20/.

$$W_{spez} = \frac{P_W}{\dot{m} * L} = \frac{P_W}{m'_L * v * L} = \frac{F_W * v}{m'_L * v * L} \quad ; \text{Betrachtung der Einheit:} \quad \frac{W}{\frac{kg}{s} * m} = \frac{W * s}{kg * m}$$

***Conveying speed v = constant = v_{nenn}* (Case A)**

During the evaluation of **v = constant = v_{nenn}** the conveying speed v = v_{nenn} constant was maintained. In order to vary the operating conditions, the filling level φ, i. e. the load on the idlers, was changed at stages 0,6; 0,7; 0,8; 0,9; 1,0 und 1,1 and hence reduced.

	No.				H.1	H.2	H.3	H.4	H.5	H.6
Calculation simulation with: v = constant = v_{nenn}; Filling level φ is reduced	1.1	**Load stage:**	**$φ_{fiktiv}$**		**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: $φ_{fiktiv}$ = $φ_{sim}$**	**$φ_{sim}$**		**0,6**	**0,7**	**0,8**	**0,9**	**1**	**1,1**
	1.5	**Load distribution due to bulk material type**	**m'_{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	m³/s	0,291	0,340	0,388	0,437	0,485	0,534
	1.7	**Conveying speed**	**v_{nenn}**	**m/s**	**4,00**	**4,00**	**4,00**	**4,00**	**4,00**	**4,00**
	1.8	Power requirement per DIN 22101: $P_W = F_W * v$	(DIN) P_W	kW	178	196	215	233	251	269

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	1.9	Specific energy consumption (DIN 22101 - conditions)	(DIN) W_{spez}	Ws/kgm	0,348	0,328	0,314	0,303	0,294	0,287
	1.10	**Specific energy consumption (single resistance method)**	$\mathbf{W_{spez}}$	**Ws/kgm**	**0,285**	**0,283**	**0,284**	**0,289**	**0,294**	**0,298**

Fig. 12: Case A – Evaluation of speed v = constant = v_{nenn}

Filling level φ = constant = φ_{nenn} **(Case B)**
For the evaluation φ = constant, the filling level φ, i. e. the load on the idlers, has been maintained. In order to vary the operating conditions, the conveying speed v was adapted in the stages . 2,4; 2,8; 3,2; 3,6; 4,0 and 4,4 m/s. Depending on the simulation (columns H 1 to H 6 of Figs. 12 and 13) the same mass flow was used as a basis (lines 1.3 and 2.3 of Fig. 12 and 13).

Comparison of simulation results
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 Figs. 12 and 13) shows, that at the fictitious belt conveyor

- the specific energy requirements W_{spez} is smaller

for **Case A**

- at a constant conveying speed v_{nenn} and simultaneously decreasing filling level φ

and for Case B

- that controlling the conveying speed v reduces these requirements while the filling level φ_{nenn} is maintained.

	No.				H.1	H.2	H.3	H.4	H.5	H.6
Calculation simulation with: φ = constant = φ_{nenn}; Conveying speed v is reduced	**2.1**	**Load stage:**	φ_{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**	φ_{sim}		**1**	**1**	**1**	**1**	**1**	**1**
	2.5	**Load distribution due to bulk material type**	m'_{Lsim}	**kg/m**	**194**	**194**	**194**	**194**	**194**	**194**
	2.6	Volume flow at above filling level	I_v	m³/s	0,291	0,340	0,388	0,437	0,485	0,534

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	2.7	**Conveying speed with: v = I_V * φ_{fiktiv} / A**	**v_{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 * v	(DIN) P_W	kW	151	176	201	226	251	276
	2.9	Specific energy consumption (DIN 22101 -conditions)	(DIN) W_{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_{spez}**	**Ws/kg m**	**0,291**	**0,292**	**0,293**	**0,293**	**0,294**	**0,295**

Fig. 13: Case B – Evaluation of filling level φ = constant= φ_{nenn}

At the load stage with a filling level of φ = 1,1 (see column H.6 in Figs. 12 und 13), 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.

A summary of the results simulated by calculations is shown in the graph in **Fig. 14** . The progression of the curve, with v = constant, to the specific energy consumption, is characterized by falling to an absolute minimum, starting from the nominal operating point (φ = φ_{nenn} = 1). At the selected simulation parameters, this minimum is at load stage φ = 0,7. Afterwards, the specific energy requirement rises again. By comparison, the curve with φ = constant does not fall as drastically – essentially in proportion to the lower conveying speed. This result is related to the characteristics of the roll deformation resistance. 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.

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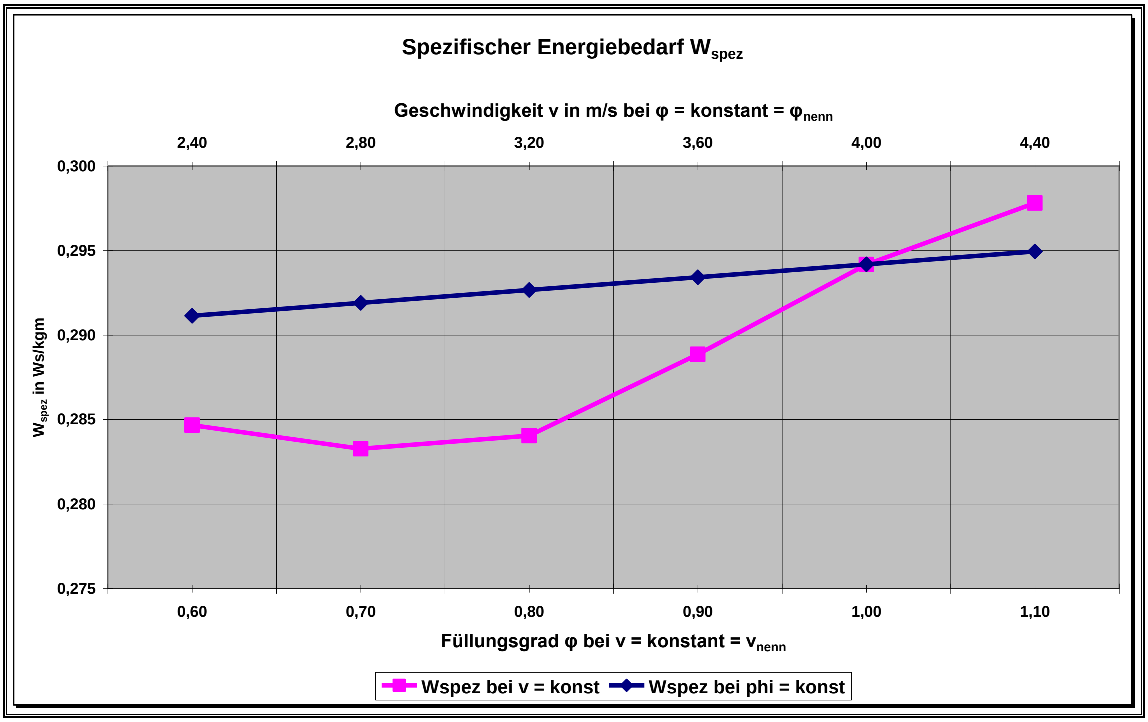

Fig. 14: Graphic illustration of the results regarding specific energy consumption of a fictitious belt conveyor

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 /21/ describes 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 (return) belt were measured. At the same time, the relevant influence quantities were also established by means of load variations. Consequently, friction coefficients per DIN 22 101 that are relevant for part-load operation, should also be made available in operating performance charts /21/. The result established by Limberg points out that, for example, the fictitious friction coefficients per DIN 22 101 often show a pronounced dependence on the actual filling level φ.
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 literature source /21/ were chosen, because they contain merely small or no misrepresentations as a result of gradient resistances. Moreover, their conveying track is also longer than 1000 m. Further data for these belt conveyors can be seen in Fig. 15 for belt conveyor no. 4 and Fig. 17 for belt conveyor no. 6.

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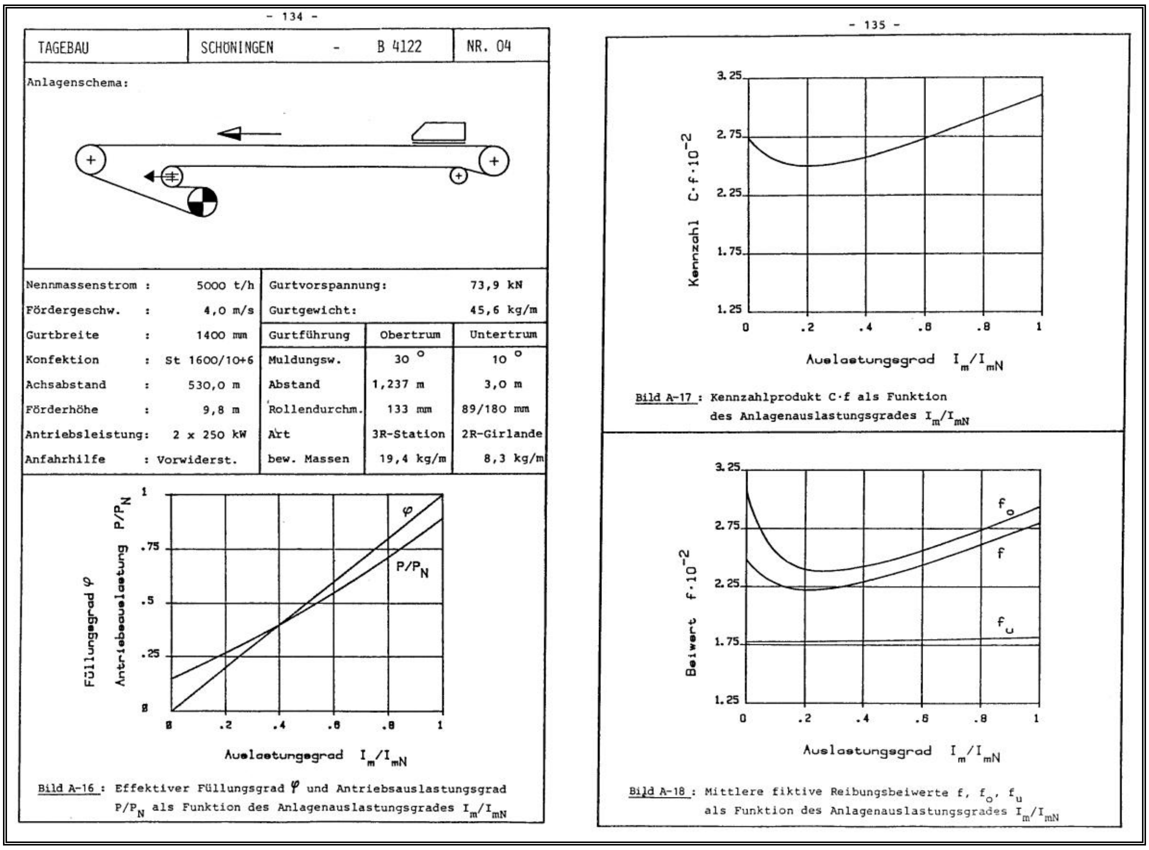

Fig. 15: Data sheet of belt conveyor no. 4 from Limberg /21/

In performance charts, Limberg talks about fictitious friction coefficients per DIN 22 101 for part-load areas (filling levels φ lower than 1) for each of these belt conveyors (Figs. 15 and 17). 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.

The results are shown in the following. 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 /9/, this result is, however, not particularly surprising. Different rubber materials for the respective cover plates can be the sole reason for this considerable difference.

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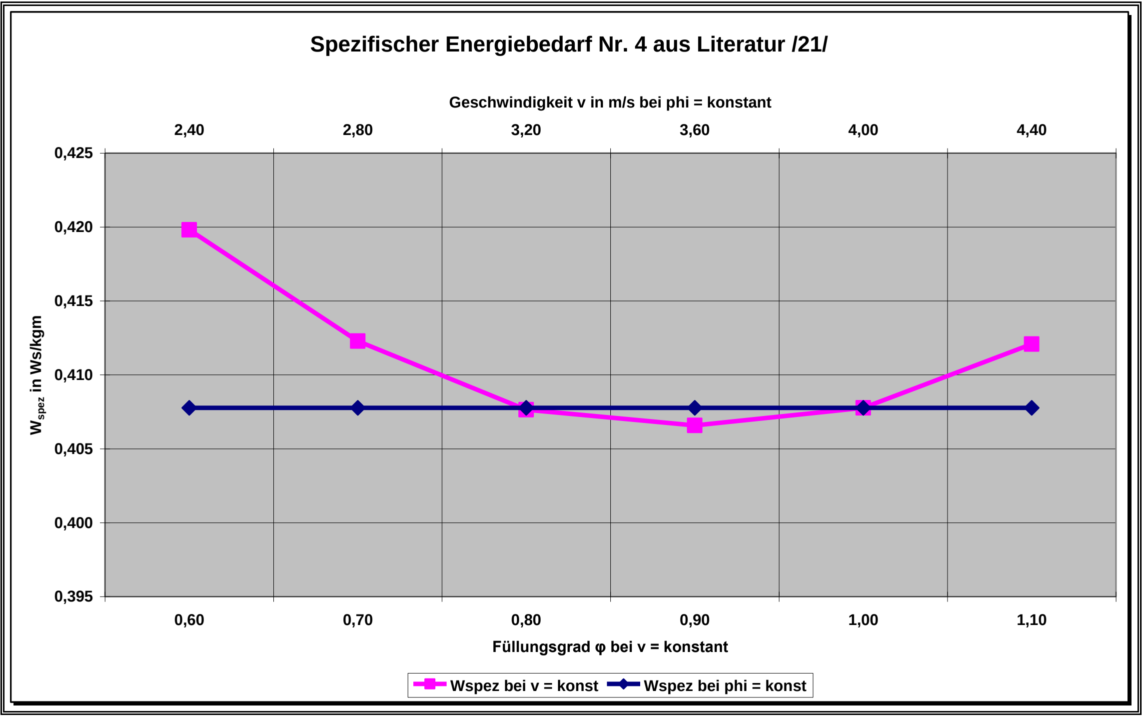

Fig. 16: Result of analysis regarding the specific energy consumption of belt conveyor no. 4 from measurements by Limberg /21/

All these analyses have, however, one thing in common: with a constant conveying speed v, i. e. with a decreasing filling level (φ gets smaller), the specific energy requirement reduces, while, by reducing the conveying speed v, i. e. controlling the conveying speed, the belt load (φ = constant) is maintained.

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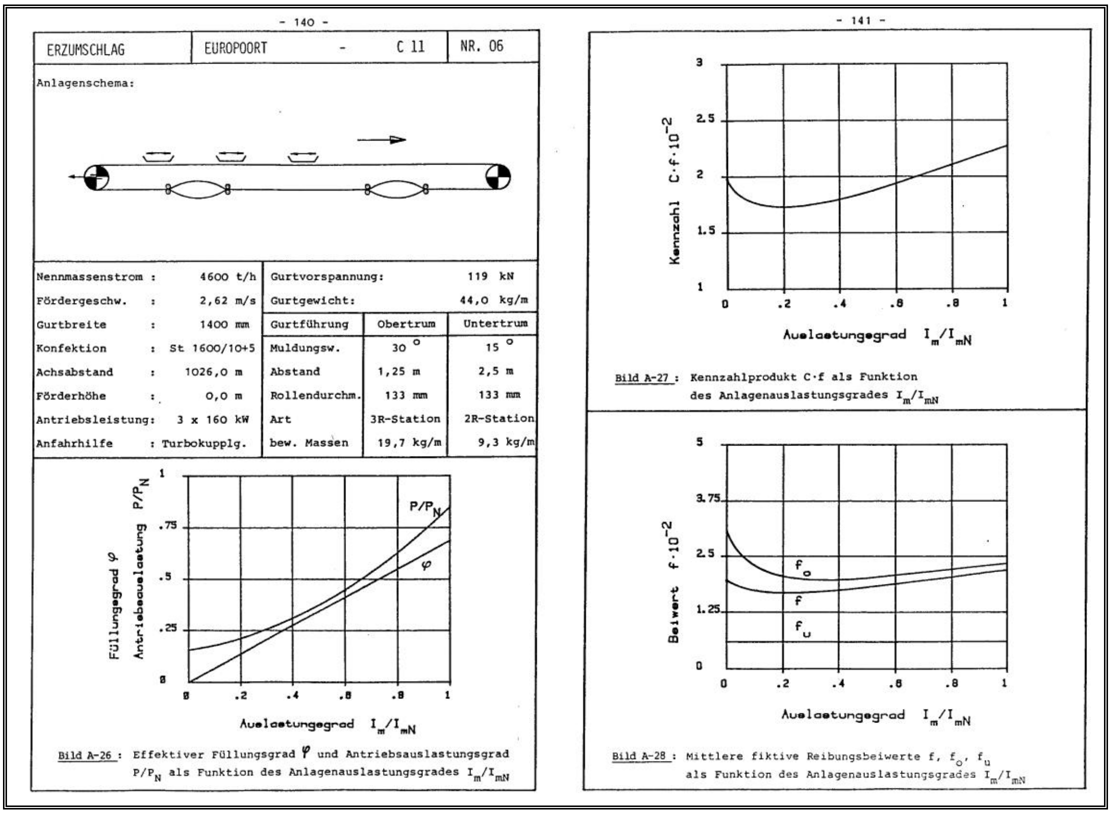

Fig. 17: Data sheet of belt conveyor no. 6 from Limberg /21/

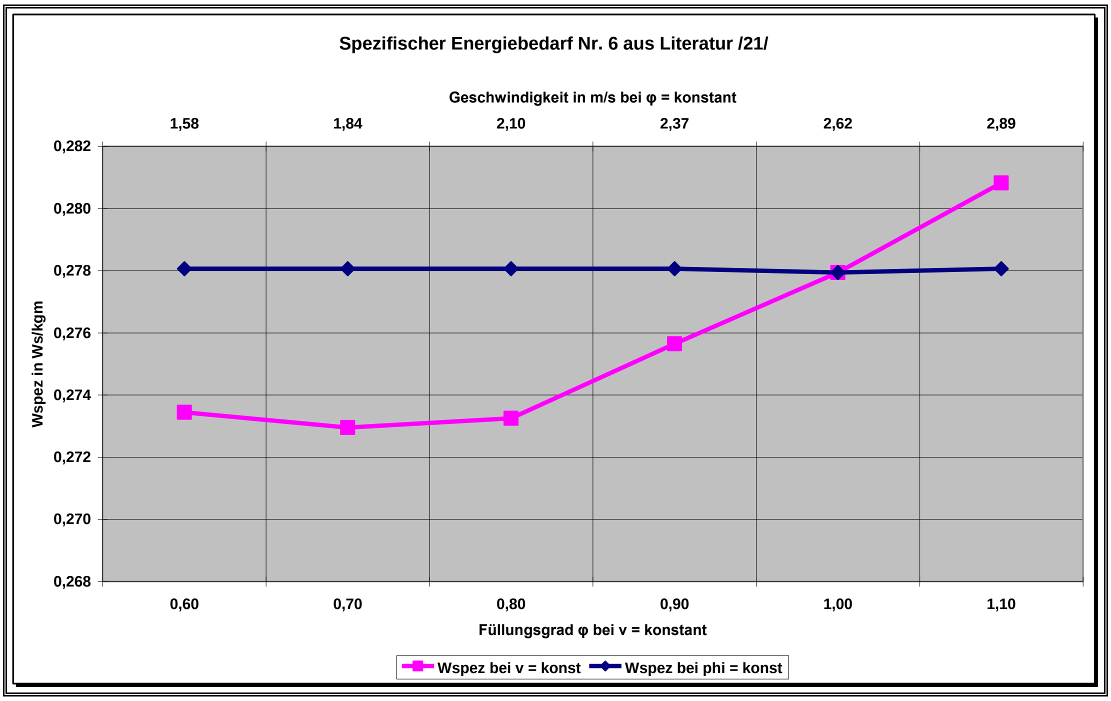

Fig. 18: Result of analysis regarding the specific energy consumption of belt conveyor no. 6 from measurements by Limberg /21/

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