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Design of Belt Conveyors with
Horizontal Curves in Special Consideration
of the Belt Speed

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BELTCON 5

1. CONCLUSION

It is shown that virtually all theoretical, experimental and empirical experiences concerning "normal" belt conveyors can be used for designing belt conveyors with horizontal curves and non-positive guide control systems.

When determining the guide force in the horizontal curve, it must be taken into consideration that the guide force component decreases with increasing belt speed, due to friction.

When taking this fact into consideration it is possible to design belt conveyors with horizontal curves to operate safely at conveying speeds, if the conveying speed differs from presently existing plants.

2. Introduction

The use of belt conveyors with curves has been the subject of various publications. These reports also included a large number of special constructions guaranteeing the curve-going ability by means of positive restricted guide elements and the use of special belts. This type of belt conveyors with additional supporting rolls, rails and special belt profiles have proved to be unecomomical compared to straight "normal" belt conveyors, especially due to relatively high specific wear of belts with positive restricted guide systems. These publications also include reports on tests with standard belts equipped with lateral deflection rollers to achieve horizontal curve-going ability. The results are not satisfactory due to constant contact between the deflection rollers and the belt. Steady belt control over a long period is not possible if the belt edges are supported by lateral guide rollers in the curve section as the belt buckles and starts creeping at the rollers. This causes premature destruction of the belt, especially on the edges.

In contrast to this, troughed belt conveyors with non-positive guide mechanism, designed with horizontal curves, have given excellent results.
Various types of belt conveyors with horizointal curves and non-positive guide mechanism are compiled in illustration 1

Lfd.-Nr. No.	Baujahr Year of construction	Kunde / Anlage Customer / System	Gesamtlänge Total length m	Höhe Height m	Fördergutstrom Material flow t/h	Gurtbreite Belt width mm	Gurtgeschw. Belt speed m/s	Kurvenradius Curve radius m	Kurvenlänge Curve length m	%	Antriebsleist. Drive capacity kW	Fördergut Material	Bemerkungen Remarks
1	1971	Holderbank, Rekingen, Schweiz, Switzerland	704	-65	500	800	2,3	1400	604	86	75	Kalkstein limestone	
2	1973	Kali-Chemie, Stade, BRD, FRG	850	13,5	200	650	1,78	1400	304	36	55	Kalisalz potash salts	
3	1977	Nordcement Hardegsen, BRD, FRG	719	-37,1	800	1000	2,1	1400	216	30	30	Kalkstein limestone	Verlängerung als Horizontalkurve extension as horizontal curve
4	1975	Kali + Salz, Wintershall, BRD, FRG	1232	187	800	1000	3,35	1400	514	42	3 x 200	Kalisalz potash salt	
4a	1982	Kali + Salz, Wintershall, BRD, FRG	1232	187	1100	1000	3,35	1400	514	42	4 x 200	Kalisalz potash salts	Leistungserhöh. increase in capacity
5	1978/79	Anneliese, Ennigerloh, BRD, FRG	231	0	siehe Bemerkungen see remarks	650	0,63	3000	180	78	11	50kg Zementsäcke cement bags	2000 St. / h uni ts/h
6	1983	Quelle, Nürnberg/Fürth BRD, FRG	1156	9	siehe Bemerkungen see remarks	1200	0,8 1,6	775 2000 1300	229 123 116	31	45	Pakete packages	20000 St / h uni ts/h
7	1985	Krupp, National Cement USA	3385	17	750	800	2,9	1800 1200 1200 1200	722 428 350 970	73	3 x 132	Kalkstein limestone	
8	1987	KHD Gemeinschaftskraftwerk, Hannover, BRD, FRG	230	0	800	1400	2	2000	218	95	55	Kohle coal	

Illustration 1: Belt conveyors with horizontal curves and non-positive guide mechanism

It was proved that these belt conveyors with horizontal curves can be operated without any problems and are reliable for decades.

3. FUNCTIONAL PRINCIPLE OF BELT CONVEYORS WITH HORIZONTAL CURVES

The belt conveyors in question concern "normal" troughed belt conveyors with convex- and/or concave curves and also additional horizontal curves. The advantages achievable by horizontal curves are, for example, described in Reference 1.

A horizontal curve R in a belt section and the active forces are illustrated in illustration 2 in order to explain the functional principle.

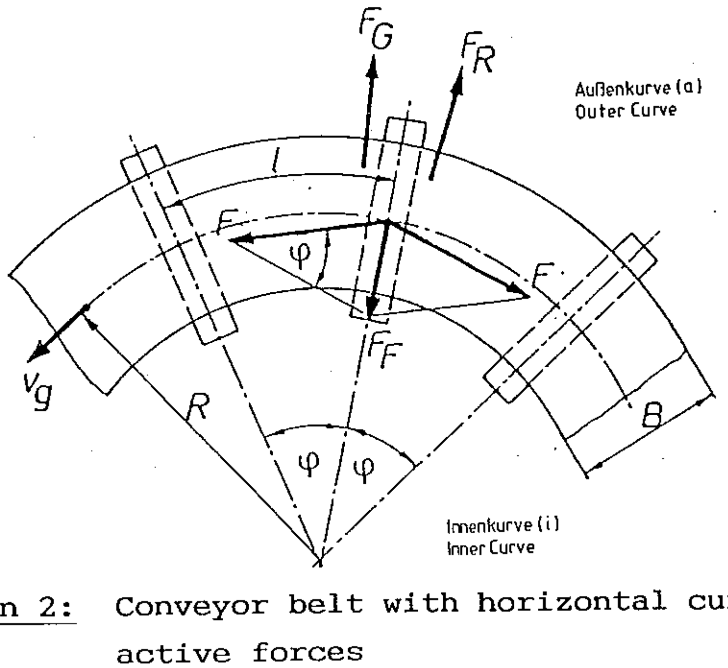


Illustration 2: Conveyor belt with horizontal curves, active forces

The locally active belt tension force F generates component F_F acting towards the inner curve. Futhermore, force F_G and F_R must act torwards the outer curve. F_G and F_R are to be described as the (non-positive) belt guide forces.

F_G is the force component as a function of the belt weight and the conveying weight.
F_R is the force component as a function of the friction between the support rollers and the belt.

Component F_G as a function of the belt weight and the conveying weight is produced by off-centred belts, by lateral drifting of the belt and/or by cambering the entire support roller assembly on the inside of the curve (see cross section, illustration 3).

Component F_R is a result of friction between the belt and tilted support rollers (see topview, illustration 3).

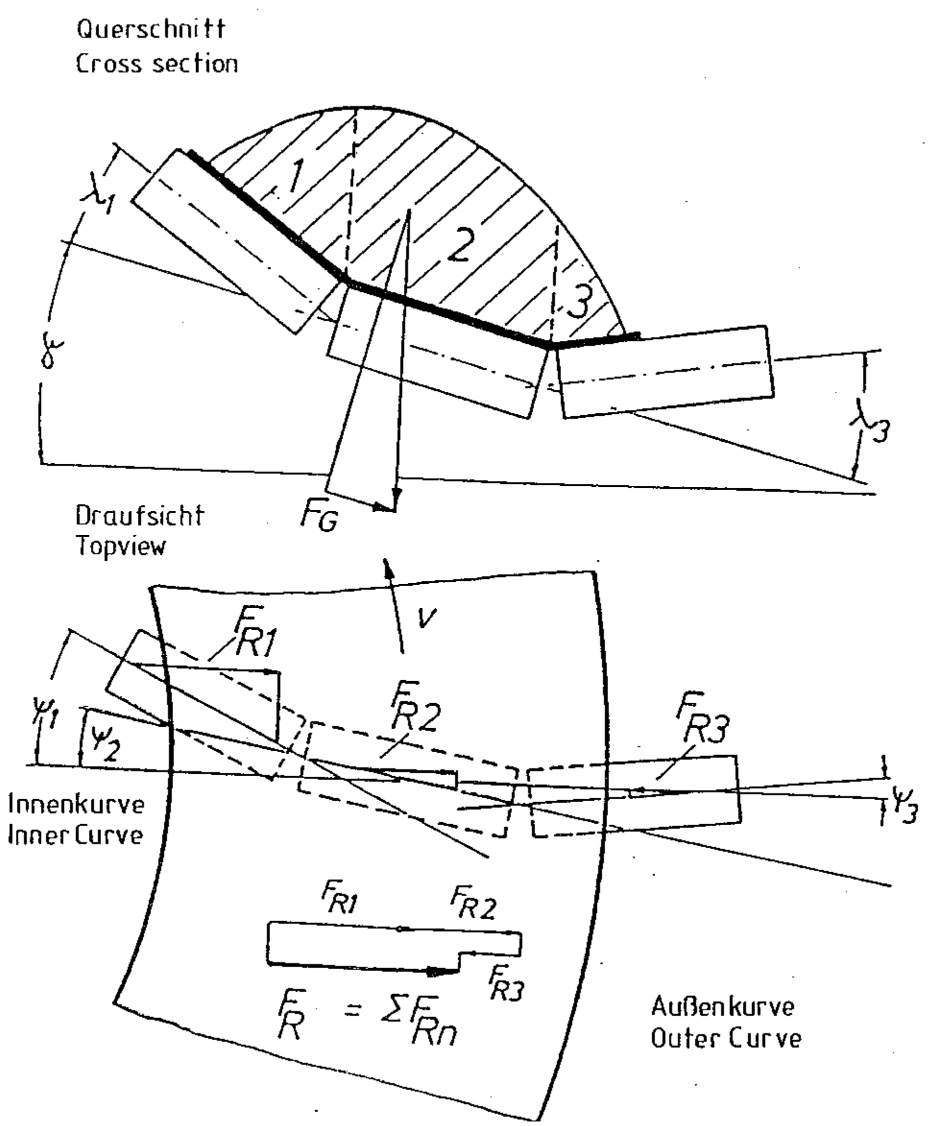


Illustration 3: Cross sectional view and topview cambered 3-partite support roller assembly with tilted support rollers

Perfect belt control is alweays guaranteed if - in case of lateral drifting of the belt in the through of the carrying rollers in extreme positions - on the inner and outer curve - the forces directed towards the centre of the trough predominate, as this is the only solution to prevent the belt from drifting away from the trough of the carrying rollers.

The respective extreme belt positions on the inner and outer curve of the trough of the carrying roller must therefore always meet the following inequation. It is supposed that the forces towards the outer curve (a) are positiv and the forces towards the inner curved (1) are negative.

$$F_F + F_{Gi} + F_{Ri} \geq 0$$

$$F_F + F_{Ga} + F_{Ra} \leq 0$$

It is only possible to meet this requirements if guide forces F_G and F_F decreases from the inner to the outer curve, should the belt drift within the support roller assembly.

The physical conditions make it possible to meet the inequation for a belt in the trough of the carrier roller, with or without load and with tilted carrier rollers. For further explanations, please refer, for example, to Reference 2.

4. (EQUILIBRUM-) FORCES IN A HORIZONTAL CURVE IN SPECIAL CONSIDERATION OF THE BELT SPEED

4.1 Locally active belt tension

The above shows that belt conveyors with horizontal curves are in fact "normal" belt conveyos. All investigations and empirical experiences concerning "normal" belt conveyors can therefore be used to determine locally active belt tensions for various operating conditions of a belt conveyor (e.g. operating continuously without load, operating continuously with load, starting). According to illustration 2, the m i n i m u m and m a x i m u m belt tension for any position in the horizontal curve must be known as this is vital for a stable position of the belt in the trough of the carrying rollers.

The locally active belt tension F is calculated with the help of the kinetic resistances. The kinetic resistance of a belt conveyor in relation to the conveying belt comprises the sum of all forces required to overcome drive forces, frictionally transmitted between the drive drum and conveying belt while the plant is stationary, i.e. the sum of locally acting individual resistances is essential to determine the required drive power.

The so-called "individual resistance method" (EWV) according to **Vierling** or the "fixed method" as per DIN 22101 is used to determine the kinetic resistance in the top and bottom rollers by adding up all resistances. The locally acting belt tension

$$F = f\ (F_H + F_N + F_S + F_{St})$$

is calculated by adding the main resistances F_H, secondary resistances F_N, special resistances F_S and inclination resistances F_{ST}. A breakdown of all resistances in the top and bottom rollers over the conveying distance is given in illustration 4.

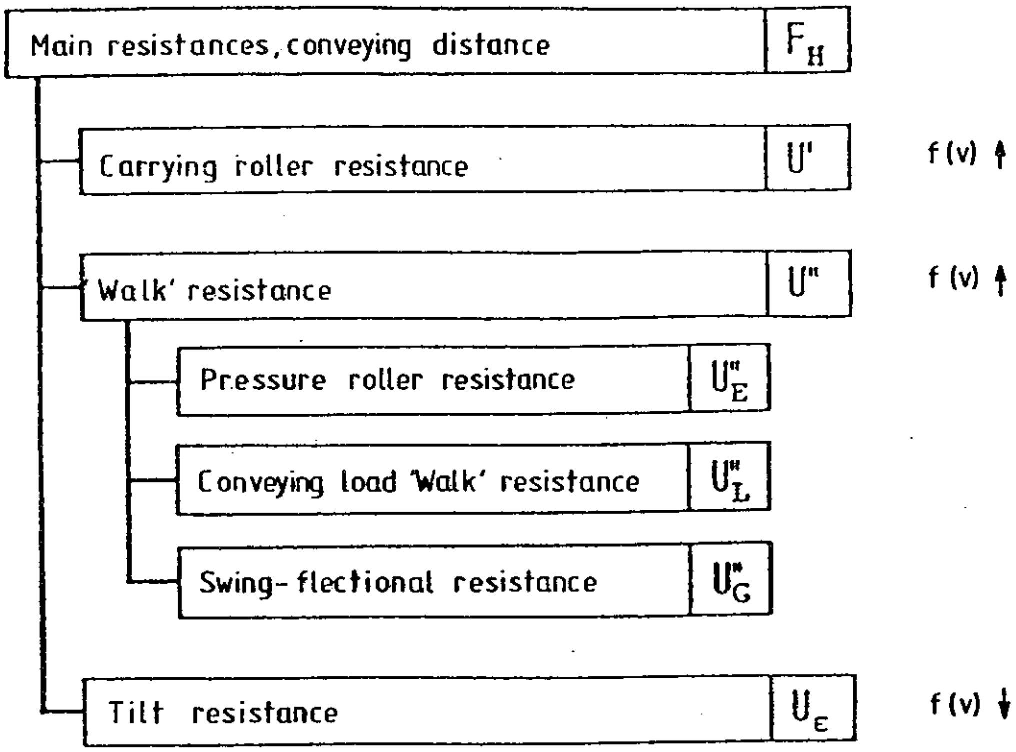


Illustration 4: Main resistances (Ref. 3)

Secondary resistances of belt conveyors, described as locally active defined kinetic resistances, are shown in illustration 5, only the most important resistant components are included in this diagram.

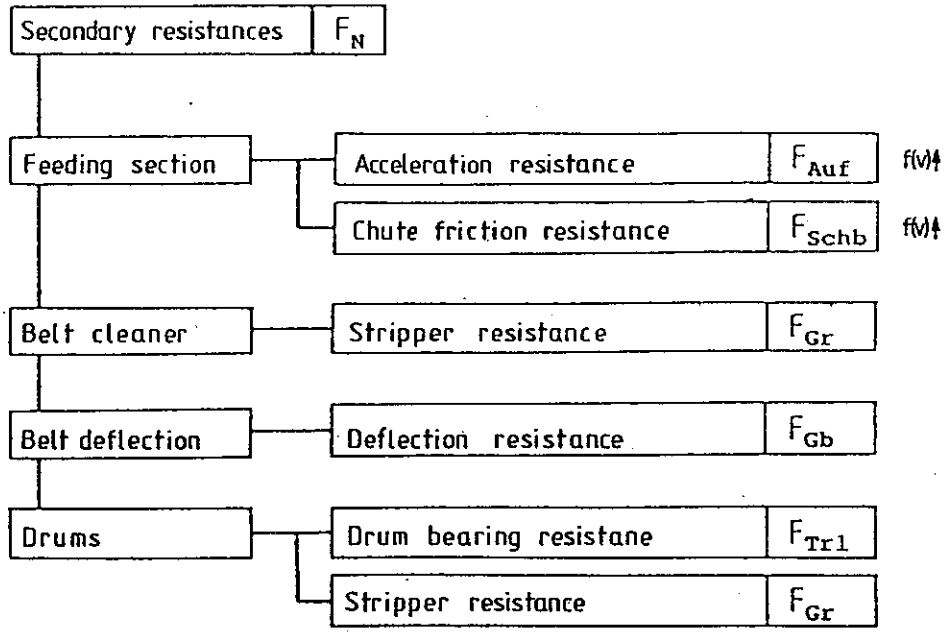


Illustration 5: The most important secondary resistances

Secondary resistances are generally only encountered in specially designed belt conveyors. E.g. when calculating section of belt conveyors with relatively short horizontal curves in relation to the overall length, the tilt-friction resistances are considered as secondary resistances.

The slope resistance takes into consideration the geodetic level difference and depends on the incline of the line. It takes a certain special position when calculating individual resistances.

Individual main and secondary resistance components, shown in detail in illustration 4 and 5 are marked with f (v), indicating that these components are influenced by the belt speed. As a rule, a high conveying speed also means higher values for individual components under otherwise identical conditions. The tilt resistance, however, will drop due to the fact that a drop in the friction resistance U is experienced - under otherwise constant conditions, as well be shown furtheron. For a detailed description and explanation of the calculation method in accordance with the "individual resistance method" we refer to Ref. 3.

Determining the total amount of main resistances in accordance with DIN 22101 is less complicated i.e. by taking into consideration a fictitious coefficient of friction f, analog to Columb's law of friction. When using the standard value as per DIN 22101 for the main resistance coefficient value f a small f-value should be selected at lower speed and a large f-value for higher speeds, apart from other criteria. Please refer to DIN 22101 for further details.

Please refer to Ref. 3 with regard to practical advise concerning f-values for certain belt speeds.

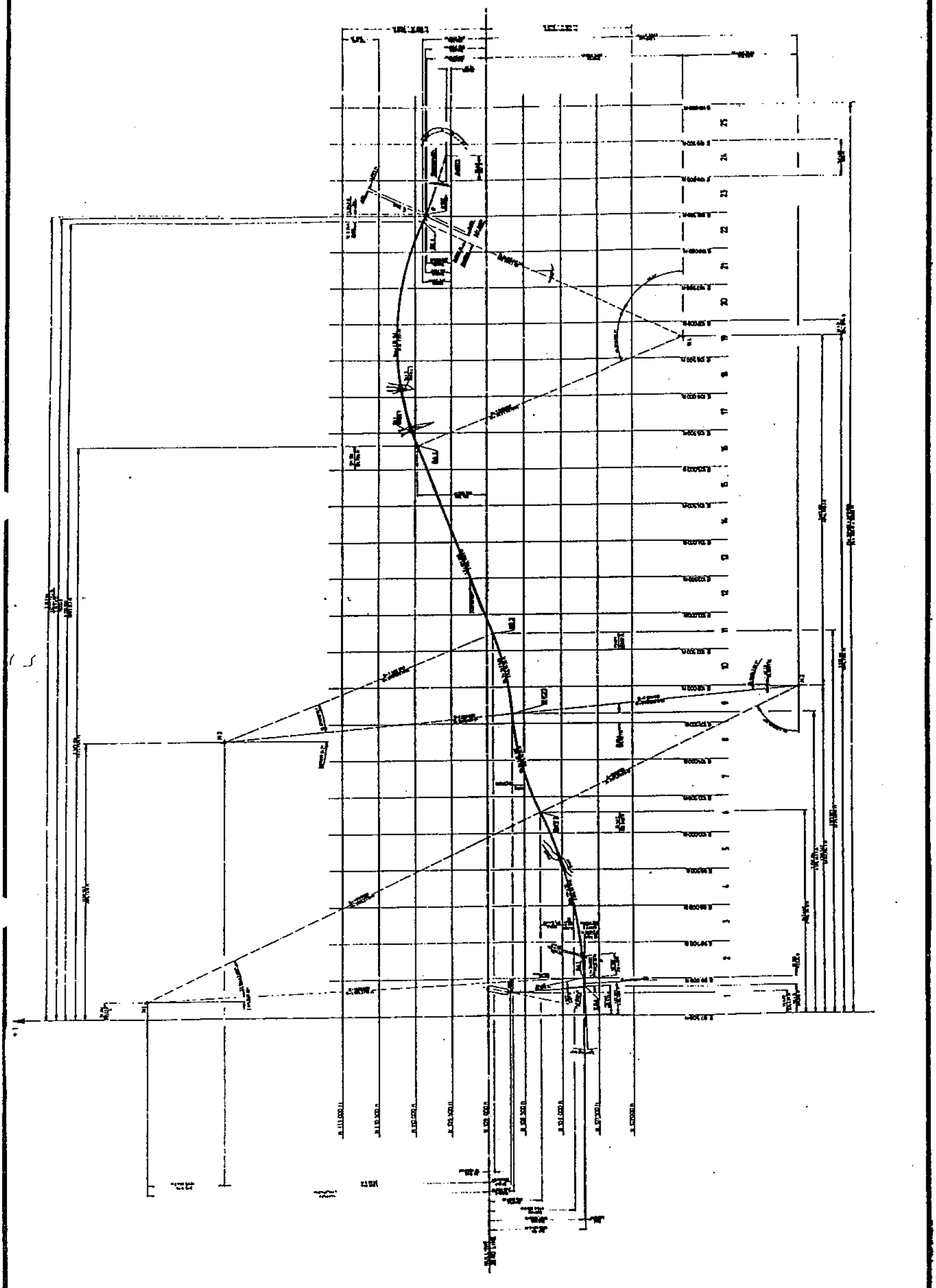
I would like to emphasize at this point my main objective is not to explain in detail existing calculation methods to determine locally active belt tensile forces - this is explained in more detail elsewhere. My main objective is to show in an overall picture that the belt speed must be taken into consideration when designing a belt conveyor with horizontal curves, how this can be taken into consideration and that a design, based on thorough knowledges, is possible.

In this respect I would like to state that calculation methods are available to calculate locally active belt tensile forces for belt conveyors with horizontal curves - with non-positive belt guiding devices - with the same accuracy as applicable to belt conveyors without horizontal curves.

The fact that these calculation methods give actually accurate results is established by on-site investigations, I would like to refer to investigations conducted at the University of Hannover by Könneker K. and Limberg H. in the course of dissertations (Ref. 3 and Ref. 4). These investigations also contain instructions according to which it is possible to obtain right from the beginning more exact results taking the characteristics of the installation into consideration.

The fact that these calculation methods can be used for belt conveyors with horizontal curves and give accurate results can be established indirectly by measuring existing plants.

For example, a belt conveyor with horizontal curves by NATIONAL CEMENT COMPANY (NNC), RAGLAND ALABAMA/USA, - and also plant no. 7 in illustration 1 - was measured. Illustration 6 shows the layout of the plant.

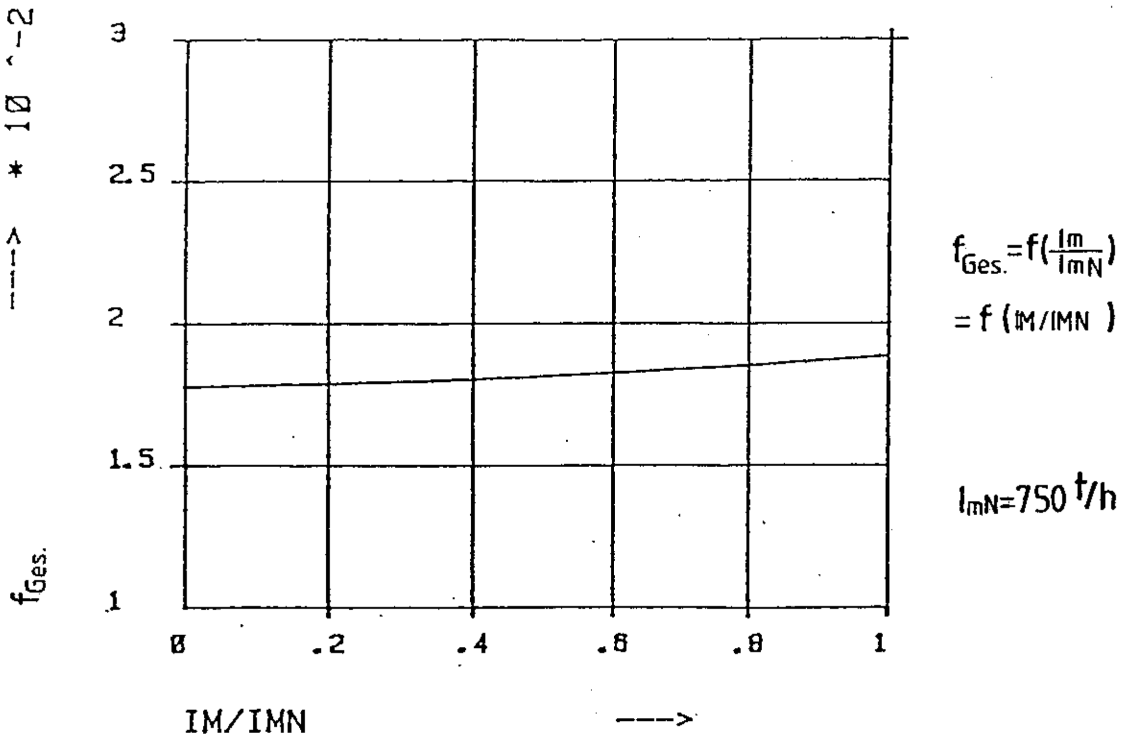


BEUMER

Bild 6: Linienführung der Anlage NCC-Ragland (Beumer)
Layout of the plant NCC-Ragland (Beumer)

These investigations were conducted during the course of a reseach project, financed by the Engineering and Rubber Industry and the Arbeitsgemeinschaft Industrieller Forschungsvereinigungen (Study Group for Industrial Reseach) via the Reseach Curatorium for Mechanical Engineering of VDMA (Association of the German Engineerung Industry), whereby on-site investigations were made possible and were financed by Messr. Beumer, Continental Gummiwerke und Messr. Krupp and undertaken by the University of Hannover and the Institute for Materials-handling Technology and Mining Equipment.

As one of the results of these on-site investigations the characteristic-product C x f was determined. Together with the mathematically determination of locally active secondary and special resistances, it was thus possible to divide the characteristic-product C x f into main resistance coefficient f and the secondary resistant coefficient C.
The fictitious friction coefficient f defined as per DIN 22101, for the top and bottom rollers in dependence on the rate of utilisation of the belt conveyor is illustrated in illustration 7.



<u>Illustration 7:</u> Mean fictitious friction coefficient for both, top and bottom rollers, based on on-site measurements for the Ragland (USA) plant.

The result of these measurements correspond well to DIN 22101.

4.2 Guide forces in the horizontal curve

As already mentioned, component F_F as a result of the local belt tensile force F must be opposed by guide forces F_G and F_R - acting towards the outer curve. Determining these guide forces is a second essential presupposition when designing belt conveyors with horizontal curves.

Quite a number of theoretical investigations were undertaken, which made it possible to determine these guide forces. We would like to refer at this point to a publication by GRIMMER - BEUMER published in 1972 (Ref. 2). These calculation methode were improved and verified by further theorectical, experimental and practical experiences.

As already mentioned, horizontal guide forces depend on the belt weight and conveying load, lateral drifting of the belt from the central position and the resulting off-center belt-load and/or by cambering the entire support roller assembly on the inside of the curve.

More recent investigations have shown that the guide force component as a result of the belt weight, occuring parallel to the lateral carrying roller, generates a guide force which is considerably larger than previously assumed.

The same effect was observed with regards to the conveying load component (Ref. 5).

The guide force component consisting of belt and conveying load do not depend on the belt speed.

However, this does not apply to the guide force component on account of tilted carrying rollers. Firstly, the following linear relation applies:

$$F_R = \mu \times F_N$$

whereby F_N stands for the carrying roller load. With increasing belt speed, however, the friction coefficient μ between belt and carrying roller decreases. The principle behaviour pattern is shown in illustration 8.

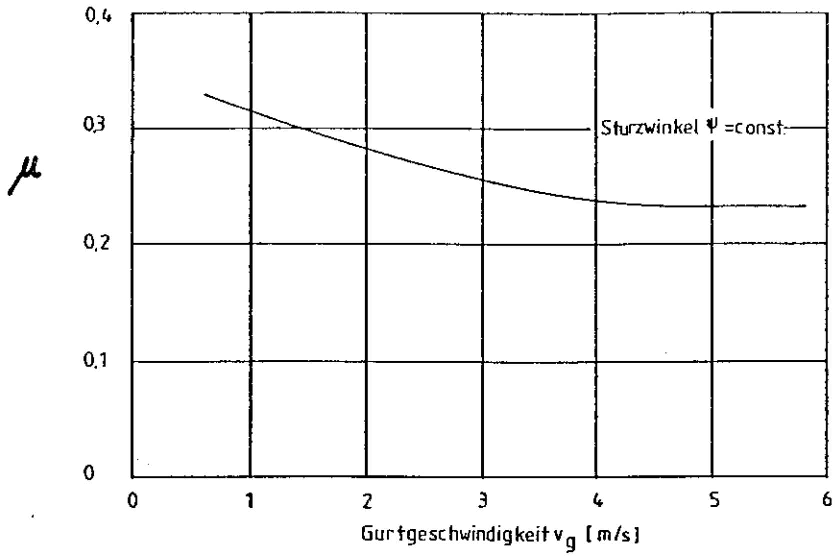


Illustration 8: Principle behaviour pattern of the fictitious friction coefficient between belt and carrying roller depending on the belt speed at fixed tilting angle.

The fictitious friction coefficient μ drops more within the section between 0.5 and 3 m/sec. compared to the section between 3 and 5 m/sec.

The changing friction coefficient μ can, for example, be adjusted by varying the admissible lateral drifting of the belt in the trough of the carrying rollers. This will either increase or decrease the guide of force component on account of the belt weight.

REFERENCES

Reference 1 Lauhoff, H.

Belt conveyors with horizontal curves - A key to decrease costs for material transport ZKG no. 4, 1987

Reference 2 Grimmer, K.-J, Beumer B.

Design and operation of belt conveyors with curves, with normal belts - Fördern und Heben 22 (1972) Nr. 4, Pages 104 - 112 and 174 - 179.

Reference 3 Limberg, H.

Investigations regarding roller-related kinetic resistances of belt conveyors. Diss. 1988, University Hannover

Reference 4 Koenneker, K.

Investigations to determine the power requirement of belt conveyors. Diss. 1984, University Hannover.

Reference 5 Grimmer, K.J., Kassler, F.

Special considerations concerning belt guidance for belt conveyors with horizontal curves, Berg- und Huettenmaennische Monatshefte, Vol. 6 1987.

Photo 1: No. 7 of illustration 1
Plant Ragland, USA
without belt

Enclosure

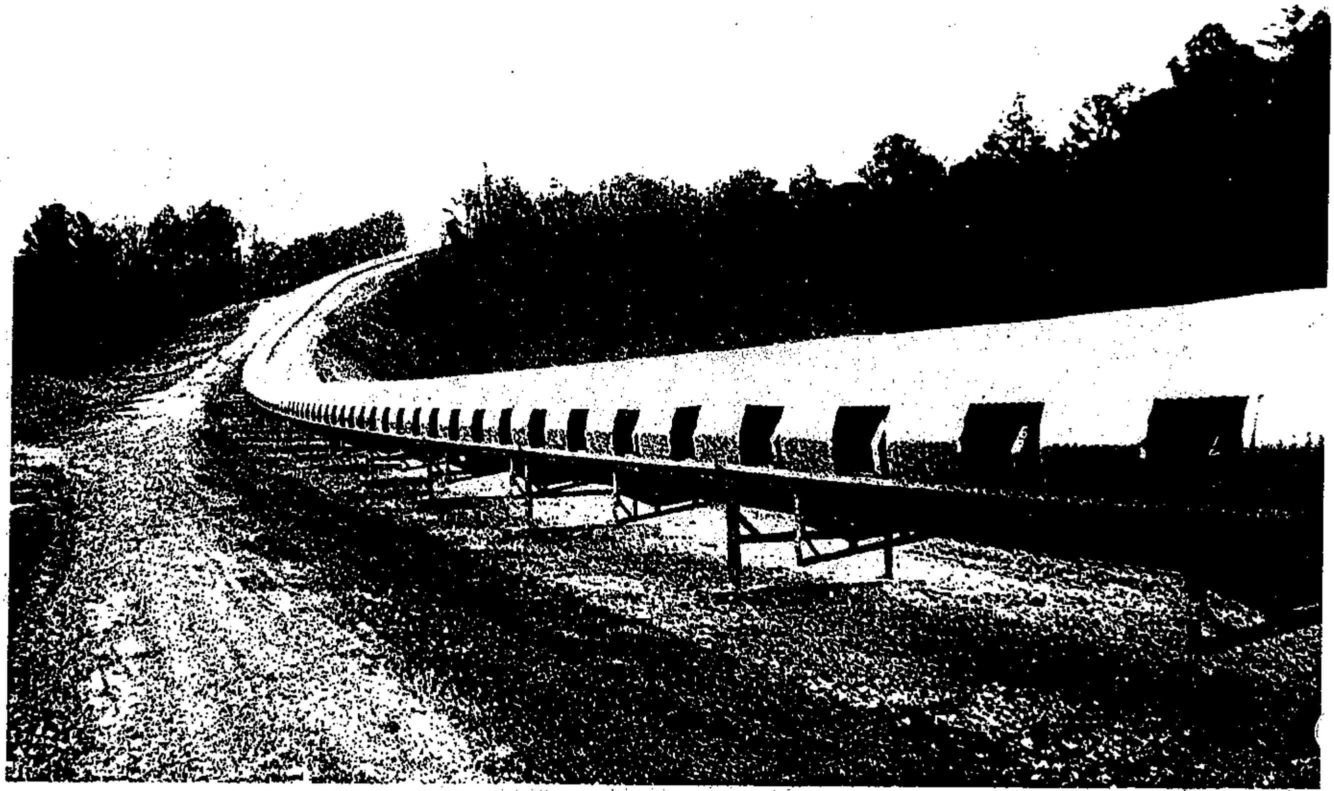


Photo 2: No. 7 of illustration 1
Plant Ragland, USA
ready for operation

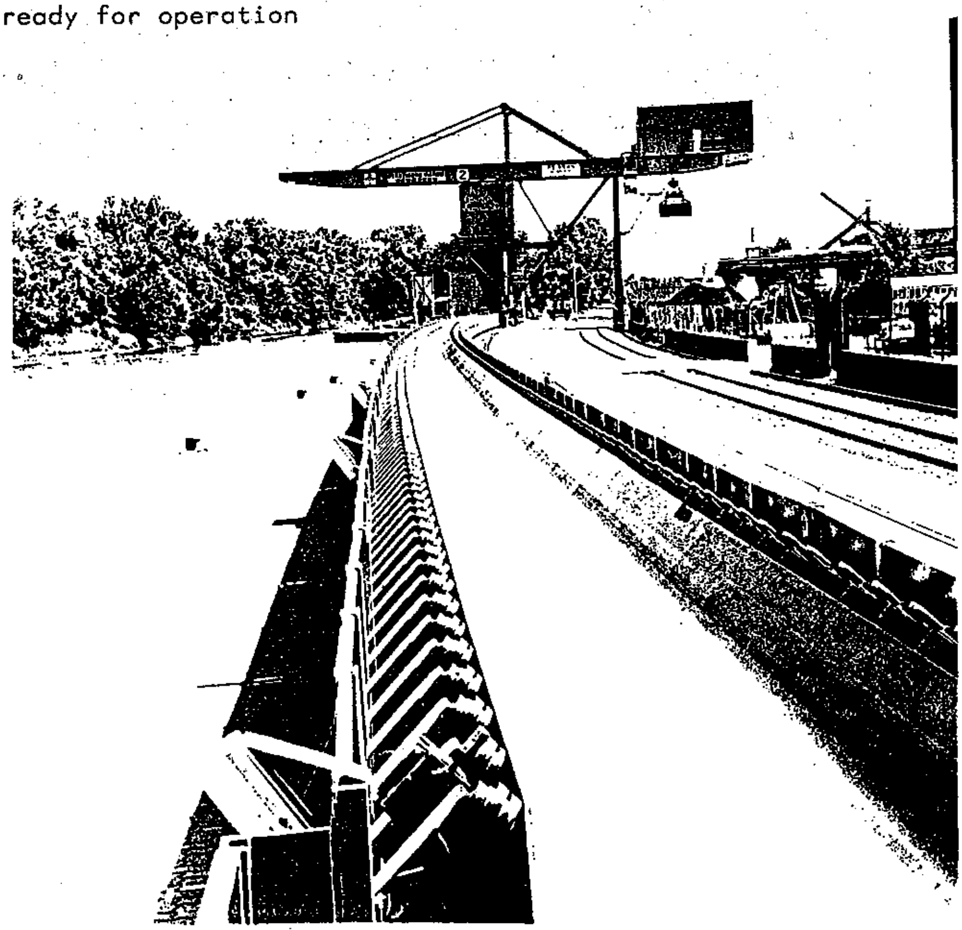


Photo 3: No. 8 of illustration 1,
KHD Gemeinschaftskraftwerk, Hannover