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DIGITAL TWIN BASED METHOD TO MONITOR AND OPTIMIZE BELT CONVEYOR MAINTENANCE AND OPERATION

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ABSTRACT: The presentation is about a newly, developed method to monitor and optimize belt conveyors, based on a high precision reproduction of the conveyor behaviour using a digital twin. By this numerical reproduction and the continuously performed synchronization between calculation and measuring, the system achieves an unmatched transparency of the belt conveyor's actual condition. Besides precise information about the overall efficiency, the system delivers early warnings about any changings of the physical state of the conveyor. The generated data allows analysis about time, place and root cause of the changes as well as quantitative statements about the operational properties of the main components in terms of energy efficiency and achievable lifetime. This enables a significant reduction of cost and downtime on the monitored conveyors. In the long run, this approach has the potential to speed up the improvement of the main components. The presentation is interesting for operators, maintenance managers and suppliers of whole belt conveyors or single components.

INTRODUCTION

For many years, belt conveyors have been robust and reliable equipment for the economic transport of large quantities of bulk material, as they are produced in particular in mining. Conveyors with lengths of a few dozen meters to more than 20 km and transport capacities from a few hundred to 40,000 t per hour are state of the art today. Reliable design is no longer a problem thanks to standardized and internationally agreed calculation methods. However, on closer inspection, it can be seen that there are large differences in the availability of different systems and virtually no operator is able to calculate their actual specific transport costs per tonne of material and per km of transport distance. The reasons for this are, on the one hand, that each conveyor system is unique and therefore difficult to compare with others, on the other hand, that until today there is no recognized procedure to determine the necessary maintenance measures correctly and at the right time. Here is an enormous potential for optimization, which was the reason to develop the system described below.

PRIOR ART FOR EVALUATING THE EFFICIENCY OF A BELT CONVEYOR

The formula work for the design of a belt conveyor according to DIN 22101(2018) and CEMA (2014) is based on an estimation of the design and operational influencing factors and aims at an economically meaningful coverage of the expected requirements in the normal operation of the system. However, this formula work is unsuitable for making accurate predictions regarding the power demand and local stress of the components for specific operating conditions "below design", or for deriving the demand in other situations from a measured power demand in a particular operating situation. This will be briefly illustrated below:

The DIN formula for calculating the main resistance F_H of a subsection i is as follows

$$\mathrm{F_{H,i}} = \mathrm{l_i} \times \mathrm{f_i} \times \mathrm{g} \times \left[\mathrm{m'_{R,i}} + \left(\mathrm{m'_{G,i}} + \mathrm{m'_{L,i}}\right) \times \cos\delta\right] \tag{1}$$

wherein

$F_{H,i}$ Main resistance of section i [N]

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l_i	Length of section i [m]
f_i	virtual friction factor of section I [-]
g	gravitational constant [m/s²]
$m'_{R,i}$	translational mass of rollers per length [kg/m]
$m'_{G,i}$	mass of belt per length [kg/m]
$m'_{L,i}$	mass of load per length [kg/m]
δ	inclination of section i [°]

Geesman (2001) discussed a measuring rig and the horizontal moving resistances F_H measured on different conveyor belts during operation as a function of the vertical load F_V. Figure 1 shows this measuring rig:

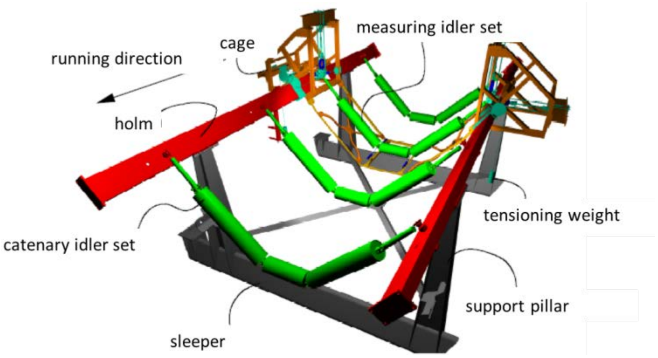

Figure 1: Measuring rig according to determine the horizontal resistance of various conveyor belts

If one applies equation (1) to an installation section of the slope $\delta = 0$ and the length of a support roller spacing of this measuring stand, the theoretical main resistances shown in Figure 2 are obtained for different virtual friction factors f compared to the actual main resistance measured for a particular belt (dashed line) and the main resistance calculated with the analytical calculation model described below (red solid line):

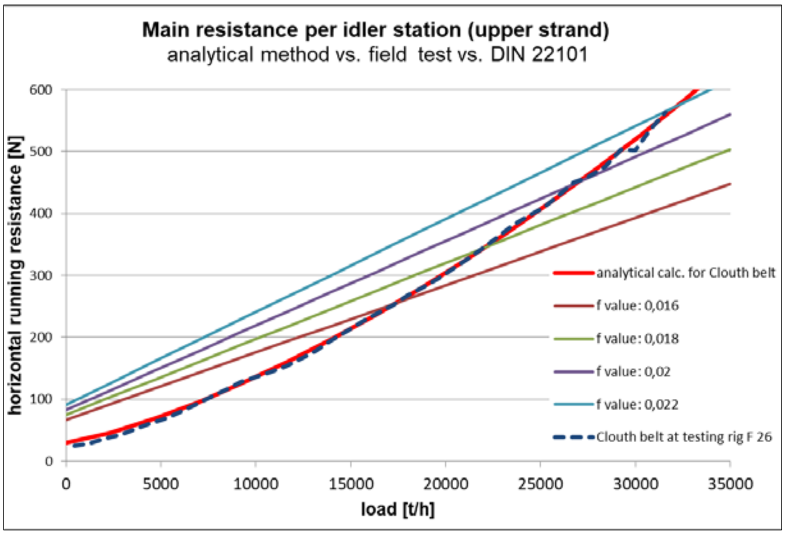

Figure 2: Main resistance calculated with different estimated f-values compared to measurements on a test rig according to Geesman (2001) and an analytical calculation method

It can be seen that with any choice of the virtual friction factor, only one loading situation can be calculated correctly. Conversely, it follows that the virtual friction factor itself depends on the load:

$$f_i = f(m'_{L,i}) \tag{2}$$

The specification of the f-value for a belt conveyor is thus only meaningful in connection with the mass flow for which this f-value applies. Even then, the evaluation of the efficiency of this belt conveyor on the basis of the f-value is highly questionable, since the mass of the belt and the idlers ($m'_{G,i}$ and $m'_{R,i}$) are included in the calculation, although only the energetic expenditure to transport the material is of interest. In fact, the running resistance of the idlers is almost independent of the translational mass of the idlers, but is largely determined by the bearing size, the bearing clearance, the seal and the bearing and sealing grease used. Support rollers with very large translational mass, but otherwise the same design would thus lead to a same main resistance, but a mathematically lower f-value.
In summary, it can be said that the f-value is not meaningful for the assessment of the energetic efficiency of a belt conveyor and thus is not suitable for continuous monitoring.

INFLUENCES ON THE MOVING RESISTANCE OF A BELT CONVEYOR

The moving resistance of a belt conveyor depends on many influences. To distinguish are:

- constructive influences
- operational influences
- maintenance status of the system

In terms of design, the moving resistance is influenced by the choice of the troughing angle, the length of the center roller, roller spacing and diameter, belt width, belt weight and speed. These parameters are usually all known and usually constant over the life of the plant. In rare cases, the speed is adapted to the current load.

The operational influences come from the conveying process and relate to the height and temporary change of the load, lump size and distribution, specific density and internal damping of the material. These values can vary and are in part unknown.

The maintenance condition also has an influence on the moving resistance. Misaligned idler rigs, lack of cleaning, incorrectly adjusted scrapers and longitudinal seals not only lead to higher energy consumption, but also to misalignment and belt damage and generally to a shorter service life of the components (belt, idlers and pulleys).

Worth mentioning is also the influence of the main components "belt" and "idlers". In particular, the belt has a large influence (essentially thickness and characteristics of the running plate), which also changes with temperature and aging state. The selection of these components takes place initially for the construction of the system by the Original Equipment Manufacturer (OEM) - often according to the specifications of the end customer. In the replacement procurement often other makes are used, which can change the power requirements. Frequent phenomenon: an old belt with thin cover plates is replaced by a new one and then there are restrictions on the flow rate, as the installed engine power is no longer sufficient.

A closer look at this issue can be found in VDI Guideline 4459 (2011), from which the following table is taken:

Table 1: Relative influence of components and operating parameters for different conveyor types

		marginal and localized components								Components along the conveyor			operational conditions			
	Capacity	Drives	Pulleys	Chutes	Scrapers	Belt flipping station	Steering device	Brakes	Dust and noise suppressing equipment	Rollers (diameter, bearing, sealing)	Idler rigs (idler pitch, troughing angle)	Belt	Belt tension	Alignment	Filling ratio	Drive control logic
short conveyor (< 100 m)	< 500 t/h	5	2	6	4	0	3	2	3	1	1	6	2	2	1	0
	500 to 3000 t/h	5	2	6	4	0	3	2	3	1	1	6	2	2	1	0
	3000 to 10000 t/h	5	2	6	4	0	3	2	3	1	1	6	2	2	1	0
medium conveyor (100 to 1000 m)	< 500 t/h	4	1,5	4	3	1	2	1,5	2	2	2,5	8	3	4	2	1
	500 to 3000 t/h	4	1,5	4	3	1	2	1,5	2	2	2,5	8	3	4	2	1
	3000 to 10000 t/h	4	1,5	4	3	1	2	1,5	2	2	2,5	8	3	4	2	1
long conveyor (1000 to 5000 m)	< 500 t/h	3	1	2	2	3	1	1	1	3	4	10	4	5	3	2
	500 to 3000 t/h	3	1	2	2	3	1	1	1	3	4	10	4	5	3	2
	3000 to 10000 t/h	3	1	2	2	3	1	1	1	3	4	10	4	5	3	2

CONCEPT OF THE "DIGITAL TWIN"

The basis of the "digital twin" is an analytical model of the belt system, which calculates the moving resistance along the belt from the current operating conditions, taking into account the structural properties. The following measured values are required for this:

- Effective power of all motors
- Belt tension at a known location
- Belt speed at a known location
- Loading signal at a known location
- Ambient temperature
- Optional: detection of belt splices in a known location

It is initially assumed that the properties of the components "conveyor belt" and "idlers" involved in the main resistance as well as the alignment state of the system are the same at all points. With optimum adaptation of the analytical model to the real belt conveyor and ideal homogeneity, the calculation of the belt force around the whole belt results in no deviation between the start and end value of the belt force. However, since the real system is not homogeneous, deviations arise which can be converted to a difference between the calculated and the measured motor power - even with ideal adaptation. The geometric mean of this difference over a sufficiently long period of time is a measure of the quality of the model and can be used to adapt the parameters of the analytical model via a suitable optimization algorithm. In reality, average deviations of well below 1% of the installed drive power are achieved. See Figure 3.

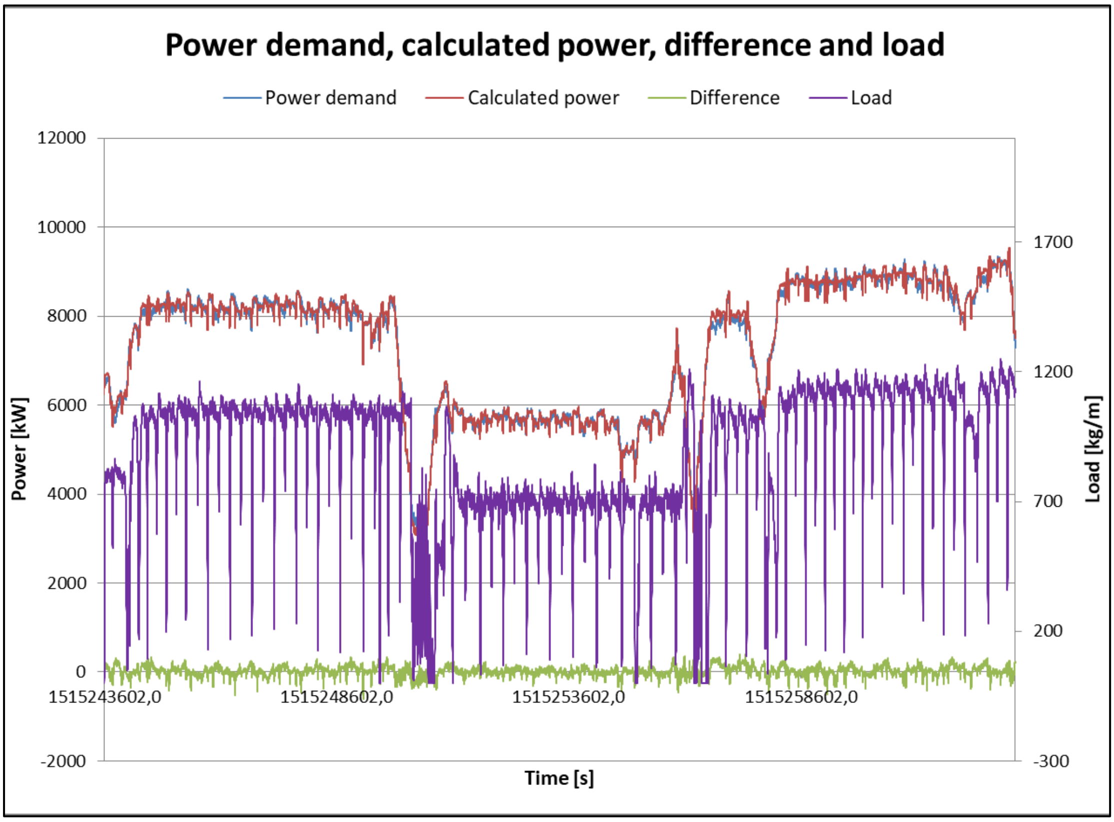

Figure 3: Illustration of the replication quality of the digital twin with changing load

The deviations themselves - in Figure 3 the green time curve - represent the inhomogeneity and thus also the optimization potential. From them, the information about the efficiency of each conveyor section and - if the passing of the belt splices is measured – of the individual belt pieces, from which the entire belt is composed can be obtained.

The analytical model is based on a mathematical-physical replication of the real conveyor. This also includes the temperature dependence of the belt properties and the heating and cooling behaviour of the belt.

The exact adaptation of the analytical model is made by skillful selection of the parameters of the functions, which describe the moving resistance as a function of the operating parameters "local load, speed, belt tension and temperature". Together with the data record that describes the structure of the conveyor, this condition parameter record maps the conveyor. Thus, the system can not only be simulated in the current operating state, but also in all possible operating conditions and for all ambient temperatures. As long as nothing changes in the physics of the system, this condition parameter set is valid and provides reliable results. Thus, in particular for a standardized operating state with a selected, uniform load and constant ambient temperature, a characteristic number can be formed which represents the specific energy requirement for transporting one ton of material over a horizontal transport distance of one kilometre. This "standardized Energy Performance Indicator" EnPI has the unit Wh / (t·km) and allows the evaluation of the energy efficiency of a conveyor system over time, or in comparison to other systems.

If something changes in the physics of the conveyor (alignment state, degree of soiling, properties of the belts and idlers) or the quality of the measurement data (incorrect data acquisition), this is detected as a permanent exceeding of the specified tolerance value and an automatic search for a new condition parameter set that meets the accuracy requirements is triggered. This is followed by a message to the responsible plant supervisor.

POSSIBLE STATEMENTS REGARDING THE OPERATING BEHAVIOUR AND THE MAINTENANCE OF A CONVEYOR SYSTEM

The EnPI is an index that provides a macroscopic overview of the condition of the conveyor system, acting as an early-warning system in the event of any deviation. With the current condition parameter set to which this EnPI applies, it is possible to make precise forecasts of the power requirements that will arise when another operating condition (load, speed, ambient temperature) occurs. With this it is possible, for example, to assess whether an increased production rate can be achieved with the installed motor power.

The simulation of the temperature behavior also predicts the development of the power requirement for the start-up of a conveyor system which has been standing for a relatively long time and therefore has adopted the ambient temperature. Thus, it is also possible to predict how the power requirement for restarting will develop with increasing downtime when the conveyor is shut down in cold weather.

The depiction of the conveyor section efficiencies shows which sections are conspicuous due to an increased energy demand and deserve special attention. Reasons for this can be:

- poor vertical alignment of the roller bearing stations → increased power demand correlates approximately quadratically with the size of the load
- poor horizontal alignment of the idler roller stations → increased power requirement is linearly dependent on the height of the load
- above-average accumulation of stiff idlers → increased power requirement is independent of the size of the load
- Friction between the belt and stationary parts of the system → if the misalignment is not due to asymmetrical loading, then an increased power requirement is independent of the size of the load, otherwise it depends on the load
- friction between conveyed material and stationary parts of the installation (for example, longitudinal seals) → above a threshold increased power requirement, which increases with the size of the load

The conveyor sections with the lowest energy consumption can be used as a reference for which improvement potential is at least achievable through a general improvement of the conveyor state. This not only reduces the energy consumption, but also increases the maximum possible transport capacity with the currently installed motor power.

If the belt conveyor is equipped with abelt splice detection, the system can also determine the efficiencies of each belt. This gives the opportunity to prefer belts for replacement that have proven to be more energy-efficient, or to make concrete specifications to manufacturers in this regard.

For a specific application, the investment and belt efficiencies shown in Figure 4 were determined over a period of five months. Since this comes from a shiftable conveyor in an open pit mine, the range of conveyor section efficiencies is wide and significantly greater than what can be expected for stationary installations. The belt efficiencies between different manufacturers and belts of the same manufacturer from different batches differ considerably. This is consistent with previous studies by Ziegler (2009), where the running resistance of the belts was determined directly with the measuring rig described by Geesmann (2001).

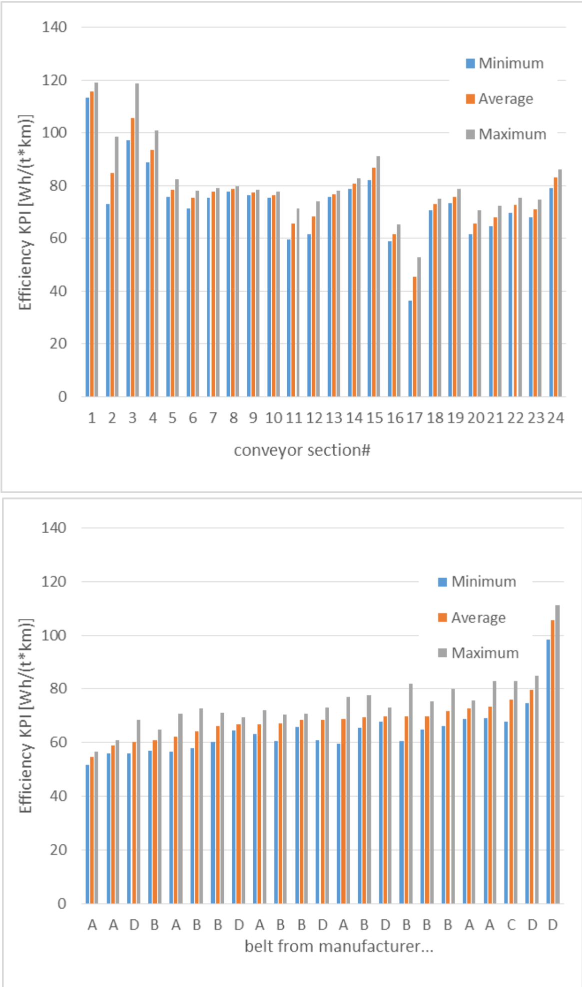

Figure 4: Calculated efficiencies of the different system sections and belts used on the basis of measurements on a real conveyor system

The system allows the continuous display of the maximum delivery rate at which the overload condition occurs under the current conditions. This can be either the exceeding the installed power of the motor with the highest load, or the slip limit of the most critical drive pulley determined from the belt pretension, the wrapping angle, and the current friction value.

From the values for the local belt tension, the modulus of elasticity of the belts and the current motor power, the drive characteristics can be displayed relative to a reference drive and from this the cause of unequal power distribution can be derived. Possible causes for this can be:

Differences regarding

- Pulley diameter
- Gearbox ratio
- Belt elongation (especially for fabric belts)
- Filling levels (when using turbo couplings)
- Ballast resistors (when using slip ring motors)
- Supply voltage at the motor
- Motor characteristic

Since all measurement data and relevant calculated values are stored in a database, the operating stresses can be determined for each point of the installation, each belt and each component for any period of observation. If a defective component has to be replaced, then the achieved load spectrum can be determined and used for comparison with other components. This makes the overall profitability transparent for an optimal selection in replacement procurement.

If sufficient data is available, the substance of the currently installed components can be determined with respect to the statistically achievable load spectrum and it can be estimated from this, how many components have to be changed by a given time in the future. Thus, the maintenance effort can be planned easily and precisely.

PERSPECTIVES FOR FURTHER DEVELOPMENT

The possibilities offered by this approach cannot yet all be estimated. In any case, it will be feasible to model the behavior of the components in sections and quantitatively correctly from the inhomogeneity. This could be used to determine the running resistance of each belt as a function of load for each temperature, speed and aging condition. This will greatly boost the optimization of the components.

As experience grows, the analytical model can be further improved, allowing the useful division of the conveyor into individual sections with higher granularity (currently, the sensible section length is about 50 m / section). This allows a correspondingly more accurate localization of deviations.

The analysis of the specific causes of deviations can be used to identify typical signal patterns for these deviations and to implement an automatic plain text message for future occurrences of this kind.

In summary, the concept of the "digital twin" opens up unprecedented transparency for the operation and maintenance of conveyor systems. The basis for this is the correct description of the technical mechanics, the permanent recording of the most important operating parameters and the constant adjustment for the automatic adaptation of the model to reality. The evaluation capabilities developed on this basis can be continually improved and used to automatically generate accurate notifications of relevant changes to the persons responsible. The exclusive expertise of a few experts becomes accessible to every operator of conveyor systems using this system.

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