Raw Coal Loading and Belt Conveyor System at the Nochten Opencast Mine

Translated from
Braunkohle Surface Mining 50
No. 2 March/April 1998
Trans Tech Publication
Clausthal – Zellerfeld, Germany
Authors:
Dr. Werner Daus, LAUBAG, Senftenberg
S. Körber, Reichwalde
Norbert Becker, Siemens AG, Erlangen

Your Success is Our Goal
A New Conveying and Loading System Based on Drives Controlled by Frequency Converter

In November 1997, twenty-five years after production commenced at Nochten opencast mine, a new conveying system, a new train loading facility, and the first stage of a coal handling area were taken into operation. The new conveyor system is only slightly longer than the old one, but cuts rail transportation distances by 16.5 km. This means that the newly erected part of Boxberg power station can be supplied with coal direct by belt conveyor (Fig. 1).

An indispensable requirement of the Lignite Planning Procedure (1992 - 1994) was the removal of the old coal loading facility from the town of Mühlrose. In accordance with the Regional Planning Act the Lignite Plan called for this relocation in terms of a "target," i.e., a planned measure with significance for regional planning which was to be implemented by 1996.

Owing to the massive investments undertaken by LAUBAG a "target amendment procedure" with respect to the loading facility relocation was applied for in 1995 and approved for 1998. The investment funds were released in May 1996, and a contract for the work was awarded to Siemens AG (as prime contractor) in November 1996.

With regard to the construction of the facility a maintenance contract was entered into with Siemens. The work had to be completed in an extremely short period of time.
In order to obtain planning permission for the facility, a 'target modification procedure' for the Lignite Plan for Nochten had to be initiated. Particularly stringent requirements were laid down with regard to emission control. The following solutions were proposed, accepted, and eventually put into effect:

- Relocation of the facility near the power station and removal of bunkers in the power station
- Particulate matter protection by means of extensive cleaning installations
- Noise protection by enclosure of drive equipment, noise-reduced rollers, reduced belt speed, erection of a building around the loading facility, and creation of a noise-protection embankment.

2.2 Reducing operating costs with the new facility

2.2.1 Belt conveyor

Significant potential for cutting costs was identified in the shape of a variable-speed belt conveyor.

In all the LAUBAG opencast mines, the workings under the F60 cross-pit spreader were greatly oversized and serviced by a number of small excavators. Essentially, there were three reasons for this:

- Compensation for the front-end working method of the F60 by the block working method of the mining machines to guarantee as far as possible the uniform and uninterrupted operation of the overburden transporter
- Changing quality modes of operation in conjunction with a high belt conveyor utilization rate owing to excess machine capacity
- Compensation for machine downtime.

These reserves were necessary to maintain supplies up to 1992/1993. Declining coal sales and changing requirements with regard to raw coal quality gave rise to new conditions. Maximum loading of the belt conveyor at all times was achieved by way of machine overcapacity.

Yet the positive effects of high belt conveyor utilization met with a price in the machine sector.

Thanks to variable-speed control, which is oriented around an optimum belt conveyor load cross-section, flexible optimization is achieved for a defined control range without the need to maintain reserves. The greatest benefits from this technical measure are anticipated in the areas of technology management, wear minimization, energy conservation, and the reduction of emissions. For this reason, this discussion will look at the technical design, operation and the initial results of the measure separately and in more detail at Point 3.

2.2.2 Coal handling plant

The new coal handling plant (Fig. 2) had to be designed to fulfill two tasks:

- To supply the refurbished Boxberg power station (installed output = 2 x 500 MW) and, if applicable, other customers with raw lignite via a train loading facility with maintenance of separate stocks (stockpile A has a capacity of 80,000 t). This stockpile is to be served by a stacker-reclaimer (KSS 10000)
- To supply the newly erected part of Boxberg power station via a system of permanent stockpiling (stockpiles B and C each have a capacity of 100,000 t). Stockpile B is also to be built up by the KSS 10000; stockpile C will eventually be served by an extended belt conveyor and a stacker. Stockpile C and the associated conveying equipment will go into operation in a second stage not until after 1999.

Stockpiles B and C are combined working (stockpile A has a capacity of 80,000 t).

In this concept, the coal is to be recovered by the KSS (when the mine has stopped working) and loaded without the need for a central control point. The process control systems required can be switched to the KSS in this case.

2.2.3 Process control system

Multimedia technology makes it easier to operate the transportation and bunker system with a minimum number of personnel while at the same time guaranteeing operational safety, system availability, and operating performance.

The process instrumentation and control systems have been configured on the basis of advanced communication technology. A redundant, open-protocol, broadband multiplex system, OTN (Open Transport Network), transmits all signals from the instrumentation and control system, including emergency shutdown, plant status monitoring equipment (diagnosis), communications equipment (telephones, command units) and video equipment along fiber optic cables.
Radio-based functions such as belt-stop and data radio (monitoring of mining machines and quality assurance system) have also been set up. Complex procedures for conventional belt-stop monitoring systems (push-buttons, horn, wiring) have been replaced by a simple radio-linked structure. The open, operator-controlled, real-time systems and standards used here allow the system to be expanded and adapted to changing needs and conditions without the need for major additional expense.

The entire system is controlled from Nochten mine’s central control point by a single operator. This control point also includes the maintenance interface (plant and equipment diagnostics), an important prerequisite for communications between system and process engineers.

The savings achieved in this area are difficult to quantify. They will, however, provide valuable development impetus for operations, organization and maintenance in the next few years.

2.2.4 Maintenance

Owing to the very short project planning and completion time LAUBAG decided to award the entire construction works to a main contractor. The most impressive concept for this work was put forward by Siemens. It was awarded the contract and, together with a number of subcontractors, built the facility in just seven months.

A major element of the contractual agreements was the link between plant construction and subsequent maintenance work. The idea was to ensure that the plant builder was interested in a lowest cost maintenance system right from the outset.

A further consideration, which pointed in favor of combining operating experience with the know-how possessed by plant builders and manufacturers. With this synthesis the aim is to attain a new quality in the field of professional maintenance work and sustained progress in all aspects of maintenance management.

In accordance with this objective new jobs are being created that reflect this development and are backed by the latest technical equipment in order to maintain the synergy between technical development and organization. An important instrument in this respect is the technical diagnostics system. In diagnosis, we distinguish between operational and expanded diagnosis.

In short, operational diagnosis means the use of product-specific software tools from a central point for selectively accessing major, technologically complex components (e.g. converter, decentralized field bus networks etc.) throughout the facility in order to record, analyze and, if necessary, correct their current status.

Expanded diagnosis means the foresighted analysis of the process and status of plant and equipment to detect any deviations from the intended status at an early date.

Here, time patterns (operating hours, changeover procedures, parameter changes), capacity-related parameters (e.g. rates of utilization, torque and temperature curves), status data (e.g. vibration characteristics, wear values) and external influences are of major importance.

The principal idea behind this concept is the gathering of data from various sources, e.g. the automation system, the status detection system and the results of inspections, and putting it together with the aid of intelligent, computer-based methods to deliver effective information. This information forms the basis for a status-oriented system of maintenance and the associated replacement parts management system. Some of the outstanding characteristics of the expanded diagnosis system are listed below:

- Highly detailed diagnosis for monitoring of stocks by means of error pattern detection and fuzzy logic support.
- Error detection on the basis of freely-definable error patterns.
- Automatic generation of maintenance orders.
- Generation of freely-definable characteristic values.
- Universality of the information flow from the automation and status monitoring system via the intelligent diagnostics system to the maintenance planning system.

Closing the interface between the diagnostics and maintenance systems creates the conditions required for status-related maintenance operations. Here, maintenance work is conducted according to actual requirements and not, as was previously the case, at fixed, static intervals. This new maintenance strategy will make a major contribution to savings on the basis of wear-related maintenance, enhanced organization and an improvement in levels of expertise due to the introduction of a sensible form of competition between the skilled mine personnel and the service providers.
3. The concept behind a variable-speed belt conveyor

3.1 Rationale
A project involving a belt conveyor system for the reliable transportation of defined bulk materials is planned. A major planning aspect is the effective handling capacity of the connected plant and equipment. These capacities are added together and, furnished with corresponding safeguards, included in the planning of the transportation capacity. This gives an average theoretical volume of material to be transported.

All subsequent calculations (e.g. drive output, number of driven drums, angle of belt contact, belt width, tensile strength, tension force, steel structure etc.) are based on this value, coupled with geometric and climatic influences and with a constant belt speed.

This approach creates a permanent problem: the greater the difference between the volume of material being transported at any one time and the theoretical formulation, the less favorable the ratio between the cost incurred (drive output, material) and the benefit obtained. If the system is not used to full capacity, potential is squandered; if the system is overloaded, disruptions are often the result. The margin above is determined by a safety factor; if a downward deviation arises, this leads to resources being wasted.

A fluctuation round a nominal load such as this can be tackled using a selective mining machine control and adjustment system. The more excavators there are, the more complex this becomes, due to the complex variety of parameters.

Example: Total capacity breakdown as a result of:
- Excavator malfunctions
- Technology-related equipment transportation during disc/block replacement.

Reduction in capacity due to:
- Initial cutting losses
- Rotary (sickle-type) cutting losses
- Subgrade/footwall excavation
- Quality-related capacity assignment in accordance with the quality assurance system
- Special excavations (overburden, relocation etc.).

A number of investigations and tests revealed that under the prevailing conditions at Nochten mine a linked open- or closed-loop control system for four mining machines with the aim of achieving a uniform volume of material being moved is not feasible. The solution is to be found in keeping the belt speed under constant control, which will be explained at Point 3.3.2. Economic efficiency constitutes a major factor when employing a belt-speed control.

As the electrical equipment had to be replaced in full after 25 years of operation, a large number of synergies arose. The added expense of the converter solution amounted to some 25% in comparison with conventional systems. Besides the question of costs, additional investigations are to be carried out with regard to the system’s endurance properties. The correlation between variable speed, increased system utilization and the wearing of major system components is especially worthy of study. The kinetic resistance properties of the belt under these conditions are also in need of re-evaluation. The start-up and run operations are of particular importance here.

3.2 Design of the drive systems
The definition of tasks for the concept was drafted by an interdisciplinary LAUBAG team. The project was implemented by a consortium made up of the following companies: Siemens (ATD Division), STAMAG (mechanical supply of the belt conveyor system), FAM Magdeburg (KSS stacker-reclaimer), BEATechnische Dienste Lausitz (KSS electrical assembly) and the construction company Schwarze Pumpe (construction supply), with Siemens (ATD Division) in the role of prime contractor.

From the preparation to the trial stage, the definition of tasks was accompanied by a research project run by the Faculty of Mechanical Engineering at Senftenberg Technical College. Details of the technical performance can be seen at Figure 3.

The belt is tensioned by motor-driven cable winch. Depending on the capacity requirements the belts are equipped with a maximum of four three-phase squirrel cage motors each driving a lower and upper belt drum via gear units.
The motors have the following parameters:

\[
\begin{align*}
\text{P} & = 900 \text{ kW} (630 \text{ kW}) \\
\text{M}_n & = 8665 \text{ Nm} (6060 \text{ Nm}); \\
\frac{\text{M}_1}{\text{M}_n} & = 2.8 (2.6) \\
\text{U}_n & = 690 \text{ V} \\
\text{I}_n & = 2 \times 455 \text{ A (630 A)} \\
\text{R}_n & = 992 \text{ min}^{-1}
\end{align*}
\]

Speed adjustment range: 500 - 1000 \text{ min}^{-1} with constant torque

Cooled system: self-cooling/integrated cooling system

Connection to two separate 3-phase winding systems.

A SIMOVERT® MASTERDRIVES inverter is connected to each of the motor. The inverters are supplied by a common direct-current link via two feed unit or feedback units connected in parallel with each other.

The converter transformer is a three-winding transformer, which means that a 12-pulse system perturbation is achieved. The converter transformer is supplied in the primary circuit by a 6 kV medium voltage unit (Fig. 4).

The drives are designed for:

- Starting torque = 1.3 \times \text{M}\n
- Maximum running torque: approx. 1.6 \times \text{M}n

- Start-up time = 60 s

- Braking time = 18 s

- Creep speed = 200 \text{ min}^{-1} at 0.8 \text{M}n for S1 operation

The inverters adjust the speed of the drives by means of a TRANSVEKTOR control. They are equipped with fully digital SIMOVERT MASTERDRIVES system components with IGBT power transistors for connection to a motor with two separate winding systems. Cooling is provided by a closed-circuit cooling system.

The braking energy occurring on shutdown is fed back to the line supply with the aid of a second thyristor bridge.

The technological controls consist of a soft ramp generator for the setpoint speed of a drive station. Each motor has its own soft ramp generator for the setpoint speed of a second thyristor bridge.

All electrical equipment (6kV, 500/400 V, converter equipment, control and monitoring equipment) is housed in a closed container (9500 mm x 6300 mm L x B).

In the case of movable equipment (K61, K62) the containers are mounted on the drive station. At permanent items of equipment (K63 to K66) the containers are positioned alongside the equipment.

The technical design of the Nochten coal belt conveyor system is documented at [1].

### 3.3.1 The load-dependent belt-speed adjustment system

Electricity consumption represents a major cost factor when operating belt conveyor systems and is influenced by a large number of parameters. The effect of these influencing factors has been looked at in detail in the relevant specialist literature, including [5, 6, 7, 10].

In the case of the belt conveyor system at Nochten the task of adjusting the belt speed according to the various quantities to be transported so as to exploit the available load cross-section to the greatest possible degree was turned into reality. This solution will be described in relation to power consumption below.

The required drive output \( P_0 \) of a belt conveyor, which has to be transmitted to the materials being transported by one or, simultaneously, by more than one drive drum, is arrived at based on the kinetic resistance \( F \) according to (4):

\[
P_{el} = \left(1/\eta\right) F \cdot v
\]

\( v \) = belt speed

\( \eta \) = efficiency of gearing and motor

The kinetic resistance \( F \) is calculated according to DIN 22 101 in equation (2).

\[
F = C_{fRT} L (m'_{G} + 2m'_{G} + m'L) \cos \delta g + H m'L g
\]

If we put equation (2) in equation (1), we obtain \( P_{el} \) with \( \cos \delta = 1 \):

\[
P_{el} = (1/\eta) C_{fRT} L (m'_{G} + 2m'_{G} + m'L) g v + (1/\eta) (C_{fRT} L g + H g) \cdot (m'L) v
\]

Using the abbreviations \( K_0 \), \( K_1 \) and \( I_m \), it is possible to write in simplification:

\[
P_{el} = K_0 v + K_1 I_m
\]

The lifting work \( H \cdot m'_{L} \cdot g \) is independent of the speed and no longer taken into consideration below.

According to [11] and [5] \( I_{mRT} \) also becomes a function of belt speed. This correlation was demonstrated during the practical trials.

By breaking down the drive output into a no-load element \( (K_0, v) \) and a load element \( (K_1, I_m) \) the following facts become apparent:

- The no-load element is proportional to the speed \( v \)
- The load element is proportional to the distance load \( m'_{L} \) and speed \( v \).

### 3.3.2 Evaluation and representation of the initial test results

The trials delivered the correlations shown at Figure 5.

Essentially, the theoretical principles in accordance with equations (3) and (4) were confirmed, see also [2, 3].

First, sufficiently significant evidence was gathered to demonstrate a proportional dependence between the electrical drive output and variable load at a constant belt speed in each case. This means that in practice \( f_{RT} \) can be assumed to be virtually constant at a fixed temperature and constant belt speed in each case. In contrast, \( f_{RT} \) decreases as the belt speed drops, i.e. specific energy consumption also decreases due to the diminishing load \( K_1 \).

The parameterization for the envelope curves \( 1, v = v_{nom} \) and \( 2, v = 0.5 v_{nom} \) was done on the basis of a performance test conducted on the Nochten belt conveyor system in the period between December 11, 1997 (10 p.m.) and December 12, 1997 (2 p.m.).

The data obtained was analyzed using linear regression; the results for the permanent conveyor lines K63 to K71 were grouped together to give standardized mean values.

---

Using the abbreviations \( K_0 \), \( K_1 \) and \( I_m \), it is possible to write in simplification:

\[
P_{el} = K_0 v + K_1 I_m
\]

The lifting work \( H \cdot m'_{L} \cdot g \) is independent of the speed and no longer taken into consideration below.

According to [11] and [5] \( I_{mRT} \) also becomes a function of belt speed. This correlation was demonstrated during the practical trials.

By breaking down the drive output into a no-load element \( (K_0, v) \) and a load element \( (K_1, I_m) \) the following facts become apparent:

- The no-load element is proportional to the speed \( v \)
- The load element is proportional to the distance load \( m'_{L} \) and speed \( v \).

### 3.3.2 Evaluation and representation of the initial test results

The trials delivered the correlations shown at Figure 5.

Essentially, the theoretical principles in accordance with equations (3) and (4) were confirmed, see also [2, 3].

First, sufficiently significant evidence was gathered to demonstrate a proportional dependence between the electrical drive output and variable load at a constant belt speed in each case. This means that in practice \( f_{RT} \) can be assumed to be virtually constant at a fixed temperature and constant belt speed in each case. In contrast, \( f_{RT} \) decreases as the belt speed drops, i.e. specific energy consumption also decreases due to the diminishing load \( K_1 \).

The parameterization for the envelope curves \( 1, v = v_{nom} \) and \( 2, v = 0.5 v_{nom} \) was done on the basis of a performance test conducted on the Nochten belt conveyor system in the period between December 11, 1997 (10 p.m.) and December 12, 1997 (2 p.m.).

The data obtained was analyzed using linear regression; the results for the permanent conveyor lines K63 to K71 were grouped together to give standardized mean values.
The stock of values available for the envelope curve (2, \( v = 0.5 \, V_{\text{nom}} \)) will have to be increased by further trials. The curve section (3) is determined by the threshold capacities of the conveyor lines for downward adjusted belt speeds (\( v - 0.5 \ldots V_{\text{nom}} \)).

A second result is obtained from the formation of handling capacity mean values over various time patterns (see Fig. 6).

During the performance test four excavators (2 SRs I300 in the high cut, 2 ERs 710 in the low cut) were in service. They were configured to run at maximum output by mine management. The maximum eight-hour output achieved in the period between 4 a.m. and 12 noon amounted to 40,223 t (a very high figure in comparison).

In evaluation of the results the sliding mean handling capacity value was obtained by 5, 15, 30 min and 1, 2, 4, 8 hour averaging (see Fig 6.). The maximum 8 hour mean value was 4643 t/h.

The following conclusions can be drawn from this series of measurements.

1. Attempts to continuously move along the length of a belt the maximum quantity of material that can be handled according to the available belt cross-section proved unsuccessful. The integration time of five minutes (5 min maximum value = 84.36%) corresponds to the running time of a longer conveyor (1800 m at 6.0 m/s).

These findings are to be consolidated during long-term testing. There exists a genuine basis for “re-optimizing” the drive output in accordance with DIN 22 101 for similar coal belt conveyor systems.

Protection against short-term peak loads can be provided by intermittent overload operation (operating mode S6 in accordance with EN 6000341).

2. With an integration time of less than four hours the integrated maximum handling capacity value lies below 50% of potential handling capacity. As a minimum requirement this necessitates a belt speed adjustment range of 50 to 100% \( V_{\text{nom}} \).

Theoretically, the control range would need to be extended downwards. A simple co-ordination of the machines so as not to drop below the 50% mark would appear to make sense.
3.3.3 Implementation of the belt speed adjustment

Loading of the K61 and K62 face conveyors is controlled from the control point according to the machines in use.

K61 e.g.:
1 excavator 50% nominal belt speed
2 excavators 75% nominal belt speed
3 - 4 excavators 100% nominal belt speed

The lower base value for the K62 belt is 75% of the nominal belt speed.

From belt K63 to the loading facility all belt lines are controlled from 0.5 - 1 v nom according to the quantity of material being transported.

The actual quantity of material being transported is determined 100 m before the point of transfer from belt K62 to belt K63 (transfer to the permanent head belt) by a Vegasonde sensor (made by VEGA, measuring principle: ultrasound). The distribution function of the data recorded with regard to the quantity of material transported is shown in Figure 7.

In the process the control system does not compensate for every peak load. Short overload peaks can be absorbed by the conveyor system (peripheral loading and storage in transfer chutes) [2]. Load-dependent control is currently being achieved as follows: the data obtained is sent via the Vegasonde sensor to a shift register, which is a pulse-clocked device, and maintained as the setpoint in accordance with the running time of the belt (e.g. 15 s at v nom) up to the K62/K63 transfer point; smaller values are suppressed during this time. The setpoint value is adjusted upwards only by a later occurring larger value.

A downward speed adjustment is achieved by means of a gradual deceleration ramp (v nom - vmin) in five to ten minutes. The complete loading control system is much more extensive and specific than described here. Further details can be obtained from the documentation [1].

Figure 7 shows two distribution functions for different load runs. For the first load run the average quantity amplitude is 45.5%, the control attains a mean speed of 60% v nom, the minimum downward speed is limited to 50%. The limit speed lines (red) correspond to the deceleration ramp described above.

For the second load run the average load-dependent belt speed is approximately 75% v nom.

During long-term testing mean belt speeds of 0.68 v nom were achieved by this method. With these settings up to 25 control operations occur in an hour. Even better speed adjustment can be achieved with steeper deceleration ramps. However, the number of control operations increases.

At present work is being undertaken in conjunction with Senftenberg Technical College and the ATD Division of Siemens to qualify these operations.

3.3.4 Energy conservation results to date

On completion of a long-term study electricity savings of 20% have hitherto been demonstrated.

This figure already takes into account converter equipment (semiconductor valves, ventilation) losses totalling 3.5%. The average belt speed has become established at v = 0.68 v nom during controlled operation. The monthly energy bills incurred so far have more than confirmed these figures.

The 20% savings can be broken down as follows:

- Load-dependent belt speed adjustment
- Savings achieved by removal of slip resistors
- Removal of starting resistors on slipring motors
- Acceleration energy reduction
- Start-up losses due to simultaneous start-up of converter-controlled belt conveyor systems

Conventional machines (wound rotor motors consecutively with time delay)
Nine conveyors, each with a start-up time of 30 s, are started up with a 20% time overlap. This gives:

\[(9 \times 30) \times 0.8 = 3.6 \text{ min} \]

Converter-driven conveyor systems with 5 s time delay

9 x 5 s = 0.75 min

\[\Delta A = 2.85 \text{ min} \times P \times \text{hour} \times z \]

\[z = \text{number of starting operations per year} \]

Resultant energy saving per annum = approx. 3% due to enhanced equipment capacity utilization on start-up (excavators and conveyors).

• **Braking energy recovery**

To date the braking energy has been converted to heat; now the braking energy is fed back to the line supply by the feedback power converters of the conveyor drives. The braking energy is calculated according to:

\[\text{m'L = Im'/v} \quad \text{see also equations (5, 10).} \]

\[\text{m'L} \equiv \text{rotating driving masses, other designations as at equation (2, 3).} \]

Savings through energy recovery per annum approx. 0.5%.

• **The remaining factors of influence**

when using converter drives in comparison with slipping motors roughly cancel each other out. These include:

• Line power factor converter \(\geq 0.98 \cos \varphi\)

• Higher transformer losses in conjunction with converters.

• Lower deterioration of motor efficiency in conjunction with converter drives.

The additional losses due to cooling (fans, air-conditioning units) and semiconductor losses amount to approximately 3.5%.

### 3.4 Effects of load-dependent speed adjustment on equipment status

In light of the operating experience gained to date any initial analysis can only point towards possible answers.

Precise findings will be obtained only on evaluation of long-term wear measurements. As already demonstrated at Point 3.3, the specific conveyor belt load per unit of length (distance load \(m_{L} \)) increases as the belt speed falls; see also equations (2), (3).

\[m_{L} = \text{ln} / \text{V} \quad \text{see also equations (5, 10).} \]

Thus, according to equation (2) there is also an increase in kinetic resistance \(F\).

This clearly shows that the correlation between the change in belt speed and the associated effects on required maintenance effort is to be considered complex and not merely proportional.

Generally speaking, the degree of wear on a belt conveyor due to friction can be worked out on the basis of the energy balance because:

1. Kinetic energy (friction, acceleration) accounts for more than 90% of energy consumption and

2. The energy savings achieved by the reduction in speed stem exclusively from the kinetic energy.

In qualitative terms this statement is based on the following assumptions:

The wear caused by friction is proportional to the generated frictional work \((A_{\text{fr}})\). The braking energy is calculated according to:

\[F \cdot v = 1.25 \cdot (F \cdot v)_{\text{un}} \]

\[\text{AR} = 0.85 \text{ARun} \quad \text{controlled} \]

According to Point 3.3.2 (Fig. 5) the following can be treated as equivalent (both occurrences take place in the same time):

\[\Delta t_{F} = 0.68; \quad v_{U} = 0.68 \cdot v_{\text{nom}} \quad \text{and} \]

\[F_{U} = 1.25 \cdot F_{U}; \quad \mu_{U} = \mu_{g} \quad \Delta t_{U} = \Delta t_{g} \]

Thus, the product of \((F \cdot v)\), which corresponds to the drive output according to Point 3.3.1, becomes an evaluation criterion:

\[\text{AR} = 0.85 \text{ARun} \quad \text{controlled} \]

Using this approach we can calculate that the wear to the moving components of a belt conveyor system is reduced on average by approximately 15% when the average belt speed is reduced to 68% of \(v_{\text{nom}}\).

The effects of wear on components will be dealt with below. We appreciate that wear processes unfold in a more complicated manner than that described here.

The extent and significance of belt wear is dealt with, in particular, at [9].

### 3.4.1 Wear on conveyor belts and idlers

The coal belt conveyor system was equipped with used belts and idlers. For this reason it is difficult to make and, more especially, prove any forecast in respect of wear.

The kinetic resistances are of decisive importance for belt and idler wear [10]:

• Indentation rolling resistance

• Vibration resistance between idler catenaries

• Grinding resistance of the material being moved and resultant friction on belt and, if applicable, idlers

• Charging and stripping resistance

• Damage caused by foreign bodies.

As already shown above, not all influencing variables exhibit a proportional relationship to speed.

The dependence relationships are in some cases extremely complicated. To permit their better estimation it is planned to convert a part of the mine conveyor system into a test section.

### 3.4.2 Changes in wear on the belt drums

The wear to the surface of belt drums in relation to the speed of the belt is to be assessed with regard to creep (elongation of the belt due to tensile forces) and frictional work due to contamination by dirt. In accordance with Point 3.4 this element of wear ought to be reduced by approximately 15%.

The slide slip is dealt with at Point 3.5.

It is safe to say at this point that where conveyor drives are used there is hardly any slide slip worthy of note. This can be taken as a basis of support for the wear analysis and its projected saving of approximately 15%.

### 3.4.3 Other subassemblies

• **Wear to the material stripping devices**

In accordance with the product of \((F_{N} \cdot V)\) the reduction in wear is likely to be directly proportional to the reduction in belt speed. A 30% reduction is considered feasible.

• **Wear behavior on baffle flaps and wear plates**

The reduction in belt speed in conjunction with an inversely proportional increase in the specific volume of material being moved \(m_{L}\), (equation (2, 3)) causes a linear reduction of the kinetic energy imparted on the baffle flaps.

\[m \cdot (V^{2}/2) = (m_{L}^{1 \text{nom}}/0.68) \cdot (0.68 \cdot v_{\text{nom}}^{2}) = 0.68 \cdot m_{L}^{1 \text{nom}} (V^{2}/2) \]

The impact face is enlarged by a varying parabola of trajectory. In conjunction with more abrasive materials (sand, gravel etc.) this can lead to additional wear. For coal savings in the range of 20% are anticipated.
3.5 Reduction in dynamic forces through use of converter-fed drives

Using converter-controlled drives produced by Siemens (ATD Division), a completely new drive system for largescale belt conveyor systems has been developed and constructed. The effects on equipment system dynamics are outlined below:

For a general understanding of the subject the major drive system control functions will be named first:

- Speed controller (via the frequency) for all motors
- Active current differential control and speed differential control for all the motors working on a drive shaft
- Load sharing control between upper and lower drive drums
- Load torque and acceleration precontrol with load torque storage on belt shutdown and
- Rate setter with rate of change limitation (first derivative of acceleration).

3.5.1 Drive characteristics

The power output of the front drive stations is generally transmitted to the belt by two driven belt drums. The drum drives are provided with a semi-rigid connection by the link formed by motor-gear-shaft-gear. A minor amount of slip caused by the elasticity of the gear components (backlash and spring effect) is contained by the active current differential control (conventionally by means of slip resistors). Providing a balance between the upper and lower drive drums is a much more complicated affair. Stretching of the belts and differences in belt diameter lead to considerable differences in speed and thus differences in load between the drums. This problem is outlined at Figures 8 and 9.

Figure 8 shows two motor characteristic curves with 4% nominal slip (slip resistors) and a difference in drum speed of 2% (drum diameter). As the speed of the belt drums is the same due to the impressed belt speed, different load distributions arise for different drum radii.

Example according to Figure 8:

Load occurrence 1:
- upper drum $M_0 = 1.0 \times M_{nom}$
- lower drum $M_0 = 0.5 \times M_{nom}$

Load occurrence 2:
- upper drum $M_0 = 1.0 \times M_{nom}$
- lower drum $M_0 = 0 \times M_{nom}$

Similar load occurrences were recorded by Senftenberg Technical College at the Nochten conveyor line prior to the conversion work (see Fig. 9).

The consequences and effects of the facts described here regarding the kinematics are considerable, cannot however be further treated at this point.

From the point of view of the plant capacity (maintenance), above all in partial load operation, removal of the permanent slip resistance (normally 3 to 4%) and a resultant drive operation with natural motor slack (0.5 to 0.7%) is to be rejected. This also applies, to the same or a larger extent, to an alignment of the permanent slip resistance to varying drum diameters at nominal load.

In the case of converter drives, such load transfer because of different drum diameters cannot arise; the load compensation equation between the drums always maintains the torque at the same load proportion.

3.5.2 The belt slip problem

Belt slide slip is caused by varying load distribution on the drive drum (see above and [3]) and mainly occurs at the lower drum during the start stage when the maximum belt tension-force relationship $T_1/T_2$ (Eytelweiner Equation) is exceeded:

$$\frac{T_1}{T_2} < e^{\mu \alpha}$$

$\mu$ = active friction value between belt and drum
$\alpha$ = drum looping angle

The reasons why slide slip occurs can be clearly recognized in Figure 9 (arrow at lower belt tension path). Due to the sharp increase in starting torque ($dM/dt$ is very high with conventional drives), the vibratory conveyor belt system causes transient recovery to take place.
According to Figure 9 (arrows), the minimum belt tension has the effect of minimal \( T_{k\min} \), and the maximum drive torque as \( T_{k\max} \). Consequently, \( T_{k\max}/T_{k\min} \) becomes extremely large, facilitating slide slip in the starting process. The relevant correlations are also illustrated in [8] and [11].

This fact can be compensated with level and adjusted torque increase during the starting process. This cannot be achieved with conventional drives, pre-tension stages only serve to reduce the problem. Converter drives fulfill this requirement by means of an adapted torque control, torque transient recovery is avoided as much as possible. A further advantage of the implementation of converter drives is the considerable reduction in friction work when belt slip occurs. With conventional units, this generates considerable frictional heat \( A_R \).

\[
A_R = 2 \pi \mu - M_{rel} \cdot \Delta n - \Delta t
\]  

The torque relief (slip) causes the entire speed range from 0 to \( n_{nom} \) to run up immediately. With a controlled converter drive this acceleration is limited to the preset range (in Nochten it is 5%).

As a result, possible slip friction with converter drives amounts to a maximum of 5% of the slip-free work, which can occur with slipping armatures. It therefore becomes apparent that belt slide slip in the starting stage of regulated converter drives is reduced immensely.

Considerable transient belt tension, which puts strain on the belt tightness and positioning, also occurs during the shut-down phase with conventional drive systems (Fig. 10).

These processes are minimized by means of adjusted rundown procedures with regulated belt drives.

3.5.3 Explanation of the starting and load characteristic curves

Converter plants are selectively started up via predetermined start inclines (speed over time, for Nochten 60 s: \( \text{d}v/\text{d}t = \text{constant} \)). The starting torque is therefore adjusted as required in accordance with the load state. As a result the acceleration torque

\[
M_a = J_{ges} \cdot (\text{d}v/\text{d}t) - J_{ges} (1/\text{r}) \cdot (\text{d}v/\text{d}t)
\]

in total is reduced considerably.

With conventional drives, the starting torque is determined by the motor characteristics set for maximum load. In the case of minimum load, the starting torque during start-up is far too high, thereby putting an unnecessary strain on the plant systems.

\[
\Delta T = \frac{M_{gea}}{M_{Manf}} \cdot 1/\text{r} - \Delta v
\]

\( M_{Manf} = \text{motor starting torque} \) is a set value

Previous test results bear testimony to this fact.

Of all the starting processes which have been evaluated, the maximum starting torque achieved was 1.07 \( M_{nom} \). However, starting peak values of 1.35 \( M_{nom} \) are the being aimed at. Starting processes with conventional drives, in full load operation, produce starting peak values of 1.5 \( M_{nom} \) the remaining starting peaks (partial load) lie insignificantly under this value. In practice, the difference between the torque starting peak values (old/new) is 28%. This evaluation is based on the highest quarter-hourly value for transport performance attained during the performance test of December 11-12, 1997:

<table>
<thead>
<tr>
<th>Belt</th>
<th>( M_{nom} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>K63</td>
<td>0.75</td>
</tr>
<tr>
<td>K64</td>
<td>0.75</td>
</tr>
<tr>
<td>K65</td>
<td>0.85</td>
</tr>
<tr>
<td>K66</td>
<td>0.69</td>
</tr>
<tr>
<td>K67</td>
<td>0.70</td>
</tr>
</tbody>
</table>

The average daily temperature was 8.5°C. If these values are converted to -20°C according to (4), the projected parameters are more errorless confirmed. Taking the correlations into account (see also 3.3.2), it must be concluded that some passages of the evaluation procedure for belt calculation in line with DIN 22 101 must be reconsidered for the implementation of converter drives. This especially applies to the determining of the safety factors (12).

3.5.4 Effects on the maintenance of the electrical units

Savings on electrical maintenance are achieved with the following components:

- SF6 switchgear instead of air-insulated units
- Use of encapsulated low-voltage units (MCC technology) instead of half-open units
- Use of decentralized relays instead of centralized low-voltage units
- Use of sensor/actuator bus or field bus installations instead of conventional star-shaped wiring layouts
- Use of converter technology instead of conventional resistance control
- Use of low-maintenance three-phase induction motors instead of slipping armatures
- Use of handheld radios for deactivating belt/stop instead of the more complicated and conventional belt/stop infrastructure (release cords or buttons)
- Installation of switching buildings in container construction next to the drive station in the case of stationary belt conveyor units (avoiding vibratory strain)
- Implementation of on-site inspections using a centrally automated diagnosis system.

Additional expense is only incurred by the cooling system for the converter units (fan, cooling aggregate). In total it has been calculated that a considerable saving in electrotechnical maintenance requirements can be achieved by the concentrated implementation of the measures named above, whereby the savings factor after the introductory phase will be in the upper half of the savings range.
4. Summary

The investment project “Relocation of Coal Loading, Nochten” was realized in the LAUBAG in 1997. This relocation was necessary in order to comply with legal pollution control regulations. At the same time, shortening the rail transport distance brought a considerable economical advantage.

The investment requirements were to be kept to a minimum by the use of existing technical equipment, and attention was to be concentrated on a promising innovation potential. In particular, the aim was to achieve results in

- Energy saving
- Efficient use of operator personnel
- Reduction in maintenance requirements.

This was to be realized in four ways:

1. Energy saving by means of a speed control or regulator throughout the entire coal belt plant
2. Automatic stacking, reclaiming and tran-loading of coal, with low operator requirements and safe operation.
3. Use of an advanced process control system with low operator requirements, with integrated communications structure and multimedia applications
4. Realization of a new maintenance management system by means of situation-relevant, diagnosis-supported maintenance, using contractors in a new complex manner.

These objectives were achieved to the largest degree possible.

In particular, this article has attempted to illustrate the technical concept and the regulation principle, as well as the results which have been achieved and which are expected, of a speed-regulated belt plant. After the theoretical investigations on hand and initial practical experience, the following effects of the use of converter controlled large belt plants compared to conventional plants are considered possible:

- Electrical power consumption: savings of between 15% and 38%
- Mechanical and electrical maintenance expenditure: savings in the main components of between 10% and 30%, in the special components savings of up to 50%
- Plant construction: reduction in the projected drive performance by 15% to 30%, and up to 30% of dynamic belt tension and bearing strain.

The initial experience gained is being implemented in the LAUBAG specification for other projects (conveyor Tgb. Janschwalde, conveyor ATS 306 Tgb. Welzow-Süd). The total completion costs for converter controlled drive solutions will not be greater than those for conventional solutions. The costs for the electrical units will rise by 15% to 20% compared to those for mechanical components (drive performance, output, belt connections, etc.).

The reports that have been presented, and the results that have been achieved, are to be consolidated by the accompanyment of further technical measurements and back-up interpretation, in order to develop further potential in the interest of high economy and decisive cost-savings in lignite mining.

This article has made concrete reference to belt conveyor plants with raw coal, the correlations are similar in the case of barren rock belt conveyor plants; there are however differences in detail. For example the speed adjustment is more balanced, the energy saving from the load dependence is somewhat less (the specific weight of overburden is greater than that of raw coal).

Bibliography