Variable-Speed Belt Conveyors Gaining in Importance
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1. Introduction
In recent years, variable-speed belt conveyors have been introduced for transporting brown coal and ore in open-cast mines in Germany and Chile. The advantages with regard to energy saving, for example, have already been pointed out [1, 2]. In the middle of the year 2000, LAUBAG equipped the Jänschwalde open-cast mine with the first speed-controlled overburden conveyor system with converter-fed three-phase drives. During 6 weeks of trial operations, the agreed technical parameters were verified and the availability requirements stipulated for the system were satisfied in full. It was therefore possible to hand over the overburden-removal system to LAUBAG on time and to budget on June 15, 2000, and to start operating the system in accordance with the terms of the contract.

Due to legal issues relating to land access, however, the system was shut down in July as the result of a legal directive. After a judgement pronounced by the Superior Administrative Court of Frankfurt (on the Oder) on September 28, 2000, it was possible to start operating the overburden-removal installation again, thus enabling continuation of coal extraction and supplies to the Jänschwalde power station.

During planning and implementation of the project, the positive experience gained with the speed-controlled coal conveyor system in the Nochten open-cast mine played an important role [1]. The approach taken there was therefore used as a basis for this project. Basic solutions which had already proved their values were supplemented with improvements in the control systems in order to cope with, for example, the different types of soil encountered during overburden removal. With the so-called inverse method of operation, whereby the unloaded conveyors can be started in a staggered manner in the direction of transport beginning from the bucket wheel excavator, the start-up times were further improved. In addition to this, advanced drive and communications systems, such as the SIMOLINK bus for highly dynamic coordination of the drive systems of a belt conveyor, contributed towards further detailed improvements. A new bus system simplifies communication and coordination between several drive systems of a belt conveyor.

The go-ahead to start work on the overburden conveyor project at Jänschwalde was given on February 10, 1999, when the contract was signed between LAUBAG and a consortium made up of FAM Förderanlagen Magdeburg and Siemens Mining Technologies. FAM took on responsibility for the mechanical engineering portion of the contract and Siemens was responsible for the complete electrical systems. In order to attain the objectives, it was of crucial importance that the customer and suppliers worked closely together with a shared understanding of and adherence to binding project-management methods.

2. Basic Requirements
Due to the approximately 30 m increase in the thickness of the overlying soil in the Jänschwalde open-cast brown-coal mine, a newly installed overburden-removal installation had to start operating at the foot of the "Hornoer plateau" in order to allow preliminary work in front of the 60 m overburden conveyor gantry at the eastern markcation.

In the initial phase of plant operation, the overburden is taken by a SRs 2000 bucketwheel excavator and transported over approximately 10 kilometers on a six-section conveyor belt line. An A2Rs 8800-110 spreader then dumps it. In the first two years, the dump will be used for rehabilitation of a section at the limit of the mine and will later be used to shape the large tipping area. The latter will be done by applying a covering layer around four metres thick which is suitable for cultivation.

In the first few years, this overburden conveyor installation will start with a yearly output of 15 million m$^3$. It will then be lengthened and later supplemented with an SRs 1300 bucketwheel excavator in order to extract approximately 20 million m$^3$ of overburden per year in the final
phase when the length of the section will be 17 km. Depending on how the demand for coal develops, overburden removal will extend as far as the "Taubendorfer-Rinne" washing-out area in approximately 2018 and then stop.

The geological requirements to be expected on the basis of glacial deposits and the relative proximity to residential areas in the direct vicinity had an important influence on the technical specifications as did the performance criteria. The latter included requirements regarding the efficiency of the installation, liquefaction of the excavated material, a high level of known occurrence of rocks and compliance with the stipulations regarding noise emission protection by means of primary measures.

3. Technical Requirements and Solutions

3.1 Drive Technology

The conveyor system for the Jänschwalde overburden-removal section of the mine includes six belt conveyors with the relevant auxiliary equipment such as belt-tensioning device, impact plate, crawler travel gear or lubrication system. In the final stage of the project, the conveyors will be driven by up to four speed-controlled motors.

For controlled three phase drives, converters of different voltage and output categories are available in the form of medium-voltage converters up to and including the megawatt range. Siemens has created similar arive solutions for several conveyor-belt installations in Germany and South America. For the Jänschwalde overburden belt conveyor, low voltage converters (SIMOVERT Master Drives with a rated voltage of 690 V), were selected, similar to the Nochten coal conveyor installation. This was the most economically efficient solution given the required motor outputs of 900 kilowatts and 1250 kilowatts. The conveyor system will be completed in several phases up to 2008. For the first phase, two drives were designed for each drive station.

Power supply, installation space, ventilation systems as well as open-loop and closed-loop control concepts had to be prepared for the final system configuration. In order to keep the interfaces to future systems simple, a separate converter with its own line rectifier and inverter was used for each motor. The parallel connection of several converters to a shared transformer has been taken into account as well as 12-pulse connection of the converters to the power supply (Fig. 1).

Drive control is provided in a technology board in the converters. One of the basic requirements was that the torque at the motor shaft should be limited to a maximum overshoot of +/- 15% of the rated motor torque during dynamic processes such as in the case of starting (t_A = 90 seconds) and stopping (t_B - 40 seconds). Each drive has its own speed controller. The speed controllers have a PI structure and stipulate the torque setpoint. Between drums 1 and 2, a load equalization controller ensures that the load is correctly distributed, taking into account different drive outputs and tolerances, for example in the drum diameters. In order to enable the rapid exchange of signals which is necessary for this, all the inverters of a conveyor station are linked to a SIMOLINK bus which uses a data transfer protocol for extremely fast and strictly cyclical process-data exchange.

3.2 Open-Loop Control of the Conveyor

Each conveyor drive station has its own open-loop control system. The installation is operated and visualized from a control center which is connected to the conveyor control units by means of bus communication.

The software of the individual conveyor control units has a modular structure - with identical modules for the same functions. They include all the control and monitoring functions which are necessary for fully automatic and controlled operation of the installation. In addition, the conveyor control units provide the control center with all the data needed for visualization and control of the installation, for fault location and for monitoring of operations.

The future expansion of the installation, which will involve among other things the inclusion of additional conveyors as well as the use of a second excavator, was taken into account when the control concept was designed.
3.2.1 Speed Control

In accordance with the general technological conditions, the speed of the conveyor system can be controlled automatically and steplessly in a range between 50% and 120% of the rated conveyor speed of 4.91 metres per second.

The main criterion for closed-loop-control is the amount of material on the belt. The aim is to have a constantly high amount of material on the belt along its whole length so that the conveyor installation is operated in the best possible way in order to keep wear and energy-consumption to a minimum.

For this purpose, the following basic information is needed:

- Volume rate of flow (extracted volume per time unit of the bucket-wheel excavator)
- Position of the loading devices at the Gbf71 face conveyor
- Actual speed of the Gbf71 face conveyor

The amount of material on the conveyor is detected and monitored by two laser scanners. The first one is located on the boom conveyor of the bucket-wheel excavator. The detected amount of material on the belt here is simultaneously used as an actual value for the excavator control unit, the aim of which is to enable the transport of material at a rate which is as uniform as possible even where extraction is taking place.

The volume of material per 5 m of belt is calculated from the value measured by the scanner and the speed of the conveyors on the excavator and of the Gbf71. A shift register which is pulsed in proportion to the conveyor speed is used to simulate the amount of material on the belt in relation to the distance. The "length" of the shift register (number of stored volume values) is variable and depends on where the excavator loads onto the belt. This Information is provided by the excavator control unit whereby the position of the excavator is derived from the movements and synchronized to measured reference points. Before transfer to the Gbf75 face conveyor, there is a second laser scanner which is used to measure and verify the original volume value taken at the excavator.

The actual volume values thus obtained are subjected to maximum evaluation and then converted into a speed setpoint or rotational-speed setpoint and passed on to the conveyor control units as a setpoint $V_{st}$.

In contrast to a coal conveyor system, the different characteristics of the various kinds of earth have to be taken into account in the case of overburden excavation. The excavated material at the Hornoer plateau can be classified into four groups:

1. light earth: sand, humus
2. heavy earth: sand, clay, gravel mixture with a clay content of over 50%; boulder clay, sand clay, gravel mixture with a clay content below 50%
3. water-saturated earth (mud)
4. rocks

Depending on the preselected material, the setpoint $V_{st}$ is limited to the following values. The type of material is selected by the excavator operator.

- light earth: 50%-120%
- heavy earth: 50%-100%
- mud: 120%
- rocks: 50% solid *)

*)until the material has left the conveyor

For starting the conveyor, the lower limit (depending on the kind of material) is stipulated as the setpoint $V_{sl}$. Enabling for the load-dependent speed controller takes place at the same time as excavator enabling.

3.2.2 Material Tracking

In order to optimize run-up times and idling times and also for indicating the amount of material on the belt to the control centre, a material tracking system was created.

Beginning at the location of the excavator, a logical link to the conveyor speed is established in order to arrive at a single value which represents the amount of material (volume) in 50 m
slices. This value is passed on in the respective control units of the conveyor stations in accordance with the current speed. When the material is transferred from one conveyor to the next, this value is transmitted to the programmable controller of the next conveyor. Each conveyor is thus able to determine the current amount of material (load) on the belt. In order to prevent loss of the current load value in the event of a power failure, the load values are stored permanently in the control units.

3.2.3 The Inverse Method of Operation - Conveyor System Starting Sequence in Material Transport Direction
In conjunction with material tracking described above, monitoring by means of load measuring devices also enables the so-called inverse method of operation in the Jänschwalde overburden-removal section. This method involves starting the installation by switching on the conveyors in the direction of transport if the conveyor is not loaded, i.e. if the system has previously been operated without a load for purposes of repairs or shutdowns. The system can thus be accelerated to normal operating speed in a minimum amount of time and energy consumption can also be improved.

3.2.4 Impact-Plate Control
For the impact plates at the transfer chutes, four positions which were to be set in relation to the conveyor speed were originally envisaged. During trial operations, however, it became apparent that stepless control of the impact plate in relation to the conveyor speed was necessary in order to avoid belt skowing as a result of material not deposited on the middle of the belt. The most favourable position of the impact plate in each case cannot be linearly derived from the speed and is therefore represented by a characteristic curve which can easily be adapted during operation. In the course of further optimization, the adhesive properties of different types of excavated material are taken into account as well. The position of the impact plate is detected by means of a cable-length transmitter which supplies an analog measured value. In order to prevent oscillation during automatic positioning, an adjustable "dead zone" has been incorporated in the control center, the current position of all the impact plates is shown in the "Drive-station status image".

3.3 Container-Type Switchgear-House Modules
Each drive station has been equipped with a modular switchgear house (Fig. 4). The modules were supplied by FEAG, St. Ingbert, a Siemens company specializing in high-quality modular switchgear-house systems. The switchgear house of each drive station is composed of three modules in which the power-supply and open/closed-loop control units are installed:

- switchgear module with low-voltage and medium-voltage switchgear, control cabinets, OTN cabinet, communication cabinet,
- convertor module with low-voltage converter, battery cabinet and uninterruptible power supply (UPS),
- transformer module with medium-voltage transformers.

A separate walled-off chamber in one of the modules is for installation of the lubrication system. The modular switchgear-house system enables the equipment to be supplied as a functional unit which is ready for immediate connection. Installation of the switchgear as well as preliminary commissioning took place under favourable conditions in the module manufacturer's factory. The time needed for final installation at the mine followed by commissioning under the difficult conditions of open-cast mining was thus considerably shortened. The medium-voltage transformers which, due to their size, had to be assembled locally were an exception to this.

3.4 Multi-Functional Communications Network via an Open Transport Network (OTN)
In the Jänschwalde open-cast mine, a multi-functional OTN communications network is now being used. This is a broadband multiplexer system developed by Siemens-Atea Belgium which, because of its robustness, is especially suited for large open-cast mining installations and is therefore widely used. Instead of several transmission channels for different services, a single redundant channel with four-fiber optical cables is sufficient. These fibers are used to transmit all the process and diagnostic data, all the video and telephony signals as well as the operator inputs.

The Venus system (Video ENhanced Universal Security management system), used for the first time here, is worthy of special mention. This system acts as a "software intersection" and enables simple assignment and connection of cameras to corresponding video terminals (monitors, recorders). This is done either per "mouse click" or as an automatic reaction to certain signals switched through to the system such as those of motion detectors. Parts of the bandwidth of the OTN system are used only for these switched-through signals (Fig. 5). In the overburden-removal section of Jänschwalde, the monitor in the plant protection center can be connected to 7 observation cameras using the VENUS video switching system. Five technology cameras can be connected to a large-scale screen in the control center. The video system is thus used for monitoring the technology of the conveyor, in particular the conveyor transfer points, and for ensuring the safety and security of the installation and monitoring the mining site while making the best possible use of existing communication channels.

4. Professional Project Management
The whole overburden removal complex was initially subdivided into several main parts for tendering purposes.
It was only later that the tender negotiations relating to coordination took place. The result was that FAM Förderanlagen Magdeburg and Siemens Mining Technologies formed an open consortium and took on overall responsibility for the overburden conveyor complex as well as for coordination of the project. Thus the work done by MAN TAKRAF on the mechanical part of the SRs 2000 bucketwheel excavator and of ABB Cottbus on the electrical reconstruction of excavator and spreader as well as extension of central control room were integrated.
Once the contract had been signed on February 10, 1999, the next important step was to make sure that the project was conducted efficiently, to group the work into packages and to plan resources. The detailed engineering was prepared in a very short time. Handover of the specifications for the electrical engineering equipment began as early as March 8, 1999, and, on March 17, the building site was opened for the large equipment. Installation of the electrical equipment began on July 7, 1999.
On June 16, 1999, the mechanical installation of the conveyor components started, followed by the electrical installation from September 4 onwards. The first completed switchgear-house modules were mounted on October 14, 1999.
In order to control the tight chronological sequence efficiently in terms of dates and content, a highly effective project controlling system based on coordinated time schedules was implemented in cooperation with the contractual partners.
On the basis of the working principles agreed on in writing by the main project managers involved, a climate of openness and mutually-supportive collaboration was created which ensured efficient cooperation over the whole period of the project.
In addition, the advantages of the Internet were fully exploited for the transfer of pictorial and planning documents. The resulting advantage in speed enabled project corrections to be implemented quickly and efficiently. The costs of business trips were considerably reduced for both parties by a staggered schedule of meetings for consultation and coordination. The use of electronic visualization equipment also substantially reduced the time needed for consultation and record-keeping.
Because the main aspects of controlling for all the contractual partners were identical, the customer was able to achieve a significant reduction in costs in his final financial accounts. The increase in clarity and mutual support was of significant help in handling the interfaces external to the project, i.e. for the provision of a power supply system and other infrastructure facilities.
The reconstruction work on the large equipment had to be completed as early as January 2000 so that the system could be placed in the position required for operation over a distance of approximately 10 km.

On March 31, 2000, when approval was given for operating the overburden-removal complex, the system was put into operation for one month without any stipulations regarding output as a condition for combined trial and productive operation. This was done over a defined period of 60 capacity shifts with binding availability criteria, the aim being to verify the required characteristics of the system.

On the basis of clear and shared quality management, it was possible to use the 15 additional optimization shifts which had been defined in advance (without any output stipulations) so that the installation was handed over on time on June 15, 2000, without any delays or claims during the construction process and attaining project safety targets. Moreover, the concrete goals of the project had been attained and all this had been done within budget.

5. Summary and Initial Operational Experience

Due to the geological conditions, it was not possible to run through all the possible eventualities of operation under full load conditions during the trials. An agreement was therefore signed to the effect that there would be a subsequent phase of "fine tuning" without any interruption to production.

Given the experience gained with the quality management system already implemented, it was possible to define measures in this phase and systematically put them into practice. The following are some examples:

- Optimization of speed-controlled impact-plate control in relation to the material transported as an essential prerequisite for ensuring correct alignment of the belts throughout the whole controlled speed range by placing excavated material in the middle of the belt.
- Various setpoint adaptations for optimum use of the performance reserves of the whole system with account being taken of the utilization situation of the drives on conveyor section 77.

During this phase, overburden removal had to be interrupted completely for one month due to a legal decision forbidding encroachment on adjacent woodland.

Subsequent to work recommencing, the optimized installation was already able to achieve daily outputs of 80 000 m$^3$ (loosened) and a peak output of more than 100 000 m$^3$ (loosened).

These output levels are expected to be the benchmark output levels as a result of the new kind of link between process values and operations and personnel management.

The described conveyor system of LAUBAG in the Jänschwalde open-cast mine is regarded as a pioneering, modern and innovative installation. The first-time use of controlled drives for overburden transport also enables load-dependent transport speeds. Sophisticated control concepts for the way in which the whole installation is operated have lead to better utilization of the installation. This is resulting in considerable improvements in the business figures [2], one of the reasons being the substantial energy savings. Noise emission levels of the conveyors have been significantly reduced. Modern diagnostic systems reduce downtime by assisting maintenance personnel diagnose and quickly rectify faults. Operational data collected by the system allow staff to analyze and optimize system performance. As a result, the operating costs are substantially reduced in comparison to conventional installations.

References


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Fig. 1: Configuration of converter ATS 79
Fig. 2: Conveyor drive station ATS 71
Fig. 3: Delivery and conveyor
Fig. 4: Switchgear house plan
Fig. 5: Venus system

Pictures available on request!

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Published in "Surface Mining", Trans Tech Publications, Clausthal-Zellerfeld, Germany, No. 1, March 2001, pp. 65-72