CHUQUICAMATA UNDERGROUND MINE PROJECT
POWERFUL CONVEYORS WITH GEARLESS DRIVES IN OPERATION

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INTRODUCTION

In 2019, Codelco's Chuquicamata mine – situated in northern Chile and one of the world's largest copper mines – was converted from an open-pit mine to an underground operation.

Over 100 years of open-pit mining had resulted in a mine that was some 1 000 m deep, 5 000 m long and 3 000 m wide. Once the rock had been mined by drilling and blasting, the ore and waste material was transported to the surface by trucks for processing or for disposal.

However, it was becoming no longer economically viable to mine deeper ore bodies using this process. Moreover, longer truck routes combined with a larger number of vehicles resulted in higher costs for vehicle maintenance and fuel, together with increased environmental pollution and safety concerns.

TAKRAF was awarded the contract to supply the principal ore transportation system moving crushed copper ore from underground storage bins to the surface processing site.

The system called for no redundancies, which meant that high system availability, minimal system wear and easy maintenance of components was critically important.

The project scope called for:

- Removal of crushed ore from 60 m high underground storage bins with a conveying capacity of 11 000 t/h
- Transportation to the surface with a minimum number of material transfer points
- Conveying of the ore from the underground tunnel exit to the existing processing plant, taking into account existing infrastructure

In designing the system, numerous innovations resulted in six patents being implemented, resulting in a modern, powerful and environmentally friendly conveyor system. Highly efficient electric drive motors replaced diesel truck engines and as a result, CO_2 emissions produced by transporting the material have been reduced by more than two thirds for the same copper production volume.

OPTIMISED UNDERGROUND BIN DISCHARGE

The conveyor system as described in this paper starts with the discharge of two large underground silos (Silo North and Silo South), each with the following dimensions of 60 m in height and 6 m in diameter.

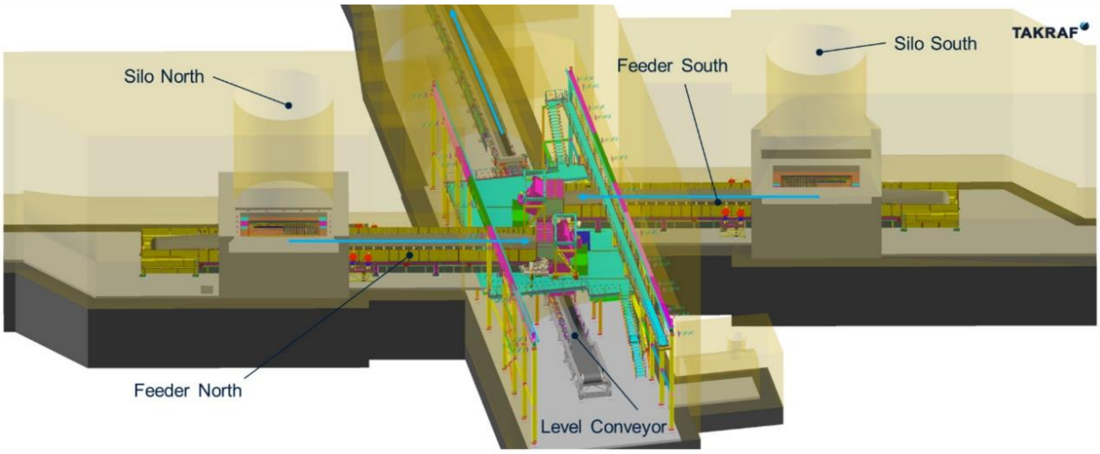

Figure 1: North and South silo arrangement.

Both silos are filled with copper ore from underground mining operations. The silos and their storage capacity thus separate the underground mining system from the conveyor system that brings the ore to the existing aboveground processing plant.

How to discharge silos of this order of magnitude?

As the standard solution, belt feeders or apron feeders are a typical design for silo discharge. However, with a distance of approximately 35 m between the center of the silo and the upstream transfer point, both standard solutions would lead to high frictional resistance, as a result of the sliding of material along the entire sidewall length.

As the main disadvantage, such conveyors would require increased maintenance efforts for frequent wear plate exchange while the sliding resistance would lead to significant energy consumption.

As the result of a system optimization study, a feeder-conveyor was identified as offering a more suitable design for the intended application. Such a feeder conveyor combines the advantages of a belt feeder for silo discharge with a standard trough belt conveyor for conveying.

Boasting the same belt width as originally planned for the original belt feeder concept and an idler trough angle of 45°, the maximum belt speed was increased to the required value in order to reach design capacity without material running on the skirts outside the feeding hopper.

As with the belt feeder, the material height on the belt outside the silo has to be adjusted with a shear gate. With the feeder conveyor, this shear gate has a circular shape and creates a material shape on the belt that fits to 100 % cross section as per CEMA definition.

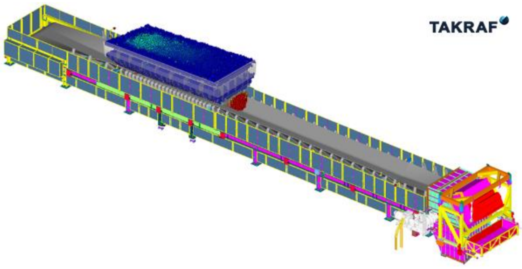

Figure 2: Feeder conveyor – 3D model.

Figure 3: Feeder conveyor – picture.

While the material shape remains constant (due to the shear gate design), the belt speed needs to be adjusted in order to achieve the conveyor capacity as requested.

A Discrete Element Method (DEM) analyses was employed in order to verify material behaviour during silo discharge, in order to determine forces on the belt and to validate the maximum required belt speed.

As the outcome, the feeder conveyor has to run at a maximum speed of 1.75 m/s in order to achieve the design capacity.

After commissioning, measurements on site have confirmed all DEM results.

Comparing the feeder conveyor with the original belt feeder concept it was possible to:

- Save 25 % of energy for conveyor operation
  (no friction between skirts and material outside the hopper area)
- Reduce wear and effort for wear plate exchange
- Reduce belt strength

The hopper outlet design defines the material flow. In order to minimize power consumption for hopper discharge and to reduce belt wear, a constant material discharge along the entire hopper outlet is important.

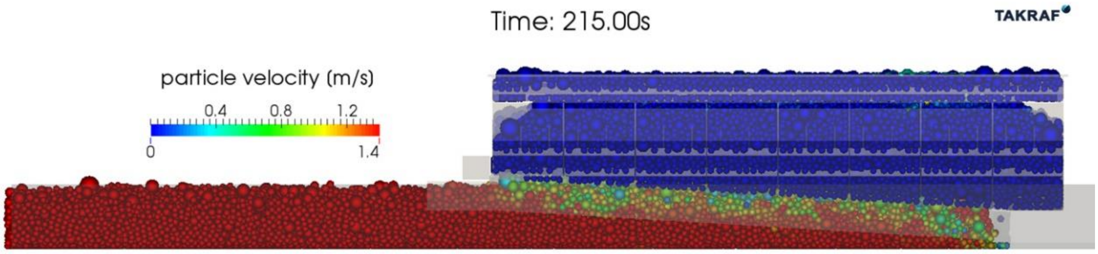

Figure 4: Particle speed at feeder conveyor discharge (red colour = belt speed).

The hopper outlet design was adjusted in order to reach these parameters. As the DEM shows, there is a material bed along the hopper outlet moving with belt speed. There will be no increased belt wear compared to a belt feeder running with a reduced belt speed.

MATERIAL TRANSPORT FROM UNDERGROUND TO THE SURFACE

The main transport system from underground to the surface utilises two principal conveyors with 6,400 m in overall length (pulley centre distance), which lift the material a total of 950 m.

A downstream conveyor system connects the different mining levels to the loading section of the first principal conveyor. For the first mining level, the downstream conveyor system consists of two belt conveyors with approximately 900 m in length.

While the downstream system will be adapted to each mining level, the principal conveyors remain unchanged during the entire life of the mine.

The major task of the project was the development of a principal conveyor arrangement with high availability, reduced wear and a high degree of maintainability.

Each underground transfer point along the tunnel requires an underground chamber with a crane for maintenance work, power supply, transformers and electrical and mechanical drive technologies, with adapted ventilation and suitable access paths.

Figure 5: Underground transfer point during the construction phase.

In order to minimize the number of transfer points, the inclined conveyor section was successfully developed employing just two conveyors. In order to achieve this feat, it was necessary to use newly developed components that redefine the performance limits of belt conveyor technology.

ST 10,000 quality conveyor belts were employed for the first time. Operating belt safety ratings of S = 5.0 require belt connections with a reference fatigue strength of minimum 50 %.

With the newly developed splice technology, a further increased splice fatigue level of 60 % of nominal breaking force was proven on the belt test rig at the University of Hanover in Germany.

Once again, new dimensions were achieved - this time in terms of installed drive power - with 10,000 kW of installed drive power per drive pulley and 20,000 kW per conveyor.

The drivetrain was developed in cooperation with the drive motor manufacturer. The main components of which are:

- 5,000 kW synchronous motor, external excitation
  - nominal speed 53 rpm, nominal frequency 7.07 Hz
  - stator voltage 2,800 V, stator current 1,061 A
  - air to water cooling
  - MV Frequency Converter ACS 6,000
- Membrane coupling to connect the pulley shaft and rotor shaft
- Drive pulley

With the following specifications:

- Simple alignment and motor air gap adjustment during installation of the drive
- Simple readjustment in the event of motor air gap deviations from the set point (e.g. after settlement)
- Complete and fully-assembled factory-tested motors on site (no motor assembly in the dusty environment)
- Simple separation of the connection between pulley and motor in the event of an accident (in order to ensure continued operation of the system for the short term with a reduced number of drive motors)

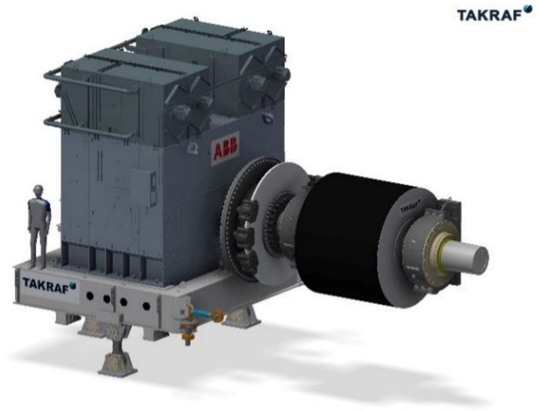

Figure 6: 5 MW drive train arrangement.

Figure 7: 5 MW drive as installed.

Maintenance of the air gap between the rotor and stator is a crucial requirement for the operation of the motors. The air gap, which is 14 mm, must only be allowed to deviate from the set point within small tolerances. Deviations in the air gap reduce the efficiency of the motor, and if the rotor and stator were to make contact with each other, it would result in damage to the motor.

The air gap itself is continuously monitored during operation. If deformations and/or subsidence in the steel structure or in the motor foundations lead to a deviation in the air gap set point, the stator has to be realigned.

To simplify this process, the spacing between the rotor and stator at the non-driven end of the motor was fixed by a support bearing.

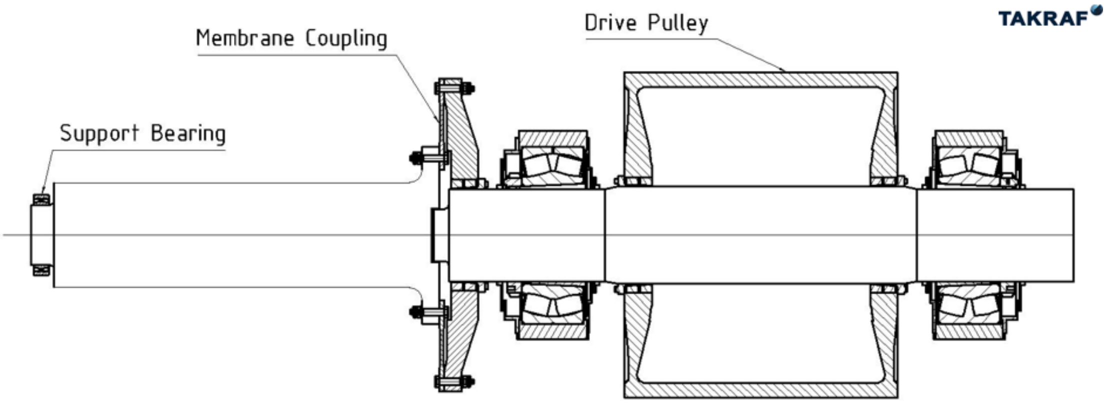

Figure 8: Mechanical components of the drivetrain.

A membrane coupling compensates for the deformation of the pulley shaft caused by belt tension. The adjustable motor frame facilitates alignment of the motor during installation and ensures simple realignment if necessary.

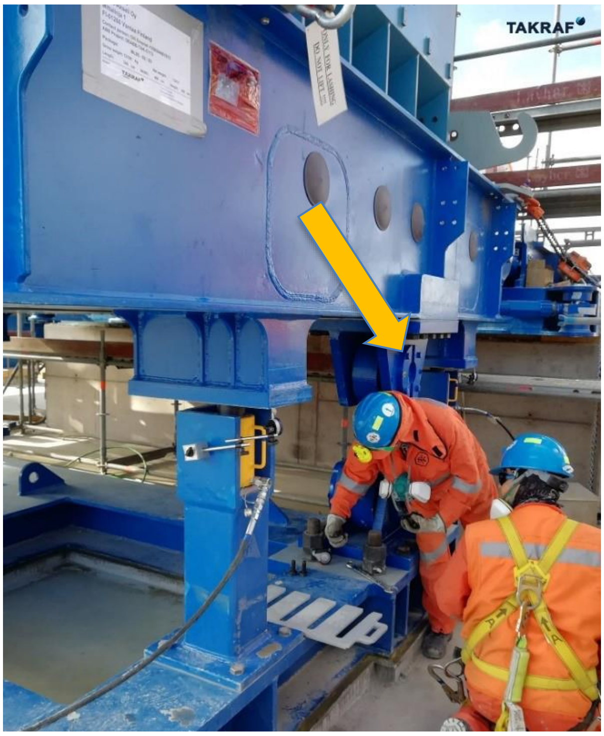

Figure 9: Motor alignment during assembly.

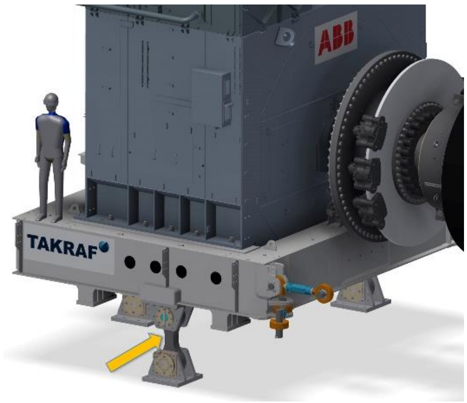

Figure 10: Motor adjustment using eccentrics and spindles.

Eccentrics and spindles allow the stator to be adjusted in all directions. Should a motor fail, it can be quickly moved into a disabled position by opening the membrane coupling and adjusting the spindles. The system can then continue to operate only with reduced power.

Customised for the high belt tension level at conveyor head end drive pulleys with the parameters:

- Max resultant belt tension 6,100 kN
- Drive torque 2 x 900,000 Nm

were developed. The pulleys with a diameter of 2,500 mm are hot vulcanised with rubber lagging. Single pulley weight inclusive coupling is approximately 60 tons.

With a maximum shaft deflection at the membrane coupling of 0.7 mm the influence of pulley shaft bending on the motor air gap is very low.

Figure 11: Drive pulley with brake disk and membrane coupling half at the fabrication facility in Lauchhammer, Germany.

Gravity take-up stations were employed at the tail end of both principal conveyors. The dynamic behaviour of the conveyors was calculated for all start-up and ramp-down scenarios. The take-up distance considers the take-up pulley movement in all relevant load cases.

FROM THE UNDERGROUND TUNNEL’S EXIT ON THE SURFACE TO INTEGRATION WITHIN THE EXISTING PROCESSING SYSTEM

The landscape surrounding the processing plants has been shaped by over 100 years of mining at Chuquicamata. In addition to the various processing systems, waste heaps, train tracks, roads, pipelines and buildings scar the landscape.

The challenge for the new conveyor system was to design a system that took into consideration this landscape for its entire length from the end of the underground tunnel to the processing plant more than 5 km away.

Figure 12: Overland conveyor OLC-01 passing over existing infrastructure.

A continuous single flight conveyor with the following parameters was developed:

- Distance of 5,330 m between the material loading point and material discharge with a difference in height of 287 m
- Horizontal curves with tight radii (1,600 m to 2,300 m) on more than 60 % of the conveyor's length
- Approximately 50 % of the conveyor's length on elevated structures, with variable lengths adapted to local conditions for foundation positioning and with support intervals of up to 96 m

At the material discharge point, a bunker building performs a limited material storage function. Two feeder conveyors remove material and feed it to the processing plants.

Figure 13: Bunker building with material discharge from the overland conveyor OLC-01.

Three 5,000 kW direct drive motors drive this conveyor, with a ST 6,800 conveyor belt with a belt safety of S = 5.1 being used.

SPECIAL CONSIDERATION OF LOW WEAR AND HIGH MAINTAINABILITY

Here again, conveyor design revolved around ensuring high system availability, minimal system wear and easy maintenance of components.

All loading points along the conveyor route were designed in order to reduce conveyor belt wear.

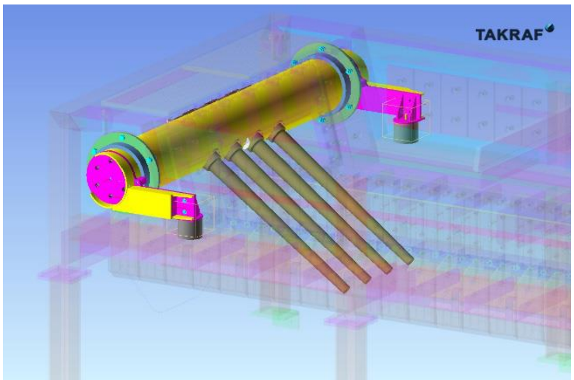

Figure 14: Grizzly finger arrangement at loading section.

The arrangement of the rock boxes and grizzly fingers was verified with simulations also employing DEM.

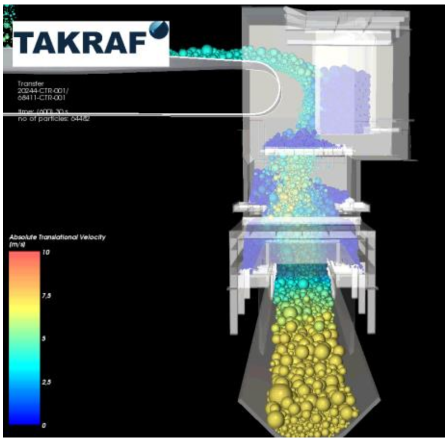

Figure 15: DEM simulation of the material transfer.

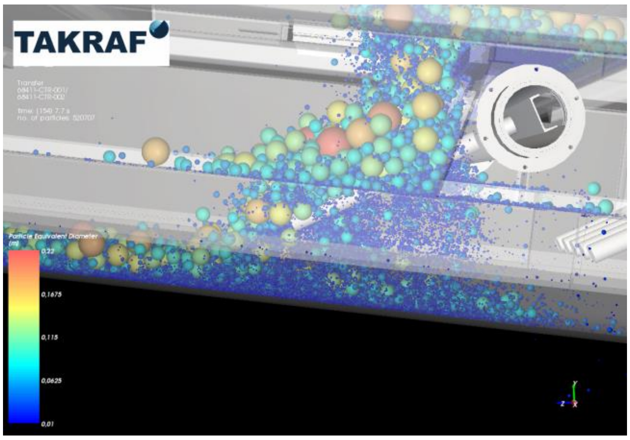

Figure 16: DEM simulation of the material transfer showing the grizzly finger in operation.

The grizzly finger separates the fine material from the larger lumps as the figures 15 and 16 show. There is a material bed of fines to protect the belt from the impact forces of larger particles.

To simplify wear part exchange, a modular system of the entire feeding area with individual segments allows for the easy and quick change of segments at site. The real wear part exchange is performed at the workshop.

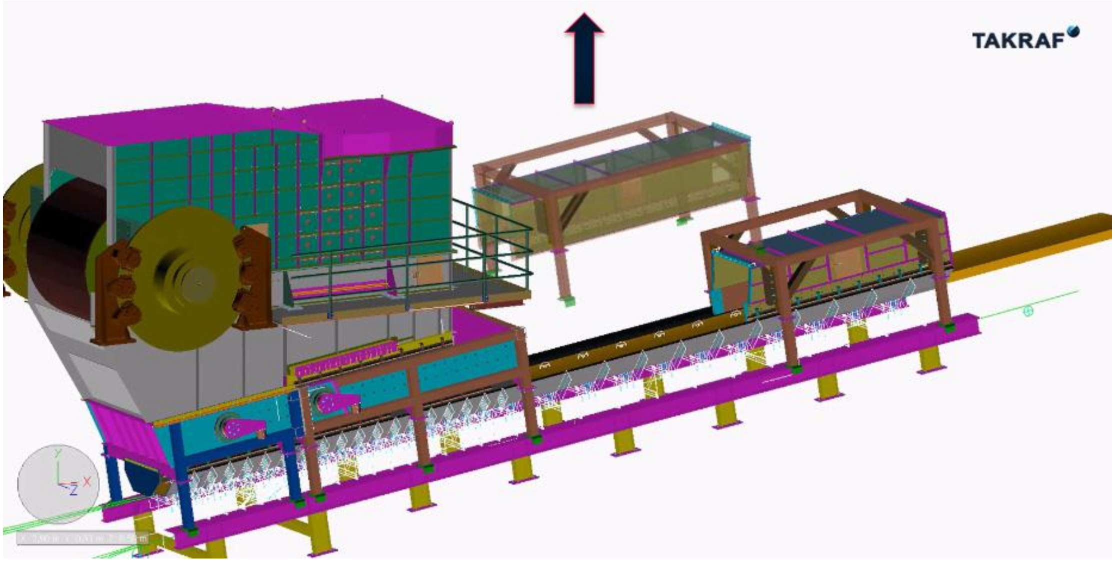

Figure 17: Modular chute system for quick segment change.

Newly designed transfer chutes allow wear plates to be replaced quickly and easily. In areas where a modular system was not applicable, the wear plates can be changed from the chute outside.

Figure 18: Chute inside.

Figure 19: Chute outside.

The wear liners in this part of the chute are readily accessible from the outside and can be changed from the outside. Therefore, a more frequent change is quite acceptable. The thickness of the liners can be measured from the outside while the conveyor is running. The change of a liner - taking the old one out and putting the new one in - will take less than 5 minutes. Figures 17 and 18 show a liner change in a test chute. The whole change took 90 seconds.

To replace idlers, a specially designed maintenance cart is able to travel along the conveyor path of the overland conveyor, enabling the conveyor belt to be lifted and worn idlers to be safely and efficiently replaced.

Figure 20: Maintenance cart for safely lifting the belt and replacing the idlers.

Special cover hoods are developed and tested in the workshop. The new design allows easy installation and disassembly. The condition of the idlers can be checked using visual and acoustic diagnostics by sensors or maintenance personnel without cover removal.

Figure 21: Belt cover sample installation at the workshop and fabrication facility in Lauchhammer, Germany.

SUMMARY

The Chuquicamata underground conveyor system has been in operation for more than three years. System parameters such as a ST 10,000 conveyor belt and 20,000 kW drive power per conveyor redefine the limits of belt conveyor technology. This made it possible to achieve the goal of reducing the number of underground transfer points, thereby justifying the use of these components.

High system availability, minimal system wear and easy maintenance of components were essential criteria when designing this system. Numerous innovations that resulted in six patents were implemented for the first time, resulting in a modern, powerful and environmentally friendly conveyor system. Highly efficient electric drive motors replace diesel truck engines and as a result, CO_2 emissions produced by transporting the material has been reduced by more than two thirds.

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Mario Dilefeld studied Mechanical Engineering at the University of Magdeburg, specialising in materials handling. Following his graduation, he earned his doctorate at the Institute of Materials Handling and Construction, Steel Construction, Logistics in Magdeburg.

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