VOITH TurboBelt 780 TPXL

New Fill Controlled Hydrodynamic Coupling

For

High Power Belt Conveyor Drives

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ABSTRACT

Mine operators, conveyor system designers, consultants and manufacturers have had opportunity over the past decades to utilize various actively controlled technologies to drive complex open pit conveyor systems. These technologies included several electrical, mechanical, hydrostatic and hydrodynamic drive solutions.

All of these technologies have their inherent advantages and disadvantages, and only after several years of operation can mine operators fairly evaluate the overall benefits (short term performance & cost vs. longer term operational and maintenance costs) of any particular drive. One of the primary drive technologies used in many open pit mines is slip ring motor drives. Slip ring (or wound rotor) motors can provide limited acceleration and operational control by using either liquid rheostat starters or solid resistor (binary stack) starting equipment. Due to the costs and maintenance associated with liquid rheostat starting systems, most mines today prefer to use the solid state resistor technology. This technology however produces sharp torque fluctuations which can cause detrimental effects on the conveyor.

Newer electrical technologies such as variable frequency drives (VFD) have been used in recent years due to the perceived desirable - but sometimes misleading - benefit from variable speed operation. Although this technology can provide added operational benefits for those limited applications requiring variable conveyor speed operation, this benefit comes at a significant additional cost of ownership, as the technology has a proven limited life (in comparison with a typical mine life cycle) and limited long term product support.

The hydrodynamic fluid coupling however, is based on technology which has been applied successfully in conveyor applications for decades. Although the base hydrodynamic technology is well proven and has inherently beneficial characteristics on conveyor applications, Voith has continuously improved on this technology to meet the increasing demands of today's challenging conveyor haulage systems. Following the Voith strategy of sustainable growth, innovation has always been tightly combined with long term customer support, provided by a global sales and service organization. As a success of this strategy Voith has become the global market leader of hydrodynamic drive solutions - not only for conveyor systems but in other application fields as well.

Recognizing a need in the market for a reliable, actively controlled drive system for the special requirements in open pit mines and other high power conveyor applications, Voith Turbo began development in 2009 of a new, actively controlled coupling which was targeted specifically for the higher powered, complex belt conveyors systems driven by 6 and 8 pole motors with 900 to 1200 rpm rotational speed.

Voith has launched the new fill controlled TurboBelt 780 TPXL coupling in 2011, and the first installations for this new technology are going to be commissioned soon in South America.

This paper will provide an overview of the TurboBelt 780 TPXL capabilities and reliability as well as detailed measured data about its performance based on the development process and operational experience.

Content overview

1. Introduction

The idea to transmit power in a rotating machine without any physical contact between the rotating elements using solely the energy of a rotating fluid is as old as some hundred years. Already at an early stage of the development of high power engines and technical machinery at the end of the 19th Century, the German scientist Hermann Föttinger realized that driving machines and driven machines pose different requirements to engineers and have accordingly very different mechanical properties. His patent from 1905 describes the principle of the hydrodynamic transmission and coupling. This is well known as the Föttinger-principle. His first hydrodynamic couplings were designed in order to dampen torsional vibrations in steam ship drive trains.

Voith considered the promising performance of this technology as substantial, and started to develop hydrodynamic transmission solutions in the 1920s. The last nine decades brought an impressive wide range of products all using the inherent benefits of the hydrodynamic transmission (fig.1):

- Wear-free power transmission
- Very high torque transmission capability
- Unmatched damping performance of vibrations and torque surges
- Controllability of speed and torque
- Excellent torque limitation characteristic
- Very reliable solution

During the last decades the range of applications has been expanded. Power plants, locomotives, trucks, mining equipment, conveyor systems, and oil & gas production equipment have all benefited from the Voith innovations.

The introduction of modern development tools as 3D-design tools, CFD analysis (computational fluid dynamics) as well as real-time data logging in field tests have contributed to the incremental innovation capabilities of Voith. Thanks to this innovation power combined with many decades of experience, Voith has become the global market leader for hydrodynamic power transmission solutions.

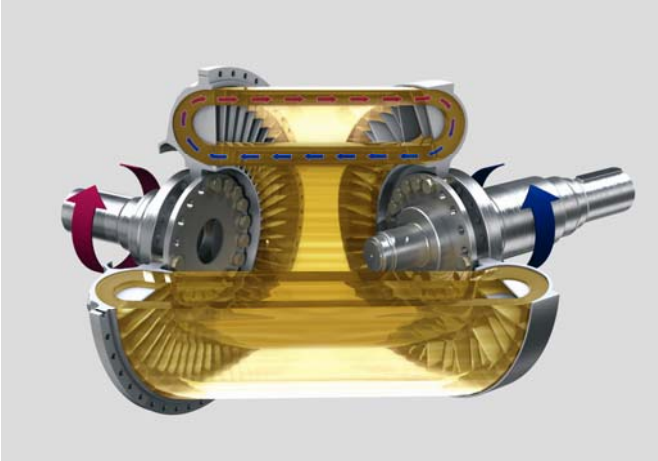

Fig. 1: Wear-free power transmission by hydrodynamics with pump wheel (left) and turbine wheel (right)

2. Hydrodynamics in Mining and Materials Handling

The Start-Up Components Division of Voith in Crailsheim, Germany has focused its development on the mining and materials handling applications. These applications require smooth start-up control as well as efficient and reliable long term operational performance. Some applications also must accommodate severe overload conditions (loss of a drive from a multiple drive conveyor) and high break away conditions (blocked chute conditions). Finally, many conveyor applications also need the drive to provide unlimited reduced speed operation (empty condition) for the purpose of maintenance and belt inspection.

Constant fill and fill controlled Voith hydrodynamic couplings are well recognized in the industry. A variety of solutions were born through the last decades for belt conveyors (fig.2), chain conveyors, stage loaders, crushers, fan drives and other high power applications. They all share the following advantages:

Fig. 2: Installation of a Voith Turbo Coupling between motor and gearbox using connecting couplings

- Gentle torque response
- Wear-free power transmission technology
- Natural load sharing properties on multiple drive conveyors
- Long service life (> 10 years without a rebuild is common)
- Extra capacity to start overloaded systems (taking full advantage of the breakdown torque capacity of the motor is required)
- Stable performance characteristics which are not adversely affected by heat (normal temperature excursions for start up do not degrade coupling components, performance, or life)
- Wide power range per size, allowing for use with larger motors on future applications
- Easy to handle proven reliable solution
- Protects motor and other drive line components

Evolution of the bladed wheel profile

In order to fulfill the customer requirements regarding torque characteristics, heat capacity or the controllability of torque Voith optimized the hydrodynamic behavior of their couplings. At the core of the hydrodynamic behavior is the circuit profile of the pump and the turbine wheel. Thus the development of the blade profile for particular requirements is crucial. Since the original Föttinger concept Voith has introduced several significant development steps.

Constant fill couplings have a special requirement regarding profile, since the oil volume is constant. Transmitted torque is a function of oil filling level. In order to start up a motor almost load free a low filling level is needed, while the continuous operation mode requires almost full filling for efficient torque and speed transmission. On constant fill couplings this filling transition has been realized using specially developed profiles with added volumes at the inner diameter - in order to reduce filling during the equipment start, and later also by creating additional volumetric chambers such as the delay chamber and annular shell (Voith TVVS).

Increasing power demand led to the use of fill controlled couplings, allowing the control of the fill level (and fill rate) using PLC control systems. The controlled start up of these more critical conveyor applications were now possible, even taking up to several minutes. For these requirements Voith developed a torque-optimized blade profile which works perfectly at all filling rates when running at standard 1500/1800 rpm. Under operation filling can actively be controlled from “empty” (no torque transmission) to “full” (maximum efficiency).

3. XL Technology Development

Voith continuously works on increasing the efficiency and power density of hydrodynamic transmissions. This resulted in a new proprietary circuit profile which increases the volume of pump and turbine wheel. The first implementation of the so called XL technology has been optimized for a very high torque ratio in order to start up high overloads. Such is most favorable for crusher and chain conveyor applications.

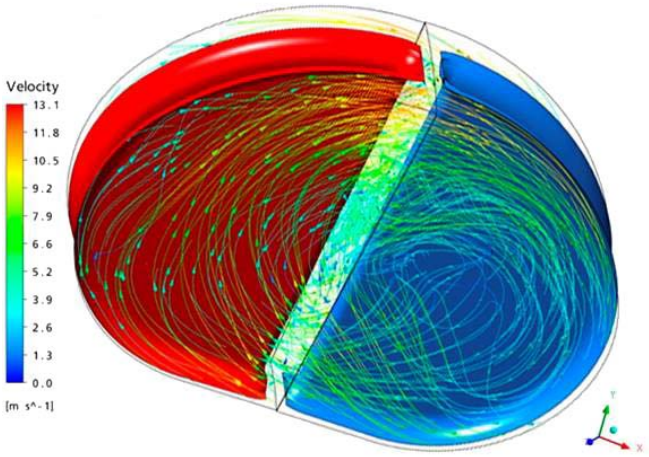

Fig. 3: The TurboBelt 780 TPXL is the first fluid coupling to be developed and built based on CFD Simulation

The next development for belt conveyors was a revolutionary step in the history of the hydrodynamic couplings, since speed of innovation has been increased tremendously. It is the first time that the use of a CFD (computational fluid dynamics simulation) tool has not just supported the optimization of a design, but was used to determine it from start to finish. The outcome (fig. 3) is a new special profile shape based on the XL technology. As a result the runners transmit twice the power across the entire performance range of the coupling - with the same diameter. The torque behavior over speed was optimized to provide some significant advantages for constant load systems like e.g. belt conveyor drives.

4. Market for innovations

Successful Belt Conveyor Applications

Fluid couplings on belt conveyor drives are no novelties. Hundreds of thousands of Voith constant fill fluid couplings protect drives as well as the belts all over the world. Voith's high power fill controlled couplings have been introduced to the market many years ago. The first fill controlled coupling for a belt conveyor drive was built for China Steel in Taiwan in 1976 (fig. 4). This coupling has served under the extreme conditions of a blast furnace at the feeder drive. The first order for a spare unit for backup was placed in 2010, while no coupling-related downtime occurred over the full period of 34 years. Voith was able to build a new coupling according to the original specifications as the customer requested.

Fig. 4: Blast furnace feeder application for robust fill controlled fluid couplings

Figure 5 shows the first fill controlled coupling application on a long overland conveyor in the Obed Mountain Coal operation in Alberta, Canada. The drive with the coupling was commissioned in 1982 and worked till 2008 without any downtime due to a coupling failure.

Many underground mining conveyor applications in the United States have benefited for decades from the advantages of hydrodynamic couplings. One of the major innovation steps was the introduction of the TPKL, a closed loop controlled robust drive solution for mining applications. The first TPKL drive lines in the U.S. were delivered and successfully commissioned in June of 1998 to a longwall mine in Alabama. More than 300 conveyor drives followed in the domestic market, and over 700 worldwide in every major mining area. Recorded data in U.S. underground mines show an uptime with Voith TPKLs higher than 97% over a long period. More recently, several of the drives that were installed from 1998-2001 in underground coal mines were rebuild for a fraction of the price of a new TPKL, and will again be conveying tons of product for decades to come. It is not uncommon to expect a Voith TPKL drive to produce in excess of 100 million tons of coal before the first overhaul.

Fig. 5: Reliable service for decades

Open Pit Mining Market Requirements

Open pit mines operate different conveyor drive technologies. Although four (4) pole motors are a common solution in many mining conveyor application, higher capacity open pit mines have often specified 6 or 8 pole motors due to the improved gearbox performance resulting from the reduced input speed. The existing Voith fill controlled couplings have been so far optimized for 1500/1800 rpm speed of the 4 pole motors. Voith recognized the performance advantages of the XL technology for these slower speed drives, and developed the new TurboBelt 780 TPXL specifically designed for the 6 to 8 pole motors.

Open pit conveyors (fig. 6) with 6 to 8 pole motors have some unique features to be considered:

- 900 to 1200 rpm speed
- Often using slip ring motors
- Power range from 950 to 2700 HP
- High tonnage (e.g. 12,000 mt/h)
- Medium length
- Frequent starting

Fig. 6: Open pit mine conveyor line in Germany

Typical drive related requirements of the customers in this market are:

- Improved belt protection
- Very high availability
- Easy maintenance and ease of handling
- At least 3 consecutive starts or more are desired
- Optimized for the speed range of 6-8 pole motors
- Cost saving potential
- Standardized drive modules

Figure 7 shows a typical design configuration of this kind of belt conveyors.

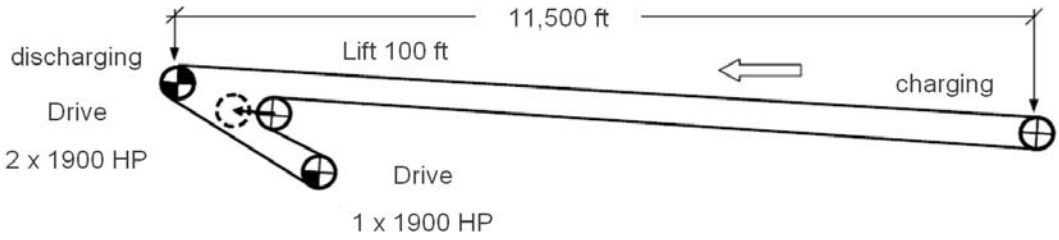

Fig. 7: Typical configuration of an open pit mine conveyor

5. The TurboBelt 780 TPXL

Key Facts

The TurboBelt 780 TPXL (fig. 8) is the response to the market requirements identified in chapter 4. The overall characteristics are optimized for very smooth acceleration of heavy masses and simplified control in belt conveyor applications. The highly integrated and compact design eases commissioning and benefits handling on site - especially on mobile belt conveyor units.

Fig. 8: The TurboBelt 780 TPXL

- Proven, wear free and reliable hydrodynamic technology
- Protection of belt and all drive components
- 50 % smaller and lighter than comparable couplings
- 100% higher power transmission compared to couplings of same size
- Multiple consecutive start-ups possible
- Start-up time of up to several minutes
- Rated power 1500 HP @ 900 rpm
- Rated power 2000 HP @ 1000 rpm
- Rated power 2600 HP @ 1200 rpm

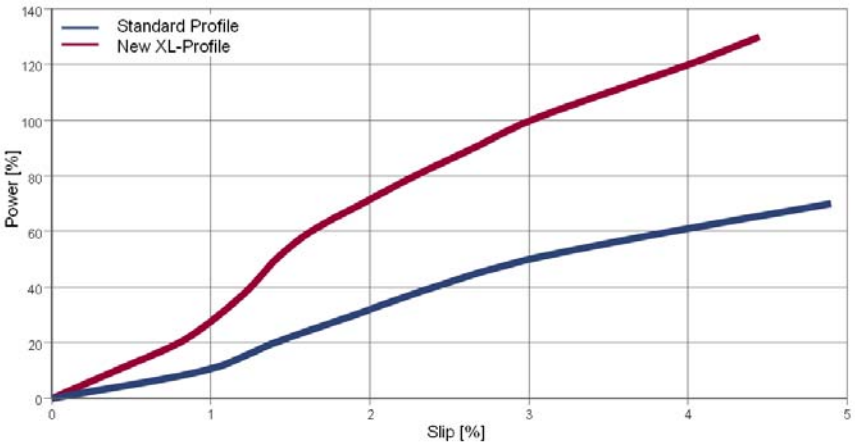

Diagram 1: Comparison of power density

The most impressive feature of the new coupling is its output power rating. Compared to the standard circuit design of conventional couplings, the new profile has been optimized to

generate a considerably higher amount of power transmitting flow while the outer diameter has been retained. Diagram 1 shows that at a slip rate of 3% the transmittable power exceeds the standard coupling design by 100%, i.e. the power is doubled with the same size of coupling. This enormous power density allows very compact drives - especially in applications where drive systems are mounted directly to the drive drum (pulley) of the belt conveyor (such as mobile conveyor systems).

Compact Design

The majority of available fill-controlled hydrodynamic configurations require two separate connecting couplings. The Voith TurboBelt 780 TPXL reduces space requirements on two accounts:

- The power density of the system is increased fourfold due to the new wheel profile
- The optional double circuit - which reduces the coupling radial dimensions considerably.

Additionally, the coupling is flanged directly to the motor. This means that there is no need for a connecting coupling between motor and coupling. The entire drive is therefore significantly shorter. As a result, the size and weight of the coupling system is 50% reduced compared to current standard solutions - an enormous benefit, especially for movable belt conveyors. The compact design (fig. 9) also makes handling during pre-assembly, transport and field installation much easier.

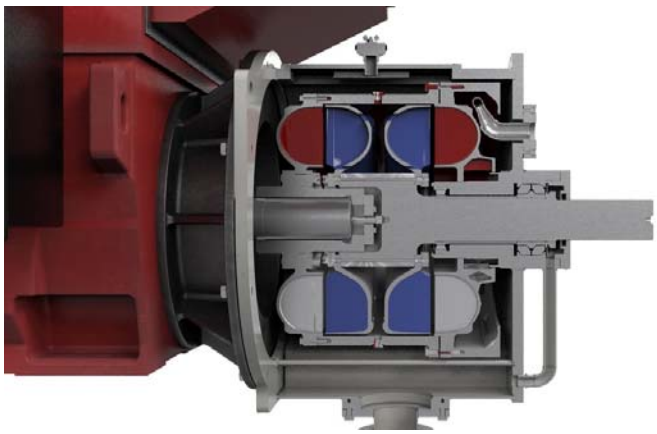

Fig. 9: Overview of the TurboBelt configuration with its double circuit and the new profile design

Reliability and Long Service Life

The hydrodynamic concept allows wear-free power transmission, which enables virtually maintenance-free operation. The encapsulated design with fabricated steel housing material thicknesses of up to 1 inch allows coupling operation even under the most severe conditions.

The roller bearings are designed for an L10 service life of at least 80,000 operating hours. Different to other start-up solutions the material and the mechanical structure are not exposed

to high heat load changes. The active oil cooling circuit maintains an optimum temperature and provides a long service life of the oil and all parts. As a result, the availability rating of the coupling achieves up to 99 %. Larger overhauls are usually not due for 10 years, and often only after 15 or more years of operation.

Simplified Control and Operational Features

Thanks to the new runner profile, the TurboBelt 780 TPXL offers a highly increased hydrodynamic intelligence, which reduces necessary control functions during the start-up phase to a minimum. Unlike traditional hydrodynamic solutions, the new coupling - after a linear filling phase - allows belt start-ups with a constant partial fill. The control function works with just a few shifts of the control valves. For a defined partial fill level, the transmittable torque remains nearly constant across the entire acceleration range. This results in a less stressed and therefore more reliable auxiliary system of the coupling.

Improved Start-up

The belt is the central component of a conveyor. It is subject to high stress levels, especially during the start-up process. Through the controlled and soft introduction of torque, the Voith coupling minimizes the impact of this stress. As the filling level in the coupling gradually increases, the belt is gently pre-tensioned until it finally breaks away. The TurboBelt 780 TPXL offers a start-up process time in a very wide range up to several minutes. The degree of acceleration torque is adaptable to the current load situation. This means that the drive always pulls the belt with the right amount of force - that dangerous longitudinal vibrations are prevented.

With its cooling circuit, the Voith TurboBelt 780 TPXL has high thermal reserves. This allows multiple start-ups without thermal overload trips, even if the belt itself is overloaded. Other drive concepts can do this only to a limited degree or not at all. In many cases, this would require an over-sized motor, inverter, or control system.

Active Load Sharing

The Voith TurboBelt 780 TPXL allows active load sharing for multi motor drives,. Due to wear or caking, the effective radius in the drive drums can, however, vary. Consequently, load is distributed to the drives irregularly. Should such adverse conditions occur, the filling level of the coupling that is under higher stress is reduced until the power transmission of both drives is once again identical. Therefore, drive drums can be operated longer than before, without overloading individual drives - a situation that would otherwise lead to a complete system switch-off.

Creep Speed Mode

Thanks to the control function of the Voith TurboBelt 780 TPXL, the belt speed can be actively regulated. A typical application for this is belt operation at creep speed - usually at 15 to 20 percent of the nominal speed - in order to inspect the empty belt.

Environmental benefits

The coupling allows the usage of highly efficient and economical squirrel cage motors with direct on-line starters. It works with biodegradable operating fluids as an alternative to conventional mineral oils. In addition the TurboBelt 780 TPXL has been designed for a service life of more than 25 years. Voith offers spare parts availability throughout the useful life of the coupling. And once it reaches the end of it's life, nearly all parts of the coupling can be recycled.

6. Testing and Data Verification

The Voith Plant in Crailsheim Germany possesses extensive testing capacities in order to evaluate new products for any kind of applications. Figure 10 shows the largest test stand with an available power range up to 6.3MW, operating the new Voith TurboBelt 780 TPXL.

Fig. 10: One of the test stands at the Voith facility in Crailsheim, Germany.

As described in chapter 5, the control of the coupling has been simplified. Thanks to the flat characteristic of torque over speed at almost any filling rate, it is possible to accelerate the belt with a controlled constant acceleration rate. The new TurboBelt 780 TPXL can be filled up to one certain partial filling level which will start up the belt conveyor. This smooth break-away and acceleration is even possible when the belt is in an overloaded condition. Diagram 2 and 3 show this unmatched behavior at 1100 HP and 2300 HP power rate. Note the very smooth torque characteristics of the TurboBelt 780 TPXL at both the low end and high end of the power range.

Start-up measurement

At the moment of the motor start the coupling is empty and has 100% slip. The diagrams below show how the increasing filling rate increases the transmitted torque up to the break-away level. Above the load torque the diagram shows a constant smooth characteristic of torque behavior - down from 100% to 75% slip). This behavior is equal to the very smooth pre-tensioning, break-away and begin of movement of the belt. The range 75% down to approximately 10% slip shows an almost constant acceleration torque, controlled around 140% of load level. After achieving the operational speed, the slip drops down below 3%, achieving high efficiency for continuous operation. High efficiency is also provided for the entire system with multiple drives thanks to the natural and active load sharing.

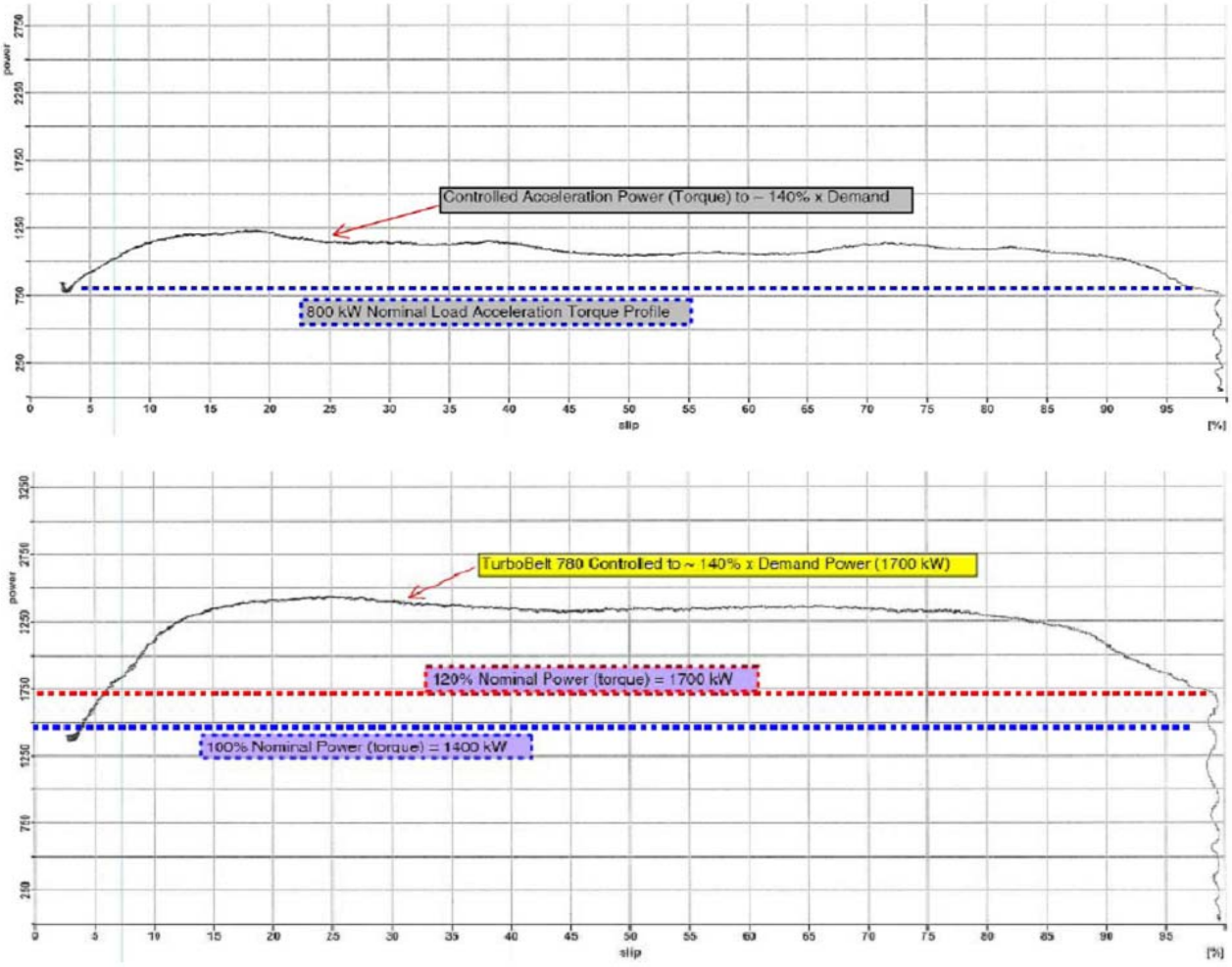

Diagram 2 and 3: Measured start-up and acceleration control behavior at 1000 rpm and different load levels. Curve reading from the right to the left (x-axis: 100 -> 3%) see explanation below.

The Voith engineering team spent hundreds of hours in order to prove the simulations into reality. The test stand measurement readings exceeded all expectations defined at the beginning of the development. Diagram 4 is an example of the measured reality where the extreme power density is shown over the slip rate during the operation at 1000 rpm. The curve includes the forward and reversing torque response (load decreasing and increasing again). Note that the torque vs. slip curves show extremely small hysteresis, proving the control characteristics of the new TurboBelt 780 TPXL.

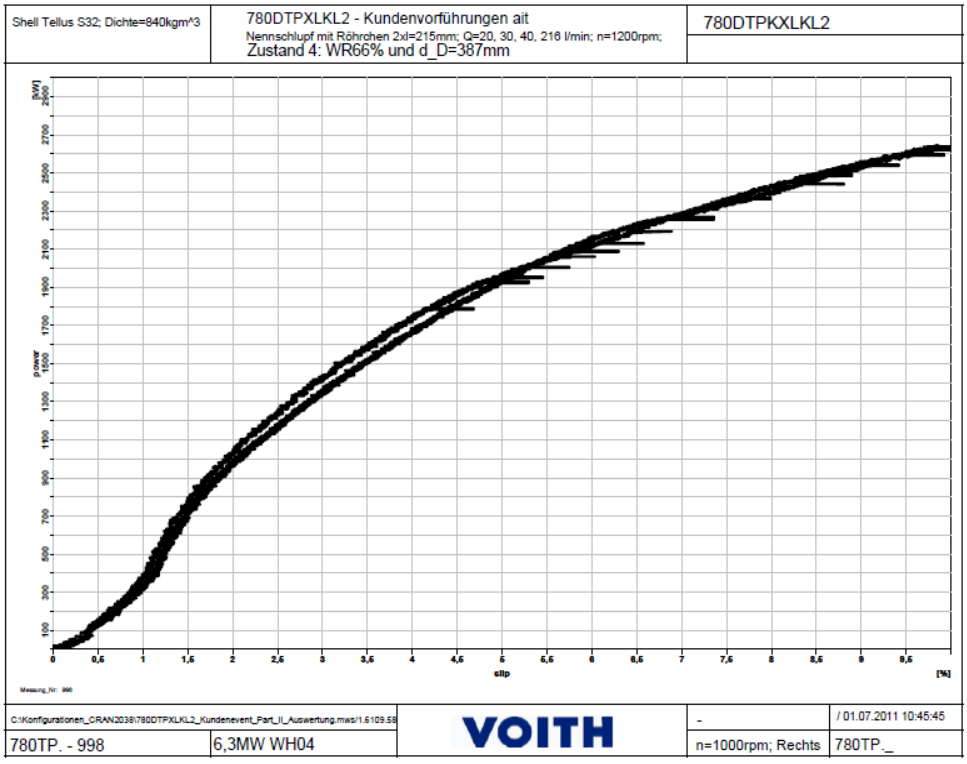

Diagram 4: Power density over the slip ratio measured on the test bench

Targeted Drive Systems

Open pit mines are often long term projects with appropriate infrastructure. A common solution in the past was the use of slip-ring motor drives with binary slip resistors. Diagram 5 shows the shifting between the resistors in order to achieve the requested torque limitation during start-up. This diagram is the ideal working process provided that the hardware switches work as designed, however any equipment or control malfunctions can otherwise generate high torque spikes. This results in poor torque/acceleration control. The generated heat is stored in the resistors' material. Their heat capacity is very limited so that usually a maximum of 3 consecutive start-ups are possible - with resistor temperatures of up to 450°C (842°F).

The working principle and the features of the TurboBelt 780 TPXL as described in this paper show advantages above the slip-ring motor solution. A cost comparison with the installation of a TurboBelt 780 TPXL revealed also a very competitive cost situation. Additionally the maintenance effort is considerably lower.

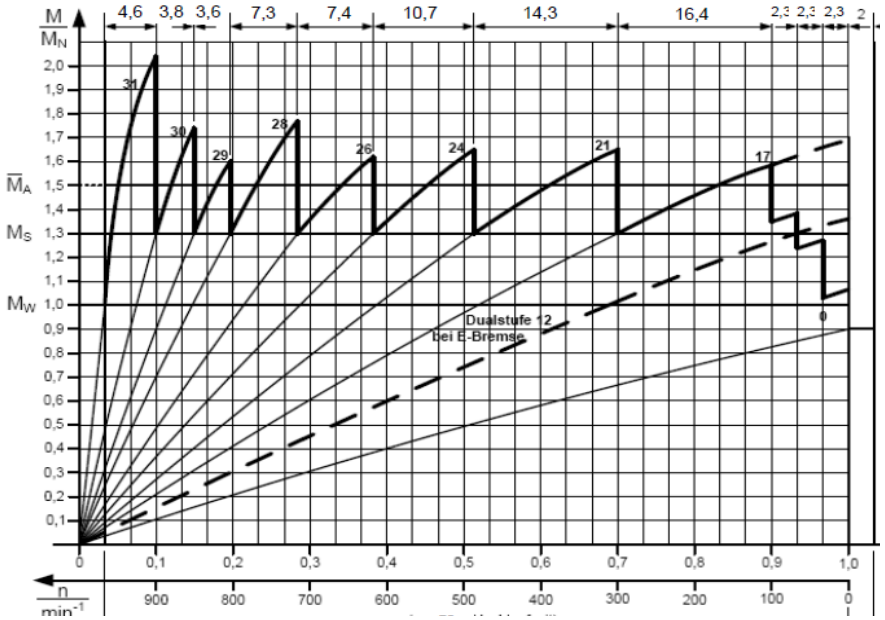

Diagram 5: Binary resistors start-up diagram of slip-ring motors. Torque limitation quality depends very much on the system design and hardware.

7. Conclusions

As a matter of fact the demand of natural resources - like raw materials - continues to grow. In order to exploit the reserves but also protect the environment as much as possible the use of modern technology is essential.

The high power density combined with the excellent control features make the Voith TurboBelt 780 TPXL a unique product. It extends the lifetime of the entire belt conveyor system considerably and reduces maintenance costs as well. This innovation is a result of the long term strategy of Voith, emphasizing sustainability in product management and environmental protection. The coupling allows the usage of highly efficient and economical squirrel cage motors with direct on-line starters. It is designed to work with biodegradable operating fluids as an alternative to conventional mineral oils.

The very low maintenance requirements and the extremely long lifetime reduce the TCO (Total Cost of Ownership) of the drive line significantly. Even more beneficial for complex open pit mine conveyor systems is the fact that absolutely smooth start-up, active and natural load sharing as well as fine tuned adjustment to current load situation avoid dynamic mechanical stresses of the entire conveyor system and reduce the correlated system TCO tremendously.

Voith Turbo, the specialist for hydrodynamic drive, coupling and braking systems for road, rail and industrial applications, as well as for ship propulsion systems, is a Group Division of Voith GmbH.

Voith sets standards in the markets energy, oil & gas, paper, raw materials and transportation & automotive. Founded in 1867, Voith employs over 40 000 people, generates Euro 5.5 billion in sales, operates in about 50 countries around the world and is today one of the biggest family-owned companies in Europe.