DATA ACQUISITION TECHNIQUES
AND
MEASUREMENT EQUIPMENT FOR BELT CONVEYORS

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1 INTRODUCTION

In order to maximize the operational life of a conveyor belt system, it is essential to understand the actual operating conditions of its equipment, and the system as a whole. This includes accurate knowledge of the operating forces, the dynamic behavior of the system, and all other significant design parameters. This information is also indispensable in forensic engineering, particularly when critical equipment has failed. In order to obtain this information, conveyors can be equipped with a variety of both temporary and permanent data acquisition equipment and sensors. This paper will discuss various types of equipment, measurement techniques, and how this information can be interpreted to maximum the life of the conveyor system.

Before discussing various data acquisition equipment and techniques, we must first understand and appreciate the reasons for obtaining this information. They include:

1. Equipment validation (typically verified during commissioning)
2. Condition monitoring and long term data trending
3. Verification of theoretical calculations
4. Forensic engineering

Of the above reasons, it's the author's opinion that equipment validation is perhaps the most important. However, this is also typically the most overlooked or ignored reason. Verifying equipment performance and operating characteristics is essential when commissioning a new conveyor system, especially for long overland conveyors [1]. Even though a new conveyer may appear to be operating properly, this does not imply that the equipment is performing within its design specifications.

There are a wide range of "hidden" problems that can easily go unnoticed without the proper measurement equipment. Perhaps even worse is when equipment is used to validate parameters which are outside of their intended purpose. For example: when an off-the-shelf wattmeter is used to verify peak starting torques and belt tensions. Although most wattmeter's will provide a good estimate of the steady state operating conditions, they are typically unacceptable for accurate determination of transient torque peaks and momentary spikes. Additionally, many PLC's and real-time displays often sample at significantly lower sample rates than are required to capture these conditions. A wattmeter's output may show a reasonably smooth and continuous starting curve. However, the actual starting curve may contain significant torque spikes. These spikes can significantly damage gearboxes, couplings, and other equipment. Depending on the conveyor geometry, torque spikes and dynamic effects can be even more damaging from holdback and brakes which are entirely hidden from a wattmeter and other "standard' conveyor equipment.

Therefore, what may ***appear*** to be happening on a particular system, and what is ***really*** happening, is often very different. By obtaining a complete set of field measurements during commissioning, a documented record exists that unequivocally shows the system's actual operating conditions. In many cases these measurements can identify problems that may have gone unnoticed. It is far easier, and substantially more economical, to solve these problems when the conveyor is initially commissioned. Equipment failures during operation can be extremely costly as they often cause the shutdown of other plant operations.

Furthermore, the underlying cause of the problem still needs to be determined. In many cases this can not be done until the system is again operational.

The above concept of preventing failures from occurring directly ties in with the second reason for data acquisition, which is condition monitoring. By properly monitoring and recording information from the system, potential failures can often be avoided, or at least approximately predicted. There are many types of condition monitoring such as: vibration and temperature monitoring of critical bearings, belt inspections, and oil analysis of gearboxes. Currently, there is large push in the industry for a more "automated" approach to conveyor maintenance in general. A few of these new approaches will be discussed later in this paper.

The third reason for data acquisition is to validate existing theoretical models and design calculations. This is an in area which is extremely valuable to the design engineer. Once the field measurements have been made, the system can be compared to the original design calculations. There are no laboratory testing procedures, failure prediction models, or engineering theories, which beat actual field measurements and test data. This is true from basic design calculations such as belt tensions and dynamic behavior, to long term effects like idler failure rates and belt cover wear. The verification of theoretical models has allowed engineers to expand the design limits of what is currently possible. This in turn has increased both the safety and reliability of new installations, and has also resulted in more economical designs.

The final reason for obtaining field measurements is for forensic engineering purposes. Something has failed (or worse, it has failed *again*), and the question is why? The cause of the failure must be determined so it can be prevented from happening again. It is often said that "the data doesn't lie" and this is never truer than in forensic engineering. In many cases the root cause of the failure is not obvious. In these instances field measurements can be used to either pin point, or rule out, possible reasons for the failure. Forensic engineering in itself is a fascinating topic. It is often equipment failures, which force engineers to reevaluate current theories and expand on ideas for new and improved solutions.

2 FIELD MEASUREMENT EQUIPMENT AND TECHNIQUES

The following sections discuss some of the more common, as well as very unique, equipment used for data acquisition and field measurements on belt conveyors. A brief description of the equipment, its accuracy, and an assortment of acquired data will be discussed.

2.1 DATA ACQUISITION SYSTEM

The most universal piece of equipment used for field measurements is the data acquisition recorder. In the past strip recorders were often used for this purpose. With the significant advanced in the digital industry, strip recorders have been replaced with high speed digital data acquisition systems (daqs). These systems are capable of storing days, weeks, and even years, of data at exceptionally high sample rates. Advances in memory cards and USB data sticks for the digital cameras and computers industry have now been incorporated in a wide range of daq equipment. These memory cards allow daqs to be used without interfacing with a PC or notebook computer.

Other advancements in data acquisition systems are not in the hardware, but in the software. Many systems now offer internet ready solutions. These setups allow users to monitor and record data, via the internet (and thus anywhere around the world). Systems like this are becoming increasingly more common as technology continues to advance.

2.2 SHAFT TORQUE & BENDING

For most standard conveying systems power is transmitted to the belt through a driven shaft. This may be via a standard motor/gearbox assembly, or a direct torque device such as a Hägglunds hydraulic motor. Any starting, stopping, or steady state anomalies will be transmitted though this shaft. The shaft “feels” what is happening on both the high speed side (motor, gearbox, fluid coupling), and the low speed side (dynamic behavior of the conveyor) of the shaft.

The most fundamental design calculation for a conveyor is the steady state power requirement. Steady state power measurements allow the belt tensions and safety factors to be determined. They also show motor load sharing capabilities and other motor concerns. In general, there are three common methods for measuring conveyor power.

The first method to measure motor power is by monitoring the motor RPM directly. Using this in conjunction with the motor power slip curve, the approximate power can be estimated. This method, however, is very crude and is only applicable to specific drive types.

The second, and more common method for measuring motor power, is using a power transducer (wattmeter) or current transducer (CT). A wattmeter measures the direct current and voltage going into a drive system. This can then be converted to motor power. When properly calibrated, these devices give accurate readings for steady state operations. However, there are various types of wattmeter’s, some significantly more accurate than others. Many wattmeter’s only measure one phase of the motor current. This arrangement cannot calculate the power factor (or phase lag) of the system, and therefore can be off by more than 5-10%. More accurate wattmeter’s monitor all input lines and internally calculate the resulting power factor. This results in far more accurate readings (1-3%). Unfortunately, the power measured in this manner still includes losses in the motors, gearboxes, and fluid couplings, as well as other losses. An engineering guess must therefore be made as to the exact losses of each of these components in order to determine the **exact** power consumed by the conveyor belt itself. Additionally, the resulting output signals from these devices tend to filter and “smooth” the real data, masking high frequency and damaging impact loads that can often be the root cause of gearbox and coupling failures.

Although wattmeter’s allow the steady state motor power to be calculated, they do not supply any information what-so-ever in regards to the braking forces, coupling and gearbox loads, or holdback torques.

This is where the third, and the most accurate, method for measuring conveyor power comes into play. By applying strain gauges on the pulley drive shafts, the torque can be directly measured. As mentioned earlier, all of the forces and dynamics loads in the system are transmitted through the drive and brake shafts.

Figure 1 shows a torque setup. Strain gauges are mounted on opposite sides of the shaft, and are often mounted in pairs. This arrangement allows for both shaft torque, and shaft bending, to be measured. Additionally, the torque strain gauges are wired such that they negate all bending and longitudinal strains. This results in a pure torsional measurement. Similarly, the bending gauges are wired together to negate torsion and longitudinal strains, and thus measure pure bending. Measurements of this nature are extremely reliable, and are accurate within a few percent [2].

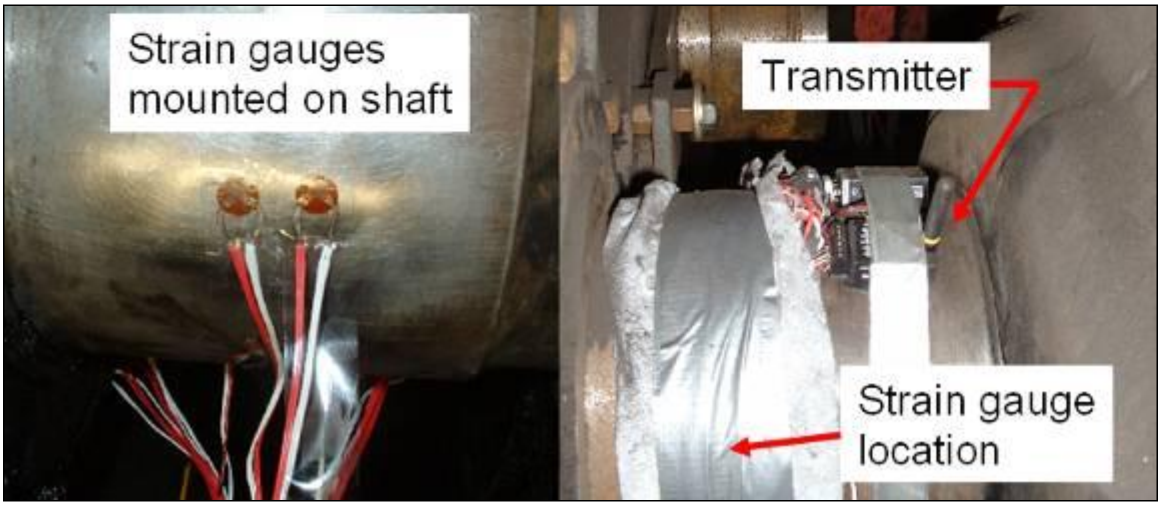

Figure 1: *Strain gauge assembly used to measure shaft torque & conveyor power*

Due to the shaft's rotation, wires cannot be directly connected from the data acquisition equipment to the strain gauges. Instead, either slip rings or wireless methods must be used. Slip rings are typically unacceptable for this type of applications since they produce excessive noise, and the physical geometry of the system does not warrant their installation.
Wireless telemetry methods however, have proven to be accurate, and very reliable. A small transmitter is attached to the rotating shaft, and a stationary pickup receiver is mounted on the gearbox or other nearby location (figure 1). There have been some major advances in telemetry transmitters and equipment in the past few years. Older equipment required the transmitting and receiving antennas be placed within a few inches of each other. Additionally, the antennas typically needed to be wrapped around the entire circumference of the shaft. New transmitters operate at much higher frequencies. This improves the signal quality, and allows the antennas to be positioned up to 5m apart. It also significantly reduces the required conveyor down time when installing the test equipment (often a major concern when a system is in full production). Depending on the shafts accessibility and its surface condition, an experienced engineer can now instrument a single drive shaft in 1-2 hours.

Figure 2 shows power measurements obtained from both shaft torque and a current transducer. The power consumption calculated directly from shaft torque is a true measurement of the conveyor power as it does not include inefficiencies and losses of the motor, fluid coupling and gearbox. Depending on the type of drive system, this value is typically 5-10% lower than the reading from the power transducer.

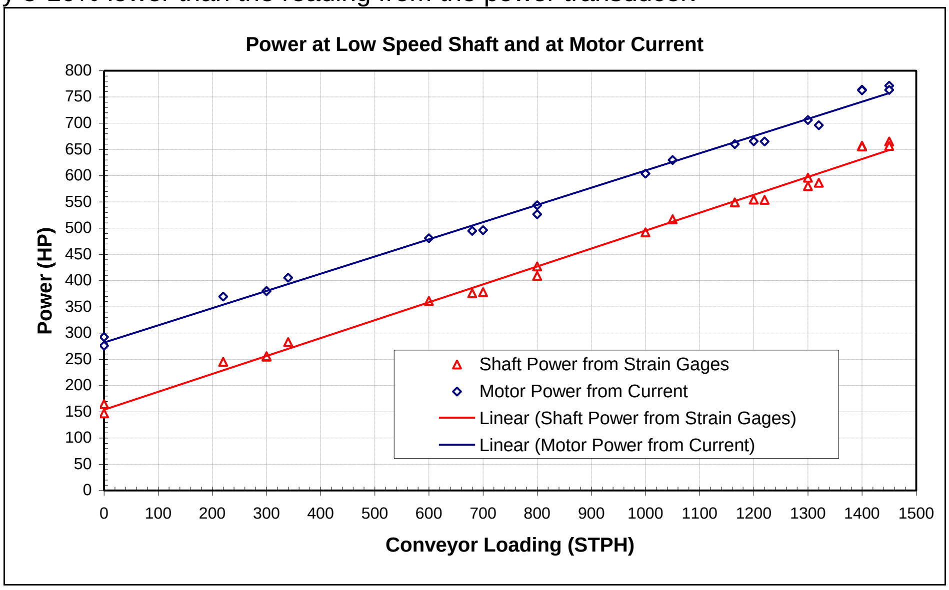

Figure 2: *Power Measurements – Shaft Torque vs. Motor Amps*

To illustrate the capabilities of field measurement equipment and technique, the measurements from a high angle sandwich belt are illustrated. This conveyor had a top and bottom belt. Each of the belts was powered by a single motor. The motors are connected to the belts with a fixed filled fluid coupling. The gear reducers have high speed holdbacks.

Figure 3 shows the startup torque for the conveyor. After the stop, the holdback on the top drive is taking the majority of the load. As the conveyor starts, the holdback torque begins to decrease until the holdback load is released and the belt begins to move. Once the conveyor begins to move, the torque on both shaft's increases. Although the fluid couplings result in a fairly smooth starting speed ramp, the system reaches full speed in less than 4 seconds. This results in a maximum motor torque of 170%.

The torque measurements also show that the motors do not load share during starting. The bottom drive torque is approximately 80% higher than the top drive.

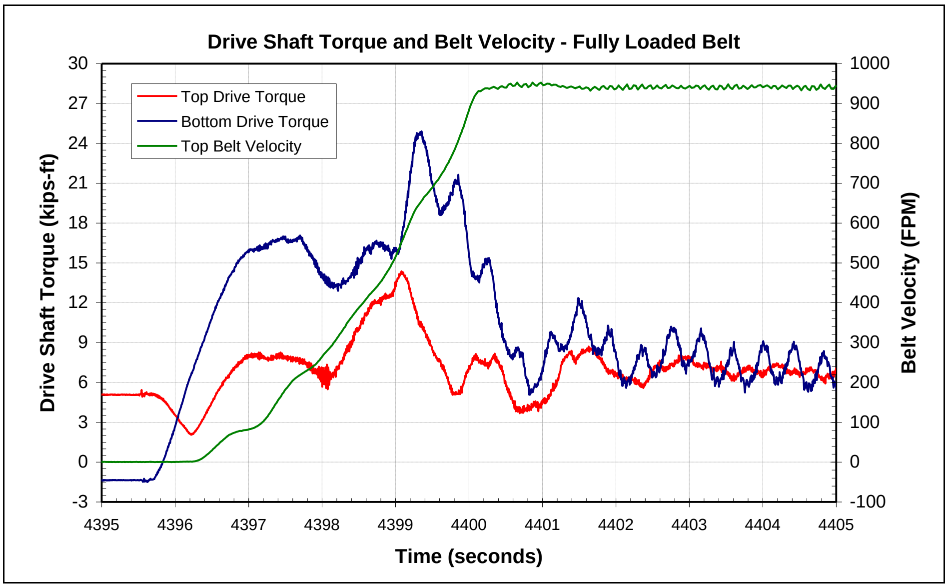

Figure 3: *Start-up torque and velocity of conveyor*

Figure 4 compares torque measurements against the motor current for the same time period. The shaft torque shows a relatively large torque oscillation on the bottom drive. The motor current however does not have this large oscillation. This illustrates the need to place strain gauges on the low speed shaft for accurate determination of the forces acting on the drive pulley.

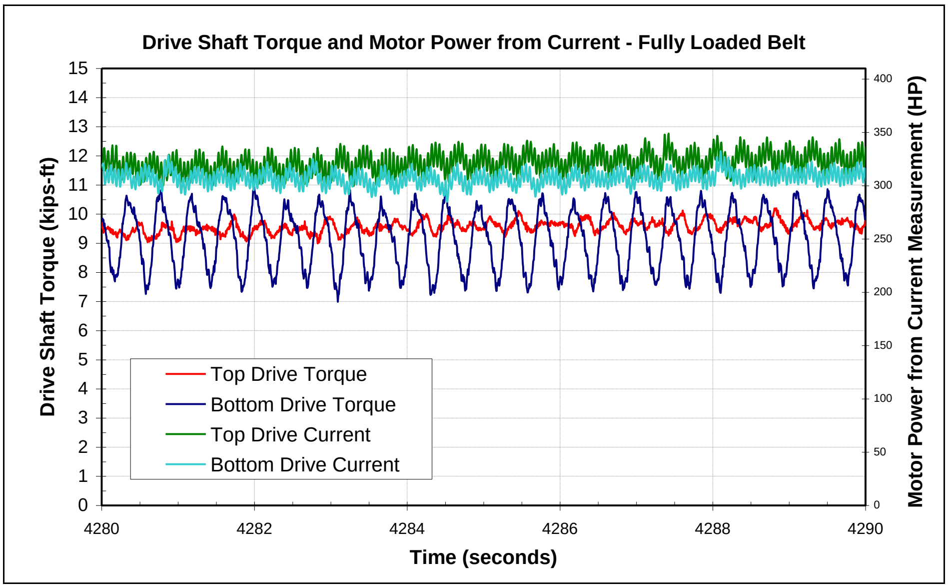

Figure 4: *Torque fluctuations in shaft torque and motor current*

Brake torque can also be accurately measured using the above technique. In this case strain gauges are placed between the brake disk and the pulley. It is often crucial to verify that the brakes are functioning properly before loading the belt with material. The actual applied torque of a brake depends on many factors including pad type, wear, heat, and environmental conditions. The applied brake torque can vary by as much as 50% to 200% of the brake's nameplate rating. Damage to the conveyor may result if brake torque is either too low or too high.

Shaft bending is yet another beneficial measurement that can be obtained by strain gauging a drive shaft. Drive alignment problems, and overly constrained drive bases can be the root problem to coupling and gearbox failures. By measuring the bending moments in the shaft, the alignment of the system can be verified, and any long term problems may be discovered and eliminated before equipment has failed. Figure 5 shows the steady state bending measurements from an overhung dual drive system. The cyclic (tension – compression) nature of the shaft bending is normal as the shaft rotates. A magnetic pickup sensor is often used in conjunction with the bending measurements to determine the absolute position, and resulting bending moment vector.

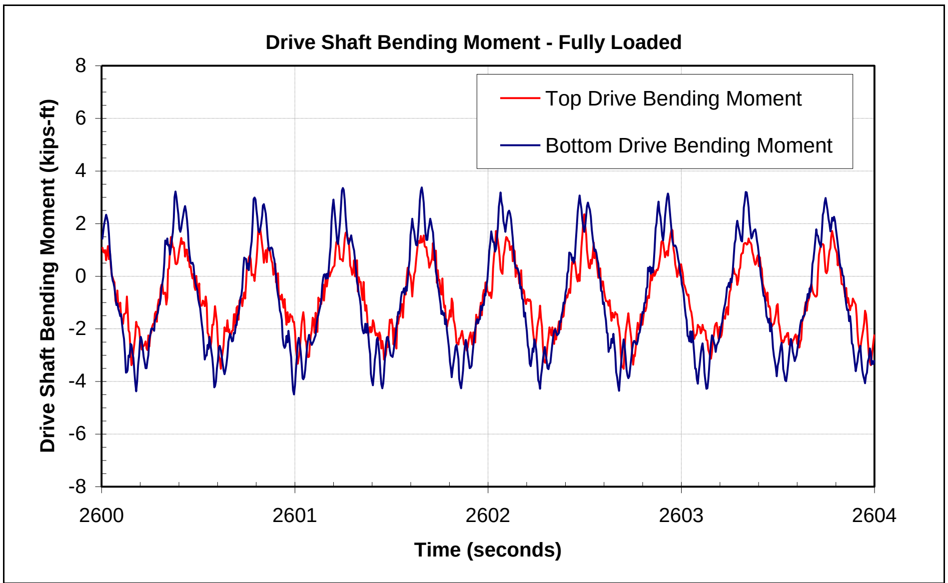

Figure 5: *Bending moments during steady state running*

Figure 6 is more interesting as it shows the maximum bending moment in the shaft as a function of material loading. Normally, the drive and gearbox are mounted such that increasing motor power (increased tonnage) counteracts the overhung weight. Therefore as the motor torque increases, the bending moment in the shaft decreases. In figure 6, the bottom drive was flipped due to geometry and space limitations. In this case, the shaft bending increases with rising motor torque. For this particular system the resulting bending moments were still within acceptable limits. However, this is not always the case.

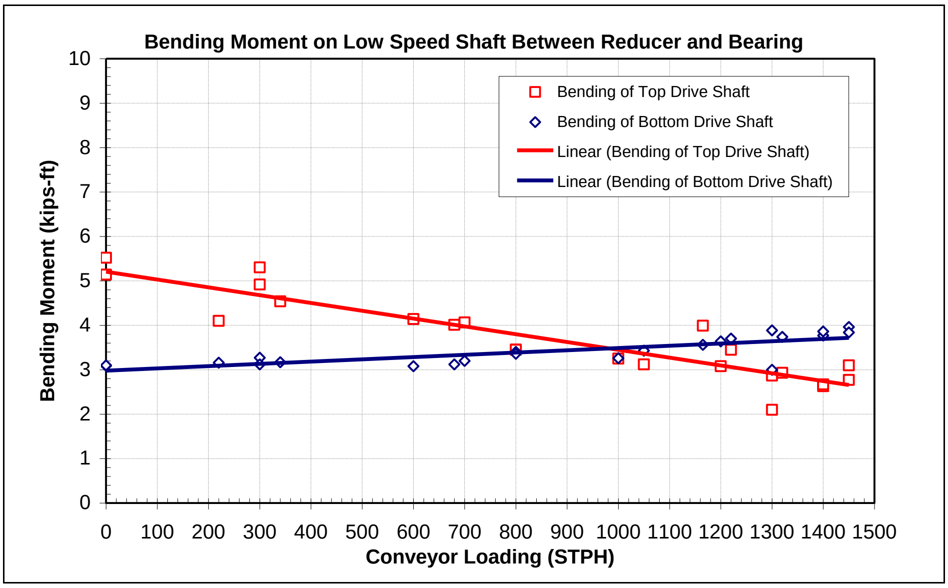

Figure 6: *Bending moment as a function of conveyor loading*

2.3 BELT VELOCITY

Although very basic, accurate belt velocity measurements should not be overlooked. This is especially true when the belt has significant dynamic behavior during starting and stopping. Dynamic shock waves can not only cause high tension peaks, but they can also result in low tension waves. This can result in excessive belt sag, and material spillage.

Currently, the two most popular methods for determining conveyor velocity are by using either a magnetic pickup sensor or an optical encoder. Magnetic pickups require a rotating metal plate or gear tooth from which they receive a pick signal or “pulse”. These devices may have anywhere from 1-32 pulses per revolution. Although the errors produced from these devices may be acceptable at steady state velocity, their accuracy, and resolution, is severely diminished at low speeds. Since velocity is often used as a feed back signal to the PLC, when starting and stopping the conveyor, these errors may be significant. For example, a magnetic pickup device with only 16 pulses per revolution, mounted on an 1800 mm diameter pulley rotating at 5.6 rad/s (belt speed is 1 m/s), will only produce 1 pulse every 350 ms. Optical encoders, on the other hand, use an etched glass disk, which is rotated through a photoelectric diode. These devices normally contain over 2,000 pulses per revolution. For the example above, an optical encoder and corresponding tachometer mounted on the same system would produce 1 pulse every 3 ms. Furthermore, unlike magnetic pickups, optical encoders output a dual quadrature signal. This allows higher noise rejection, increased accuracy at low speeds, and the ability to infer the rotational direction.

A typical optical encoder setup is shown in Figure 7. An optical encoder and wheel assembly are mounted on an adjustable arm and then fixed to the conveyor structure. Generally velocity measurements are taken at both the head and tail end of the conveyor to capture the time delay and dynamic effects of the belt.

Figure 7: *Simple velocity measurement using an optical encoder and measurement wheel*

Velocity encoders can also be mounted on drive pulleys to detect belt slip and other anomalies. To do so, two velocity units are used. One unit is mounted on the belt to measure belt speed. The other unit is mounted on the pulley lagging to measure the pulley speed. Any velocity difference between these two, taking into account the difference in radii, is an indication of belt slip.

Figure 8 is a rather interesting graph of the belt velocity at the head end of a high angle sandwich belt conveyor. A sandwich belt conveyor consists of two belts, with the material "sandwiched" in-between. This allows material to be transported at not only very steep angles, but in many cases straight up. Figure 8 shows the belt speed of the top and bottom belts as a function of shaft torque (i.e. material loading). When the belt is empty there is significant slip between the two belts. The speed difference is a result of the different motor slip-torque characteristics of the two motors. The difference in speeds can result in material spillage and other problems.

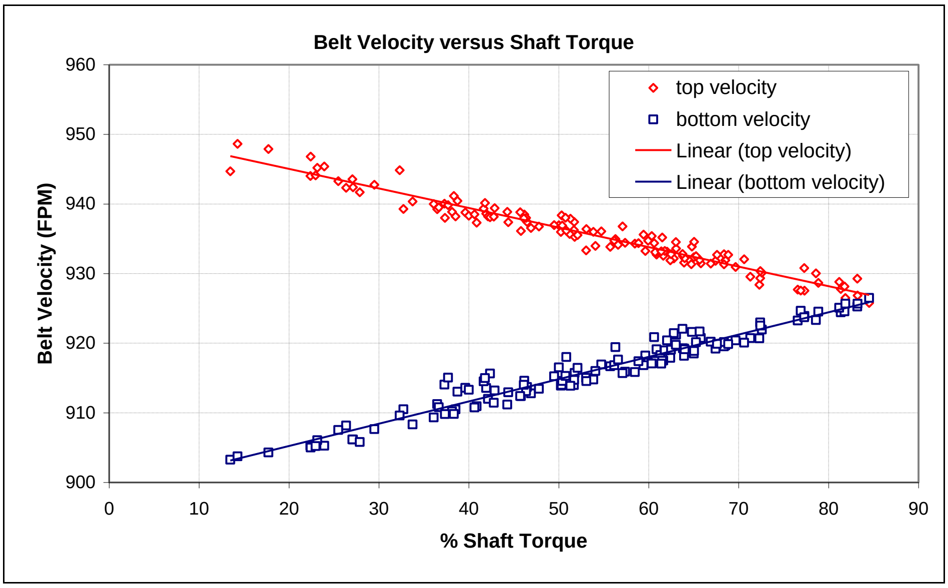

Figure 8: *Velocity of top and bottom belt of a sandwich conveyor*

2.4 TAKE-UP FORCE AND DISPLACEMENT

The take-up system is often considered the "heart" of the conveyor [3]. Its type (fixed, winch, or gravity), and tension, governs the conveyor design. Without accurate take-up tension information the belt safety factors, drive tensions ratios, pulley loads, and other significant design factors cannot be accurately calculated. The take-up system can also be the root cause of many conveyor problems, especially for fixed take-up systems. If the tensions are too high, belt splices, pulleys, and conveyor structure can be damaged. If there is too little tension, drives slippage and material spillage can occur.

The take-up tension can easily be measured by using "off the shelf" calibrated load cells. For gravity take-up systems it is best to install the load cell on the take-up pulley carriage rather than the counterweight. This allows the take-up hysteresis (resulting from cable sheaves) to be measured.

Take-up displacement is measured with the same equipment that is used for measuring conveyor velocity. In this case however, the dual quadrature signal is summed together to provide an equivalent displacement instead of velocity. The accuracy of this technique is less than 1% and well within the required precision.

2.5 BELT SIDE TRAVEL

Belt side travel measurements are important to conveyors with horizontal curves. In horizontal curve areas, both the carry and return side idlers are banked towards the inside of the curve. As the conveyor is loaded, the belt tensions increase, which causes the belt to "pull" towards the inside of the horizontal curve. As the belt moves inwards, it is also forced upward by the banking angle of the idlers. Gravity counteracts this movement and holds the belt in position. When the belt is empty, the tensions are generally lower and the belt moves to the outside position. Steady state and dynamic (starting/stopping) measurements are important in order to verify that the installed banking angles are adequate, and to verify theoretical models for future conveyor designs.

Side travel measurements are also important in validating the belt construction and splice alignment. Factory and field construction defects are highly repeatable and measurable.

To measure side travel an optical encoder is mounted at the pivot point of a movable arm with a side guide roller on one end. The rotation of the optical encoder can be multiplied by the length of the arm to determine the position of the belt.

2.6 ACOUSTIC MEASUREMENTS

Acoustic measurements can be of vital importance when designing overland conveyors. In many cases, the conveyor system may travel through, or near, a populated area. It is often extremely useful (and in many cases required) to be able to accurately predict the amount of noise a particular conveyor system will generate. This, however, can also be extremely difficult to theoretically predict. Noise generation is a function of belt speeds, material type and tonnage, idler arrangement, hood cover design, bearing and seal construction, and the structure itself. Fortunately, this is one of the easier measurements to record. A high quality sound meter can be purchased, and usually comes with a calibration device. Measurements can then be made on a variety of conveyor systems, with the data stored in a common database. This database can then be referenced for future conveyor designs.

2.7 OTHER MEASUREMENTS

Although the above list encompasses some of the main measurement equipment used for field measurements, there are many other items worth mentioning. Weight scale readings, temperature measurements, and an assortment of PLC control signals, are but a few of the additional items that must be recorded in order to get a complete and accurate representation of the conveyor system. This information is then combined with other measurements in order to fully understand the complete operational behavior of the system, and the cause and effect relationships between components.

3 CONDITION MONITORING

There is usually a plethora of condition monitoring equipment permanently installed on a belt conveyor system [5, 6]. This includes: belt rip detection, motor protection, belt displacement switches, chute pluggage sensors, vibrations and temperature sensors, and so forth. Additionally, some of the equipment already described can be permanently installed on a conveyor (load cells, velocity encoders, position sensors). Unfortunately however, long term trending of this information is often either difficult to access, or simply ignored until after a problem has occurred. This is unfortunate as this information can often be used to predict potential problems that may arise. Changes in motor power curves, or belt take-up tensions, can be an indication of imminent problems.

Many mines however are using state-of-the-art condition monitoring technology to their economic advantage. The ability to instantly access the current operating state of a conveyor, or entire plant, from anywhere in the world via the internet is a tremendous advantage to any mine operator. Another simple example of long term condition monitoring is the use of hand held data recorders for maintenance personal [4]. When routine equipment is repaired or replaced this information is entered into the device. For example: when a maintenance crew goes out to replace idlers with worn shells or failed bearings, the specific idler roll and its location is entered into the hand held device. When the idler location has been entered, a replacement history of the idler frame set is displayed on the screen. Excessive replacement of the same roller would indicate the frame may be misaligned and needs adjustment (which can be done right then and there). The idler inventory is also automatically updated thereby simplifying record keeping of supplies.

A more advanced, and unique, type of condition monitoring is the CBT belt C.A.T. scanning system [7]. It can be used to monitor, and accurately predict, the condition of steel cord belts and splices. It is a non-contact device, which operates while the belt is running. It not only detects cable breaks, but is sensitive enough to pick up even the most minor damage to cords and individual wire strands. Figure 9 shows a typical data measurement and the actual belt upon inspecting the damaged area.

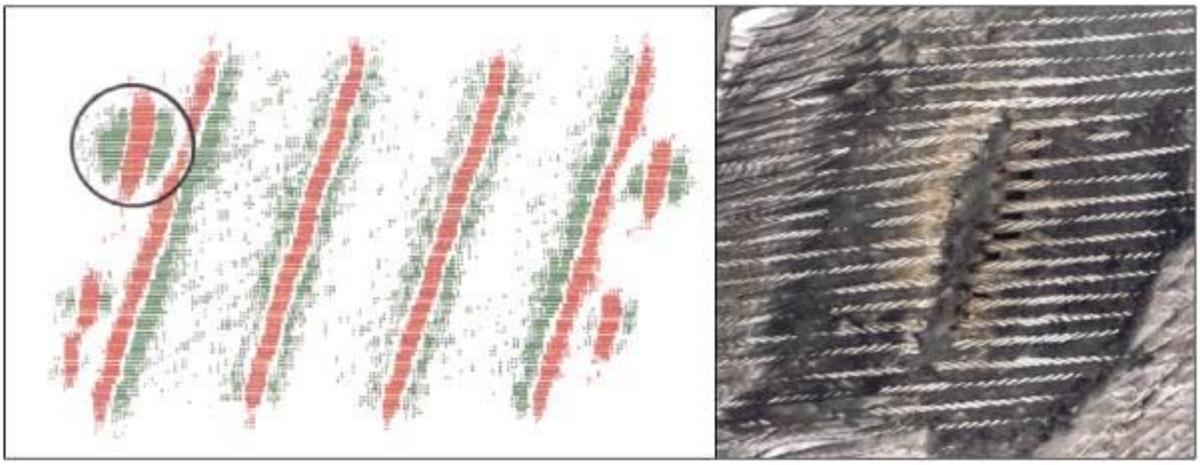

Figure 9: *CBT Belt C.AT. Scanning System - field measurements and actual belt damage*

Another area of current interest in conveyor monitoring is automated “smart” systems. One such concept involves a moving trolley that travels along the conveyor and “listens” (audio response) or “feels” (vibration measurement) each idler set [8]. This type of system would keep a record, or signature, of each idler set. It could then compare this historical information to the current operating condition and determine if an idler failure was imminent. In the future the trolley would not only identify idlers failures (or potential failures), but would return to the specific location and replace the roll when the conveyor was shutdown.

4 CONCLUSION

Accurate field measurements are essential to understanding the operational behavior and long-term performance of belt conveyor systems. By performing a complete set of field measurements on a conveyor, the system can be given a “clean bill of health” right from the start. In many cases, potential problems can be identified, and corrected, before they cause damage to expensive equipment. Fields measurements are also invaluable in forensic engineering, condition monitoring, and the validation of theoretical models. This paper has discussed some of the most commonly used equipment, as well as, some of the more cutting edge technology.

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