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Belt Conveyor Idler Roll Behaviors

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This paper reviews the impact of the idler set on the performance of belt conveyors. Idler rolls as part of the load support system and their interaction with the conveyor system will be discussed. In particular, the rotating performance of the individual idler roll concentrating on the rotating resistance and life of the bearing and seal design are addressed in detail. A basis for the development of performance specifications for use in conveyor design that takes advantage of the idler manufacturers design and manufacturing expertise is discussed.

INTRODUCTION

This paper reviews the impact of the idler set on the performance of belt conveyors as they support the weight of the belt and bulk material. Idler rolls and their assembly in sets are an integral part of belt conveyors used to transport a wide range of bulk materials and applications. Almost as much as the belt itself, they affect the behavior of the conveyed material, the power used and the overall suitability of the conveyor. Idlers have been developed to perform adequately for various installations but indentifying the most appropriate is not that clear. This paper attempts to review the impact that idlers have on conveyors, describe the range of product produced and provide insight into their selection.

The Role of the Idler in Conveyor Operation

Awareness of the ways that idlers affect the conveyor and interacts with other components is necessary for optimal selection.

The nominal role of an idler roll is to provide load support with low resistance to movement. Radial loading from belt and material over a particular idler spacing is the principal requirement of most rolls. This load also includes absorbing impact at the loading point and belt tension when located in curves. These can be a difficult load to quantify but modern conveyor designs conveyor design methods have improved the understanding and control for clearer idler implications.

Assemblies of idler rolls are created to control the belt profile, typically to form a trough or tube. This will not be discussed in depth but it should be acknowledged that the trough form, consistency and flexibility can have an important effect on the idler roll behavior. Troughing rolls develop axial load due to being angled to vertical as wing rolls in a trough and to the belt direction to provide guiding or tracking forces. Aspects of mounting method, alignment, self cleaning etc. are important aspects of idler frame design.

External interaction with the conveyor system goes beyond the primary function of supporting a normal load to include longitudinal load or power and operating behavior.

All of the conveyor longitudinal "main" resistances are transferred via the idler rolls.

- Trampling loss power is due to reforming the material cross section. Material lifting and acceleration reactions transfer load to the wing roll from the center roll in this process. Troughing angle and idler trough influence this resistance.
- Viscoelastic belt cover indentation develops at the rollers. Larger diameter rolls can be expected to have lower losses.
- Transverse friction from roller misalignment is affected by roll mounting variations established by the frame manufacture and installation. The transverse rubbing reaction is also affected by the idler roll material and its friction to the belt.
- Nominal rolling resistance of the idler bearing and seal is a direct impact of the idler design and is discussed below. Load and manufacturing induced frame and shaft deformations affect the rolling resistance as well.

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In addition to the vertical support, the idler set affects the lateral belt operation in several ways.

- Alignment of the idler rolls perpendicular to the belt and parallel to one another provides a smooth running load with balanced lateral loads and good belt tracking. Imperfect orientations of the rotational axis to the local belt path causes axial friction with power and wear consequences to the belt and the idler shell. This is set by the idler frame and local belt stretch or as when garland idlers are allowed to swing in the direction of belt movement.
- When one end of a roll is ahead of the other the belt tends to be pushed in the direction of the latter. This can be used to advantage for tracking.
- The toughed or "V" return idler provides a balancing for the belt and material weight as both wing rolls funnel their weight to their lower position. Guidance through horizontal curves relies on a similar balance against the radial component of the belt tension.
- Conveyor noise and vibration are evidence that wear, damage, and additional power loss is occurring as well as being objectionable in its own rite.
- Belt flap or inter idler belt vibration is driven or excited through small idler roll runout, TIR, or radial variation at the rotational frequency.
- Belt slap implies a vertical bouncing at the idler at frequencies away from the belt natural frequency. It is due to high roll TIR.
- The resonance frequency of steel roll shells can be in the audible range.
- The support frame can bounce or vibrate as affected by its stiffness in several modes.

IDLER ROLL DESIGN

The idler roll provides a basic radial support against gravity and belt tension in the case of curved belts, and to force belt bending and material cross section. In doing this the roll also allows longitudinal movement with only a small though accumulating belt tension increase part of which is attributable to the roll torsional resistance to rotation. Minimizing this resistance and matching the idler roll life to that of the conveyor are the primary design goals at a particular radial load beyond enabling a cost effective and well "behaved" rotating construction.

Construction

The idler roll design is fundamentally simple comprising a rotating outer cylindrical surface and a pair of bearings almost universally mounted on a stationary shaft. Though a wide range of shaft, bearing positioning components and outer cylinder material are used, the design can be identified nominally with a diameter, length and material, each with various impacts on the conveyor as described above. The bearing set design has the primary affect on idler performance. It can be defined as an imbedded antifriction rolling element on a stationary shaft with components locating it to the outer shell and protecting it from the outside world. The bearing load rating is fundamental to its selection.

Idler Rotating Resistance

The idlers power, a basic loss though not necessarily the major loss as described above, is due to the torsional resistance to rotation at the bearing set. This is typically modeled to be the accumulated friction due to the (1) rolling element sliding and deformation hysteresis which is load sensitive, (2) shear of the lubricant which is primarily speed related and (3) the seal drag which varies widely with design.

Bearing Rolling Resistance. The bearings used in today's bulk material handling conveyors are virtually always precision machined, hardened, ground and polished set of elements designed and assembled to roll in similarly treated and lubricated "races." The result is to develop as close to pure rolling as possible with minimal deformation and sliding forces for low resistance to rotation and long life while resisting radial and axial displacement. Lubricant for the relatively low speed operation of idler bearings is generally provided with grease which is placed around the rotating elements and bleeds out lubricating oil to the rolling contact. The viscous grease is subject to shear and churning due to contacting various elements which causes speed and temperature varying resistance to movement and roller rotation.

Two basic bearing types are used with unique characteristics in several regards. In both, the outer ring is pressed into a bore of the rotating roller. This clamping fit prevents movement and frettage wear of the bearing outer ring. The inner ring is a small clearance slide on fit to the shaft so that the rolling elements are not preloaded. The bearing bore should be restrained from sliding or loping on the shaft when the roll is lightly loaded.

- Ball bearing idlers use spherical rolling elements in correspondingly radiused grooves or races to distribute the contact forces and provide some axial resistance. The variation in rolling radius due to the depth of the groove causes sliding friction and wear and prevents disassembly when optimized with a full ball complement. Initial clearances between the balls and races allows for thermal expansion, slight angular misalignment and slight allowance for compression of the outer ring when pressed into the roll. Ball bearing idlers are commonly prelubricated and available equipped at the bearing plant with a precisely fitting seal. Special designs have been developed that are more tolerant of soft contaminant through the race shape and clearance.
- Roller bearings, typically with tapered rollers, have a wider contact width for lower pressures and increased radial capacity. While the use of tapered rollers additionally provides high resistance to axial forces the contact path is also not purely cylindrical with a tapered rolling radius and inevitable sliding. The wide rollers better resist transverse moments from flexible shafts and stiff roll ends but this can increase rolling pressures and reduce the allowable load. The wide roll also reacts differently with the lubricant. This can be seen with increased relubrication recommendations (SKF 1991, 2005). In addition, rolling resistance can be seen to decrease with increasing speed, counter to normal grease viscosity behavior. This is presumably due to more grease being pushed out of the roller path with the higher dynamic pressures from high speed.

Assembly Considerations. The bearing set must be thought of as including the shaft with a method of attachment to the idler frame and a bearing axial locating feature as well as a rotating housing to transfer the support forces to the outer shell. The assembly is inevitably imperfect in aligning the bearing rolling elements with their inner and outer races. Additional deformation develops under load. Both of these displace the bearing out of the optimal purely circumferential rotation causing additional rolling element sliding with frictional loss, noise and wear as well as higher contact stress and shorter fatigue life. The product and manufacturing process designer must address the bearing needs in a number of ways to maintain the rolling action designed by the bearing with consistency and efficiency. The two bearing types used in idlers require fundamentally different axial support and assembly which must be incorporated into the design. Both must clamp the outer race to prevent movement and wear but the axial freedom varies between the two.

Grease Contribution to Rotating Resistance. Grease is identified here as a separate component since it contributes uniquely to the idler power performance. Grease is necessary for lubrication and can also be used for seal functions discussed below. In any case, as a viscous material it resists shear strain. This resistance causes idler drag that varies with strain rate, the grease stiffness or shear strength and the total shear area. These relate to the rotating speed and bearing mean diameter, the temperature and the amount of grease, respectively with all influenced by the conveyor design, the environment and the idler design. Therefore, fully understanding the impact of grease on conveyor power requires characterizing it for the possible range of speeds and temperatures for a particular design.

Grease is composed of a lower viscosity lubricating base oil that flows at the rolling contact and a higher viscosity carrier or thickener that stores the oil and releases it to the lubricate surfaces that are near it. The thickener provides the greater flow resistance as it is forced to shear between the bearing elements and seal components. Thickeners are produced in a wide range of base materials with varying strength, temperature, miscibility and cost characteristics. Unfortunately from the perspective of predicting the roll drag due to lubricant, grease is too stiff to work with common oil viscosity tests.

Instead, the apparent viscosity, often characterized through pumpability tests (NLGI, 1982), can be used. Cone viscosity instruments designed for uniform shear strain can compare torque to rotating speeds at different temperatures also demonstrate the expected performance of particular greases. Arveson (1934) was among the first to observe that the log of the apparent viscosity of grease typically varies linearly with the log of the shear strain rate. In addition, this linear relationship repeats itself as parallel lines for different temperatures. This allows Time Temperature Shifting (TTS) to conveniently characterize the viscous resistance to idler rotation for a particular idler with only a few measurements applicable to a wide range of applications. It must be acknowledged that the temperature of the grease is inevitably different than the ambient temperature and that grease is displaced differently for different stiffness's and speeds. Nonetheless, the author has found that the log linear nature of the test results maintains sufficient accuracy to use TTS to extrapolate between and beyond test conditions. These cannot be used interchangeably for steady running and for cold startup due unless the heat transfer properties of the idler are well known.

Rotation of Bearing Seals. Finally, a seal is always provided to protect the precision bearing elements from contaminants such as fine abrasive grit and moisture that damage the precise bearing elements and the lubricant diminishing the rolling effectiveness. These will often have their own resistance to rotation both intentional and due to manufacturing variations. In addition, seal effectiveness can be thought of as a power criterion if a major part of the bearing life is spent with poor lubrication or rough rolling pathways. Several functional concepts are used to isolate the bearing from the outside environment. Though their effectiveness and drag ranges widely, the two are generally inversely related.

IDLER LIFE

Life versus design can be thought of as the maximum possible life of a loaded roll and the factors that contribute to not fully experiencing this life. The following descriptions of common idler components.

Bearing Life

The bearing life is ultimately limited by the contact stresses between the rolling element and the races that they run. Several scenarios can develop that must be addressed in the design of the bearing set.

A classic AFMBA fatigue calculation, relevant to long life under steady loading, is commonly used for sizing a bearing appropriate to the desired roll rating or radial load. While it does include useful statistical probabilities of a bearing lasting for a particular number of revolutions, this oversimplified calculation is probably given too much credence in conveyor engineering. Ultimately though, it is still worthwhile as a benchmark since the failure mode it represents implies a range of conditions which encompass others that can be much more difficult to evaluate and be sustained. When all of the loads are sufficiently understood, alternate advanced selection criteria may be relevant in the development of an idler roll but use in specification would be very difficult due to the wide range of inputs. Most bearing manufactures publish dynamic load ratings or capacity of their product for use in this equation as well as a static load rating which serves as an allowable for infrequent overloads which could cause minor damage that accelerated fatigue failure. Lubricant life is also a limit to the applicability of the statistically possible cycle life and must be accounted for as an overiding limit or by relubrication.

Bearing sizing, friction and lubricant life can use newer methods (SKF 1991, 2005) developed by bearing manufacturers which better represent actual bearing design and materials. As with the nominal ratings, these methods should be considered specific to the bearings from the respective manufacturer.

Standards groups continue to evolve to incorporate new technology and understanding. Ref ISO 281:2007. These should be considered but can still come up short to fully represent the total operating condition so their usefulness in specifications is limited.

Though bearing size has a significant effect on cost, availability and economies of scale as well as design philosophy can influence the selection of a heavier bearing than may be "needed," especially since oversizing can reduce the importance of the various issues discussed below.

A wide range of additional bearing loads can occur which affect the actual stress in the race. These can significantly affect the accuracy of the simple radial calculation and should be included in the bearing sizing and friction assessment.

- Axial roll loads from transverse belt reaction and wing roll gravity loads.
- Angular loads that cause axial stress from shaft deflection under load.
- Axial and angular preload from assembly.
- Radial preload from press fit assembly.
- Dynamic radial loads from belt flap impact and idler runout.

Bearing race fatigue calculations implies the surfaces and lubrication are maintained substantially as manufactured. The rolling surfaces are subject to various abuses that must be prevented or tolerated with oversizing or comparison to the bearings static load capacity.

- Impact dents or brinelling of the races from handling and dynamic belt and material loads.
- False brinelling from shipping vibrations.
- Sliding between rolling elements and races due to assembly distortions.
- Contamination causing breakdown of the lubricant with subsequent sliding.
- Grit contamination scratches serve as crack initiation sites for spalling fatigue wear.

Seals for Bearing Life

The latter two identified above are major limitations to the actual life of idler rolls. Significant costs are commonly added for seals between the rotating and stationary components to isolate the bearings from external contaminants so they can function as intended. High performing seals for severe applications generally require more power. The nature of seals and their suitability range as follows.

Most idlers will have a stationary or rotating cover over the outer shaft extending to or past the bearing cavity diameter. The rotating design has a smaller diameter and therefore less open area but any material that enters this way is trapped between the bearing and this cover.

Labyrinth Designs. Labyrinth is a general term for non-contacting, frictionless isolation that creates a, bending, narrow and usually long path making it more difficult for material to pass to the bearing. Alternating rotating and stationary elements create axial and radial passages where the width of the passages is governed by the ability/cost to prevent contact and whether they are grease filled. In general, empty or grease filled, labyrinths only delay contaminant passage and can be quickly overwhelmed in very dirty applications. Circumferentially varying passages can provide a pumping action as well. Labyrinth seals are inherently frictionless though this changes dramatically when they are overloaded and fill with contaminant.

Grease filled labyrinths will have higher drag due to the grease shear discussed above but can serve to delay passage of dirt to the bearing. It will absorb contaminant and while mixing and churning, eventually transfer it to the bearing if unimpeded or isolated from clean grease. Though moisture will mix with grease over time, it can be useful to isolate incidental or wash water splash from getting into the bearing cavity. Some, though not all, of grease filled seals include relubrication systems. In this case, the used grease is typically purged into the seal so that the dirtiest grease in the labyrinth is also purged from the roll, at least to some extent. If grease refreshment is counted on for extending the bearing life, it should be understood that the effectiveness of regreasing systems varies widely.

A specialized and effective labyrinth like design is commonly used at the entrance to the bearing cavity. These dry seals provide roof like protection and centrifugal rejection of contaminant through the shape of the rotating and stationary grooves before it enters the internal seal. Very dirty or wash down environments can overload the centrifugal rejection groove.

Another special labyrinth design with ultra small gaps is used to limit the amount and especially size of dirt migrating to the bearing to that which is relatively benign to the rolling contact. These require special construction and materials to maintain the precision of the assembly.

Contact Seals. Contacting lips of various design and materials are used to prevent ingress of contaminant. They can be rotating or stationary and axially or radially acting. Oil type rubber lip seals are common but soft radial washers of felt or foam are also used. These can absorb dirt but in the process become hard and passages develop allowing dirt ingress. A rotating seal will inherently have lower drag since the contact radius will be smaller for lower torque. It can be expected that internal seals will wear less since they are less likely to be exposed to grit. Accordingly, external contact seals can effectively exclude contaminant but are likely to wear more quickly. Seals in regreasable idlers must deflect to allow grease to pass without causing damaging high pressures.

Balances of effectiveness, wear life and drag are inherent in contact seal design since contact implies rotation of rubbing frictional surfaces. For instance, deflected seals will maintain their effectiveness as they wear though this may require higher initial drag. Thin, soft seals will deflect with less contact force and drag but have less volume for wear life.

Subcomponent and assembly variability is an important consideration implying a range of sealing performance and drag consequences.

The seal available with many ball bearings satisfies many of the issues discussed above and should be understood to often have particularly good value.

Reservoirs or dead zones can delay the passage of contaminate or provide a low pressure accumulating region. These can be useful in less dirty application outside of a contact seal so that pressure does not build up against a contact seal causing it to wear.

Additional sealing should be considered to prevent fines and water from penetrating under the stationary seal and bearing inner race. A minor seal behind the bearing is often provided to prevent bearing contamination from moisture or rust from the interior of the roll. A rear seal may also be necessary for many regreasing systems.

In some parts of the world with wide daily temperature fluctuations, a vent is provided to allow air exchange without penetration through the bearing cavity.

Roll Wear. The belt contact surface wear can also be the limit to idler life. The driving influence should be considered the belt contact and alignment of belt movement normal to the roll centerline. This can be affected by installation, frame design, belt curves or idler spacing. Analysis requires understanding of the local belt stretch as affected by belt sag or misalignment. In lieu of confidence in belt to idler alignment, the roll tube diameter, thickness or material are often selected to accommodate applications that prevent tight control of belt to roll sliding or where fugitive materials are expected that cause roll wear.

The above illustrates the range of designs that are produced. Few if any of these elements can be said to have obvious and universal benefit over their alternates especially when cost of production is considered. These costs must be understood to include the impact of economies of scale, labor, capital investment and production flexibility as well as raw material and delivery. To varying degrees bearing manufacturers have refined their product and their selection and rating methods. These technical advances should allow improved designs but also require diligence to analyze the range of loads, nominal and secondary, with the environment, external and internal, over the life, steady running and other, of the idler. Beyond the design and analysis, the total product should be understood to operate as an assembly and be proved statistically relevant to how it is manufactured and how it will be used.

IDLER SELECTION

The wide range of product design and component sizes commercially available makes the selection of the best idler for an application difficult. The selection and purchase process itself is often bewildering with many parties and possible combinations of components all deserving evaluation. Though specific design elements may be indicated for a particular application or the conveyor owner may have overriding paradigms or selection rationale, a comparison strategy is needed to obtain the lowest cost/benefit ratio meeting the minimum operating requirements of the particular project and as a basis for performance specifications. A financial comparison tool or model, with implied or specific guesstimates of the future value of the components, downtime and labor can be used with great benefit. Nonetheless, characterization of the component itself has to fit in this framework to provide a consistent decision making process.

No conveyor component, especially idlers, can be evaluated on their own because they can be used differently with various other components and practices resulting in a wide range of net conveyor performance. As is commonly understood, a conveyor is a system with balances and compromises among its components inherent in the overall design process. The best we can hope for is that these decisions are done consciously and in a manner that acknowledges the tradeoffs among the components, including how they are used in the design and how they are installed and maintained. In addition to these judgments identification of key operating categories allows commercial implications to be evaluated for the complete conveyor design. The following overlap somewhat but identifying and focusing on them for interaction with other design decisions can clarify how they affect the overall initial and future cost.

- Nominal **capacity** of the idler is commonly available in steps that match the commercially effective bearing offerings from bearing manufacturers. Shaft and frames will typically be designed to match the bearing capacity at specified life expectations and rotating speeds. In other cases or for optimization, the balance with these structural elements will affect the overall cost efficiency.
- Idler **life** is often associated with the statistical expectation for the bearing fatigue life with the applications load and speed. This is appropriate only for a best case or maximum starting point. In many installations, failed rolls will have experienced seal failure or roll tube wear due to difficult operating conditions, insufficient sealing, poor idler alignment, inappropriate maintenance, etc.
- **Performance** assessment is primarily a power issue through the rotating resistance of the bearing and seal. In many designs, life and drag will be inversely related. When power is critical, matching the seal design to the application is required for overall cost efficiency. In difficult environments, power must often be sacrificed as a necessary cost for satisfactory life. Therefore, idler rotating resistance is usually secondary to life since the consequence can be accepted through initial incremental expenditures for increased belt tension and conveyor power.
- Rotating **behavior** affects the conveyor through interaction with the other components and the system parameters. Roll runout and balance can have negative effects on component life, material stability and operating noise as discussed above. Idler set frame stiffness can have similar effects. Again, the acceptable level should be assessed in combination with the other elements of the system, especially belt speed, for the least compromises to the idler manufacturer's efficiency and idler cost. Roll runout and imbalance can also apply additional loads to the bearings through radial accelerations that develop while rotating.

As discussed above, various combinations of design details can provide comparable operating results so that specifying details such as bearing type or bore do not benefit the cause of value. Instead, requirements should state the application and the expectation of the product.

Paralleling the key operating parameters, the following are recommended information to be provided in addition to the fundamental parameters of belt width, trough shape and roll diameter when identifying the idler to be used for a particular application.

- The expected roll load or the various options for roll load with their costs should be clearly understood to allow optimization with belt speed and idler spacing.
- Life expectations in operating hours and the operating environment with expected installation and maintenance should be clearly stated. In some cases, test result requirements in accelerated seal tests or tubing thickness minimums may be justified.

- When critical to the overall conveyor required roll drag performance may be identified. The expected drag should always be requested to be provided with guarantees of statistically relevant proof from the actual or equivalent production lots.
- Maximum allowable roll runout and imbalance should be specified in a statistical manner relative to the proximity of a multiple of the roll rotational speed to the natural frequency of the belt flap or vibration modes and to the additional dynamic load relative to the nominal bearing load.

It should be acknowledged that the range of product details and requirements can get lost in the midst of the other selection decisions required of a conveyor design. Additionally, invaluable in depth experience is difficult to collect from the point of view of a system designer or integrator. The idler manufacturer however is in position to know their product and to collect experience if they are willing to spend the time to follow up on installations, take measurements, develop tests, investment in manufacturing flexibility, etc.

Particular insight on the roll design corresponding to the application and how it is integrated into the product design should be assessed in the final purchase decision, perhaps to fine tune the product offering and its cost.

In addition, understanding the interaction of the idler with the system and the ability to evaluate the final design can provide a value to the conveyor designer, protect the products reputation and reduce warranty risks.

Optimally, trade groups such as the Conveyor Equipment Manufacturers Association (CEMA) in North America that are in position to develop clear language and appropriate assessments will continue to do so as they have in the past in the spirit of aiding their business by making it easier to use their product right.

CONCLUSION

Idler procurement for best value has many issues as discussed above. Understanding the purposes of the idler and the various influences on how these purposes are accomplished is clearly a benefit to the procurement process. Focused product specification aids by establishing a consistent and appropriate set of expectations for the particular application. Likewise, understanding what can go wrong and collected experiences add to the quality of the final purchase decision.

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