AN OVERVIEW OF THE COMMON CONVEYOR DRIVE FAILURES

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INTRODUCTION

This paper reviews the commonly occurring failures of conveyor drives as a system, and relates these to modern analysis techniques that aid in reducing the occurrences of these failures.

Generally, failure of the conveyor drive results in the loss of capacity and/or production, which results in economic losses. Hence, the thorough understanding of the failures experienced on, and commonly associated with, conveyor drives, can ensure against future losses through preventative measures and improved designs.

This paper aims to link the use of modern analysis techniques and software tools to the prevention and reduction of failures within the conveyor drive. The common failures of the conveyor reducer, high and low speed couplings, baseplate and torque arm are discussed.

THE CONVEYOR DRIVE

A simple conveyor drive consists of the following required or primary components, (Figure 1):

- **i. Electric motor**
- **ii. Input or high-speed coupling**
- **iii. Geared reducer**
- **iv. Output or low-speed coupling**
- **v. Baseplate**
- **vi. Torque arm**

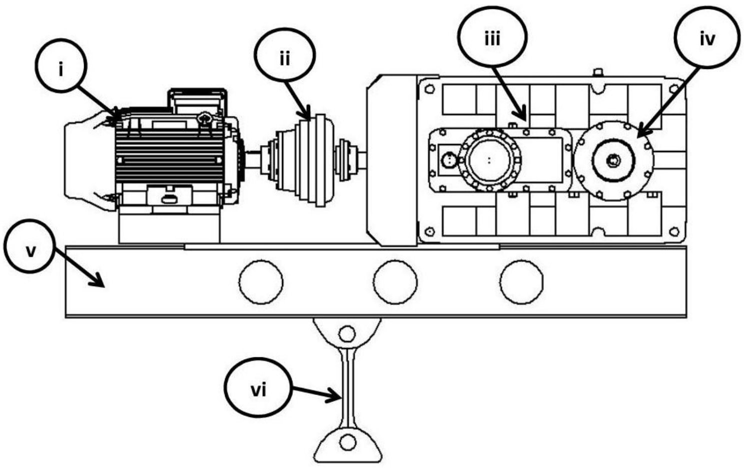

Figure 1. A simplified conveyor drive

The primary components, specifically the geared reducer and electric motor, are the more costly components of the conveyor drive. Modern input or high-speed couplings, such as fluid couplings, further increase the cost of the conveyor drive. The financial losses of a system failure can be reduced by limiting the consequential damage to other components in the case of failure of one primary component.

These components are viewed as the fundamentals of the conveyor drive and are specifically selected or designed to transmit the required drive torque through a defined configuration. There are other components in a conveyor drive that are considered ancillary or secondary. These components however, affect the operational characteristics of the conveyor drive. These secondary components include:

i. Anti-rollback devices
ii. Disc and drum brakes
iii. Fly wheels

GEARED REDUCER FAILURES

Being the largest and most complex of the components in a conveyor drive, the geared reducer is the part with the most failures. The failures reviewed in this paper include the following:

i. Failure of the shafts within the reducer
ii. Failure of the gear teeth
iii. Failure of the reducer bearings

FAILURES OF CONVEYOR REDUCER SHAFTS

Most failures of reducer shafts result from fatigue and overloading. Due to the stop-start nature of conveyors, these two failure modes are inter-related. With the repeated stop-starts of the conveyor, the mean stress amplitude experienced within the reducer can be relatively large. This may result in low cycle fatigue, where cracks originating through overload conditions grow through torsional and/or rotational bending fatigue.

The high-speed input shafts of conveyor reducers are particularly prone to this failure mode. This is due to the high-speed operation of this shaft, generally at 1 500 rpm, which is the synchronous speed of a 50 Hz 4-pole motor commonly used on conveyor drives in South Africa. This speed can increase to 1 800 rpm for a 60 Hz 4-pole motor as used in North America. To put this into an operational context, for *106* cycles takes approximately eleven hours of operation.

Another factor that contributes to the fatigue experienced by the high-speed shafts is the small shaft diameters. Generally the input shaft of a reducer is designed for the torque rating of the reducer. The effects of fatigue are very rarely considered during the sizing of the input shaft; the consideration of fatigue would result in much larger shafts and input gears. With these larger input gears, larger secondary reduction gears are required to prevent interference of later reductions, driving reducer costs upwards. It is common practice of gear unit manufacturers to check the input shaft of catalogued reducers for static load conditions, equal to the specified drive power, with a high service factor, generally in the range of 2–4, to overcome fatigue. But this still results in a finite life for the shaft. For fatigue consideration it is recommended that the shaft be designed for a minimum of the required service factor cubed, which for a moderately loaded conveyor reducer would be 1.5^3 or 3.375, or for a heavily loaded conveyor reducer would be 2^3 or 8. Due to the small diameters of the high-speed shafts, the largest deflections within the reducer are experienced within this shaft. Correct shaft alignment is critical to reduce torsional and bending fatigue.

The AGMA standard, which specifies the design analysis procedure for enclosed bevel-helical drives, stipulates that the design procedure allow for a momentary overload of 200%. This can easily be achieved on a synchronous motor which can allow for up to a 400% nominal power overload. The AGMA standard also allows for a limited number of peak stress cycles of up to 10 000 for bevel-helical drives. The standard also clearly assumes that the whole drive train must be free from torsional and all other vibrations.

It is stated that the gear manufacturer is not responsible for the system analysis, which should conform to the AGMA standard and be valid for application, unless clearly identified by contractual agreement. The AGMA standard covers a stress analysis procedure applicable to shafts. However, torsional stiffness to limit deflections should also be considered for the applicable system. The AGMA standard was first drafted in 1953, as *AGMA 260.01, Shafting - Allowable Torsional and Bending Stresses.* It was later replaced by AGMA 6001-C88 in 1988, which incorporated not only shafting, but housings and keys.

While the design procedure established in the AGMA standard should form the initial sizing within the design process, it has become advisable to undertake further analysis to refine the design to take into account fatigue. With modern advances in finite element analysis (FEA), it is necessary to analyse the geared reducer shafts for fatigue under every conceivable operating condition of load and deflection. Due to the nature of the input shaft of a reducer, there are many points that are considered stress-raisers. These points include shoulders at diameter changes and undercuts at the gear interfaces. The effects of these stress-raisers can be further amplified as a result of deflections. Thus, it is important that the torsional stiffness of the system and deflections be taken into account.

FAILURE OF THE GEAR TEETH OF CONVEYOR REDUCERS

Another common failure of the conveyor reducer is the damage to gear teeth. Many of these failures can also be attributed to fatigue and overloading. This paper focuses on two main forms of failure, namely pitting and fracture failures.

Pitting Failures of Gears

Pitting is a surface fatigue failure of the gear tooth. It occurs because of the repeated loading on the tooth surface. The contact stress exceeds the surface

fatigue strength of the material. Material is removed from the fatigue regions and pits are formed. The pit itself gives rise to a stress concentration which spreads to the adjacent regions until the whole surface is pitted. (Figure 2). Consequently, a high impact load in the pitting area can cause a fracture in the already weakened tooth. However, this is a high cycle form of fatigue, resulting only after many millions of cycles.

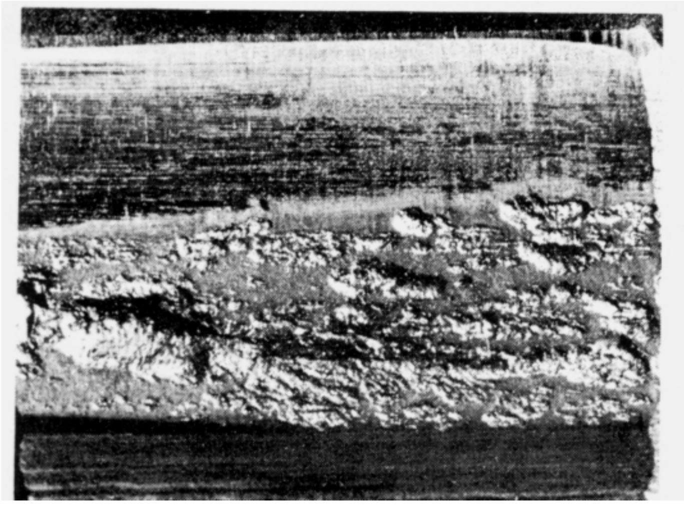

Figure 2. Pitted gear tooth [2]

This mode is the most common failure of the conveyor reducer gears. It is particularly prevalent on the bevel gears of the bevel-helical conveyor reducer, due to these gears generally experiencing concentrated loads on the gear tooth surface. The loading pattern of the bevel gears in mesh, which is affected by misalignment, is very important, as any hard contacts at the high operational speed of these gears are likely to lead to pitting failures.

Pitting failures are particularly common on the conveyor geared reducers. Short-term overloads of the gear unit, due to the stop-start of the belt, may be concentrated on particular points along the face of the gears, leading to gradual pitting. To improve the pitting resistance of the gears, the stress concentrations along the face should be removed. This can be achieved through precision grinding or shot-peening of the gears. This ensures that the surface is less susceptible to fatigue.

Bending Failures of Gears

Tooth fracture or bending failure is one of the most dangerous gear failures and commonly results in damage to other components. Shafts and bearings, for example, are damaged by pieces of the broken teeth. Tooth fracture may be the result of high overloads, both in static conditions or by impact, repeated overloads resulting in low cycle fatigue, or high cycle fatigue of the material during regular operation. In the case of a bending fatigue failure, the fracture is concave (Figure 3), and is convex when the failure is due to overload.

The bending fatigue failure of gear teeth is caused by the growth of a crack originating in the gear tooth. The crack usually begins at the weakest point, normally the root of the tooth or at the fillet, where high stress concentrations exist simultaneously with highest tensile stress from bending and/or from surface defects, such as pitting. (Figure 2). The crack slowly spreads over 80% to 90% of the gear's life. Thereafter, sudden fracture occurs.

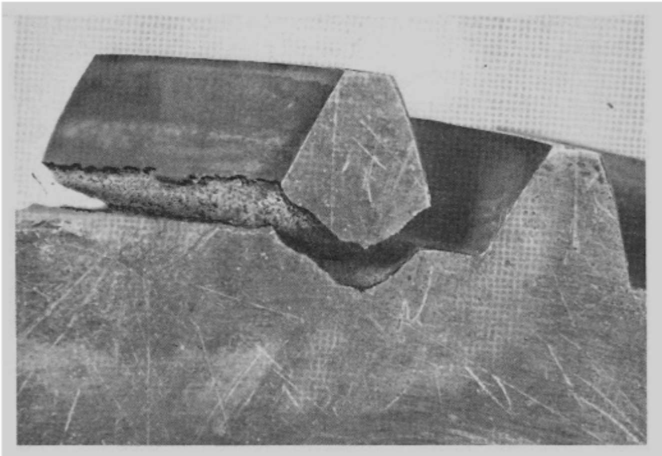

Figure 3. Bending fatigue failure [2]

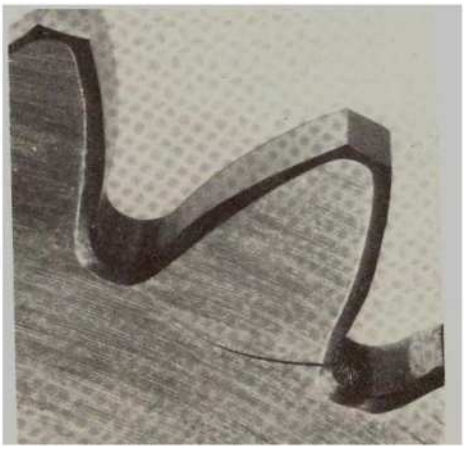

Figure 4. Bending failure – root crack [2]

In some cases, a single overload can break a tooth. A more common occurrence is the plastic yielding of a group of teeth in one load zone from a single high impact load. The plastic yielding displaces the pitch on these teeth with respect to the other teeth on the gears, thus subjecting them to abnormally high dynamic loads in normal operation. These cracks then propagate very quickly under normal operation until sudden fracture occurs.

The design of the gears can aid in limiting the occurrences of bending fatigue failures. By using a higher pressure angle gear, the root bending strength of the gears can be increased. However, the higher the pressure angle of the gears, the higher the generated noise levels as well. The most common pressure angles used on conveyor reducer gears are 20°, 22.5° and 25°. It is recommended that the

higher pressure angle of 25° be used to optimise the bending strength of the gears, while the axial overlap ratio of the gears is optimised to mitigate the increase in noise generated by the higher pressure angle. This is applicable to both the helical and bevel gears of the conveyor reducer. However, it should be noted that while the higher pressure angle increases bending strength, it is detrimental to the pitting resistance of the gears.

The bevel gear set of the right-angled conveyor reducer, owing to the conical shape of the bevel teeth, can experience a bending failure of the teeth at the toe (the narrow end) of the gear. At the toe, the bevel gear root is narrower and has less load carrying capacity. To prevent this failure, the meshing pattern should cover a large area of the face with a bias to the heel (the wider end) where the root is wider.

The geared reducer of the conveyor drive is particularly prone to bending failures along the shaft where an anti-roll-back device is located. This is due to the braking torque applied by the anti-roll-back devices to counter the torque generated on the gear unit by the belt. During the start-up of the belt without a torque limiting measure, such as a fluid coupling or VFD, the high torque output from the motor can contribute to the bending fatigue of the geared reducer. So it is beneficial to ensure that each conveyor drive is equipped with a torque limiting measure.

The fatigue strength of the gear teeth can be optimised using modern gear analysis tools. These software programs can perform the following analyses along with finite element analysis:

i. Gear tooth geometry optimisation
ii. Loaded tooth contact analysis
iii. Gear strength maximisation
iv. Gear root stress analysis

These analyses ensure that the design can be implemented in conjunction with a finite element analysis of the housing to prevent deflections of the gear case from causing localised load concentrations within the gear meshes.

The Use of Finite Element Analysis for Gear Strength and Failure Investigation

Commercially available finite element software can be used to analyse the bending and contact strength of helical gears. This subject has been the topic of many papers published as far back as 1994.[3] These works focused on the modelling of the gear tooth to determine the root bending strength.

In 2002, a paper entitled 'Stress Analysis of a Helical Gear Set with Localized Bearing Contact'[4] was published which further improved the use of finite element analysis on helical gear teeth. This study investigated the contact and bending stresses of a helical gear set with localized bearing contact. An important conclusion was: "The proposed FEA method can accurately calculate the contact and bending stresses. This model can be extended further to investigate the load share and transmission errors under load." This information can be used to make

certain that the design of the gear teeth is optimally balanced for both bending and contact strength.

These papers demonstrated the value of the introduction of technologies into the design of gearing. While these tools are widely available in industry, they are used selectively and generally not in the manufacture of conveyor drives, which have come to be considered as a catalogue item not always fully validated for operating conditions. The value of finite element analysis of the gear teeth also adds value in the determination of the root causes of conveyor reducer failures. If the operating failure conditions are unknown, the use of finite element analysis to simulate the experienced failures can aid in determining these conditions. Once these conditions are understood, the existing design can be improved to prevent future failures, or used to determine an alternative solution.

Failure of the Bearings of Conveyor Reducers

As per 'The Practical Factors Affecting Conveyor Gear Unit Bearing Lives "[5] the most common bearing failures in conveyor reducers are due to factors such as inadequate lubrication and contamination. Often the fatigue failures in conveyor reducers are due to localised load concentrations in the bearing from misalignment and/or contamination. This leads to pitting of the bearing rollers and raceways.

The most commonly used bearings in conveyor reducers are spherical roller and tapered roller bearings. The spherical roller bearing has excellent radial load carrying capacity per millimetre of outer diameter compared to most other bearings. The spherical roller bearing, having an outer ring with an internal spherical profile, can adjust to support static and dynamic misalignment, making it very robust in this application. However, the load ratio of the applied radial load to the load rating of the bearing should be adequate to prevent the bearing being operated with too light a load. A bearing operating at too light a load does not adequately disperse the lubricant and is prone to skidding.

The tapered roller bearing is commonly used within the conveyor reducer for its high axial load carrying capacity. It does however, have a lower radial load carrying capacity than the spherical roller bearing, so where both axial and radial load carrying capacity are required, it has become common practice to pair a tapered roller and a spherical roller bearing. It must be noted that the tapered roller bearing is more prone to fatigue attributed to misalignment than the spherical roller. Due to the construction of the spherical roller bearing and its ability to transmit misalignment, it should be ensured that the misalignment produced during operation is within the acceptable limits for the selected bearings.

With many suppliers and manufacturers utilising engineering skills as a sales and marketing tool, closer links between designers and engineers have allowed the gear unit manufacturers to improve their bearing selections. Many bearing manufacturers have self-developed software tools that allow for the internal analysis of the selected bearings under expected operating conditions. These programs analyse the bearing under a given load, fit and temperature variation,

determine the operating clearance, load sharing and relative roller loads. The advantage of using these tools in the design of the conveyor reducer confirms that under expected operating conditions, the induced shaft misalignment does not lead to localised load concentrations and thus increased fatigue.

It is assumed that by specifying a higher L10h life for a conveyor reducer, the resultant larger bearings will be more robust. This is a misconception. The larger the bearings, the more likely the bearings are to be lightly loaded. It has been found that the optimal bearing life to ensure sufficient operation, is 50,000 hours L10h unmodified. This ensures adequate loading and fatigue resistance.

Baseplate Failures

Not usually considered a critical component of the conveyor drive, the fabricated baseplate plays an important role in the structural rigidity of the conveyor drive. The baseplate must be rigid enough to support the transmission components, i.e. the reducer, high-speed coupling and electric motor, under both static and dynamic operating conditions. The baseplate must be rigid enough to oppose both torsional (twisting) and bending (flexing) deflections. Any deflections within the baseplate causes misalignment in the transmission components and increases the effects of fatigue in the drive train.[6] This leads to shaft and bearing failures. A primary failure of the baseplate is then inevitable in the secondary or consequential failures of the drive train components. It is thus important to ensure that every precaution is taken to prevent these failures from occurring.

The fabrication of the baseplate itself makes it prone to high cycle fatigue in the fabrication welds. To prevent this fatigue, the baseplate must be designed to reduce the stress induced in these welds. This can be achieved through the use of finite element analysis on all baseplates, also preventing the out-dated design method of simply increasing size and therefore the cost, from being used as a design standard. Stress-relieving of the base plate prior to machining is also an excellent way to reduce internal stresses and limit fatigue.

The use of fatigue life prediction methods applied to the fabricated base for all expected operating conditions, can help to reduce failures while limiting the cost of the fabricated baseplate. This analysis should focus on the torsional rigidity of the baseplate and must include a modal analysis.

Coupling Failures

Couplings form an important part of the conveyor drive, imparting many of its defining characteristics. On a conveyor drive there are two couplings, the input or high-speed coupling and the output or low-speed coupling. Each coupling is designed for different purposes, and thus has different failures.

High-Speed Coupling Failures

The high-speed coupling, connecting the electric motor to the conveyor reducer, is a vital component in the transmission of torque from the motor to the pulley. This is the coupling more prone to fatigue as a result of its high-speed operation. The

assembly of the motor and conveyor reducer on the baseplate requires the use of a flexible coupling. High-speed couplings are often selected late during the design of the conveyor drive, without considering the complex requirements of the system. Couplings are a critical component in determining and achieving overall system performance. Coupling selection involves a number of design criteria such as application, torque, misalignment, stiffness, inertia, speed, shaft mounting, operational environment, space limitations, service factors and cost. All these criteria must be taken into consideration in the selection of a high-speed coupling to ensure that the coupling will work properly without premature failure.

Modern analysis tools should be used to analyse the system for both torsional and bending stiffness. These should be used to ensure that the selection of the input or high-speed coupling is optimised for the specific application.

Low-speed Coupling Failures

The shaft-mount conveyor drive utilises a rigid coupling, more specifically a rigid flange coupling, to mount the conveyor drive to the pulley shaft. The rigid flange coupling consists of a male and female half coupling made from high quality steel.

Since a rigid flange coupling rigidly connects the reducer output and the pulley shaft, it can transmit bending across this connection; bending stress induced can result in fatigue failures. It is therefore important to ensure good alignment.

It is important that the coupling is located where the bending moment is practically zero. A rigid flange coupling can cause premature conveyor reducer and/or pulley shaft bearing failures if misaligned. The larger the conveyor drive, the higher the mass and inertia. Thus the greater the generated misalignment, the greater the induced stresses in the reducer output shaft and the pulley shaft. This is a leading cause of fatigue failure of the geared reducer output shaft. It is therefore important to prevent failures of the low-speed coupling in order to prevent consequential damage to the rest of the conveyor drive. The important preventative method for rigid flange couplings is to ensure that during installation, the measured misalignment is within acceptable coupling specifications.

Torque Arm Failures

A catastrophic failure of the conveyor drive torque arm is very rare. This is due to the fact that prior to catastrophic failure, the failure of the torque arm results in consequential damage to the other components of the conveyor drive, such as the conveyor reducer. Generally, the failure of the torque arm leads to the inability of the drive to self-align to the drive pulley causing damage to the low-speed shaft, bearings and coupling.

Many torque arm failures are the result of fatigue due to misalignment from poor installation or re-installation. In poor installations, the torque arm is restricted and does not allow the conveyor drive to move freely, generating high stresses with the output and pulley shafts. The misalignment of the conveyor drive to the conveyor pulley creates increased loads within the torque arm. The torque arm

generally consists of a rod with tie-rod ends, which are self-aligning through encased plain spherical roller bearings. The simple torque arm only allows applied load in the same plane of rotation of the conveyor pulley.

The torque arm is generally designed to operate in compression, or with a downward force into the support structure. This acts as a fail-safe in that the conveyor drive moves a shorter distance to the ground, the nearest fixed surface, than the torque arm operating in tension. The compressive nature of the load on the torque arm elevates the allowable fatigue loads experienced compared to tensile loads. The fatigue strength of the welds used to fabricate the torque arm mountings is greater in compression than in tension; this increases the fatigue life of the torque arm. It also increases the likelihood of a buckling failure. Finite element analysis prevents buckling failures during static or dynamic operational conditions.

It is recommended that the torque arm be designed to allow the conveyor reducer to self-align. Hence, the torque arm should allow an adequate amount of internal misalignment to ensure that the conveyor drive is aligned to the pulley shaft at all times.

CONCLUSIONS

With the advancement of modern analysis techniques and tools, the design of the conveyor drive can be greatly improved to ensure adequate performance under operational conditions. The use of the many analyses mentioned in this paper can aid in reducing and limiting failures during operation. However, it must be stated that the analysis should consider the full range of operational conditions, dynamic and static, bending and torsional. Failure of a single drive conveyor results in a complete stop in throughput which can be extremely costly, while the failure of a drive on a multiple drive conveyor, while not complete, does lead to a loss nonetheless. Another advantage of the implementation of modern design tools is the reduction of total life costs of the conveyor drives used in critical industries worldwide. Improvements within engineering are driven by the economic implications involved, thus should the most costly components of the conveyor drive not utilise the full capabilities of the technologies available?

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