# Analyzing Synchronous Belt Failure

## The Gates Corporation

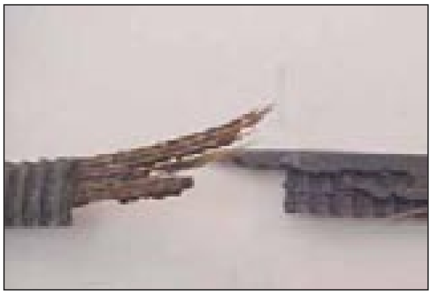

Figure 1—Normal fatigue failure.

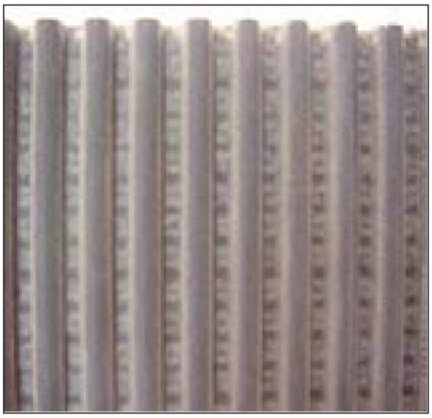

Figure 2—Fuzzy belt tooth appearance from wear.

### Introduction

If you're replacing your belts more than once per year, it's time to analyze your drive. From belt crimping damage to high belt installation tension to sprocket misalignment and adverse environmental conditions, this guide walks you through how to identify the reasons behind premature failure and makes recommendations on corrective and preventive measures.

Synchronous belt failure results in ever-decreasing performance and often-costly belt replacement. A careful diagnosis of your drive's underlying issues, however, will ultimately save you money and maintenance time.

### Part 1: Common Causes of Belt Failure

Identifying the cause of belt failure can be challenging. In this section, we'll define, illustrate and diagnose some of the most common culprits, so you'll be prepared to correct the problem and take preventive measures in the future.

***Normal belt wear and failure***. A failure that occurs when a belt reaches its ultimate tensile cord fatigue life, after running for a period of two to three years, may be considered to be normal. Belt tensile failure due to cord fatigue after a long running period is considered to be ideal. Figure 1 illustrates a jagged 45-degree belt fracture that is typical of tensile cord at the end of its fatigue life.

Synchronous belt teeth can also fail, but that is considered to be a non-ideal type of belt failure. After a long period of service, belt teeth may appear to be worn, although they should retain their original size and form. Protruding fibers from the jacket may give belt teeth a fuzzy appearance, as illustrated in Figure 2.

No corrective action is needed for belts performing for a long time period. Belt life can vary significantly from application to application due to numerous factors, including the transmitted power level, the environment, belt installation tension, shaft/sprocket alignment, sprocket condition and even how the belt was handled prior to and during installation.

***Belt crimp failures***. A "crimp" type belt failure often resembles a straight tensile failure as illustrated in Figure 3. A straight type of break like this may occur when belt tensile cords are bent around an excessively small diameter. A sharp bend may result in large compressive forces within the tensile members, causing individual fibers to buckle or crimp and reducing the overall ultimate tensile strength of the belt. Belt crimping damage is most commonly associated with belt mishandling, inadequate belt installation tension, sub-minimal sprocket diameters, and/or entry of foreign objects within the belt drive.

Belt crimping due to mishandling can result from improper storage practices, improper packaging and belt handling prior to and during installation.

Belts operating in an under tensioned condition may allow belt teeth to ride out of the sprockets until an acceptable belt tension level is achieved. This phenomenon is called "self-tensioning." Self-tensioning can be most clearly observed at the point of lowest dynamic belt span tension, or where the belt teeth are entering the driven sprocket grooves. When a belt is self-tensioning, the belt teeth ride up out of the sprocket grooves until increased span tension from the approaching tight side tension forces the belt teeth back down into the sprocket grooves. The point at which the belt teeth are forced back down into the sprocket grooves often results in a sharp, momentary point of bending that can result in belt tensile cord damage. This point of tensile cord damage is referred to as a crimp. If the tight side tension does not force the belt teeth back down into the sprocket grooves, the belt will ratchet. Belt ratcheting can also result in tensile cord crimp and belt tooth damage.

Subjecting belts to sub-minimal bend diameters can also result in belt tensile cord damage, or crimping. This can be caused by sprockets or flat backside idlers in sub-minimal sizes, or even hand bending a belt too sharply.

Foreign objects located between the belt and sprocket can also result in belt crimping. They can lift the belt away from the sprocket at a sharp angle, creating a point of tensile cord crimp. Tools used to force belts onto sprockets, such as screwdrivers or bars, can also cause belt cord crimp damage. Belts subjected to foreign objects or improper use of tools during installation may not fail immediately after being damaged; however, the overall belt life will be reduced.

***Shock load***. Shock loading in belt drives occurs when higher-than-normal intermittent or cyclic torque loads are generated by the driven equipment. These shock loads result in higher-than-normal belt stresses and can act as a catalyst for belt failure. While conventional V-belt drives may exhibit intermittent slip under peak torque load conditions, synchronous belt drives must transmit the entire magnitude of the peak loads.

Severe shock loads can result in belt tensile breaks with a ragged and uneven appearance, as illustrated in Figure 4. The particular belt teeth engaged in the sprocket at the instant of the shock load may also develop root cracks and/or exhibit tooth shear. If the shock load occurred only once, or was cyclical and repetitious at one specific location around the belt, the remaining belt teeth may appear normal. Figure 5 illustrates how root cracks caused by shock loading can propagate through the teeth. Cracks forming at the tooth roots sometimes move towards the tooth tips. Teeth containing multiple cracks may then shear, leaving only a portion of the tooth behind.

The shock loads generated by the driven equipment may be an inherent part of system operation or may result

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**Figure 3—Crimp failure.**


**Figure 4—Typical shock load failure.**


**Figure 5—Tooth root crack propagation.**

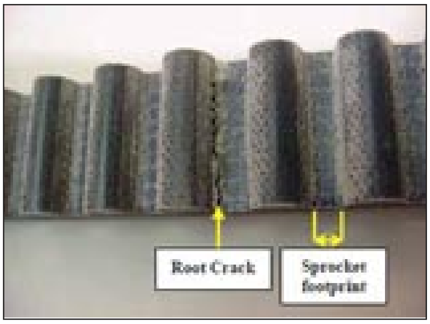

**Figure 6—Crushed land areas.**

Figure 7—Excessive land area wear.

Figure 8—Tooth separation failure.

Figure 9—Excessive tooth wear.

Figure 10—Extreme belt edge wear.

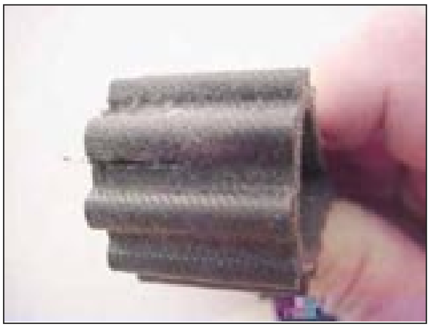

Figure 11—Uneven belt wear.

from an occasional harsh condition such as jamming. If the drive shock loads cannot be eliminated, the belt tensile strength may need to be increased or the synchronous belt drive replaced with a more forgiving V-belt drive system capable of intermittent slip.

## Part 2: Improper Belt Installation Tension

In this section, we'll focus on the effects of improper belt tensioning–from applying excessive installation tension to insufficient tension–to help prevent premature belt failure.

***High belt installation tension***. Applying excessive installation tension to a synchronous belt may result in belt tooth shear or even a tensile break. Many belts that have been excessively tensioned show visible signs that sprockets have worn the belt land areas. Figure 6 illustrates a belt with crushed land areas and a crack that formed at the root of the belt tooth. A root crack will often propagate down to the tensile member and travel to the next root crack. Individual belt teeth will then separate from the body of the belt and often fall off. Figure 7 illustrates a belt that had been over tensioned on large sprockets. High belt land pressures caused excessive belt land area wear, ultimately revealing individual tensile cords. In order to prevent belt wear problems like these, proper belt installation tension levels must be determined and set accurately.

***Low belt installation tension***. Applying insufficient installation tension to belts operating on moderately to heavily loaded drive systems may also result in premature failures. A common belt failure mode resulting from insufficient belt installation tension is referred to as tooth rotation. Belt tooth rotation can occur as belt teeth climb out of their respective sprocket grooves (self tensioning) and drive loads are no longer applied at their roots. Drive loads applied further down the belt tooth flanks cause the belt teeth to bend (like a diving board) and "rotate." Belt tooth rotation can result in rubber tearing at the base of the belt teeth along the tensile member. As rubber tearing propagates, belt teeth often begin to separate from the belt body in strips, as illustrated in Figure 8. Failures due to excessive tooth rotation may resemble failures caused by insufficient rubber adhesion to the tensile cords. Unlike tooth rotation failures, failures from insufficient rubber adhesion leave the exposed tensile members clean where the belt teeth were once located.

As belt teeth climb out of their respective sprocket grooves to self tension, belt ratcheting or tooth jumping may occur before rubber tearing and belt tooth separation occurs. Belt tensile cord damage resulting from ratcheting can cause premature belt tensile failures. These tensile failures may resemble crimp-type breaks (straight and clean) as well as shock load-type breaks (jagged and angled). If belt ratcheting does not occur and belts continue to operate while self tensioning, excessive belt tooth wear often occurs. This tooth wear is referred to as "hook wear" and results from improper belt tooth meshing with the sprockets, as shown in Figure 9. Hook wear-type belt failures result from insufficient belt installation tension and from weak drive structures that allow center distance flexing while the drive system is under load.

Increasing belt installation tension levels generally prevents premature belt failures due to tooth rotation and hook wear. If increasing the belt installation tension level does not prevent this type of failure, the drive structure may not be rigid enough to prevent deflection. Added structural support may be necessary to improve belt performance. If it is not practical to increase belt installation tension levels, increasing the sprocket diameters will allow higher drive loads to be transmitted with less belt tension.

## Part 3: Belt Drive Hardware Problems

In this section, we'll examine the negative effects that problems with belt drive hardware have on the operation and life of your belts.

***Sprocket misalignment***. Belts operating on drives with angular shaft misalignment or tapered sprockets often exhibit an uneven wear pattern across the belt tooth flanks and uneven compaction in the land areas (in between belt teeth) due to the uneven application of load to the belt. Belt failures often occur from tooth root cracks or tears initiating on the side of the belt that is carrying the highest tension and propagating across the belt width, ultimately resulting in tooth shear. One edge of the belt may also show significant wear due to high tracking force and may even roll up or attempt to climb the sprocket flange(s). Figure 10 shows extreme belt edge wear from a high tracking force.

Belts operating on flanged sprockets with parallel misalignment (offset sprockets) may exhibit excessive belt edge wear on both edges if the belt is pinched between opposite flanges. Belt failures may then occur by tooth root cracks or tears initiating from both edges of the belt. These tears may eventually extend across the entire width of the belt, resulting in tooth shear.

Belts operating on a combination of both flanged and non-flanged sprockets with parallel misalignment may walk or track partially off of the non-flanged sprocket(s). The portion of the belt remaining engaged with the non-flanged sprocket(s) will carry the full operating load and may develop a concentrated area of wear after running this way for a period of time. Figure 11 shows concentrated wear across the majority of the belt tooth face with a portion relatively unworn. A root crack has also developed below the worn area. This may ultimately result in premature belt failure due to either tensile or tooth fatigue.

***Sprocket(s) out of specification.*** Premature belt failures resulting from sprockets either manufactured or worn outside of design specifications are difficult to recognize. This is partly due to the fact that sprockets are rarely inspected closely when a belt fails. Premature belt failures are often assumed to be the fault of the belt alone.

Belts operating on sprockets that are out of dimensional specification often show a high degree of tooth flank wear with the jacket flank exhibiting a fuzzy or flaking appearance, as shown in Figure 12.

Curvilinear (HTD and GT) belts operating on subminimal sprocket diameters usually fail by land disintegration, illustrated in Figure 13, and tensile breaks. Trapezoidal (XL, L, H) belts will usually fail by tooth root cracks and tooth shear; however, tensile breaks are not uncommon.

A higher rate of sprocket wear may occur from belts that have been installed with excessive installation tension. Belts that have been in operation for a long time have sometimes had the tooth facing or jacket completely worn away. Belts in this condition indicate that significant sprocket wear may have also occurred. Belts worn to this point also sometimes allow belt tensile members to contact the sprockets resulting in a grooved wear pattern around the outside circumference.

A good indication of sprocket wear is when a ridge along the tip of sprocket teeth becomes visible, as illustrated in Figure 14. Use caution: severely worn surfaces on sprocket faces may become very sharp. It is best to use a screwdriver or other tool to feel for the ridge in order to prevent finger cuts. When a ridge on the sprocket face is detected, the sprockets should be replaced.

The most rapidly and severely worn sprockets are most commonly found in abrasive atmospheres. Severely worn sprockets often exhibit groove wear as well as a reduction in the outside finish diameter. A typical belt failure on worn sprockets exhibits polished land wear and may have teeth worn to the point of serious dimensional distortion (hook wear). Sprockets plated with a hard chrome finish can be used to extend the sprocket life in abrasive atmospheres.

Another indication of severe sprocket wear is when replacement belt life is noticeably reduced from previous belts. When this occurs, sprockets should be examined closely for excessive wear.

***Excessive sprocket run-out.*** Belts operating on sprockets with radial run-out are subjected to a cyclic rise and fall in belt tension as the sprockets rotate. The greater the run-out, the higher the peak belt tension grows. Belts subjected to significant cyclic peak tensions exhibit land areas with a crushed appearance. Crushed land areas and tooth shear are both visible in Figure 15. A crushed land area condition may appear similar to belts operating on moderate size sprockets under excessively high tensions. Belts subjected to extreme cyclic belt tension variations often fail from either tooth shear or tensile break.

Excessive sprocket run-out is most often observed when sprockets are mounted improperly on bushings, or when minimum plain bore sprockets are improperly re-bored and mounted.

### Part 4: Negative Effects of Environmental Conditions

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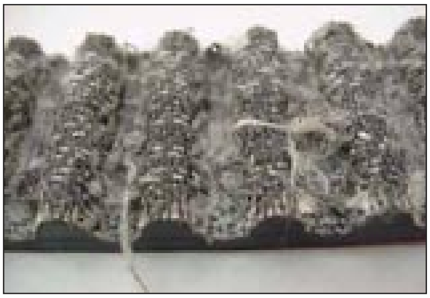

**Figure 12—Extreme tooth wear from worn sprockets.**

**Figure 13—Land disintegration.**

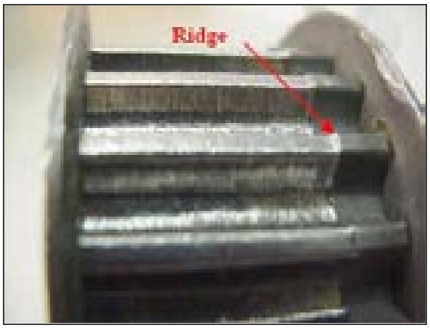

**Figure 14—Excessive sprocket wear.**

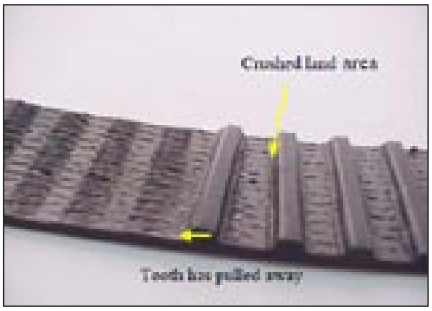

**Figure 15—Extreme land crushing and wear from excessive sprocket runout.**

**Figure 16—Extreme wear from abrasion.**

In this section, we'll zero in on the environmental conditions—abrasive atmosphere, heat degradation, chemical degradation and foreign objects—that can negatively impact your belts.

***Abrasive atmosphere*.** Belts operating in abrasive atmospheres on applications like foundry shakers, taconite processing equipment and phosphate mining conveyors often exhibit a high degree of belt land and tooth flank wear. Worn areas frequently have a polished appearance. Figure 16 illustrates a severely worn Gates Poly Chain GT2 belt that ran in a highly abrasive environment. Sprocket wear is generally rapid in abrasive environments; therefore, sprockets should be replaced along with belts. To extend the life of belts and sprockets, a sealed guard that is pressurized with clean air can be installed to help keep out abrasive dust and contaminates.

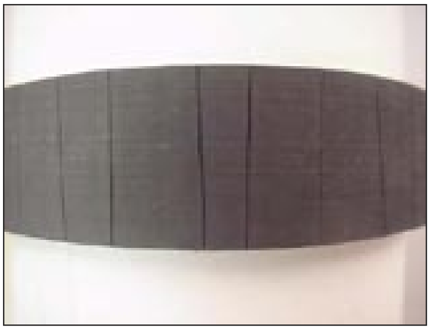
**Figure 17—Cracking from high-temperature operation, rubber.**

***Heat degradation*.** When rubber belts operate at elevated temperatures (greater than 185°F) for prolonged periods of time, the rubber compound gradually hardens resulting in back cracking due to bending. These cracks typically remain parallel to the belt teeth and usually occur over land areas (in between belt teeth), as illustrated in Figure 17. Belts generally fail due to tooth shear, which often leads to tensile cord fracture. High-temperature rubber belt constructions are available for belt drives that must operate in high-temperature environments. These special belt constructions help to improve belt service.


**Figure 18—Melting from high-temperature operation, polyurethane.**

The body material used in urethane belts such as Poly Chain GT Carbon belts is thermoplastic, meaning it has a melting point. When subjected to environmental temperatures in excess of 185°F, the teeth may begin to soften and deform. In addition, the tensile cord to urethane adhesion loses its integrity. Figure 18 illustrates a Poly Chain GT2 belt that was exposed to a high environmental temperature.

***Chemical degradation*.** Rubber belts subjected to either organic solvent vapors or ozone will resemble belts that have been subjected to high environmental temperatures. The rubber compound will harden and belts will exhibit back cracking. The cracking pattern will differ, though, in that the compound hardening occurs mostly at a surface level allowing cracks to form in both lateral and longitudinal directions. A "checkered" appearance may result.


**Figure 19—Tensile cord failure from debris.**

***Foreign objects*.** The introduction of foreign objects between a belt and sprocket often damages both belt teeth and tensile cords. Tensile cords often fracture internally (see Figure 19) or fail later due to crimping, as shown in Figure 20. Once a portion of the tensile cords has fractured, the remaining tensile strength of the belt has been reduced considerably. This often results in a dramatic reduction in belt life. If belt damage from debris is noticeable, the belt should be replaced and the sprockets checked for damage. Damaged sprockets should also be replaced.


**Figure 20—Crimp failure due to debris.**

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