

## Next Generation Carbon Synchronous Belts. *Making Roller Chain Obsolete?*

### Introduction

Is a synchronous belt drive system really any match for a roller chain drive in high-torque applications? Thirty years ago one might have answered no, but that's not the case today. New materials, construction and designs have led to synchronous belt drive systems that outperform equivalent size roller chain drives in a wide range of applications, yielding cost advantages for users, and greater design versatility for engineers.

### Content

- Roller Chain History and Development
- Six Key Problems with Chain Drives
- The Synchronous Alternative
- Addressing Chain Drive Problems
- Conclusion
- Resources

### Roller Chain History and Development

The chain drive is one of the oldest forms of power transmission known to man. There is evidence of chain driven water lifts as early as 225 B.C. Leonardo da Vinci's sixteenth century sketches of a chain drive bore a strong resemblance to the modern silent chain. However, real advancements in the use of chain drives in power transmission applications began in earnest during the late 1800s with development of cast iron detachable chain, quickly followed by cast pintle chain—the forerunner of chain as we know it today.

In the beginning of the twentieth century, chain expanded into applications such as bicycle and automobile drives, both for transmitting power to the drive axle and for synchronizing cam shafts. Industrial applications soon followed; by 1913 the roller chain industry was one of the first in the world to publish user standards.

The popularity of chain drives today stems from their ability to transmit high torque, at relatively low cost, while utilizing readily available stock components. Furthermore, until recently, chain drives were the only practical method of creating low speed, high torque applications that would work over a wide range of ratios with virtually unlimited center distances.

Both equipment manufacturers and maintenance departments in today's industrial plants have used chain drives for years and are very comfortable with the technology; but this reflex reaction has its down side. Chain drives have inherent weaknesses that have long been accepted in the belief that no other practical option existed. In fact, a practical alternative does exist in the form of the modern carbon synchronous belt drive.

## Anatomy of a Roller Chain

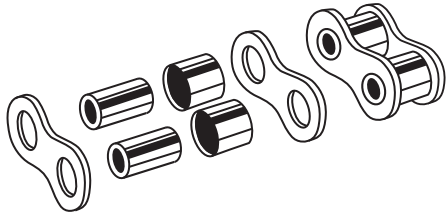


Figure A. Standard Roller Link

Roller chain consists of alternating inside and outside links that are interconnected. Inside links are generally comprised of six pieces. *Bushings* are press fit in sets of two into two *roller link plates* so that they are spaced apart appropriately, and remain parallel. Free turning *rollers* are included on the outside of the bushings, and are restrained between the two roller link plates. This entire assembly is called a *roller link*, as illustrated in Figure A.

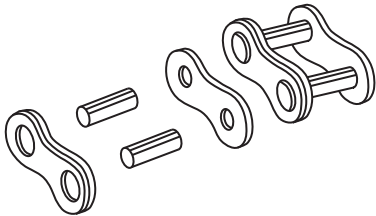


Figure B. Standard Pin Link

Each roller link is joined to the next by outside links that are generally comprised of four pieces. Two *pins* that pass through the bushings of adjacent roller links are either press fit or held in place with cotter pins between a pair of *pin link plates*. These pin link plates separate the adjoining roller links at the appropriate distance. This assembly is called a *pin link*, as illustrated in Figure B. When in operation, the rollers engage into the teeth of mating sprockets to transmit power and motion.

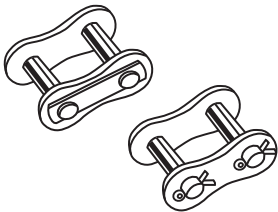


Figure C. Spring Clip and Cotter Pin Connecting Links

*Connecting links* join the ends of a length of roller chain to form a continuous or endless chain. Connecting links look much like pin links, but with one pin link plate detachable. Spring clips are used to retain the detachable pin link plate onto the pins in roller chains up to the #60 size. Roller chains in the #80 size and larger use cotter pins through the pins instead of spring clips. (See Figure C.) In some heavy duty roller chains, pin link plates are press fit onto the pins. Connecting links add two pitches to a length of roller chain, so that the total number of rollers remains even.

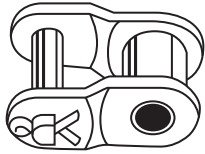


Figure D. Offset Link

Offset links also join the ends of a length of roller chain, but add only one additional pitch, making the total number of rollers odd instead of even. An offset link appears like a normal roller link on one end, but the pin link plates are flared outward so that the other end can connect to the roller chain via a cotter pin. (see Figure D.) Offset links are generally used in conjunction with connecting links to connect the roller chain to the roller link-like end of the offset link.

Individual connecting links reduce the normal power rating of roller chain by up to 20% (up to 35% for offset links), depending on the manufacturer. This reduction in the maximum allowable load must be taken into account when designing or evaluating roller chain drive systems. The strength-decrease ratio can be greatly reduced by using *tap-fit connecting links*, or avoided altogether by using *endless roller chain*, which is produced by the manufacturer in specific lengths, but available only on a made-to-order basis. The vast majority of roller chain is sold in non-endless form and joined together using connecting links.

## Six Key Problems with Chain Drives

A roller chain drive today is not really much different than it was 50 years ago. While gains have been made in horsepower ratings, increased operating life, reliability and reduced maintenance, these improvements are what you might expect from a mature technology. The real issue is that chain drives are a high maintenance drive system. There are six key problems associated with chain drives.

### 1. Stretch or Elongation

Roller chain wear results in stretching, or elongation. Elongation is caused primarily by pin/bushing wear due to joint articulation during sprocket entry and exit, as illustrated in Figure 1.

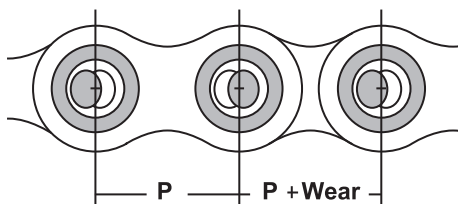


Figure 1. Roller Chain Pin and Bushing Wear

Pin/bushing wear results in pitch elongation as illustrated in Figure 2. Pitch elongation increases interference between the roller chain and sprockets, and results in a cumulative effect over the entire length of roller chain. Manufacturers recommend roller chain replacement when elongation reaches approximately 3 percent.

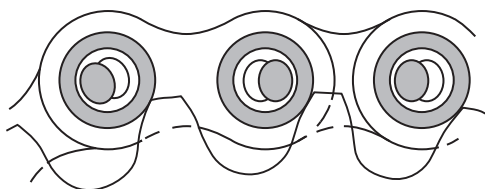


Figure 2. Elongated Roller Chain Meshing With A Sprocket

When the chain has “stretched” 3%, it is heavily worn. All the components of the chain (rollers, pins and bushings) have lost their case hardened surface, and failure is imminent. In everyday terms, what does 3% “stretch” mean? It means that maintenance personnel will have to adjust the chain tension several times over the life of the drive. To be more precise, a 100-inch (254 cm) chain drive will require about 1.5 inches (3.81 cm) of center distance “take-up,” which equates to 3 inches (7.62 cm) of apparent chain stretch.

## 2. Lubrication

Lubrication is absolutely essential for reasonable chain and sprocket life expectancy. Proper lubrication reduces the wear on all moving surfaces of the chain, and helps cushion the drive from the impact of shock loads. Thus in designing or selecting a chain drive, the method of lubrication is every bit as important as any other drive design factors being considered.

The loads and speeds under which the chain drive operates determine the lubrication system required. The higher the speed, the more sophisticated and costly the lubrication system. On many drives it is not uncommon for the lubrication system to cost considerably more than any other component.

Even without a sophisticated lubrication system, it is essential that chain drives be enclosed in many areas of a plant, to avoid contamination of the finished product. For this reason, some plants choose not to lubricate certain chain drive applications, even though the chain industry estimates that a non-lubricated chain will wear up to 300 times faster than one properly lubricated.

## 3. Speed and Ratio Limitations

Roller chain is predominantly used for low speed, high torque applications. Capacity starts to decline between 2,000 to 3,000 feet per minute (610 to 914 meters/minute). For higher speed applications, silent chain and HV chain are used. Silent chain capacity will peak at about 5,000 ft/min (1524 m/min), while HV chain has a peak of approximately 6,500 ft/min (1981 m/min).

There is a price to pay for this higher speed. Silent chain drives will cost 4 to 5 times more than standard roller chain drives, and HV is 30 to 35% more expensive than silent chain. In addition, both require sophisticated lubrication systems as well as proper chain cases, seals, etc.

Another problem arises in the servicing of these drives. Because there are so many variations of silent chains, some with center guides, double-center guides, side guides, or various combinations of all of the above, rarely are the sprockets for silent chain stock items. Made-to-order products are very costly and have long lead times, all of which makes these drives rather undesirable, unless there are no other options.

Roller chain drives are capable of speed ratios as high as 12:1. However, single-strand roller chain drives with speed ratios above 7:1 are not recommended in order to maintain an adequate wrap angle on the small sprocket. For maximum service life with speed ratios above 5:1, compound (multiple stage) drive systems are recommended. Roller chain drives with high speed ratios should have at least 120 degrees of wrap on the small sprocket so that 1/3 of the teeth are in mesh.

## 4. Chordal Action

Another major problem with roller chain drives is the variation in speed or surging caused by the acceleration and deceleration of the chain as it goes around the sprocket link by link. This variation in speed is called *chordal action* or *polygonal effect*. It starts as soon as the pitch line of the chain contacts the first tooth of the sprocket. This contact occurs at a point below the pitch circle of the sprocket. As each roller engages with a sprocket tooth, the link plates remain rigid and the pitch line momentarily rises and falls until the next roller engages the sprocket. This rising and falling of the pitch line results in rhythmic velocity changes, which translate into tension changes, or vibration, during drive operation. (See Figure 3.) To further compound the problem, this chordal effect will be transmitted through the entire drive system, affecting the chain, the sprockets, bearings and seals, as well as the driven component.

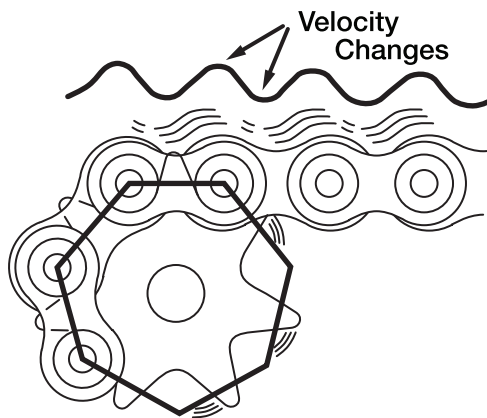


Figure 3. Chordal Action or Polygonal Effect

Chordal action is inversely proportionate to the number of teeth on the sprocket. As the number of teeth in the sprocket decline, the variation in the chain speed increases dramatically. For example, the velocity variation for a 10-tooth sprocket is approximately 5%, a 15-tooth sprocket is about 2%, and a 20-tooth sprocket is about 1%.

## 5. Shock Loading and Backlash

Shock loading and backlash can cause substantial damage to all components of the chain. As the chain and sprockets wear, the combined impact of shock loading and backlash will result in higher maintenance. This problem becomes even more complex because, contrary to manufacturers' recommendations to replace sprockets when replacing chain, few maintenance departments actually replace the sprockets until they are noticeably worn. This will dramatically shorten the life of the replacement chain.

## 6. Maintenance Cost

While initial costs of roller chain drives can be quite low, the cost of maintaining these drives can be substantial. In order to keep equipment running, it is absolutely essential that chain drives are lubricated and retensioned on a regular basis. The labor costs to perform this "regular" maintenance, along with the associated downtime and lost productivity, represent a significant investment in time and money.

## The Synchronous Alternative

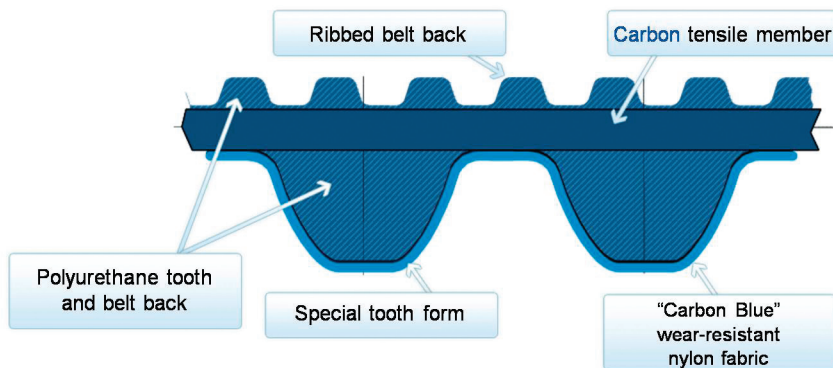
The engineers who developed the original timing belt, which was a light duty rubber synchronous belt for the sewing machine industry, had no idea that their original concept would someday have the capacity to meet and exceed the ratings for chain drives as well as heavy duty V-belts. New designs, materials and construction have yielded a belt drive system with performance characteristics that rival chain drives.

## History and Evolution

Synchronous belt design underwent substantial development since the 1940s, much of it centered on overcoming the problems associated with chain drives. Early synchronous belts could not handle the torque of chain drives at low RPMs. Second generation synchronous belts, known as HTD belts, were developed in the 1970s to displace chain drives, but they were not a practical alternative in most low speed, high torque applications, because the belt had to be 4 to 5 times wider than the chain, and it cost significantly more. It took another 15 years for the materials and technology to evolve to a stage where a synchronous belt could compete with a chain drive. The first of these belts, the Gates Poly Chain® GT® belt, incorporated a patented curvilinear tooth profile that minimized meshing interference, while decreasing backlash by 45-50% over the HTD belt, and substantially more over roller chain. Made with polyurethane compounds combined with aramid fiber tensile cords, this belt provided a truly suitable replacement for many chain drives.

The Gates Poly Chain GT belt underwent several evolutions in design since its introduction over 20 years ago. The latest evolution incorporates a carbon fiber tensile cord that gives the belt greater strength, flexibility, moisture resistance and power density.

## Anatomy of a Carbon Synchronous Belt



Unlike the many components that make up a roller chain, which lead to wear and high maintenance, the carbon synchronous belt is a single integrated unit with no maintenance requirements.

## Why Carbon Cord?

Research and development surrounding carbon fiber has progressed steadily over the past three decades. First used by NASA in rockets and space capsules, carbon fiber is now a material of choice in commercial aircraft design, even superceding metallic materials in certain critical areas. Gates has pioneered the use of carbon fiber in a dynamic application, in the tensile member of a synchronous belt. This patented carbon cord design gives the belt performance attributes, including:

- High flex fatigue resistance (better than steel, glass and aramid fibers)
- High modulus (pitch fit stays constant at various loads)
- Dimensional stability (negligible elongation under load)
- High strength to weight ratio
- Environmental resistance (no degradation from water, oil, most contaminants)
- High power density for more compact drive designs

## Addressing Chain Drive Problems

Carbon synchronous belt technology gives designers and users a synchronous belt drive system that can exceed roller chain capacities while maintaining the same dimensional characteristics. On a cost comparison basis, a Poly Chain® GT® Carbon™ belt drive will cost approximately one-third more than an equivalent roller chain drive initially. Over the life of the drive, however, the synchronous belt drive system will cost considerably less, considering the expense of maintaining the chain drive and the more frequent need to replace chain and sprockets as they wear. In testing and in field applications, Gates Poly Chain GT belts lasted three times longer than chain, and the sprockets lasted ten times longer than chain sprockets.

## No Stretch or Elongation

As previously mentioned, the 100 inch (254 cm) chain requires about 1.5 inches (3.81 cm) of center distance takeup. A similar length carbon synchronous belt requires 0.04 inches (1.016 mm) over the life of the belt. The need to tension a carbon synchronous belt drive on a regular basis is virtually eliminated.

## No Lubrication

A carbon synchronous belt drive requires no lubrication. Without the need for lubricant and lubrication systems, as well as the elimination of ongoing problems associated with contamination of the finished product, leaking seals and lubricant disposal, a carbon synchronous belt drive will yield a sizable annual saving.

## Wide Range of Speed Ratios

Carbon synchronous belts will work well over a wide speed range, from the slowest speeds associated with roller chain, to the high speed applications common to silent chain and V-belt drives. The speed limitation for a carbon synchronous belt drive using standard cast iron sprockets is 6500 ft/min (981 m/min). However, with made-to-order sprockets, speeds as high as 10 -12,000 rpm (3048 - 3658 m/min) can be achieved with stock belts. Stock ratios available with off the shelf components go as high as 10:1.

## No Chordal Action

Having a constant angular velocity, carbon synchronous belt drives are much smoother running than roller chain. The belt's modified curvilinear teeth enter and exit the sprocket grooves cleanly, eliminating speed variation and vibration as the pitch line of the belt moves around the sprocket relative to the pitch line of the sprocket. This single attribute will improve the performance of bearings and seals, as well as all associated equipment. In addition, it will eliminate the transfer of related shock and vibration to the finished product.

## Handles Shockload

Because a carbon synchronous belt is manufactured in a one-piece construction, without an assortment of pins, rollers and bushings common to every link of a chain drive, shock loading is handled exceptionally well.

## Lower Cost of Maintenance

Maintenance is virtually eliminated with carbon synchronous belt technology. Assuming that the belt is properly installed, it will never need to be retensioned. No lubrication is required. The absence of chordal action makes the belt smooth-running, reducing wear and tear on other drive components. There is no metal-to-metal wear, so both belt and sprockets last considerably longer than roller chain. Taken together, these attributes result in a maintenance-free drive system that reduces the material and labor cost of maintenance, while at the same time improving uptime and productivity.

## Conclusion

Will the carbon synchronous belt make roller chain obsolete? Certainly not. Roller chain will continue to play a strong role in industry, for example, in extremely high-temperature applications, in applications that require attachments to the chain to perform a specific function, or in applications that require an extremely long center distance that would be physically impossible to do with belting. However, one should not assume that roller chain is the only viable alternative for high torque drives. Technological advances in synchronous belt design, materials and construction have now reached the point where these drives can match roller chain width-for-width in a wide range of applications, with the added advantage of a competitive initial cost and a minimal ongoing cost of maintenance.

## Additional Resources

Engineering assistance is available from Gates Corporation. Contact the Gates Product Application Helpline, (303) 744-5800, or email [ptpasupport@gates.com](mailto:ptpasupport@gates.com). For application-specific information on the Gates Poly Chain® GT® Carbon™ belt drive system, go to [www.gates.com/nothingtougher](http://www.gates.com/nothingtougher).