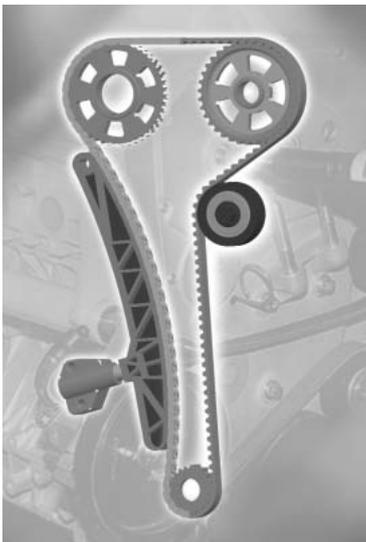


Zahnriementriebe und ihre Vorteile  
hinsichtlich Reibverlusten und Akustik

# Timing Belt Drives and their Advantages Regarding Engine Efficiency and NVH Characteristics



Gates Corporation's Power Transmission Division, the world leader in Synchronous Drive Technology, develops and supplies belt drive systems for the automotive industry. This article deals with the advantages of Timing Belt drives when compared to chain drives regarding fuel consumption and acoustic behaviour. Investigations were made for Timing Belt drives in both dry and oil mist environments.

## 1 Introduction

A synchronous belt drive system is currently the most commonly used technology in Europe for modern engine overhead camshaft drives. Great efforts on material development and drive systems design optimisation have been made over the past years to enable life time timing belt drive systems. Many timing belt drives capable for engine life time have been successfully introduced to the market for several years.

Timing belt drives have significant advantages when compared to chain drives. Some examples are excellent elongation behaviour and good damping characteristics under load, which allow a timing belt to achieve an accurate control of the camshaft timing over the entire engine lifetime. This guarantees the highest efficiency with respect to fuel consumption and emissions. Another important aspect is the ability for a belt drive system to incorporate additional components such as water pumps and injection pumps within a single layer drive. This leads to significant packaging advantages.

This article deals with two additional fundamental advantages of a belt drive system against a chain drive, namely reduced friction losses and better acoustic behaviour.

## 2 Definition of Function

The main purpose of both timing belt and chain drives is to drive the camshaft of combustion engines synchronously with to the crankshaft. Each error in synchronization between camshaft and crankshaft causes deterioration of fuel consumption and emissions. General design requirements are similar for both technologies. All drives have to be durable, compact, silent, efficient and must be optimized for system and maintenance costs.

Automotive timing belts are a composite of heat resistant Nylon fabric, heat resistant rubber compound and high tensile glass cord. Due to the nature of this product and the involved material combination it is able to compensate high dynamic shock loads without permanent elongation and wear. Conversely a chain, constructed of numerous

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metal links has a very high stiffness and minimal damping characteristic. This leads to an inability to resist high dynamic shock loads without wear and irreversible elongation. Chain elongation caused by wear over time (up to 10 times more than a belt) is very critical to emission control. An example for this behaviour is given by the use of timing belts in "unit injector" diesel engines. On such high dynamic, highly loaded systems, chain technology cannot compete with timing belts.

Tensioners in the slack side span maintain the system tension and compensate for wear and elongation of either belt or chain over the system life time. On belt drive systems the tension is applied by hydraulic or spring loaded devices through plastic or steel pulleys utilizing ball bearings. All belt tensioning devices are characterized by the ability to operate fully independent from the engine oil circulation. On chain systems the tension is applied to the chain by hydraulic tensioners, in most cases through plastic friction guides. Chain tensioners need a direct connection to the engine oil pressure system.

Chain drives require all spans to be guided by additional guides to minimize chain span vibrations. Belt drive systems require guidance by additional pulleys only in the case of very long vibrating spans and in case of potential collision of the belt with surrounding engine parts.

More recently, applications for timing belts used in an oil environment have been given higher priority. Here the timing belt is used in a typical chain environment inside the engine. This has been brought about due to packaging reasons but also to use the advantages of belt drives such as better NVH performance and reduced friction losses which lead to improved fuel consumption.

### 3 Test Set-up

Gates and its Japanese sister company Gates Unitta Asia have made several studies [1] on the comparison of friction losses of a belt drive system with a chain drive system.

Throughout these investigations the influence of parameters such as tension level or tensioner type were looked at and a comparison was drawn up between the two types of drive system.

An additional study was initiated comparing the acoustic behaviour of timing belt and chain drives.

#### 3.1 Test Concept for Friction Loss Study

The friction loss studies were carried out on a test stand designed to permit installation

of different types of cylinder heads, **Figure 1**. The test stand consists of an electric motor which drives a shaft through a belt drive system. This shaft was designed such that the driving torque could be measured through a strain gauge system attached to it. The cylinder head was mounted on a machined plate on the top side of the tester. The camshaft drive system connects the cylinder head with the strain gauged shaft.

To ensure a controlled test environment, a hot box was mounted on the front of the test stand, enclosing the test drive system. The environment within the box was controlled to 100°C.

A heated, pressurised oil system was included to supply lubrication to the cylinder head and pressure to the tensioner for the chain drive system. The oil temperature was controlled to 100°C; the oil pressure was monitored and controlled to reflect the actual oil system as if in an engine situation.

Tests were performed with a gasoline 3-cylinder, 3-valve head. The comparison included the influence of the kind of tensioning device as well as two different types of chain, a roller chain and a silent chain, **Figure 2**. The chain drive was tested under normal conditions in an oil environment. The Timing Belt drive was measured only under dry, non-oil conditions.

The test stand for these studies was designed such that the centre distance of the drive was variable. This allowed measurement of friction loss with and without the tensioner for the belt drive system and the guides for the chain drive system. An evaluation could therefore be made of:

- the total friction losses in the drive
- the friction losses due to the valve train (A)

- the friction losses due to the tensioner/guide (B)
- the friction losses due to shaft bearings and meshing (C).

For details see **Figure 3**.

#### 3.2 Test Concept for Acoustic Investigation

The acoustic comparison was carried out on a motored engine test stand. For this a serial 4 cylinder 1.2 l gasoline engine with a 4 valve cylinder head was used. It was modified so that a belt or a chain camshaft drive system could be installed. Pistons and rods were removed. Oil temperature and pressure were controlled throughout the speed range.

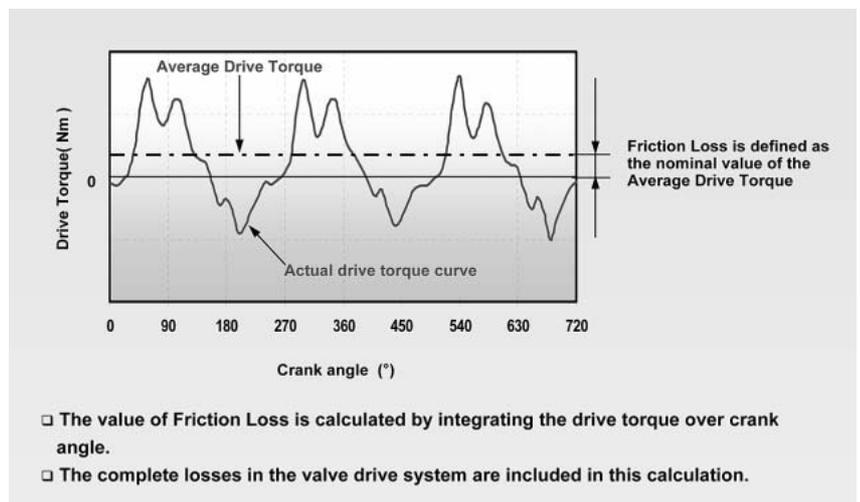
Some preparatory work was required prior to making the measurements. The slack side of the drive was guided and tensioned by a specially designed and prepared guide for the belt drive system. A tight side idler was also included to give acceptable routing for the belt, **Figure 4**.

For this study an 8 mm pitch belt, 20 mm wide, with 21 grooves on the crank pulley, was compared to the standard, serial roller chain drive with 20 grooves on the crank. Both configurations were measured under fixed tension conditions (installation tension 150 N at cold condition).

All tests were performed in a semi-anechoic chamber. Measurements were carried out simultaneously using an artificial head at a distance of 1m from the drive and a near-field microphone at a distance of 10 cm from the centre drive.

### 4 Study of Friction Loss

The definition of friction loss in a drive system is generally accepted as being the differ-



**Figure 5:** Definition of friction loss

ence between the average torque in a drive and zero. The average torque is determined by integration of the area under the measured torque curve for the drive, **Figure 5**.

On the friction loss study with the 3 cylinder head, the comparison was made between:

- timing belt drive with 8.00 mm pitch, fixed as well as automatic mechanical tensioner at three tension levels
- roller chain drive with 8.00 mm pitch and hydraulic autotensioner at preset level
- silent chain drive with 6.35 mm pitch and hydraulic autotensioner at preset level.

#### 4.1 Effect of Installation Tension on Friction Losses of a Belt Drive

The installation tension was varied in the area of 50 N to 300 N. The friction losses for the timing belt system were affected by the installation tension; the highest installation tension gave approximately 0.75 Nm increase at low engine speed and 0.5 Nm increase at mid to high engine speed, **Figure 6**. These losses can be explained due to increase in friction between the belt and pulleys and due to extra losses in the tensioner bearings.

#### 4.2 Effect of Drive Type on Friction Losses

Through the speed range of the engine, the highest friction losses were measured with the silent chain system, followed by the roller chain system. Absolute values were measured between 3.9 Nm and 4.3 Nm. The difference between the two chain systems is up to 0.3 Nm.

The best results were given by the timing belt system with absolute values of min. 2.6 Nm and max. 3.4 Nm. The difference between the best chain system and the comparable belt system thus varied from 0.9 Nm to around 1.1 Nm, **Figure 6**.

#### 4.3 Comparison of Friction Losses by Guide/Tensioner

The friction losses in a chain drive system due to the guide/tensioner are 4 to 5 times those of a belt drive system tensioner, obviously due to sliding friction for the chain system against rolling friction for the belt system. The influence of increased tension was not measured, **Figure 7**.

#### 4.4 Effect of Tensioner Type on Friction Losses in a Belt Drive System

At low installation tensions, a belt drive system with auto tensioner gives no significant improvement over a fixed tensioner drive. As

installation tension is increased, the auto tensioner gives an improvement of 0.3 to 1.0 Nm, depending on engine speed.

#### 4.5 Overall Comparison of Friction Losses

At 2000 rpm, the shaft bearings account for around 50 % of the total losses in the valve-train drive system. This is valid for both the timing belt and the chain system. The tensioner in a belt system can reduce the loss to 7 % or less while the guide/tensioner losses in a chain system can equate to between 15 and 20 %.

Overall the belt system reduces the frictional losses by as much as 30 % versus the chain drive system, **Figure 8**.

#### 4.6 Calculation of Fuel Consumption Improvement

A formula for the evaluation of fuel consumption improvement is defined as shown in **Figure 9**.

Based on the assumption that the valve train and the timing drive together account for 20 % of the total loss in an engine [2] an improvement in fuel consumption of 2 % can be achieved, **Figure 9**. This improvement in efficiency, linked to the fact that timing accuracy of a belt drive system over engine life is much better than that of a chain system due to less elongation, means that an engine designed with a belt drive for the camshaft will also have improved emissions over life time compared to an engine with a chain drive system.

### 5 Results of Acoustic Comparison

The acoustic comparison was not performed on the test stand used for the friction loss measurements but on the previously mentioned 4 cylinder motored engine.

Looking at the Campbell diagrams for the two configurations, **Figure 10**, on the chain drive system, the meshing order (20<sup>th</sup> order) and the harmonics (40<sup>th</sup> and 60<sup>th</sup> order) were quite visible.

On the timing belt drive system measurement there were no visible meshing orders (21<sup>st</sup> order) or harmonics (42<sup>nd</sup> and 63<sup>rd</sup> orders).

Whilst carrying out the acoustic study, a subjective assessment of the noise characteristic was made. The outcome of this was that the chain drive system had a more "metallic" noise and emitted a high pitch "whistle" type noise which was more disturbing to the ear than the Timing Belt drive. This was reflected in the Campbell diagram with the appearance of high acoustic pressure values at high frequencies.

In general the overall noise level of the engine was around 2-5 dB(A) higher with the chain drive than with the timing belt drive system, **Figure 11**. This result was confirmed both with the artificial head and with the near field microphone. It has to be considered that this study was done on an electrically driven engine with no combustion noise. If combustion noises were taken into account then the 2-5 dB(A) measured difference would be slightly reduced due to the increase in overall noise level.

### 6 Summary

At a time when engine designers and manufacturers are striving for greater efficiency from their engines and when regulations with regard to emissions are becoming more and more stringent, there is an ever increasing amount of evidence supporting the results from the above studies that a timing belt drive system is more advantageous than a chain system for a camshaft drive. Fuel consumption can be reduced and the NVH characteristic of the engine can be improved significantly. Engine timing, and therefore emissions, can be better maintained over drive lifetime. The inbuilt damping characteristic and tunable stiffness of a belt drive system can also be used to the advantage of the design- and simulation engineer from both an engine performance and an acoustic point of view.

These aspects of a belt drive system have always applied. A well designed belt drive system is capable of in excess of 300.000 km lifetime and comes with less fuel consumption/emissions and better NVH performance.

### References

- [1] El Mahmoud, M.A.; Ishiki, S.; Kubota, A.: Comparison of Friction Losses between belt and chain. VDI-Bericht 1758, 2003
- [2] Toyota Technical Review Vol. 50 No. 2: A study of low friction engine