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Belt drive systems

Potential for CO_2 reductions and how to achieve them

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Introduction

Schaeffler has volume produced components for belt drive systems since 1977. For the past 15 years, Schaeffler has worked on the development of complete belt drive systems in timing drives (Figure 1) as well as in accessory drives (Figure 2).

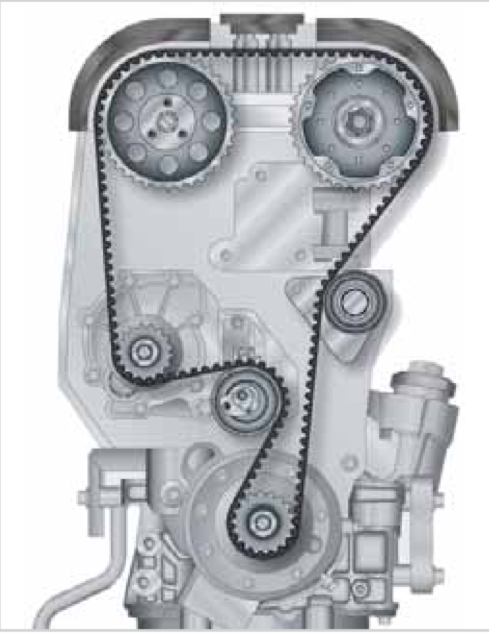

Figure 1 Timing drive

Considering the fact that over 100 million belt drive components are produced annually, this means that, on average, almost two belt drive components manufactured by Schaeffler are installed in every vehicle.

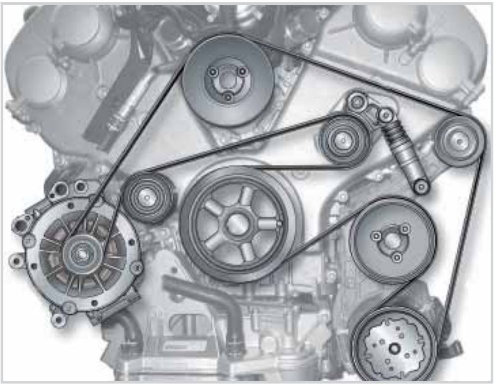

Figure 2 Accessory drive

Tension pulleys and idler pulleys

One use of INA idler pulleys is to reduce noise in critical belt spans, to prevent collision problems with the surrounding structure, to guide the belt or to increase the angle of belt wrap on neighboring pulleys. These pulleys have the same rating life and noise development requirements as belt tensioning systems. For this application, high-precision single-row ball bearings with an enlarged grease supply volume have proven sufficient.

Figure 3 Steel pulley

Figure 4 Plastic pulley

If required, double-row angular contact ball bearings (Figure 3) are used that also have an optimized grease supply volume. These bearings are equipped with high-temperature rolling bearing greases and appropriate seals. Standard catalog bearings are not as suitable for this application.

The tension pulleys installed consist of single or double-row ball bearings specially developed, optimized and manufactured by INA for use in belt drive applications. Depending on the application, pulleys made from glass fiber reinforced polyamide or corrosion protected steel can be added.

Thanks to Schaeffler's highly developed tooling and manufacturing technology, the pulleys made from highly temperature resistant, glass fiber reinforced polyamide (Figure 4) are just as good as the steel pulleys when it comes to roundness and running characteristics and may offer significant cost and weight benefits. Adjusted dust covers made from steel or plastic may also be used.

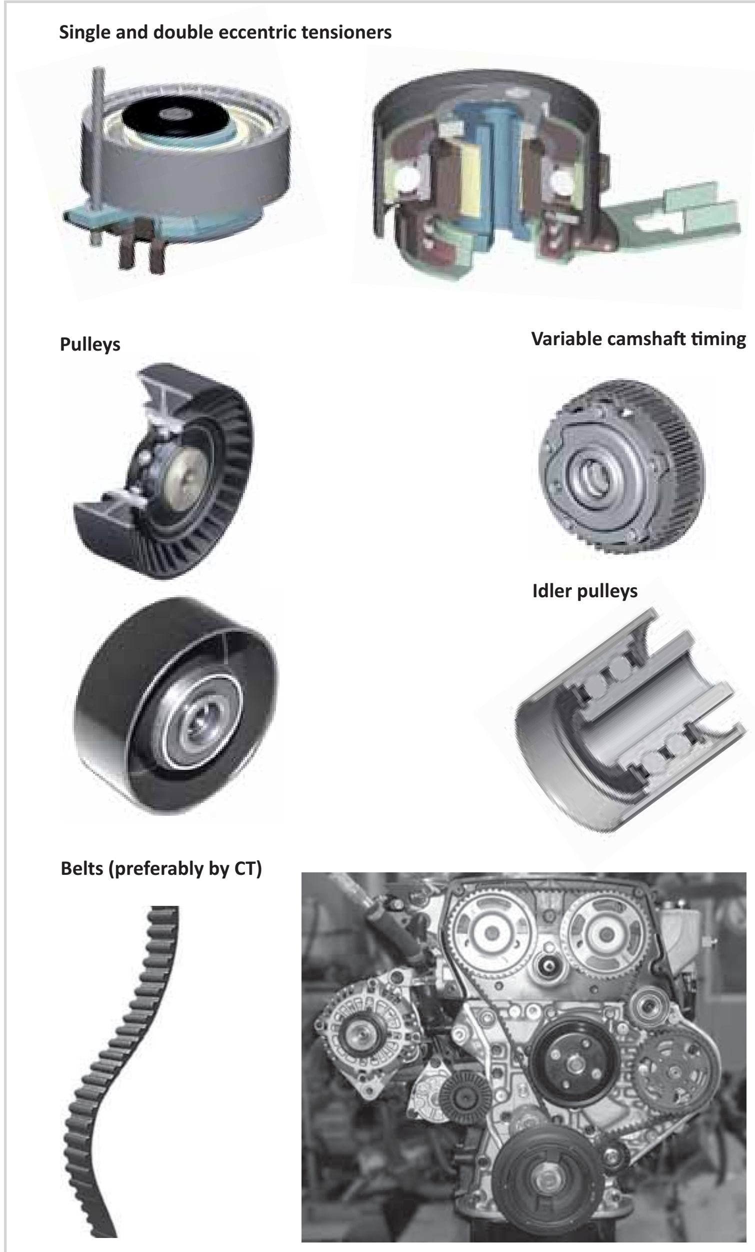

Figure 5 Products in the timing drive

Timing drive

Timing belt drives (Figure 5) that drive camshafts or balancer shafts have been volume produced for internal combustion engines for 40 years. In older designs, the timing belt was preloaded via either an accessory with eccentric bearings in the timing belt drive (e.g. water pumps) or through manually adjustable, fixed tension pulleys (e.g. eccentric tensioners).

This type of system does not allow for optimal adjustment of the belt force since neither belt force fluctuations resulting from temperature or wear nor dynamic effects (belt vibrations, impacts from the valve train) are compensated. Compensation of such fluctuations and effects by means of automated belt tensioning systems is essential in modern timing belt drives since this is the only way that a system life of up to 240 000 km and more (depending on the engine life) required in today's automotive industry can be achieved.

Belt drive systems not optimally preloaded are susceptible to noise and susceptible to wear. Using an automated belt tensioning system considerably reduces preload force dispersion during initial installation and also keeps the preload force across the engine's operating temperature range at nearly consistent levels. Automated belt tensioning systems have been used in timing belt drives in internal combustion engines since the early 90s and have largely replaced fixed systems for the reasons described above.

The above conditions result in the following primary requirements for automated tensioning systems:

- Provide simple adjustment of the specified belt force during initial installation and maintenance (compensation of belt, diameter and position tolerances)
- Maintain a defined belt force that is as consistent as possible under all operating conditions for the duration of the required system life (compensation of heat expansion, belt elongation and wear, consideration of crankshaft and camshaft dynamics)
- Ensure an optimal noise level while also reducing belt vibrations
- Prevent gear teeth jump

Potential for CO_2 reductions in timing drives

Compared to chain drives, both dry and oil lubricated timing belts, that can be used to drive oil pumps, balance shafts and camshafts, significantly reduce friction (measurements have determined up to 30 %), thus helping reduce fuel consumption. The friction benefit of timing drives compared to chain drives can reduce a vehicle's fuel consumption by 1 to 2 %, also decreasing the emission of carbon dioxide (CO_2). Figure 6 shows a comparison of the friction curves for timing drives and chain drives.

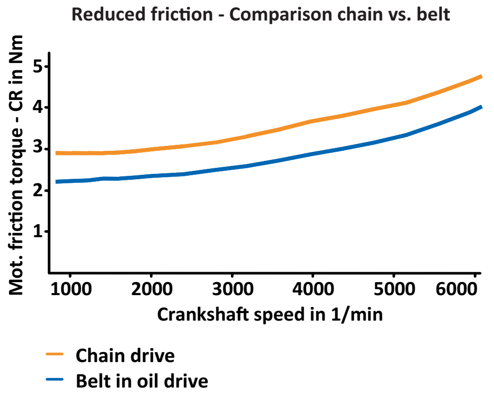

Figure 6 Friction curves of chain vs. belt

A test completed at IFT, Clausthal-Zellerfeld that compared the measurements for a timing belt drive and a chain drive has shown that the timing belt drive has considerable benefits. The test was performed on a 1.6 liter, 4-cylinder gasoline engine. The test was initially conducted on the original version with a timing chain and then with the timing belt version. The test setup is shown in Figure 7.

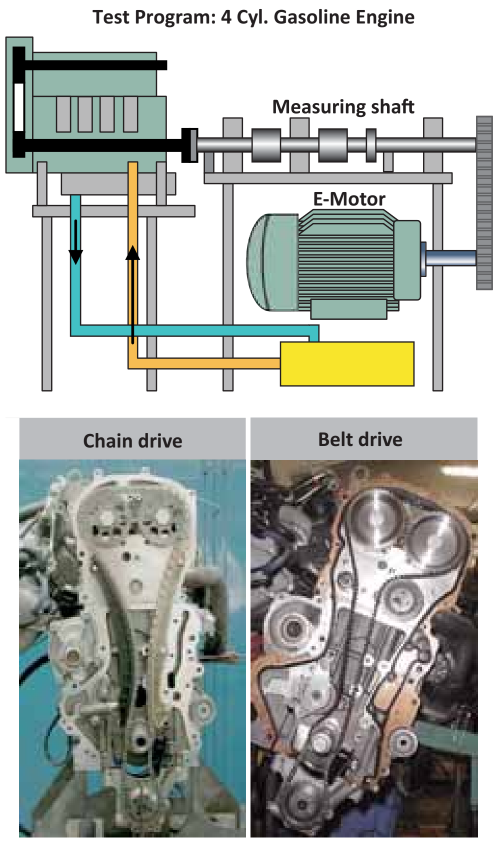

Figure 7 Test setup

The timing belt in oil has already operated for more than 240 000 vehicle kilometers in the vehicle fleet owned by Continental and thus demonstrated its endurance capability. This also means that the oil-resistant timing belt lasts the entire life of the engine.

It will initially be used for oil pump drives and timing drives. This innovation will later also be developed for additional applications, such as higher demanding balance shaft drives, to further reduce CO_2 emissions.

Accessory drive

In modern internal combustion engines, accessories are almost exclusively driven by poly-V belts.

The primary requirements for accessory drive systems (Figure 8) and their automated tensioning systems are listed below:

- Automated belt force adjustment during initial installation and maintenance (tolerance compensation of all drive components)
- Nearly consistent belt force during the entire life of the belt drive (compensation of belt elongation and wear)
- Nearly consistent belt force across the entire engine temperature range (compensation of heat expansion of all components affecting the drive)

Figure 8 Products in accessory drives

- Reduction of dynamic belt force peaks
- Minimization of slip, noise and belt wear
- Rating life increase for the entire belt drive system
- Optimal reliability of the overall belt drive system
- Minimization of friction loss in the overall system

Modern, optimally adjusted accessory drive systems (Figure 8) are maintenance free and can run for up to 240 000 km, given by optimal system development.

Mechanical belt tensioning units

Mechanical belt tensioning units (Figure 9) represent a cost-optimized solution for automatically tensioned poly-V belt drives. The required belt preload force is usually generated by the torque of a torsion spring as well as the lever arm and the tension pulley. The damping package consists of a friction element (disk, ring and cone) that is preloaded by the torsion spring. As the lever arm moves, a relative motion in the damping package is generated, causing friction and, consequently, damping. The belt preload force (via the spring's torque) and damping are adjusted to match the application. The materials used allow consistent damping values to be achieved via the temperature and frequency and with minimal run-in effects. Different designs permit optimum usage of the available design package.

Hydraulic belt tensioning systems

Hydraulic belt tensioning systems provide a solution for poly-V belt drives with high requirements. They consist of a hydraulic component with an integrated pressure spring and hydraulic leakage gap damping as well as a lever arm with an attached tension pulley. The hydraulic leakage gap damping acts in a controlled way and in proportion to the speed, causing damping to be generated only when needed. The optimal adjustment of the required belt preload force to the relevant application is carried out via the integrated pressure spring and the converted lever ratio. The required damping is set by selecting the leakage gap. The properties of the hydraulic oil used ensure the lowest possible damping temperature dependency in combination with excellent resistance to aging – all with hardly any wear. An example design is shown in Figure 10.

Component overview

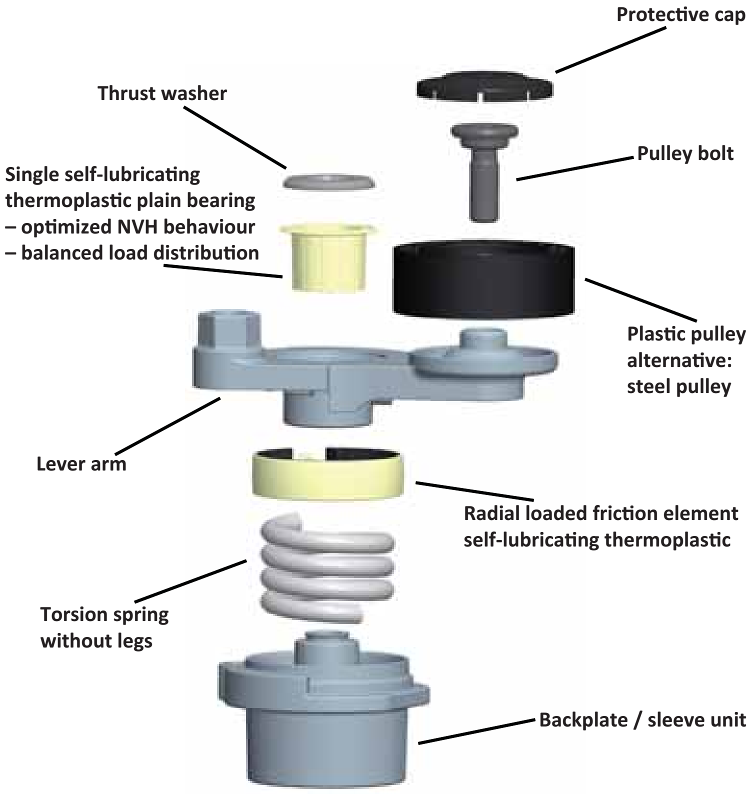

Figure 9 Mechanical belt tensioner

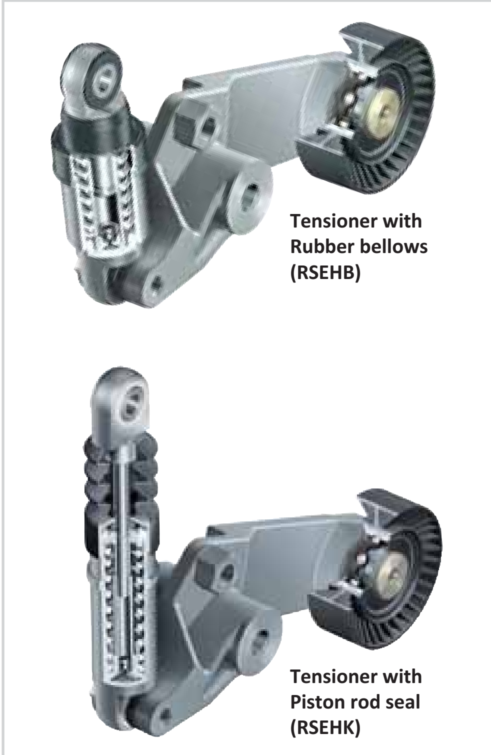

Figure 10 Hydraulic belt tensioner

Overrunning alternator pulley

Alternators have the largest inertial torque in an accessory drive, greatly affecting belt drive behavior. An overrunning alternator pulley decouples its inertial torque from the cyclic irregularities of the crankshaft in an internal combustion engine.

Advantages

The positive effects on the accessory drive include:

- Minimization of belt vibrations
- Reduction of force peaks in belt drives
- Reduction of tensioner movement
- Increase in belt life
- Improved noise behavior in the belt drive
- Reduction of belt slip on the alternator pulley during upshift (particularly in fast shifting dual-clutch and automatic transmissions)
- Less strain on the overall system during engine start and stop-and-start function
- Preload force reduction in the overall system, leading to reduced CO_2 and frictional loss

Decoupling function

The large mass of the generator cannot follow the high irregularities of the crankshaft at engine start and drive resonances. Thus it comes to differences of rotation angle speeds of crankshaft to alternator. Contrary to a rigid wheel the overrunning alternator pulley opens in overhauling direction. The alternator mass and their influences are decoupled from the accessory

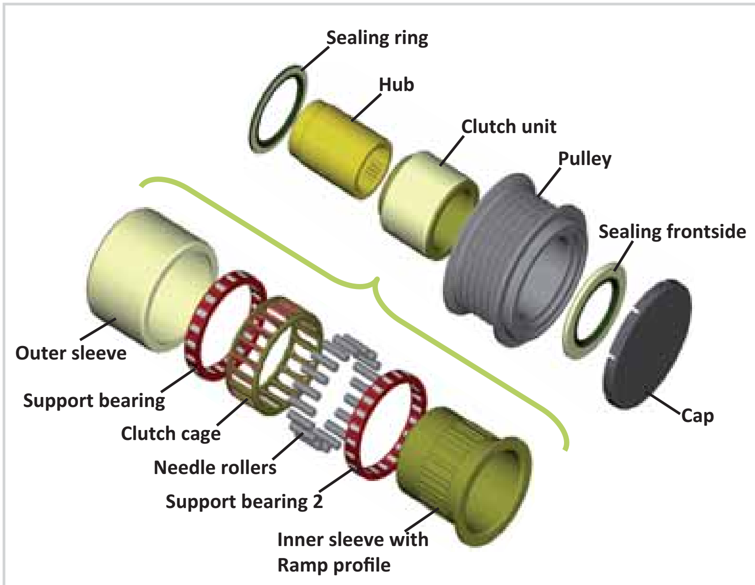

Figure 11 Overrunning alternator pulley

drive. In addition, the overrunning alternator pulley decouples the alternator's inertial torque during a significant engine speed deceleration (shifting gears, upshifting).

Structural design

The overrunning alternator pulley (Figure 11) consists of a pulley with an outside diameter suitable for using a poly-V belt, a one-way clutch unit with bearing supports, an inner ring and two seals. Following installation, an end cover is snapped onto the front of the alternator shaft to protect it from ambient media (e.g. penetration of contamination, salt water deposits).

A modular system has been developed for overrunning alternator pulleys to provide an economical and flexible solution for customer inquiries. The one-way clutch unit and the seal components are standard parts.

Unlike spring decouplers, an overrunning alternator pulley does not have its own resonant frequency and does not have to be adjusted to varying alternator sizes.

Potential for CO_2 reduction in accessory drives

The details of accessory drive components described above show that a wide range of parameters must be considered to achieve the functional operation and rating life of the overall system. Targeted investigations through dynamic simulation with Simdrive 3D™ and testing have yielded belt preload as the main influencing parameter with regard to friction losses in the accessory drive. Belt preload has a significant effect on:

- Bearing friction in tension pulleys and idler pulleys
- Belt expansion
- Belt bending
- Contact losses between the belt and the pulley, particularly the radial compression of the belt
- Bearing friction within all accessories (is not considered in analysis below)

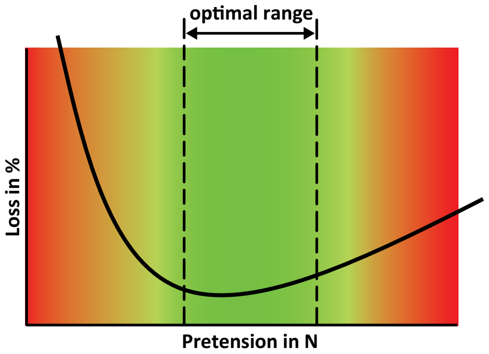

Figure 12 Friction curve

- Load at 1st crankshaft bearing (is not considered in analysis below)

When the functional limits and system tolerances are considered, an engine-specific optimal preload range can be determined (Figure 12).

Figure 13 compares potential savings using a sample drive layout. Assuming a basic system with a mechanical belt tensioner and a preload of 350 N required for this system, the potential savings when using an alternator decoupler can be determined. Some savings can be achieved compared to the basic system without changing the belt preload. If an alternator decoupler with an overrunning alternator pulley ("OAP" in

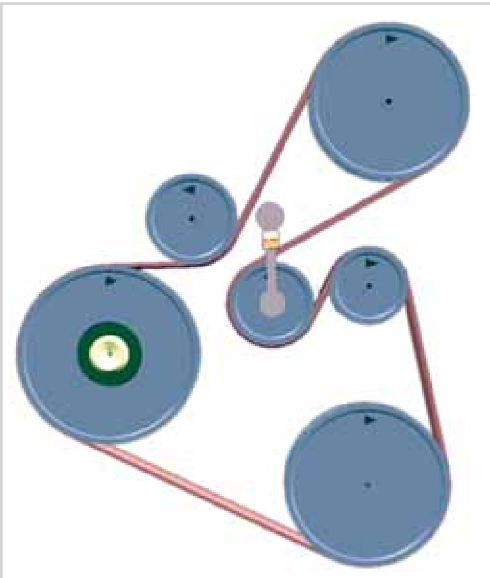

Figure 13 Simulated drive

Figure 14) or a spring-elastic alternator decoupler is introduced, the preload can potentially be reduced to 280 N, resulting in friction and loss savings of 14 to 20 % in the drive system (Figure 14).

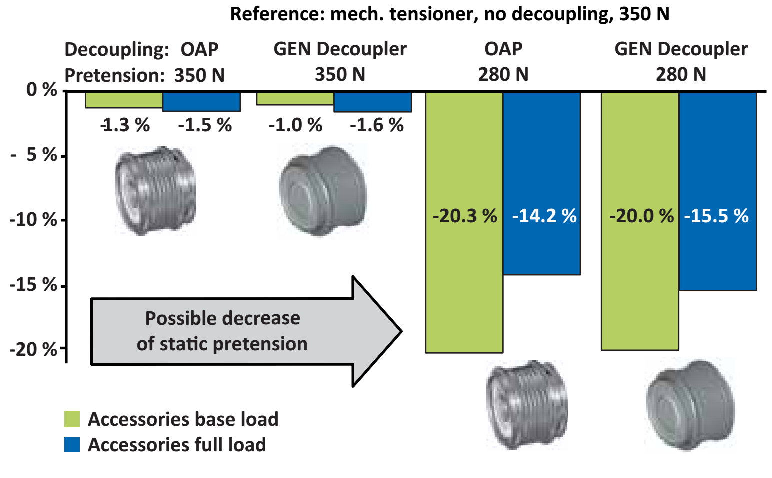

Figure 14 Potential savings for friction losses

Even greater savings can be achieved when a pulley decoupler is used right on the crankshaft itself. Compared to the basic system, a frictional loss reduction of up to 36 % can be achieved in the drive system (Figure 15). In this example, a preload of 230 N ensures optimal friction reduction while maintaining the system's functional operation and rating life.

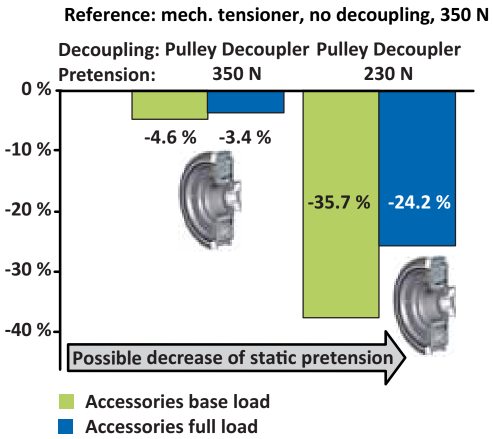

Figure 15 Potential savings for friction losses

Pulley decoupler

LuK is a well-known specialist for transmission and clutch components and has an extensive portfolio of products for the reduction of torsional vibrations in vehicle power trains. These products include dampers in clutch disks, dual-mass flywheels, torque converter clutches and double-clutch transmissions. LuK also solves torsional vibration problems in internal combustion engines and has developed the product group of engine dampers. The internal crankshaft damper (ICD) was presented during the 2002 LuK Symposium [1]. The ICD has been volume produced successfully for several years in addition to other engine dampers. Development activities currently focus on the reduction of torsional vibrations for belt drives. One related development is the Pulley decoupler.

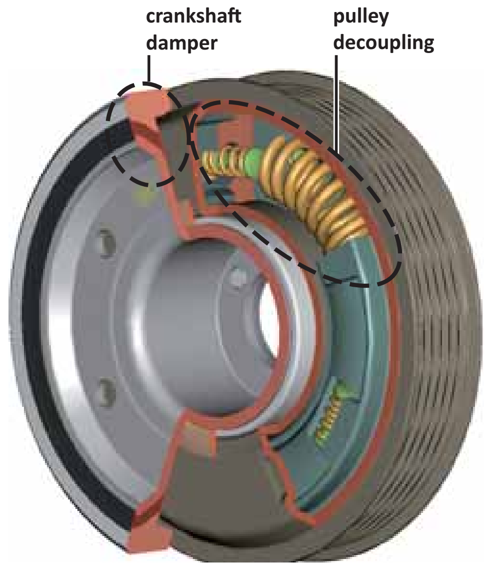

Figure 16 Pulley decoupler with integrated crankshaft damper

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The decoupled pulley on the crankshaft of the internal combustion engine has two main functions:

1. Driving the belt drive for accessory drives while simultaneously decoupling this belt drive system from the cyclic irregularities of the crankshaft.
2. Providing damping for the torsional vibrations resulting from the eigenfrequencies in the crankshaft – flywheel vibration system.

The function and structure of the two partial systems (Figure 16) are described below.

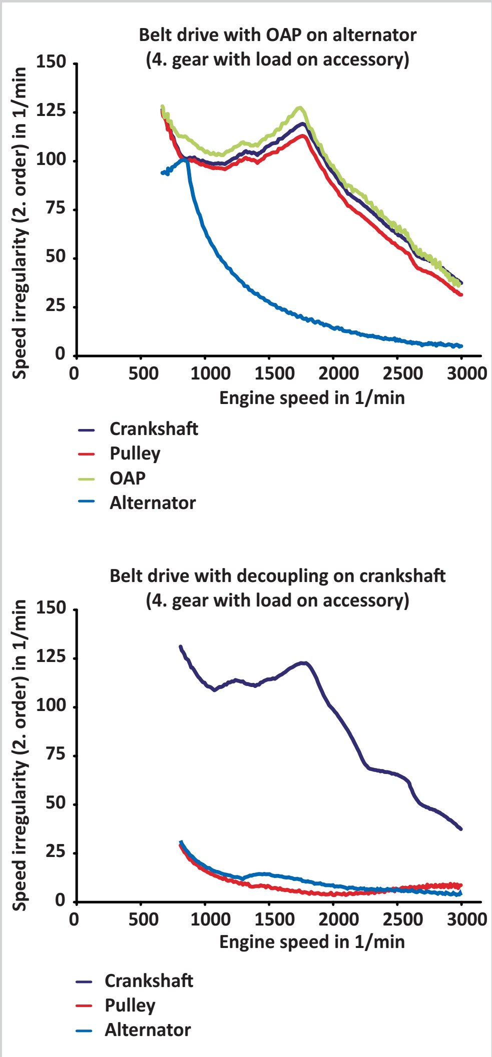

Figure 17 Belt drive measurements

Belt drive decoupler

The periodic ignition in the internal combustion engine generates a cyclic irregularity that is applied to the accessories via the belt in the form of torsional vibrations. When the engine operates at the eigenfrequencies of the belt drive system, the system can be excited to generate resonance vibrations.

A pulley decoupler mounted on the crankshaft is used to minimize belt vibrations induced by these cyclical irregularities of the crankshaft. The measurements in Figure 17 show a comparison of a belt drive system with overrunning alternator pulley (OAP) and fixed pulley on the crankshaft with a belt drive decoupling system (the second order of the engine speed for each). The isolation of the entire belt drive can be improved significantly by the decoupler on the crankshaft.

In many applications, the first eigenfrequency of a belt drive without decoupling is in a speed range of 1000 and 1500 1/min. With the pulley decoupler a further spring system is added to the vibration system. This lowers the natural frequency clearly below the idle speed of the internal combustion engine, and the belt drive is operated in the above-critical range, resulting in a reduced load for all components in the belt drive.

Decoupled pulleys for crankshafts available on today's market contain spring elements made

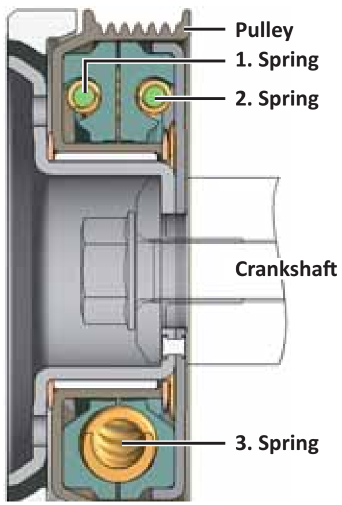

Figure 18 Cross section of pulley decoupler

Figure 19 Exploded diagram of pulley decoupler

from elastomers. Although these elastomers represent a relatively inexpensive material for spring elements, their functional operation and lifetime greatly depend on the temperature and number of load cycles. As requirements increase (increasing cyclic irregularities of the engine, larger number of engine starts, higher drag torques, rising ambient temperatures), the application range for "elastomer decouplers" becomes more and more limited.

In the LuK Pulley decoupler, the spring element design utilizes coil springs in the component shown (Figure 18 and 19). The three arc springs and the force transmission are guided in two plastic cups located under the belt track. The pulley is guided with a plain bearing on the hub.

In the decoupler and for the entire belt drive, an eigenfrequency via the arc-shaped springs is shown. This frequency is below idle speed and allows the required above-critical operation of the belt drive. When starting the engine, this eigenfrequency must be passed through. In an unfavorable case, a resonance may be generated that coincides with the eigenfrequency in the dual-mass flywheel – power train combination. Since a relief angle function is integrated in the pulley decoupler, resonances are prevented from passing through the eigenfrequencies of the belt drive in their earliest stages. The required clearance angle is realized in the component by an adjusted torsion capability between the plastic cups and the contacting sheet metal parts.

This results in a characteristic curve for the decoupler (Figure 20) composed of several different curves including the characteristic curve of the arc-shaped spring package C2 as well as two relief angle curves. Transitional springs have been integrated in the component for the transition between the curves that, via their serial connection with the arc-shaped springs, result in a soft transition C1 for the entire spring curve. Isolation is further improved by reducing the total spring rate in the lower moment range.

With the design and curve structure described above, there is an additional option of a bidirectional transmission of the moment in the decoupler. Besides driving the accessories in the belt drive, the decoupler can be used in applications that call for a start function of the internal combustion engine or a boost function via the alternator in the belt drive. In these cases, the moment flow runs in the opposite direction in the belt drive.

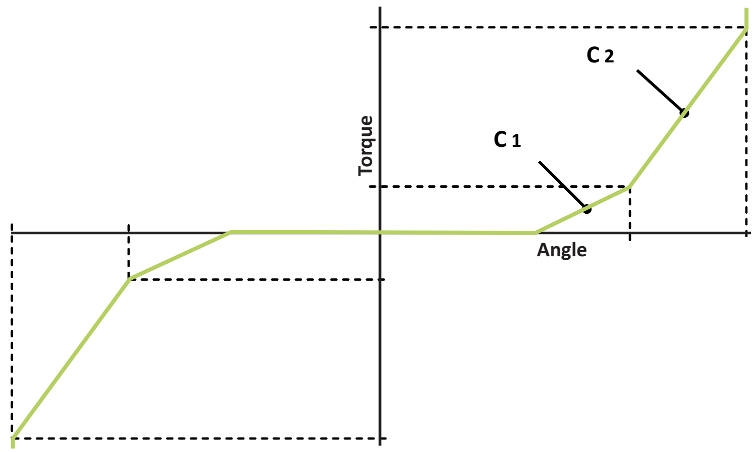

Figure 20 Characteristic curve of a pulley decoupler

Figure 21 Dual pulley decoupler for alternator start and 2-belt systems

For applications that require a higher torque for the alternator start or boost functions compared to the actual drag function, an asymmetrical characteristic curve can be achieved in a dual damper (Figure 21).

Torsional vibration damping

A torsional vibration damper has been integrated in the assembly for another main function (Figure 16). This is used to reduce resonance vibrations in the crankshaft that are generated by the ignition frequency of the engine [2]. Here the crankshaft-flywheel vibration system is excited in several eigenfrequencies.

The torsional vibration damper will be tuned on the first eigenfrequency within a range from 300 to 400 Hz. Depending on the number of cylinders, crankshaft design and the masses of the crankshaft and the flywheel, the eigenfrequencies are excited by the dominant exciter orders in the engine's entire speed range. In this process, the flywheel vibrates against the crankshaft with the attached masses such as connecting rods and pistons.

This eigenfrequencies can be dampened by a free mass via a spring and damping element at the free end of the crankshaft. In small or medium series engines, this is usually a mass ring that is coupled to the crankshaft by means of a vulcanized or pressed-in rubber track [3]. In larger engines, this application may also include viscous dampers. The optimal adjustment of the mass, spring and damping reduces resonance vibrations in the crankshaft and achieves an improvement in the NVH behavior as well as lifetime of the crankshaft.

System evaluation with engine and power train

Pulley decouplers and the adjacent accessories and components in a belt drive are designed using state-of-the-art simulation tools. Besides Simdrive 3D™ the Schaeffler Group also uses DyFaSIM. This program was developed by LuK and is the result from many years of development and design of torsion dampers and dual-mass flywheels. The program permits the simulation of the entire vehicle power train from the engine through the vehicle to the wheel as well as belt drives and their behavior.

Using the simulation technology employed for the development of the dual-mass flywheel [4] allows a complete evaluation by expanding the power train models to include models for belt drive systems. Interactions of the belt drive with the engine, the coupled single or dual mass flywheel and the power train can be integrated into the investigation.

When parameters such as slip, belt vibrations, belt tensioner forces and bearing forces in the accessories are considered, simulations allow an optimal belt decoupler design decoupling the belt drive from the excitations of the internal combustion engine. This results in a reduction of accessory losses which in turn leads to a reduction in fuel consumption and CO_2 emissions for the internal combustion engine.

Summary

In the past, high-quality belt drive components were often regarded as the necessary “problem solvers” in difficult applications. In future, highly efficient complete systems (Figure 22) in timing drives and accessory drives will be indispensable to increase comfort and reduce CO_2 emissions as much as possible.

Timing drives must be reanalyzed to take low friction characteristics into account. The benefits of a chain drive are counteracted by the disadvantage of increased friction among others. Here, results clearly point to the benefits of timing belt drives.

In accessory drives, decoupling in the crank shaft pulley provides significant advantages for the entire belt drive. Reducing the applied cyclic irregularities allows the load for all components in the drive to be reduced. In combination with the pulley decoupler including arc-shaped steel springs, potential for optimization can be seen. The potential savings shown in Figure 23 are possible.

The skillful application and combination of products in Schaeffler’s portfolio allows the greatest possible CO_2 savings to be achieved in belt drive systems.

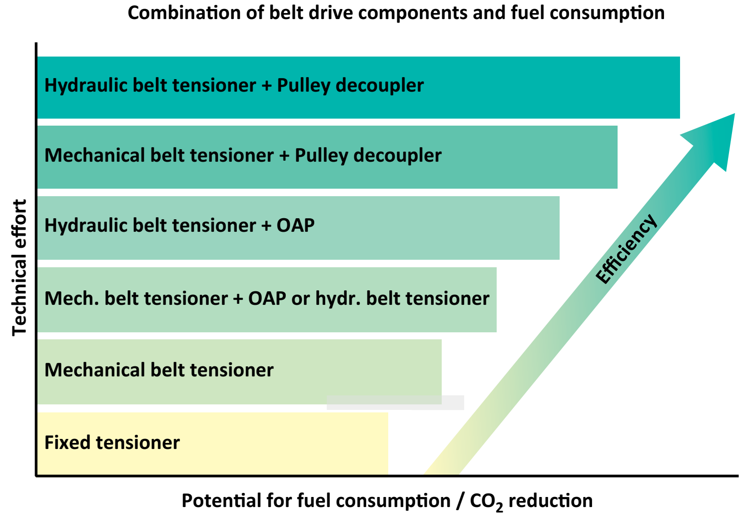

Figure 22 Potential for optimization

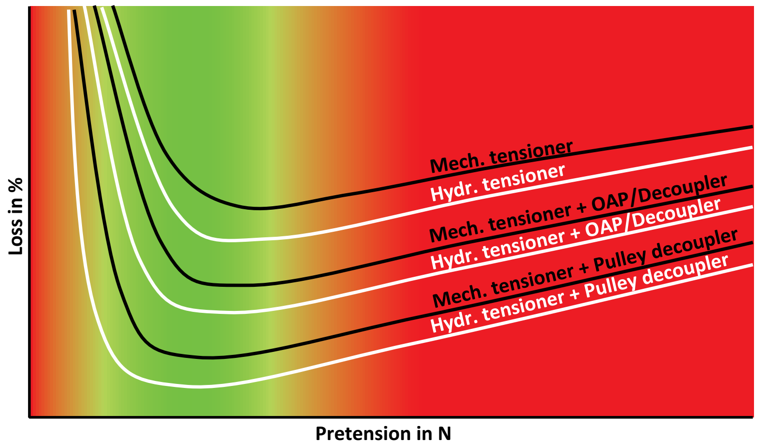

Figure 23 Optimization curve

Literature

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