Internal Crankshaft Damper (ICD)

Friedrich Gerhardt
Christian Fechler
Steffen Lehmann
Hermann Langeneckert

New Application for LuK Torsional Vibration Damper

In addition to the familiar products for reducing torsional vibration problems in the vehicle drive train – which include dampers in the clutch discs, dual mass flywheels and dampers for torque converter clutches – LuK has been actively working on problems with torsional vibrations in combustion engines as well. One new development in this problematic area is a torsional vibration damper for the crankshaft.

Crankshaft Torsional Vibrations

The crankshaft of a combustion engine is a self-oscillatory system that is subject to vibration and thus possesses all of the problems associated with resonance breakthroughs and longer periods running at the resonance speeds.

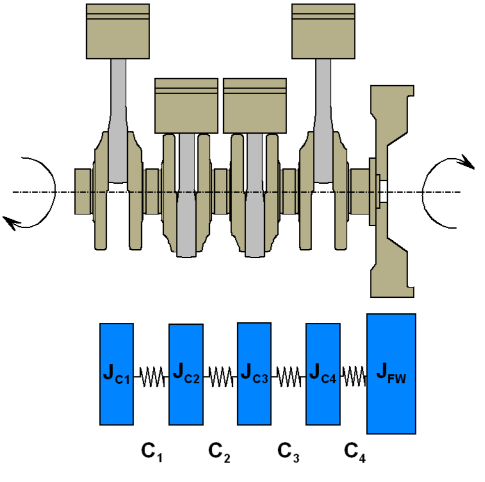


Fig. 1: Crankshaft as a Vibration System

The large amplitudes of the vibration angle (torsion between one crankshaft end and the other) are a major part of these problems because they cause noise and can lead to impermissibly high torsional strain in the crankshaft, resulting in torsional breaks.

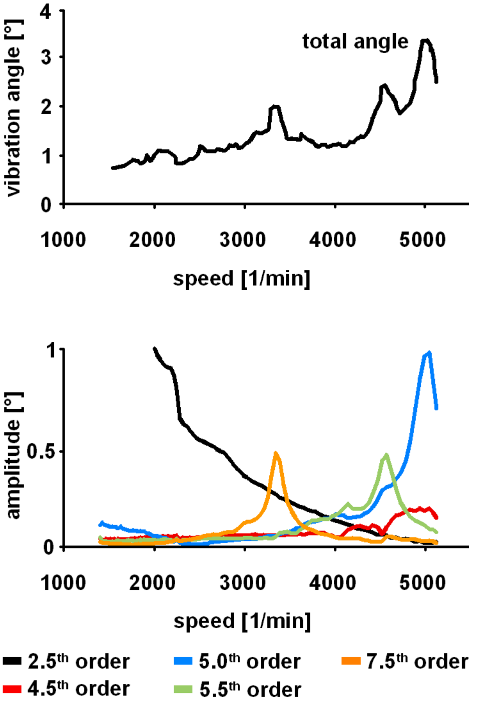


Fig. 2: Vibration Angle and Order Analysis of a Crankshaft without Damper

Figure 2 shows a measurement of a crankshaft from a diesel engine without vibration damper. The illustration shows the vibration angle between the flywheel and the other end of the crankshaft at cylinder 1 as well as the order analysis of the vibration amplitudes of the free end of the crankshaft over the average speed. The total vibration angle between the end of the crankshaft and the flywheel at the various resonance speeds is sometimes more than twice the allowable value. By observing the individual orders, it becomes clear that the maximum values for this engine's vibration angle are reached primarily in the 5^{th}, 5.5^{th} and 7.5^{th} orders. These excite the first natural frequency of the crankshaft, which is approximately 420 Hertz.

Vibration Damper Function

Vibration dampers or vibration absorbers are used to reduce the load on the crankshaft. State-of-the-art vibration dampers either have a spring coupling (rubber damper) or no spring coupling (viscosity damper).

A damper with a spring coupling consists primarily of a rotating mass with a defined mass moment of inertia (hereinafter inertia), which is connected to the crankshaft via spring elements. The damper's natural frequency, which must be tuned to the crankshaft's natural frequency, is a result of the torsional spring rate of the spring elements and the inertia of the rotating mass.

The basic effect of a damper with a spring coupling on the resonance curve of a crankshaft is illustrated in Figure 3.

The vibration properties of the crankshaft are changed by the damper. The system has an additional degree of freedom – at zero damping, the original resonance disappears completely – however two new resonances result. At very high damping, there is no effect. The damper is quasi-rigid, resulting in approximately the same frequency and amplitude as the original crankshaft resonance. If the damping is correctly designed, neither the new nor the original resonances are disruptive.

At least in the passenger car sector, the crankshaft dampers used outside of the engine are secured to the free end of the crankshaft and are frequently integrated into the belt pulley (Figure 4 above). Depending on the system (power consumption capacity of the spring elements, energy exchange, temperature dependence of damping and spring rate) certain minimum inertias are required for functionality.

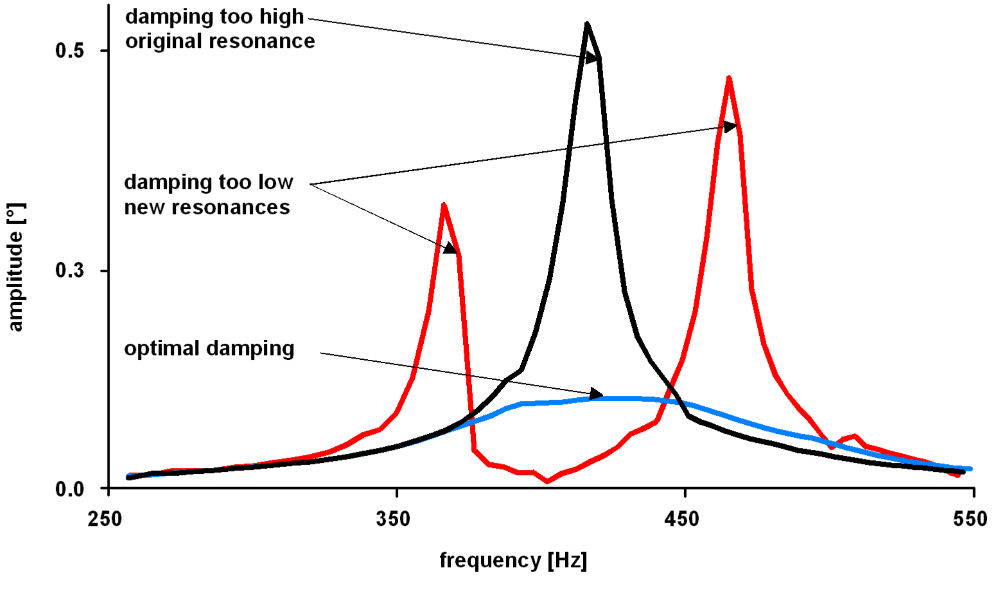
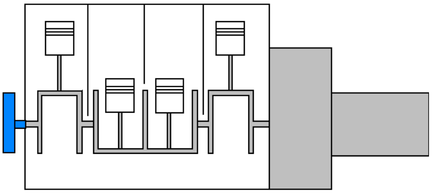
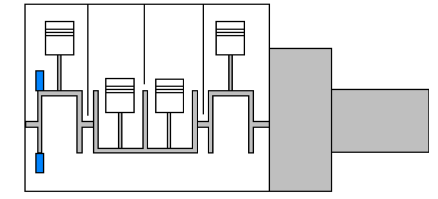


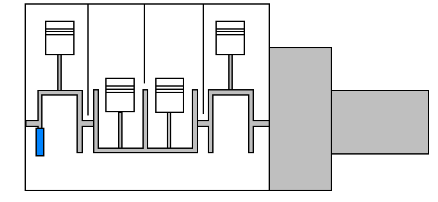
Fig. 3: Simplified Illustration of the Amplification Function of a Crankshaft with Spring-Coupled Vibration Damper



external damper



internal damper German patent 536 929



internal damper ICD

Fig. 4: *Arrangement of Crankshaft Dampers*

Internal Vibration Damper

For a few new generations of engines (in part due to engine compartment space), the ancillary units are no longer driven via a belt or chain on the free end of the crankshaft, but rather via other means. In order to truly be able to use the associated engine compartment advantage, the vibration damper must be removed from the region of the eliminated belt pulley.

There were patents for spring-coupled dampers directly in the crankcase as early as the 1930s. In these patents, either annular dampers were placed on the existing outside diameter of the crank web (figure 4 center) or fairly complex mechanisms were built into the crank web. The additional engine compartment space needed for this and the complicated usage conditions in the crankcase prevented the implementation of such ideas and, until now, have precluded the use of rubber or viscosity dampers in the crankcase – at least in passenger car engines.

LuK's idea was to integrate the damper into the crank web with as little effect as possible on the space requirements (figure 4 bottom). Thus, the damper cannot be designed as a closed ring, but must be horseshoe-shaped.

The result of LuK's efforts is the **I**nternal **C**rankshaft **D**amper (**ICD**), which is shown in figure 5 installed on a crankshaft that has been modified for the damper.

The damper is located on the first crank web and is secured to the crankshaft with two radial bolts and, depending on the application, one or two axial bolts and then installed with this in the engine block (figure 6). At the same time, the damper also replaces one of the counterweights for the crankshaft.

Fig. 5: *Crankshaft with ICD*

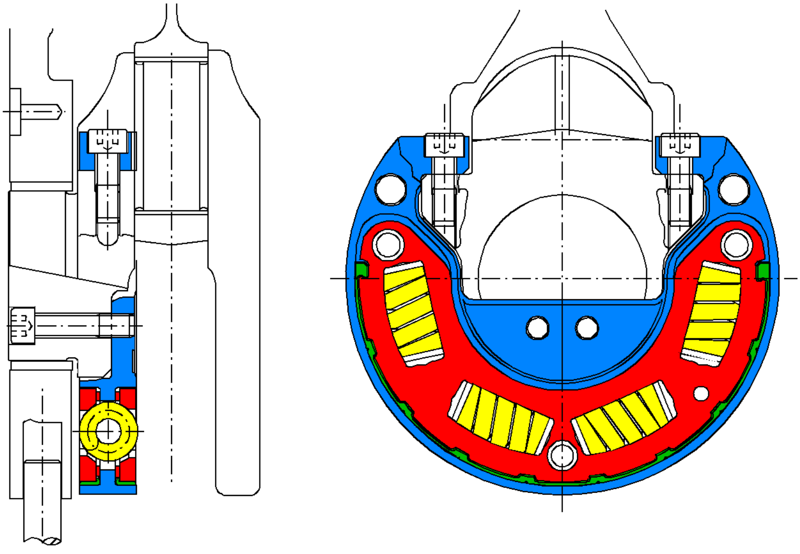


Fig. 6: *Sample ICD Installation*

ICD Design and Function

The ICD is a spring-coupled damper. The housing is connected directly to the crankshaft with a damping device located between the housing and the rotating mass (figure 7). The rotating mass itself is made up from two metal plates to guide the springs, a spacer plate and an axial spring element for tolerance compensation, connected by spacer bolts. The friction damping occurs primarily in the plastic plain bearings, which absorb the centrifugal force of the rotating masses. The spring elements are steel coil springs guided in spring caps.

The coil springs are preloaded against one another to prevent discontinuities when the rotating mass crosses the zero point. When deflected in one direction, half of the springs are compressed further while the remaining half are released, without completely eliminating the preloading.

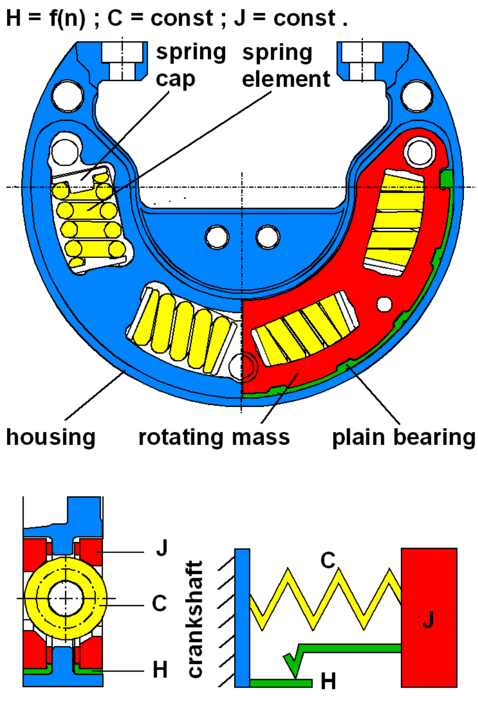


Fig. 7: *Design and Function*

The advantage of steel coil springs over rubber spring elements is their constant spring rate over temperature, and they allow a larger vibration angle due to their greater energy absorption capacity. Thus, a damper with steel coil springs requires a lower inertia than a rubber damper to achieve the same effect. This is the only thing that makes a functioning crankshaft damper possible within the limited engine compartment relationships in the crankcase.

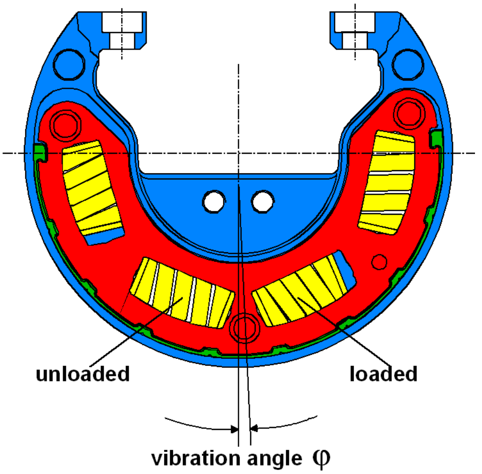


Fig. 8: *Coil Spring Activation during Damper Vibration*

The forces acting on the plain bearing are inevitably speed dependent due to the damper's unclosed shape. The coil springs can be so positioned that the resultant spring force can reduce or increase the bearing force over the speed to achieve the optimal damper friction depending on the application (figure 9). The advantage of this solution is that a large portion of the damping is independent of the force of an axial spring element and its wear and setting performance over the service life. The centrifugal force of the damper rotating masses for generating the friction damping remains constant.

The interaction of centrifugal force and coil spring preload force permits the realisation of different hysteresis and friction curves over the speed (example shown in figure 10).

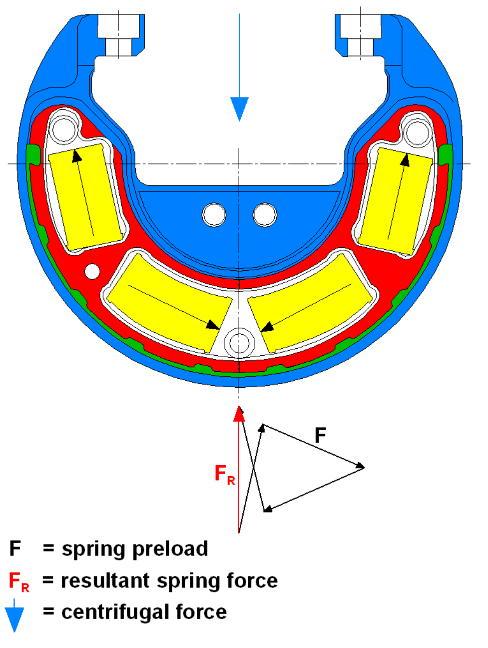


Fig. 9: *Spring Preload in the ICD*

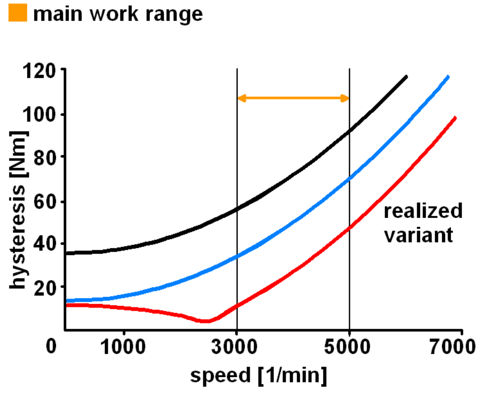


Fig. 10: *Possible Friction Variants in the ICD*

Simulation and Measurement

In addition to the engine and damper characteristic values determined by the design, the crankshaft simulation calculations are based on data gathered from measurements on the engine.

The vibration behaviour of the crankshaft was replicated in these simulations. Figure 11 shows the vibration model of the crankshaft from the previously mentioned diesel engine and a comparison of the calculated crankshaft vibration angle without damper against the use of the ICD developed by LuK. The resonance peaks in the crankshaft vibration angle are significantly reduced.

The theoretical reductions in the crankshaft's vibration angle that were calculated in the simulation model when the ICD was used are confirmed by the measurements on a real engine (figure 12). The reduction in load on the crankshaft is also demonstrated in the order analysis. The main orders (5^{th}, 5.5^{th} and 7.5^{th} order) are significantly reduced (figure 13).

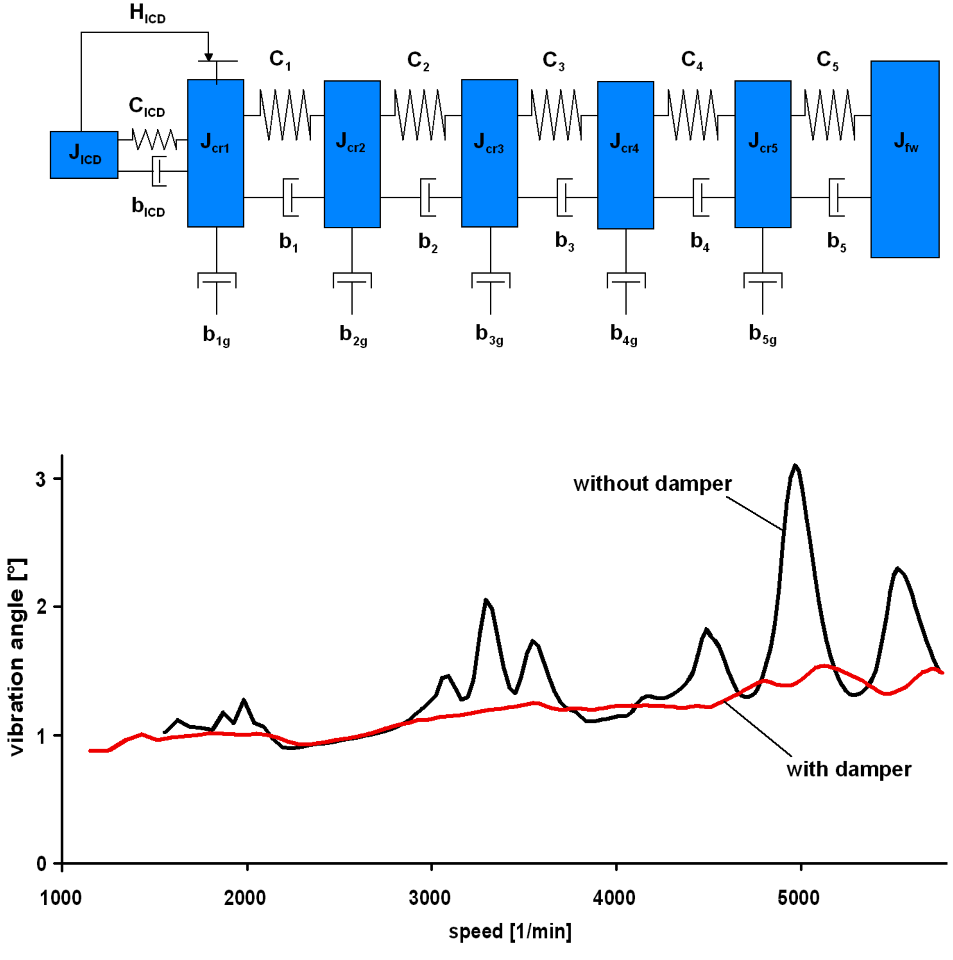


Fig. 11: Simulation Model of the Crankshaft with ICD and Vibration Angle Calculated between the two Ends of the Crankshaft with and without ICD

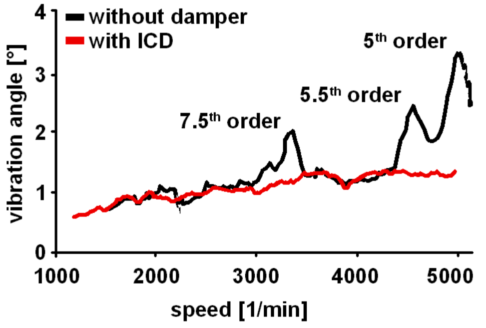


Fig. 12: Measurements of the Crankshaft's Vibration Angle with and without ICD

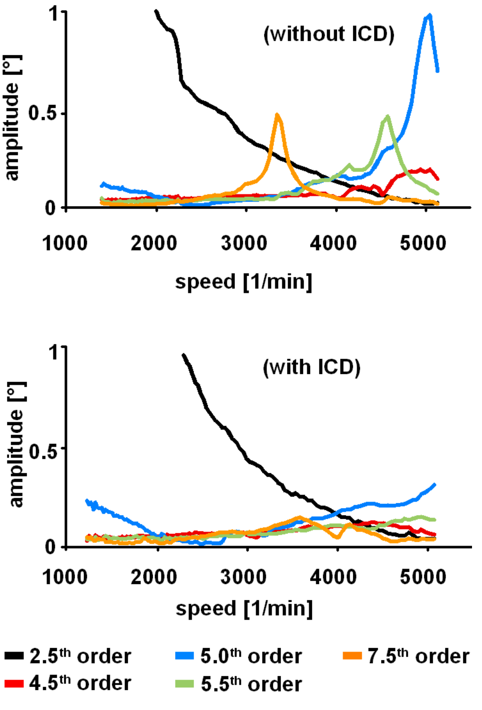


Fig. 13: Comparison of the Order Analyses of the Crankshaft Measurements with and without ICD

Potential for Expansion

All of the above considerations are based on the use of a single ICD on the crankshaft. In the meantime, LuK is working on applications (e.g. 6-cylinder gasoline engines) in which the effect would be insufficient due to the inertia of the rotating masses that could be achieved or in which impermissibly high loads would occur in the damper. In this case, it is possible to use two nearly identical dampers on the first two crank webs (figure 14). To do this, the axial bolts of one damper must be tightened through holes in the crankshaft. These holes are later used to secure the second damper.

Fig. 14: Securing Two Dampers to the Crankshaft

Summary

The LuK ICD can be used with starter/generator systems and engines with beltless drives for the ancillary units. The installation of the damper in the crankcase allows for a shorter engine length. Since the damper is installed in lieu of a counterweight and the external damper is eliminated, the engine weight can be reduced by up to 2 kg. By using steel coil springs, the damper function is independent of the temperature and achievable within relatively narrow tolerances. Different damping characteristic curves can be achieved in different ICD applications. Thus, the LuK ICD represents an additional option for reducing crankshaft torsional vibrations.

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