Permanently Engaged Starter Systems with Dry Running One-way Clutch

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Being the future standard in all vehicle categories, stop/start systems shall allow a further reduction in fuel consumption. However, there is little acceptance of conventional solutions by the end customers up to now due to their operational behaviour.To improve the system behaviour and in particular the starting performance of a combustion engine, BorgWarner is developing a compact dry running permanently engaged starter system that can be easily integrated into existing powertrains.

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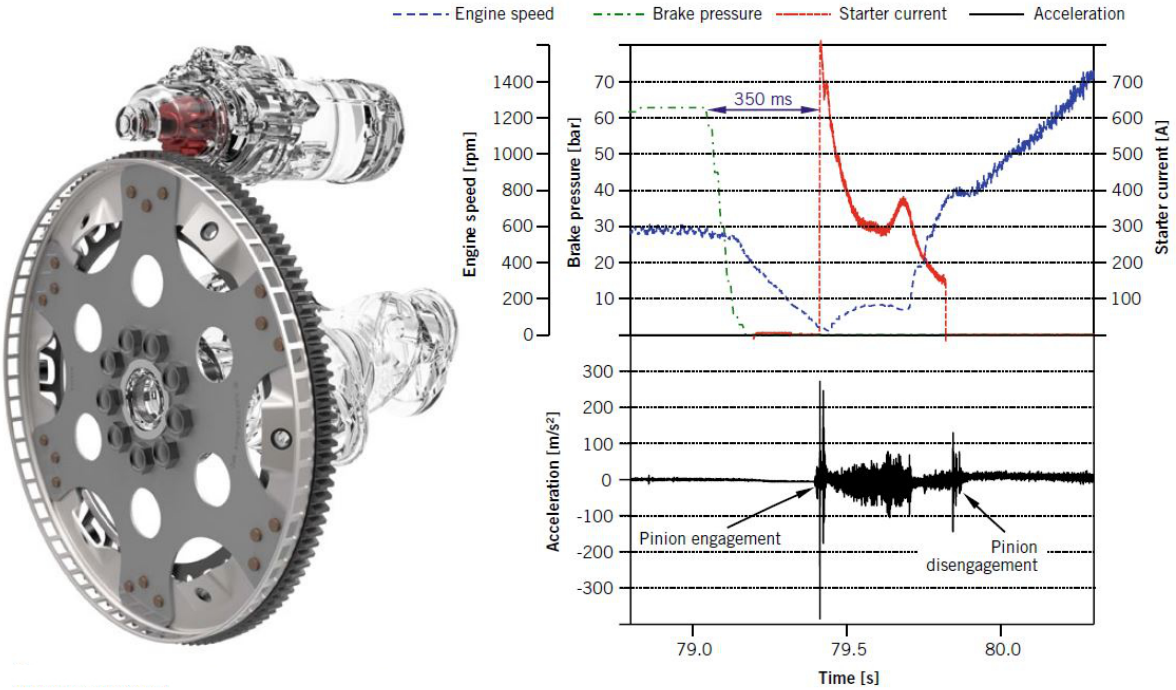
Current Conventional and Future Stop/Start Systems

Besides increasing the efficiency of powertrains in passenger vehicles, it is expedient to shut off the combustion engine as often as possible to achieve a further significant reduction of fuel consumption and greenhouse gas emissions. For increased acceptance by drivers, stop/start systems should provide a constant comfort, and high functional reliability. Future stop/start systems must therefore have the following system functions and features:

- change-of-mind and quick-start capability
- repeatability of starting behaviour
- toleration of crankshaft backlash at engine stop
- reduction of torsional vibrations during cranking
- improvement of NVH behaviour (Noise, Vibration, Harshness)
- engine shutoff while the vehicle is moving.

In a conventional stop/start application with a pinion shift starter and the starter ring gear permanently fixed to the crankshaft, the engine cannot be restarted – especially under its self-load speed – until the crankshaft has completely stopped or is at least rotating at very low speeds. If the driver requests a restart in this case, there is a start delay which the driver could misinterpret as an engine stall. The measurement shown in the following figure shows this “change-of-mind” situation for a vehicle with an automatic transmission.

The system waits for 350 ms from the moment when the driver releases the brake pedal until the starter can be driven. For vehicles with automatic transmissions in particular, this start delay is unacceptable for the driver and prompts him to frequently disable the system manually. The following figure also shows the NVH behaviour (acceleration



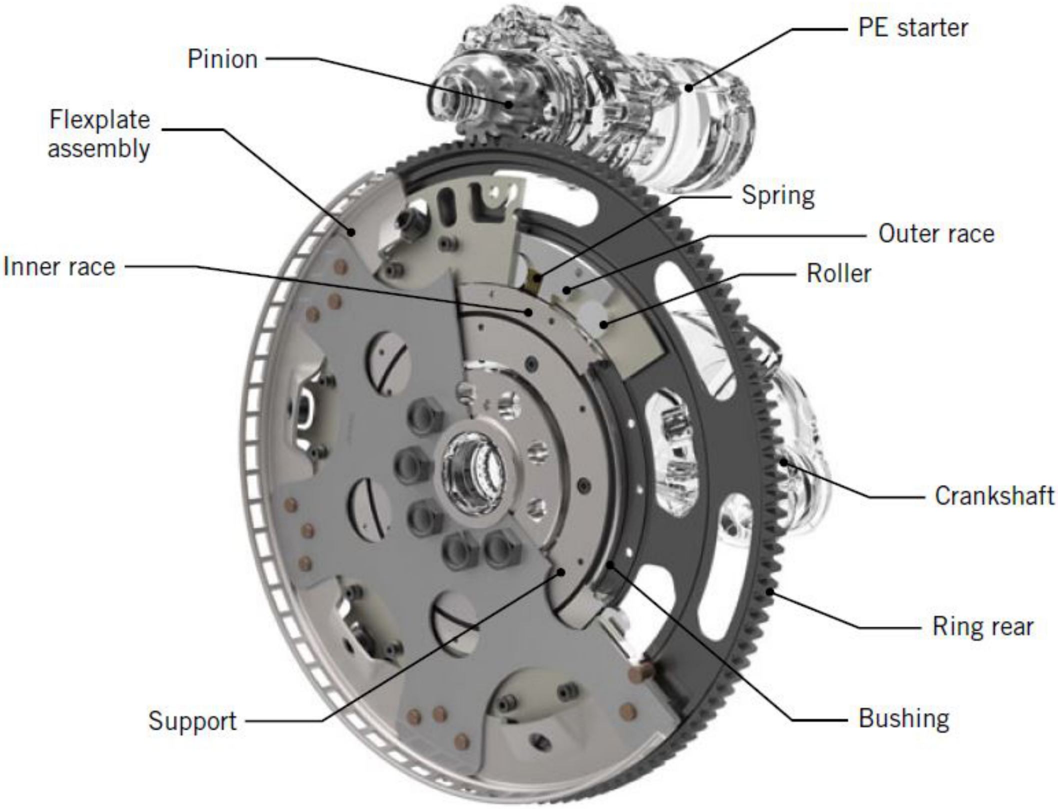
Conventional stop/start system, "change-of-mind" situation

sensor on the gearbox). The impacts resulting from the engagement and disengagement of the pinion are clearly perceptible, as is the stimulation due to the gearing during cranking. The repeatability of the starting process is poor due to the mechanical engagement of the pinion.

There are other enhanced stop/start technologies besides these conventional systems, but they require additional installation space or show a disadvantageous NVH behaviour. Starter generator systems have the best performance in terms of NVH and response time, but they add high costs to the system and require an additional pinion starter for cold starts. The dry running permanently engaged starter (PES) system presented here matches the performance of beltdriven systems but has the simplicity of a pinion starter and is suitable for integration into any kind of powertrain. As a plug and play system located between the engine and the transmission, it replaces the original starter ring gear that was there beforehand and uses existing interfaces with only minor modifications to the powertrain. Knowing the load spectrum allows the PES to be designed as a sturdy unit. The load spectrum takes the torques into account as well as the number of load changes occuring under different operating conditions such as key start, warm start and change-of-mind.

Design

First permanently engaged starter systems are already on the market. Here an OWC (one-way clutch) is used to disconnect ring gear and crankshaft [1]. In contrast, the dry running permanently engaged starter system from BorgWarner is located in the dry environment between the combustion engine and the transmission, see following figure. For this reason, there are high requirements regarding the resistance of the system against corrosion and contamination. It can be integrated into a flexplate or flywheel depending on the powertrain and has interfaces to



Dry running PES system for flexplate application

crankshaft, crankcase and starting device. At the heart of the dry running PES system is a one-way roller clutch between ring gear and crankshaft. The starter ring gear is mounted to the crankcase. As the starter only rotates during engine start and at low speeds, this arrangement has certain advantages compared with a ring gear supported by a bearing on the crankshaft. In this case, the bearing would have to permanently rotate at the same speed as the engine and tolerate the axial and radial vibrations of the crankshaft.

The torque introduced into the starter ring gear is transferred via the inner race of the roller one-way clutch to the outer race, which is integrated into the flexplate, and finally to the crankshaft. Once the engine speed exceeds that of the starter ring gear, the one-way clutch takes over and the starter motor can be shut off. At a certain crankshaft speed below the engine idle speed, the rollers completely lift off the inner race due to centrifugal forces. The roller one-way clutch of the dry running PES system compensates axial and radial movements of the crankshaft and flexplate as well as misalignment and axial run-out of the crankshaft flange.

As the starter pinion of a PES system is permanently in tooth contact with the starter ring gear, the tooth geometry of starter pinion and ring gear can be optimised with regard to NVH behaviour and durability, whereas the pinion and ring gear of a conventional starter system are optimised for easy engagement of the pinion. In contrast, the contact ratio of the gearing of a PES system can be increased significantly and backlash can be reduced. Also, there is no additional wear due to axial movement of an engaging pinion. In conventional systems, in which the starter

ring gear is permanently fixed to the crankshaft, the areas of the ring gear toothing that transfer the load during engine cranking are always the same. In opposition to those systems, the toothing of the ring gear in a PES system is loaded statistically and thus even. It is also possible to improve the NVH behaviour still further by using helical gears.
A stop/start system with a permanently engaged pinion therefore provides many possibilities for improving the NVH behaviour of the ring gear and pinion meshing as well as the durability of the gear set to sustain an increased number of starts and stops [3].

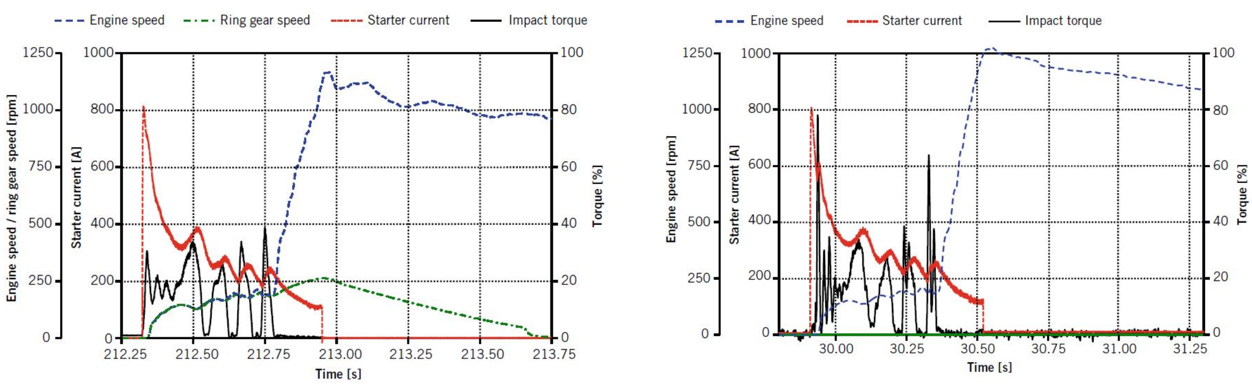
Vehicle Testing and Operating Performance

The vehicle testing of the dry PES system has been successfully performed on powertrains with manual transmissions and automatic transmissions. The measurement of the key start of a dry PES system shows five torque peaks which the one-way clutch has to transfer, see figure below. To accelerate the engine from a standstill, the starter motor has to overcome a breakaway torque followed by a virtually constant mean torque. Due to the torsional fluctuation of the engine during cranking, there are four more torque peaks once the one-way clutch re-engages.

The total number of load changes, for which the one-way clutch must be designed, is derived from the number of torque peaks in combination with the amount of engine stop/start cycles or based on a load spectrum.

A comparable key start with a conventional pinion shift starter is shown below. The torque impacts rise steeply and have a high peak value because of the rigid connection of the flexplate to the crankshaft. Due to the lower torsional stiffness, the torque impacts of the dry PES system are considerably lower. This has positive effects on the NVH behaviour of the starter system during cranking [3] and on the durability of the ring gear. In addition, smaller torque impacts are transferred through the crankshaft to the accessory drive of the engine during engine start.

Another advantage which can be directly experienced by the end customer is the change-of-mind capability of the dry PES system. While the engine is coming to a standstill after being switched off, the starter motor can be driven to assist the restart of the engine, see figure on the next page. The one-way clutch engages when crankshaft and ring gear are both rotating at the same



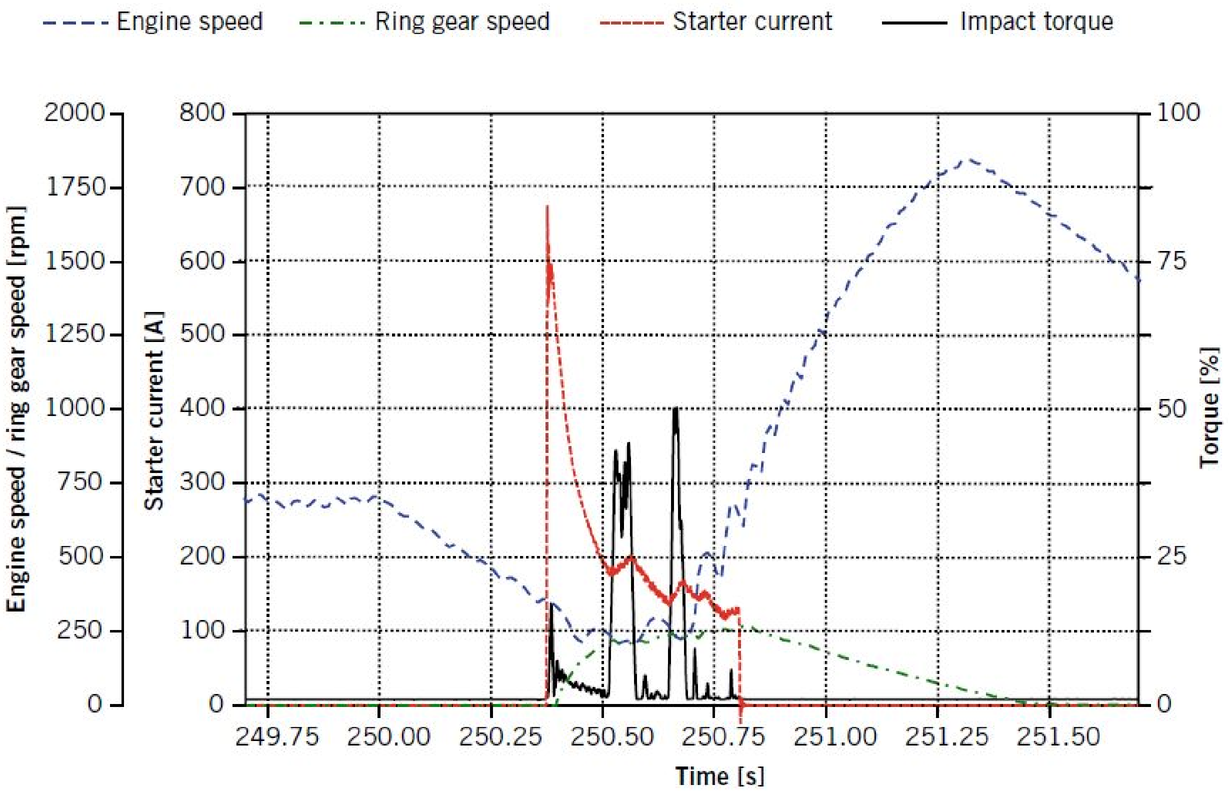
Key start measurement of automatic transmission: dry PES (left) and pinion shift starter (right)

speed and transfers the torque from the starter motor to the crankshaft, so that the engine can be started again with fuel injection. This significantly improves response time and repeatability of restarts.

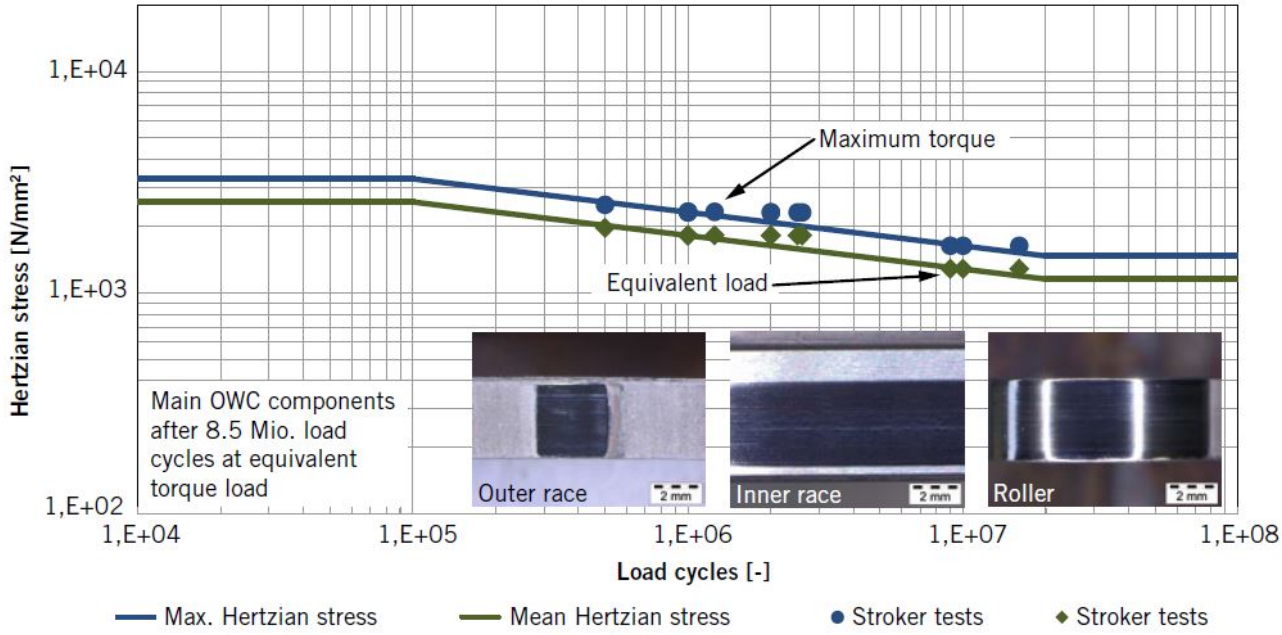
Durability, Drag Torque and Wear

The durability tests of the dry PES system were carried out on stroker test rigs in particular, with the maximum torque and the equivalent torque of a specific application. On the basis of these tests, which included salt water spray tests, it was possible to demonstrate the durability and overload capacity of the dry PES system in terms of torque respectively Hertzian stress. Depending on the application and the load profile specified, the S/N curves, see figure next page, allow the main components of the dry PES system to be adequately dimensioned and a suitable choice of base materials, heat treatments or surface coatings to be made.

The dry PES system is different from other systems in that it shows zero drag torque above the idle speed of the combustion engine. The roller and spring system is designed to completely disengage at idle speed (750 rpm in this case) due to centrifugal forces, and there is no contact between the components rotating at engine speed and the stationary components of the PES system. For this reason, the dry PES system shows no power dissipation whatsoever in normal operation of a combustion engine. There is an extremely low drag torque below the disengagement speed, see figure below. During starting and stopping of the engine, the

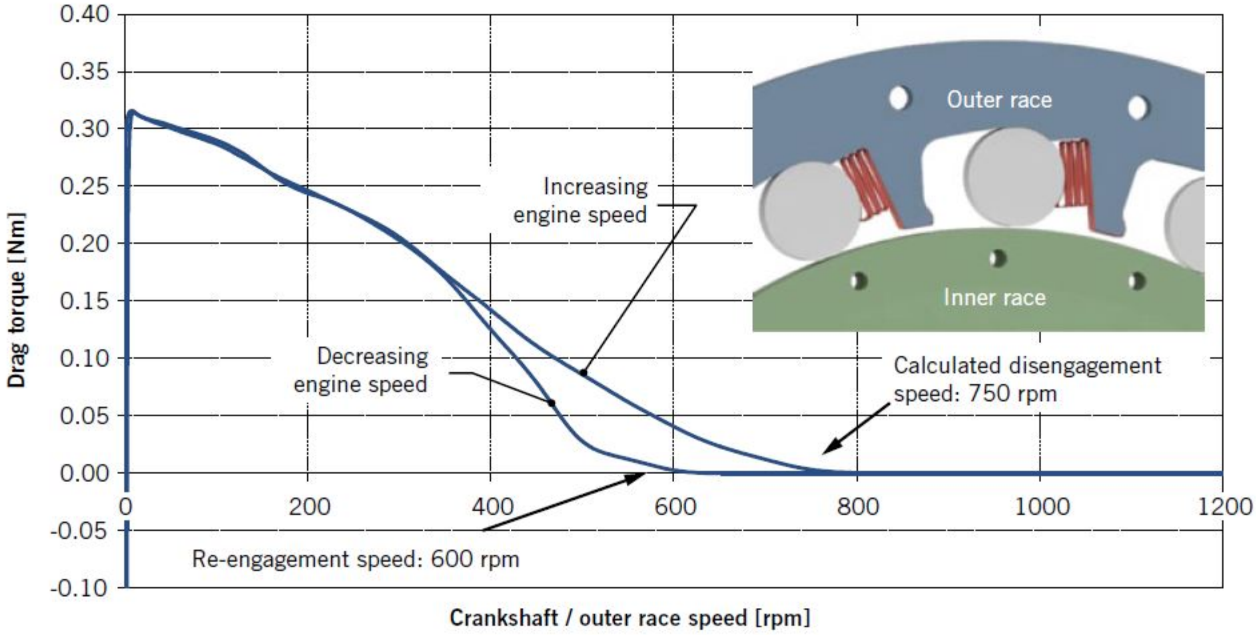


Change-of-mind start of a dry PES with manual transmission



S/N curve of the main components of the dry PES

rollers rotating with the outer race have temporary contact with the inner race. The resulting wear is extremely low, however, and is provided for in the design of the PES by allowing for a corresponding number of engine starts and engine stops [3]. A certain hysteresis occurring between disengagement and re-engagement is being considered in the sys-



Drag torque measurement of a dry PES system

tem layout, so that it does not affect the change-of-mind capability.

Conclusion and Outlook

The new BorgWarner dry running permanently engaged starter system is a solution that allows a very good stop/start behaviour to be achieved. On the basis of simulations [2], bench test results and measurements made in several demonstrator vehicles, the benefits of this system were demonstrated. The advantages in the system behaviour such as response, repeatability, NVH, robustness and the absence of drag losses were demonstrated in bench tests and in real vehicles. The results of this advanced development are the basis for several customer development programmes of the systems.

BorgWarner's dry PES system not only provides the above advantages compared to present stop/start systems; in combination with a matching engine application, it also opens up great potential for future technologies in automotive powertrains with combustion engines. The system allows advanced sailing and coasting with early engine shutoff, even to the extent of enabling an "idling-free" vehicle, and is able to handle a large number of engine stop/start cycles, especially in hybrid applications. These technologies support further fuel savings and increase driving comfort. With their improved operational behaviour, in particular their starting performance, dry PES systems will ultimately contribute to a wider acceptance of stop/start systems by the end customers.

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