

A Friction Comparison between Chain and Belt-Drive Systems

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ABSTRACT

Concerns over greenhouse gas emissions are driving governments and the automotive industry to seek out ways of reducing vehicle CO₂ emissions. Engine friction reduction is one means of reducing CO₂ emissions, through fuel consumption improvements. Of the different systems within the engine, the camshaft timing drive can contribute around 5 to 10% of the overall engine friction. It is therefore a system that can benefit from careful optimisation.

MAHLE has undertaken a motored friction-testing program on a 2.2 litre turbocharged diesel engine with the following different types of camshaft timing drive:

- Chain drive with hydraulic tensioner. This is the standard configuration for this engine.
- Chain drive with friction tensioner
- Wet belt drive
- Dry belt drive

Testing was conducted to allow the differences in friction between the different drive configurations to be calculated, by comparing each camshaft drive against the standard chain drive system. Using the frictional differences as a basis, the changes in fuel consumption from the standard configuration were predicted for a drive cycle. Changes in CO₂ emissions were then calculated. Experimental uncertainty levels were assessed during the analysis of the results.

This paper considers the approach to the testing, the testing process and the test results.

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INTRODUCTION

The work described in this paper was part of a collaborative research project involving the British Government's Technology Strategy Board, Ford Motor Company Ltd, Mahle Powertrain Ltd and Lubricants UK Ltd. The research project was entitled 'Engine Optimisation For Reduced Parasitic Losses (S0052K)'. Its aim was to establish methods for CO₂ reduction for the next generation of engines.

The camshaft timing drive makes up a significant proportion of total engine friction. For this reason a sub-project was initiated to independently determine the friction of four alternative camshaft timing drive systems. The aim was to rank the drive systems in order of CO₂ emissions, so giving guidance on which drives would be suitable for a low CO₂ output engine. This sub-project was carried out by Mahle Powertrain Ltd at its Northampton site. It is this sub-project that is considered in this paper.

To make the results relevant it was decided by the project stakeholders that the torsional excitement of the camshaft timing drive should be as representative of normal engine running as possible. For this reason it was decided to measure the motored camshaft drive friction on an engine that included the components responsible for the majority of camshaft timing drive torsional excitation. Ford Motor Company Ltd provided a 'Puma' 2.2L turbocharged diesel engine. The crank, pistons, valvetrain and high-pressure fuel pump were all retained in the engine for the testing.

Two other major constraints were applied to the project with the aim of ensuring relevant results:

- The non-standard camshaft timing drive systems were made as production representative as possible. In the design and procurement of the drive systems Mahle worked with two OEM camshaft timing drive system suppliers to achieve this.

• Due to the expected small differences in camshaft timing drive torque between the different variants, the measurement uncertainty of the results needed to be considered to make sure that the results from the testing were understood in the correct context.

GENERAL ENGINE MODIFICATIONS

The engine has many sources of internal friction. To control the friction repeatability of some of these sources to acceptable levels may have required a large effort. The oil, water, PAS and vacuum pumps, along with the turbo and EGR systems, did not have a significant influence on the friction behaviour of the camshaft timing drive. Therefore, to prevent unnecessary expenditure of effort or potentially poor total engine torque repeatability, these parts were removed from the engine or disabled.

Small amounts of material were removed from around the cylinder head and block castings in the areas of the timing drive runs to allow access for the non-standard camshaft-timing drive systems.

New front covers were produced to allow packaging of the non-standard camshaft timing drive systems.

BASE ENGINE

The same base engine was used for all testing with the aim of keeping the base engine friction the same. Only the cam timing drive components were changed. No new components were fitted to the base engine during the testing program. Previously used base engine components always remained in the same locations and orientations for subsequent tests. All base engine components were the original production items fitted to the engine. The crankshaft TV damper was fitted for all of the testing.

FUEL SYSTEM

In this Puma engine the high-pressure fuel pump is driven from the rear end of the inlet camshaft. Therefore, to provide torsional vibration levels representative of real-life running the fuel pump needed to be loaded. The engine was required to be motored for the friction tests. To avoid combustion it was not possible to inject fuel into the engine's cylinders. Instead another identical head, complete with standard injectors, was positioned behind the engine and a custom high-pressure fuel pipe was manufactured to take the fuel from the pump to the injectors. A catch tray was installed under the remote head to collect the injected fuel.

The fuel from the catch tray was drained back to a rig produced by Mahle for this project. The rig also provided the automated functions of fuel temperature control, fuel filtering, fuel storage and supplying a pressure regulated (low pressure) supply of fuel to the high-pressure fuel pump. The fuel temperature control and pressure regulated supply were included so that the torque variance of the fuel pump was kept within required limits.

The ECU and loom for the engine were retained for control of the high-pressure fuel pump loading. The ECU software was modified so that the fuel pump could operate at 3 distinct, user selected, loads. The loads were chosen to cover the low, medium and high loading regions of an NEDC drive cycle.

Standard pump grade diesel was used for all testing.

OIL SYSTEM

As well as the oil pump being disabled, the standard oil cooler and filter were removed from the engine. A new oil inlet plate was fitted to introduce conditioned oil from a separate rig into the engine oil gallery. The rig was again custom made by Mahle. The function of the rig was to provide temperature control, pressure control, filtration, de-aeration and oil scavenge from the engine. These functions were necessary to keep the variance of the engine torque to required levels between tests. The oil was scavenged from the engine by means of a vertical standpipe installed in the sump. The standpipe height was set to keep the oil at the minimum dipstick level.

COOLANT SYSTEM

With the water pump disabled a rig was also produced to circulate temperature-controlled coolant around the engine. Coolant was introduced into the block and collected from the rear of the cylinder head. The thermostat was removed from the engine. The temperature was controlled by the rig to keep the engine torque variance below a required level between tests.

CAMSHAFT TIMING DRIVE SYSTEMS

Each camshaft drive system was made up of the following major components:

- Belt/chain
- Cam sprockets/pulleys
- Crank sprocket/pulley
- LHS belt/chain guiding device
- RHS belt/chain guiding/tensioning device

Figures 1, 2, 3, 4 show the test engine fitted with each of the respective camshaft timing drive systems. The major components are indicated in each figure.

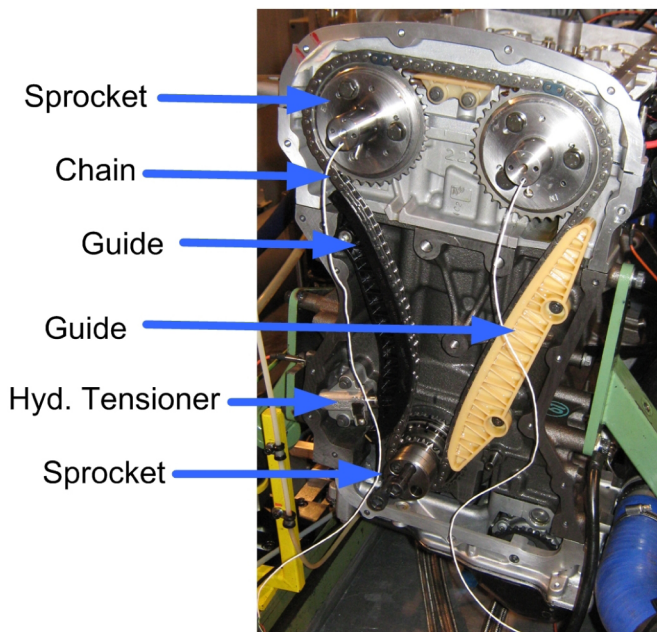


Figure 1. The Original Ford Chain With Hydraulic Tensioner Camshaft Timing Drive System

All of the major drive system components were original production parts for the 'original Ford chain with hydraulic tensioner' system. In this setup the camshaft sprockets had 38 teeth and the crankshaft sprocket had 19 teeth.

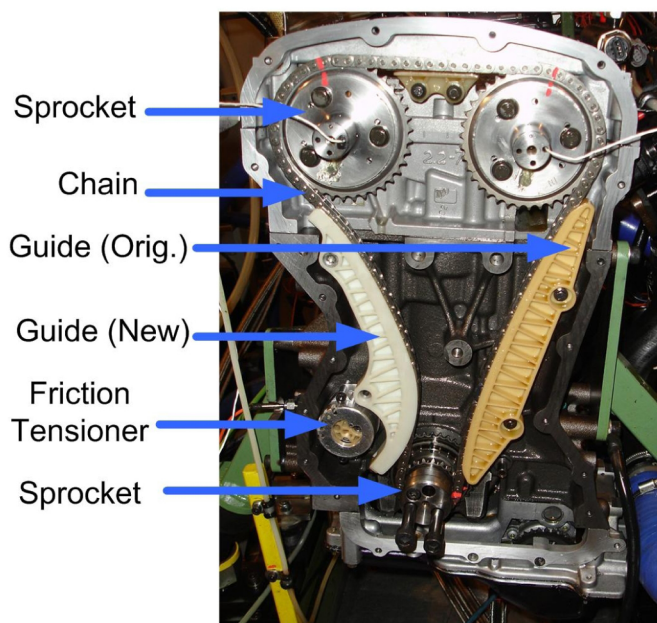


Figure 2. The Chain With Friction Tensioner Camshaft Timing Drive System

The 'chain with friction tensioner' system retained all of the parts from the 'original Ford chain with hydraulic tensioner' system with the exception of a new friction tensioner connected to a new RHS guide.

The new components were designed/procured in conjunction with one of our OEM camshaft timing drive system supplier partners and the project stakeholders. This ensured that the system was as production representative (for system performance) as possible given the packaging constraints of the existing engine.

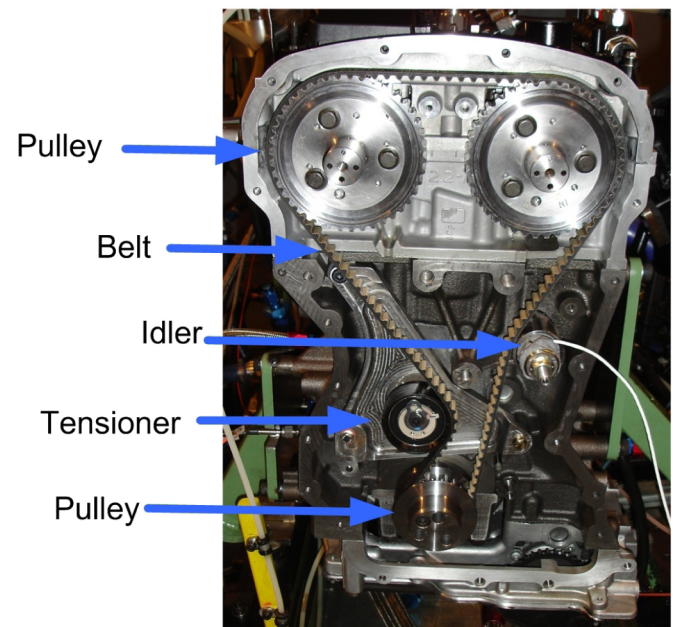


Figure 3. The Wet Belt Camshaft Timing Drive System

Each of the major camshaft timing drive components was changed when moving to the 'wet belt' system from the 'chain with friction tensioner' system. In this setup the camshaft pulleys had 42 teeth and the crankshaft pulley had 21 teeth. Each component was designed/procured in conjunction with one of our OEM camshaft timing drive system supplier partners and the project stakeholders. This ensured that the system was as production representative (for system performance) as possible given the packaging constraints of the existing engine.

The 'dry belt' system used the same major components as the 'wet belt' system. The 'wet belt' parts were moved forward slightly with spacers to allow a thin front cover to be placed behind them to seal the oil into the chain case.