# Knock, Knock - Part 3

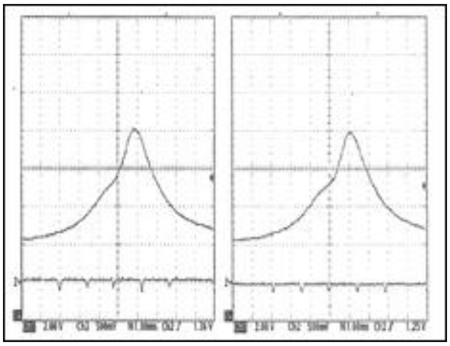
Knock testing on the dyno.

*By Tim White*

## Experimenting with Knock

A 2-litre Toyota 3S-FE engine was used as the guinea pig - this engine is the same as fitted to the Toyota Celica and Camry from 1986. To enable full control over engine tuning parameters, a MoTeC M4 engine management system was used. A programmable unit allowing full control over fuel injection quantity and spark timing, the MoTeC ECU also contains a data logging facility that records such parameters as engine speed, manifold pressure, fuel-air mixture and spark timing. The engine was mounted on a Schenck Dynabar 230 water-brake dyno.

A fibre-optic pressure transducer was selected to measure cylinder pressures. The main benefit was the sensor's size: as shown here, it was small enough to be mounted in a specially modified spark plug. Optrand Inc, the manufacturer of the pressure transducer, performed the work on the spark-plug. Fitting the actual transducer was then quite straightforward, although it required modification of a standard spark-plug socket to tighten the plug. A slot was cut in the socket to allow it to fit over the pressure sensor mounted on the side of the plug. Difficulty was experienced with making the plug seal to the cylinder head - the sealing washer was examined but no defects were found. The problem was solved by tightening the plug more than would usually be required, although no damage was incurred to either component in the process.



A Tektronix TDS 240 Digitising oscilloscope was used to monitor cylinder pressure information provided by the fibre optic sensor. The output from the pressure transducer and a crankshaft position sensor (described later) were both displayed. The oscilloscope was then connected to an inkjet printer to enable the pressure curves to be plotted. Cylinder pressure and knock intensity could be read directly off these plots using the MAPO method described earlier.

A signal was required to reference the output from the cylinder pressure transducer relative to crankshaft position. An infrared phototransistor was used to provide the signal. An electrical circuit was constructed to both power the sensor from the same supply as the pressure transducer and to modify its output to a usable form. The sensor was mounted to face the driveshaft flange on the dynamometer. Reflective tape was used to mark positions corresponding to 60 and 30 degrees before TDC, TDC and 30 and 60 degrees after TDC for cylinder number one.

With both this and the engine's modified crank trigger sensors connected, cylinder pressure could be measured with respect to crankshaft position using the oscilloscope.

## Method Of Inducing Knock

A method of making the engine knock was required. A combination of advancing the spark timing and using an inferior fuel was chosen. Low-octane fuel was used to initially induce knock, with variation of the spark timing then used to change the intensity of the knock. The MoTeC computer enabled spark timing changes to be made with the keyboard of the PC. Regular unleaded petrol (91 octane) did not have a low enough octane number to induce knock in the engine at the desired operating points and so an inferior fuel was required for testing the engine under knocking conditions. A fuel of 78 octane, "Light Straight Run Naptha", was provided by a Caltex Oil Refinery.

A method of testing was devised that would enable the isolation of knock as the only factor affecting engine output.

1. An operating point for the engine would be selected.
2. A baseline measure of engine output would be established using high-octane fuel to ensure that knock did not occur. Using the MoTeC computer, spark timing was adjusted until Minimum advance for Best Torque (MBT) was established.
3. The spark timing was then varied either side of MBT to establish a power versus ignition timing curve for the particular operating point and the high-octane fuel.
4. The engine was then run on a fuel of inferior octane number. The process detailed in (3.) was repeated to obtain a power versus ignition timing curve for the low-octane fuel.

The procedure (1) through (4) was repeated for a number of operating points at different engine speeds and loads (ie inlet manifold pressures). This enabled the investigation of how the effect of knock on power output varies with these two parameters. The two power versus ignition timing curves were overlaid on a single graph. This enabled direct comparison of engine output for both knocking and non-knocking operation for a set value of spark timing.

A total of ten operating points were chosen:

1. Engine speeds between 2,000 and 4,000 rpm were chosen at increments of 500rpm.

2. Each speed was tested at two throttle settings. The throttle settings corresponded to manifold pressures of approximately 80kPa and 100kPa. These high settings were chosen since knock is most common at high manifold pressure, in particular Wide Open Throttle.

The baseline tests were each performed using "premium" unleaded petrol (PULP) with an octane number of 96. Knock was induced by blending regular unleaded petrol (ULP) with Light Straight Run Naphtha (LSR). ULP has an octane number of 91, and blends linearly for octane number with LSR, which has an octane number of approximately 78. The octane number obtained by mixing the two fuels in various proportions is given in the table below.

| **Octane Number** | **Regular ULP (%)** | **LSR Naptha (%)** |
|---|---|---|
| 78 | 0 | 100 |
| 80 | 30 | 70 |
| 81 | 40 | 60 |
| 83 | 50 | 50 |
| 85 | 60 | 40 |
| 86 | 70 | 30 |
| 88 | 80 | 20 |
| 90 | 90 | 10 |
| 91 | 100 | 0 |

The fuel blend used at each operating point depended on the engine's tendency to knock at that point. The blend for each point was chosen so that knock would begin to occur at an ignition timing approximately five degrees retarded from the MBT found for non-knocking operation. The blend used at each point is given in the table below.

| **Speed** (rpm) | 2000 | 2500 | 3000 | 3500 | 4000 |
|---|---|---|---|---|---|
| **Load** (kPa) | | | | | |
| 80 | 83 | 78 | 78 | 78 | 78 |
| 100 | 87 | 87 | 87 | 87 | 87 |

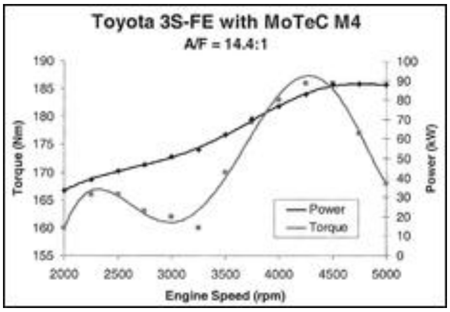
## Results

Before any knock testing was carried out, the engine was tuned on the dynamometer. The MoTeC software allowed the fuel injection quantity and spark timing to be defined on three-dimensional maps. Both of these parameters were specified at increments of 10 kPa manifold absolute pressure (MAP) and 250 rpm throughout the entire operating range. During operation, the computer interpolated between these points to determine the amount of fuel and spark advance to provide under any conditions of speed and load.

The engine was initially tuned to give a slightly rich (14.4:1) mixture. A mixture that is slightly rich:

- Increases the tendency of the engine to knock;
- Results in maximum engine output at a given operating point.

Spark timing was set to MBT to give an indication of the potential output of the engine and to obtain base performance figures for non-knocking operation.

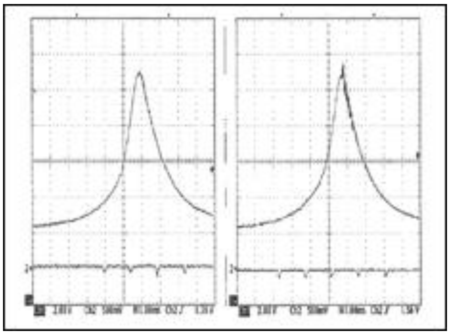


The torque and power curves for the tuned engine are shown here. Maximum torque occurred at 4,250 rpm with maximum power between 4,750 and 5,000 rpm. The engine was not tested past 5,000 rpm owing to the level of noise and vibration produced at high speeds. In fact the high level of vibration at of the dynamometer cradle resulted in several mechanical failures of the dynamometer flexure strips.

## The Effect Of Knock On Power Output

The data was recorded in three forms. Firstly, the engine torque output for each ignition timing setting at each operating point was recorded. This enabled calculation of the engine power output. The oscilloscope reading was stopped and held during each of these torque readings. The screen was plotted to enable measurement of the cylinder pressure and if knocking, the knock intensity. Upon testing all ignition advance settings at each operating point, logged data from the MoTeC computer was downloaded. These files contained data that allowed calculation of the specific fuel consumption (SFC) at each setting.

At each of the ten operating points, curves showing the engine's power versus spark timing were drawn, using test results. Curves for both knocking and non-knocking operation at each operating point were constructed. The curves were then overlaid to see whether there was any difference between the two. The curves were constructed in the Microsoft Excel spreadsheet program to obtain lines-of-best-fit ("trendlines") for the scatter data. The line representing knock intensity on the results is not a line-of-best-fit *per se*. For this analysis a "moving average" type trendline was selected instead.



This graph is a typical example of how power output dropped with the timing increased until knock occurred. Two curves appear on the graph: one for non-knocking operation (using 96 octane fuel) and another for knocking operation (using a lower octane blend). The level of knock intensity is also given as a moving average for when knock is occurring with the low octane fuel.

The difference between the two curves then shows the effect of knock on the power output of the engine.

Many other graphs of engine behaviour were made; the clear trend that may be seen from the majority of these graphs is as knock begins to occur and as its intensity increases, useful power output from the engine decreases. Other measurements of the relationship between knock and specific fuel consumption were also made, and these results are summarized below.

## Conclusions

- Some researchers have claimed that slight knock may increase the power output of an engine. The tests carried out showed no evidence of this. **As knock intensity increased, more power was lost.**

- Power loss with knock at a particular speed was found to be related to the engine's volumetric efficiency at that speed. Knock had the greatest effect on power at the speeds where volumetric efficiency (and thus torque and BMEP) were lowest. At the higher speed, turbulence in the cylinder is highest. It is believed that this increased turbulence prevents the pressure waves associated with knock from transferring their energy to the cylinder walls. Their energy is then better retained in the cylinder for the duration of the power stroke and is used to drive the piston.

- Power loss with knock of a given intensity was found to be relatively less at throttled conditions than at WOT. While the reason for this is unclear, it is thought that a lower inlet MAP will result in a lower peak combustion pressure. This lower pressure may result in less energy transfer from the knocking pressure waves to the cylinder wall. The result is more energy remaining in the cylinder to drive the piston.

- **The presence of knock was found to have a detrimental effect on efficiency**. The brake specific fuel consumption of the engine increased with knock intensity at all operating points tested. The percentage increase in BSFC was found to be the same as the percentage decrease in power. The reasons for the efficiency loss are the same as for the power loss. Knock results in an increased rate of heat transfer from the combustion chamber to its walls. This heat is then unavailable to do useful work in driving the piston.

## Summary

The testing carried out here showed that spark-knock reduces the power output and efficiency of an engine. Based on the results of these tests, the power loss accompanying knock is most likely due to the increased heat loss to the combustion chamber walls.

In Part 1 of this series, the question was posed whether some knock should be accepted in the quest for maximum engine performance. It was asked whether the increase in performance gained by choosing a higher compression ratio for an engine could outweigh any performance loss caused by the knock that resulted. The answer appears to be "yes".

The power gain from raising the compression ratio was not directly studied. Yet the effect that knock of moderate intensity has on performance was found to be small enough to be easily outweighed by other changes. The change performed here was to advance the spark timing past the knock limit toward MBT. On the test engine this resulted in a power rise, even though knock of moderate intensity was occurring. It follows that the losses would probably also be outweighed by increasing the compression ratio.

At the higher compression ratio, the engine would start to knock before the spark timing was advanced all the way to MBT. But the power level would continue to rise as the timing was advanced past the knock limit. Even though the knock would reduce the power from that which could be achieved with a non-knocking, higher octane fuel, the gain from the higher compression ratio **may** outweigh the loss from the knock.

**Editor's note: This series of articles is based on a Bachelor of Engineering thesis presented to the University of New South Wales, School of Mechanical and Manufacturing Engineering, by Tim White in November 1999. The thesis is entitled 'The Effect of Spark-Knock on the Performance of a Modern Spark-Ignition Engine'.**

Knock, Knock - Part 1
Knock, Knock - Part 2