Combustion instability detection during catalyst heating phase of GDI cold start

Introduction

The combustion quality of engines is always important but especially so when the catalyst has not yet reached sufficient temperature to neutralise engine-out pollutants. Usually, the three-way catalyst surface temperature required for significant HC reduction is above 300ºC and the vehicle's cold start calibration is designed to reach these temperatures as quickly as possible.

However, the methods employed to increase the exhaust gas temperature can inadvertently lead to combustion instability and therefore tailpipe emissions of high HC at a time when the catalyst is not fully converting them.

Spark retard is a typical technique which provides a late burn and high exhaust gas temperatures.

Multiple fuel injections are also often applied during the catalyst heating phase with the main fuel injection occurring during the intake stroke (to promote good mixing of the cylinder's homogeneous charge) but with secondary injection(s) occurring during the compression stroke to try to aid combustion stability by providing a rich pocket of gas at the spark plug's electrodes. The retarded spark and relatively poor fuel vaporisation are factors which make achieving combustion stability particularly difficult during this crucial part of the engine's operation.

Fast FIDs are widely used by calibrators to identify combustion problems and to study the real time cycle-by-cycle HC emissions during this critical phase. Their help in identifying the spark retard limits and other factors associated with combustion quality are often used in conjunction with fast CO& CO_2 measurements (for fast lambda) as well as cylinder pressure information.

Example: Vehicle and Engine

A 2008 model year Peugeot 308 (Euro 4) with 1.6 litre turbocharged GDI was used for this testing on a robot-driven chassis dynamometer (*Figure 1*). The vehicle had both a close-coupled starter catalyst and a main catalyst packaged together.

Figure 1: Vehicle on chassis dynamometer

Fast response gas analyzers (including the fast FID) were position at the pre-catalyst and post-catalyst sampling points to provide the engine-out and tailpipe data (*Figure 2*). A standard bench emissions analyzer was used to sample the emissions from the dilution tunnel.

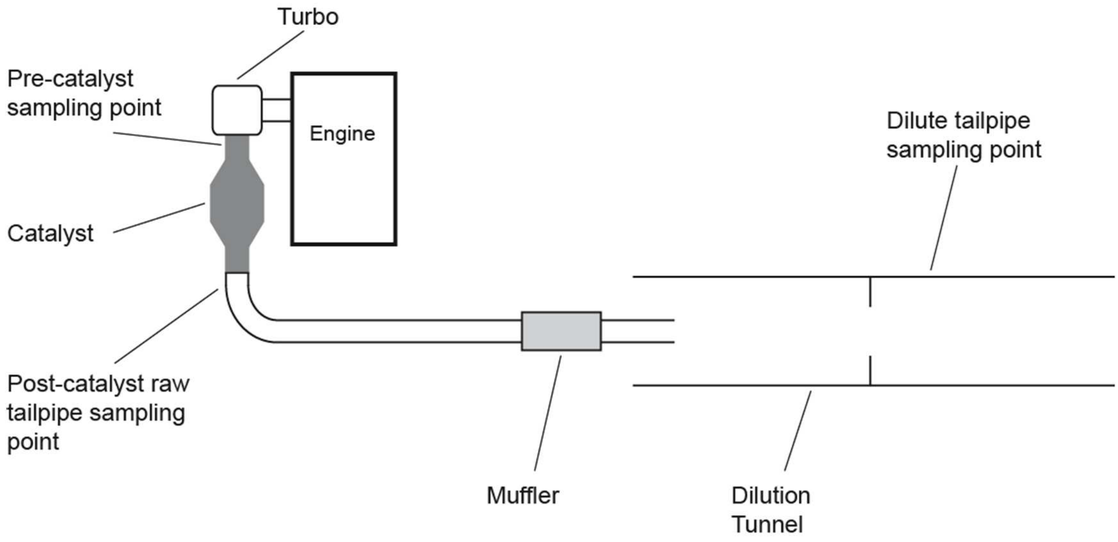

Figure 2: Emissions sampling points

The vehicle was driven on the New European Drive Cycle (NEDC) from 20ºC ambient conditions and the results from the cold start and catalyst heating phase were logged.

Results

The cumulative tailpipe HC mass emissions (shown in blue in the upper plot of *Figure 3*) show the light-off characteristics of the 3-way catalyst from the cold start, but it is clear that a significant contribution to the total cycle's tailpipe HC emissions (which total 1g after 1200s) were associated with the catalyst heating phase (which, from other observations ends at 68s). The catalyst is largely active by the start of the 2nd acceleration at 53s but there is evidence of some breakthrough from poor combustion during the gear change at 57s; a spike appearing in the tailpipe.

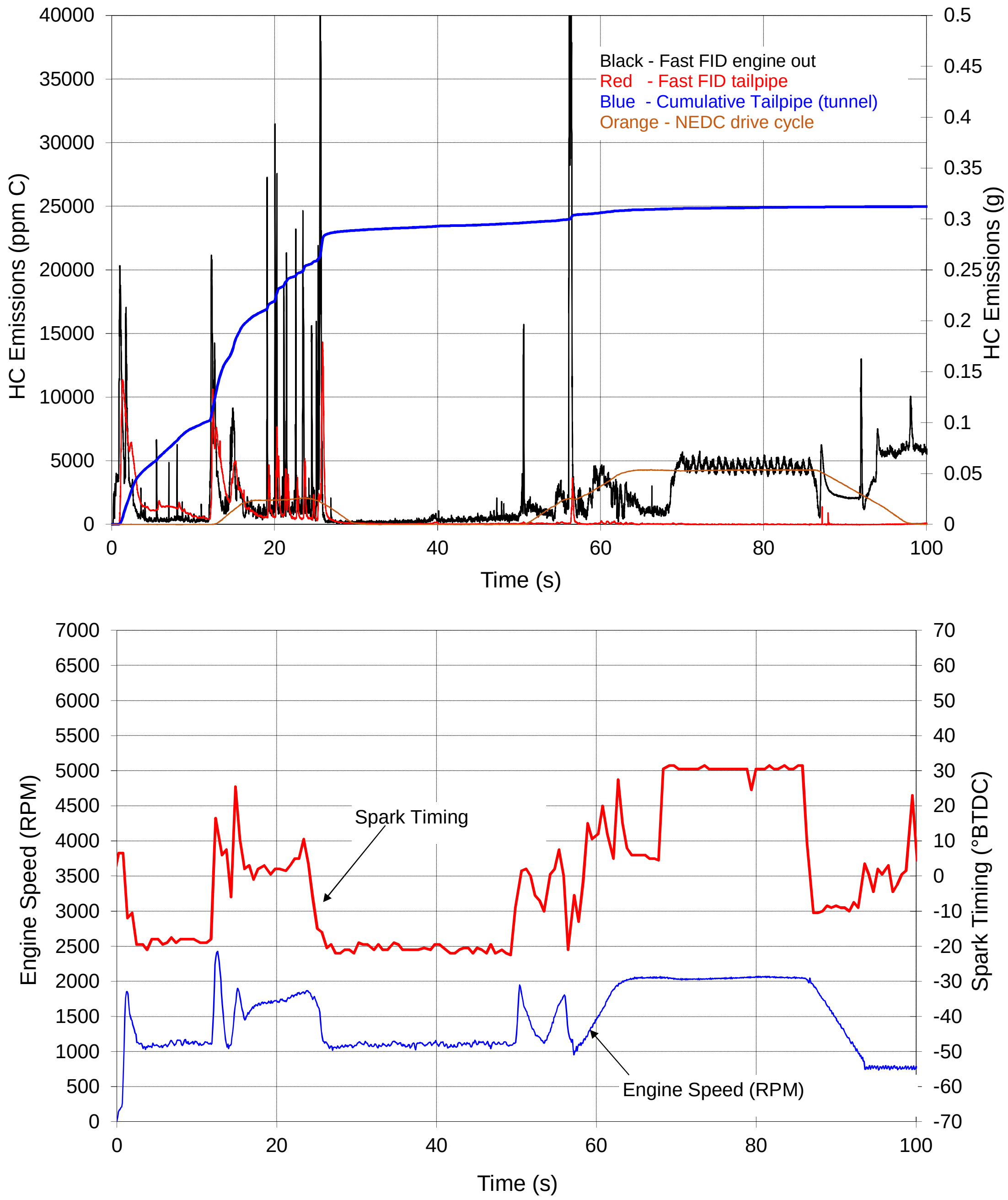

Figure 3: Cold start HC measurements and spark timing

Most of the combustion instability occurred during the first gear cruise from 18-27s. The catalyst heating strategy of this vehicle included double fuel injection events and retarded spark timing as shown in the lower graph in *Figure 3*.

The data for the cold start and first gear cruise is expanded from 0-30s in *Figure 4* in an attempt to study this more closely.

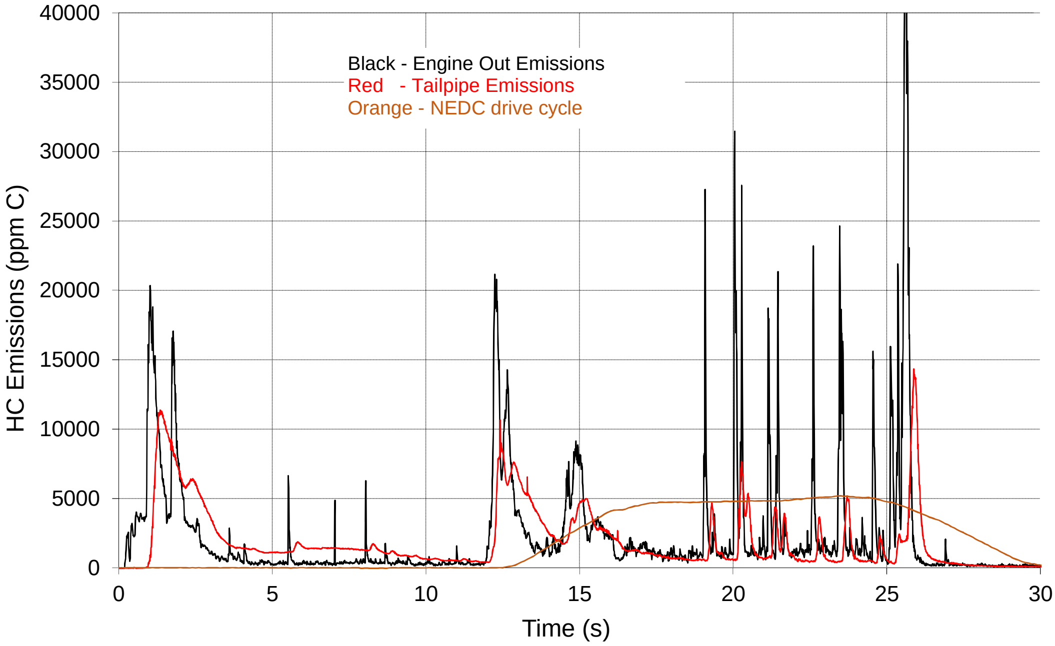

Figure 4: First 30s of cold start and catalyst heating phase

The data shows the (largely unconverted) HC passing through the catalyst with a few very short duration single poor combustion events in the engine-out HC between 5 and 10s. There are some high HC emissions associated with the transient during the first acceleration at 11s but the 1st gear cruise (a steady state condition where one might expect combustion to be stable), during which the spark timing has been retarded to approximately 3 degrees after Top Dead Centre, is exhibiting sporadic combustion problems which are translating to the high tailpipe HC emissions shown in *Figure 3*.

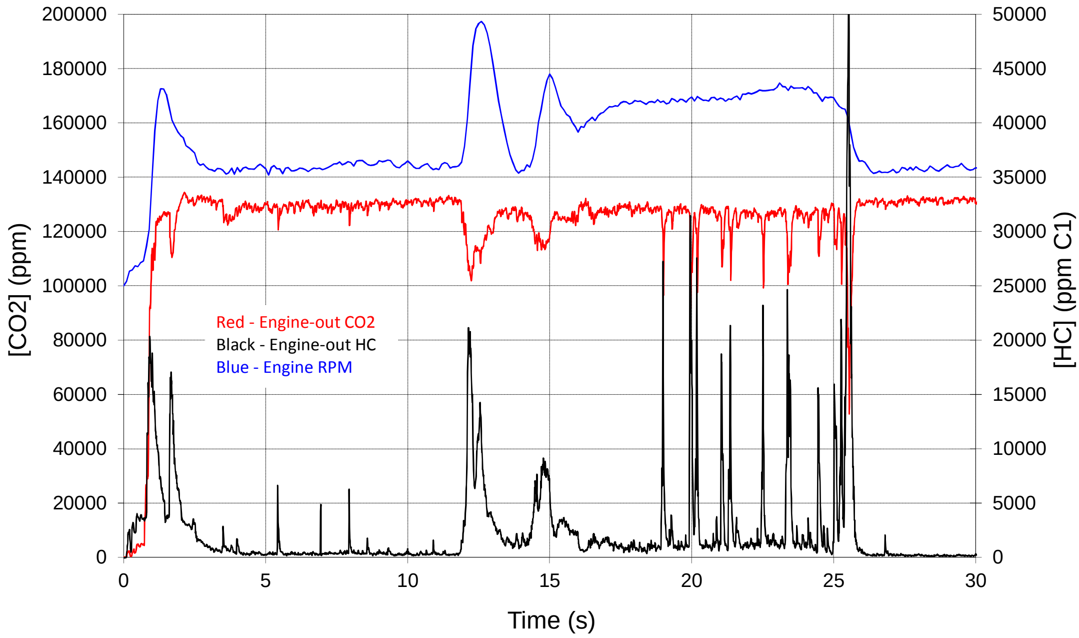

Figure 5: Fast CO2 engine-out gas data complementing the combustion instability observations

A fast response NDIR was also used to measure the engine-out CO_2 simultaneously with the fast FID and the data from this is shown in red in *Figure 5*. The sporadic absence of CO_2 indicates that combustion was either absent or incomplete from those cycles which are producing the high HC levels; the peaks of engine-out HC aligning precisely with the troughs in the CO_2 signal.

On reviewing this data, the calibrator could adjust spark timing, fuel injection timings and quantities and other parameters to eliminate the combustion instabilities.

As described previously, this data was recorded after the turbo and shows the total engine-out emissions from all 4 engine cylinders. Further analysis of each cylinder by positioning the fast FID and NDIR sample probes in each of the individual exhaust ports would identify the precise cycles and cylinders with poor combustion and, via the NDIR's fast CO& CO_2 data, the combustion lambda could be calculated.

Conclusion

The fast FID is an effective calibration tool for identifying the limits of spark retard and other engine control parameters during the cold start and catalyst heating phase of GDI engine operation. This can help optimise combustion and minimise tailpipe emissions.

The HC signature provides information about the quality of combustion and the precise timing of such issues. It furthermore provides a direct measurement of the real time emissions of this legislated pollutant.