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A New Technique to Study the Response of Catalysts to Transient Conditions

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ABSTRACT

This paper reports on a new technique for the study of the response of exhaust catalysts to rapid emision transients. A very high frequency response hydrocarbon concentration measurement system is described, and as an example of the capabilities of the system, the resonse of a conventional three-way catalyst to a lean misfire is reported. It is shown how the break-through and characteristic response are related to the air fuel ratio for one running condition.

INTRODUCTION

Any technology which offers a better understanding of the emissions behaviour of automobiles is of importance. There is a constant effort to obtain the very lowest possible emissions. Although for some years the three-way catalyst has proven to be very effective, recent tightening of the emission limits, and the discovery that the in-service conformability of catalysts may not be satisfactory, due in part to engine misfiring, has refocussed attention on the catalyst.

The major contribution to the total hydrocarbons during the drive cycle is during the cold start, and further significant emissions occur during transients if rich conditions exist for long enough to exceed the oxygen storage capability of the catalyst. In addition, the storage behaviour of catalysts is of importance in understanding better their characteristics.

This paper presents some results showing the response of a conventional three-way catalyst to a lean misfire condition for a range of air fuel ratios. The use of conventional emmissions equipment for this task is not possible, since the transients are too fast. Therefore the Cambustion HFR 300 high frequency response hydrocarbon detector has been used for this work. This is thought to be the first use of this instrument for this purpose, but early versions have already been used for transient exhaust emission (e.g. 1,2) and in-cylinder studies (3,4,5). Details of this FID-based instrument can be found in those papers. Suffice it to say here that it has a time constant of the order of 1 millisecond, and is able to perform continuous HC concentration measurements in a fluctuating pressure and temperature environment, with an accuracy comparable with standard FID instruments.

EXPERIMENTAL

The experimental set up is shown in fig.1. The engine was a conventional 4 cylinder in-line gasoline engine of 2 litres capacity, and for these tests was run at a constant speed of 1500 rpm. The ignition timing was fixed at 30 DBTDC, and the throttle was fixed at a position giving approximately half load. The fuel pulse width was fixed at a value giving the desired air fuel ratio as measured using an NTK Micro Oxyvision sensor.

The two hydrocarbon sensor modules were calibrated, prior to the tests, by flooding the exhaust system with span gases. The calibration gave 0.87 and 0.81 volts per 1000 ppm propane for the upstream and downstream sensors respectively.

A lean misfire event was induced to occur on cylinder 1 once per 40 engine cycles, by fueling with exactly half the amount of fuel normally injected. A typical result is shown in fig. 2, which is for an AFR of 14.2. The very high frequency response is shown by the detail on the upstream hydrocarbon signal. The spikiness of the signal is in fact due to the fact that the engine has four cylinders, and a misfire was only induced in cylinder 1. This means that the high concentration hydrocarbon

'slug' initially sits largely in cylinder 1's exhaust branch, and then mixes into the other streams piece by piece on successive exhaust events. At the conditions of this test, it is observed that the catalyst is able to effectively oxidise the unburnt fuel. The mean level post catalyst is approximately 100 ppm, compared with 2300 ppm upstream of the catalyst.

The time delay through the catalyst, if this is sensibly indicated by the delay between the first sign of the transient at each sample point, is about 0.1 seconds, equivalent to a mean velocity between the sample points of about 0.5 m/s. The differential diffusion rate of differing hydrocarbon species (the basis of operation of the gas chromatograph for example) can be discounted as an effect here as the flow along the exhaust system will be highly turbulent, and thus the mixing processes in the system will be dominated by turbulence. Differential diffusion in the catalyst itself will occur, as the flow there is laminar, but the times available are much too short to be of relevance.

Fig. 2 also shows pressure signals from the same cylinder, and the misfire is clearly seen. The time delay between the EVO event on that cycle and the arrival of the first HC spike at the upstream catalyst is seen to be about 0.14 seconds, corresponding to a mean velocity along the exhaust system of about 10 m/s. This velocity is well in excess of that required to produce turbulent flow in the exhaust system leading to the catalyst.

Figs 3,4,5,6,7 and 8 show the main test data. The trend in the 'base' HC level upstream of the catalyst follows the expected trend, that is the level decreases with increasing AFR. The downstream sensor also shows the expected 'base' level trends. As the mixture becomes leaner (figs 3,4,5), the average hydrocarbon level becomes lower, although the breakthrough at an AFR of 18.5 is noticeablely greater than at the richer mixtures.

At mixture strengths significantly richer than stoichiometric, the behaviour of the catalyst is rather more complex. At an AFR of 12.5, Fig.8, a high 'base' post-catalyst HC level (1710 ppm, compared with 2250 ppm pre-catalyst) is merely temporarily increased during the transient misfire. In fact at this AFR a total misfire did not in fact occur, as can be seen by the relatively small area under the upstream HC signal. Thus there is perhaps little excess oxygen associated with the misfire to help the conversion process.

The result at an AFR of 13.3 is much more difficult to explain. The main drop in the level of the downstream sensor is explained in terms of the catalyst's increased HC conversion efficiency as it is supplied with an excess oxygen pulse. After this event, the HC conversion efficiency gradually falls as the stored oxygen from the misfire is consumed. The smaller drop in the HC level just prior to the HC pulse arrival at the upstream sensor is rather strange at first sight. How can the HC conversion efficiency of the catalyst suddenly improve when no extra oxygen is available?

The explanation is thought to be that at the time of the EVO event following the misfire, there is a significant pause in the exhaust flow rate, since the contents of the cylinder are at a much lower temperature, and thus of a higher density. Thus the velocity in the catalyst reduces, and there is more time available for HC conversion. The timing of the feature is consistent with this explanation, and in fact there is a very similar feature in fig. 3, albeit very small, as the HC levels are so small.

It is important to realise that the main downstream HC feature following the misfire is reversed in 'sign' between the runs at AFR's of 14.2 and 13.3. In the leaner case, the large excess HC 'breaks through, whereas with the richer case, it is the excess oxygen pulse associated with the misfire which has the dominant effect.

CONCLUSIONS

A new technique for the dynamic study of the transient behaviour of catalysts has been presented. It has been shown how under rich conditions, the catalyst responds in a complex way to a lean misfire, and that under leaner conditions, a conventional catalyst can cope with large HC pulses at a typical running condition. This work could be extended to a much fuller study, involving more persistent misfires as well as other operating conditions, but the object has been here to evaluate a technique, and this has been done.

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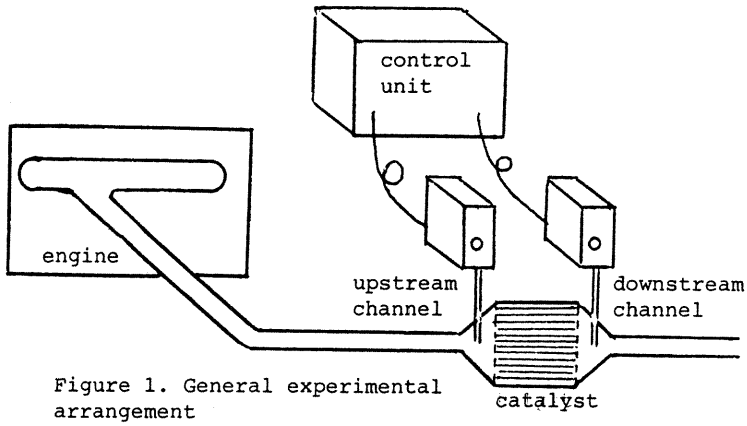

Figure 1. General experimental arrangement

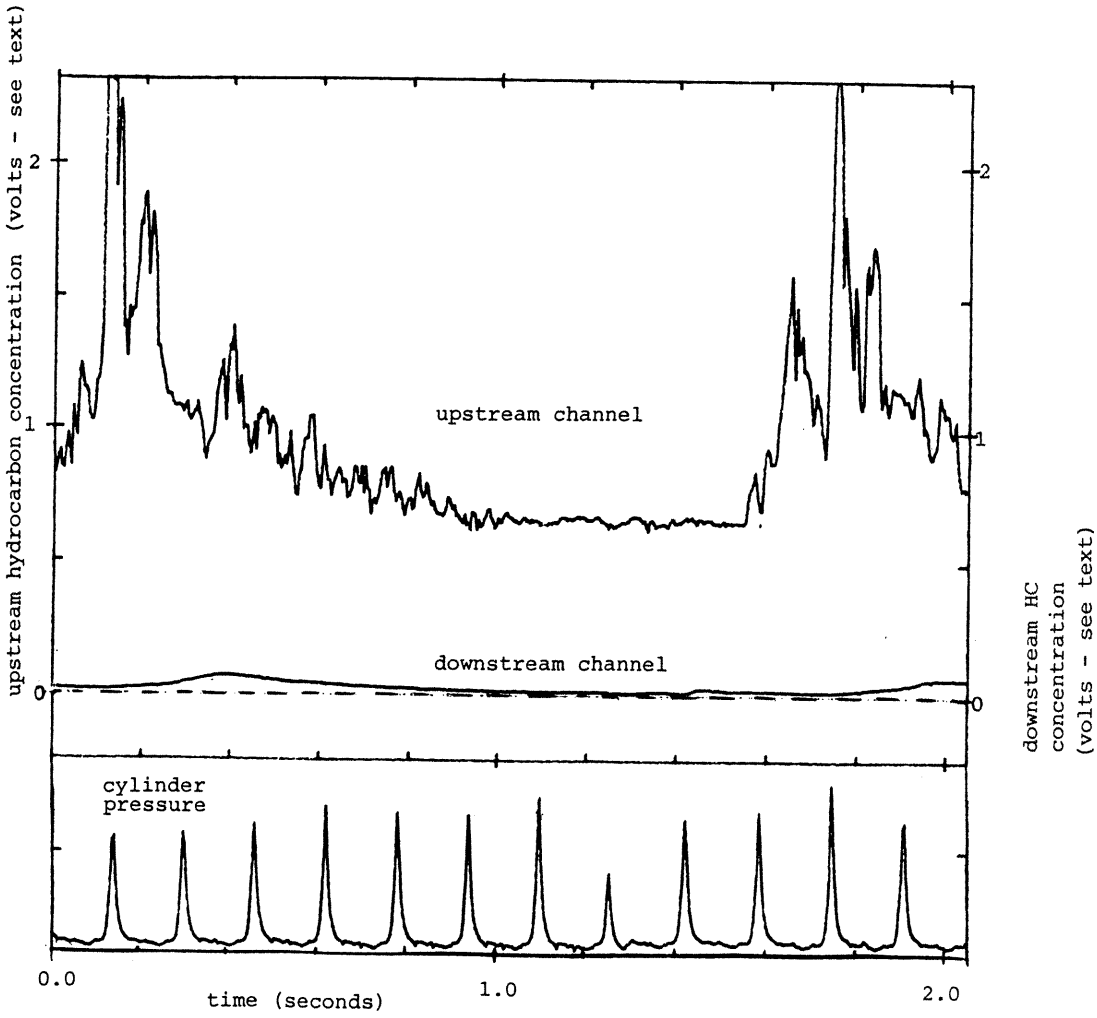

Figure 2. Typical upstream and downstream HC signals and in-cylinder pressure.

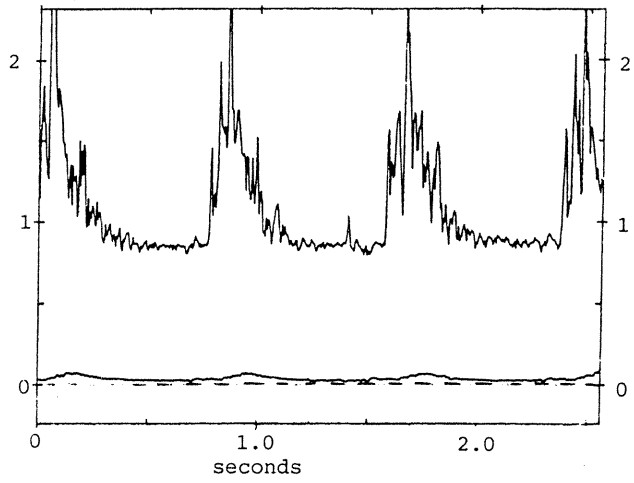

Fig.3 AFR 14.2, load 66 Nm, fuel pulse 6 ms.

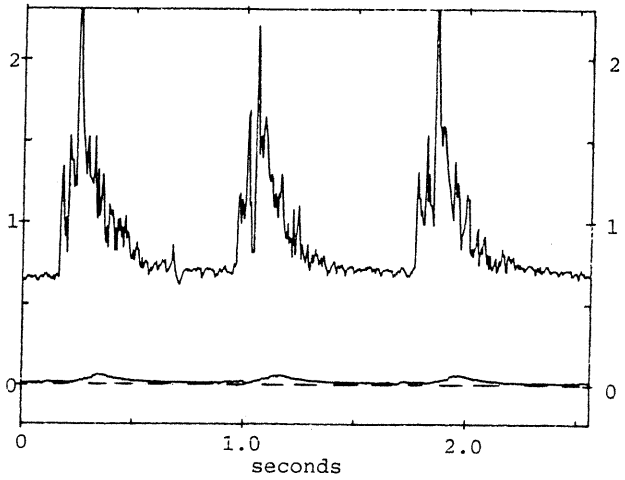

Fig 4 AFR 15.5, load 59 Nm, fuel pulse 5.5 ms.

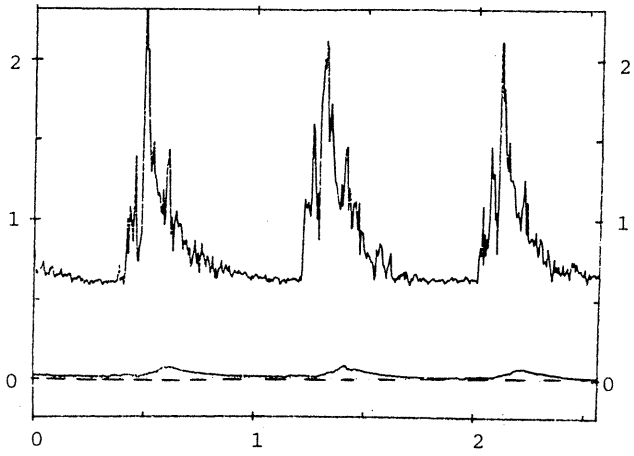

Fig.5 AFR 16.9, load 53 Nm, fuel pulse 5.0 ms

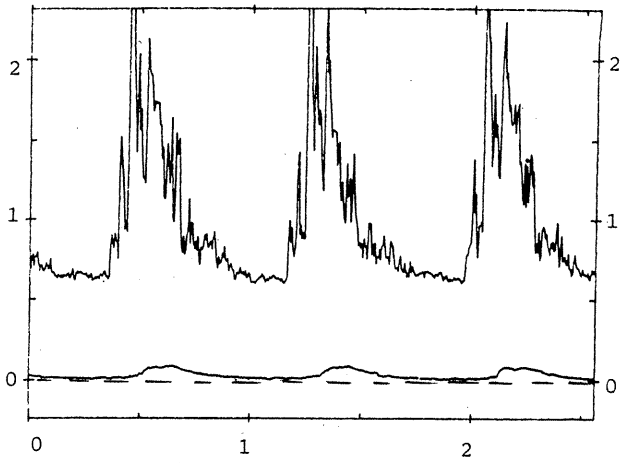

Fig 6. AFR 18.5, load 47 Nm, fuel pulse 4.5 ms.

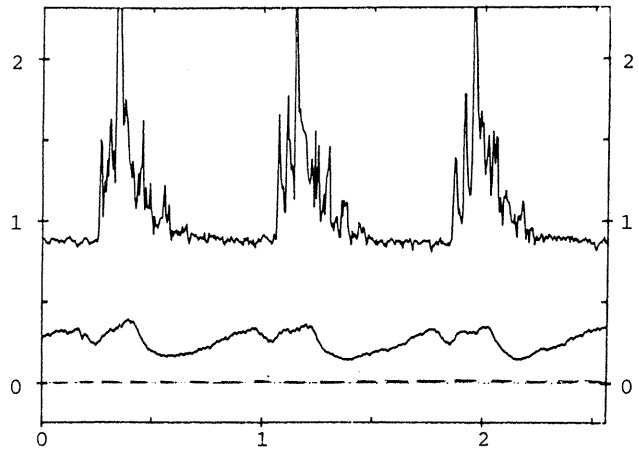

Fig 7. AFR 13.3, load 66 Nm, fuel pulse 6.5 ms.

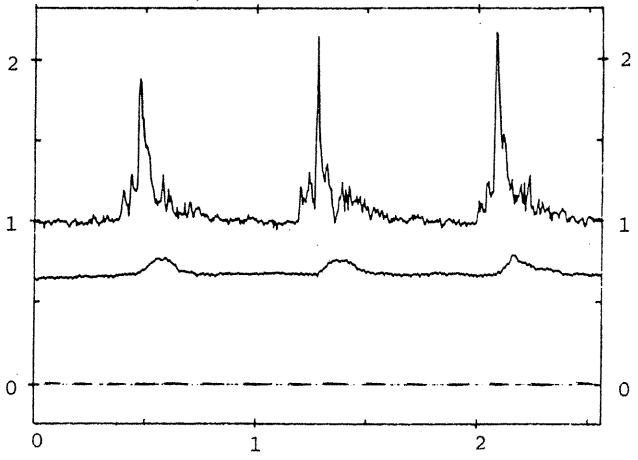

Fig. 8. AFR 12.5, load 65 Nm, fuel pulse 7.0 ms.