AUTOMOTIVE ELECTRONICS

with NICK de VRIES MIAME, AMSAE, FI Diag.E.,

Catalysers, lean burn and the oxygen sensor

It's some time since this column looked at this interesting subject, so this month I've decided to do so. Among other things we look at the feasibility of making your own PC-controlled O_2 sensor test meter and signal injector, prompted by the availability of a high grade oxygen sensor. However I also explain why you have to use some care in interpreting the readings from any of these simple testers.

In the bad old days before catalyst technology, some of the more adventurous vehicle manufacturers attempted to achieve pollution control by means of the 'Lean Burn' principle. These engines typically ran mixture strengths around the Lambda 1.3 mark (19:1 AFR).

The Lean Burn system was notorious for 'flat spotting' and generally behaving badly in awkward situations — often from standing starts or halfway across an intersection! While the concept was good, the emission of oxides of nitrogen was unacceptably high, and with engine management systems being in their infancy, the precise control necessary to keep these designs running at constant peak efficiency was simply unachievable.

To try and convert a contemporary engine to run at the kinds of air/fuel ratios for Lean Burn is a major undertaking. Today's engines simply won't run above Lambda 1.2 (17.5:1 AFR). However, some manufacturers are returning to the Lean Burn pathway (notably Toyota and Honda), and with specially designed combustion chambers are running mixture strengths of Lambda 1.4-1.6 (20-22:1 AFR). These designs require a completely new approach to the combustion chamber design, with special attention to eliminating crevices — such as the sharp valve clearance 'flycuts' in the piston crown in some high compression/valve angle applications.

Any design that incorporates protrusions into the combustion chamber must also be redesigned, to eliminate the chance that the inevitably higher temperatures which accompany the lean burn chemistry could ignite the mixture at an inconvenient moment (pre-ignition).

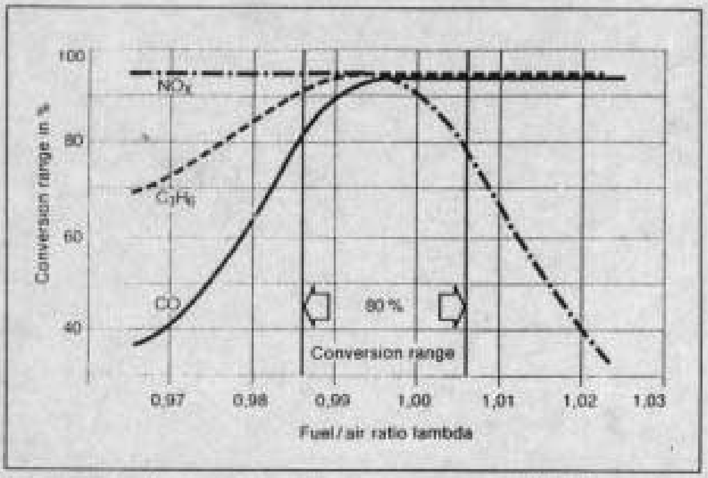

Fig.1: The three way catalyser works best at this band of operation, providing the engine keeps feeding it little bursts of fuel known as the 'Lambda Frequency'. (Courtesy Bosch Australia).

The Lean Burn concept has been revived by our own local manufacturers for the average vehicle, but when operating under certain conditions. When the right conditions are met, such as constant speed over 100km/h for five consecutive minutes, the firmware in the ECU begins to reduce the injector pulse width and operate the engine in the 'Lean Burn' mode.

This gives great fuel savings during highway driving, but the emissions of oxides of nitrogen tend to rise dramatically and the need for a three-way catalyst treatment (hydrocarbons and carbon monoxide, plus oxides of nitrogen) is clear.

There was an argument that oxides of nitrogen emitted at that point in the drive cycle (between towns) didn't matter. However the residents of suburbia close to freeways may take a different view, don't you think?

Now that emissions legislation has tightened even further, the adoption of catalytic converters in the exhaust stream has meant that the consumer enjoys a more responsive engine — although at a small sacrifice of economy. As vehicle emissions legislation stands at the moment, catalyst technology is coping very well and most manufacturer's emissions labs are pouring their resources into improving the fuel economy of their model line-up.

The purpose of all this preamble is to set the background and lead into an explanation of the function of the oxygen sensor in more detail.

In the January 1994 edition of *EA*, my predecessor Al Younger presented an article on the 'King of all Sensors' — the oxygen sensor. Included in the story was a design for making your own O_2 sensor tester, with a ten-LED display. In reading back over the story I couldn't help noticing a gap in the information that Al presented, and as a consequence there seemed to be a need for another article that goes into more depth. So here goes!

As Major Al quite rightly pointed out, the catalyser has a maximum effi-

Fig.2: The heavy duty oxygen sensor from Bosch. Note the almost complete metal casing around the sensing tip. (Courtesy Bosch Australia).

ciency rating of about 90 to 95% at almost exactly the stoichiometric point. To run the catalyser in its best operating band it must be fed a small amount of carbon monoxide and hydrocarbon, to keep it 'lit'. The ECU therefore maintains a routine of varying the pulse width of the injectors very slightly when in light throttle conditions, to provide 'fuel' for the catalysing process.

In medium to wide throttle conditions, there is plenty of excess fuel escaping from the combustion chambers to keep the catalyst furnace fairly roaring. I mentioned a small sacrifice in fuel economy for catalyst technology, and it should be quite plain now where the extra fuel is going.

Fig.1 shows the conversion efficiency of a three-way catalytic converter with a Lambda frequency of 0.5Hz, showing how well the system can work when the complete engine management plan comes together.

As some of this column's readers may be aware, a number of O_2 sensor testers have recently appeared on the market, purporting to interpret the sensor voltage output into the corresponding percentage of O_2 plus Lambda or AFR values. Furthermore some testers have appeared with their own sensors built into a manifold (rather than use the vehicle's own sensor), which attaches into the tailpipe.

It is important to note however, that these testers must be used in conjunction with a Gas Analyser and some form of Engine Analyser, before firm conclusions can be drawn from the readings.

Inquiries by yours truly at Robert Bosch Australia have unearthed a special purpose oxygen sensor with some interesting additional benefits. Designed especially for research, the oxygen sensor in question was built to provide the input for the Bosch LA2 Lambda Analyser.

Unfortunately I only have the information about the LA2 Lambda-Anzelge in German, so I won't reprint it here just now as my spell checker will probably have a fit. (Maybe Bill Gates will consider a translator as part of the next Word Upgrade?)

Luckily the info on the sensor itself was in English, and combining this with a range of source material from other Bosch publications and notes from some Society of Automotive Engineers seminars, I am able to present a bit more detail here.

Special sensor

The first thing that strikes you about the sensor is its four wires, rather than just one or perhaps three for a heated device. The '0 258 104 002 Oxygen Sensor' was designed principally for a wide range of test applications, with good resistance to thermal and physical shock by means of the protective metal 'thimble' covering the outer ceramic electrode.

This 'full metal jacket' casing around the tip (see Fig.2) means that exhaust-borne contaminants are less likely to damage the sensor, and brief exposure (several dyno runs) to leaded fuel should be well within its operating tolerances.

So how does it work, you ask? A small hole about 1.5mm in diameter in the end of the sensor tip allows sufficient ingress of the sample gas to ensure a rapid response (50ms at 800°C).

Given the exhaust gas speed through most automotive tailpipes under driving conditions, the reduction in size of the sampling orifice is not a significant impediment to the speed of analysis when balanced against the benefits of sensor longevity and resistance to contamination.

The output from the sensor fits the standard for all 'solid electrolyte' Zirconium Oxide (ZrO_2) type sensors, with the characteristic 'step' profile from rich to lean at the Lambda 1 point (Fig.3).

What is lambda?

At this point perhaps, I should go into more of an explanation about the meaning of Lambda (λ). Essentially it is the ratio of the *actual* air-fuel ratio divided by the *ideal* air-fuel ratio.

For example if the actual AFR was say 14.5 and the ideal for leaded fuel is 14.7:1, then the Lambda value would equal 0.986. Conversely by working the formula backwards, multiplying 14.7 by 0.8, for example, gives us the rather rich mixture composition of 11.76:1 AFR.

The only thing to bear in mind is that the ideal AFR is not the same for all fuels. CNG (compressed natural gas), for example, reaches the stoichiometric point at 16.06:1.

Sensor voltage

Before we start to get too far into the nitty gritty of what the O_2 voltage readings represent, it is as well to offer a word of caution. At the high end of the scale (0.7 - 1.0 volts) it gets increasingly difficult to be certain of the actual oxygen content in the sample gas. Although the sensor voltage keeps rising as the fuel mixture gets richer, the oxygen concentration hov-

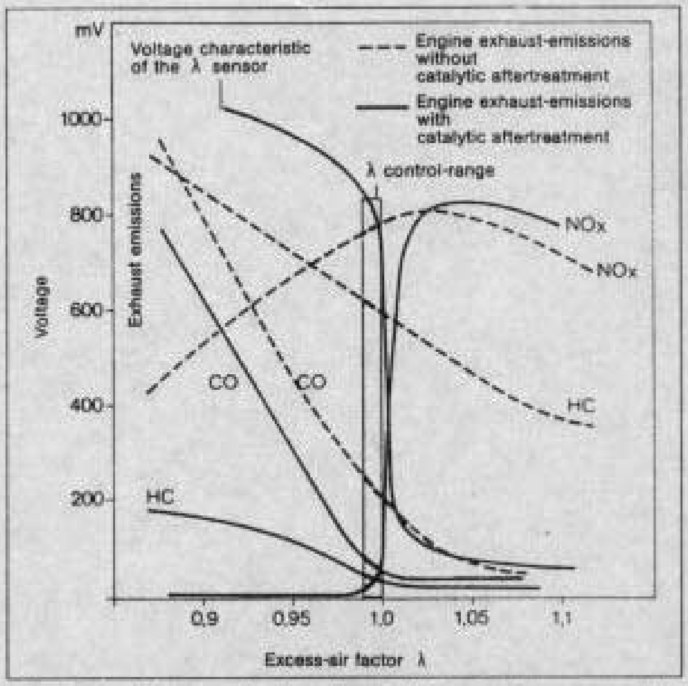

Fig.3: Significant reductions in pollution levels are possible using catalyst technology. (Courtesy Bosch Australia).

ers around the 0.2 - 0.3% mark before the catalyst.

Generally speaking, at rich mixture concentrations, the hydrocarbon content rises. This cools the sensor and has a significant effect on its output of the sensor. Despite the heating element attempting to keep it above the minimum operating temperature, variations occur that make it hard to be sure of the actual percentage (see Fig.4).

Not only that, but at the rich end of the operating spectrum for petrol engines, the exhaust oxygen concentration changes very little from excessively rich (λ<0.85) to the lean end of best power (λ=0.95). Taken in isolation therefore, the O_2 readings alone can be a bit misleading, as there are many contributing factors that come into consideration.

The more expensive exhaust gas analysers on the market today go into a great deal of software contortions to come with a meaningful Lambda and AFR figure, based on measuring more than just one gas. So that's why some discretion/experience must be used when diagnosing your car with the oxygen sensor only. Specialist vehicle repairers use expensive equipment for the very good reason that their reputation depends on it giving them the truth, the whole truth and nothing but the truth!

Having said that, there is nothing to stop you from checking that your vehicle is in a good state of tune, including an exhaust gas test (preferably with printout) on a dynamometer at your local tune-up specialist, to establish a starting point from which to 'take off and land' with your DIY diagnosis.

The voltage curve

If you look at my chart in Fig.5, you will observe the linear 'Oxygen versus Lambda' response of the sensor from Lambda 0.95 to 1.4. Out of necessity I have reduced the chart to fit the magazine; however you can see the six plot points making up the curve, and as we don't really care what happens after Lambda 1.3, I think we can ignore the rest.

The voltage output from the sensor, on the other hand, is not so obliging when it comes to nice clean linear responses. Looking at the chart in Fig.3, the characteristic stepped voltage output from Lambda 0.92 to 1.1 looks the same as other zirconium oxide sensors.

Twin sensors

I was recently made aware of a new design using one sensor before and one sensor after the catalyser, on a sophisticated system fitted to an imported exotic. Now I'm only surmising about the implications here, but it seems to me that the only explanation can be a sort of 'double check' by the ECU to see if the catalyser is functioning properly.

If the oxygen level before and after the catalyser is the same, then it is safe to assume that there was no change in the levels of CO, HC and NOx concentrations, and the ECU needs to 'relight' the catalyser. When the 'cat' is hot and functioning correctly, the excess air left over from combustion is used up within the catalyser monolith during the conversion process, leaving a close to zero level of O_2.

By monitoring the 'before and after' difference in oxygen, the ECU can more accurately control the efficiency of the conversion capability of the catalyser.

Planned project

The staff designers at *Electronics Australia* have very generously offered to describe the electronics and programming required to build your own digital oxygen sensor analyser for use with a laptop computer, based on the heated oxygen sensor from Bosch mentioned earlier (part number 0 258 104 002). Having said that, any automotive oxygen sensor will do, but the accuracy depends on the sensor being fully hot, and therefore a heated sensor is best.

An interesting feature of the project will be the ability to 'inject' an accurately known voltage level into the ECU's O_2 sensor port, to simulate rich, lean or perfect values. The advantage of this additional capability is to check the response of the ECU at the injector, and it also provides a stable setting for base adjustments.

If you already own or have access to a laptop (or desktop computer if you don't wish to test a mobile vehicle), the cost of the project will depend largely on whether you are going to use the sensor already fitted to your vehicle or take the project further and build a 'tailpipe tester' complete with manifold and clamp.

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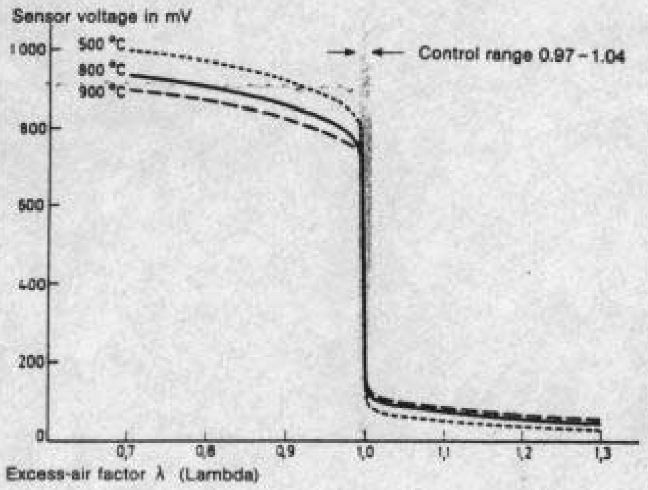

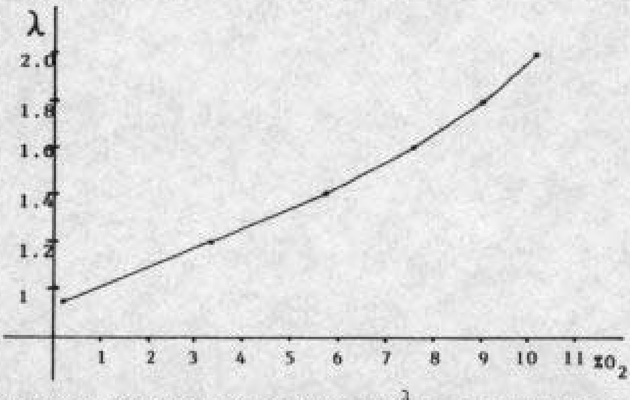

Fig.5 (above): On the 'lean' side of the oxygen sensor's output, there's an almost linear relationship between oxygen level and Lambda. Fig.4 (left): A voltage/temperature chart emphasising the error that can creep in when only one gas is measured using an unheated oxygen sensor. (Courtesy Bosch Australia).

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purpose sensor is $428.00 plus tax. But trade prices vary, so it's worth shopping around for the best deal.

Useful tool

Earlier this year I had the task of resetting the mixture and base idle settings on an Audi 2.0 with KE Jetronic — i.e., a mechanical/electronic hybrid system that uses an electro-magnetic actuator to vary the fuel pressure in response to the oxygen sensor.

Having reset the ignition timing and base idle speed 'by the book', it was just not possible, using the prescribed factory method, to achieve anything like an acceptable result for smoothness combined with low emissions. Finally, in desperation, I used my 'New Age DEFIA' to inject 0.45 volts into the ECU (after first disconnecting the oxygen sensor), and I was then able to set the correct mixture values and idle speed.

When the vehicle's own oxygen sensor was reinstated, the ECU seemed quite happy with the result and the Audi left the shop running smoothly and cleanly without the 'ramping' effect.

This procedure, of course, raises the prospect of testing the integrity of the EFI system in still more detail. When the mid point oxygen level is injected into the ECU, the resultant exhaust gas emissions should be in the stoichiometric 'window' before the catalyser.

Referring to Fig.3, it will give you an idea where the gas levels should be if the injectors and spark plugs are clean, the fuel pressure is perfect and all the relevant filtration and ignition timing is OK. From that standpoint, it shouldn't be too difficult to figure out which ingredient is causing the problems in the resultant gas mix.

Well, that's about it from me for another month. Hopefully the new *EA* O_2 Sensor Tester/Injector project won't be too far away. Cheers for now! ❖