# Understanding and tuning the Injection Pump of Land Rover Tdi Engines

## The Disclaimer:

***This article is presented for the interest of readers from information gathered from various sources including Bosch technical literature and the internet. The author makes no claims to be an expert on diesel engine tuning, nor for the accuracy of this information. The author cannot accept any responsibility for the consequences of actions taken by others using any or all of this information. Make sure you fully understand the information and accept the consequences before making any use of it.***

***There's no such thing as a free lunch - if you modify your engine to give better performance it will be working harder and components may wear out sooner than otherwise. If you get things wrong it may well 'wear out' a lot sooner…***

## The Basics

The Land Rover 200Tdi & 300Tdi engines of the late '80s to late '90s utilise the Robert Bosch VE-type diesel injection pump. Like all diesel engines, the purpose of the injection pump is to deliver a precisely-metered charge of diesel fuel to each cylinder injector, in the firing order of the engine. The Bosch VE injection pump uses a single pump plunger to produce these high-pressure fuel charges. The pump mechanism includes a distributor section to direct each successive charge to the appropriate cylinder injector, in the required order.

The actual fuel charge delivered to the injectors is proportional to the pump stroke. The effective stroke is continuously adjusted according to the throttle position and the engine speed (rpm). This function is performed by the mechanical fly-weight governor mechanism within the pump. In a naturally-aspirated diesel (or assuming the boost pressure remains constant in a turbo-charged engine), the governor will adjust the pump stroke to try to maintain a particular engine rpm at any given throttle setting. That is, unlike a carburetted petrol engine where the throttle directly alters the quantity of air/fuel mixture drawn into the cylinders, in a diesel the throttle merely adjusts the 'rpm setpoint' of the engine.

At a fixed throttle position, as the load changes (e.g. the road rises or falls slightly) the fly-weight governor will increase or decrease the fuel charge to attempt to keep the engine rpm constant, within limits of course. A bit like a very basic 'cruise control'. In practice, the engine rpm and hence the vehicle speed will vary quite a bit as the load changes, despite the best efforts of the governor. [***If you want to get technical, this is because a fly-weight governor is a 'proportional action' type of controller and will settle at a different 'steady state' point for each different load on the engine.***]

## Boost Compensation

Now, the description above stated "assuming the boost pressure remains constant in a turbo-charged engine..." Of course, it rarely remains constant for very long. For this reason, the Bosch VE injection pump used on 200Tdi and non-EDC[1] 300Tdi LR engines has a boost compensator (also called a manifold-pressure compensator or 'aneroid') to enable it to further control fuel delivery in proportion to the boost

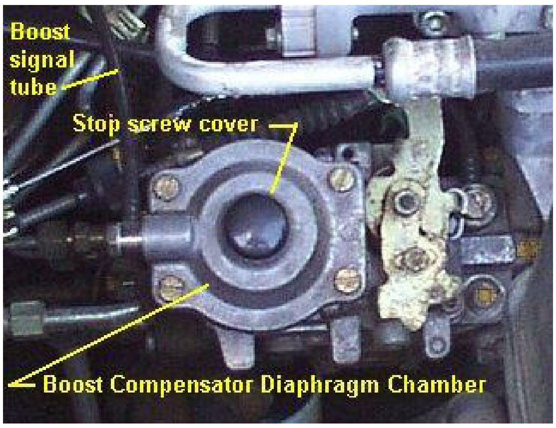



Figure 1

[1] Electronic Diesel Control, fitted to some late model 300Tdi engines

pressure at the turbo-charger air outlet. This is necessary as the mass of air in the cylinders varies greatly as the boost pressure increases from zero to full boost. At low boost pressures, the cylinder air mass is much smaller and is not sufficient to fully combust the maximum fuel charge. Therefore, the boost compensator's job is to reduce the maximum fuel charge when the boost pressure is less than maximum. A tube from the turbo air outlet to the diaphragm chamber on the top of the boost compensator transmits the pressure signal.

In order to consistently achieve low smoke emissions on every vehicle leaving the assembly line, it seems the 'standard' settings of the boost compensator are very conservative. That is, they severely restrict the fuel delivery at less than full boost in order to ensure low smoke emissions. This seems to result in the legendary off-idle sluggishness of the Tdi engines.

By carefully adjusting and optimising the boost compensator settings for a particular engine, significant improvements can be had in off-boost and low to mid-range rpm performance, without excessive smoke emissions. [***By the way, if you are making black smoke you are just wasting fuel, not making more power. The object is to have the engine just on the brink of making smoke when under full throttle, at any combination of rpm and boost pressure.***]

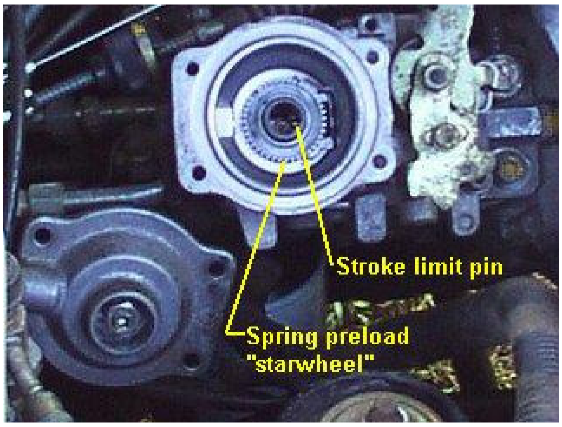



**Figure 2**

Boost compensation works by automatically adjusting the position of a pump **Stroke Limiting Pin** within the pump. This pin lies horizontally through the pump body and it's end is visible at the bottom of the boost compensator well. When in the rearward position (away from the front or drive end of the pump) the pump delivers it's 'high boost' fuel charges to the injectors, as defined by the internal design of the pump. When this pin is pushed forward, the fuel charge, for any given rpm and throttle setting, is reduced to compensate for the reduced air charge to the cylinders when the boost pressure is lower.

The stroke limiting pin is positioned by the up and down movement of an eccentric **Control Cone** attached to a diaphragm which senses boost pressure. When there is effectively no boost, such as when idling, the diaphragm/control cone is held in the fully up position by its spring and sits against the stop screw in the top cover. In this position, the limiting pin is bearing against the thickest (bottom) part of the control cone. Therefore it is pushed forward to it's most restrictive position.

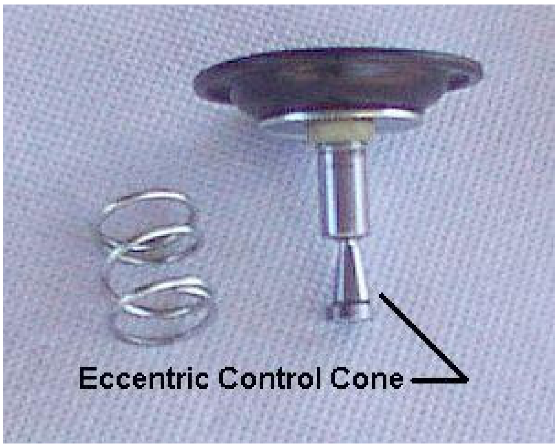



**Figure 3**

As boost pressure increases, the pressure above the diaphragm begins to overcome the spring force and the control cone is pushed downwards. The stroke limiting pin now bears against a narrower part of the control cone and is allowed to move backward slightly, allowing increased fuel delivery. Eventually, when maximum boost is achieved, the diaphragm/control cone no longer moves any further downward, the limiting pin ceases to move further rearward and fuel delivery is solely determined by the governor, with no additional restriction from the boost compensator.

## Boost Compensator Adjustments

There are three adjustments available in the VE pump boost compensator:

1. The rotational position of the eccentric **control cone** at the bottom of the diaphragm/cone assembly, adjusted by rotating the assembly. (See Fig. 3)
2. The diaphragm spring pre-load, adjusted by rotating the **'starwheel'** on the lower spring seat (See Fig. 2),
3. The diaphragm/cone rest position, adjusted using the Torx **stop screw** and locknut in the diaphragm cover (See Fig. 4).

The following sections shall examine each of these adjustments in detail and explain their effect on fuel charge delivery, with reference to the appropriate photographs and diagrams.

Mine originally 1pm now set 9am minimum

### 1. Diaphragm rotational position

1.1. As shown in Figure 3, the control cone is mounted eccentrically on the diaphragm shaft. Therefore, as the diaphragm/cone assembly is rotated through 180 °, the side of the cone which bears against the stroke limiting pin will change from the 'most forward' to the 'most rearward' This is the fundamental adjustment which determines the overall range of stroke limit pin movement.

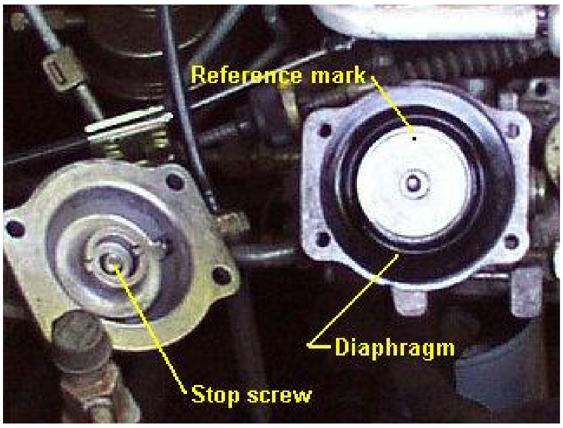



Figure 4

1.2. As shown in Figure 4, the position of the diaphragm/cone assembly is determined by the 'centre punch' reference mark near the edge of the central steel plate of the diaphragm. **It is <u>essential</u> to note the original position of this reference mark when the diaphragm cover is first removed**.

1.3. The eccentric control cone in my 300Tdi is marked "13H". Presumably there are a range of different pins available to characterise the VE pump for different engine applications. Mine 13 200tdi

1.4. For the following description, the position of the diaphragm is described in terms of degrees of rotation from the 'maximum' position. This is defined as that which orients the control cone to its 'most rearward' position. That is, the position which allows the stroke limit pin to travel most rearward. Therefore the 'maximum' position corresponds to the **maximum fuel position**. In the case of my assembly this coincided with the reference mark being at the 'twelve o'clock' position (to the top/high/tappet cover side, as shown in Figure 4 above). I do not know if this is always the case.

1.5. Also for this description, the travel of the stroke limit pin is defined as starting from the 'most rearward' position able to be achieved (maximum fuel position). That is, 0.0mm of travel is achieved when the diaphragm is positioned so that the control cone is 'most rearward' and the diaphragm is in the fully depressed position. The pin travel may be thought of as 'millimetres of restriction', when 0.0mm means zero restriction of fuel delivery.

1.6. The chart, Figure 5, shows the approximate relationships between the diaphragm rotational position and it's effect on stroke limit pin position. [***The dimensions listed are approximations to the nearest millimetre from measurements taken from my 13H assembly and should not be taken as precise nor completely accurate.***]

1.7. The diaphragm/control cone assembly has a total vertical travel of about 10.0mm. At the bottom of the effective travel, it's diameter where the stroke limit pin bears is about 9.0mm. At the top of effective travel it's diameter is about 5.0mm. It is mounted about 1.0mm off-centre.

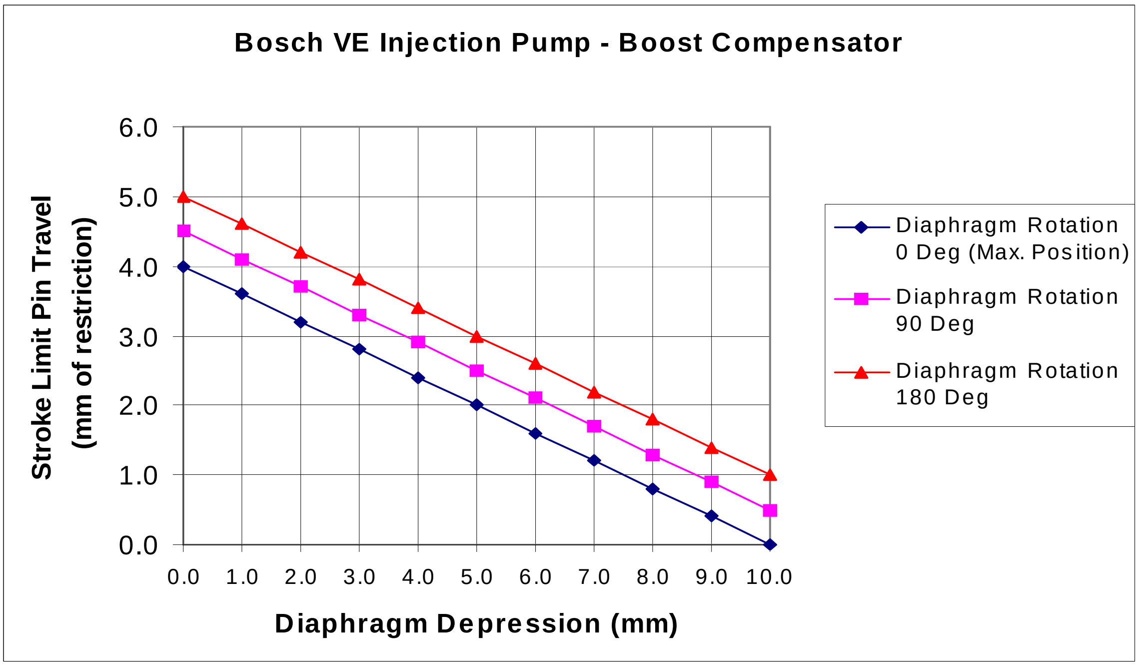



**Figure 5**

Therefore, as shown in Figure 5, the stroke limit pin will move about 4.0mm as the diaphragm/control cone moves downward over it's 10.0mm of travel. This 4.0mm of travel may be varied from the '0.0 to 4.0mm' range to the '1.0 to 5.0mm' range by rotating the diaphragm up to 180 degrees from the 'maximum' position. As the diaphragm/control cone is symmetrical, it doesn't matter which way it is rotated from the 'maximum' position. Also note that 180 degrees of rotation (½ turn) represents the full range of adjustment available.

## 2. Diaphragm Spring Pre-Load

2.1. Figure 2 shows the 'starwheel' which adjusts the spring pre-load. My spring, marked "7 712", appears to be a linear coil spring. Therefore I have assumed a linear relationship between boost pressure on the diaphragm and diaphragm/control cone depression, shown in Figure 6.

2.2. To simplify the chart, I have also assumed the maximum boost is exactly 1.0 bar and that there is some spring pre-load position which results in exactly 10mm of depression at 1.0 bar.

Again, the intention is not to present absolutely accurate measurements, rather to indicate the relationship between the adjustments and the behaviour of the boost compensator.

2.3. The 'starwheel' is the lower mount for the spring and has a right-hand thread. Turning it clockwise (CW) lowers the spring mount and reduces pre-load. Turning it counter-clockwise (CCW) increases pre-load. It is held in the set position by two spring-loaded 'fingers' which engage the 'teeth' on the outer edge at about the 1 o'clock and 5 o'clock positions. To adjust the 'starwheel', the fingers need to be held away from the wheel with, say, two small screwdrivers. **Again, it is <u>essential</u> to note the original position of the 'starwheel' before any adjustments are made.** The 'starwheel' should be marked with scribe mark or permanent marker at the 12 o'clock position so that any adjustments can be referenced to the original position.

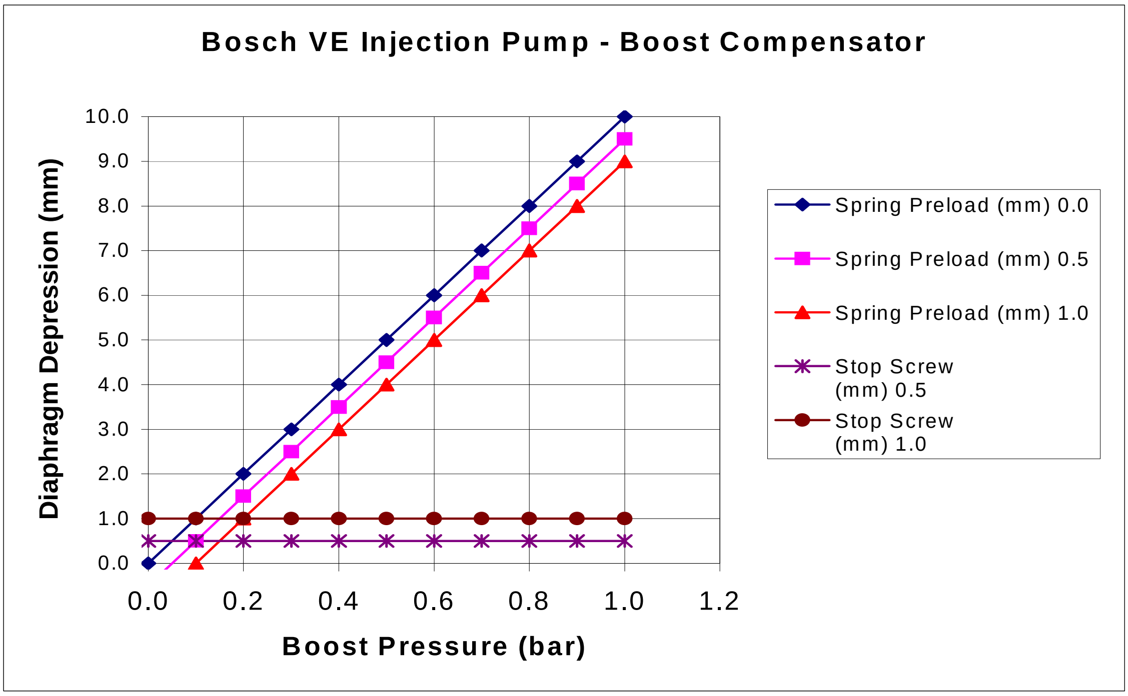


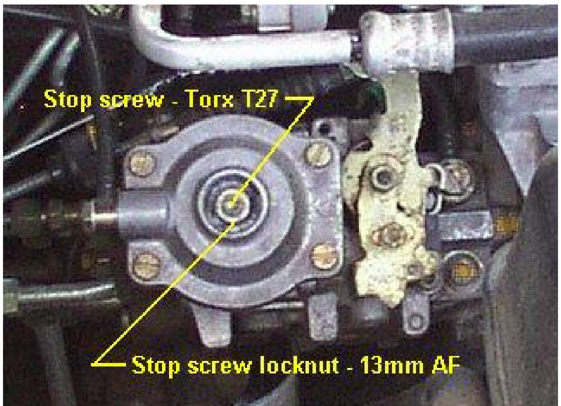

**Figure 6**

2.4. Figure 6 shows the pre-load in millimetres. I have not measured the pitch of the 'starwheel' thread to relate turns with millimetres of vertical travel of the spring mount. Again however, the object is to show the effect of increasing/decreasing pre-load on fuel delivery. As shown in Figure 6, increasing pre-load means a higher boost pressure will be needed to depress the diaphragm to a certain point and hence to allow the stroke limit pin to move rearward to a particular point. Conversely for reducing pre-load.

4.58mm of thread exposed above star wheel not adjusted as no turbo fitted at present

## 3. Diaphragm rest position

3.1. Figure 7 shows the stop screw with Torx 27 head and locknut. The action of the stop screw is also shown in Figure 6. It sets a minimum diaphragm depression regardless of boost pressure (or the lack thereof). In conjunction with the other adjustments, it sets the fuel delivery limit when there is no boost, such as when first moving off from rest at low rpm.




Stop screw had 2.11mm thread above locknut now 2.66mm

3.2. The stop screw is accessed by removing the light steel cap pressed into the recess on top of the diaphragm cover. This can be removed by carefully prising it out with a rocking motion, using two fine screw shows the original cap replaced with a 22mm chair leg plug, after adjustment. This improves waterproofing.

3.3. **Yet again, it is essential to carefully record any movements of the stop screw, in terms of turns (or fractions of turns) clockwise (CW) or counter-clockwise (CCW), from the original position**. This will allow you to return to the original settings at any time if you require. It is possible to file a small notch in the screw.

## 4. Doing the adjustments

There are two (at least?) ways to approach the 'tuning' process. The 'conventional' approach is to start with simple stop screw adjustments and work inward towards the more complex adjustments. I believe a better method is to start from the most fundamental adjustment, the diaphragm position, and then progressively refine the tuning with the finer adjustments. However, I will present the tuning process in two stages to encompass the advantages of both approaches.

### Adjustments Stage 1

An immediate and noticeable improvement in off-idle pick-up can be had by adjusting only the stop screw. If not confident about delving further into the innards of the boost compensator, this is a good place to start. You will need a T-27 Torx bit and a 13mm socket. Amongst other sources, Torx bits can be purchased in fairly cheap sets from Dick Smith Electronics.

After removing the screw cap, just 'crack' the locknut loose, taking care to avoid moving the Torx screw (see Figure 7). If not corroded, the locknut should turn freely without disturbing the screw. If so, loosen the locknut about one turn. Now, taking careful note of the amount of movement, turn the Torx screw inwards (CW) 1½ turns. Carefully re-tighten the locknut. The diaphragm cover is light die-cast alloy – do not over-tighten any nuts/screws.

Now take it for a drive. If your engine was 'factory standard' to begin with, this should have a noticeable effect on off-idle and low boost (<1800 rpm) driveability. If it also results in unacceptable black smoke, re-adjust the screw a little back towards the original setting (***Don't forget to record each setting (in terms of turns or fractions of turns) from the original position***.) Once happy with the results, either replace the original metal cap or fit a substitute cap as mentioned above.

### Adjustments Stage 2

If confident about the results of stage 1 and ready to progress further, firstly return the stop screw to its original position. This is so that the subsequent adjustments can be evaluated individually without interference from this initial adjustment.

For this stage you need to find an appropriate 'test hill' – somewhere, preferably in a 100/110 km/h zone where you can maintain full throttle in a high gear for a good distance, ideally more than a kilometre.

From this point on it would also be advisable to have an Exhaust Gas Temperature (EGT) indicator (also known a Pyrometer) fitted to monitor for dangerously high EGT conditions. An EGT of 720 °C has been recommended as the maximum safe temperature for typical modern turbo-diesel engines. My understanding is that an EGT of more than 720 °C for an extended period of time will begin irreversible deterioration of the turbo-charger metal structure, especially the turbine housing, exhaust turbine blades and wastegate valve & seat.

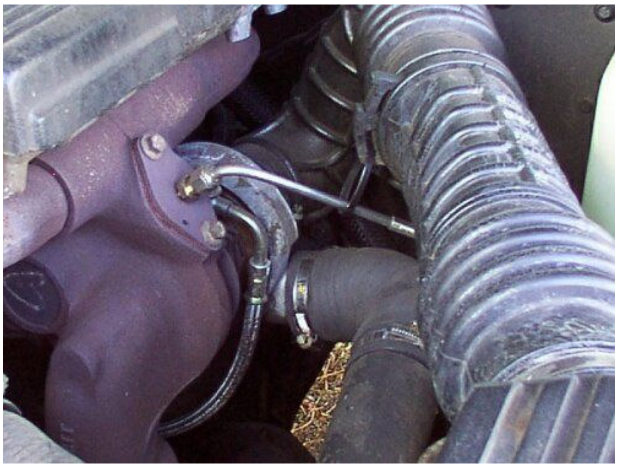


**Figure 8 - EGT Thermocouple**

Also, before beginning the adjustments, it is advisable to do a 'base line' run, using the original 'factory' settings. To do so, run up the test hill at full throttle and >2500rpm, to establish the level of black smoke (if any) and, if possible, record the maximum EGT. Also desirable is an observer to monitor smoke levels while the driver concentrates on driving…

To proceed, then:

**Stage 2A**: Remove the four slotted pan-head screws securing the diaphragm top cover and lift off the cover (see Figure 4). Take care not to kink or damage the boost pressure signal tube. Next, **locate and record the position of the diaphragm reference mark** in terms of (approx.) degrees CW or CCW from the 12 o'clock (top) position. For example, my original position was about 100° CCW (or between 8 and 9 o'clock, if you prefer).

Now, rotate the diaphragm in either direction until it 'pops' up and then withdraw the diaphragm/control cone from the well (see Figure 3). Take care that the spring does not fall out. You should now be able to see the 'starwheel' and perhaps the end of the stroke limit pin in the bottom of the well (see Figure 2). If the stroke limit pin is not visible, operate the throttle lever by hand and the pin should be pushed back into the well. Release the throttle lever and carefully push the stroke limit pin forward with a small screwdriver, to allow the control cone to be returned later.

Next, examine the assembly and work out where the reference mark is when the control cone is in the most rearward position (relative to the front/drive end of the pump). In my case the reference mark is at 12 o'clock when the control cone is rearward. Wherever the mark is for your diaphragm, record this as your "maximum" position – the position which will give maximum fuel delivery for any given level of diaphragm depression. And this is as good a place to start as any.

Return the assembly to the well, ensuring the spring is correctly seated, and rotate to reference mark to the "maximum" position. ***Do not make any other adjustments at this time***.

Now take a drive up the test hill at full throttle and check the smoke level once full boost is achieved (say, above 2500 rpm). Do not be too concerned about smoke emissions at no boost/low boost engine speeds (under 2500 rpm) at this point.

If the black smoke is unacceptable (or EGT rises quickly to the danger zone), readjust the diaphragm position. As mentioned earlier, if starting from the "maximum" position it doesn't matter which way the diaphragm is rotated. 30° increments (1 o'clock, 2 o'clock etc.) should give noticeable changes. Continue adjustments and test runs until the results are satisfactory (***and don't forget to record the final setting!)***.

**Stage 2B:** Once happy with the full boost performance and smoke emissions, next evaluate the emissions as boost is increasing (typically between 1500 and 2500 rpm at full throttle in a manual transmission vehicle). If excessively smoky, an <u>increase</u> in spring pre-load is indicated. This will delay the depression of the diaphragm (and hence increased fuel delivery) until the boost builds to a slightly higher level, reducing excessive smoke. Conversely, if little or no smoke is being generated during full throttle acceleration through this rpm range, a decrease in spring pre-load will add a little more fuel in this range. Adjustments of spring pre-load in 90° (¼ turn) increments should give noticeable changes. Record the final setting once satisfied with the results.

**Stage 2C:** Finally, adjust the stop screw to give acceptable off-boost performance and smoke emission (and record it!). This is probably best achieved by repeatedly starting-off from standstill. To obtain the best 'launch' performance, it may be necessary to tolerate some smoke emission just off idle or if the engine is ever 'lugged' along, below 1500 rpm.

## Adjustments Stage 3

No mention has yet been made of another commonly mentioned adjustment – that of the maximum fuel delivery screw and locknut on the rear of the pump. This adjustment may involve physical defeat of an anti-tamper device. Also, small adjustments of this screw (only ¼ turn) can cause dramatic increases in maximum EGT. Adjustments of the maximum delivery screw should be made with extreme caution and only with an EGT gauge installed.

I have experimented with maximum delivery screw adjustments but, as my vehicle already produces a slight black smoke haze at full throttle/full boost and will generate maximum acceptable EGT levels after a relatively short period under full throttle/heavy load conditions, I feel there is little potential for useful further improvement by increasing the maximum fuel delivery, with the current amount of air available to the engine. It has been returned to the original position.

Many other articles on this subject talk about improving the intercooling capacity by either piping in additional intercoolers and/or upgrading the original intercooler with a higher capacity core, etc. These measures and/or increasing the maximum boost pressure by adjusting the wastegate setting are all aimed at increasing the maximum air mass charged into the cylinders. If you do this then, yes, it now becomes possible to combust more fuel and adjustment of the max. delivery screw may be justified. However, beware! - there's only so much you can get out of 2.5 litres and expect it to give a long service life…


**Figure 9 - EGT Digital Indicator**

If such additional mods are planned my recommendation would be to perform the boost compensator optimization with the 'standard' intercooler/boost pressure configuration first, then re-tune after each additional change. That is, after fitting an upgraded or extra intercooler or increasing boost pressure. If the max. fuel delivery screw is to be adjusted, I would do this first, achieving acceptable smoke/EGT at full throttle/heavy load, before re-tuning the boost compensator.

## The end bit

The author welcomes any feedback on this article and/or references to reliable sources of technical information on the Bosch VE pump. Please send any comments/information to ian@thermoguard.com.au . Digital EGT gauges, with maximum temperature recording, can be obtained from ***ThermoGuard Instruments*** [ www.thermoguard.com.au ].

Hope this information is found useful.

Ian Petersen
***ThermoGuard Instruments***

Revision Notes:

| Revision | Date | Description |
|---|---|---|
| 0 | Jan 2003 | Original Issue. |
| 1 | May 2003 | Some terminology changed to match Robert Bosch Technical Instructions. |
| 2 | Jul 2004 | Minor revisions to improve clarity |