Electronic engine control:

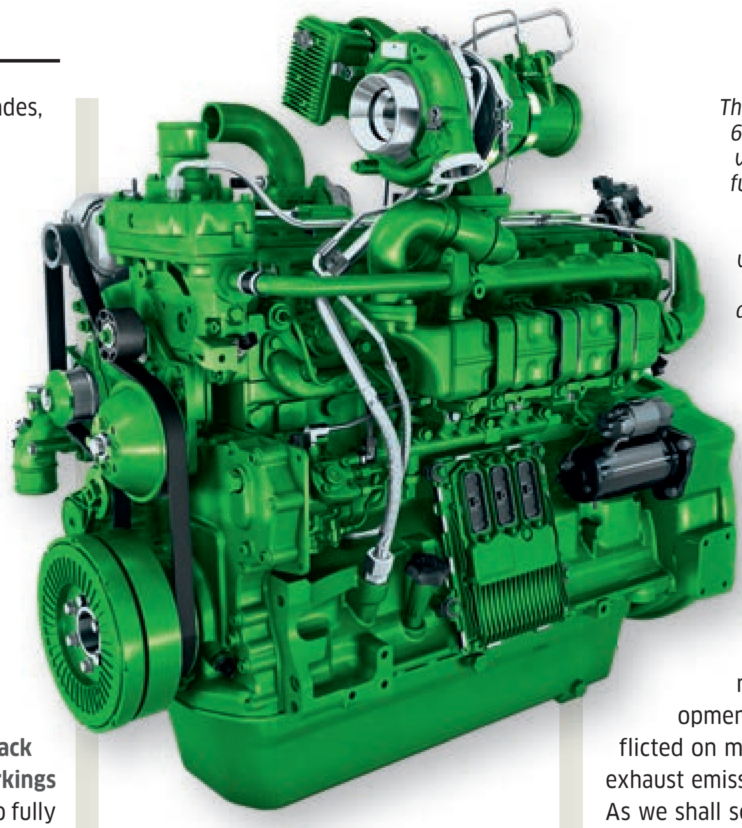
The brains behind engine operation

High-tech electronic control systems play a major part in the operation of today's diesel power plants. Where engine adjustments were once made using spanners, screwdrivers and no small degree of guesswork, modern motors now rely on sensors and computers. We take a look at the role of the ECU – the engine control unit

Andy Collings

Over the past couple of decades, the design of diesel engines has been subjected to dramatic change – not so much as to how an engine works, but more in the way its main components are controlled and fine-tuned to maximise power, fuel economy and comply with ever tighter emission regulations.

And while most of us can get our heads around the advantages offered by common rail fuel injection systems, turbochargers and electronic cooling fans, there remains a host of inter-reactive control systems that help these components and many more to achieve greater levels of efficiency.



The engine used in the John Deere 6R tractor range employs a four-valve high pressure common rail fuel injection system which operates at 2,000 bar pressure and works in conjunction with a variable geometry turbocharger designed to provide the correct amount of boost. NOx emissions are reduced by the engine's Exhaust Gas Recirculation system.

But to start with, a very brief look back to remind ourselves of the inner workings of a diesel engine if only to be able to fully appreciate and understand how the use of electronic management has helped to achieve the performance levels we now expect from modern motors.

The diesel engine is a compression ignition engine that uses pistons to compress air in the cylinders to raise the temperature of the air to the point where it can ignite the diesel fuel injected into the top of the cylinder. A typical compression ratio would be somewhere between 15:1 and 22:1 and this would result in a cylinder head pre-ignition pressure of about 40 bar and an air temperature of 550°C. When turbocharged, cylinder pressure can be as high as 150 bar and the temperature generated can climb to 900°C – significantly higher than the ignition point of diesel, about 250°C.

Getting the fuel into the cylinder at the correct time and in the required volume was to prove to be a taxing problem with early diesel engines which, after several different designs, settled on a mechanically driven in-line pump that employed a series of small high pressure pumps to deliver measured amounts of fuel to the cylinders.

It is fair to say that the diesel engines in the early years were heavy, slow running, noisy and perhaps only slightly cleaner to operate than a coal-fired steam engine, but when compared to old gasoline engines they were vastly more efficient and, when running, probably more reliable.

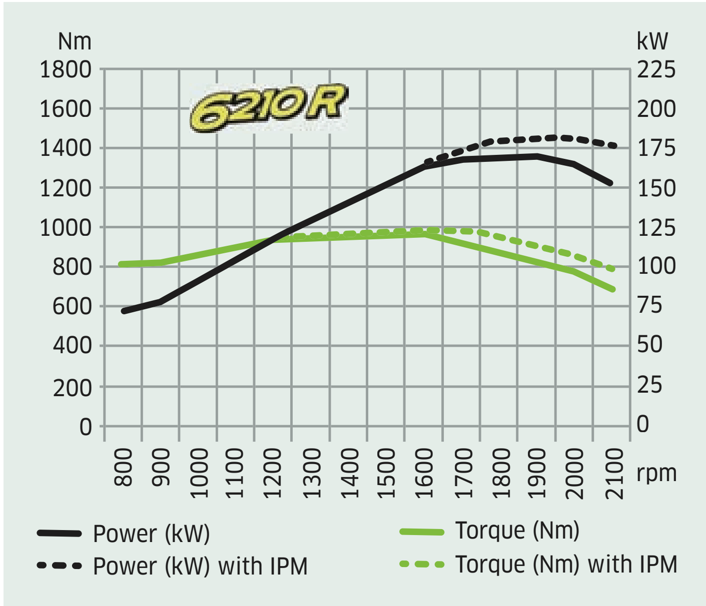
There was, however, plenty of room for improvement and, with the introduction of common rail fuel injection, turbochargers and intercoolers, fuel efficiency improved along with an increase in torque output. But one of the biggest drivers in modern diesel engine development has been the demands inflicted on manufacturers by mandatory exhaust emission reduction requirements. As we shall see, designing an engine that complies with these stringent requirements has meant even greater demands also being placed on electronic engine management systems.

At the heart of the electronic management system is the engine control unit (ECU), which is in effect a pre-programmed computer (the buzz word is 'mapped') having the ability to react to operational changes within the engine in terms of fuel injection, temperatures, cylinder pressures and so on – the whole package. The unit, which needs to be sufficiently robust to provide the required reliability while working in what can be hostile conditions, receives its info from sensors placed within the engine.

First, then, a look at how electronic engine

management scores with common rail fuel injection, and what is required of it. For starters there needs to be a system to monitor and maintain the pressure in the fuel reservoir, which is the common rail where fuel pressures can be as high as 2,000 bar. A sensor monitors fuel pressure and feeds information back to the ECU, which then activates the high pressure pump to maintain the pre-set pressure.
Injectors are opened and closed by either solenoid-activated valves or by the increasingly popular piezo-operated valves that are used by the very latest diesel engines. Anyone who has owned a gas lighter that ignites when a lever is squeezed will have drawn on the effect caused when certain crystal material is compressed to produce electricity – piezoelectric. Reverse the effect and add electricity to the crystal and it rapidly expands albeit by a small amount. However, with sufficient crystal slices stacked together the movement is sufficient to open the injector valve and shut the instant the electricity flow is shut off – a much faster opening and shutting cycle that allows accurate and numerous injection pulses to take place.
It should be noted that the timing of fuel injection has a big effect on emission levels and fuel consumption. If the fuel is injected when the piston is still rising, efficiency is reduced and extra fuel is used; and if injection is too late, torque is reduced and there will be extra emissions caused by incomplete combustion.
One of the key tasks for the ECU, then, is to provide a sequence of timed fuel injections rather than just the one injection for each combustion cycle. There are normally three different modes, though this can vary with engine design, with the trend now towards fewer rather than a greater number of fuel injections.
The first is pre-injection, a short pulse of fuel that has two effects: it reduces combustion noise and it also reduces NOx emissions. This is followed by the main injection during which the bulk of the fuel is delivered. The final phase, the post-injection reduces soot emissions. Using huge injection pressure means the fuel is atomised and, as a result, can have access to a greater volume of oxygen in a smaller period of time.

PowerTech PVX engine performance, John Deere 6210R



The ECU works to create the best possible delivery of power. John Deere calls it Intelligent Power Management. Graph: John Deere.

Engine lingo explained

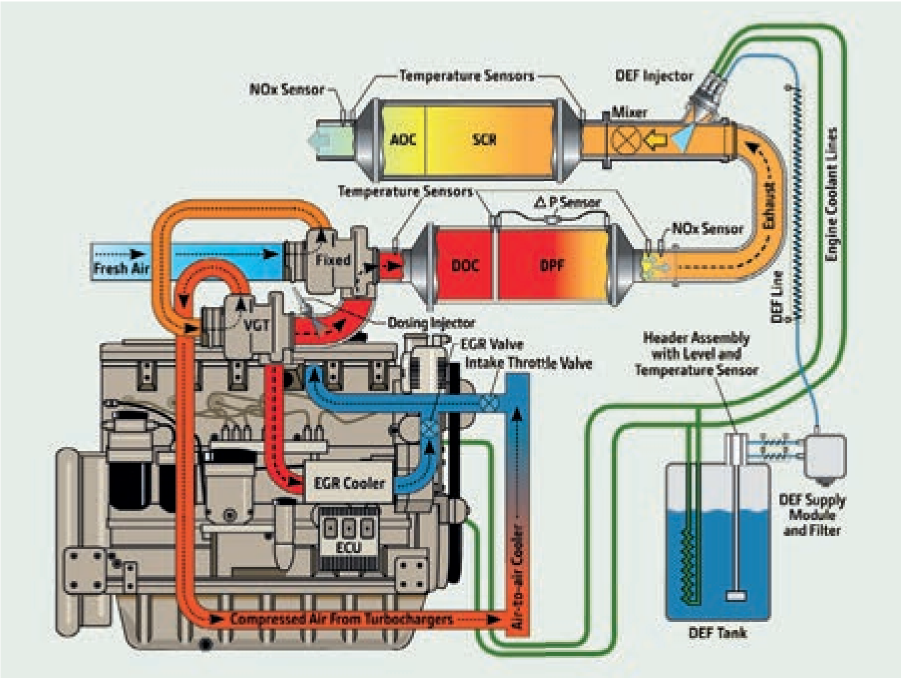
ECU: Engine Control Unit
HPCR: High Pressure Common Rail
VGT: Variable Geometry Turbocharger
EGR: Exhaust Gas Recirculation
DOC: Diesel Oxidation Catalyst
DPF: Diesel Particulate Filter
SCR: Selective Catalytic Reduction
DEF: Diesel Exhaust Fluid
AOC: Ammonia Oxidation Catalyst

Those impressed by precision will need to know that fuel amounts can be as low as just one cubic millimetre for pre-injection rising to 50 cubic millimetres for the main injection phase – and the duration of an injection is normally 1-2 milliseconds. The key aim is to get the fuel and air together as fast as possible.
Clearly, it's a tough job being a fuel injector and it has been estimated that during its working life it will have opened and closed over a billion times.

All of which is pretty heady stuff but the ECU has a lot more to contend with when it comes to calculating how fuel is used – it has to 'know' the engine speed, crankshaft position, the boost pressure, engine coolant temperature and oxygen levels which vary with operating altitude and ambient temperature. Provided by sensors, this information is utilised by the ECU to compute fuel injection timings and duration so that engine efficiency is maximised.

One of the latest engines to be developed by Deutz is this 12.8-litre, six-cylinder motor, which is turbocharged, intercooled and uses EGR with SCR exhaust after-treatment to achieve Stage IV emission control. Electronic engine management not only results in more efficient power delivery but also reduced fuel consumption, says Deutz.

PowerTech PSS Final Tier 4 technology



Stage IV – Deere's Integrated Emissions Control system, which draws heavily on the ECU, comprises cooled exhaust gas recirculation, an exhaust filter with diesel oxidation catalyst (DOC) and diesel particulate filter (DPF), and then a selective catalytic reduction (SCR) canister and an ammonia oxidation catalyst (AOC). Urea is injected into the exhaust stream to reduce NOx. Note the high number of sensors that feed information back to the ECU.

A point to note with diesel fuel systems is that while we still tend to call the 'go-faster' pedal/lever the throttle, it has no direct control over the quantity of fuel injected; its movement is now considered to be a request for more or less torque which, when selected, will be maintained by the ECU through automatic changes in fuel quantity made as loads change.

The demand for more power is not answered simply by increasing the amount of fuel injected (up to the 'smoke limit') but also by increasing the volume of air produced by the turbocharger which, by definition, has a response time slower than the injectors. To reduce excessive fuel being fed to the engine and an inappropriate air/fuel ration being created, the ECU provides a fuel increase at a rate that allows the turbo time to spool up sufficiently.

With the engine running it's time for the tractor to do some work. When using a basic mechanical gearbox it is the operator who makes decisions regarding gear selection, whereas a stepless transmission opens up new opportunities of optimising fuel efficiency with ratio selection and sustaining engine speed for pto operation.

One conundrum is that best efficiency and best power never occur at the same point. The best fuel efficiency will normally not be at near-maximum torque 'wide open throttle', but at some intermediate engine speed – typically somewhere around half maximum engine speed; this is because frictional losses increase significantly with engine speed. Maximum power will nearly always be at the highest engine speed, but with a fuel economy that is perhaps around 25% worse.

ECU and emission control

It's time to turn our attentions to exhaust emissions and the important part the ECU plays in ensuring emissions are suitably controlled – not that designers haven't already made big strides in this department through the way fuel is delivered to and combusted in the cylinders, the design of the combustion chamber, tiny fuel droplets, four valves/cylinder and, as we've noted, accurate engine speed control, measured fuel, timing, high injection pressure, temperature and air/fuel ratio sensing, all of which help to decrease NOx and hydrocarbons.

But with demands now as low as they are, designers have had to look for other systems to help reduce particulates and NOx emissions and meet required standards. And this has imposed further duties on to the hard-working ECU.

Exhaust gas recirculation (EGR) allows a proportion of the exhaust gas to be mixed with the intake air, an action that reduces NOx emissions by lowering the concentration of oxygen in the combustion chamber. This, in turn, reduces the peak temperatures during combustion, which largely determines the NOx levels.

For those who may struggle to understand the effect of EGR, the easy way is to consider an 'opposite' – oxy-acetylene welding and cutting where, to increase combustion temperatures, all the nitrogen from the air has been removed so that the fuel/oxygen reaction doesn't have so much 'dead' gas to heat up. In the case of EGR, a greater quantity of dead gas, nitrogen and carbon dioxide is allowed to dilute the inlet air.

The ECU is not just about emission control; it also has a host of other duties to perform in and around the tractor – accelerator pedal, engine speed, transmission, temperatures, fan control, cruise control, speed limiting, hydraulic control, pto speeds... The list is long, and it's fair to say that there are few elements within a modern tractor that are not now monitored by the ECU.

Power output from the new Perkins 854F-E34TA engine has been boosted to 121hp through the use of a single stage turbo and wastegate. The four-cylinder 3.4-litre engine uses SCR, and there is a dependence on the ability of the 1,800 bar common rail and four-valve cylinder head design to improve combustion and reduce particulate formation so that a DPF filter is not required.

To control the system there is an EGR valve that is electronically operated. When the engine is idling, the valve is closed to prevent any exhaust gas flow into the manifold, but, when the engine is warm and operating under load, the valve is opened and allows exhaust gas into the intake manifold – the actual volume controlled by the ECU in respect of changing engine loads.

When peak torque is required, the EGR loop is closed, since power from the engine is ultimately limited by the quantity of oxygen available. But at other conditions, EGR reduces NOx, up to a limit at which excessive soot is produced.

Now in common use are Diesel Particulate Filters (DPF) which, made from porous ceramic materials, filter out particulates from exhaust gases. These filters are very efficient and operate at all temperatures, from cold start to maximum power. Some types take advantage of the fact that NO_2 can oxidise soot at low temperatures (250°C) – the 'continuously regenerative trap'.

For most systems, however, soot gradually builds to a point that pressure sensors on the inlet and outlet indicate a soot quantity that should be removed, and the ECU then instigates a regeneration process. This requires a temperature of 600°C, which can be created by adding a fuel injection pulse late in the cylinders' working stroke, resulting in a very hot exhaust gas.

NOx control by after-treatment is becoming necessary, and there are many different systems coming to market. They can be spilt into 'batch' and 'continuous'. The former consist of chemical NOx traps that have to be occasionally regenerated by exposing them to 'rich' components – typically fuel injected into the cylinder at the start of the exhaust stroke, which would be impossible with older mechanical injection systems.

The latter is usually called Selective Catalytic Reduction (SCR), which relies on a Diesel Exhaust Fluid (DEF) urea solution, better known as AdBlue. These set-ups are increasingly employed by tractor engines as a means of reducing NOx emissions. The additive is metered into the exhaust at a rate set by the ECU and is thermally converted to ammonia, which reacts with NOx in the presence of a catalyst to form nitrogen and oxygen.

There is further work for the ECU when it comes to diagnosing engine faults – faults flagged up if a sensor reading is deemed to be too low or too high for its given monitoring task. For more technical diagnosis, dealer mechanics are now issued with computers that can be plugged into ECU units to help with the identification of engine faults, and there is a trend towards remote diagnostics, which allow modern engines to be monitored from afar.

Summary: The ECU has a busy time, and it's reasonable to assume that without it the modern diesel engine would struggle to start and operate with any degree of efficiency or, in respect of emission compliance, legally. Over the years the reliability of ECUs has increased to the point now that they have become an accepted, if not totally understood, component of a modern tractor.