

Emissions

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Abstract

Automotive emissions are a growing concern as the number of cars on the road increases. More pressure is being put on motorsport teams and manufacturers to keep reducing their vehicles' emissions. In this assignment, automotive emissions were researched along with emission control systems and the relevant legislation. Euro standards have been discussed and the upcoming Euro VII standards predicted in terms of the general direction. Two engines were also tested, and discussed in terms of the modifications required to bring them up to Euro VI and VII standards.

Contents

1. Introduction	3
2. Research	4
3. Methodology	9
4. Results	10
5. Analysis	11
6. Conclusion	14
7. Bibliography	15
8. Appendices	19

1. Introduction

Emissions have been a major concern within the automotive industry since the 1950s (Melosi, N.D.) and various ways have been employed to tackle them. Governments around the world have implemented legislation to ensure that manufacturers are working towards reducing the emissions produced by their vehicles. Motorsport governing bodies, more recently, have also been changing and adapting regulations to improve the emission standards, as this has been largely ignored for a long time due to the low number of competition vehicles in use.

In this report, emission legislation and regulations will be discussed, and emission control systems will be researched and explained. Particular focus will be placed upon emission regulations in motorsport and how these affect the performance of competition vehicles. Emission control systems will also be tested for operation using appropriate methods.

The aims of the assignment are to review various emission control systems and their effectiveness as well as discuss how these are affected by legislation and motorsport regulations. Manufacturers' and race teams' different approaches towards emission reduction will also be discussed.

2. Research

2.1 Automotive Emissions and Pollution

The automotive industry significantly affects the environment in many ways. Although this report focuses primarily on emissions produced during a vehicle's exploitation by the consumer, the overall impacts will also be discussed. The entire product life should be considered when evaluating the environmental impacts within any industry, and often the production and end of life stages are not mentioned in detail for automotive applications. As an example, there are currently many debates around the true environmental impact of hybrid and electric vehicles, due to the complexity in producing and recycling batteries. Amongst others, this is discussed by Hanley, 2018, however the author seems to have a level of bias towards electric vehicles and a somewhat political background to the article.

Foster (N.D. Cited in Melosi, N.D.) estimated that "one-third of the total environmental damage caused by automobiles occurred before they were sold and driven". However according to a National Geographic article (Car Buying Guide, N.D.) "most of an automobile's environmental impact, perhaps 80 to 90 percent, will be due to fuel consumption and emissions of air pollution and greenhouse gases". Therefore, it is difficult to establish the true extent of manufacturing emissions, but they mainly involve the energy used to extract and process materials, as well as transportation.

Recycling and servicing/maintenance are quite similar environmental problems. Again, they involve energy needed for processing and transportation, but they also cause soil and water pollution. "Plastics, toxic battery acids and other products may stay in the environment" but around three-quarters of a modern car can be recycled (Car Buying Guide, N.D.). Component wear, such as tyre particles and brake dust, also contributes to soil and/or water contamination.

Noise pollution from cars affects 30% of people in the UK according to Environmental Protection UK (N.D.) – "Sources include engine noise, tyre noise, car horns, car stereos, door slamming, and squeaking brakes".

Exhaust gas emissions are most often discussed and tackled from all of the different types. The combustion process is an exothermic reaction which should theoretically produce carbon dioxide and water only (De Leon, 2001). However, it is not a perfect process due to incomplete combustion and the complexity of the atmospheric air mixture. There are additional reactions and products formed, including carbon monoxide, sulphur dioxide, nitrogen oxides, nitrous oxide, volatile organic compounds (VOC), hydrocarbons (HC) and particulate matter (PM) (Pisupati, N.D.).

Carbon dioxide is also a product of fermentation and respiration, and can be recaptured from the atmosphere by plants, through photosynthesis. It contributes to the greenhouse effect as it traps radiant energy within the atmosphere. (Encyclopaedia Britannica, 1998)

Carbon monoxide is a product formed due to incomplete combustion and is a colourless and odourless gas. It is a concern for emissions as it is toxic at low concentrations. CO poisoning

can be lethal due to its strong attraction to iron found within the red blood cells. (Thompson, 2005)

Most of the global nitrous oxide comes from natural sources within the earth's nitrogen cycle, but some is also produced in internal combustion engines due to the nitrogen content in atmospheric air. It is a greenhouse gas which has a significantly higher effect than carbon dioxide. (EPA, N.D.)

Ammonia emissions are mainly due to agricultural activity – according to the EEA (2014) “agriculture was responsible for 94% of NH₃ emissions in 2011”. Ammonia is a secondary pollutant, as it is formed by a reaction between nitric oxide (NO), carbon monoxide, and hydrogen which is formed by a reaction between the carbon monoxide and water produced. It is a reactive compound, which can produce suspended particulate matter through reactions with other compounds in the atmosphere. (Borsari; Vicente De Assunção, 2017)

Volatile organic compounds are carbon-based compounds which can cause irritation, headaches, nausea and dizziness as well as damage to the liver, kidneys and nervous system and cancer, according to Envirovent (2016). They are linked to hydrocarbon emissions as they are contained within fuels.

Hydrocarbons are another concern for automotive emissions. A report by Abha and Singh states:

Petroleum hydrocarbon molecules, which have a wide distribution of molecular weights and boiling points, cause diverse levels of toxicity to the environment. The toxicity of the hydrocarbon molecules and their availability for microbial metabolism depend on their chemical and physical nature. Petroleum is toxic and can be lethal depending upon the nature of the petroleum fraction, the way of exposure to it, and the time of exposure. (Abha; Singh, 2012)

Hydrocarbons are emitted through incomplete combustion and venting systems (as evaporative emissions).

Sulphur dioxide is a pollutant heavily affecting urban areas and is linked to acid rain. It is produced by the combustion of sulphur containing fuels. Sulphur dioxide causes health problems in the respiratory system, particularly affecting asthmatics. It also has extremely negative effects on terrestrial and aquatic ecosystems, in the form of acid rain. (Larssen; Hagen, 1996)

The term NO_x refers to nitric oxide and nitrogen dioxide. These are formed by the oxidation of atmospheric nitrogen at high temperatures. Although nitric oxide is not a health concern, it can further react with oxygen to form more nitrogen dioxide, which is an irritant gas. It causes respiratory systems as well as being linked to the formation of particulate matter and ground level ozone. (BMI Group, N.D.)

Particulate matter can be any solids or liquids suspended in the air between a few nanometres and up to 100 micrometres in size. Within the automotive industry, particulate matter is mainly formed of elemental carbon and trace metals (from fuel additives and component wear). Particulate matter causes respiratory and cardiovascular conditions at both short and long-term exposure. It can also be lethal. (AQEG, 2005)

2.2 Emission Legislation

Over decades, legislation regarding automotive emissions has been changing and developing globally. The state of California was the first to implement emission regulations back in 1961 when the smog problem in Los Angeles was a growing health concern (Bryner; Hankins, 2018). The rest of the United States followed in 1970, when congress passed the Clean Air Act and the Environmental Protection Agency was set up (EPA, N.D.).

In Europe, research had already begun in 1956, and the first legislation put into place in 1970 (Smith; Davies, 1996). 'Euro' emission standards for new cars were first introduced in 1992 and were always designed to become stricter with time (RAC, 2018). The Euro standards set out limits for carbon monoxide, hydrocarbons, oxides of nitrogen and particulate matter (EPUK, N.D.). This suggests that the European Union is mostly concerned by the main toxic pollutants rather than greenhouse gases. However, CO₂ is also considered under separate regulations. EU Regulation 443/2009 states:

This Regulation sets the average CO₂ emissions for new passenger cars at 130 g CO₂/km, by means of improvement in vehicle motor technology, as measured in accordance with Regulation (EC) No 715/2007 and its implementing measures and innovative technologies. (Regulation (EC) No 443/2009)

A target of 95g has been set for 2020.

The current standard is Euro VI, which has been in force since 1st September 2014 (RAC, 2018) and is due to be replaced by Euro VII soon. The figures for Euro V and VI were announced in Regulation (EC) No 715/2007 and for the first time applied particulate matter limits to spark ignition engines, due to the introduction of direct petrol injection.

Apart from Euro standards, vehicles in the UK are also subject to an annual MOT test and roadside checks can be carried out (Gov.uk, N.D.). This ensures that vehicles are maintained to continuously meet certain emission standards.

2.3 Emissions in Motorsport

In motorsport, emissions have been a largely ignored problem for many years. Legislation is still not applicable to vehicles used on private land such as competition vehicles (other than road-going championships which enforce legislation to be met through regulations, and rally cars which use the public highway). The motorsport industry is often perceived as non-green (Business, Innovation and Skills Committee, 2010).

One of America's biggest motorsport series, NASCAR, has been a long way behind other series and legislation in terms of becoming 'green'. Based purely on the fuel consumed by the cars during race weekends, NASCAR produces around 1.8 million kilograms of carbon dioxide per year. Although this is a large number, it seems far less significant when compared to the 5.4 billion tonnes of carbon dioxide produced globally. Up until 2007 the series had still been using leaded fuel, showing just how little regard had been given to protecting the environment. (Layton, 2009)

The Le Mans 24h race however, has been a leader within motorsport for new, eco-friendly technology. The first hybrid race car appeared as early as 1998, however the technology was insufficiently developed to successfully qualify for the race (Watkins, 2012). Alternative fuels have also been widely explored in the race – Audi have been very successful using diesel fuel since the introduction of the R10 in 2006, and Peugeot soon followed with the same approach in the race for fuel economy (Roy, 2010). The FIA and the Automobile Club de l'Ouest are also discussing the introduction of hydrogen fuel cell cars for 2024 (Errington, 2018) and the ACO wants to encourage the development of zero-emission powertrains for the race (Sheehan, 2016). In 2009, the ACO implemented new regulations allowing electrical hybrid systems to be used on competing vehicles, however they would not be classified until 2010 (Collins, 2008). In addition to pushing for cleaner cars, the ACO have also made efforts to offset the CO₂ produced during the racing by planting trees and 'buying' carbon stored in the ground through the Carbon Forest+ initiative (Fabbri, 2018).

Formula 1 has also been taking big steps towards greener racing in recent years. Some even claim it could be the world's most sustainable sport. According to Sylt (2015), Formula 1 has "the power to make millions of cars all over the world greener thereby reducing emissions on a far greater scale than the series could ever hope to achieve", and this is due to the technology transfer within manufacturer teams – this makes Formula 1 far more sustainable in the big picture than many other sports with a smaller direct carbon footprint. The carbon dioxide emissions of the cars themselves were around 1.5kg per kilometre in 2007, but this was only 0.3% of the sports emissions. The rest was through the teams' operations, development and manufacturing (Miller, 2016).

Based on articles around emission reduction in motorsport, it seems like most if not all series are focused on reducing carbon dioxide emissions – generally meaning the cars are more fuel efficient. Formula one has been downsizing engines since 2006 when 3.5L V10 units were replaced by the 2.4L V8. In 2014, the regulations changed again to introduce 1.6L V6 hybrid-electric powertrains, closer to the general direction of the automotive industry. The rules also specified a fuel usage limit – previously cars were using around 150kg of fuel per race, while the new limit was specified at 100kg (Benson, 2014).

Motorsport UK is the governing body for all UK motorsport activity and currently applies a number of regulations linked to emission reduction. This includes the use of regular pump fuel, catalytic converters, noise limits and spill kits for cleaning up spillages (Motorsport UK, 2019).

2.4 Emission Control Systems

Manufacturers have developed and applied a number of different control systems in order to meet the stricter emission standards imposed on them.

EVAP systems are a simple solution to evaporative hydrocarbon emissions. Fuel evaporating from the vehicle could make 20% of the vehicles total emissions if it is uncontrolled, but the fuel tank must also be vented to prevent a vacuum forming as fuel is used. With an EVAP system, the fuel tank is sealed from the atmosphere, and a canister containing active charcoal, which bonds with fuel vapours. A purge valve is fitted between the canister and the intake system of the engine, and once the vehicle is in motion and warmed up, the valve will open to

release fuel vapours into the engine and air into the fuel system. With the introduction of OBD II, EVAP systems were able to detect vapour leaks within the system. (Carley, N.D.)

Positive Crankcase Ventilation systems also reduce evaporative emissions, but those caused through blowby into the crankcase. Similarly to the EVAP system, the PCV system also circulates the gases back into the intake to be burned. A valve is fitted to prevent the backflow of gases and a separator to prevent oil burning. (Lampton, N.D.)

Catalytic converters were one of the first systems fitted to combat exhaust emissions. They are a component of the exhaust which contains precious metals (platinum, rhodium and palladium) to act as a catalyst to reactions with oxygen (King, 2017). A reduction catalyst is used to separate NO into oxygen and nitrogen, while an oxidation catalyst is used to convert carbon monoxide into carbon dioxide, and hydrocarbons into carbon dioxide and water (Jackson, 2017). Catalytic converters have also become a source of pollution, as they emit ammonia due to the reduction reaction (American Chemical Society, 2000).

Secondary Air Injection is a system linked to the catalytic converter. During a cold start, there is not enough temperature for the catalytic converter to function effectively, but reactions can still take place with enough oxygen. Air injection systems use pulsing air, or a pump to supply this oxygen, therefore reducing hydrocarbon and carbon monoxide emissions in the warm up phase. This also generates heat which brings the catalytic converter up to a more efficient temperature more quickly. (Hella, N.D.)

EGR, or Exhaust Gas Recirculation is a system which reduces NO_x emissions, which form at high combustion temperatures. Exhaust gas is recirculated into the intake, replacing some of the fresh charge. This causes a drop in the combustion temperature, reducing the formation of NO_x. This however causes an increase in particulate matter emissions on diesel engines. (Cambustion, N.D.)

3. Methodology

Two engines were used to test their various emission control systems using an oscilloscope. The Ford engine has emission figures around the Euro III / IV numbers, while the Ecotec has figures around Euro IV / V.

The testing was dynamic, and care had to be taken to ensure that safe working practices were maintained at all times. This included wearing PPE such as protective boots and lab coats, as well as using exhaust extraction and taking general care to stay clear of moving or hot parts and making others aware when cranking the engine.

Before beginning any tests, the battery leads of the oscilloscope were connected to the engine battery, ensuring result accuracy. A suitable earth point was located for the black lead, and the pins were tested as follows:

Pins 21, 24 and 35/39 (Simultaneously) on the Ford engine.

Pins 42 and 52 on the Ecotec.

Scope patterns were collected from these tests for analysis.

4. Results

Appendix 1 shows the scope pattern for pin 21 on the Ford engine. This is the idle control, which is a plunger type on this engine. The signal will always keep the same shape with different loads, but the voltage will drop as the current rises. This is a step up from the previous rotary idle valves, which allowed less control. The same type of idle control valve is fitted to the Ecotec, however this is controlled by pulse width modulation and produces a square wave (See Appendix 5).

Appendix 2 shows the scope pattern for the camshaft position sensor on the Ford engine. The presence of this sensor suggests that sequential injection is used, but also allows the engine to operate in 'limp' mode should the crankshaft sensor fail.

Appendix 3 confirms that the Ford engine carries out fuel injection sequentially – it shows two injectors which have a staggered pulse. Previously, simultaneous injection was used, which often caused fuel condensation (increasing HC emissions).

Appendix 4 shows the functioning of the EGR valve on the Ecotec engine. This only pulses when the engine is warm, and the throttle is opened. At this stage, the EGR valve is only on or off, not fully variable.

5. Analysis

5.1 Engine Testing

In terms of emissions, the main differences between the two engines are the EGR system fitted to the Ecotec, the knock sensor fitted on the Ecotec and the type of SAI system used. The Ford engine used a pulsed air system, while the Ecotec uses a pump – a more controlled system.

Looking at the Ecotec (as the more modern engine of the two), there is no modification that would be required to bring it up to Euro VI standard, as the Euro V and VI standards for petrol cars are identical. However, some improvements could be made in order to match the most modern units. Firstly, the idle control valve could be replaced by a fly-by-wire throttle system. This means that the throttle linkage is now electronic and closely controlled by the ECU, and more capable of adapting to various driving conditions. Air metering should be upgraded to a hot film sensor for maximum accuracy. The ignition system should be changed from a wasted spark system to the more modern coil on plug, saving the energy losses through high tension leads and unnecessary sparks, as well as giving more accurate ignition timing. The EGR valve should be upgraded to a progressive type to allow accurate control of recirculating gases. The management system should also be able to monitor all of the emission controls for operation. This will require a second lambda sensor after the catalytic converter. Upgrading the lambda sensor to a wideband sensor would also be beneficial to shorten processing time. These changes would allow this engine to be comparable to the most modern engines.

Further looking into the future, potentially Euro VII standards, more radical changes would have to be made, such as replacing the valvetrain with electronic solenoids. See 5.4 for more information.

5.2 Euro VII Standards

It is already known that the European Union aims to reduce average CO₂ emissions to 95g/km (Regulation (EC) No 443/2009). It is likely that Euro VII standards will be applied around the same time (Frost, 2016). Since Euro IV, the limits have not changed except for those relating to NO_x for compression ignition vehicles. It is believed that the European Union will focus on carbon dioxide emissions rather than the toxic pollutants covered by Euro Standards (Car Keys, 2017). It is also suggested that new emission legislation will focus on densely populated areas (AECC, 2018). Based on this, Euro VII may involve low emission zones and may be encouraging the use of zero-emission vehicles in these high pollution areas.

5.3 Future of Motorsport

Looking at motorsport, it is very easy to fit more emission control devices to reduce the toxic emissions just like the Euro Standards have done. However, competition vehicles are still used in a very different manner – always working at their limits. This means the overall pollution per kilometre will be much great. The industry is mainly focused on reducing fuel consumption and carbon dioxide. This falls in line with the European Union's current focus and will surely help

develop road cars to meet Euro VII Standards. As manufacturers search for new ways to reduce emissions, the concepts will most likely be tested and developed in the motorsport environment. As already discussed in the research section, race series have already been heavily involved with alternative fuels and hybrid systems. The Formula e series is a good example of a championship set up with the development of new technology in mind. It is likely that more and more series will start introducing hybrid and electric vehicles.

5.4 Solutions to Meeting New Standards

Manufacturers are currently pushing to develop the internal combustion engine as well as alternatives such as electric vehicles. These will most likely be the solutions to emission problems in both the automotive and motorsport industries.

Many manufacturers are willing to keep the internal combustion engine alive. This includes Mazda, who in recent years have been implementing homogenous charge compression ignition engines. This is difficult to achieve but allows a combination of the benefits of diesel and petrol engines. It was previously rumoured that Formula One teams have used a combination of spark ignition and HCCI to help save fuel in the current turbo V6 era.

Koenigsegg have made two different developments in order to achieve higher efficiencies. One of them is the replacement of the mechanical valve train with solenoids. This removes the need to drive camshafts and gives far greater adaptive control – with infinitely adjustable valve lift and timing. The throttle body can also be removed, further simplifying the unit. The manufacturer has also produced hybrid-electric vehicles with no gearbox. The electric motors are used for low speed torque, allowing the heavy and inefficient gearbox to be removed altogether.

Hybrid-electric and electric vehicles are probably the biggest developments in recent years. More and more manufacturers are switching to hybrid power, and some are developing electric vehicles for zero-emissions. This is the direction that top-level motorsport is taking slowly, as more series are switching, or at least talking of switching to hybrid or electric vehicles. The problems regarding battery technology and the recycling of batteries still remain, but this could be something that the motorsport industry may encourage the development of.

48 Volt systems are similar to a hybrid system. With the current widespread use of stop-start systems, a 48V motor-generator would replace the conventional starter motor and alternator. 48V remains a safe voltage to work with, however it would require blending in with 12V components for lighting or infotainment for example. (Howard, 2017)

A system running at 48V also has lower currents running through the wiring harness, meaning the harness can be reduced in cross section to save weight, further improving emissions. The carbon dioxide reduction is around 70% of the reduction of full hybrids, but at just 30% of the cost. (Menon, 2019)

Hydrogen fuel cells are another option being discussed, and as mentioned in the research section, this is something that the ACO want to look into for Le Mans. The main problem is sourcing hydrogen fuel and storing it, and again, motorsport may be a development ground for this technology.

Some manufacturers are also looking into transmission technology. In recent years cars have been gaining gears, and different gearbox types have been developed. Continuously Variable Transmissions have also become more widely used to try and maintain engines running at their most efficient speed range. But the efficiency of the CVT also has to be considered. Other automated types of gearboxes have been developed to make driving easier and take more control away from the driver. One of the effects of this is that driving behaviour is more ecological.

One of the problems which is more difficult to resolve is the driver behaviour. People rarely drive in a way which is most protective of the environment, and hence autonomous vehicles have been linked to emission reduction. This is a huge step in adaptive control, which means the vehicle can be adjusted for maximum efficiency at a wide range of conditions.

Taking all of these possible solutions into consideration, it is highly likely that both industries will head towards a combination of technologies, whilst other ideas will be developed.

6. Conclusion

In conclusion, automotive emissions were looked into within both the automotive and motorsport industries. Emission control systems were reviewed, and legislation and motorsport regulations discussed, as well as discussing how teams and manufacturers are approaching emission problems. Euro VII standards will be coming in the near future as the European Union tries to improve general air quality. It remains unknown which direction these standards will be taking, but it is certain that the EU wants to tackle carbon dioxide emissions. The future of both industries is an exciting one, as many manufacturers are developing their own technology and ideas about what the solution to vehicle emissions will be. It is very likely that in the next 10-20 years, the range of different vehicles in use on the roads will be expanding.

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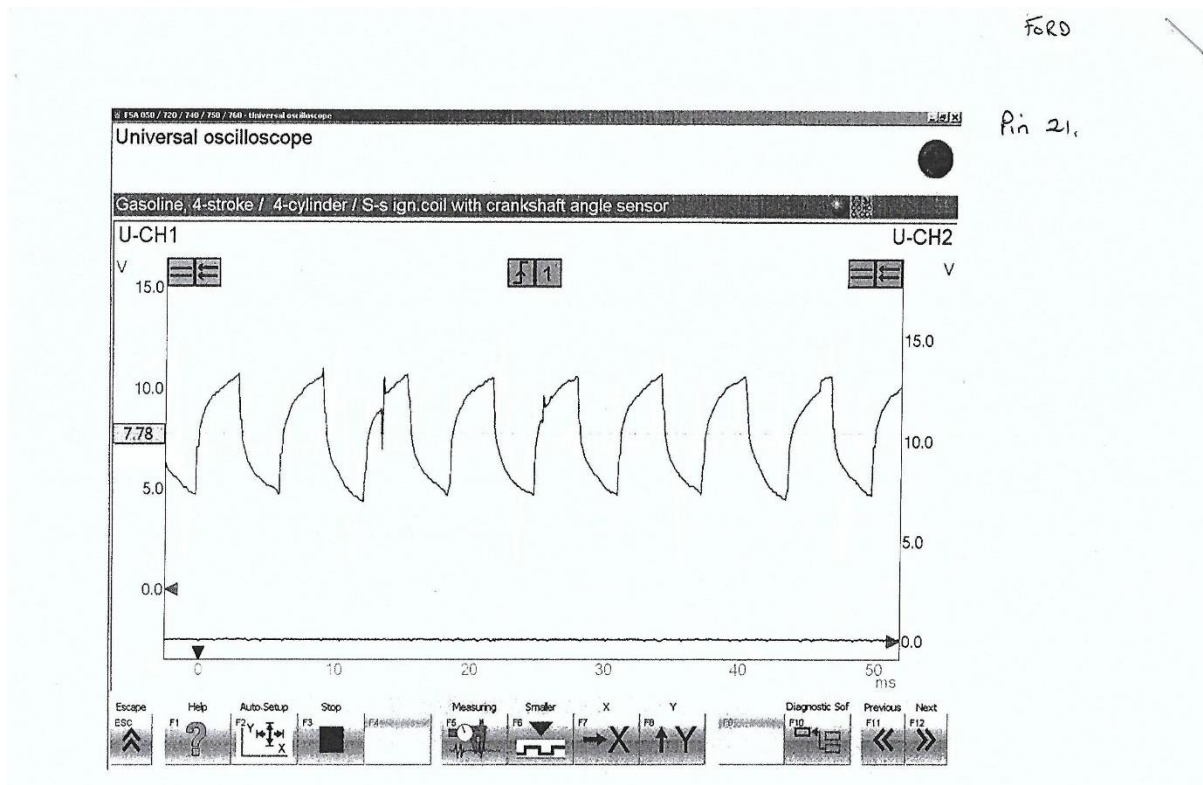
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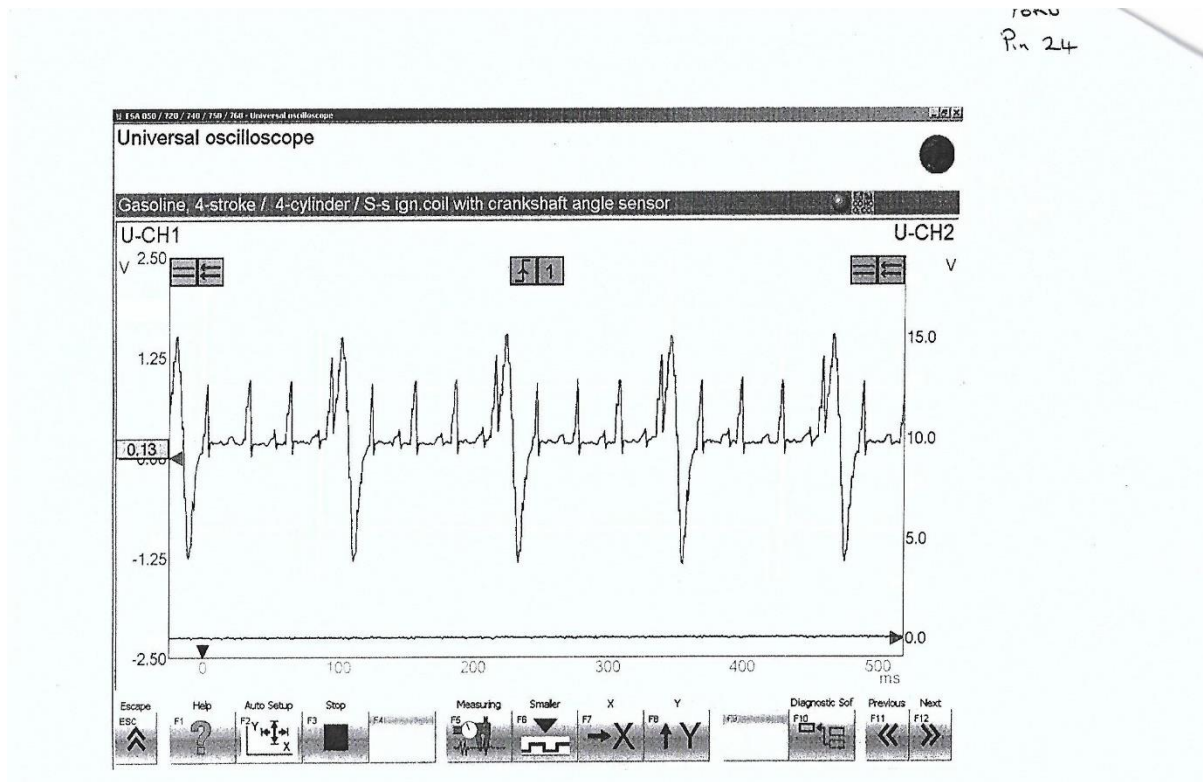
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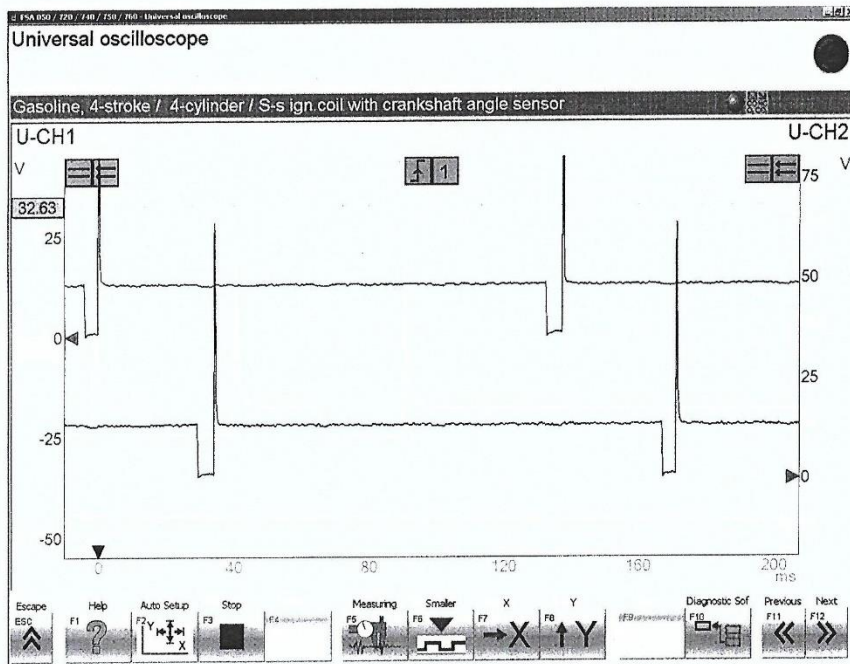
8. Appendices



Appendix 1: Ford Idle Control Valve (pin 21).



Appendix 2: Ford camshaft position sensor (pin 24).

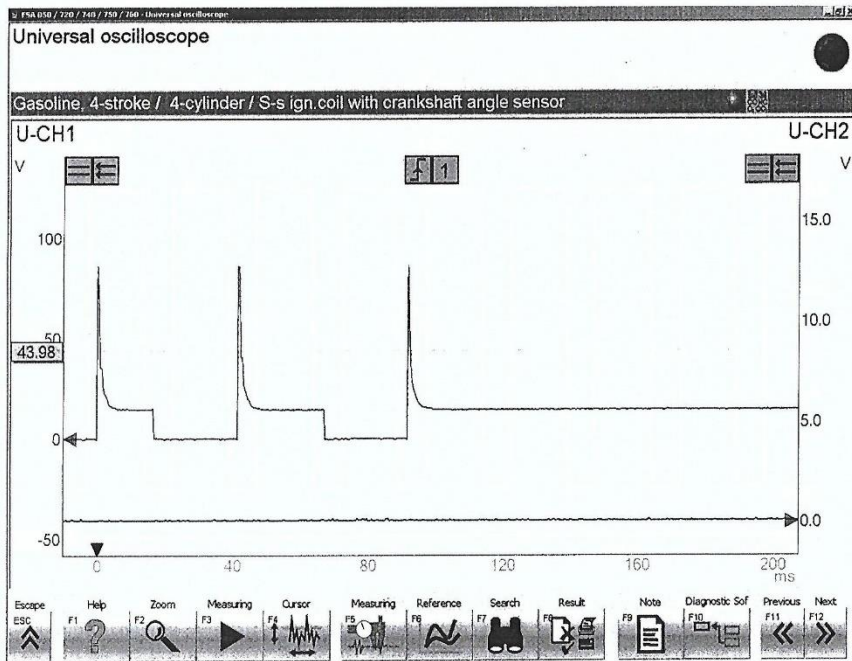


ford.

Pin 35

Pin 39.

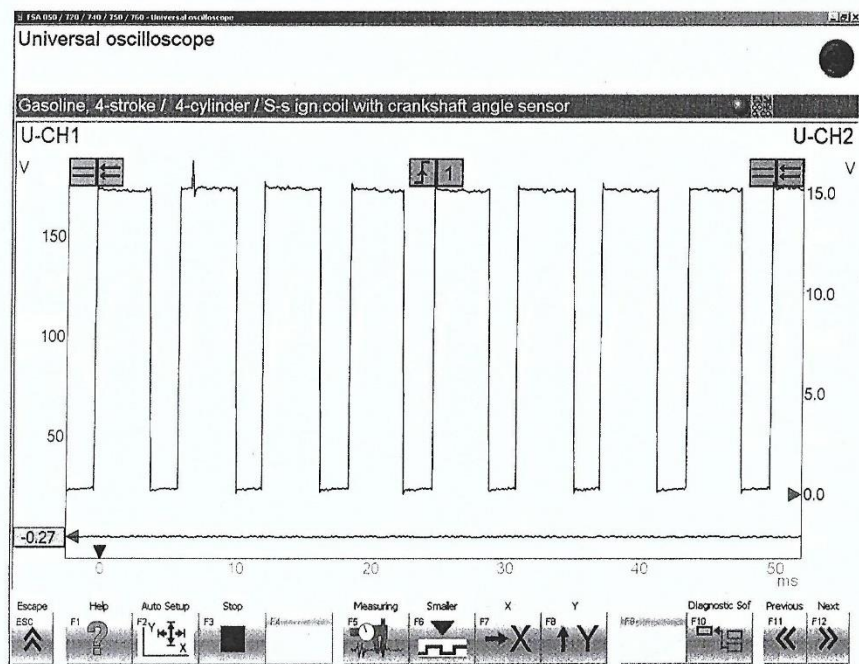
Appendix 3: Ford fuel injectors (pins 35 and 39).



ECOTEC

Pin 42.

Appendix 4: Ecotec EGR valve (pin 42).



Appendix 5: Ecotec idle control valve (pin 52).