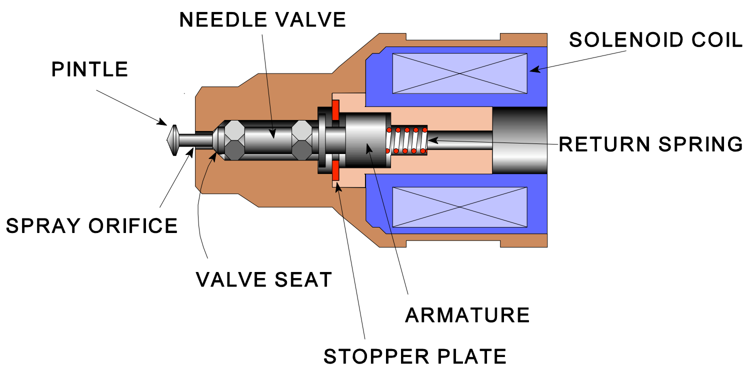
Fuel Injectors

TAG Electronic Systems supply pintle type fuel injectors. Other types of injectors, without pintles, are available. These "orifice" injectors rely on an orifice to atomize the fuel. Multi-Jet orifice injectors are variants using several orifices to generate multiple fuel jets from one injector to prevent wetting of the inlet duct, particularly on multi-valve engines.

Neither of these types of injector is recommended where maximum engine performance is sought (i.e. if performance at operating temperature is more important than emissions at cold start and warm-up). The atomisation performance of conventional orifice type injectors is worse than comparable pintle injectors, making them generally unsuitable for motorsport applications.



Principle of Operation

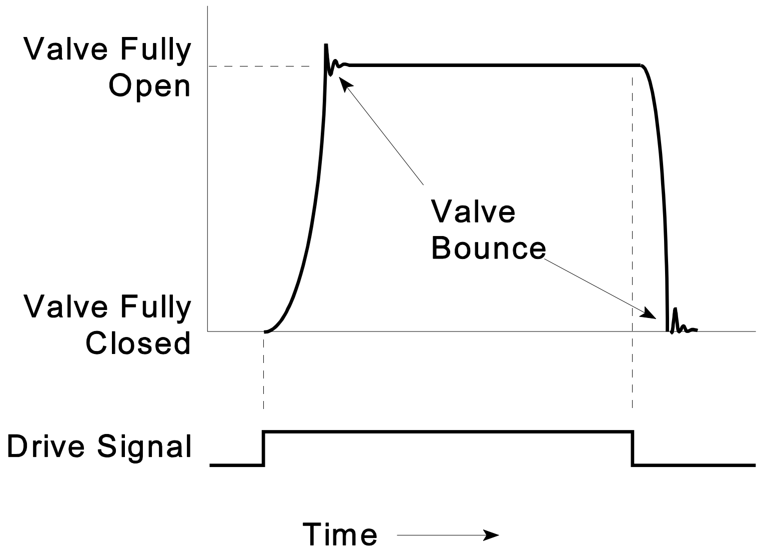
In the closed condition (i.e. no fuel flow) the valve is sealed against the seat by a combination of the return spring force and fuel pressure. This keeps the injector closed with no electrical supply. When a voltage is applied (the "drive signal"), the electrical current in the solenoid coil generates a magnetic field which generates a pulling force on the needle valve. When this force overcomes the force exerted by the fuel pressure and the return spring, the needle valve starts lifting and fuel begins to flow. The needle valve continues lifting until it hits a mechanical stop, at which point full fuel flow is established. Fuel emerging from the injector is atomised as it passes the valve seat. It then impinges on the pintle, which further atomizes the spray and makes it take on a hollow, conical shape.

When the electrical current is switched off, the magnetic field decays until the force is less than the combined fuel pressure and return spring force. The valve then begins to close and fuel flow reduces, until the valve contacts the seat.

Supply Voltage and Fuel Pressure

In solenoid operated fuel injectors the quantity of fuel injected is controlled by the duration of the electrical drive signal.

The flow rate is governed by the area of the annular orifice formed between the injector body and the movable needle part of the valve. At a constant fuel pressure, the volumetric flow rate through the fully open injector remains constant. If the fuel pressure is not constant, then the flow rate will change as the square root of the pressure change.



The inertia of the needle and the time taken to build up or destroy the magnetic field in the solenoid mean that the valve response does not exactly follow the logic drive signal (see Diagram). There is a delay between applying the drive signal and the valve becoming fully open and a similar, usually shorter, delay on closing.

TVB

TVB is a measure of the relationship between the time that the valve is demanded to open and time the valve is actually open. An allowance is made for the reduction in flow rate when the valve is partially open. TVB must be considered when calculating the duration of the drive signal pulse to give the required fuel quantity.

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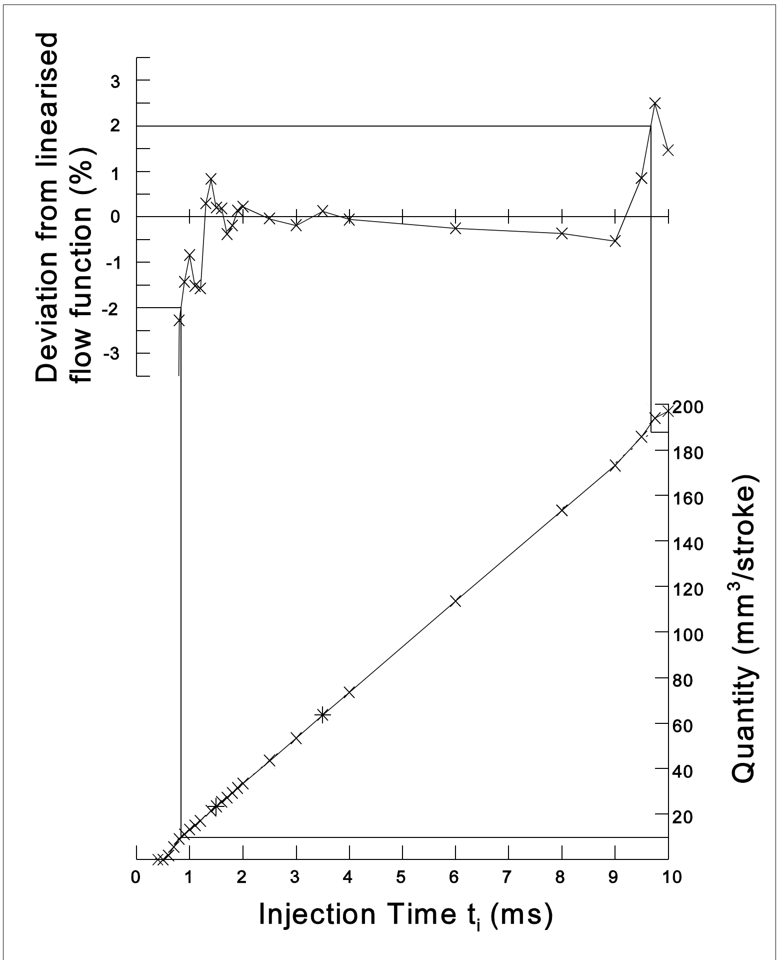
TVB depends on the battery voltage (influencing the current build up in the solenoid) and on the fuel pressure (which assists the return spring in closing the valve). The significance of the effect of voltage on TVB is widely recognised, with most ECUs incorporating TVB correction maps for changes in battery voltage (e.g. during cranking).

The significance of changes in fuel pressure on TVB is often undervalued as its real detrimental effect may only become apparent once the injector is mounted in a fuel rail (together with other injectors). The fuel pressure in a fuel rail can pulsate significantly, with multiple injectors opening and closing. If TVB is highly sensitive to fuel pressure variations, large and unpredictable variations in fuel delivery at small pulse times will cause poor throttle response, increased fuel consumption and a subsequent increase in lap times. Injector testing is normally carried out on rigs designed to eliminate pressure fluctuations so that the results can be reproduced at other test sites. Because of this, the fuel pressure dependency of TVB is not generally published by injector manufacturers.

Linear Operating Range

The flow through an injector will only be constant during the time the injector is fully opened (assuming fluid characteristics and pressure remain unchanged). Flow is reduced during the period the needle valve is opening and closing because of the reduced area of the annulus between the needle and the valve seat. This means that the response of the injector is nonlinear if the drive signal has a very short duration. If the injector is repetitively pulsed (as is the case in a combustion engine) the flow will also be nonlinear if the duration of the drive signal approaches a 100% duty cycle (i.e. the needle valve has not fully closed before the next drive signal is applied).

The shortest injection time that provides a flow rate within ±2% of that predicted by the linear relationship is called the Minimum Linear Pulse Time (MLPT). This is the shortest injection time that can be used to deliver a reliable fuel quantity. The ratio of the highest injected quantity that is within ±2% of the linear relationship to the injected quantity at the MLPT is referred to as the Dynamic Flow Range (DFR) of the injector. When comparing injectors some manufactures specify MLPT and DFR to ±5% limits, as this provides more attractive figures. In demanding applications, such as motorsport, a ±5 % variation in fuelling within the operating range of the injector is generally unacceptable. All figures quoted by TAG use the tighter ±2% limit.



Fuel Pressure: 12barg	Test Fuel: n-Heptane
Slope: 20.105mm^3/ms	TVB: 0.340ms
MLPT: 0.833ms	DFR: 18.917

An typical plot of injector characteristics

Selecting an Injector

Ideally the flow rate of the injector (meaning the amount of fuel being precisely injected) should be selected such that the required pulse width for full load is as short as possible. This helps to prevent unburnt fuel leaving the combustion chamber during valve overlap. At the same time, the selected flow rate of the injector should not be so high as to cause significant parts of the low load fuel map to require injection times below the MLPT for the injector.

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APPLICATION NOTES

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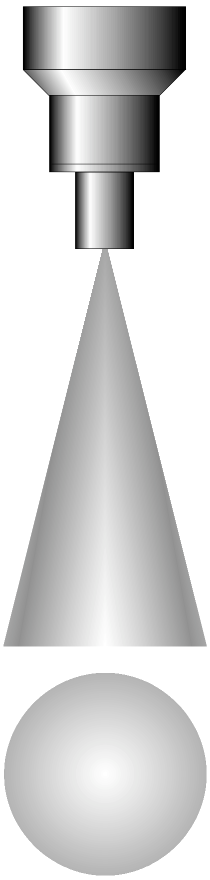
Single or Twin Injector Per Cylinder

Where a very wide dynamic fuelling range is required (typically for a DFR of greater than 8), for example in a high revving or turbocharged engine, it may not be possible for one injector to cover the entire engine fuel demand (from idle to full load) accurately. In these cases, a twin injector per cylinder installation can be considered, with one injector covering the low load conditions and the other (or both) injectors covering the full load requirement. In such an installation, the low load injector may be selected with a lower or identical flow rate to the full load injector.

Cone Angle and Injector Installation

The cone angle of an injector spray is the geometrical spray distribution of the fuel with the injector permanently on and operating in static air. Pintle injectors can generate a hollow cone between almost 0° and 90°. A wider cone angle gives better mechanical mixture preparation (i.e. a more homogeneous air/fuel mixture which can give better power and fuel consumption). However, this is only the case if the injector installation allows the spray to enter the inlet duct of the engine. With high-revving engines, significant air pressure pulsations can occur in the inlet duct which may force air back out of the inlet trumpet. To ensure that all of the fuel injected is delivered to the correct cylinder and not blown back out of the trumpet or drawn into an adjacent cylinder, it is necessary to have a high fuel velocity in the direction of the inlet valve. This can be achieved with a narrower cone angle and/or a high fuel pressure, typically above 8barg.



Besides the air pulsation hindering the fuel entering the inlet duct, a wider cone angle can also lead to significant wall wetting of the inlet duct. This may lead to drivability problems (and higher emissions), particularly at lower engine temperatures. It may also require a more sophisticated acceleration enrichment/enleaning strategy for best dynamic performance of the engine, even at optimum engine operating temperature.

Some applications have tried to overcome the poorer mixture preparation of injectors by mounting (narrow cone) injectors almost perpendicular to the air stream. They try to compensate for the poor mechanical atomisation by generating a swirl effect. This approach is not recommended. Although it may improve steady-state results, it will usually perform very badly under dynamic operating conditions.

A counter-measure sometimes used to deal with poor atomisation is to mount injectors further away from the inlet duct, giving the air and fuel more time to mix. Again, this can only really help in steady-state conditions and will lead to significant hesitation when the engine is accelerated. In twin injector installations, one injector may be mounted away from the inlet duct as long as the other injector is mounted close to the inlet. A sophisticated acceleration enrichment must be used to cover the transition from one to two injectors otherwise the mixture will become lean during acceleration.

Taking all of these factors into account, and bearing in mind that the cone angle will be distorted inwards to some extent by the air stream, a cone angle of approximately 50° is best for most motorsport applications. Combined with a high mechanical atomisation (from high fuel pressure), such an injector can be mounted close to the inlet valve of the engine, injecting towards the inlet port and providing good mixture preparation in both steady-sate and dynamic operating conditions.

Atomisation Performance

Improved atomisation performance will always improve the fuel consumption and power output of an engine but the effect will vary from engine to engine. Gains reduce progressively when the droplet size gets very small. The atomisation performance of an injector is mainly dictated by the design and quality of machining of the pintle, sizing of the valve (orifice, seat, lift etc.) and the velocity of the fuel as it leaves the injector. As rules of thumb: an increase in fuel pressure (hence fuel velocity) results in a reduction in fuel droplet sizes and an injector with a higher static flow rate will have a larger droplet size.

When considering the atomisation performance of fuel injectors, it is necessary to be aware that some manufacturers quote a single value for SMD for an injector (SMD = Sauter Mean Diameter, is a way of comparing the atomisation performance of different injectors). The single value for SMD can be misleading as it characterises the steady state performance. In a pulsed spray (the mode of operation in an engine) SMD varies throughout the duration of the spray. Successive measurements will show high SMD values at the leading edge (as fuel must be accelerated to its steady state velocity). This decays to the steady state SMD value once the spray has been fully established, then decays further in the tail end of the spray. This effect means that mixture quality can suffer at very short pulse widths.

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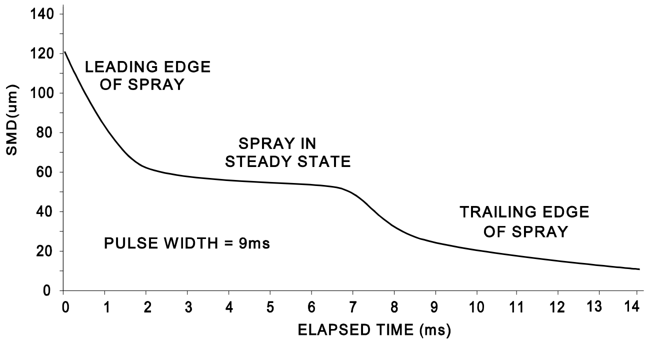
APPLICATION NOTES
Fuel Injectors

ELECTRONIC SYSTEMS

Good atomisation performance has been one of the main considerations in the design of all TAG high performance motorsport injectors, which is why they have a special pintle design and have been designed to run with very high fuel pressures and large cone angles.



Typical atomisation performance

TAG Electronic System's latest injector, the TSR, provides excellent atomisation performance, particularly when run with a fuel pressure of 30barg where Sauter Mean Diameters below 20µm have been recorded. The TSR injector is one of the only injectors in the world where the original design is not based on mass-market compromises. It is also, to the best of our knowledge, the first and only injector for motorsport applications that reliably operates at fuel pressures up to 30barg. It is, at present, the ultimate injector for motorsport.

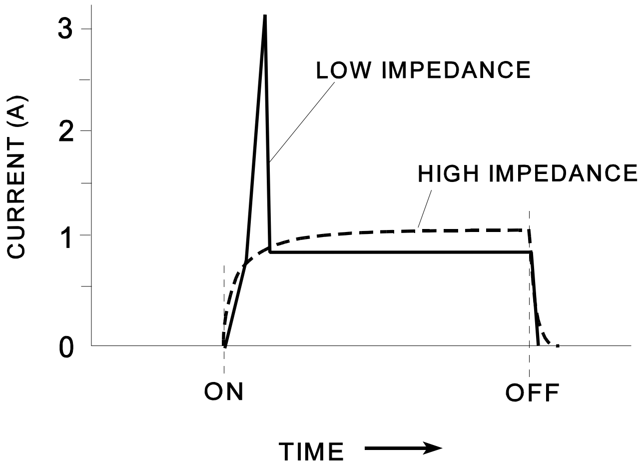
Solenoid Coil Impedance

In order to deliver fuel accurately over the widest possible range of flow values to cover fuelling demands from idle to full throttle, an injector should have the shortest possible opening and closing times. This is achieved by optimising the magnetic circuit and minimising the pintle mass.

Most mass market injectors use a high impedance solenoid coil, with a resistance of about 8 to 14 ohm. The introduction of high impedance injectors was one of the most important steps in reducing the cost of mass market fuel injection systems at the beginning of the eighties. Most injectors used in motorsport are also of high impedance as they are either based on mass market products or are designed to meet limitations in the electronic control units. These injectors can use a low cost drive stage that simply applies a voltage across the coil for the entire period of the injection pulse. The current through the coil (as well as the resulting magnetic performance) is determined almost entirely by its resistance. The use of high impedance injectors is popular with designers of cheaper motorsport electronics (due to its simplicity) but it compromises the performance of the injector and hence that of the engine.

TAG Electronic Systems injectors are designed to get the best performance from an engine, so our high performance motorsport fuel injectors use low impedance solenoid coils with resistance of 2 ohm or less. These low impedance solenoids require a more complex, current-controlled drive stage. These stages can be designed so that they recover almost all the energy stored in an opened injector, hence the firing of the low impedance injectors takes very little electrical power. Such an optimised stage can drive a much higher current through the injector, resulting in a high magnetic force and a very fast opening. As soon as the injector is opened the current is reduced, leading not only to reduced heat build-up in the injector but, more importantly, to an ability to close faster as less energy is stored in the magnetic field. An ECU injector stage which has been designed for a low impedance injector can drive a high impedance injector with no modification.

TAG's TSR injector takes this principle a stage further by using a specially-designed coil with very low impedance (around 0.64 ohm) and very low inductance. The magnetic and hydraulic circuits are also optimised. A specially developed drive stage is used with this injector to achieve very low MLPT, even at fuel pressures as high as 30barg.



Typical Injector Drive Current Waveforms

TAG's specially designed motorsport injectors are "no compromise" products.

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