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HIGH PRESSURE FUEL SYSTEM FOR HIGH SPEED DIESEL ENGINES WITH SUITABLE ELECTRONIC CONTROL

SAŽETAK

VISOKOTLAČNI SUSTAV GORIVA ZA BRZOHODNE DIESELOVE MOTORE S IZRAVNIM UBRIZGAVANJEM, S ODGOVARAJUĆOM ELEKTRONSKOM REGULACIJOM

Dvostruka sapnica s regulacijom ubrizgavanja uz kontrolu tlaka i visoki tlak ubrizgavanja predstavljaju važne čimbenike za dobra svojstva izgaranja u čitavom području Diesellovih motora velikih brzina s izravnim ubrizgavanjem.

S opisanom se konstrukcijom postiže kombinacija tangencijalnog i aksijalnog progiba goriva na početku ubrizgavanja i prije dolaska u ulaze sapnice, time smanjujući brzinu ubrizgavanja i prodiranje goriva prije izgaranja. Također se povećava raspršivanje goriva tijekom paljenja. Kombinacija ovih svojstava smanjuje ispuštanje štetnih plinova za vrijeme paljenja i buku uslijed izgaranja. Nakon što započne postupak izgaranja, igla sapnice potpuno otvori prigušnice goriva i raspršivači pod visokim tlakom ubrizgavaju gorivo izravno u već postojeći plamen. Dvostruko vodena igla sapnice osigurava sposobnost obnavljanja i trajnost navedenog sustava. Precizno baždarenje i jednostavno održavanje odlike su opisane opreme. Svi su elektronski i električni elementi smješteni izvan motora, te nisu izloženi toplini motornog ulja. Elektronski sustav regulira količinu ubrizganog goriva i vrijeme ubrizgavanja. Sustav ima ugrađen precizni indikator o količini ubrizganog goriva i regulaciji ubrizgavanja.

1. ADAPTION OF THE HIGH PRESSURE INJECTION SYSTEM TO THE COMBUSTION REQUIREMENTS

The application of a high pressure injection system improves the fuel atomization and reduces the injection time in the entire engine map area. This increases the potential for NO_x and Particulate emissions reduction. The so caused delayed combustion results in reduced peak pressures and reduced thermal cylinder impingement. It increases the power potential of the engine.

The high injection pressures, with increased injection rate, deliver a higher amount of fuel into the combustion chamber during the ignition delay period.

The fuel impingement on the combustion chamber walls, with the negative influence on the combustion process, is also increased by high injection pressures. Both factors increase hydrocarbon and noise emissions. The disadvantages are more marked for vehicle certification processes, where the low load factor dominates in the test procedure.

The injection rate control and more intensive atomization of the fuel spray avoid the mentioned disadvantages. The advantages of high injection pressure can be utilized in the whole engine map area.

The STEYR developed two-stage nozzle with the simple control of the cross section of the nozzle holes (Figure 1) fulfills these requirements. In the first stage the nozzle needle opens only a portion of the nozzle orifices. By specific design, a combination of tangential and rectangular fuel flow deflection is achieved before entering the nozzle holes.

The fuel flow configuration and the reduced nozzle cross section area together increase the atomization of the fuel and reduce the fuel penetration during the ignition delay period. Despite the high injection pressures a reduced ignition delay, and a better distribution of fuel in the combustion chamber is achieved.

After the start of combustion the nozzle needle opens the nozzle orifices completely. The high pressure sprays inject the fuel into the already existing flame and the fuel penetration is reduced despite of the high injection pressure. The uniform distribution of the fuel to the nozzle holes in the first stage with the limited needle lift is achieved by double nozzle guide (Figure 2). This nozzle design enables also, due to the achieved uniform nozzle hole cross section, engine optimization with smaller needle lifts in the first stage. The nozzle design with short rim reduces also the deformation of the nozzle body and does not influence the accurate geometry of the double-guided nozzle needle.

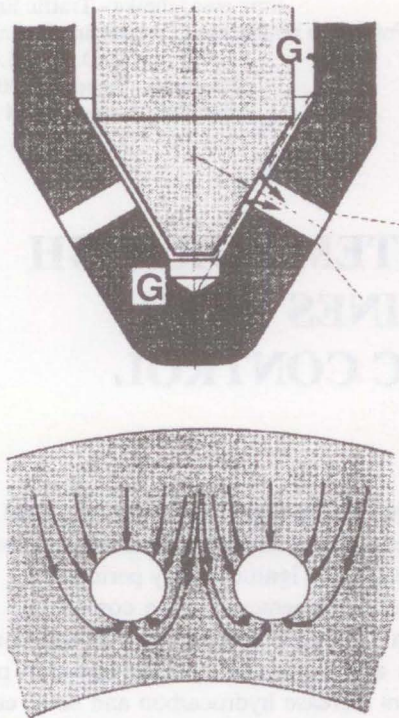


Figure 1 - Cross section through the nozzle with the limited lift of the needle and the fuel flow to the nozzle holes in the first stage.

The classic Diesel fuel injection pumps are assembled and calibrated before installation into the engine. The installation forces do not change this calibration. On the contrary, the Unit Injectors are assembled with high vertical forces into the engine head. These forces can change the clearances of the major components and change the fuel delivery calibration. That is a disadvantage of many new, high pressure Unit Injector designs.

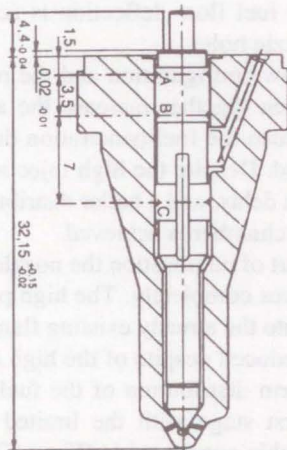


Figure 2 - STEYR nozzle design with double guided needle and minimal deformations of the nozzle body by the assembly forces.

STEYR Unit Injection design allows the assembly forces to pass outside the critical elements, avoiding any change in the Unit Injector calibration.

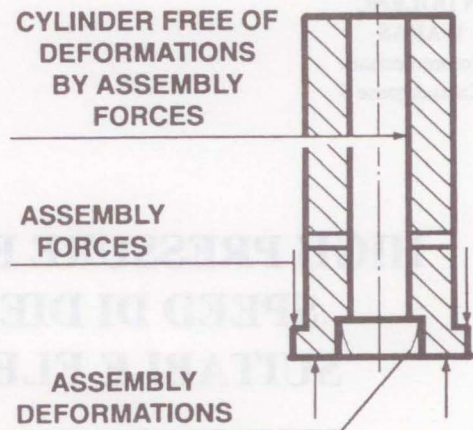


Figure 3 - STEYR Unit Injector barrel design. The inside cylinder surface is not affected by the assembly forces.

The above solution allows also the reduction of the clearances of the pumping elements and minimizes the amount of the leaking fuel, making them more suitable for the high injection pressures.

High pressure gradients without any kinds of secondary oscillations are advantage to the combustion process. They influence the possible reduction in particulate emission.

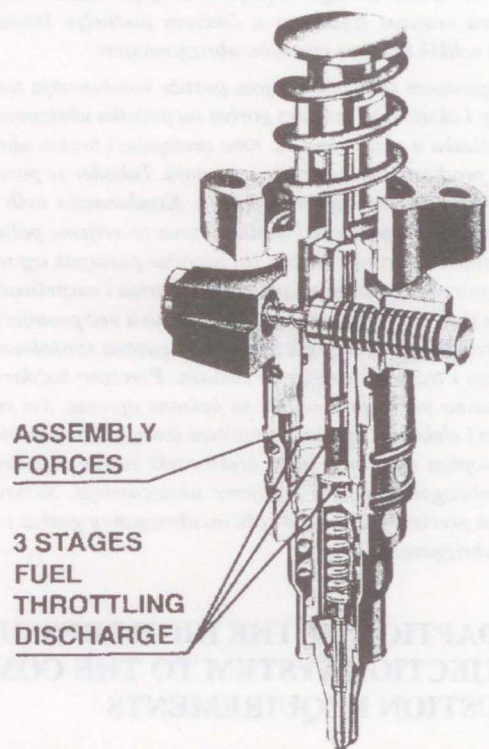


Figure 4 - STEYR electronically controlled Unit Injector with adjustable reference point stops for automatic calibration.

Short distances between the plunger and the nozzle holes and a good hydraulic damping of the discharge fuel flow at the end of injection allows high pressure gradients at the end of injection, and high injection pres-

tures to be achieved without cavitation damage. The STEYR electronically controlled Unit Injector has the shortest distance between the controlling barrel spill ports and nozzle holes (Figure 4). The short hydraulic connection has additionally - three stage discharge damping. The result is an extremely harmonic injection pressure pattern at high pressure level.

These features are of the highest importance for the future high mileage emission stability. The results with the STEYR Unit Injectors show no significant emission deterioration during the life of the engine.

The described two-stage injector throttles the fuel flow during the first stage. The high throttling rate results in a fuel flow deviation between the injectors. But the uniformity of the fuel distribution between the cylinders is very important for the vehicles with high EGR requirements in the emission certification engine map area. The combination of the volumetric Unit Injector con-

trol and throttled first injection stage does not result in deviations of fuel delivery between the cylinders. The combination of the time controlled Unit Injector and the nozzle with injection rate reduced by throttling in the first stage, does not have sufficient accuracy for the amount of injected fuel.

High speed DI Diesel engines have mostly the camshaft integrated into the cylinder head (OHC). The timing belt or chain used and lightweight design result in a higher amplitude of the camshaft oscillations. The fuel delivery rate of the camshaft operated Unit Injectors varies with the camshaft oscillations. This camshaft oscillations influence additionally the amount of injected fuel with time controlled Unit Injectors. These deviations are more severe with the partial load, and influence very much the capability of high EGR rates required for vehicle test procedure certifications. High injection pressure reduces the injection duration and the accuracy of the in-

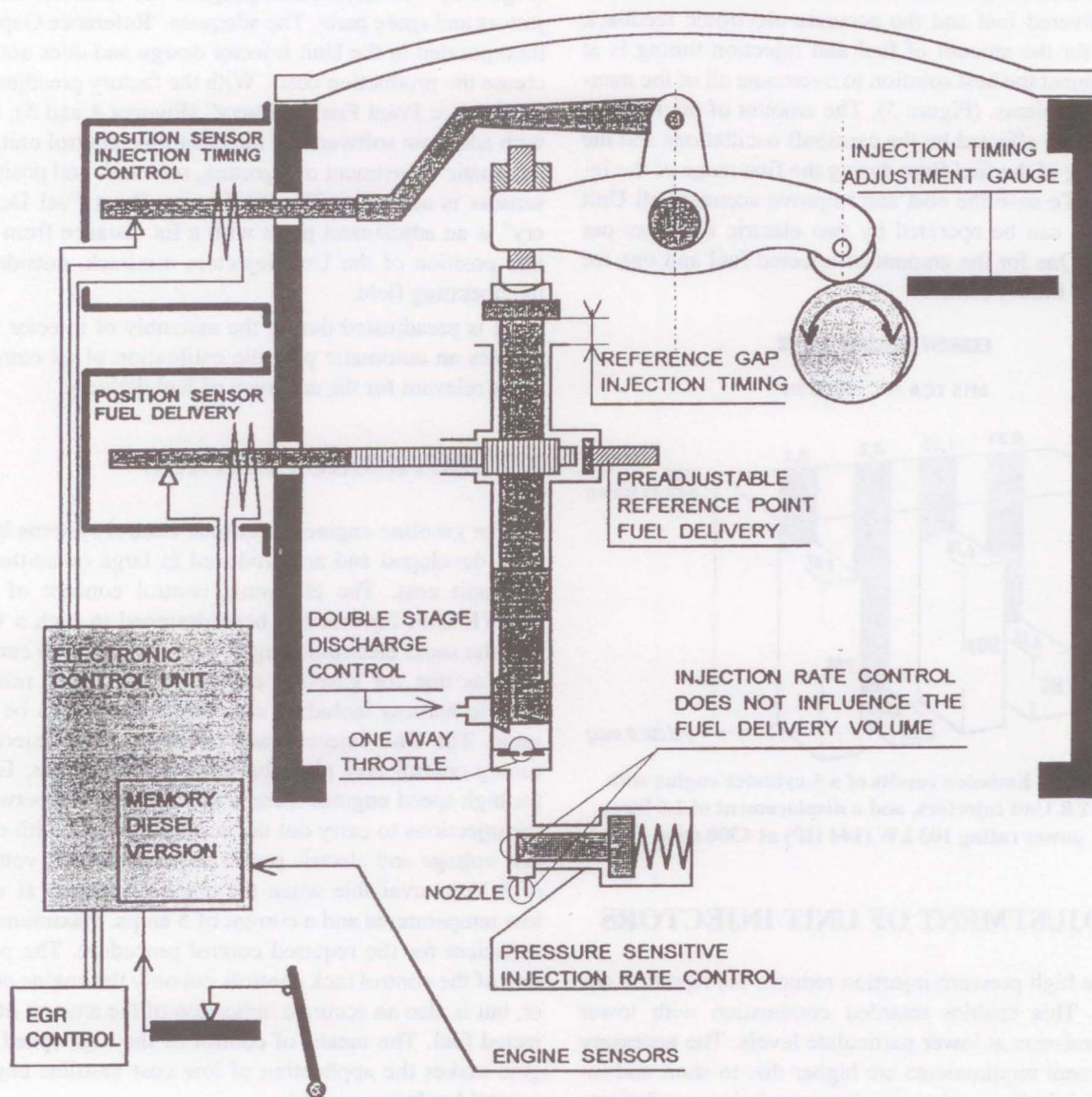


Figure 5 - STEYR Unit Injector

jected fuel volume is more sensitive to the camshaft oscillations. The Heavy Duty engines with a very rigid camshaft drive, without injection rate control by a throttling device, are more suitable for the time controlled camshaft operated Unit Injectors. For Heavy Duty engine certification, according to the required test procedure, the low power emission values are not of high influence (Figure 6). The time controlled Unit Injectors are, however, very suitable for combustion research work on one cylinder engines. The governor of one cylinder engines neutralizes the fuel delivery deviations caused by camshaft oscillations and the throttling devices. The results are however not suitable for multicylinder engines. A fuel quantity measurement per cylinder would be required to neutralize the mentioned disadvantages.

Electronic unit injector with injection rate control and accurate volumetric fuel delivery.

The STEYR Unit Injector with volumetric control of the delivered fuel and the accurate electronic feedback signal for the amount of fuel and injection timing is at the moment the best solution to overcome all of the mentioned problems. (Figure 5). The amount of the injected fuel is little affected by the camshaft oscillations and the throttling of the fuel flow during the first stage of the injection. To save the cost and improve accuracy all Unit Injectors can be operated by two electric actuators per engine. One for the amount of injected fuel and one for injection timing control.

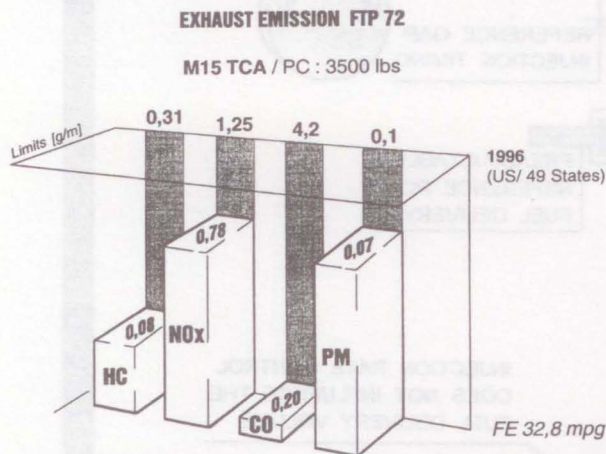


Figure 6 - Emission results of a 5-cylinder engine with STEYR Unit Injectors, and a displacement of 2.6 litre; power rating 103 kW (144 HP) at 4300 rpm.

2. ADJUSTMENT OF UNIT INJECTORS

The high pressure injection reduces the injection duration. This enables retarded combustion with lower NO_x emission at lower particulate levels. The necessary adjustment requirements are higher due to short and intensive injection and more severe emission regulations.

The tests carried out on the high speed DI Diesel engines show the requirements for injection timing accuracy of $\pm 1^\circ$ CA and the amount of the injected fuel should not vary more than $\pm 1.5\%$ of the fuel necessary for full power. These figures are required for production and field service. These requirements are most important for heavy vehicles requiring vehicle certified engines with very high EGR rates.

The design of the timing control components is shown on Figure 7. The electronically operated actuator rotates the excentric rocker arm shaft (Figure 5). With this timing control mechanism the injection rate profile does not change with timing advance. (Figure 8). With the time controlled solenoid operated Unit Injectors, the advanced timing reduces injection rate at the same time, and that is a negative factor for engine cold starting (Figure 9). For accurate timing adjustment of the STEYR Unit Injector only an adjustment gauge is necessary (Figure 5). The adjustment gauge is the same for all injectors and spare parts. The adequate "Reference Gap" is incorporated in the Unit Injector design and does not increase the production costs. With the factory preadjusted "Reference Point Fuel Delivery" (Figures 4 and 5), and with adequate software for the electronic control unit, an automatic adjustment of injectors, solenoid, and position sensors is achieved. The "Reference Point Fuel Delivery" is an adjustment point with a fix distance from the idle position of the Unit Injectors minirack, outside of the operating field.

It is preadjusted during the assembly of injector and enables an automatic periodic calibration of all components relevant for the accuracy of fuel delivery.

3. ELECTRONIC CONTROL

For gasoline engines electronic control systems have been developed and are produced in large quantities at low unit cost. The electronic control concept of the STEYR Unit Injector has been designed in such a way that the same electronic engine control hardware can be used as that for gasoline engines. The vehicle related electric harness including connectors could also be the same. The Unit Injector rack positioning and injection timing control take place between two injections. Even for high speed engines there is enough time left between the injections to carry out the accurate control with only low voltage and electric power requirements. A voltage of 5 Volts available when the engine is started at very low temperatures and a current of 5 amps. maximum are sufficient for the required control procedure. The position of the control rack controls not only the engine power, but is also an accurate indication of the amount of injected fuel. The means of control of the high speed engine makes the application of low cost gasoline engine control hardware possible.

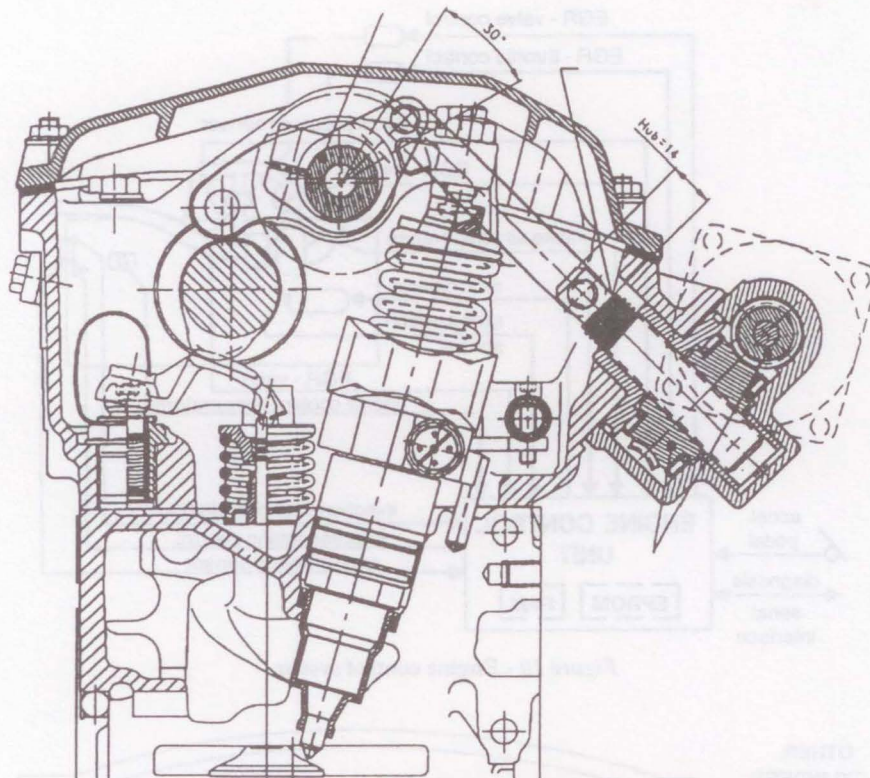


Figure 7 - Design of the timing control mechanism

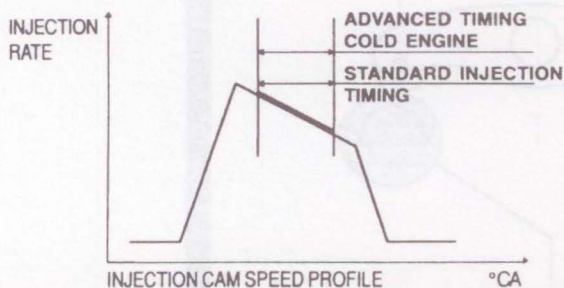


Figure 8 - Injection rate pattern not influenced by injection timing control with excentric rocker arm shaft.

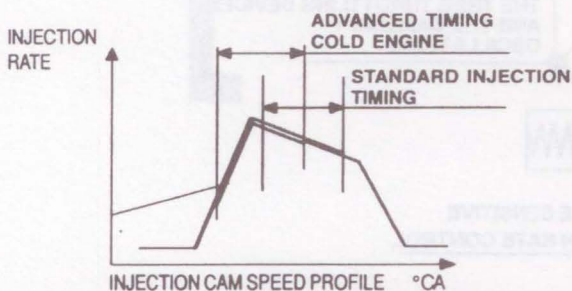


Figure 9 - Injection rate pattern influenced by timing control with solenoid valve.

All electric and electronic components are placed outside the engine and are not exposed to the hot engine oil (Figures 5, 10). In combination with all these properties the durability of the components is much higher and service much easier.

With the STEYR system, the control of the automatic transmission can be integrated in the electronic hardware, and the engine monitoring system for gasoline engines can also be used for diesel engine applications.

In cases where the electric current supply is interrupted or too high temperature is indicated, the fuel injection will automatically be cut off to avoid any engine damage. A simple low cost limp home capability is possible as an option.

4. COMPARISON WITH OTHER NEW DEVELOPMENTS

All new developments in injection equipment are based on electronic control. The STEYR camshaft operated UI with volumetric control needs min. 5 V and 5 amps. electric power, while other EUI and HEUI developments, time controlled with solenoid valves, need much higher electric power and additional battery capacity.

For the high pressure gradients needed, the short hydraulic connection between the spill ports and the nozzle orifices is very important (Figures 5, 11 and 12).

The longest hydraulic connection between the control solenoid and nozzle is on the cam operated and time controlled Unit Injectors (Figure 11).

On the hydraulically operated Unit Injector (HUI) the critical hydraulic length is also short, but in combination with the hydraulic amplifier, additional masses re-

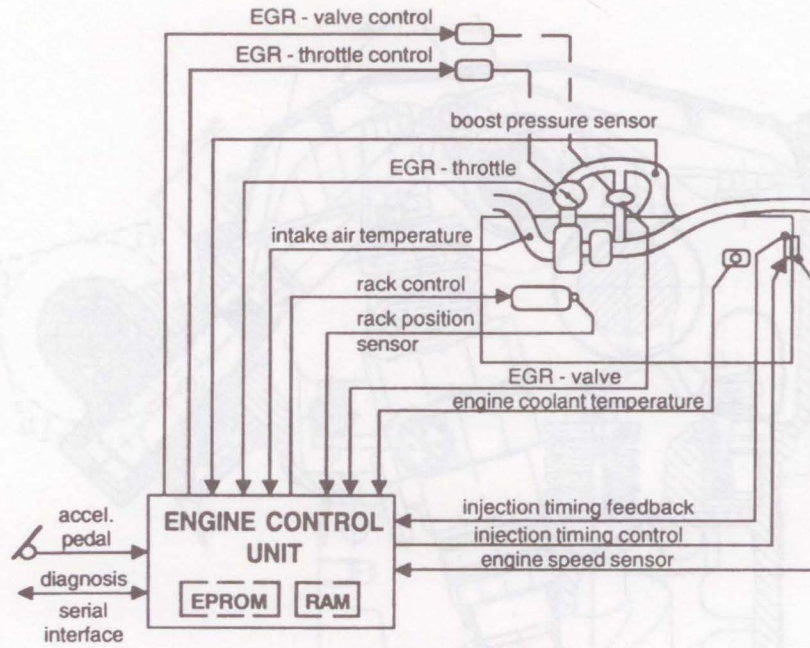


Figure 10 - Engine control system

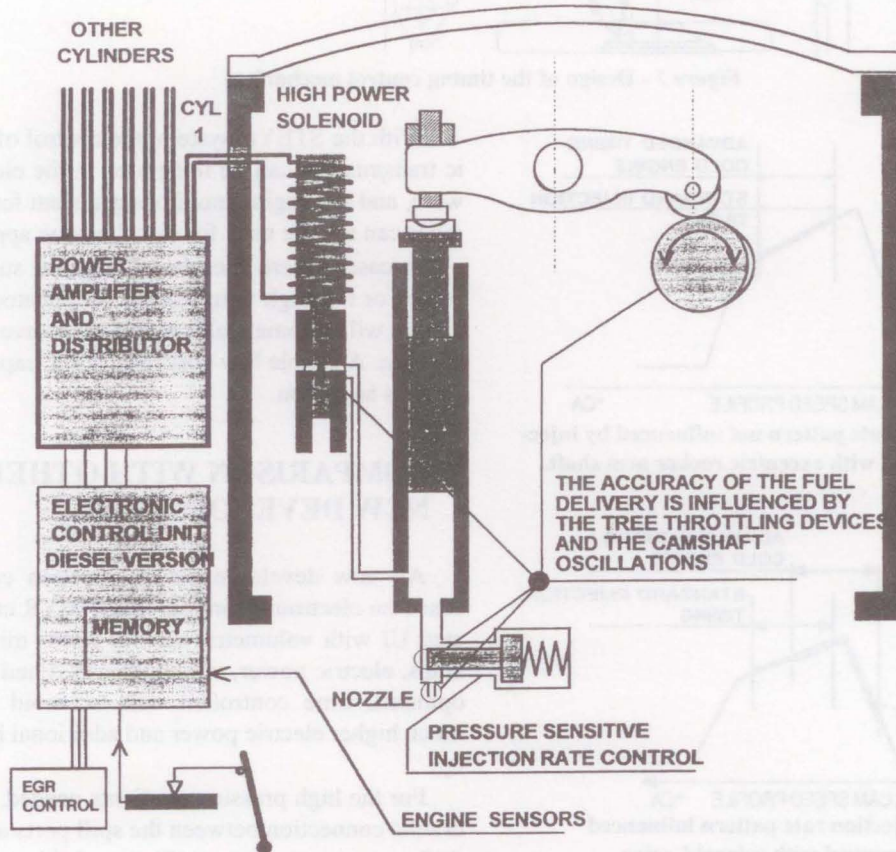


Figure 11 - Unit injector
Electronic solenoid valve unit injector with injection rate control

duce the possibility of high pressure gradients and freedom of cavitation.

For heavy duty truck applications all the described systems give good results. If the engine speed exceeds

3500 rpm the hydraulically operated and electronically controlled system (HUI - Figure 12) will not have a high enough pressure gradient at the end of injection. For light duty truck applications high engine speed has many

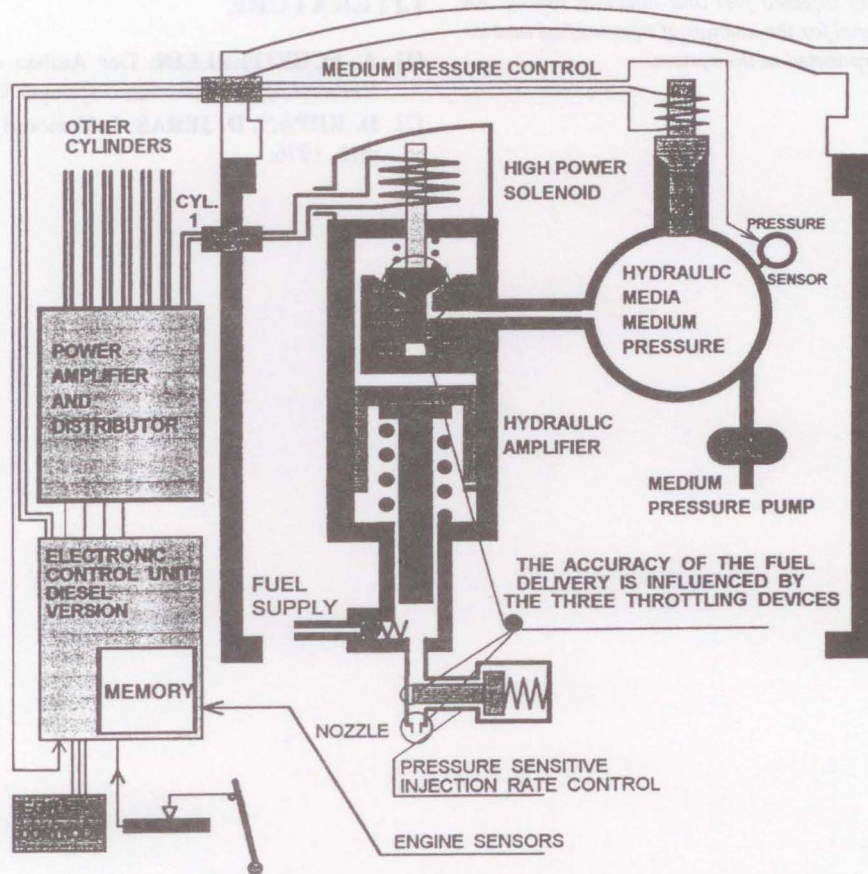


Figure 12 - Unit injector

Electronically controlled common rail Unit Injector with hydraulic amplifier and injection rate control

advantages. The engine weight and the powertrain are similar to gasoline engine driven cars. The camshaft operated and solenoid controlled UI (Figure 11) is very sensitive to nozzle cross section control camshaft oscillations. The injection rate pattern (Figure 9) shows the disadvantages for cold starting with advanced injection timing.

This solution is not very suitable for high speed Diesel Engines.

The hydraulically operated and electronically controlled Unit Injector (HUI - Figure 12) is very sensitive in the accuracy of fuel delivery when injection rate control is applied. That is an additional reason why this system is not suitable for high speed engine applications.

The introduction of additional fuel quantity sensors for each injector can improve this situation.

5. CONCLUSION

The STEYR developed Unit Injector with volumetric delivery control has a high suitability for passenger cars, light duty trucks, and heavy duty applications. The simple and reliable injection rate control reduces the combustion noise and improves the emission results.

For electronic control the gasoline engine hardware can be used. The standard gasoline engine battery capacity is sufficient. The system brings low cost and high suitability for all applications.

SUMMARY

The double-stage nozzle with pressure controlled injection rate control together with the high injection pressure are important factors for good combustion properties in the entire engine map area of DI high speed Diesel Engines.

With the described design a combination of tangential and rectangular deflection of the fuel at the beginning of injection and before entering the nozzle holes is achieved, thus reducing the rate of injection and the penetration of the fuel prior to combustion. The atomization of the fuel during the ignition delay period is also increased. The combination of these properties reduces the ignition delay emissions and combustion noise. After the start of combustion, the nozzle needle opens the fuel orifices completely and the high pressure sprays inject the fuel directly into the already existing flame. The double - guided nozzle needle assures the reproducibility and durability of the said system. The accurate calibration and simple maintenance are incorporated in the described equipment. All electronic and electric components are placed outside of the engine and are not exposed to the hot engine oil. The electronic system

controls the amount of injected fuel and injection timing. An accurate feedback signal for the amount of injected fuel and injection timing is incorporated in the system.

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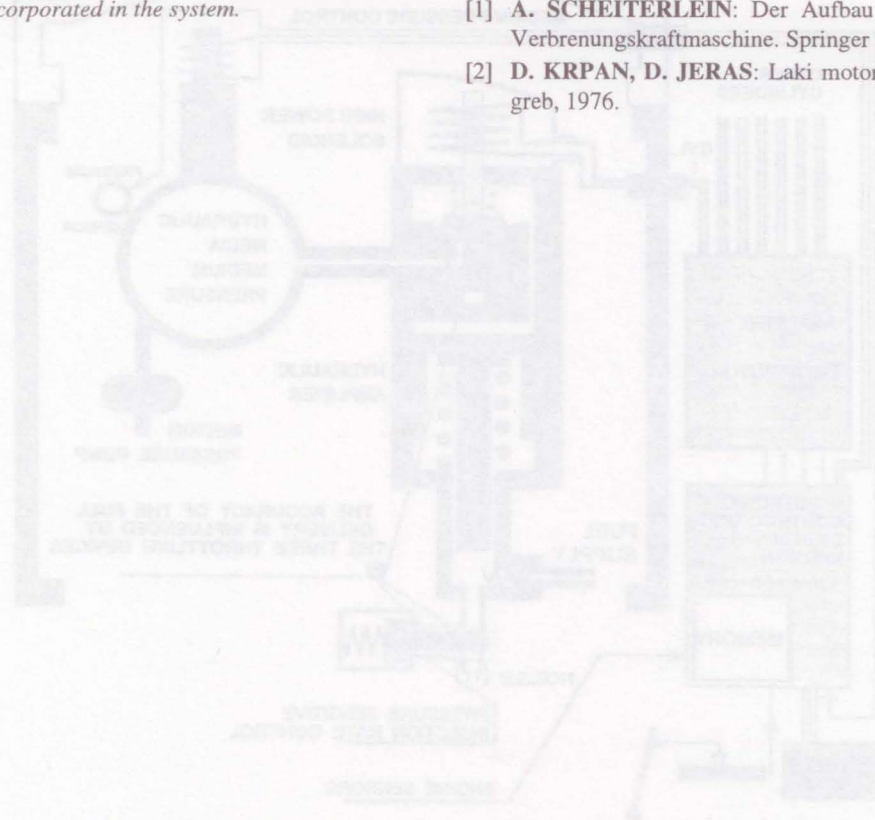


Figure 1 - Fuel system with electronic control and injection timing

The electronic control for the amount of injected fuel and injection timing is incorporated in the system. An accurate feedback signal for the amount of injected fuel and injection timing is incorporated in the system.

ABSTRACT

The article describes a high pressure fuel system for high speed diesel engines with suitable electronic control. The system consists of a high pressure pump, fuel injectors, and an electronic control unit. The control unit receives feedback signals from the injectors and adjusts the fuel flow and injection timing accordingly. The system is designed to provide accurate fuel delivery and timing for high speed diesel engines.

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