Subject: Injector Operation

The injectors we produce deliver diesel fuel directly to the cylinder in volumes ranging from 3-350 cubic millimeters per injection at injection pressures ranging from 30-1800 bar (430-26000 psi) depending on demand. The injectors are controlled directly by an unbalanced 2-way servo valve that receives a pulse width modulated signal from the engine ECM. Fuel injection events last between 1 and 2 milliseconds and occur 3 to 5 times per power stroke of the piston depending on the application. Fuel leaves the injector through an injector nozzle that has between 5-7 orifice openings that measure at most 0.25 square millimeters. The typical service life of the injector takes it through more than a billion open/close cycles.

The injector goes through four phases of operation for each fuel injection event. In the first phase the injector is closed with high pressure fuel applied and the solenoid has not received the pickup current, this is the resting position.

In this resting position the injector is held in hydraulic balance by applying high pressure fuel through the throttling Z-orifice to the top of the valve stem. The pressure against the valve stem is held in a chamber controlled by the A-orifice on top of the valve body. The pressure in the valve chamber acts on the valve stem in a downward direction having the tendency to keep the nozzle needle against its seat. Simultaneously high pressure fuel is applied to the pressure bearing shoulder of the nozzle needle. The pressure against the nozzle needle shoulder is contained in the nozzle annulus and is directed in an upward direction having the tendency to lift the nozzle needle from its seat. Since the two chambers containing high pressure fuel are acting in opposite directions they cancel each other. The nozzle needle is then held against its seat with spring pressure exerted by the nozzle spring. The a-orifice is held closed with spring pressure from the valve spring acting on the valve ball and valve ball holder assembly.
After the pickup current is sent to the solenoid the injector begins the second phase of operation. This second phase is the start of injection, it begins with the pickup current being sent to the solenoid. This pickup current creates an electromagnetic force which is exerted onto the armature to create lift of the ball and ball holder assembly from the A-orifice. This allows the high pressure fuel to escape through the A-orifice into the area above the valve. This escaped fluid is returned to the fuel tank. As the high pressure fuel escapes into the space above the A-orifice the pressure between the valve pressure chamber and the pressure annulus of the nozzle becomes unbalanced. This pressure unbalance allows the nozzle needle to open and fuel injection occurs.

The third phase occurs when the nozzle is fully open. After the start of injection the pickup current is reduced to a holding current. As the valve stem travels upward to the top of the valve pressure chamber it reaches a hydraulic stop created by the fuel flow between the A and Z orifice. The fuel flow between the A and Z orifice also controls the rate of ascent of the valve stem and therefore the rate at which the nozzle needle moves. The nozzles fully open position is reached when the valve stem is resting against the hydraulic stop in the valve pressure chamber. At this fully open phase the pressure balances in the injector reach an equilibrium point. The total amount of fuel delivered into the cylinder at this point becomes directly proportional to the time the nozzle needle is opened. It is important to note that the nozzle needle does not reach its fully open position at every injection event. Each original equipment manufacturer has independent fuel maps based on the fuel needs of the engine at specific load points. Some of these points use shorter trigger periods than what is required for the nozzle to reach its fully open position.

The fourth and final phase of the injection cycle occurs when the holding current is dropped. At this point there is no longer an electromagnetic force acting on the armature to create lift of the valve ball and valve ball holder. This allows the valve spring to return the ball and ball holder back to the resting position covering the A-orifice. Once the A-orifice is covered, fuel fills the valve pressure chamber through the Z-orifice. The size of the Z-orifice controls the rate of descent of the valve stem and nozzle needle. Once the pressure in the nozzle pressure annulus and the valve pressure chamber are equal the nozzle spring holds the nozzle needle on its seat and injection stops.