

DRAFT extract from Marine Diesel Basics 2 - How Things Work

© 2024 Marine Diesel Basics

Diesel Fuel

Fuel Injection

Diesel engines work on the principle that fuel will ignite if injected into air that is hotter than the liquid's auto-ignition temperature. In order to inject diesel into the hot (compressed) air in an engine's cylinders, the fuel must be at a higher pressure than the air in the cylinders. This challenge proved very difficult to overcome until Robert Bosch produced the first practical injection pump in 1927 using a barrel and helix plunger.

Since then, fuel injection on diesel engines has changed greatly in the last 90 years – from fully mechanical systems, to fuel systems fully operated by electricity and a computer. On fully mechanical engines, the throttle and governor control engine speed, and therefore camshaft speed, and the camshaft controls the operation and timing of the lift pump, injection pump and injectors. On fully electronically-controlled engines, a computer calculates fuel pressure and injection timing and operates the high pressure pump and the injectors, often with several bursts of fuel within a single combustion event.

See *Working Principle of a Diesel Engine* on page xx

Functions of the Fuel Injection System

Whether fully mechanical or fully electronically-controlled, the functions of the fuel injection system on a diesel engine are:

- raise the fuel pressure to the pressure needed to inject diesel into the cylinders
- meter the exactly amount of fuel to be injected for each power stroke
- time when diesel is injected into the cylinders
- atomize the diesel so effectively so that it ignites immediately and burns completely to extract as much energy from the fuel as possible and minimize toxic emissions
- remove excess fuel, and heat and any air, from the injectors to return to the fuel tank (which acts as a heat sink) or to the secondary fuel filter

The speed and power of a diesel engine is controlled by the timing and amount of fuel injected into each cylinder (unlike a gasoline engine where these are controlled by controlling (*throttling*) the air intake).

Many fuel injection systems have been developed, with a steady evolution towards higher and higher injection pressures and to full electronic control, which offers improved fuel economy and lower emissions. The fuel injection systems that have had widespread, commercial adoption and are installed on most marine diesel engines include:

- **pump–line–nozzle (PLN)** – fully mechanical, with an inline pump housing a row of plungers sending pulses of fuel under high pressure through separate lines/pipes to the injectors
- **distributor** – single pump and either mechanically or electronically controlled fuel metering and governor supplying pulses of fuel under high pressure through separate lines/pipes to the injectors
- **unit injector** – unit injector system (UIS) and unit pump system (UPS). High fuel pressure is generated at or very close to each injector
- **common rail** – single pump charges a single high pressure tank/reservoir (*rail*) which supplies fuel to electronically-controlled injectors

DRAFT extract from Marine Diesel Basics 2 - How Things Work
© 2024 Marine Diesel Basics

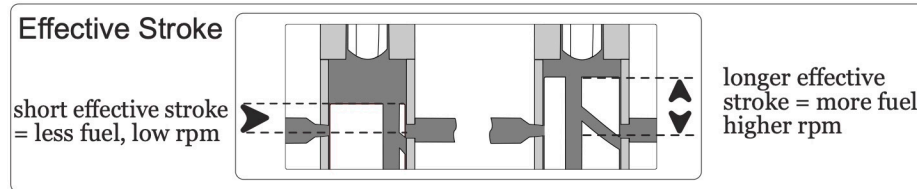
Fuel Injection

Diesel injection pumps are precision instruments with many parts, including multiple springs, installed and timed to work together with very close tolerances. For example, the gap between a plunger and its barrel may be less than two microns. When correctly adjusted, injection pumps are very reliable and robust and should not need adjustment, except for periodic maintenance. The engine's idle speed and maximum rpm are usually factory-set or set by a mechanic. Best practice is to keep the injection pump clean and to avoid altering settings, except to loosen nuts at the injectors to bleed air from the injection pipes, if not self-bleeding.

In the event of a problem in the fuel supply, the priority is to isolate the problem without jumping to conclusions or dismantling the injection pump. If the problem is confirmed to be in the pump, best practice is to send the pump to an injection pump calibration shop which has the correct tools and equipment for a thorough overhaul.

What is Effective Stroke?

In an inline injection pump, the stroke of the plunger (the distance it travels up and down) is fixed. However, rotating the plunger changes the distance between the top of the plunger and where the helix opens to the spill port. This distance is called the *effective stroke* because it describes the length of time the plunger can build pressure and the amount of fuel that can be injected into each cylinder as the plunger is moving upwards. Once the spill port opens, fuel injection stops because the upwards movement of the plunger is no longer building pressure.



Sample Fuel Pressures Generated by Fuel Injection Systems

| type | Bar | Megapascal MPa | psi |
|-------------------|------------|----------------|----------------|
| Inline PLN | 800 - 1200 | | 5,800 - 19,500 |
| Unit Injector | 2200 | 250 | 30,000 |
| HEUI | | 162 | 23,500 |
| Unit Pump System | 1800 | | 26,000 |
| DB2 | | | 6,700 |
| VE | 1800 | | 26,000 |
| CRDI Common Rail | 690 - 2000 | | 20 - 29,000 |
| solenoid injector | 2500 | 250 | 36,000 |
| piezo injector | 2700 | 270 | 39,000 |

Source: engine and pump manufacturers

NOTE: Constant pump development over decades means that the fuel pressures generated have increased with each generation of the same pump design.

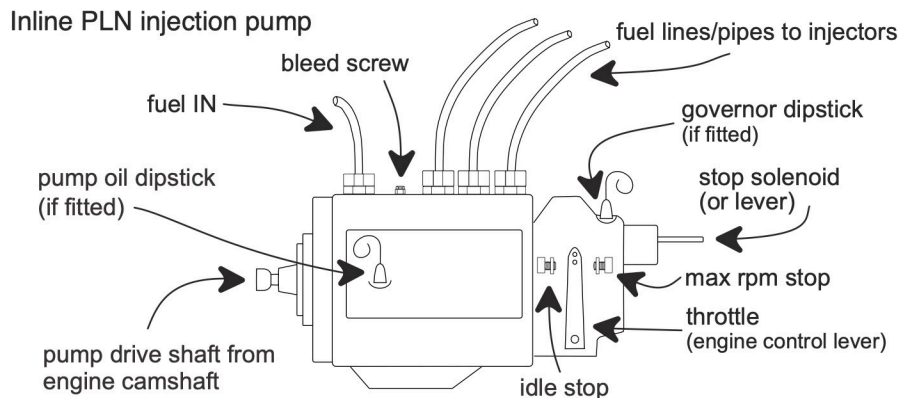
DRAFT extract from Marine Diesel Basics 2 - How Things Work
© 2024 Marine Diesel Basics

Diesel Fuel

Pump-Line-Nozzle (PLN) Pump, Helix, Inline, Jerk Pump

Diesel engines with no electronics use a mechanically-driven and mechanically-controlled injection pump and injectors. The pump provides pulses of pressurized fuel through separate metal pipes (lines), to each injector and cylinder. The inline pump:

- pressurizes the diesel fuel
- measures (*meters*) the amount of fuel to be injected by the injectors, according to the position of the engine throttle
- controls the timing of injection (just before top-dead-centre on each compression stroke)



How an Inline Pump Works

There are many different models of inline pumps, each with variations of designs of pump body, plunger and barrels, fuel delivery valves and ball bearings, fuel control racks, retainers, roller tappets. However, the operating principles and basic components are the same across the range of inline jerk pumps.

The key components of an inline fuel injection pump are the *barrel* and the *plunger*; one pair (set) for each cylinder of the engine. The plunger is mated to its barrel with an extremely close fit – about 2 microns. Heat and grease in the palm of the hand can be enough to make a plunger too tight fit in its barrel. Diesel in the barrel both lubricates and seals the gap with the plunger. This is one of the reasons why diesel engines require very clean diesel fuel.

Plungers on most marine diesel engines have one vertical and one diagonal (*helix*) cut which meter the quantity of fuel to be injected and control for how long fuel is injected. Rotating the plunger changes the position of the cuts relative to the fuel spill port, thus supplying more, or less, fuel to the engine cylinder to increase or decrease rpm, or to stop the engine. All the plungers in a pump rotate in unison and are controlled by an arm (*rack*) connected to the governor and the throttle (engine control lever).

Each plunger also moves up and down in the barrel which pressurizes the fuel. As the pump's camshaft turns (at half engine rpm), the lobes (*eccentrics*) on the shaft push up the plunger inside its barrel in the firing order of the engine (eg. 1-3-4-2). This pressurizes the fuel and when the pressure overcomes the resistance of a spring, a delivery valve opens and a pulse (wave) of fuel is sent through the steel pipe to an injector in the engine's firing order.

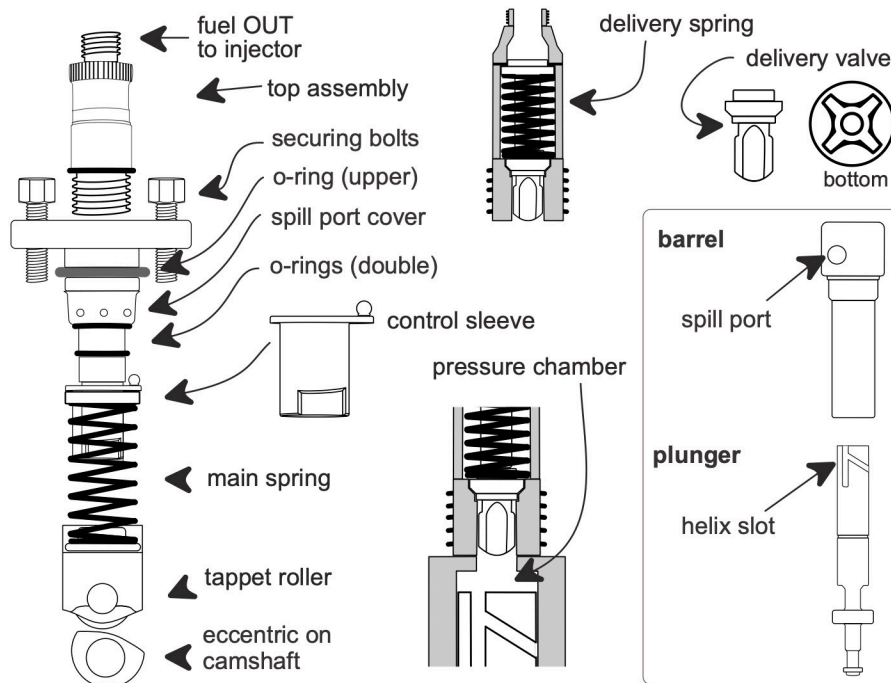
DRAFT extract from Marine Diesel Basics 2 - How Things Work
© 2024 Marine Diesel Basics

Inline Fuel Injection

Fuel pressure falls and injection stops as soon as the helix cut in the plunger reaches the fuel spill port; the timing of this happens (and therefore how much fuel is injected into a cylinder) depends on the position of the helix relative to the fuel spill port. The plunger continues to move up the barrel to TDC (top dead centre) but pressure stays low and there is no fuel injection.

The fill port is uncovered (opens) as the plunger moves back down the barrel drawing fresh fuel into the pressure chamber and a new fuel cycle begins.

See *Effective Stroke*, page 159



- **control sleeve** is connected to the rack and rotates the plunger (and helix) according to the governor or the position of the engine throttle
- **delivery spring** closes the delivery valve as soon as fuel pressure drops
- **delivery valve** (check valve) lifts when the fuel pressure overcomes the delivery spring
- **helix slot** meters amount of fuel injected into the cylinder by allowing fuel to spill from pressure chamber according to the setting of the control rack
- **main spring** forces the plunger to move down as the camshaft rotates
- **o-rings (double)** isolate diesel fuel from the pump's lubrication oil
- **o-rings (upper)** seals diesel fuel inside the pump assembly
- **pressure chamber** – the space between the top of the plunger and the bottom of the delivery valve, where the fuel is pressurized
- **securing bolts** fasten the barrel-plunger assembly to the pump housing
- **spill port** drains fuel – dropping fuel pressure – after the *injection event*
- **spill port cover** protects soft metal of aluminum pump assembly from erosion from the discharge of diesel high pressure
- **tapper roller** (follower) follows the eccentric on the cam shaft, pushing the plunger up and down by about 12 mm (the *stroke*)