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## **2007 Engine Management**

**Model: All with 6-Cylinder for 2007**

**Production: from 9/2006**

# **OBJECTIVES**

After completion of this module you will be able to:

- Describe the changes to the new engine management systems
- Understand the operation of the HPI system
- Understand parallel turbocharging
- Understand the N51 SULEV II engine features

## NG6 Engine Management

To accompany the new NG6 engines, 2 new versions of engine management systems are introduced for 2007. Both systems are variations of the MSV70 engine management which is familiar from the N52 engine for 2006.

The two systems are as follows:

- MSV80 Engine Management for N52KP and N51 (SULEV II) engines
- MSD80 Engine Management for the N54 engine

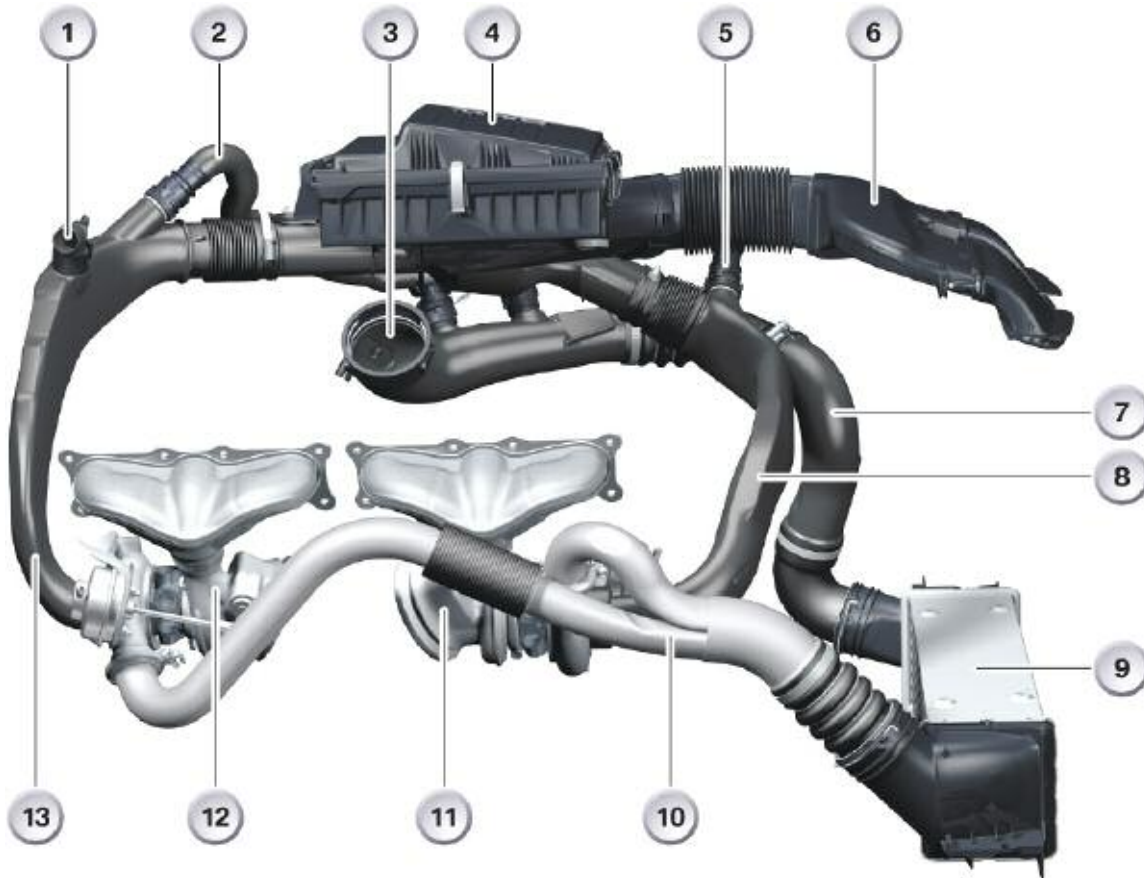
Both systems use enhanced processing and are adapted to each of the specific engine applications. Both of the control modules are identical and adapted from MSV70.



The information contained within this training module is only intended to review the updates to the engine management systems as it applies to the N54, N52KP and N51 engines. For more detail on the NG 6 engines beginning with the N52, refer to the training module “ST501 - New Engine Technology”.

# Air Management

With regard to the N54 engine, the air intake ducting plays a significant role due to the requirements for a turbocharged engine. In principle, the energy of the escaping exhaust gases is utilized to “precompress” the inducted fresh air and thus introduce a greater air mass into the combustion chamber. This is only possible if the air intake ducting is leak-free and installed properly.



Index	Explanation	Index	Explanation
1	PTC heater, blow-by gases (in turbo mode)	8	Charge air suction line, bank 1
2	Recirculated air line, bank 2	9	Intercooler
3	Connecting flange, throttle valve	10	Charge air manifold
4	Air cleaner	11	Turbocharger, bank 1
5	Recirculated air line, bank 1	12	Turbocharger, bank 2
6	Air-intake snorkel	13	Charge air suction line, bank 2
7	Charge air pressure line		

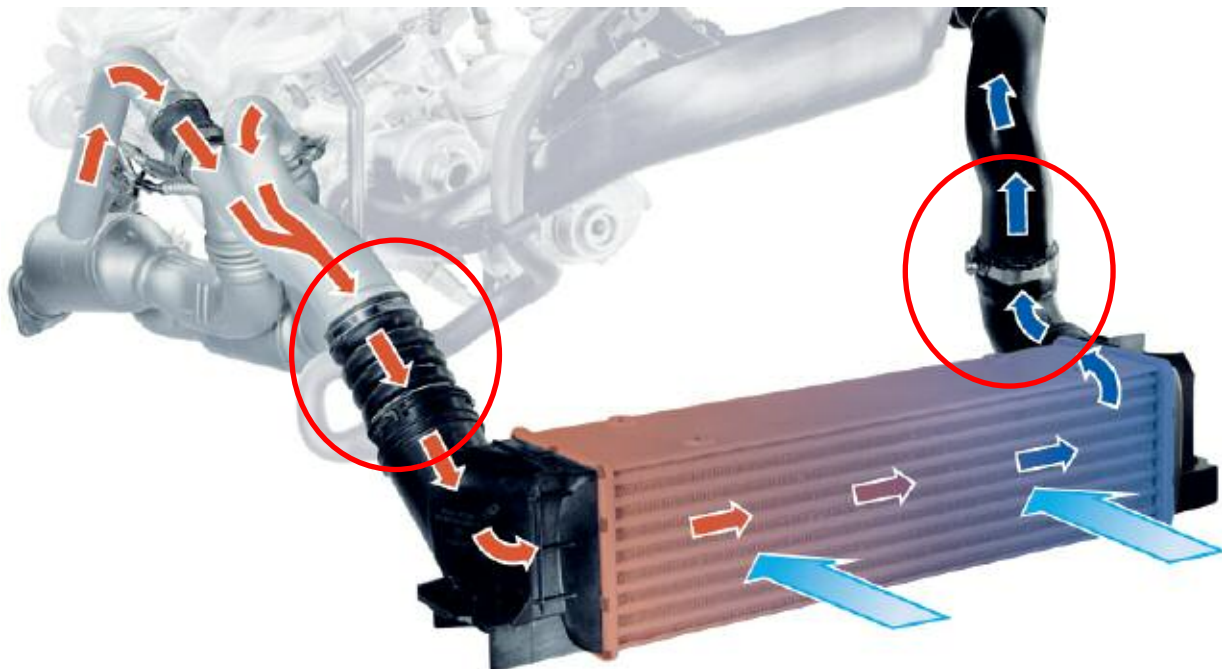
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It is important to note, when carrying out work on the air-intake ducting, it is very important to ensure that the components are installed in the correct positions and that all pipes are connected up with tight seals.

A leaking system may result in erroneous boost pressure. This would be detected by the engine management system and ultimately result in in “limp-home” operation. This would be accompanied by a noticeable loss of engine power.

For some of the connections, there are special tools designed to connect and disconnect some of the ducting to ensure proper “leak-free” connections.

### Example of Intercooler Connections

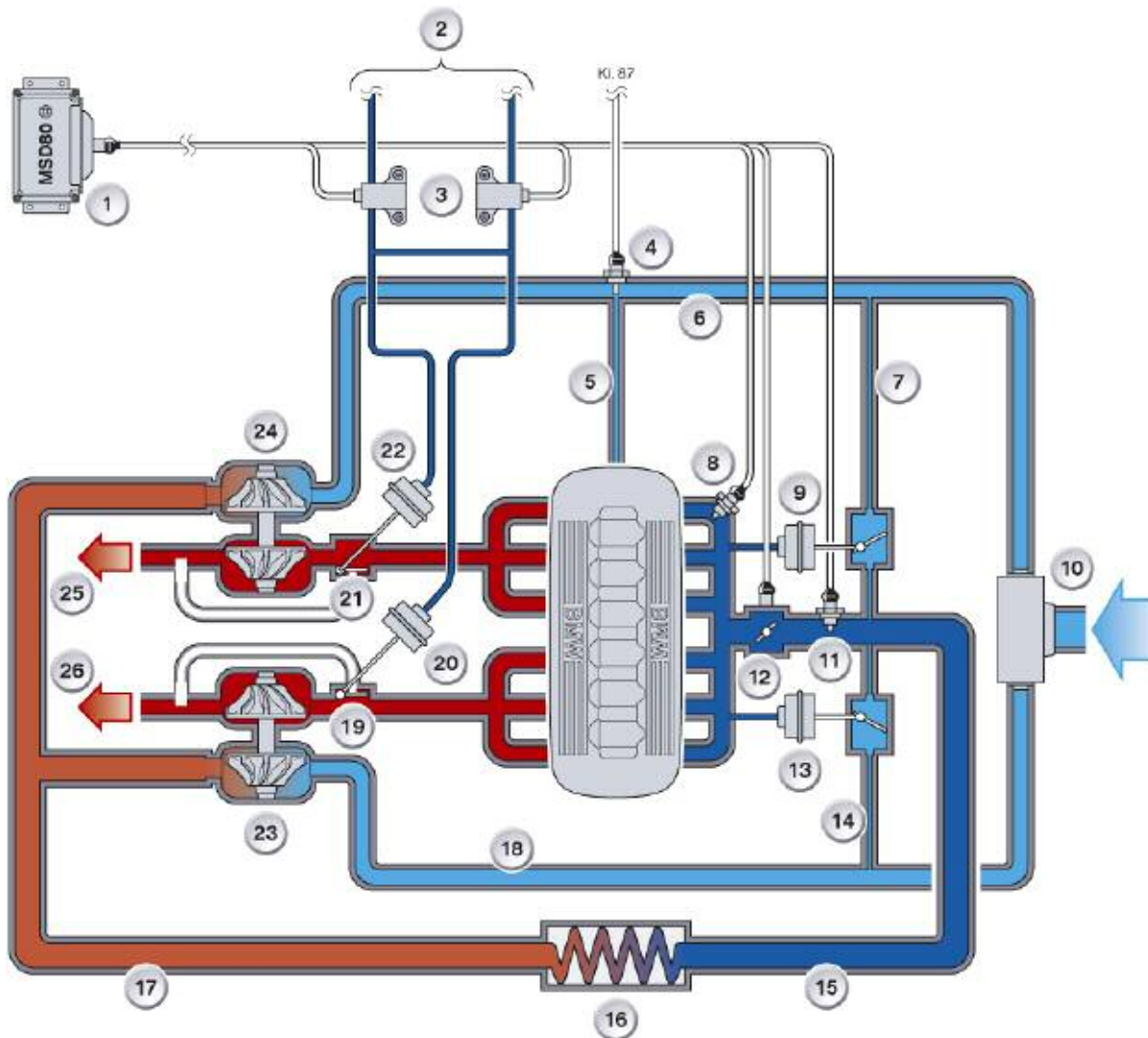


## Air Ducting Overview

The fresh air is drawn in via the air cleaner (10) and the charge-air suction lines (6 + 18) by the compressors of turbochargers (23 + 24) and compressed.

Because the turbochargers can get very hot during operation, they are connected with the engine's coolant and engine-oil circuits. The charge air is greatly heated when compressed in the turbocharger, making it necessary for the air to be cooled again in an intercooler (16).

The compressed and cooled charge air is routed from the intercooler via the throttle valve (12) into the intake manifold. The system is equipped with several sensors and actuators in order to ensure that the load of fresh air is optimally adapted to the engine's respective operating conditions. How these complex interrelationships are controlled is discussed in the following.





<b>Index</b>	<b>Explanation</b>	<b>Index</b>	<b>Explanation</b>
1	MSD80 Engine control module	14	Recirculated-air line, bank 1
2	Lines to vacuum pump	15	Charge air pressure line
3	Electro-pneumatic pressure transducer	16	Intercooler
4	PTC heater, blow-by gases	17	Charge air manifold
5	Blow-by line turbocharged operation mode	18	Charge air suction line, bank 1
6	Charge air suction line, bank 2	19	Wastegate flap, bank 1
7	Recirculated-air line, bank 2	20	Wastegate actuator, bank 1
8	Intake manifold pressure sensor	21	Wastegate flap, bank 2
9	Blow-off valve, bank 2	22	Wastegate actuator, bank 2
10	Air cleaner	23	Turbocharger, bank 1
11	Charge air pressure and temperature sensor	24	Turbocharger, bank 2
12	Throttle valve	25	To catalytic converter, bank 2
13	Blow-off valve, bank 1	26	To catalytic converter, bank 1

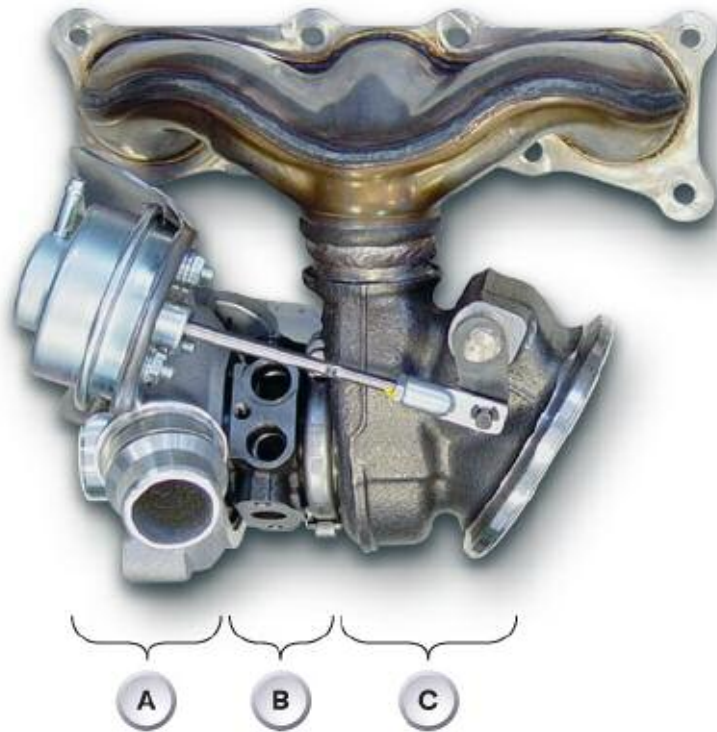
## Exhaust Gas Turbocharging

The turbocharger is driven by the engine's exhaust gases, i.e. exhaust gases under pressure are routed by the turbocharger turbine and in this way delivers the motive force to the compressor, which rotates on the same shaft.

It is here that the induction air is precompressed in such a way that a higher air mass is admitted into the engine's combustion chamber. In this way, it is possible to inject and combust a greater quantity of fuel, which increases the engine's power output and torque.

The turbine and the compressor can rotate at speeds of up to 200,000 rpm. The exhaust inlet temperature can reach a maximum of 1050°C. Because of these high temperatures, the N54 engine's turbochargers are not only connected with the engine-oil system but also integrated in the engine-coolant circuit.

It is possible in conjunction with the N54 engine's electric coolant pump even after the engine has been switched off to dissipate the residual heat from the turbochargers and thus prevent the lube oil in the bearing housing from overheating.



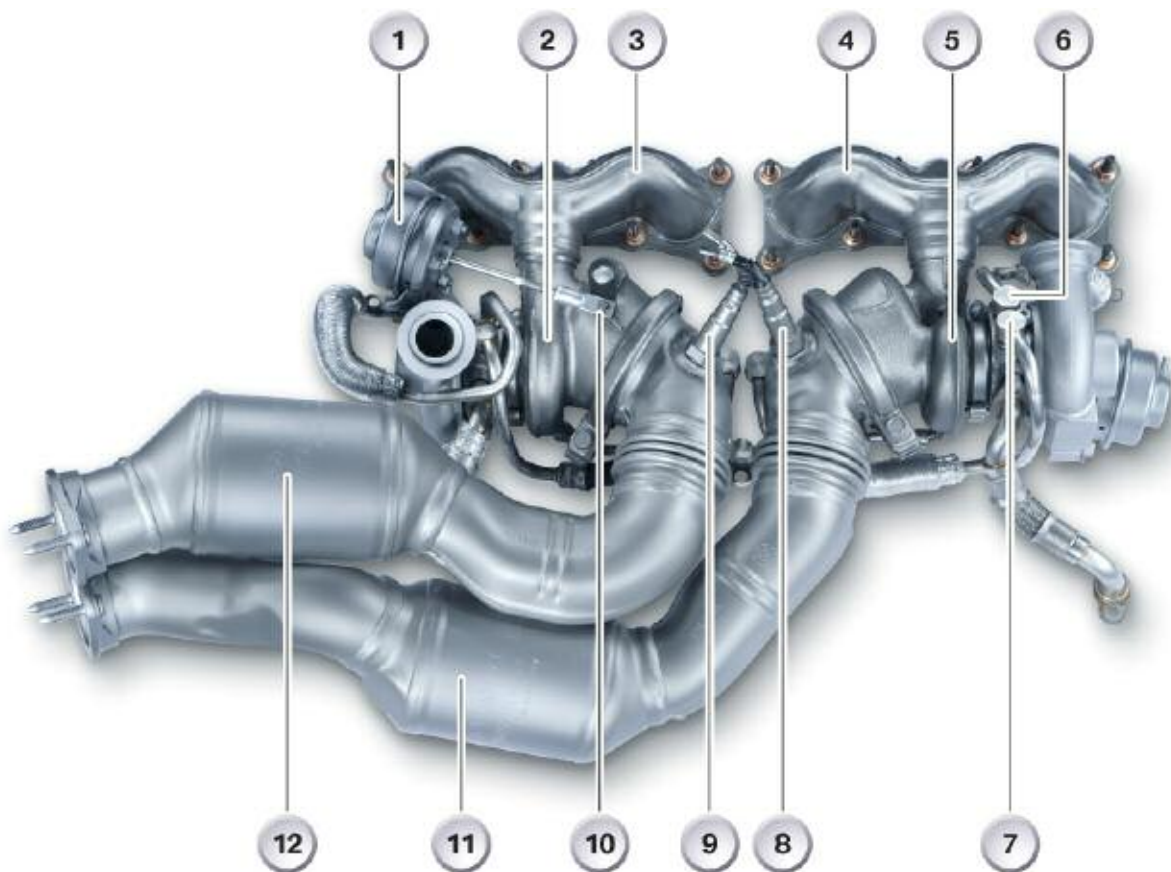
Index	Explanation
A	Compressor
B	Cooling/lubrication
C	Turbine

## Bi-turbocharging

Utmost importance is attached to turbocharger response in the N54 engine. A delayed response to the driver's command, i.e. the accelerator-pedal position, is not acceptable. The driver therefore must not experience any so-called "turbo lag".

This requirement is met in the N54 engine with two small turbochargers, which are connected in parallel. Cylinders 1, 2 and 3 (bank 1) drive the first turbocharger (5) while cylinders 4, 5 and 6 (bank 2) drive the second (2).

The advantage of a small turbocharger lies in the fact that, as the turbocharger runs up to speed, the lower moment of inertia of the turbine causes fewer masses to be accelerated, and thus the compressor attains a higher boost pressure in a shorter amount of time.



Index	Explanation	Index	Explanation
1	Wastegate actuator, bank 2	7	Coolant supply
2	Turbocharger, bank 2	8	Planar broad-band oxygen sensor, bank 1
3	Exhaust manifold, bank 2	9	Planar broad-band oxygen sensor, bank 2
4	Exhaust manifold, bank 1	10	Wastegate actuating lever
5	Turbocharger, bank 1	11	Catalytic converter, bank 1
6	Coolant return	12	Catalytic converter, bank 2

## Boost-pressure Control

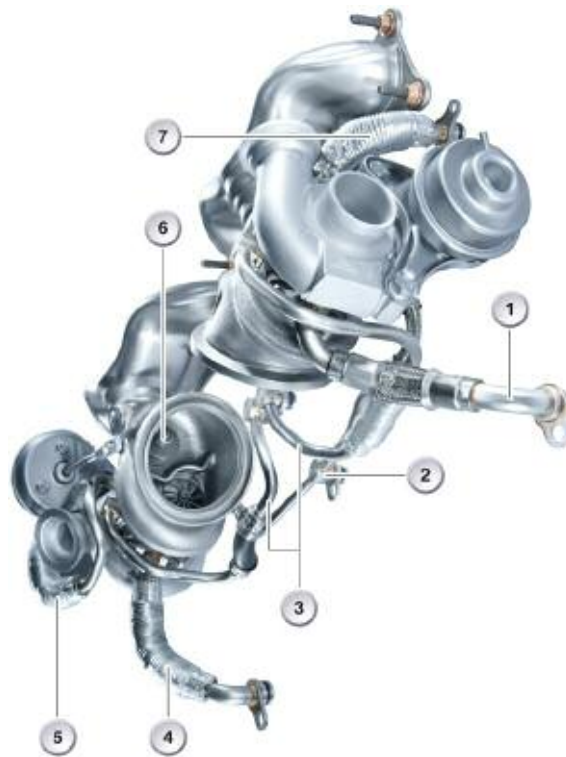
The boost pressure of the turbochargers is directly dependent on the flow of exhaust gas which reaches the turbocharger turbines. Both the velocity and the mass of the exhaust-gas flow are directly dependent on engine speed and engine load.

The engine-management system uses wastegate valves to control the boost pressure. These valves are operated by vacuum-pressure actuators, which are controlled by electropneumatic pressure transducers via the engine-management system.

The vacuum pressure is generated by the permanently driven vacuum pump and stored in a pressure accumulator. The system is designed to ensure that these loads and consumers do not have a negative influence on the brake-boost function.

The exhaust-gas flow can be completely or partially directed to the turbine wheel with the wastegate valves. When the boost pressure has reached its desired level, the wastegate valve begins to open and direct part of the exhaust-gas flow past the turbine wheel.

This prevents the turbine from further increasing the speed of the compressor. This control option allows the system to respond to various operating situations.



Index	Explanation	Index	Explanation
1	Oil return, bank 1	5	Coolant return, bank 2
2	Oil supply	6	Wastegate valve
3	Coolant supply	7	Coolant return, bank 1
4	Oil return, bank 2	8	

---

In the idle phase, the wastegate valves of both turbochargers are closed. This enables the full exhaust-gas flow available to be utilized to speed up the compressor already at these low engine speeds.

When power is then demanded from the engine, the compressor can deliver the required boost pressure without any noticeable time lag. In the full-load situation, the boost pressure is maintained at a consistently high level when the maximum permissible torque is reached by a partial opening of the wastegate valves. In this way, the compressors are only ever induced to rotate at a speed which is called for by the operating situation.

The process of the wastegate valves opening removes drive energy from the turbine such that no further increase in boost pressure occurs, which in turn improves overall fuel consumption.

At full-load the N54 engine operates at an overpressure of up to 0.8 bar in the intake manifold.

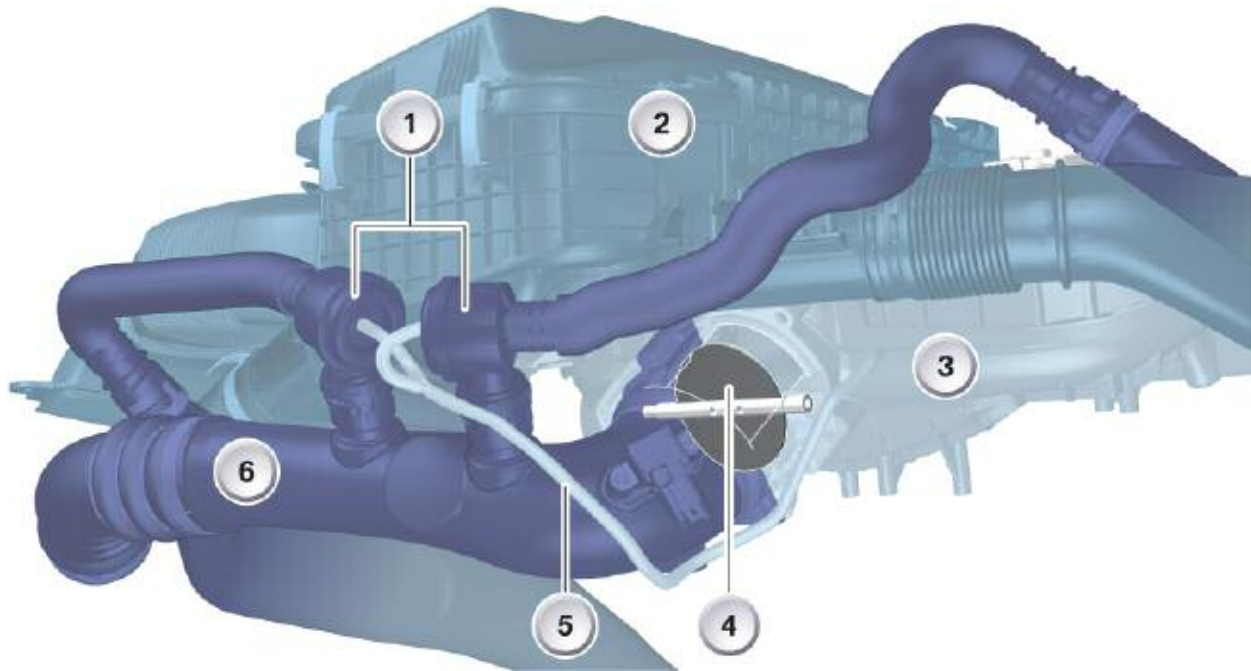
## Blow-off Control

The blow-off valves in the N54 engine reduce unwanted peaks in boost pressure which can occur when the throttle valve closes quickly. They therefore have an important function with regard to engine acoustics and help to protect the turbocharger components.

A vacuum pressure is generated in the intake manifold when the throttle valve is closed at high engine speeds. This leads to a build-up of high dynamic pressure after the compressor which cannot escape because the route to the intake manifold is blocked.

This leads to a "pumping up" of the turbocharger which means that:

- a clearly noticeable, disruptive pumping noise can be heard,
- and this pumping noise is accompanied by a component-damaging load being exerted on the turbocharger, since high-frequency pressure waves exert axial load on the turbocharger bearings



Index	Explanation	Index	Explanation
1	Blow-off valves	5	Throttle valve
2	Air cleaner (ambient pressure)	6	Control line, blow-off valves
3	Intake manifold	7	Charge air pressure line

---

The blow-off valves are mechanically actuated spring-loaded diaphragm valves which are activated by the intake-manifold pressure as follows:

In the event of a pressure differential before and after the throttle valve, the blow-off valves are opened by the intake-manifold pressure and the boost pressure is diverted to the intake side of the compressor. The blow-off valves open starting from a differential pressure of 0.3 bar. This process prevents the disruptive and component-damaging pumping effect from occurring.

The system design dictates that the blow-off valves are also opened during operating close to idle (pressure differential  $P_{\text{charger}}/P_{\text{suction}} = 0.3$  bar). However, this has no further effects on the turbocharging system.

The turbocharger is pressurized with the full exhaust-gas flow at these low speeds and already builds up a certain level of induction-air precharging in the range close to idle. If the throttle valve is opened at this point, the full boost pressure required is very quickly made available to the engine.

One of the major advantages of the vacuum pressure-actuated wastegate valves is that they can be partially opened in the mid-range in order not to allow excessive induction-air precharging to the detriment of fuel consumption. In the upper load range, they assume the required control position corresponding to the necessary boost pressure.

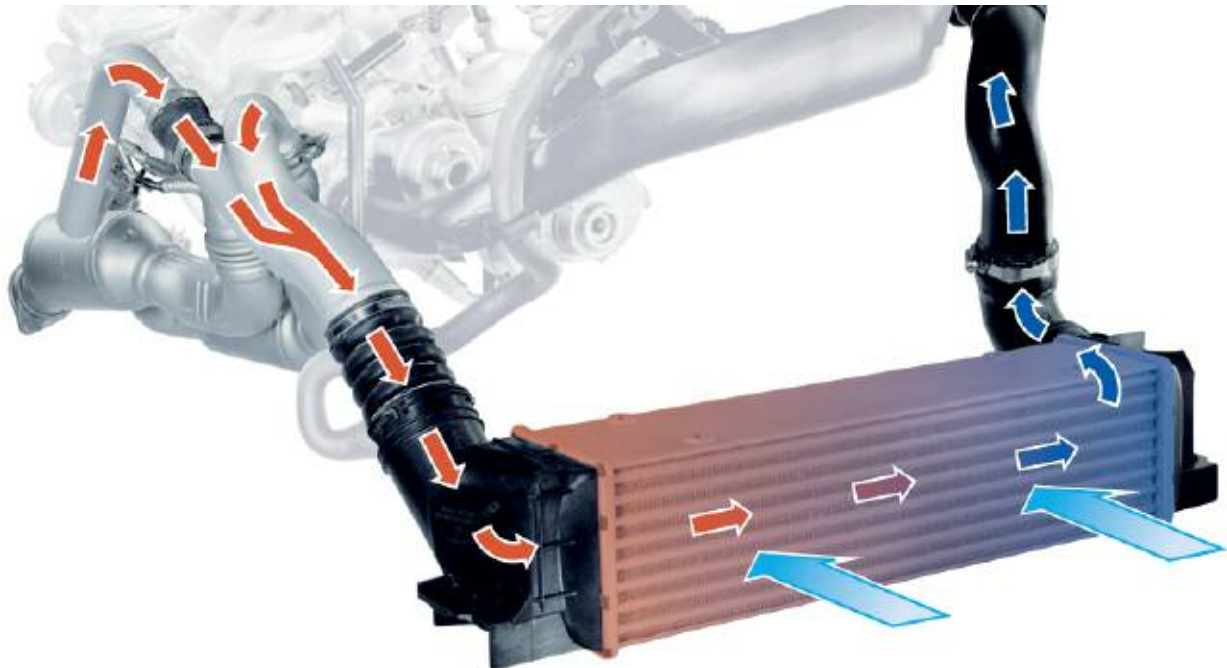


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## Charge-air Cooling

Cooling the charge air in the N54 engine serves to increase power output as well as reduce fuel consumption. The charge air heated in the turbocharger by its component temperature and by compression is cooled in the intercooler by up to 80°C.

This increases the density of the charge air, which in turn improves the charge in the combustion chamber. This results in a lower level of required boost pressure. The risk of knock is also reduced and the engine operates with improved efficiency.



## Load Control

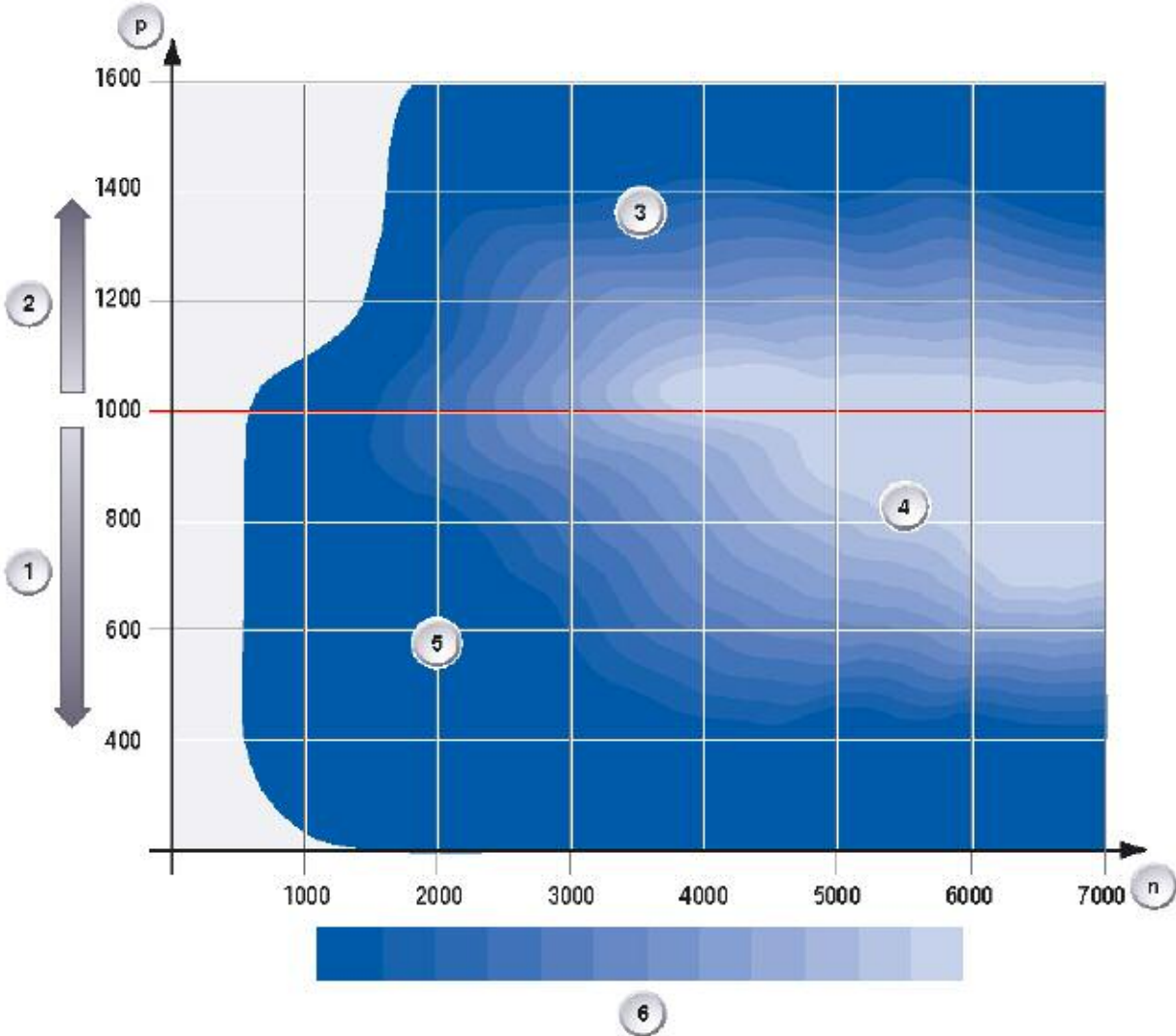
Load control of the N54 engine is effected by means of the throttle valve and the waste gate valves.

The throttle valve is the primary component in this process. The wastegate valves are actuated to bring about a fine tuning of the boost pressure. At full load the throttle valve is completely open and load control is undertaken by the wastegate valves.

The load-control graphic shows that the wastegate valves are integrated in load control in all operating situations of the N54 engine on the basis of map control.



### Load Control Overview



Index	Explanation	Index	Explanation
n	Engine speed in RPM	3	Wastegate controlled as a function of boost pressure
p	Absolute pressure in the intake in millibar	4	Wastegate partially opened
1	Naturally aspirated engine operation	5	Wastegate closed
2	Turbocharged operation	6	Dark = Wastegate fully closed Light = Wastegate fully open

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## Controlled Variables

The following variables, among others, influence control of the N54 engine's boost pressure:

- Intake-air temperature
- Engine speed
- Throttle-valve position
- Ambient pressure
- Intake-manifold pressure
- Pressure before the throttle valve (reference variable)

The electropneumatic pressure transducers are activated by the engine control unit on the basis of these variables. The result of this activation can be checked from the boost pressure achieved, which is measured before the throttle valve.

There follows a comparison of the boost pressure achieved with the setpoint data from the program map, which can if necessary give rise to an activation correction. The system therefore controls and monitors itself during operation.

### ■ Limp-home Mode

In the event during operation of malfunctions, implausible values or failure of any of the sensors involved in turbocharger control, activation of the wastegate valves is shut down and the valve flaps are thus fully opened. Turbocharging ceases at this point.

The list below sets out those components or functional groups of the N54 engine in which a failure, a malfunction or implausible values result in boost-pressure control being deactivated. The driver is alerted to a fault of this type via an EML indication.

- High-pressure fuel system
- Inlet VANOS
- Exhaust VANOS
- Crankshaft sensor
- Camshaft sensor
- Boost-pressure sensor
- Knock sensors
- Intake-air temperature sensor

One principle of vehicle repair is particularly important in this respect:

**It is important to focus on the causes rather than the effects.**

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With regard to the diagnosis and subsequent repair of turbocharging components, it is important to ensure that they are also actually identified as defective components with the diagnostic technology available.

It is always vital to ensure that the cause of the fault is determined and rectified and that if necessary work is not carried out on symptoms of fault consequences. Thus, for instance, a leaking flange on the intercooler can have far-reaching consequences.

The N54 engine also is governed by three golden rules of procedure:

1. Do not rashly trace loss of power and engine malfunctions back to the turbocharger. To avoid the replacement of turbochargers which are in perfect working order, the following should be observed:

When blue smoke emerges from the exhaust system, check whether the air cleaner is contaminated or the engine is consuming too much oil because of wear. Or, if the crankcase ventilation system is faulty. Only then resort to checking the turbocharger. If the turbocharger is running too loud, inspect all the connections on the turbocharger pressure side. If black smoke or a loss of power is detected, in this case too check the engine and the connecting pipes first.

2. Main causes of turbocharger damage:

- Insufficient lubrication and consequently bearing failure. Compressor and turbine wheels will grind in the housings, the seals will be damaged and the shaft may also shear off.
- Foreign bodies damage the turbine and impeller. The resulting imbalance will reduce efficiency and may cause the rotors to burst.
- Contaminated lube oil causes scoring on shaft journals and bearings. Oilways and seals will become clogged and cause high oil leakage losses. Elements entering the turbocharger system from the outside such as sand, dirt, screws and the like will be trapped by a filter before the compressor.

Service the filters at regular intervals (service intervals). Take care to keep the clean-air area of the air cleaner and the air ducting to the compressors clean and free from all types of particulates.

3. Do not make any alterations to the turbocharger. Never attempt to alter the boost-pressure control linkage. The turbocharger has been optimally configured at the factory. If the turbocharger operates at higher boost pressures than permitted by the engine manufacturer, the engine may run hot and pistons, cylinder heads or engine bearings may fail, or the safety function of the engine electronics may respond and activate the engine's limp-home program.

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### **Air Management N52KP and N51**

As far as the air management system on the N52KP and N51 engines is concerned, the previous intake manifold system on the N52 is carried over. Depending upon application, the engines will use the 3-stage DISA or the single stage (No DISA) intake manifold.

For more information on the DISA system refer to the previous training material in the training course “ST501 - New Engine Technology”.



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## Throttle Valve

On all variants of the new NG6 engines, the throttle valve has been upgraded and is now referred to as EGAS 08 by Siemens/VDO. The throttle valve flap itself is now made from plastic.

The primary difference between the new EGAS throttle as compared to the previous unit is the throttle feedback system. The previous system used a potentiometer, whereas the new throttle uses a “contactless” system featuring magneto-resistive technology. The technology is similar to that used on the eccentric shaft sensor on Valvetronic systems.



The magneto-resistive sensors are integrated into the housing cover. This sensor allows throttle position feedback to achieve an extremely high degree of accuracy.

In the throttle valve, these sensors permit 100 times the power than the previous potentiometers and therefore ensure reliable signal progression to the DME. The sensors are also non-wearing. The one sensor outputs the analog signal in the range from 0.3 to 4.6 V and the other sensor inverts it again from 4.6 to 0.3 V.

By forming the differential, the ECM calculates the plausibility of the signal. A new plug ensures optimum contact quality. In this plug, the contact force acting on the pin is decoupled from the plug-in force.

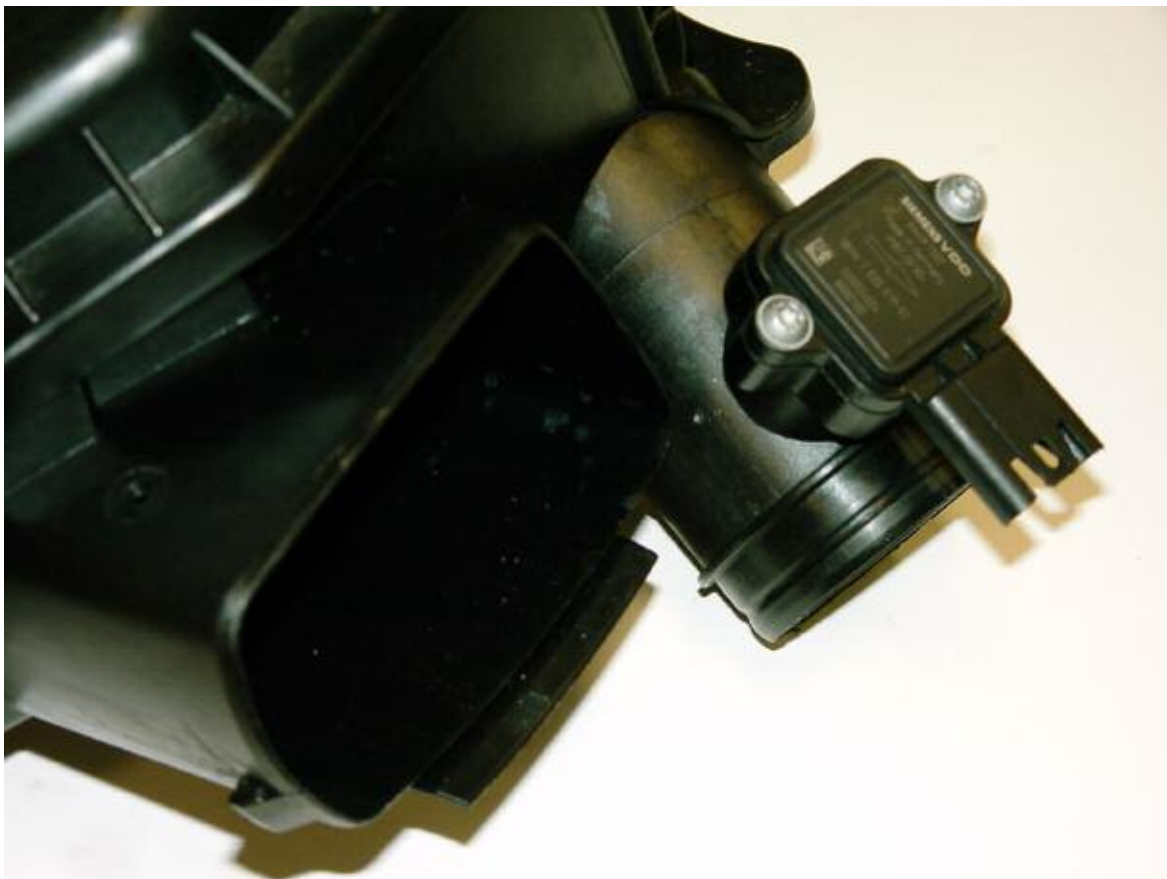
Consequently, the contact force is 10 times greater than that of a conventional plug connector.

**Note: It is possible to twist the connector before plugging it in. This can cause damage to the harness and connector. BE sure to install connector properly to avoid damage.**

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## Hot-Film Air Mass Meter

The HFM on all new NG6 engines has been upgraded to a digital HFM. The output of the sensor is a digital signal in which the duty cycle responds to changes in air mass.

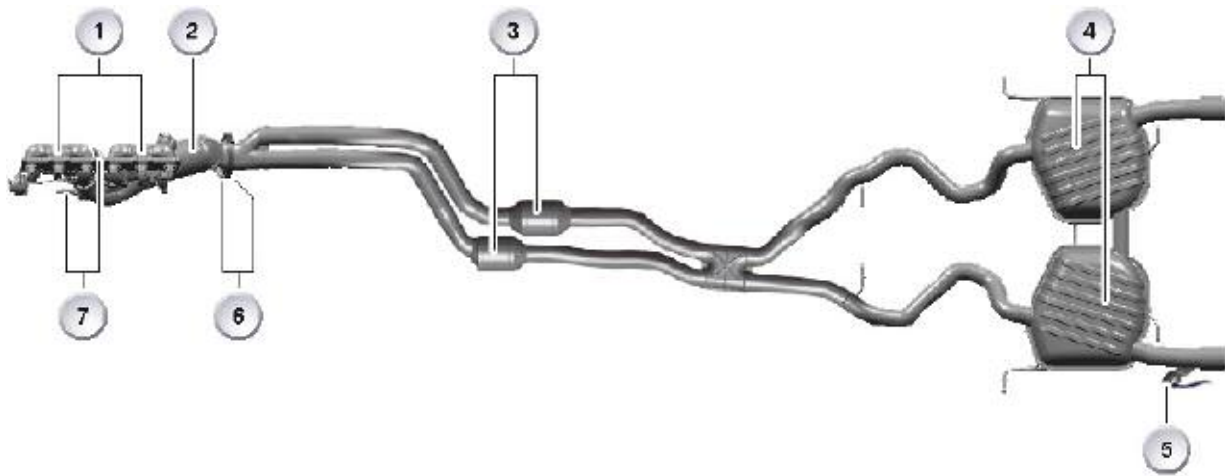


## Exhaust System

E92 vehicles with N54 engines are equipped with a dual exhaust system. The entire system is made from stainless steel, which ensures that it will function throughout the vehicle's service life.

Upstream primary catalytic converters with downstream underfloor catalytic converters are used. The lambda oxygen sensors installed are the same as those in the N52 engine.

The N51 engine is also equipped with an additional underbody catalyst to complement the existing "near engine" catalyst. The N51 also features improved catalyst coatings to help comply with SULEV II requirements.



Index	Explanation	Index	Explanation
1	Exhaust manifold	5	Exhaust flap
2	Upstream catalyst - 2 x 0.7 liters	6	Oxygen sensors (catalyst monitoring)
3	Underfloor catalyst - 2 x 0.85 liters	7	Oxygen sensors - Wideband planar
4	Rear mufflers, each approximately 16 liters		

# Fuel Supply and Management

Direct injection is one of the most decisive cornerstones in the concept of the N54 engine. The complex requirements of the combustion process can only be met with this injection process, which is described in the following.

Direct injection achieves a higher compression ratio when compared with a turbocharged engine with manifold injection. At the same time, the exhaust-gas temperature is reduced under full load. Another advantage of this injection process is the improved efficiency in part-load operation.

The N52KP and N51 engines continue to use the conventional “manifold injection” system from the N52.

## High Precision Injection (HPI)

High-precision injection represents the key function in the concept for as economic a use of fuel as possible. The new generation of petrol direct injection satisfies the expectations placed on it with regard to economic efficiency without compromising on the engine's dynamic qualities.

High-precision injection provides for more precise metering of mixture and higher compression - ideal preconditions for increasing efficiency and significantly reducing consumption.

This is made possible by locating the piezo injector centrally between the valves. In this position, the new injector, which opens in an outward direction, distributes a particularly uniform amount of tapered shaped fuel into the combustion chamber.

The new direct injection of BMW HPI spark ignition engines operate according to the spray-directed process.

### HPI Function

The fuel is delivered from the fuel tank by the electric fuel pump via the feed line (5) at an “feed” pressure of 5 bar to the high pressure pump. The feed pressure is monitored by the low-pressure sensor (6). The fuel is delivered by the electric fuel pump in line with demand.

If this sensor fails, the electric fuel pump continues to run at 100% delivery with terminal 15 ON.

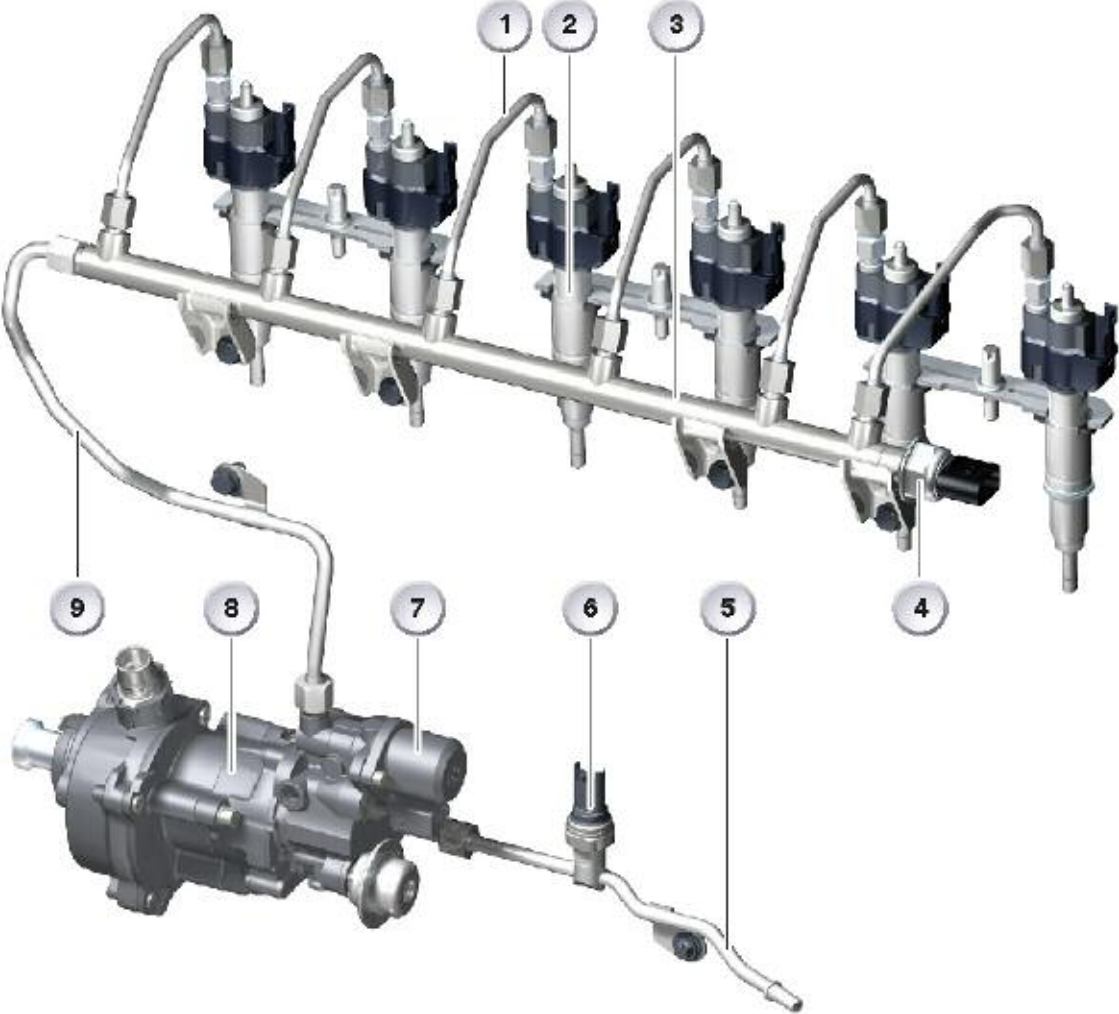
The high pressure pump is driven “in-tandem” with the vacuum pump which is driven by the oil pump chain drive assembly.

The fuel is compressed in the permanently driven three-plunger high-pressure pump (8) and delivery through the high-pressure line (9) to the rail (3). The fuel accumulated under pressure in the rail in this way is distributed via the high-pressure lines (1) to the piezo injectors (2).



The required fuel delivery pressure is determined by the engine-management system as a function of engine load and engine speed. The pressure level reached is recorded by the high-pressure sensor (4) and communicated to the engine control unit.

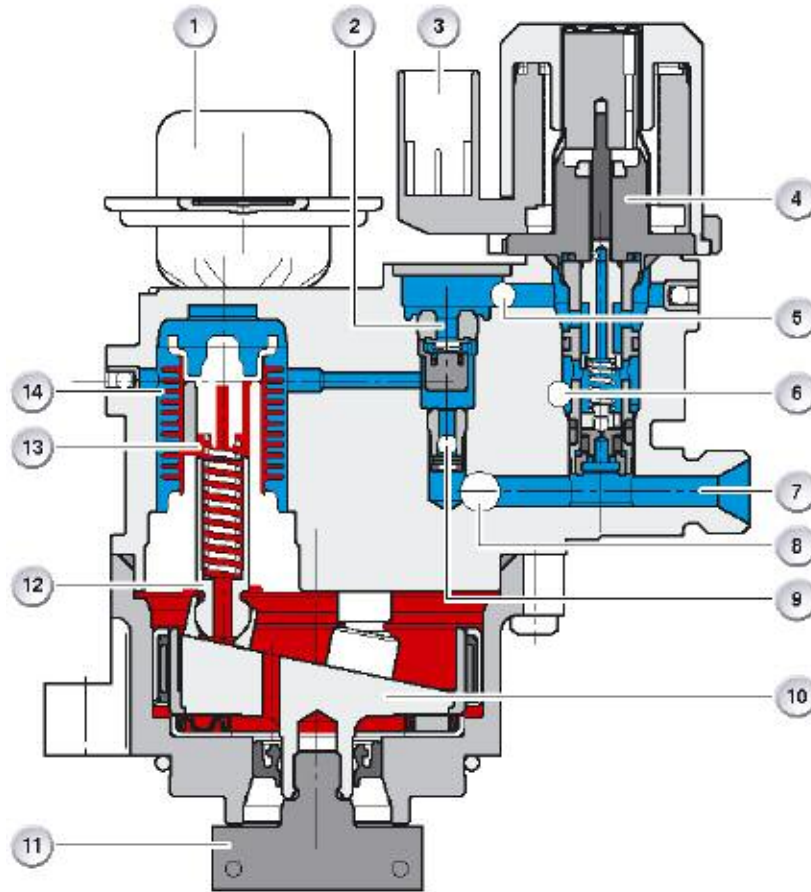
Control is effected by the fuel-supply control valve (7) by way of a setpoint/actual-value adjustment of the rail pressure. Configuration of the pressure is geared towards best possible consumption and smooth running of the N54 engine. 200 bar is required only at high load and low engine speed.



Index	Explanation	Index	Explanation
1	High-pressure line to injector (6)	6	Low-pressure sensor
2	Piezo injector	7	Fuel supply control valve
3	Fuel rail	8	Three plugger high pressure pump
4	High pressure sensor	9	High pressure line (pump to rail)
5	Feed line from in-tank pump		

## High Pressure Pump Function and Design

The fuel is delivered via the supply passage (6) at the admission pressure generated by the electric fuel pump to the high-pressure pump. From there, the fuel is directed via the fuel supply control valve (4) and the low-pressure non-return valve (2) into the fuel chamber (14) of the plunger-and-barrel assembly. The fuel is placed under pressure in this plunger-and-barrel assembly and delivered via the high pressure non-return valve (9) to the high pressure port (7).



Index	Explanation	Index	Explanation
1	Thermal compensator	8	Supply passage, pressure limiting valve
2	Low pressure non-return valve (check valve)	9	High pressure non-return valve (x 3)
3	Connection to engine management	10	Pendulum disc
4	Fuel supply control valve	11	Drive flange, high pressure pump
5	Return, pressure limiting valve	12	Plunger ( x 3)
6	Supply from electric fuel pump (in-tank)	13	Oil filling, high pressure pump
7	High pressure port to fuel rail	14	Fuel chamber ( x 3)

The high-pressure pump is connected with the vacuum pump via the drive flange (11) and is thus also driven by the chain drive, i.e. as soon as the engine is running, the three plungers (12) are permanently set into up-and-down motion via the pendulum disc (10).

Fuel therefore continues to be pressurized for as long as new fuel is supplied to the high-pressure pump via the fuel-supply control valve (4). The fuel-supply control valve is activated by means of the engine management connection (3) and thereby admits the quantity of fuel required.

Pressure control is effected via the fuel-supply control valve by opening and closing of the fuel supply channel. The maximum pressure in the high-pressure area is limited to 245 bar. If excessive pressure is encountered, the high-pressure circuit is relieved by a pressure-limiting valve via the ports (8 and 5) leading to the low-pressure area.

This is possible without any problems because of the incompressibility of the fuel, i.e. the fuel does not change in volume in response to a change in pressure. The pressure peak created is compensated for by the liquid volume in the low-pressure area.

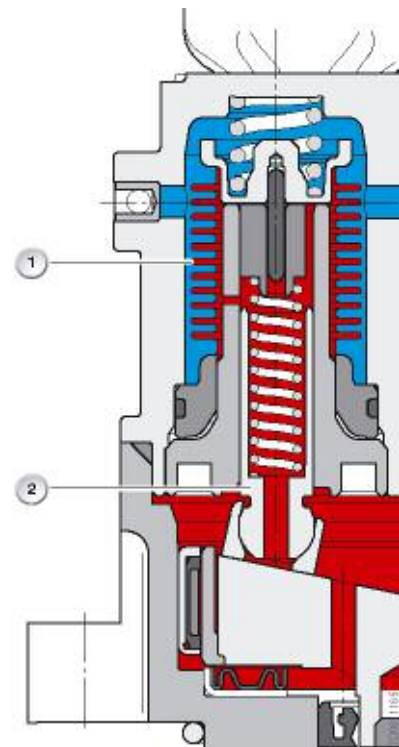
Volume changes caused by temperature changes are compensated for by the thermal compensator (1), which is connected with the pump oil filling.

#### ■ Pressure Generation in High-pressure Pump

The plunger (2) driven by the pendulum disc presses oil (red) into the metal diaphragm (1) on its upward travel. The change in volume of the metal diaphragm thereby reduces the available space in the fuel chamber. The fuel thereby placed under pressure (blue) is forced into the rail.

The fuel-supply control valve controls the fuel pressure in the rail. It is activated by the engine management system via a pulsewidth modulated (PWM) signal.

Depending on the activation signal, a restrictor cross-section of varying size is opened and the fuel-mass flow required for the respective load point is set. There is also the possibility of reducing the pressure in the rail.



Index	Explanation
Red	Oil filling
Blue	Fuel
1	Metal diaphragm
2	Plunger

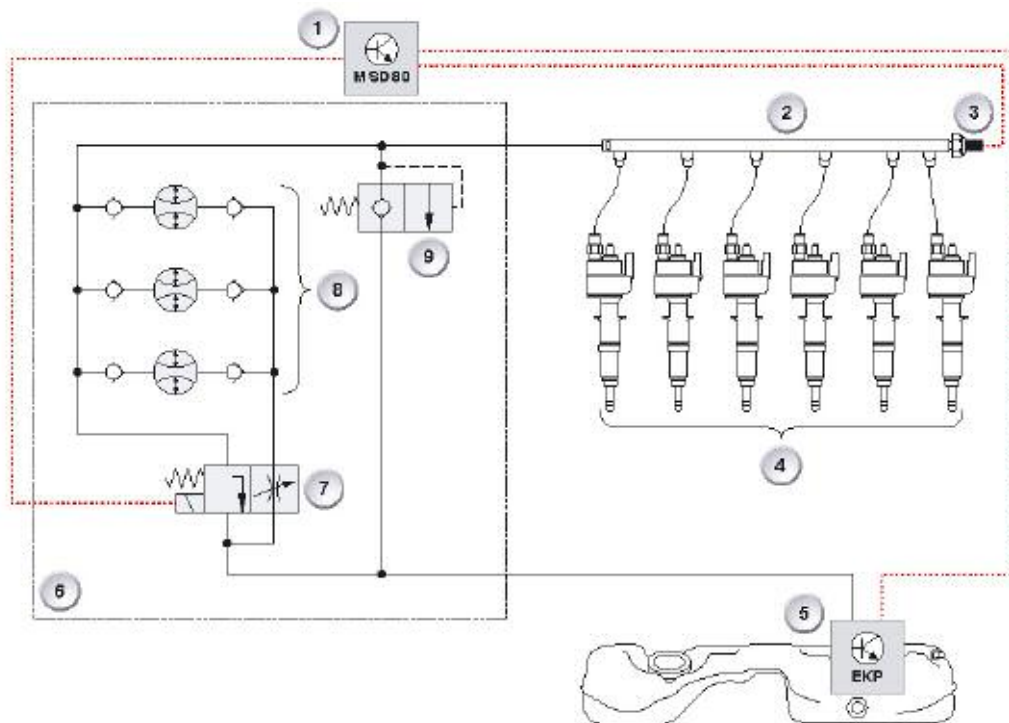
## Limp-home Mode

If a fault is diagnosed in the system, such as e.g. failure of the high-pressure sensor, the fuel-supply control valve is de-energized; the fuel then flows via a so-called bypass into the rail.

In the event of HPI limp-home mode, turbocharging is deactivated by an opening of the wastegate valves.

Causes of HPI limp-home mode can be:

- Implausible high-pressure sensor values
- Failure of the fuel-supply control valve
- Leakage in the high-pressure system
- Failure of the high-pressure pump
- Failure of the high-pressure sensor



Index	Explanation	Index	Explanation
1	Engine control module (MSD80)	6	High-pressure pump
2	Fuel rail	7	Fuel supply control valve
3	High pressure sensor	8	High pressure pump with non-return valves
4	Piezo injectors	9	Pressure limiting valve with bypass
5	Electric fuel pump		

## ■ Fuel System Safety

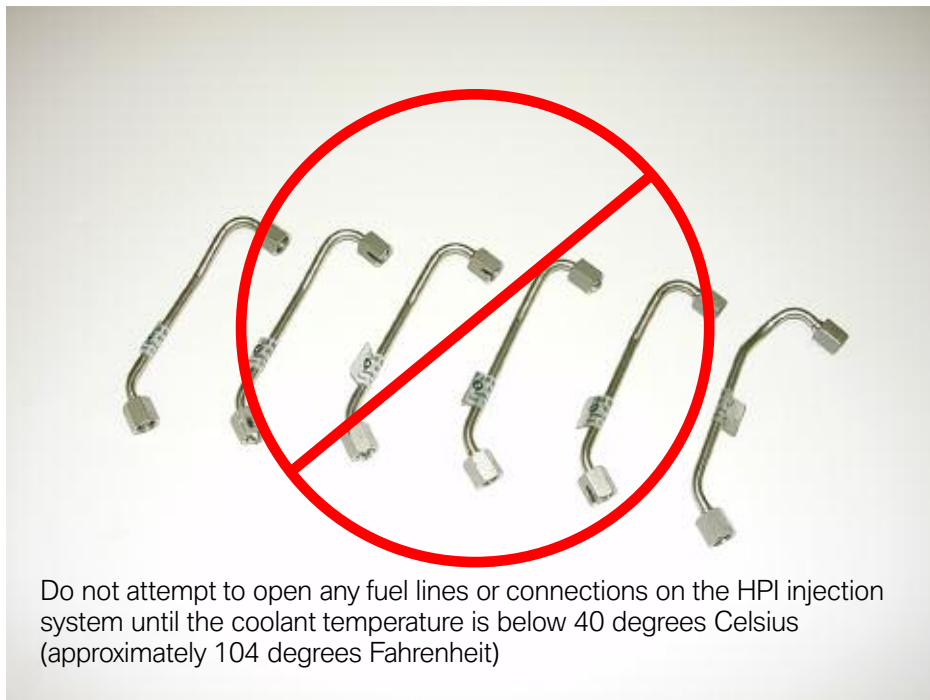
Working on this fuel system is only permitted after the engine has cooled down. The coolant temperature must not exceed 40 °C. This must be observed without fail because otherwise there is a danger of fuel sprayback on account of the residual pressure in the high-pressure system.

When working on the high-pressure fuel system, take particular care to ensure conditions of absolute cleanliness and follow the work sequences described in the repair instructions. Even the tiniest contaminants and damage to the screw connections on the high-pressure lines can cause leaks.

**ACHTUNG!** Öffnen des Kraftstoffsystems bei Kühlmitteltemperatur über 40 °C nicht zulässig. Gefahr von Körperverletzung. Reparaturanleitung beachten.  
**CAUTION!** Do not open the fuel system if the coolant temperature is above 40 °C/104 °F – risk of injury! Consult the repair manual.  
**ATTENTION !** Il est interdit d'ouvrir le système d'alimentation en carburant lorsque la température du liquide de refroidissement est supérieure à 40 °C. Risque de blessure. Respecter les instructions du Manuel de réparation.  
**¡ATENCIÓN!** Prohibido abrir el sistema de combustible cuando la temperatura del líquido refrigerante supera los 40 °C. Peligro de lesiones. Consultar el manual de reparaciones.  
**注意!** 冷却液温度高于40摄氏度时禁止打开燃油系统。存在身体伤害的危险。注意维修说明。

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## Piezo Fuel Injectors

It is the outward-opening piezo-injector that renders possible spray-directed direct injection and thus the overall innovations of the N54 engine. Due to the fact that only this component ensures that the injected fuel spray cone remains stable, even under the prevailing influences of pressure and temperature in the combustion chamber.

This piezo-injector permits injection pressures of up to 200 bar and extremely quick opening of the nozzle needle. In this way, it is possible to inject fuel into the combustion chamber under conditions released from the power cycles limited by the valve opening times.



The piezo-injector is integrated together with the spark plug centrally between the inlet and exhaust valves in the cylinder head. This installation position prevents the cylinder walls or the piston crown from being wetted with injected fuel. A uniform formation of the homogeneous air/fuel mixture is obtained with the aid of the gas movement in the combustion chamber and a stable fuel spray cone.

The gas movement is influenced on the one hand by the geometry of the intake passages and on the other hand by the shape of the piston crown. The injected fuel is swirled in the combustion chamber with the boost air until a homogeneous mixture is available throughout the compression space at the point of ignition.

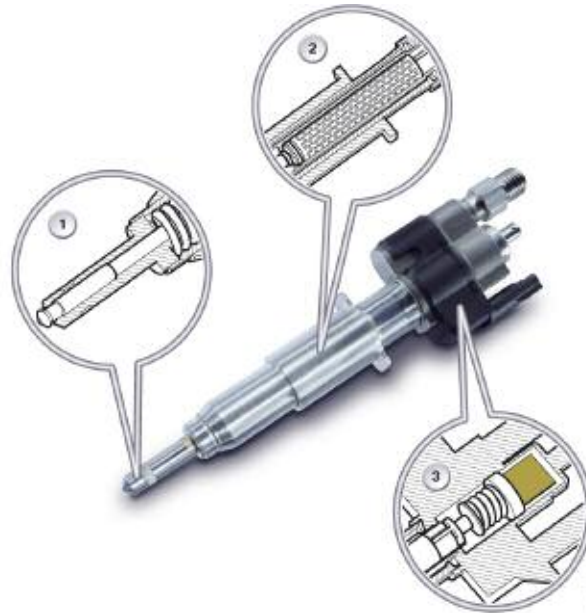
Note: When working on the fuel system of the N54 engine, it is important to ensure that the ignition coils are not fouled by fuel. The resistance of the silicone material is significantly reduced by heavy fuel contact. This can cause sparkover at the spark-plug head and with it misfires.

- Before making modifications to the fuel system, remove the ignition coils without fail and protect the spark-plug slot against the ingress of fuel with a cloth.
- Before refitting the piezo-injector, remove the ignition coils and ensure conditions of absolute cleanliness.
- Ignition coils heavily fouled by fuel must be replaced.



## ■ Injector Design and Function

The piezo-injector essentially consists of three sub-assemblies. The expansion of the energized piezo-element lifts the nozzle needle outwards from its valve seat. To be able to counter the different operating temperatures with comparable valve lifts, the injector has a thermal compensating element.



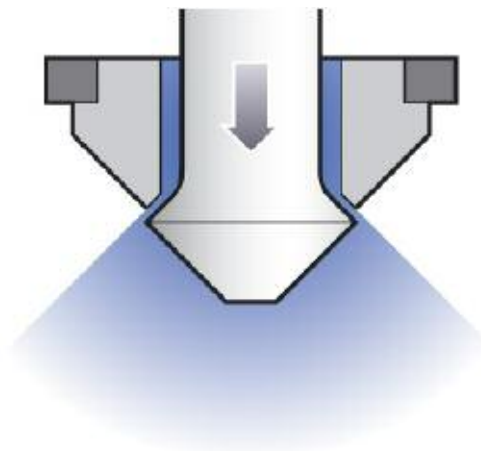
Index	Explanation	Index	Explanation
1	Outward opening nozzle needle	3	Thermal compensator
2	Piezo-element		

The nozzle needle is pressed outwards from its tapered valve seat. This opens up an annular orifice. The pressurized fuel flows through this annular orifice and forms a hollow cone, the spray angle of which is not dependent on the backpressure in the combustion chamber.

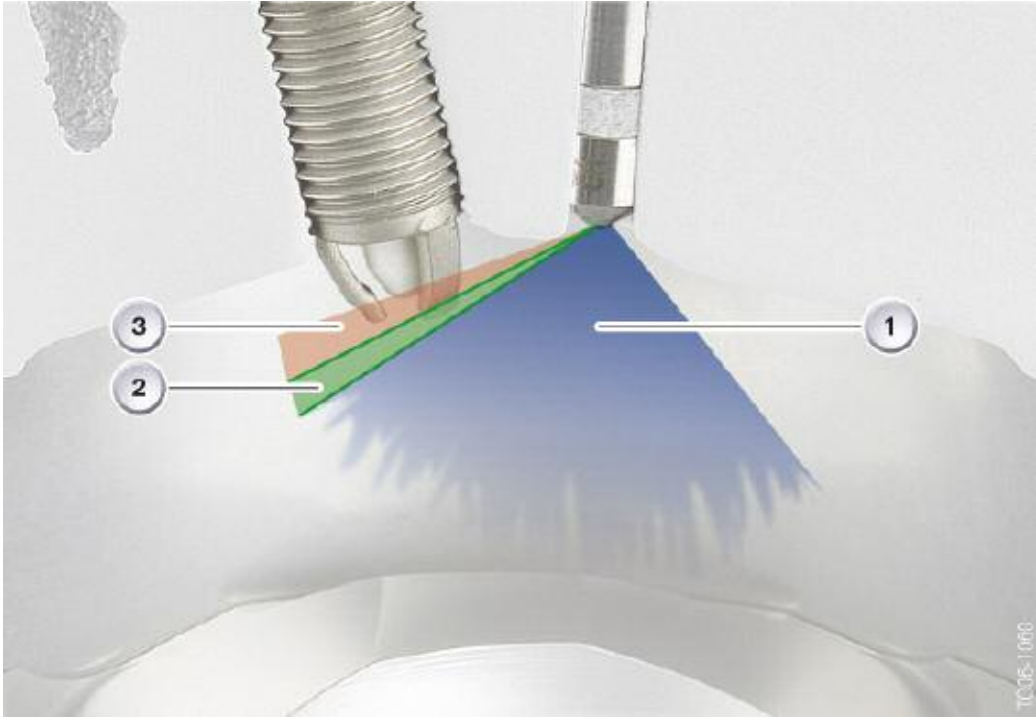
**Note: Do not attempt to clean the injectors in any way. This may result in damage which can effect the spray pattern.**

**Any divergence in the spray pattern can cause damage to the spark plug or the engine itself.**

### Outward opening injector nozzle needle



The spray cone (1) of a piezo-injector can diverge during operation (2). Due to the formation of soot inside the engine, such divergence is perfectly normal and acceptable to a certain extent. If, however, spray divergence reaches the stage where it begins to spray the spark plug wet, the spark plug may incur damage.



Index	Explanation	Index	Explanation
1	Ideal "spray" cone	3	Non-permitted divergence of spray cone
2	Permitted divergence of spray cone		

**Note:** Replace the Teflon sealing ring when fitting and removing the piezo-injector. This also applies when an injector that has just been fitted has to be removed again after an engine start.

**A piezo-injector provided with a new Teflon sealing ring should be fitted as quickly as possible because the Teflon sealing ring could swell up. Please observe the repair instructions and follow without fail.**

**When fitting, make sure that the piezoinjector is correctly seated. The hold-down element for securing the piezo-injectors must rest on both injector tabs, otherwise the necessary force is not applied to the piezo-injector. Do not clean the nozzle-needle tip of the piezo-injector.**



## ■ Injection Strategy

Injection of the fuel mass required for the operating situation can take place in up to three individual injections. Which option is used in the relevant operating situation is dependent on engine load and speed. Here, the actual time resulting from the engine speed available for metering the fuel is an important framework quantity.

A special situation during the operation of any engine is the range in which a high load occurs at low engine speed, so-called "Low End Torque" operation. In this operating situation, the required fuel mass is metered to the engine in three individual injections.

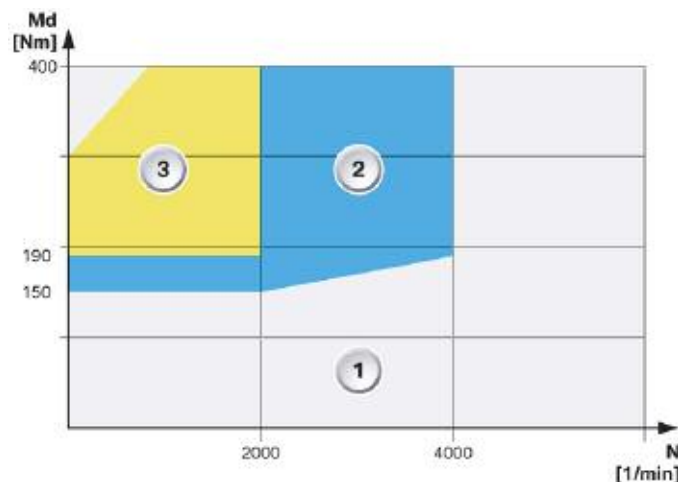
This results in a highly effective mixture formation which in the final analysis has the effect of both increasing power output and saving fuel.

In order to bring the catalytic converters up to operating temperature as quickly as possible, the N54 engine has a catalyst-heating mode for when the engine is started from cold. In this mode, combustion heat is intentionally introduced into the exhaust train and not used first and foremost to develop power output.

The point of ignition is moved to 30° (crankshaft degrees) after TDC. The main quantity of the required fuel is injected before TDC and mixed with the boost air. The piston is situated after TDC in its downward travel such that the air/fuel mixture is already expanding again, which reduces the ignitability of the mixture.

In order to ignite the mixture reliably, a small residual quantity of fuel is injected 25° after TDC and this guarantees an ignitable mixture at the spark plug. This small fuel quantity therefore provides for ignition of the residual charge in the combustion chamber.

This operating mode is set by the engine-management system after a maximum period of 60 seconds from engine starting but is terminated if the catalytic-converter response temperature is reached earlier.



Index	Explanation	Index	Explanation
1	Single injection event	3	Triple injection event
2	Double injection event		

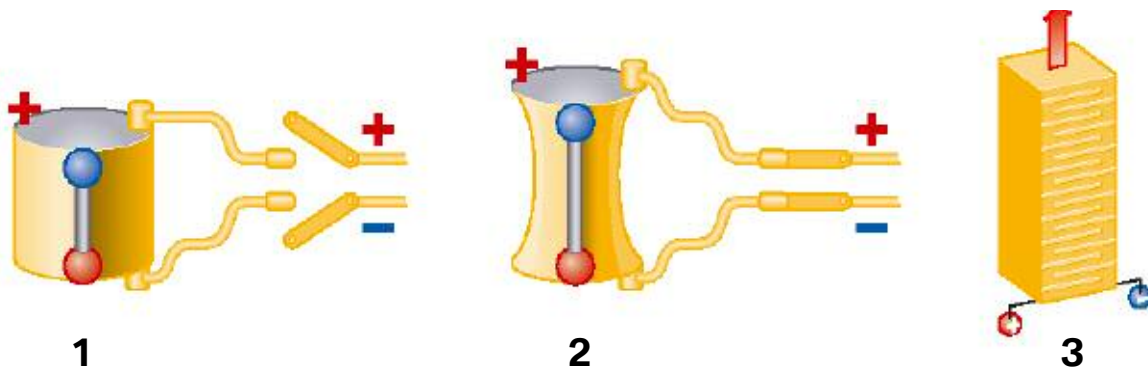
## Piezo Element

The movement of the nozzle needle in the injector is generated no longer by a solenoid coil but rather by a piezo-element.

A piezo-element is an electromechanical converter, i.e. it consists of a ceramic material which converts electrical energy directly into mechanical energy (force/travel). A familiar application is the piezo cigarette lighter - when a piezo-crystal is pressed, voltage is generated until a spark flashes over and the gas ignites.

In the case of the piezo-actuator, voltage is generated so that the crystal expands. In order to achieve greater travel, it is possible to design a piezo-element in several layers.

The actuator module consists of layers of the piezo-ceramic material connected mechanically in series and electrically in parallel. The deflection of a piezo-crystal is dependent on the applied voltage up to a maximum deflection; the higher the voltage, the greater the travel.



Index	Explanation	Index	Explanation
1	Piezo crystal - not energized	3	Piezo element in layers (stacked)
2	Piezo crystal - energized		

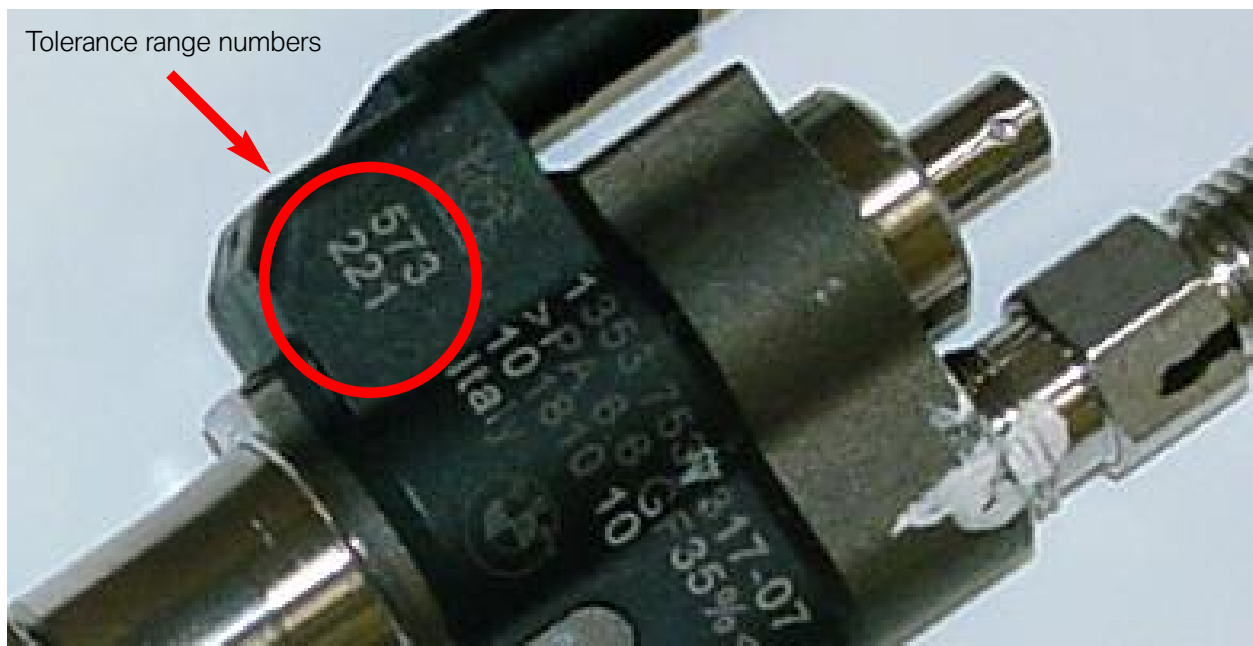
## ■ Injector Adjustment

When the injectors are manufactured, a multitude of measurement data is recorded at specific points in the factory. In this way, the tolerance ranges for injector-quantity adjustment are determined and specified in a six-digit number combination.

Information on the lift performance of the injector is also added for injector voltage adjustment. Injector adjustment is required because of the individual voltage demand of each piezo actuator. An allocation is made to a voltage demand category, which is included in the number combination on the injector.

These data items are transmitted to the ECM. During engine operation, these values are used to compensate for deviations in the metering and switching performance.

**Note: When replacing an injector, it is absolutely essentially to carry out an injector adjustment.**



### ■ **Injector Control and Adaptation**

The fuel mass required for the operating situation is injected by the piezo-injector into the combustion chamber. This mass can be influenced by three correcting variables:

- the rail pressure
- the injector opening time
- and the injector opening lift

The injector opening time and the injector opening lift are activated directly at the piezo injector. The opening time is controlled via the ti signal and the opening lift via the energy quantity in the activation of the piezo-injector.

### ■ **Injector Adaptation**

The fuel masses and injection cycles determined from the load/speed map are included in a pilot-control program map. Here, while further framework parameters are taken into consideration, the energy quantities and injector opening times required to activate the injectors are determined.

The N54 engine can be safely and reliably operated with these program-map values.

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## ■ Optimization

For optimization of:

- Emission values
- Smooth running
- Fuel consumption
- Power output

the controlled variables of energy quantities and injector opening times are continuously monitored. This occurs on a bank-selective basis by way of lambda closed-loop control.

The residual oxygen in the exhaust gas is measured in each case for cylinder bank 1 and cylinder bank 2. This measurement result is compared with the values expected from the set correcting variables. The result of a deviation is that the injector opening signal is adapted. This adaptation is stored in the control unit and is therefore available for subsequent engine operation. However, these stored values are lost when the system is flashed and must be relearned. A further adaptation of the injector activation takes place depending on time and use. This cylinder-selective adaptation involves a check of the residual-oxygen content with a conclusion as to the cylinder causing the situation. To this end, it is necessary for part of the exhaust-gas flow not to be swirled in the turbocharger. For this reason, the flap of the wastegate valve must be fully opened, i.e. swung out of the exhaust-gas flow. This wastegate-flap position extends beyond its normal opening position in engine operation. Based on the result of this cylinder-selective monitoring, the energy quantity is adapted if necessary to activate the injectors.

Furthermore, the cylinder-selective adaptation includes if necessary an adaptation of the injector opening signal based on smooth running monitoring of the N54 engine. Overall adaptation of the injectors is limited to a 15% additional quantity.

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## Ignition Management

Most of the ignition system components have remained the same for all NG6 engines for 2007. There are some minor changes to the ignition coils that apply to all versions. The coils have been optimized for more durability.

### Spark Plugs

The spark plugs for the N51 and N52KP remain the same as N52. However, the N54 uses a completely new spark plug from Bosch. The spark plug design consists of a 12mm thread which contrasts from the 14mm design on the N52 which prevents any possibility of improper installation. The hex on the spark plug is also a 12 point design which requires a special tool. The tool (socket) has a “thinwall” design to facilitate access in the confined area of the N54 cylinder head.



### Spark Plug Diagnosis (N54)

Due to the proximity of the spark plug to the fuel injector nozzle, any divergence in the fuel spray may cause possible spark plug damage. This makes spark plug diagnosis an important part of N54 service concerns. Information gained by the spark plug diagnosis may indicate possible fuel injector faults. Spark plug replacement interval has been reduced to 45,000 miles for the N54.

The illustrations below can be used to assist in spark plug diagnosis:



The spark plug above shows a normal wear pattern with no excessive electrode wear or insulator damage.



The spark plug above shows a normal wear pattern for a spark plug with high mileage. Spark plug is due for replacement.



The spark plug above shows erosion of the electrode on one side which could be an indication of fuel spray "diversion".



The spark plug above shows erosion of the electrode on one side and damage on the insulator nose. This could also be an indication of fuel spray "diversion".

## Emissions Management

The N54 and N52KP meet ULEV II requirements for 2007. There are not many changes to the emission systems on these engines. The N54 engine has 2 underbody catalysts in addition to the “near engine” catalysts already in use from the N52.

The N51 engine, however, is a SULEV II compliant engine which meets the 2007 requirements. In addition to the 5 existing SULEV states of California, New York, Maine, Massachusetts, and Vermont - four states have been added for 2007. These states include, Connecticut, Rhode Island, Oregon and Washington State.

The N51 emissions measures include:

- Secondary Air System with mini-HFM
- Radiator with “Prem-air” coating
- Lower compression ratio (10:1) via modified combustion chamber and pistons
- Underbody catalyst in addition to “near engine” catalyst
- Activated carbon air filter in air filter housing
- Steel fuel lines with threaded fittings and sealed fuel tank
- Crankcase ventilation system integrated into cylinder head cover
- Purge system piping made from optimized plastic

**Note: The SULEV II information above is only preliminary and is accurate as of 8/06. Additional information will be released as it becomes available.**



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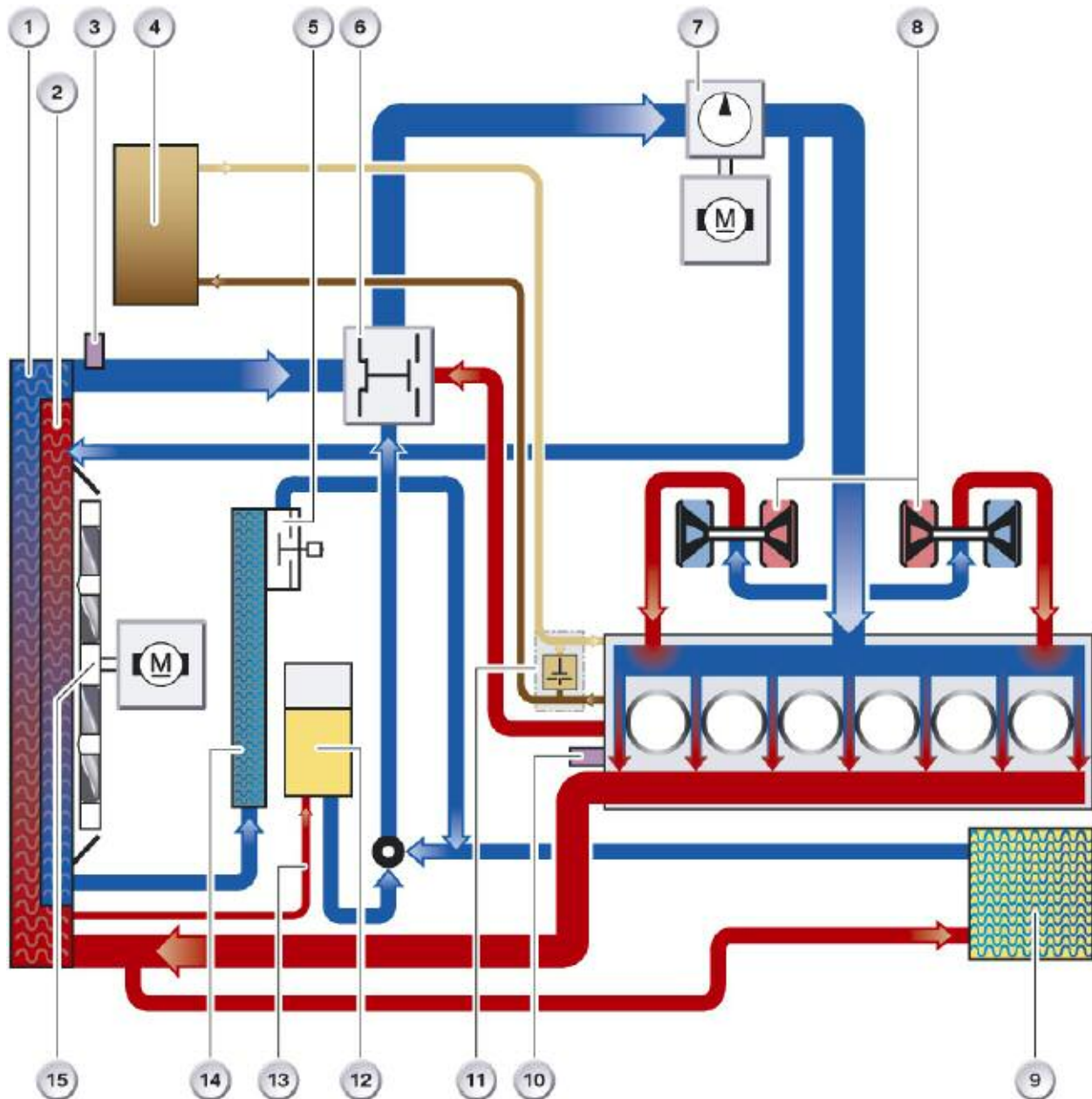
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# Performance Controls

## Cooling System

The cooling system of the N54 engine consists of a radiator circuit and an isolated oil cooling circuit. The fact that there is an isolated oil-cooling circuit ensures that heat is not introduced via the engine oil into the engine's coolant system.



Index	Explanation	Index	Explanation
1	Radiator	9	Heat exchanger
2	Gear-box oil cooler	10	Outlet temperature sensor, cylinder head
3	Outlet temperature sensor	11	Thermostat, engine oil cooler
4	Engine oil cooler	12	Coolant expansion tank
5	Thermostat for gearbox oil cooler	13	Vent line
6	Map thermostat	14	Gearbox oil cooler
7	Electric coolant pump	15	Fan
8	Exhaust turbocharger		

There is a significantly greater quantity of heat on account of this engine's increased power of 75.5 kW/l in comparison with other 3-liter spark-ignition engines.

This boundary condition is satisfied by the engine cooling system with its increased performance. This increase in power was to be realized in spite of some factors less advantageous to cooling.

Factors to be mentioned here are:

- Approximately 15% less flow area is available on account of the intercooler located below the radiator.
- The already small amount of space provided by the engine compartment is further limited by the accommodation of further components.
- Because the exhaust turbochargers are cooled by the coolant, an additional quantity of heat is introduced into the system via these turbochargers.

Measures for increasing cooling-system performance:

- Coolant pump with increased power - 400 W/9000 l/h
- Separation of water and engine-oil cooling
- Radiator with increased power
- Electric fan with increased power 600W for all gearbox variants

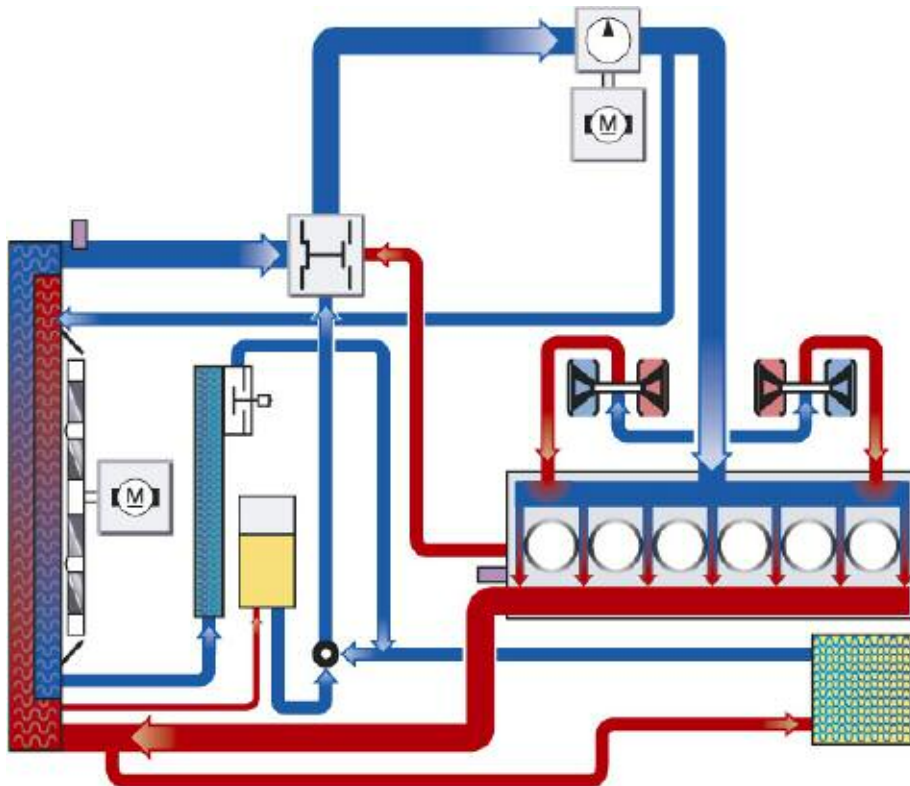
Charge-air cooling is described in the section dealing with air-intake ducting.

## Cooling System Overview

The structure of the coolant circuit is the same as that of the N52 engine. The engine is flushed through with coolant in accordance with the cross-flow concept. Cooling output can be influenced as a function of load by activating the following components:

- Electric fan
- Electric coolant pump
- Map thermostat

It is also possible in an N54 engine in conjunction with an automatic gearbox to utilize the lower area of the radiator to cool the gearbox by means of the gearbox-oil cooler. This is achieved as in the N52 engine with control sleeves, which are introduced into the radiator tank.



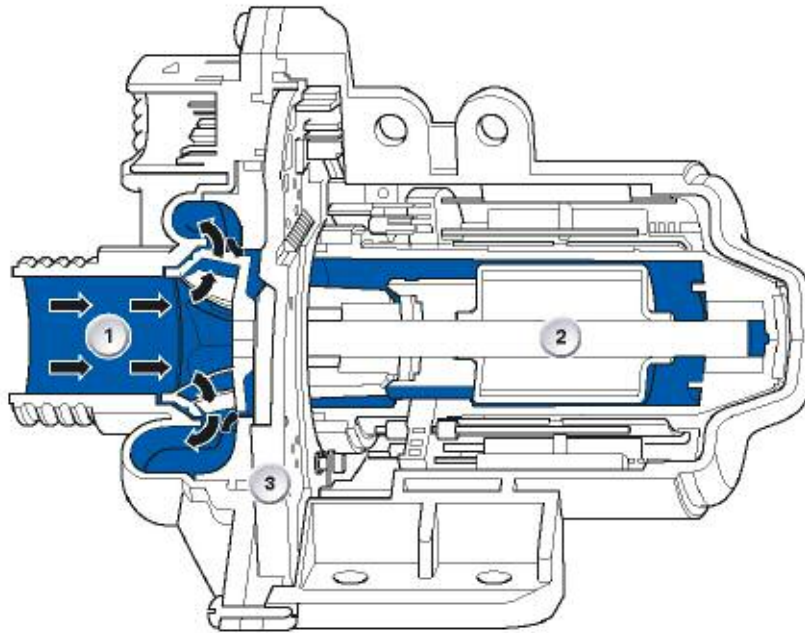
## Radiator

Design measures have been used to increase the performance of the radiator itself. The performance of a radiator is dependent on its radiation surface. However, the intercooler still had to be installed underneath the radiator, and this meant that it was necessary to compensate for the smaller flow area available.

Compared with the N52 engine, the radiator used in the N54 engine has a block depth which has been increased to 32 mm. In addition, the water pipes are situated closer together than in previously used radiators. The upshot of this is an increase in the utilizable radiation surface.

## Electric Coolant Pump

The coolant pump of the N54 engine is an electrically driven centrifugal pump with a power output of 400W and a maximum flow rate of 9000 l/h. This represents a significant increase in power of the electric coolant pump used in the N52 engine, which has a power output of 200 W and a maximum flow rate of 7000 l/h.



Index	Explanation	Index	Explanation
1	Pump	3	Electronics for coolant pump
2	Motor		

The power of the electric wet-rotor motor is electronically controlled by the electronic module (3) in the pump. The electronic module is connected via the bit-serial data interface (BSD) to the MSD80 engine control unit.

The engine control unit uses the engine load, the operating mode and the data from the temperature sensors to calculate the required cooling output. Based on this data, the engine control unit issues the corresponding command to the electric coolant pump.

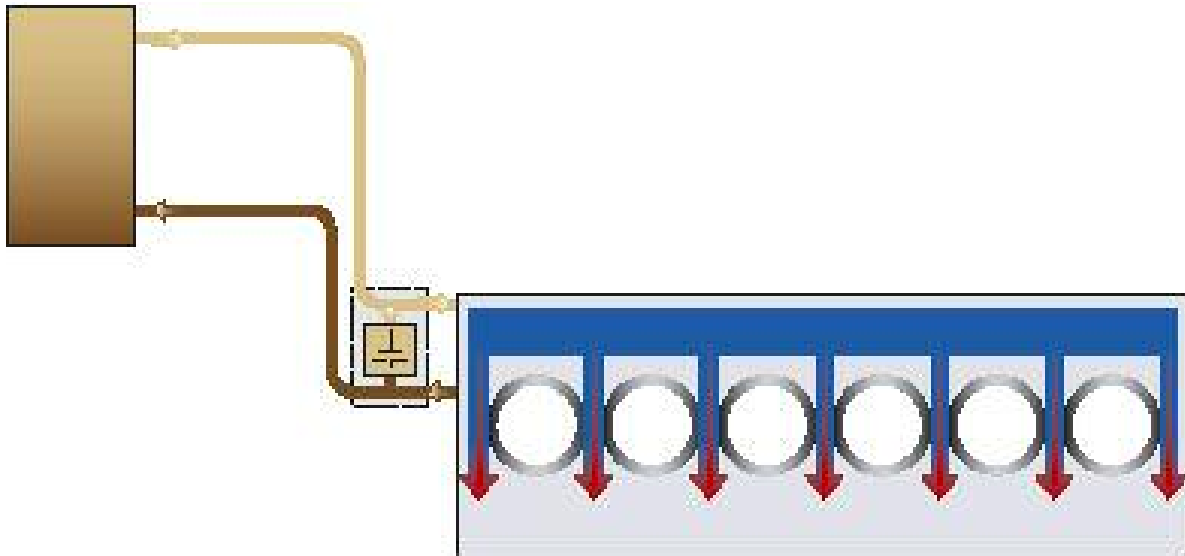
The electric coolant pump regulates its speed in accordance with this command. The system coolant flows through the motor of the coolant pump, thus cooling both the motor as well as the electronic module. The coolant lubricates the bearings of the electric coolant pump.

**Note: The same rules apply to all electric coolant pumps. The pump must be filled with coolant when removed for service to prevent any corrosion. Also, the pump impeller must be turned by hand before installation to ensure the pump is not siezed.**

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## Engine-oil Cooling

The N54 engine is equipped with a highperformance engine-oil cooler. The pendulum-slide pump delivers the oil from the oil sump to the oil filter. A thermostat flanged to the oil-filter housing admits the oil to the engine-oil cooler. The engine-oil cooler is located in the right wheel arch in the E92. The thermostat can reduce the resistance opposing the oil by opening the bypass line between the feed and return lines of the engine-oil cooler. This ensures that the engine warms up safely and quickly.



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## Heat Management

The engine control unit of the N54 engine controls the coolant pump according to requirements:

- Low output in connection with low cooling requirements and low outside temperatures
- High output in connection with high cooling requirements and high outside temperatures

The coolant pump may also be completely switched off under certain circumstances, e.g. to allow the coolant to heat up rapidly during the warm-up phase. However, this only occurs when no heating is required and the outside temperature is within the permitted range.

The coolant pump also operates differently than conventional pumps when controlling the engine temperature. To date, only the currently applied temperature could be controlled by the thermostat.

The software in the engine control unit now features a calculation model that can take into account the development of the cylinder head temperature based on load. In addition to the characteristic map control of the thermostat, the heat management system makes it possible to use various maps for the purpose of controlling the coolant pump. For instance, the engine control unit can adapt the engine temperature to match the current operating situation.

This means that four different temperature ranges can be implemented:

- 108°C ECO mode
- 104°C Normal mode
- 95°C High mode
- 90°C High + map-thermostat mode

The control system aims to set a higher cylinder-head temperature (108°C) if the engine control unit determines ECO (economy) mode based on the engine performance. The engine is operated with relatively low fuel consumption in this temperature range as the internal friction is reduced.

An increase in temperature therefore favors slower fuel consumption in the low load range. In HIGH and map-thermostat mode, the driver wishes to utilize the optimum power development of the engine. The cylinder-head temperature is reduced to 90°C for this purpose. This results in improved volumetric efficiency, thus increasing the engine torque. The engine control unit can now set a certain temperature mode adapted to the respective operating situation. Consequently, it is possible to influence fuel consumption and power output by means of the cooling system.

The temperatures specified only ever represent a target value, the attainment of which is dependent on many factors. These temperatures are first and foremost not attained precisely.

The consumption-reducing and power increasing effects arise in each case in a temperature spectrum. The function of the cooling system is to provide the optimal cooling output according to the boundary conditions under which the engine is being operated.

### Intelligent Heat Management Options

The previous section dealt with the various temperature ranges in which heat management is effected. However, an electrically driven coolant pump makes available even further options. For instance, it is now possible to warm up the engine without recirculating the coolant or to allow the pump to continue to operate after turning off the engine to facilitate heat dissipation. The advantages offered by this type of pump are listed in the following table:

<b>Consumption</b>	<ul style="list-style-type: none"> <li>• Faster warm-up as coolant is not recirculated until needed</li> <li>• Increased compression ratio due to greater cooling output all full load as compared to similar engines without this option</li> </ul>
<b>Emissions</b>	<ul style="list-style-type: none"> <li>• Faster engine warm-up by drastically reduced pump speed and the lower volumetric flow of coolant</li> <li>• Reduced friction</li> <li>• Reduced fuel consumption</li> <li>• Reduced exhaust emissions</li> </ul>
<b>Power Output</b>	<ul style="list-style-type: none"> <li>• Component cooling independent of engine speed</li> <li>• Requirement controlled coolant pump output</li> <li>• Avoidance of power loss</li> </ul>
<b>Comfort</b>	<ul style="list-style-type: none"> <li>• Optimum volumetric flow               <ul style="list-style-type: none"> <li>- Heating capacity reduced as required</li> <li>- Residual heat with engine stationary</li> </ul> </li> </ul>
<b>Component Protection</b>	<ul style="list-style-type: none"> <li>• After-running of electric coolant pump = improved heat dissipation from engine switch off point. Allows protection of turbochargers by reduced oil “coking” during heat soak.</li> </ul>





## System Protection



In the event of the coolant or engine oil being subject to excessive temperatures while the engine is running, certain functions in the vehicle are influenced so that more energy is made available to the engine-cooling system, i.e. temperature-increasing loads are avoided.

These measures are divided into two operating modes:

- Component protection
- Emergency

Engine oil temp (T-oil C)	Operating mode	Display in Cluster	Power output reduction, Air conditioning	Power output reduction, Engine	Torque converter clutch lockup
148			Start 0 %	Start 0 %	
149			–		
150	Component Protection		–		
151	Component Protection		–	From here = clear reduction	
152	Component Protection		End - 100 %		
153	Component Protection				
154	Component Protection				
155	Component Protection				
156	Component Protection				
157	Component Protection			End @ 90 %	
158	Emergency				Active
159	Emergency				Active
160	Emergency				Active
161	Emergency				Active
162	Emergency				Active
163	Emergency				Active

**Measures and Displays for Coolant Temperature**

Coolant (T-Coolant)	Operating mode	Display in Cluster	Power output reduction, Air conditioning	Power output reduction, Engine	Torque converter clutch lockup
115					
116					
117	Component Protection		Start 0 %	Start 0 %	
118	Component Protection		-	From here = clear reduction	
119	Component Protection		-	-	
120	Component Protection		End - 100 %	-	
121	Component Protection			-	
122	Component Protection			-	Active
123	Component Protection			-	Active
124	Component Protection			End @ 90 %	Active
125	Emergency				Active
126	Emergency				Active
127	Emergency				Active
128	Emergency				Active
129	Emergency				Active

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