Reference Manual

N47TU ENGINE

Technical Training

Technical training.
Product information.

N47TU Engine

BMW Service

Edited for the U.S. market by:
BMW Group University
Technical Training
ST1305 7/1/2013

General information

Symbols used

The following symbol / sign is used in this document to facilitate better comprehension and to draw attention to particularly important information:

⚠

contains important safety guidance and information that is necessary for proper system functioning and which it is imperative to follow.

Current applicability and country-specific models

The BMW Group produces vehicles to meet the very highest standards of safety and quality. Changes in terms of environmental protection, customer benefits and design make it necessary to develop systems and components on a continuous basis. Consequently, this may result in differences between the content of this document and the vehicles available in the training course.

This document describes the fundamentals of left-hand drive vehicles in the European version. In vehicles with right-hand drive some operating elements or components are arranged differently than shown in the graphics of this document. Further discrepancies may arise from market-specific or country-specific equipment specifications.

Additional sources of information

Further information on the individual topics can be found in the following:

- in the Owner's Handbook
- in the integrated service technical application.

Contact: conceptinfo@bmw.de

The information in the document is part of the BMW Group technical training course and is intended for its trainers and participants. Refer to the latest relevant BMW Group information systems for any changes/supplements to the technical data.

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N47TU Engine
1. Introduction

The N47 engine family is a further development of the M47 engine family and has been available in Europe and other markets for quite some time. With the N47 BMW introduced for the first time an engine design with the chain drive located on the force transmitting (flywheel) side of the engine. Since the camshafts gears are located at the rear, the front of the engine can be built much lower (this is beneficial for pedestrian protection). Another benefit is that rotational vibrations are significantly reduced due to the inertial mass of the transmission which results in a reduction of load on the chain drive. As a further advancement in efficient dynamics strategy BMW has decided to introduce the N47TU engine to the US market (as from 7/2013). The N47TU engine will be the first BMW four cylinder diesel engine available in the US market.

The engine will be launched with the following models.

Series	N47D20O1
F30	328d and 328xd
F31	328d and 328xd

The N47TU and the N57TU engines are considered second generation BMW diesel engines (in the US market). The exhaust after-treatment systems and components of the N47TU and the N57TU have been especially design to comply with current (ULEV II) US market emission regulations and thus differ from those used with the previous US diesel (M57D30T2) engine.

1.1. BMW 328d

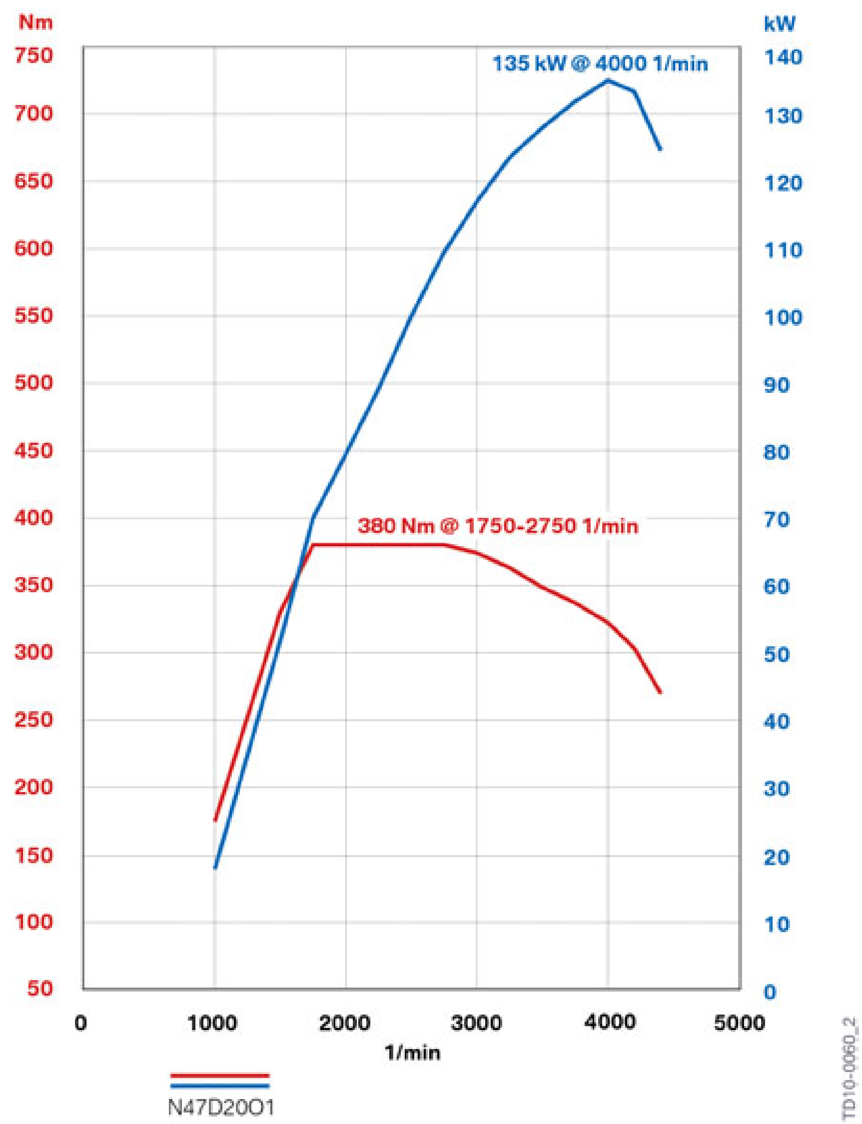
The BMW 328d is the series introduction model which sets new environmental standards in mid-range vehicles with the lowest fuel consumption and emissions in its class. The rpm level is reduced relative to the speed by a longer final drive gear ratio. In addition, the dual-mass flywheel enables the engine to operate at an even lower rpm range.

1.1.1. Technical data

The following table shows the technical data of the N47TU engine.

N47TU Engine

1. Introduction



Full load diagram BMW 328d

Engine specifications	Unit	N47D20O1
Design		R4
Displacement	[cm³]	1995
Bore/stroke	[mm]	84/90
Power output	[kW/HP] [rpm]	135/181 4000
Power output per liter	[kW/l]	67.67
Torque	[Nm/ft-lb] [rpm]	380/280 1750 – 2750
Compression ratio	[ε]	16.5 : 1
Valves per cylinder		4

N47TU Engine
1. Introduction

Engine specifications	Unit	N47D20O1
Fuel consumption in accordance with the EU	[l/100 km]	4.7
CO_2 Emission	[g/km]	125
Digital Engine Electronics		DDE7.2.1
Exhaust emissions legislation		ULEV II
Top speed	[km/h/mph]	230/143
Acceleration 0 – 60 mph	[s]	7.4
Gross vehicle weight	[kg/lbs]	1980/4365

1.2. Engine identification

1.2.1. Engine type

The engine type is used in technical documents for clear identification of the engine. However, often only an abbreviation is used.

This abbreviation is used to assign an engine to an engine family.

Position	Meaning	Index	Explanation
1	Engine developer	M, N P S W	BMW Group BMW M Sport BMW M GmbH Supplied engines
2	Engine type	1 4 5 6 7 8	4-cylinder in-line engine (e.g.) 4-cylinder in-line engine (e.g. N47) 6-cylinder in-line engine (e.g. N57) -engine (e.g. N63) -engine (e.g. N74) -engine (e.g. S85)
3	Modifications to the engine block concept	0 1 – 9	Engine block Modifications, e.g. combustion process
4	Working process or fuel and if necessary installation position	B D H	Gasoline engine, longitudinal installation Diesel engine, longitudinal installation Hydrogen engine, longitudinal installation
5+6	Displacement in 1/10 liter	20	2.0 liter displacement
7	Performance class	K U M O T	smallest lower middle TOP TOP
8	Release relevant revision	0 1 – 9	New development Revision

Itemization of N47D20O1 engine type

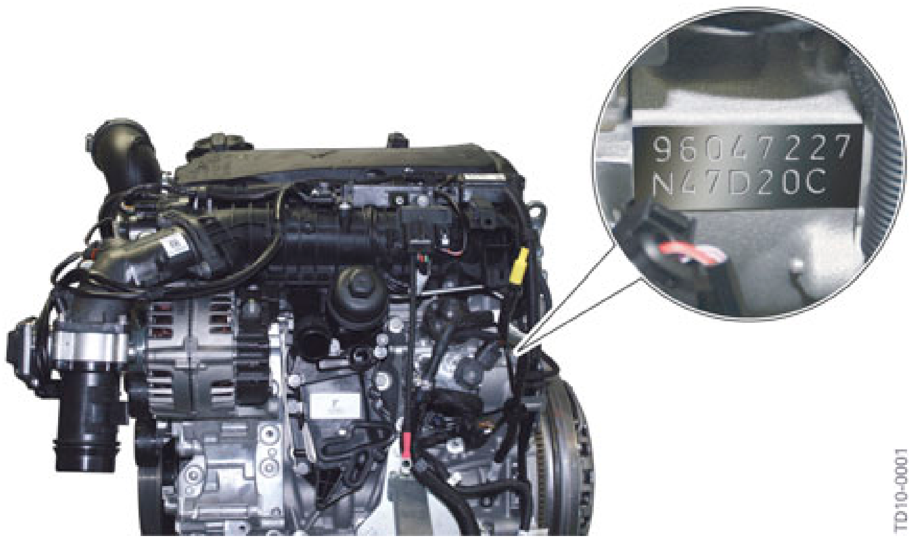
Index	Explanation
N	BMW Group development
4	4-cylinder in-line engine
7	Direct fuel injection and exhaust turbocharger
D	Diesel engine, longitudinal installation
20	2.0 liter displacement
O	Upper performance class
1	1st Revision

1.2.2. Engine identification

The engines have an identification on the crankcase for clear recognition and assignment. The engine identification is also required for approval by the authorities. By using the TOP engine there is a further development of this identification and a reduction from the previous eight to seven digits. The engine number is located over the engine identification on the motor. This sequential number in combination with the engine identification provides a unique identification of each individual engine. The first six digits correspond to the engine type.

Position	Meaning	Index	Explanation
1	Engine developer	M, N P S W	BMW Group BMW M Sport BMW M GmbH Supplied engines
2	Engine type	1 4 5 6 7 8	4-cylinder in-line engine (e.g.) 4-cylinder in-line engine (e.g. N47) 6-cylinder in-line engine (e.g. N57) -engine (e.g. N63) -engine (e.g. N74) -engine (e.g. S85)
3	Modifications to the engine block concept	0 1 – 9	Engine block Modifications, e.g. combustion process
4	Working process or fuel and if necessary installation position	B D H	Gasoline engine, longitudinal installation Diesel engine, longitudinal installation Hydrogen engine, longitudinal installation
5+6	Displacement in 1/10 liter	20	2.0 liter displacement
7	Type check issues (modifications which require a new type checking)	A B – Z	Standard As needed, e.g. ROZ87

N47TU Engine
1. Introduction



N47TU engine identification and engine number

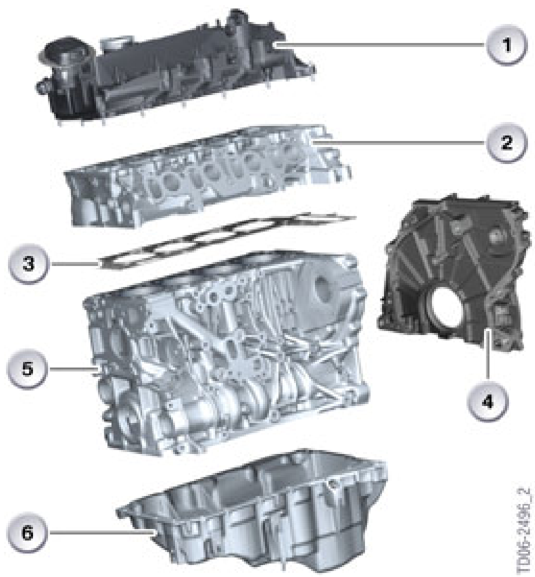
Index	Explanation
96047227	Sequential engine number
N	BMW Group development
4	4-cylinder in-line engine
7	Direct fuel injection and exhaust turbocharger
D	Diesel engine, longitudinal installation
20	2.0 liter displacement
C	First technical revision

N47TU Engine

2. Engine Mechanical

2.1. Crankcase

The crankcase, also known as the engine block, comprises the cylinders, the cooling jacket and the crankshaft housing. The crankcase of the N47TU engine is based on the previous N47 engine (not available in the U.S. market).



N47TU engine block

Index	Explanation
1	Cylinder head cover
2	Cylinder head
3	Head gasket
4	Timing case cover
5	Crankcase
6	Sump

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The engine oil sump and timing case cover use a silicone Loctite gasket 5970 sealant. Please follow proper repair instructions and procedures available in ISTA.

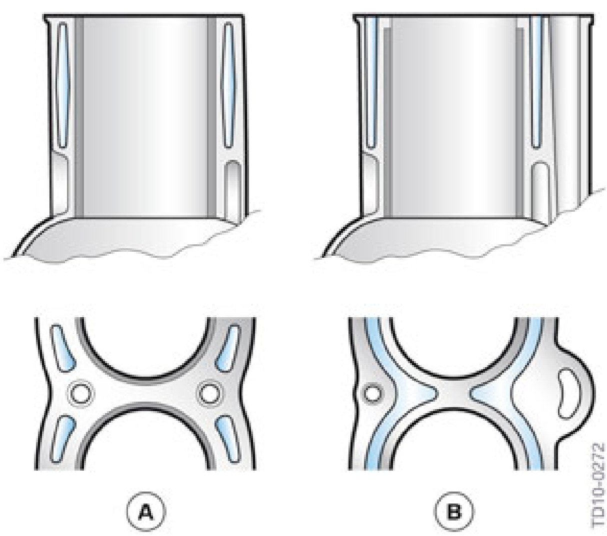
The special features of the crankcase of the N47TU engine are:

- Crankcase made of aluminium
- Balancing shafts integrated in the crankcase
- Chain drive located on the force transmitting (flywheel) side
- Majority of pressurized oil ducts are precast

- Main bearing cap made of sintered metal
- Closed-deck design
- Main bearing pedestal with side walls that extend downwards and individual main bearing caps
- Main bearing caps with indent fit
- Dry, thermally-joined, grey cast-iron cylinder sleeves

2.1.1. Design

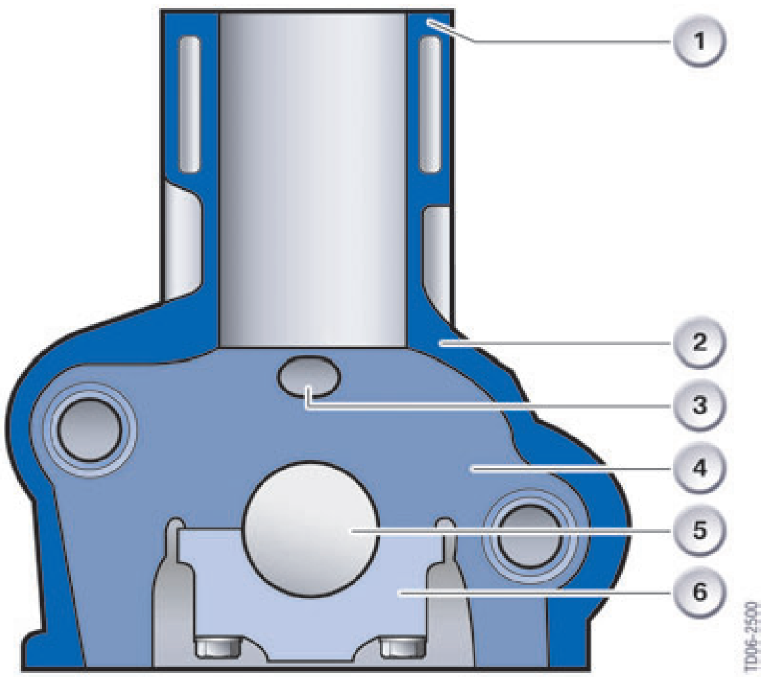
The N47TU engine is equipped with a crankcase with a closed-deck design. As the name suggests, a closed deck is, to a large extent, closed in the area surrounding the cylinders. There are holes and openings for oil pressure and return channels, coolant circulation channels, crankcase vents and cylinder-head bolts. The coolant-channel openings connect the coolant chamber surrounding the cylinders with the coolant jacket in the cylinder head. While this design does have certain disadvantages in respect of cylinder cooling in the TDC range, its benefits outweigh those of the open-deck design what with the greater rigidity of the deck and thus less deck deformation, less cylinder twist and better noise characteristics.



Comparison of an open and closed deck design

Index	Explanation
A	Closed deck
B	Open deck

The design of the main bearing pedestal area is therefore of particular importance because this is where the forces acting on the crankshaft bearings are absorbed. The different types of design are distinguished by the partition between the crankcase and the sump and the design of the main bearing caps. In the N47TU engine, the partition is below the center of the crankshaft; the side walls of the crankcase extend downwards. Individual main bearing caps are used. This design provides high rigidity and is cost-effective to manufacture.



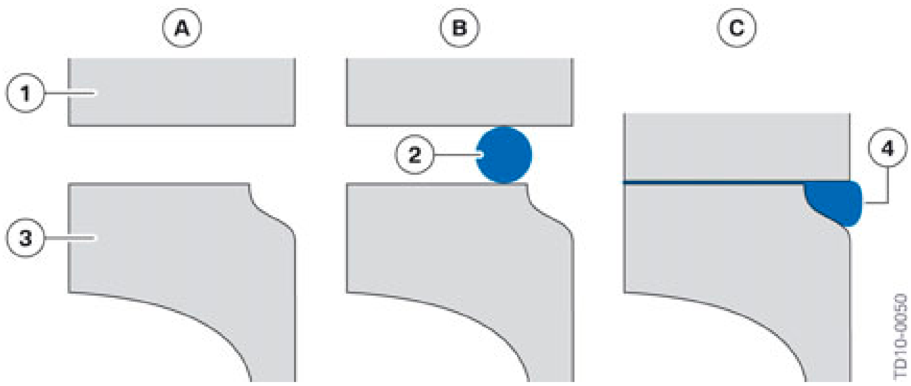
N47TU crankcase layout

Index	Explanation
1	Deck
2	Crankcase
3	Ventilation window (aperture)
4	Bearing pedestal
5	Crankshaft bore
6	Main bearing cap

The bearing pedestal is the top half of a crankshaft main bearing in the crankcase. Bearing pedestals are always integrated into the cast of the crankcase. As with previous BMW engines the N47TU engine uses ventilation windows in the bearing pedestals above the crankshaft. When the engine is running, the air and vapor inside the crankshaft cavity are continuously in motion. The action of the pistons has a pump-like effect on those gases. The ventilation windows reduce these losses because they facilitate pressure compensation in the entire crankcase. They are inserted from the front of the engine.

2.2. Oil Sump

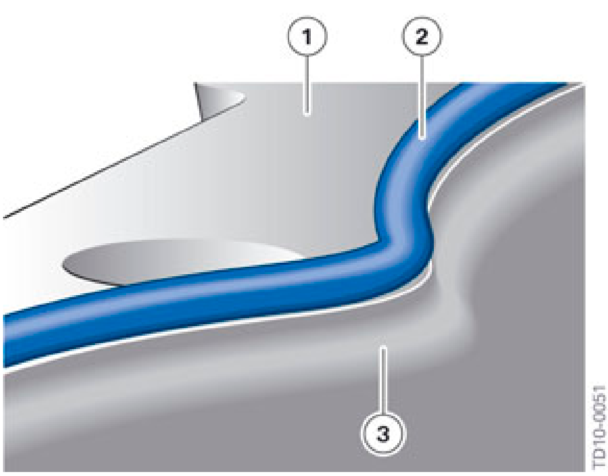
The engine oil sump and timing case cover gaskets use a silicone Loctite gasket 5970. The oil sump was machined with chamfer to use the silicone gasket. This chamfer is located on the inside of the flange, which serves as a defined reservoir for the excess silicone.



Schematic diagram of oil sump gasket

Index	Explanation
A	Components without silicone bead
B	Components with silicone bead
C	Components bolted with silicone gasket
1	Crankcase
2	Silicone bead
3	Oil sump with chamfer
4	Silicone exits through the bolted connection in the prepared space in the oil sump

A chamfer is necessary with a surface gasket so that excess sealing compound can accumulate in the space prepared in a controlled manner, where it can not be dissolved later by the oil leaks.



Positioning of the silicone bead

Index	Explanation
1	Oil sump sealing surface
2	Silicone bead
3	Chamfer on the inside of the oil sump

2. Engine Mechanical

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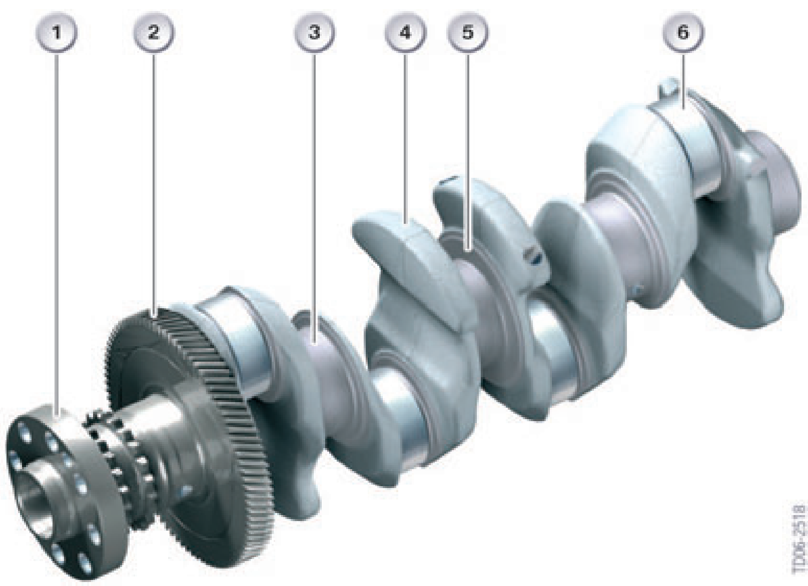
The engine oil sump and timing case cover use a silicone Loctite gasket 5970 sealant. Please follow proper repair instructions and procedures available in ISTA.

2.3. Crankshaft

The distance between the big-end bearing journals and the crankshaft axis produces a stroke of 90 mm on the N47TU engine. The angle between the big-end journals determines the firing interval between cylinders.

Counterweights create a balance of inertial forces around the crankshaft so as to produce even rotation of the shaft. They are designed in such a way as to also compensate for some of the oscillatory (vibrating) inertial forces in addition to the rotational (revolving) inertial forces.

The crankshaft of the N47TU engine is equipped with five counterweights. An odd number of counterweights is unconventional and this is because the drive gear for the balancing shafts is located at the crank web of the last counterweight. This counterweight is therefore made smaller than the others and the crank web before it is fitted with an additional, smaller counterweight.



N47TU crankshaft

Index	Explanation
1	Output flange
2	Balancing shafts drive gear
3	Main bearing journal
4	Counterweight
5	Axial bearing thrust surface
6	Rod bearing journal (big-end)

Crankshaft specifications	Unit	N47TU
Material		37Cr4 BY
Type		Forged
Main bearing journal diameter	[mm]	55
Rod bearing (big-end) diameter	[mm]	50
Number of counterweights		5
Number of main bearings		5
Position of thrust bearing		3

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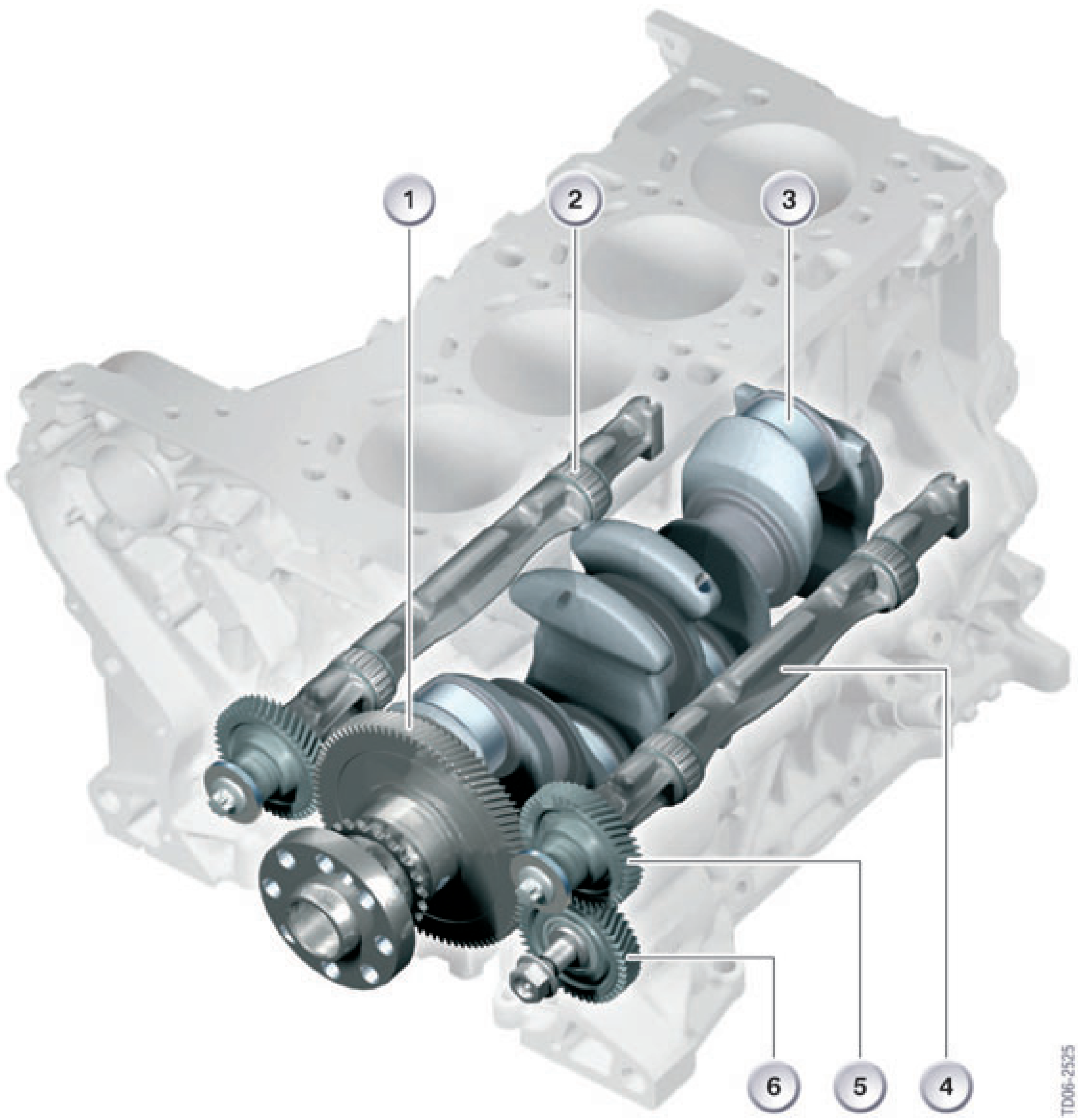
Always refer to the proper repair instructions for more information and follow the special bearing classification procedure when servicing the crankshaft and bearings on BMW engines.

2.4. Balancing shafts

Inertial forces are produced by the crankshaft drive during engine operation. The inertial forces can be distinguished as being rotational forces (turning motion) and oscillatory forces (to-and-fro motion). Rotational forces in the crankshaft drive are compensated for by counterweights and counterbalancing. Oscillatory forces, however, can only be compensated for to a certain extent. With the 4-cylinder in-line engine in particular, inertial forces are generated that cannot produce the smooth engine operation desired by means of counterweights. The use of balancing shafts minimizes this disadvantage inherent in the operating principle of 4-cylinder in-line engines. While their operating principle has remained the same, the installation of balancing shafts in the N47TU engine differs entirely from their installation in previous BMW diesel engines. In the N47TU engine, the balancing shafts are individual parts installed inside the crankcase.

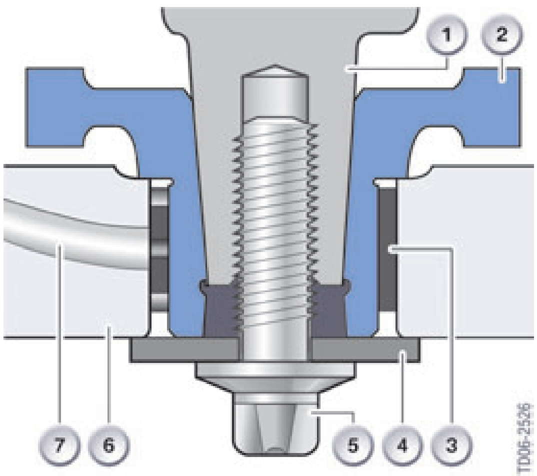


N47TU engine balancing shafts

Index	Explanation
1	Crankshaft drive gear
2	Needle bearing
3	Crankshaft
4	Balancing shaft
5	Balancing shaft drive gear
6	Idle gear

The graphic shows the crankcase from the rear (flywheel side) of the engine.

The balancing shafts are driven by a helically cut gear ring on the final crank web. On the right-hand side of the engine (exhaust side), an idler gear is fitted in front of the balancing shaft to reverse the direction of rotation. The drive gears of the balancing shafts are each connected to the balancing shaft by a tapered connection. The tapered connection is pressed together by a bolt connection.



N47TU balancing shaft drive gear connection

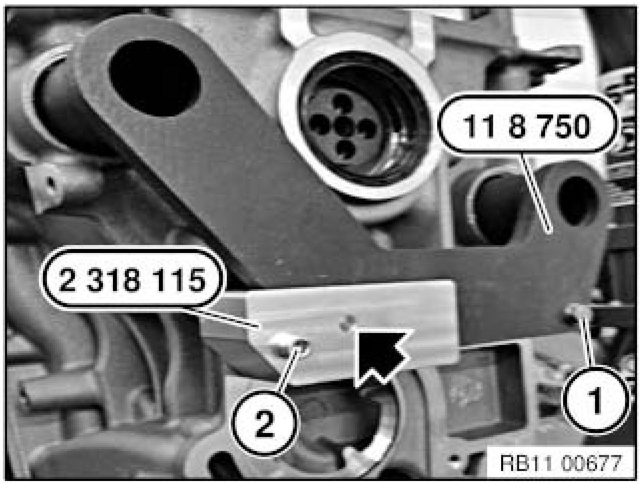
Index	Explanation
1	Balancing shaft
2	Drive gear
3	Bushing
4	Thrust washer
5	Bolt
6	Crankcase
7	Oil passage

The thrust washer that is used for the connection and a thrust surface on the drive gear form the thrust bearing for the balancing shafts. Two needle bearings for each balancing shaft form the radial bearing. These are not supplied with extra oil. The thrust bearing is supplied with lubricating engine oil through an oil passage. The bore in the bushing assumes the role of a restriction. The oil reaches the axial thrust surfaces through a gap in the bushing. For the balancing shaft to turn at twice the speed of the crankshaft, the drive gears of the balancing shafts are half the size (44 teeth) of the gear on the crankshaft (88 teeth). Alignment marks are used to time the gears to the rotating assembly (see repair instructions for more information).

The idler gear reverses the direction of rotation of the balancing shaft on the exhaust side of the engine. To keep the rotation speed the same, it is the same size as the drive gears of the balancing shafts. It is mounted on its shaft by an angular-contact ball bearing. This shaft is fitted and bolted in by a steel bushing pressed into the crankcase. A sleeve is used because manufacturing tolerances are better maintained than if the shaft were fitted directly into the aluminium crankcase. The tooth flanks of the idler gear are coated to make circumferential backlash adjustment possible.

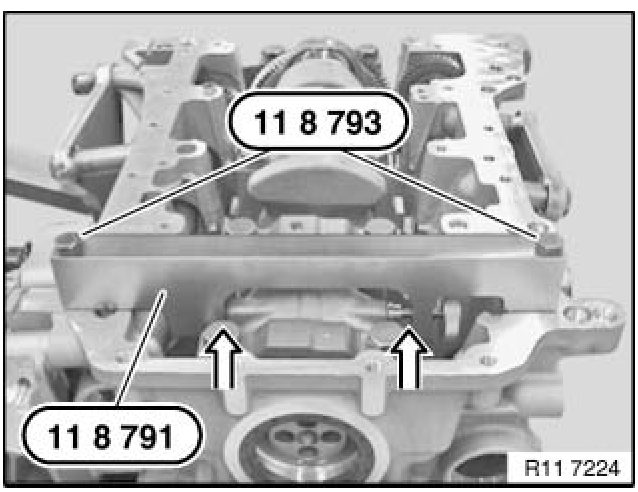
N47TU Engine
2. Engine Mechanical

When removing and installing the balance shaft sprockets, the special tool # 11 8 750 must be used in combination with the special tool # 2 318 115 to properly lock and align the balance shaft. If special tool # 2 318 115 is not installed, as per proper repair instruction, the balance shaft or tool may be damaged.



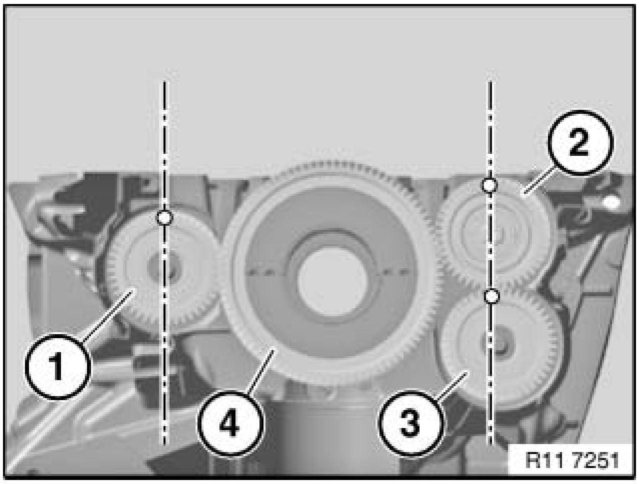
Balance shaft locking tools for the N47TU

Special tool # 11 8 791 must also be used to hold the crankshaft in position to properly time the balance shafts. Please refer to the proper repair instructions available in ISTA.



Special tool 11 8 791 must be used to hold the crankshaft in position to time the balance shafts

When re-installing the balance shafts and gears, the gear markings should be aligned as shown in the illustration below. These marks are used to time the balance shafts to the crankshaft. The idler gear is specially coated and must be replaced every time its removed. Therefore correct back lash must be set during assembly. Please refer to the proper repair instructions available in ISTA.



Balance shaft gear alignment marks

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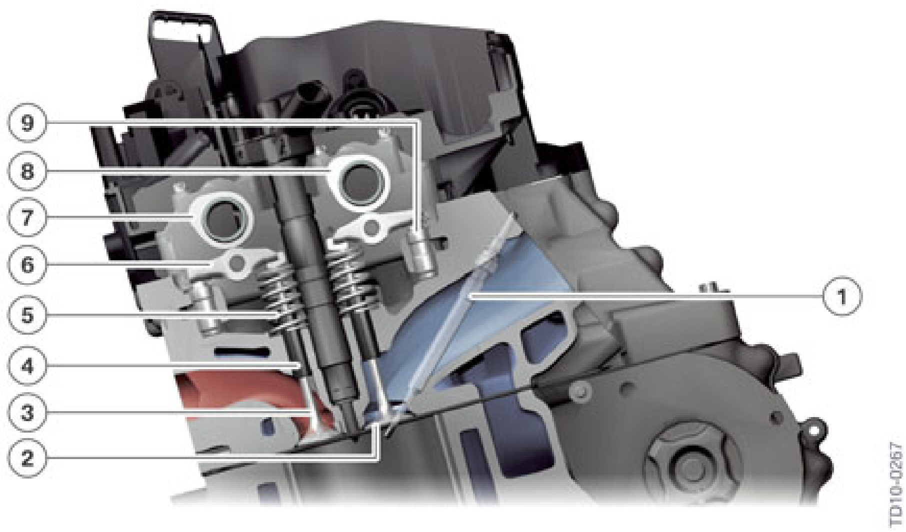
When removing and installing the balance shaft sprockets, the special tool # 11 8 750 must be used in combination with the special tool # 2 318 115 to properly lock and align the balance shaft, otherwise component/tool damage may occur. Please follow the proper repair instructions as illustrated in ISTA.

2.5. Cylinder head

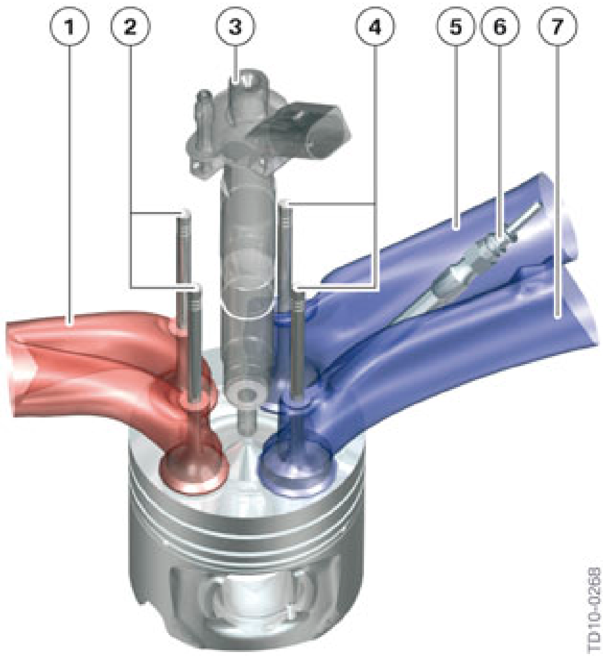
The cylinder head of the N47TU engine is made from a single part. A special feature is the camshaft carrier. Both camshafts are supported in this carrier. This design simplifies the manufacturing process. The camshaft carrier is made from the aluminium-silicon alloy AlSi9Cu3(Fe).



N47TU cylinder head

Index	Explanation
1	Glow plug
2	Intake valve
3	Exhaust valve
4	Valve guide
5	Valve spring
6	Roller cam follower
7	Exhaust camshaft
8	Intake camshaft
9	Hydraulic valve clearance adjuster

The N47TU engine has four valves per cylinder. The four-valve concept provides for a better gas exchange and a greater volumetric efficiency of the combustion chambers than the two-valve concept. The reason for this is that four valves have a larger overall valve surface and thus a better cross-flow section than two valves. The four-valve cylinder head also enables the injector to be situated centrally. This combination is needed to guarantee a high specific power output with low exhaust emissions.



Intake and exhaust ports in the cylinder head.

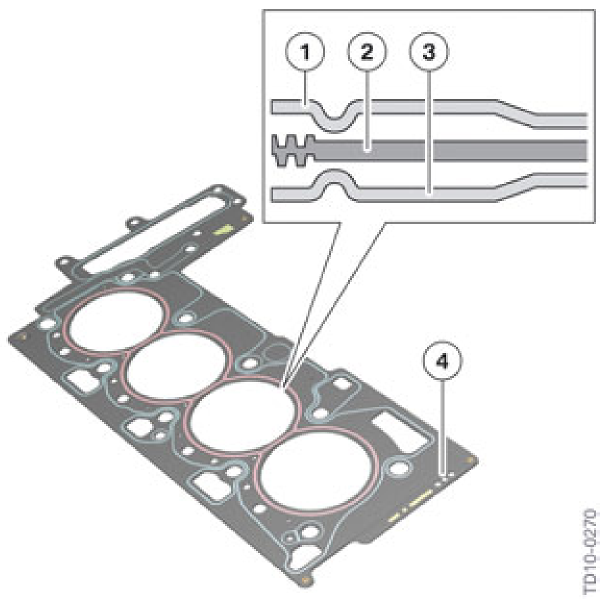
Index	Explanation
1	Exhaust ports
2	Exhaust valve
3	Injector
4	Intake valve
5	Swirl port
6	Glow plug
7	Tangential port

A distinction is made in the case of the intake ports between the swirl port and the tangential port, which provide for optimum mixture preparation and cylinder charge. The swirl and tangential ports are already separated in the intake manifold and are routed separately from each other in the cylinder head. The exhaust ports for each cylinder are already joined in the cylinder head so that only one exhaust port feeds into the exhaust manifold.

2. Engine Mechanical

2.6. Cylinder head gasket

The cylinder head gasket is a very important component in any combustion engine. It is exposed to enormous thermal and mechanical loads. The cylinder head gasket must be able to seal four different zones. These zones are; combustion chamber, atmosphere, engine oil ducts and coolant ducts. Generally speaking, two types of gasket are used for cylinder head gaskets: soft-material gaskets and metal-layer gaskets. The N47TU engine uses a three-layer metal-layer gasket.

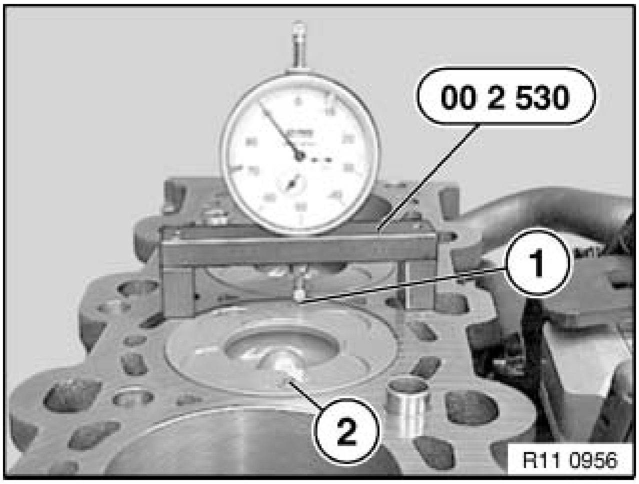


N47TU cylinder head gasket

Index	Explanation
1	Outer spring steel layer
2	Intermediate layer with impressed stopper
3	Outer spring steel layer
4	Identification of cylinder head gasket thickness

Metal-layer gaskets are used in engines which are subjected to high loads. Today these gaskets consist of multi-layer sheet steel inserts. The primary characteristic of a metal-layer gasket is that the seal is essentially determined by integrated bead and stopper layers in the sheet steel inserts. The deformation properties of the metallic cylinder head gasket on the one hand enable the gasket to adapt optimally to the components in the cylinder head area and, on the other hand, provide for a high degree of elastic recovery to compensate for component deformation. Such elastic recovery arises in response to thermal and mechanical loads. The two spring steel layers (function layers) of the cylinder head gasket are made from a spring band. The stopper is impressed onto the intermediate layer (spacer layer).The spring steel layers are made from stainless steel. Additional partial coatings optimize the function of the cylinder head gasket.

The cylinder head gasket comes in three different thicknesses, depending on the respective piston protrusion. The thickness is identified in the cylinder head gasket by holes, where one hole signifies the thinnest and three holes signify the thickest.



N47TU piston protrusion measurement.

Measuring the piston protrusion:

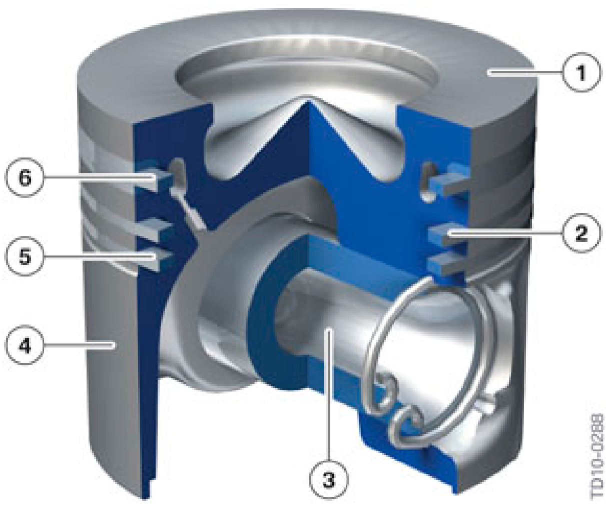
- Clean piston at measuring points (1 and 2).
- Fit dial gauge at measuring point (1) on cleaned piston and determine highest point by rotating crankshaft.
- Measure and note down piston protrusion at measuring points (1 and 2) on all 4 pistons.
- Determine thickness of cylinder head gasket using the table below.

Holes	1	2	3
Gasket thickness N47D20O1 engine	0.92 mm	> 0.92 – 1.03 mm	> 1.03 – 1.18 mm

2.7. Pistons

The pistons are adapted to the new requirements. Thus the combustion chamber is always adapted to the injectors.

The piston of the N47TU engine is made of an aluminium-silicon alloy. So-called full-skirt aluminium pistons are used. On account of the pairing of material with the grey cast iron cylinder wall the surface of the piston skirt is coated with graphite, reducing friction and improving acoustic performance. The cast-in ring carrier on the first piston ring serves to protect the piston ring against wear.



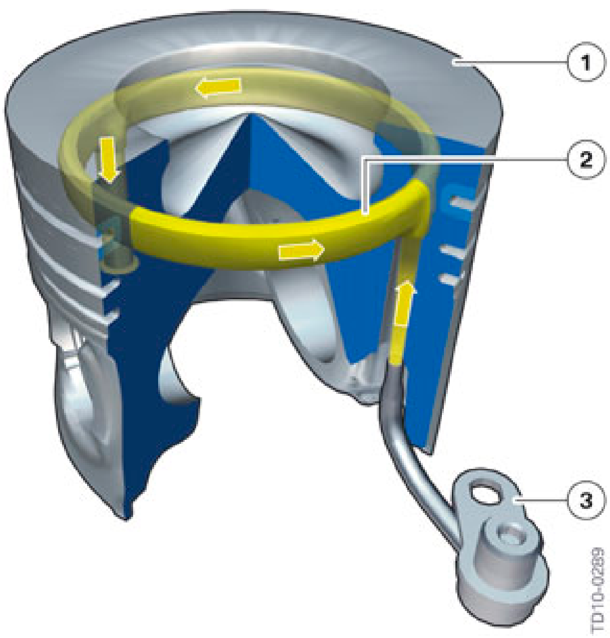
N47TU piston

Index	Explanation
1	Piston crown
2	2nd piston ring
3	Piston wrist pin
4	Piston skirt
5	3rd piston ring
6	1st piston ring

A combustion chamber recess is located in the piston crown. The “omega” shape of the combustion chamber recess is determined by the combustion process and the valve arrangement. A further difference is that there are no valve reliefs, since the valves are arranged vertically to the piston crown. This is referred to as a so-called reduction of dead space. Because the piston crown has no valve reliefs, the air during compression flows more favorably out of the gap between the piston crown and the cylinder head. The range of the piston ring zone is divided into the so-called fire land between the piston crown and the first piston ring and the ring land between the second piston ring and the oil scraper ring. The pistons are adapted to the new requirements. The combustion chamber is thus always matched with the injector. The pistons and the injectors are designed to comply with the ULEV II exhaust emission standard.

2.7.1. Piston cooling

The piston ring zone features a cooling duct (ring duct) to enable the heat to be dissipated effectively from the piston crown. An oil spray nozzle supplies the under side of the piston with cooling oil. It is pointed directly at a bore in the piston which leads to the cooling duct. The piston stroke circulates the oils and provides for the so-called "shaker effect". The oil vibrates in the duct and with it improves the cooling effect, as more heat can be transferred to the oil. The oil flows through a drain bore back into the crankcase.

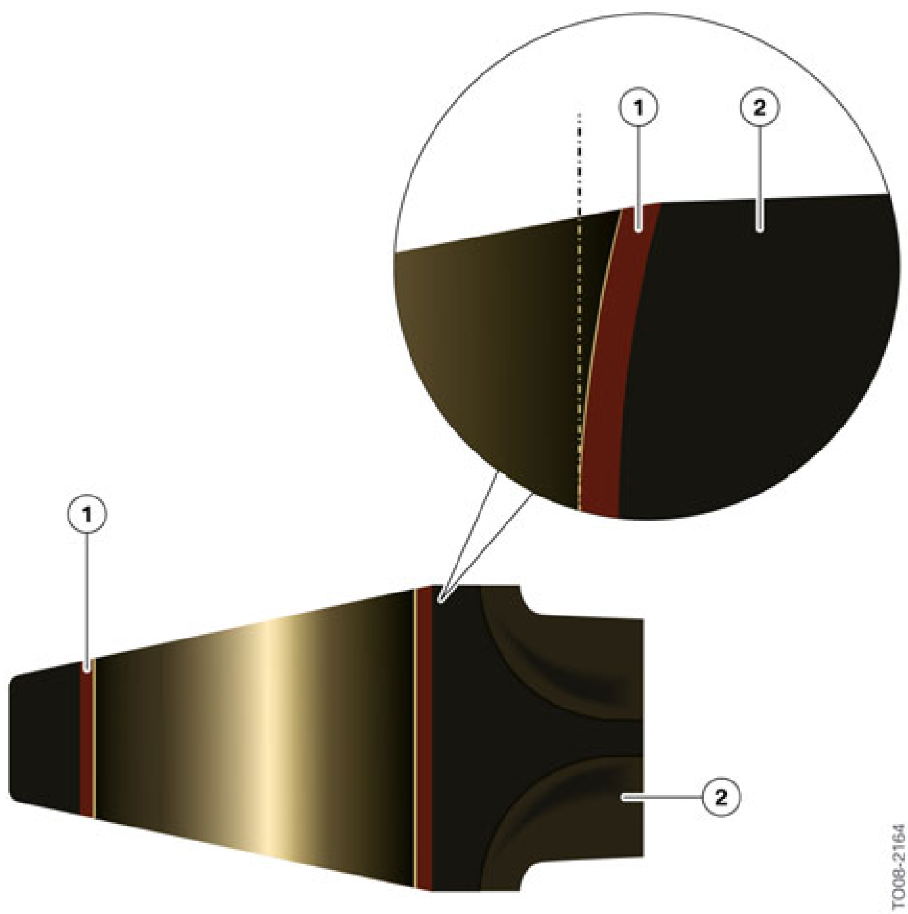


N47TU piston cooling duct

Index	Explanation
1	Piston crown
2	Cooling duct
3	Oil spray nozzle

2.8. Connecting rods

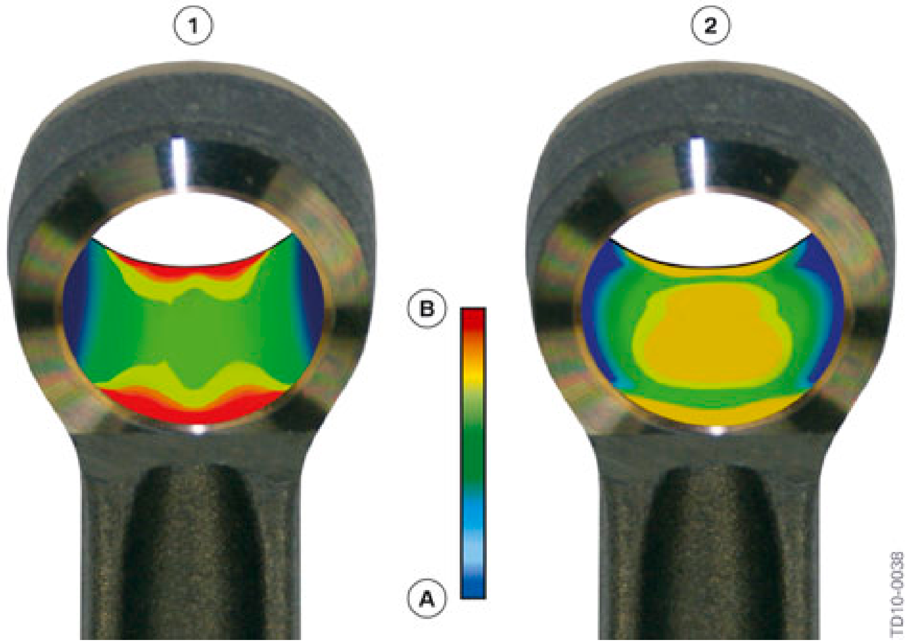
The connecting rods have a large journal inside diameter of 143 mm. As with the N20 the N47TU uses a specially formed hole in the small end of the connecting rod. This formed hole is machined wider on the lower edges of the wrist pin bushing/bore. This design evenly distributes the force acting on the wrist pin over the entire surface of the rod bushing and reduces the load at the edges, as the piston is forced downward on the power stroke.



N47TU connecting rod eye

Index	Explanation
1	Bushing
2	Connecting rods

The following graphic shows the surface load comparison on a standard connecting rod with and without the machined formed hole. Due to combustion pressure (on a connecting rod without the machined formed hole) the force exerted by the piston via the wrist pin is mainly transmitted to the edges of the rod bushing. If a formed hole is machined in the small connecting rod eye (illustration 2), then the force is distributed on a larger area and the load on the edge of the sleeve is reduced significantly. The force is then transferred over a larger surface.



Comparison of force distribution on the connecting rod eye

Index	Explanation
A	Low surface load
B	High surface load
1	Without formed hole
2	With formed hole

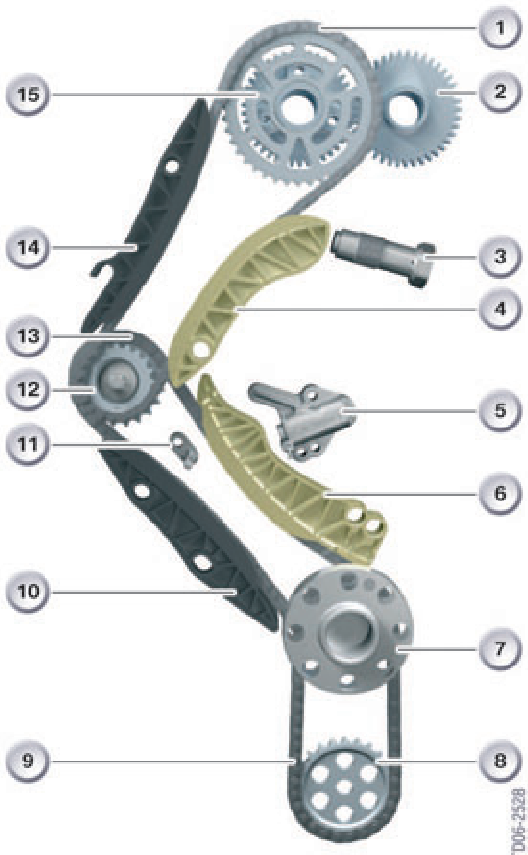
2.9. Valvetrain

2.9.1. Design

The N47TU chain drive is located on the force transmitting (flywheel) side of the engine. Since the gears of the camshafts are located at the rear of the engine the rotational vibrations are significantly reduced due to the inertial mass of the transmission which results in a reduction of load on the chain drive.

The chain drive is comprised of a sprocket on the crankshaft, chain guides, chain tensioners with tensioning rails, an oil supply, one sprocket on the high-pressure pump and one on the camshaft and, finally, the chain itself with the length of the chain as short as possible. The part of the chain that is not under tension is called the slack side. The chain is always tensioned on the slack side. This is done by means of a tensioning rail that is operated by a chain tensioner. Oil is supplied by an oil spray nozzle, which sprays engine oil onto the chain. The oil/vacuum pump is also chain-driven by the crankshaft.

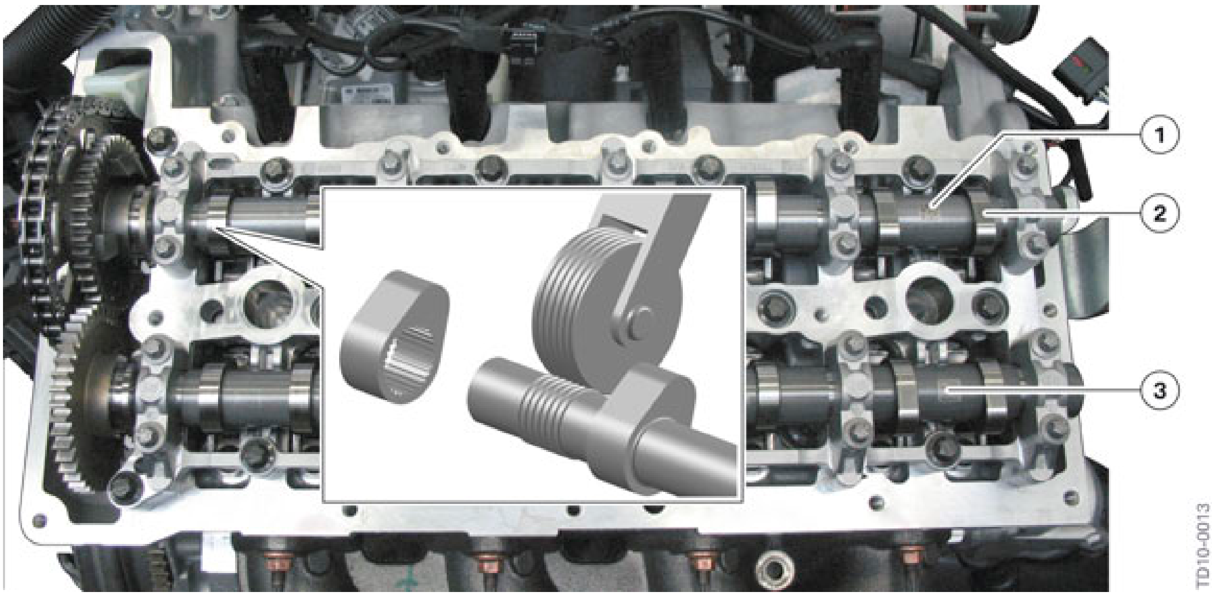
N47TU Engine
2. Engine Mechanical



N47TU engine chain drive shown.

Index	Explanation
1	Upper chain
2	Exhaust camshaft gear
3	Upper chain tensioner
4	Upper tensioning rail
5	Lower chain tensioner
6	Lower tensioning rail
7	Crankshaft
8	Oil vacuum/pump sprocket
9	Oil vacuum/pump chain
10	Lower chain guide rail
11	Oil spray nozzle
12	High-pressure pump sprocket
13	Lower chain
14	Upper guide rail
15	Intake camshaft sprocket

Assembled type camshafts using the Presta method are installed in the N47TU engine.



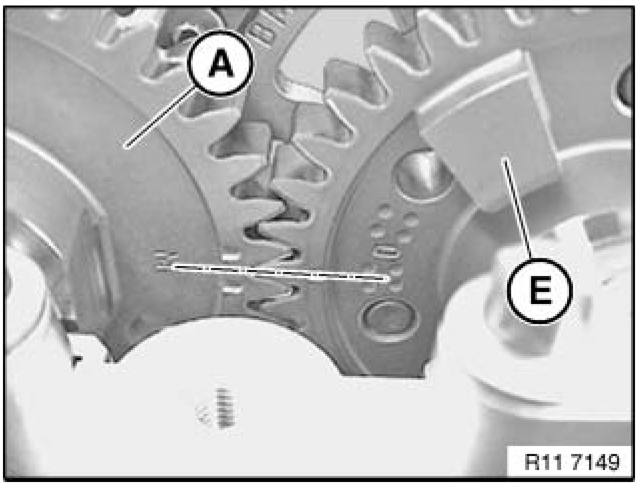
The Presta method used to manufacture the assembled camshafts of the N47TU

Index	Explanation
1	Intake camshaft
2	Cam lobe
3	Exhaust camshaft

The Presta method is used in the manufacture of all BMW diesel engine camshafts. With the Presta method, the tube is widened by rolling and given a radial profile (pitch-less thread) at the relevant position intended for the seat of a cam lobe or another component. The appropriate part is then pressed on at the desired angle. The bore of the part being pressed on has a longitudinal profile. This creates a positive and non-positive connection between the shaft and the component that was pressed on. Since the drive gear is also fitted in this manner, it is connected to the shaft and cannot come loose.

2.9.2. Camshaft timing

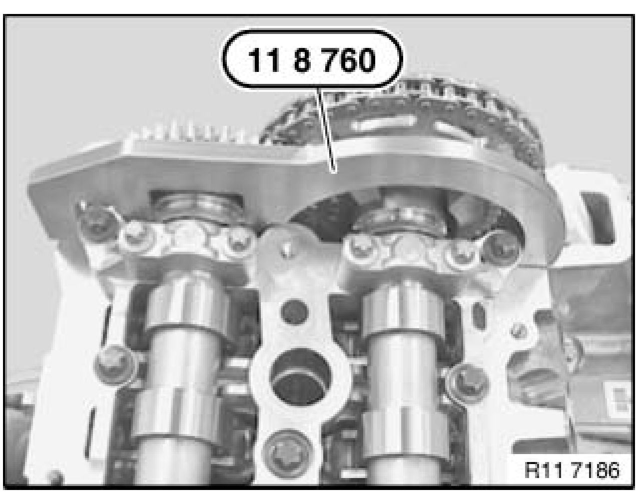
The intake camshaft is driven by the crankshaft by means of a chain on a sprocket. Additional gears transmit the drive force from the intake camshaft to the exhaust camshaft. These gears are permanently connected to the camshafts. Markings on the gears help the installer to position the camshafts correctly during assembly.



N47TU engine camshaft timing marks aligned.

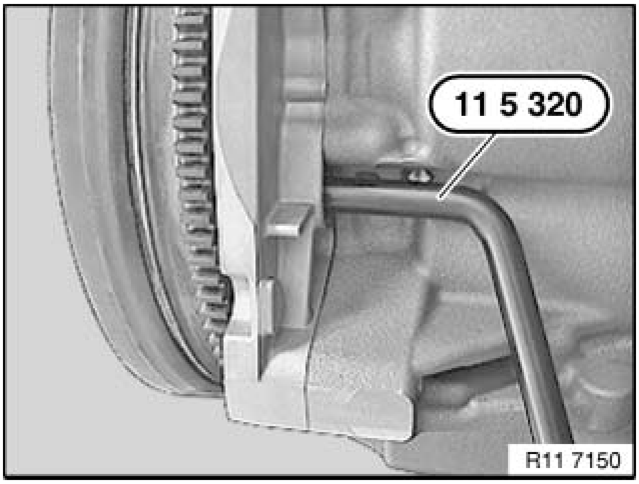
The double-flatted neck is used for the special tool to ensure correct positioning during installation of the gear of the exhaust camshaft. The special tool is only positioned on one camshaft. The sprocket is bolted onto the intake camshaft. Elongated holes make it possible to adjust valve timing. The bolt connection is arranged/spaced at a 120° angle so it is not necessary to turn the camshafts to be able to tighten all the bolts.

Special cam timing tool 11 8 760 is placed over the exhaust camshaft with the sprocket timing marks aligned. The tool should be flush to the cylinder head. (see figure below)



N47TU engine camshaft timing special tool 11 8 760.

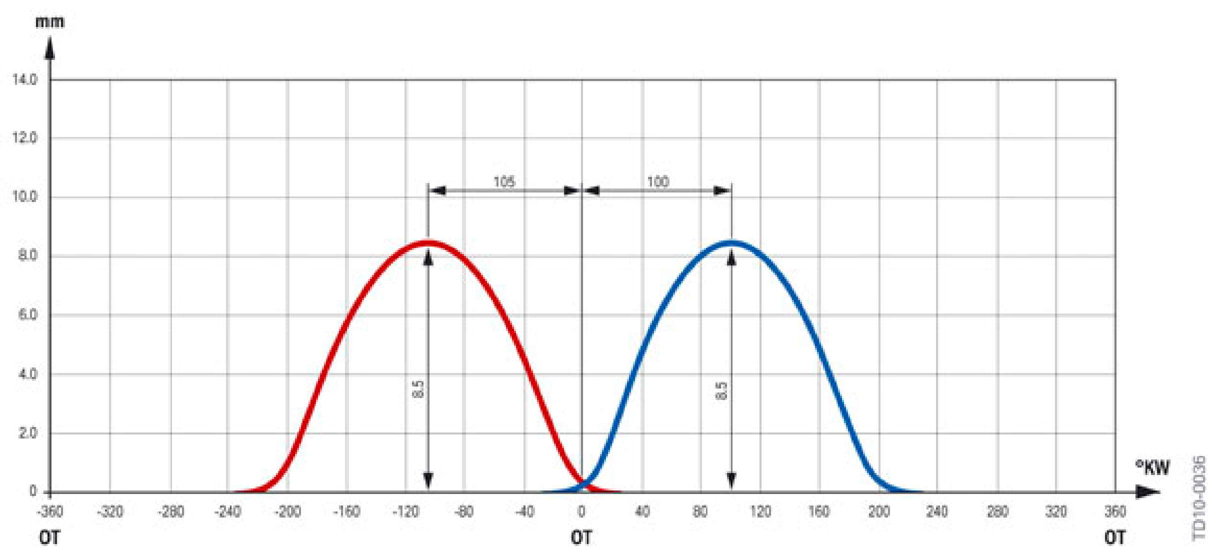
Special tool 11 5 320 is used to lock the crankshaft in the TDC firing position of cylinder #1.



Special tool 11 5 320 is used to lock the crankshaft of the N47TU engine

2.9.3. Valve timing

The timing of the N47TU engine was modified (when compared with the previous N47) and newly designed camshafts and exhaust valves were installed.



N47TU engine, timing diagram. (Red is the exhaust valve and Blue is the intake valve)

Valve timing specification	Unit	N47TU intake	N47TU exhaust
Valve diameter	[mm]	27.2	24.6
Max. valve lift	[mm]	8.5	8.5
Spread	Crankshaft rotation degrees [°]	100	105

2. Engine Mechanical

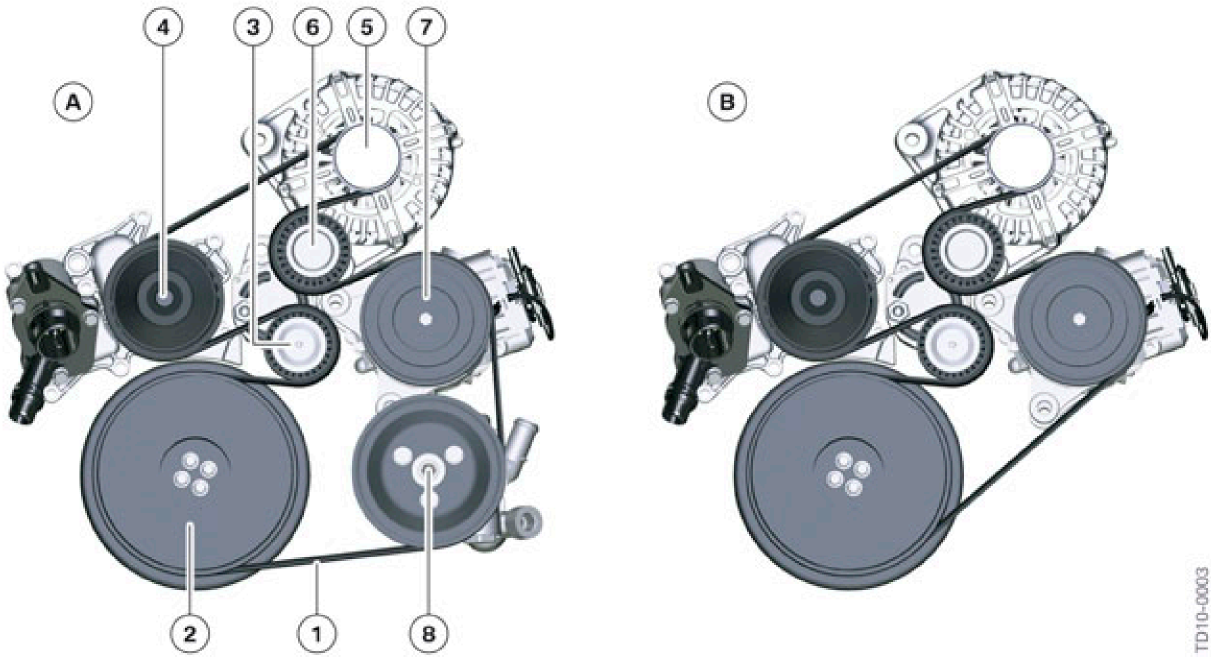
Valve timing specification	Unit	N47TU intake	N47TU exhaust
Valve opens	Crankshaft rotation degrees [°]	352.4	140.7
Valve closes	Crankshaft rotation degrees [°]	567.1	363.9
Valve opening period	Crankshaft rotation degrees [°]	214.7	223.1

N47TU Engine

3. Belt Drive

The arrangement of the belt drive is shown below. Two variations of the belt drive are available depending on vehicle options and market.

3.1. N47TU Engine



N47TU engine drive belt variants

Index	Explanation
A	With hydraulic steering (Not for U.S.)
B	Without hydraulic steering (with EPS)
1	Single-sided poly-V belts
2	Torsional vibration damper
3	Tensioning pulley
4	Coolant pump
5	Alternator
6	Deflecting roller
7	Air conditioning compressor
8	Power steering pump

The deflecting roller is mounted on the belt tensioner. The belt tensioner requires a hexagon head for locking and unlocking. The belt tensioning force can be reduced to about 100 Nm. The alternator has a belt pulley freewheel for reduction of belt squealing when starting the engine.

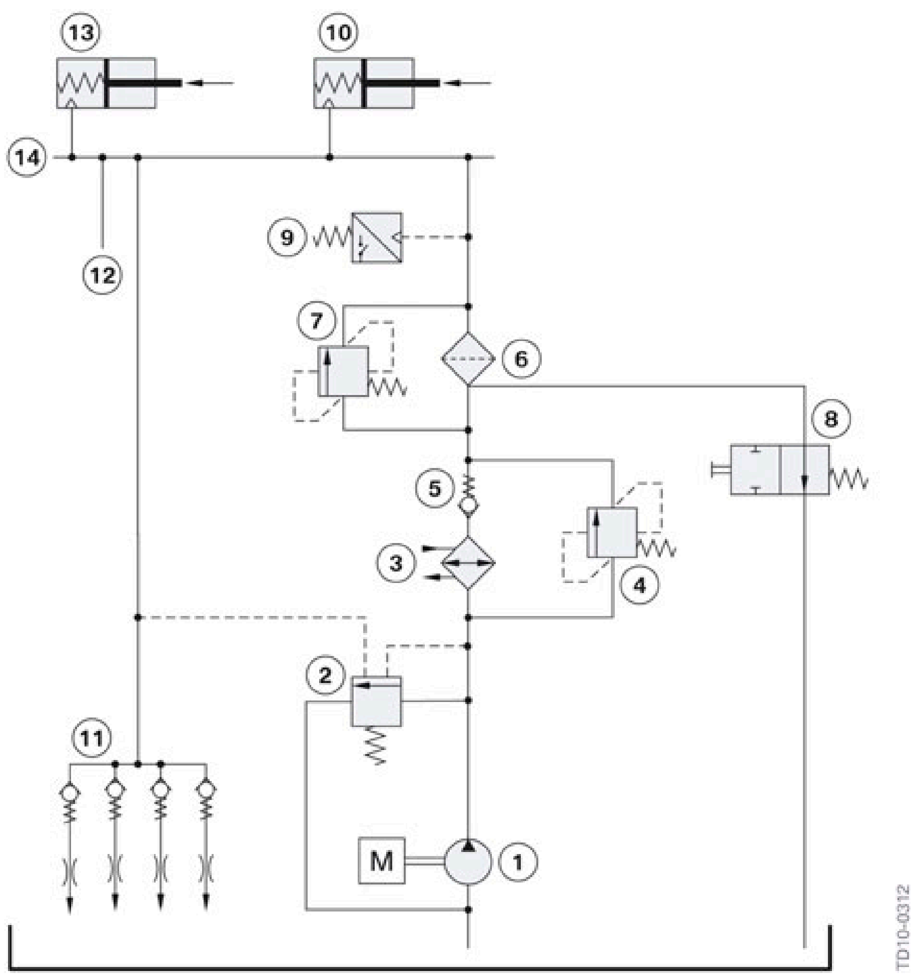
N47TU Engine

4. Oil Supply

4.1. Oil circuit

The N47TU engine is equipped with a forced-feed lubrication system.

In a forced-feed lubrication system, the oil pump takes in oil from the sump through an intake pipe and pumps it onwards into the circuit. The oil flows through the full-flow oil filter and then passes into the main oil channel, which runs parallel to the crankshaft in the engine block. Branch galleries lead to the main bearings of the crankshaft. The crankshaft has corresponding holes to feed oil from the main bearings to the crank pins and connecting rod journals. Part of the oil is branched off from the main oil passage and fed to the corresponding lubrication points in the cylinder head. The oil ultimately returns to the sump. Either it passes through return channels or it simply drips back there freely.



N47TU engine oil circuit

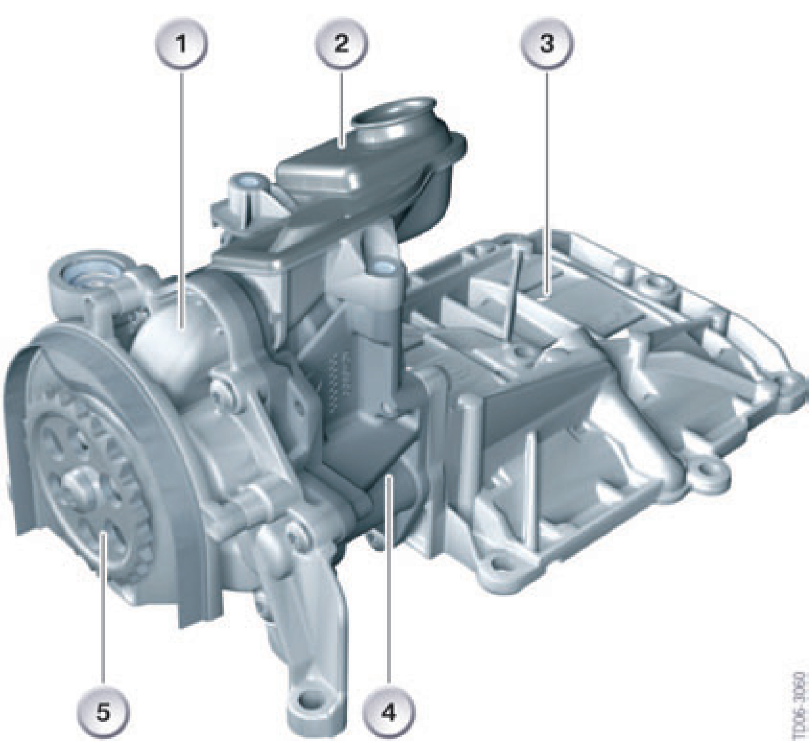
Index	Explanation
1	Oil pump
2	Pressure limiting valve
3	Engine oil/coolant heat exchanger
4	Heat exchanger bypass valve

Index	Explanation
5	Non-return valve
6	Oil filter
7	Filter bypass valve
8	Oil filter outlet valve
9	Oil pressure switch
10	Lower chain tensioner
11	Oil spray nozzles with piston cooling valves
12	Lubrication points in the crankcase
13	Upper chain tensioner
14	Lubrication points in the cylinder head

4.2. Oil pump

The oil pump takes the oil from the oil pan via the intake pipe or oil pickup pipe. The intake pipe opening is positioned below the oil level under all operating conditions. The intake pipe is fitted with an oil screen that keeps coarse dirt particles away from the oil pump. The intake pipe is a separate component and is bolted onto the oil pump.

In the N47TU engine, the oil/vacuum pump is also chain-driven by the crankshaft.



N47TU combination oil/vacuum pump

4. Oil Supply

Index	Explanation
1	Oil pump
2	Intake pipe
3	Reinforcement shell
4	Vacuum pump
5	Oil/vacuum pump sprocket

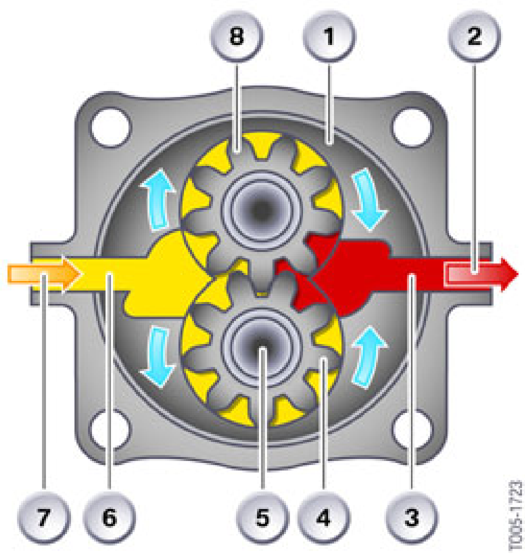
The oil pump plays a central role in the N47TU engine as it does in all modern combustion engines. The high output and the enormous torque produced, at even low engine speeds, demand that a high rate of oil flow be guaranteed. This is necessary for reasons of high component temperatures and bearings being subjected to high loads. On the other side, a demand-oriented oil pump is required in order to achieve low fuel consumption. There are different types of oil pumps to meet these requirements. A spur-gear oil pump is being used in the N47TU. It is chain-driven by the crankshaft (crankshaft: oil pump ratio i = 21:24); the theoretical delivery rate is 16 cm^3 per revolution of the oil pump.

The oil pump and the vacuum pump are combined in one component. Although they share the drive of the crankshaft, they are separate in their function.

The reason for the unusual installation location of the vacuum pump is to reduce the engine height dimension. It was designed in this manner with passive pedestrian safety in mind. The pump is a vane-type pump with aluminium housing (AlSi9Cu3) with a steel rotor and a plastic vane. It is chain-driven together with the oil pump by the crankshaft (See the Vacuum system section for more information).

4.2.1. Spur-gear oil pump

Spur-gear oil pump uses two meshed gears, of which one is driven. The tips of the teeth that are not engaged pass along the pump housing and convey oil from the intake into the pressure chamber. The quantity of residual oil that remains in the base of the tooth poses a problem. This squeezed oil can build up to very high pressures, making it necessary to have pressure relief grooves in the pump housing and cover that drain the oil into the pressure chamber.

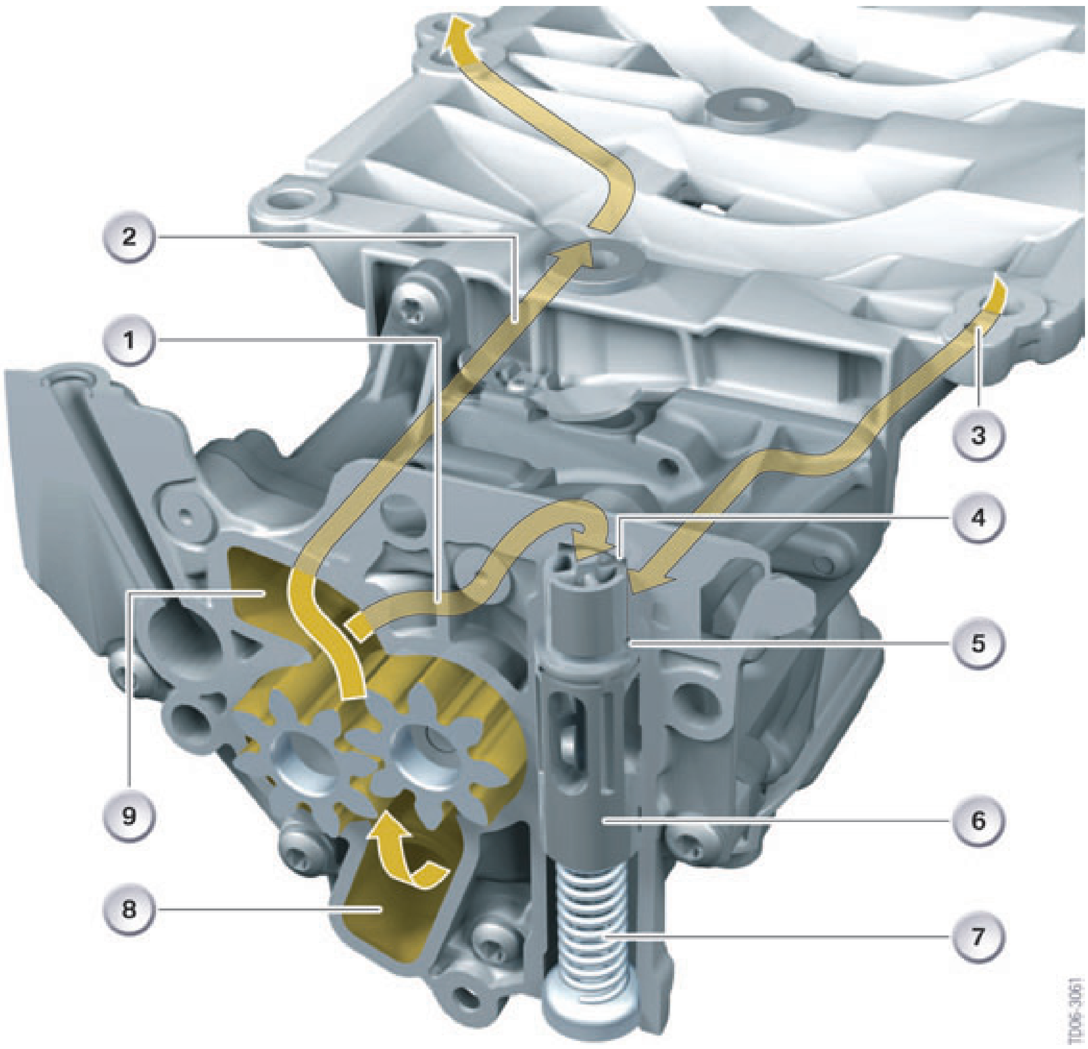


Spur gear oil pump

Index	Explanation
1	Oil pump housing
2	Pressurized oil
3	Pressure chamber
4	Gear wheel (oil pump gear)
5	Drive shaft
6	Intake chamber
7	Oil intake
8	Gear wheel (oil pump gear)

4.3. Pressure limiting valve

The pressure limiting valve protects against excessively high oil pressure, e.g. when starting the engine with the oil cold. It protects the oil pump, oil pump drive, oil filter and oil cooler. The pressure limiting valve is located on the pressure side between the oil pump and oil filter. It is fitted as close as possible downstream of the oil pump. In the N47TU engine, it is fitted in the oil pump housing itself and has an opening or cutoff pressure of 3.7 bar.



N47TU oil pump with pressure relief valve

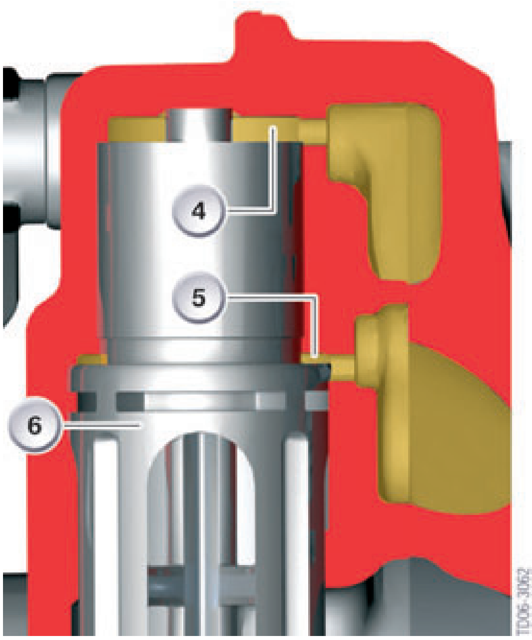
Index	Explanation
1	Oil to upper control chamber
2	Unfiltered oil duct to the oil filter
3	Clean oil duct to the lower control chamber
4	Upper control chamber
5	Lower control chamber
6	Control piston
7	Return spring
8	Intake side
9	Pressure side

In the N47TU engine, oil acts on the pressure limiting valve downstream of the filter, but also directly downstream of the pump.

N47TU Engine
4. Oil Supply

The oil is taken in by the spur-gear oil pump and delivered to pressure side (9). A duct carries oil (1) from pressure side (9) to upper control chamber (4) of the pressure limiting valve, causing pressure to build up downstream of the oil pump and upstream of the oil filter. The remaining oil flows through unfiltered oil duct (2) to the oil filter and finally into the main oil duct. Oil returns to the oil pump housing through clean oil duct (3) and from there supplies lower control chamber (5) of the pressure limiting valve through an oil hole. As a result, the oil circuit system pressure is present in the control chamber (downstream of the oil filter).

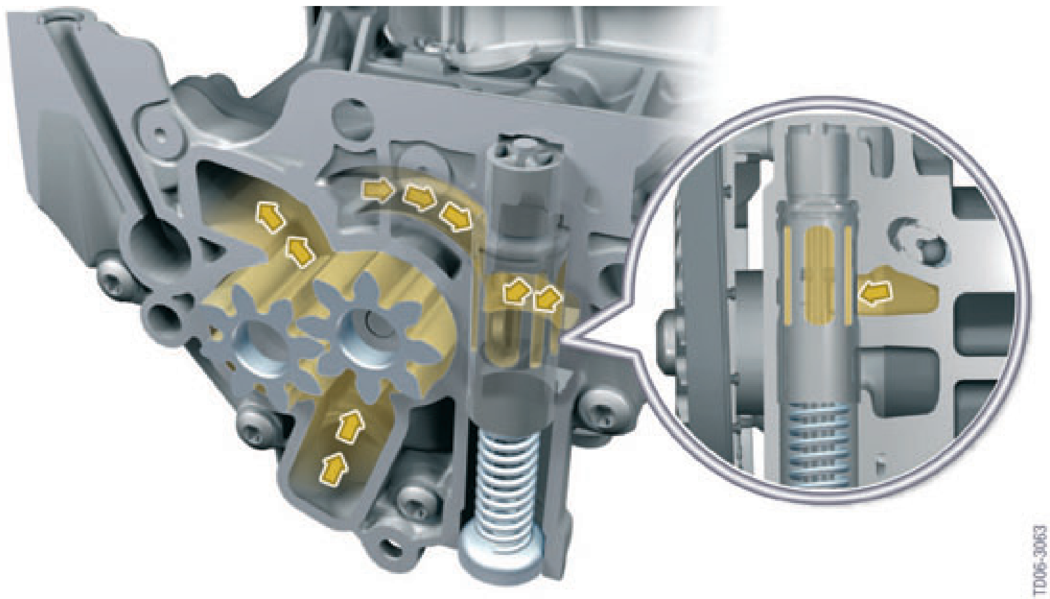
The control chambers are located on one side by control piston (6), which is acted on by a return spring (7).



Control chambers in the pressure limiting valve of the N47TU

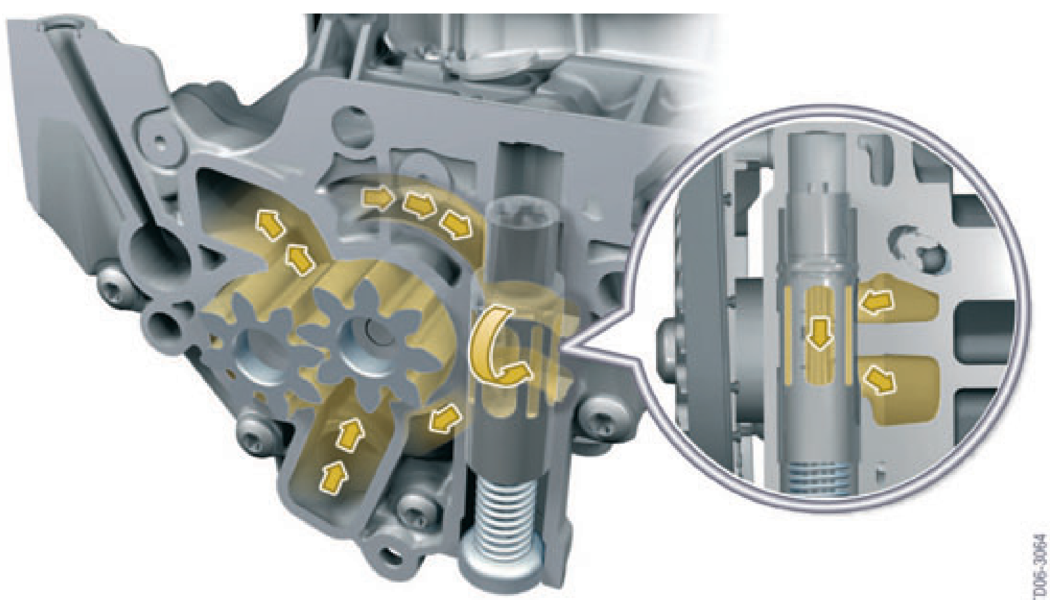
Index	Explanation
4	Upper control chamber
5	Lower control chamber
6	Control piston

At low oil pressure, the pressure limiting valve is closed.



Pressure limiting valve closed

The spring force of the return spring determines the opening pressure of the pressure limiting valve. If the system pressure in the oil circuit increases, and thus in the control chamber, the control piston is moved against the spring force. Due to the special shape of the control piston, a connection between the pressure side of the spur-gear oil pump and the intake section is opened.



Pressure limiting valve open

The oil circuit is for all intents and purposes closed briefly. As a consequence of the pressure ratios, a certain amount of oil flows from the pressure side and into the intake section. The more the control piston opens, the greater the volume of oil that flows away. This causes a drop of pressure in the system. Since the control piston is opened by system pressure, there is a return to equilibrium. In this way, the pressure in the system cannot exceed a desired maximum value, which is determined by the force of the return spring.

4. Oil Supply

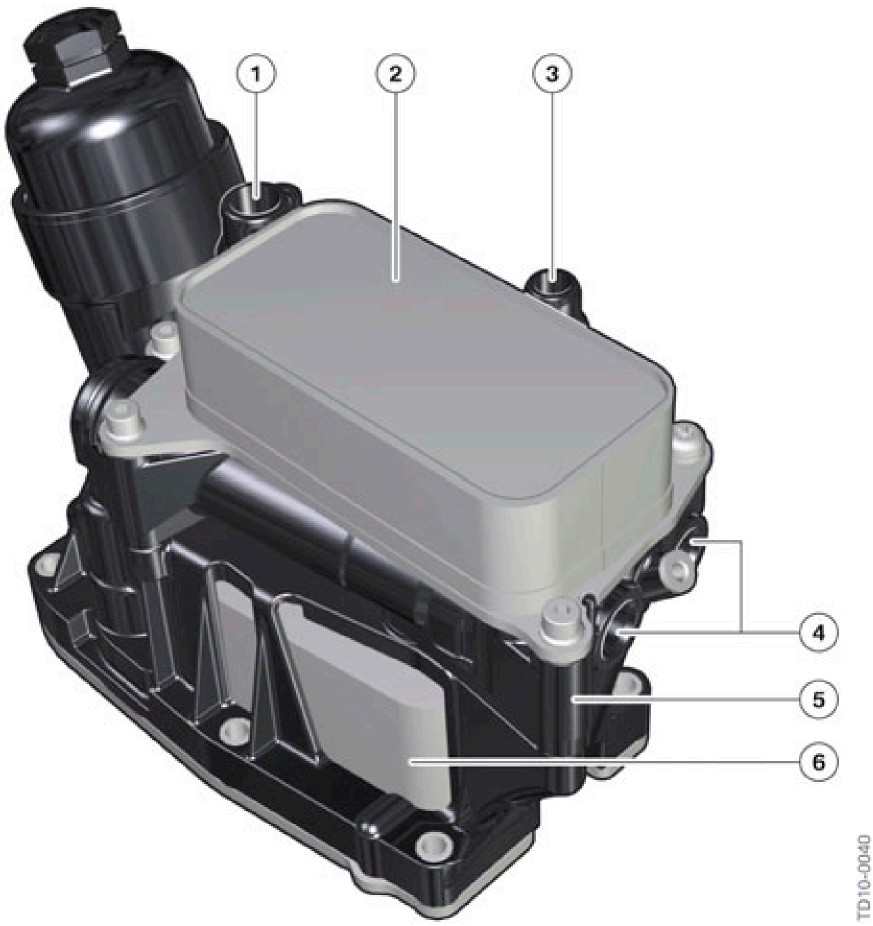
The reason why oil acts on the control piston directly downstream of the pump and also downstream of the filter is because:

- As a result of the connection with the oil circuit downstream of the filter, it is system pressure that is present and not the pressure between the oil pump and oil filter. A clogging of the oil filter causes a drop in downstream pressure, while the pressure upstream increases. If the pressure limiting valve were to be opened only in response to the pressure downstream of the pump, the pressure limiting valve would now open even though maximum system pressure had not been reached. In extreme cases, this could reduce the oil supply at the lubricating points.
- If the control piston were to be controlled only by oil downstream of the oil filter, a very high pressure would build up in the engine oil circuit during a cold start (at extremely low temperatures and thus with a correspondingly viscous oil) until the oil reached the pressure limiting valve and the pressure were regulated down. The high pressure could lead to damage of components and, due to the increased drive output required for the oil pump, also cause a deterioration in the starting characteristics of the engine.

The superposition of two pressures at the pressure limiting valve helps to achieve optimum component protection and, at the same time, ensure a reliable supply of lubricating points and good cold-start characteristics.

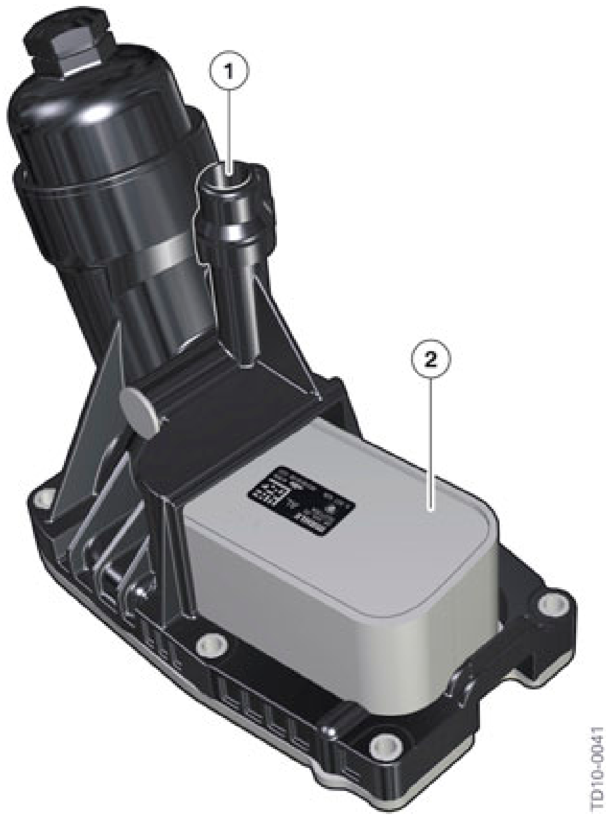
4.4. Oil filter module

The oil filter housing contains valves, filter elements and gaskets. In addition the transmission fluid-to-coolant heat exchanger is also integrated into the oil filter housing.



N47TU engine oil filter module with integrated transmission fluid-to-coolant heat exchanger

Index	Explanation
1	Connecting branch for heater return
2	Transmission fluid-to-coolant heat exchanger
3	Coolant connection from radiator
4	Connection for transmission oil lines
5	Oil filter module housing
6	Engine oil-to-coolant heat exchanger



N47TU engine oil filter module with integrated transmission fluid-to-coolant heat exchanger

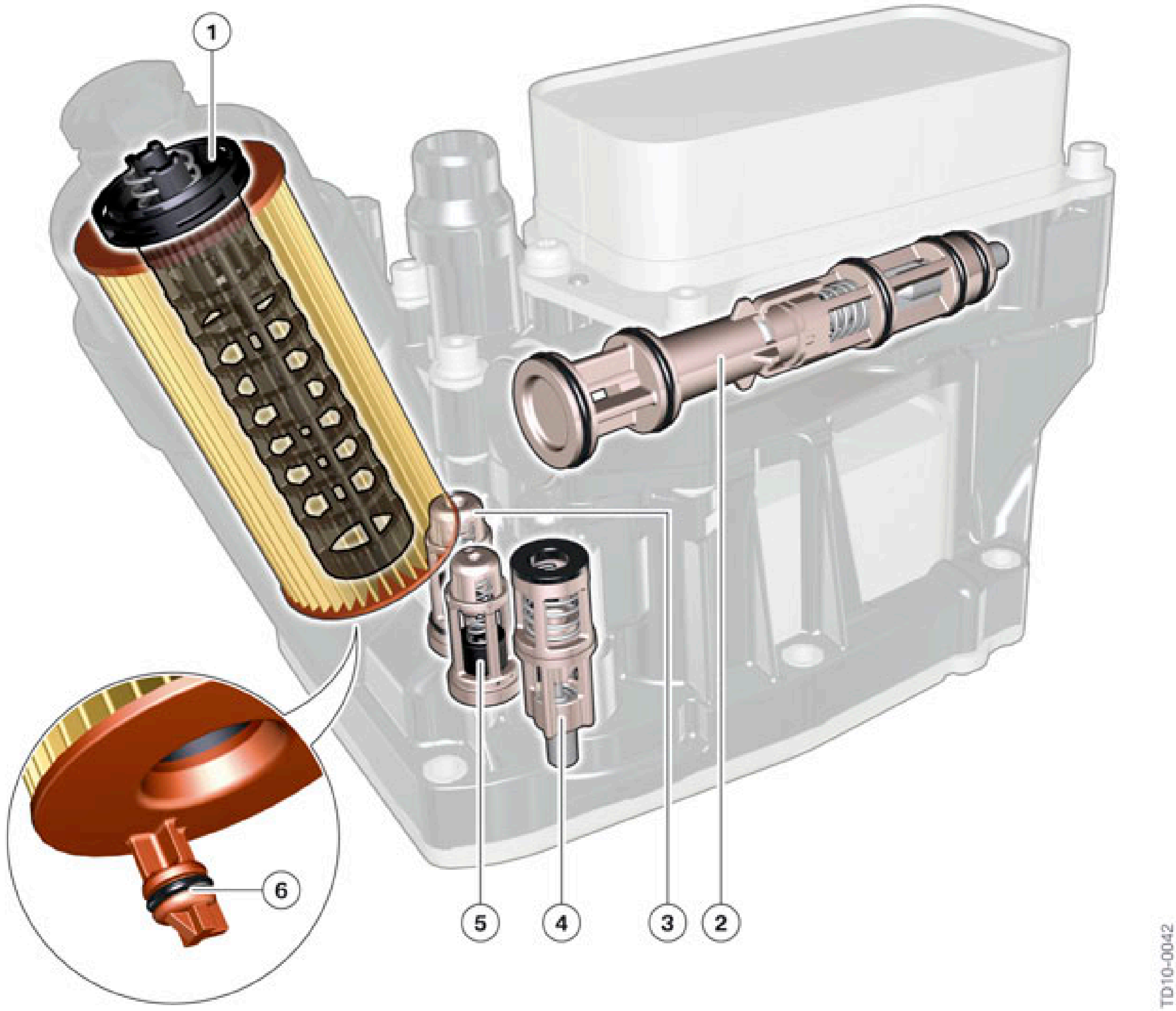
Index	Explanation
1	Connecting branch for heater return
2	Engine oil-to-coolant heat exchanger

4.4.1. Transmission oil cooling

Automatic transmission vehicles use a transmission fluid cooling system.

N47TU Engine

4. Oil Supply



N47TU engine, transmission fluid cooling system valves and thermostats

Index	Explanation
1	Filter by-pass valve
2	Thermostat for transmission fluid cooling
3	Non-return valve
4	Transmission fluid heat generator thermostat
5	Heat exchanger by-pass valve
6	Discharge valve

Filter by-pass valve

The filter by-pass valve ensures that in the event of a plugged filter, the engine oil still gets to the lubrication points of the engine. It opens before and after the oil filter at a differential pressure of 2.5 bar ± 0.3 bar.

Thermostat for transmission fluid

A thermostat for the transmission fluid temperature control is also integrated in the oil filter module. Transmission fluid flows through the thermostat. If the temperature of the transmission fluid increases to ≥ 88 °C, the thermostat opens and releases the coolant flow from the low temperature cooler of the cooling system in the transmission (fluid-to-coolant) heat exchanger. Simultaneously the transmission fluid thermostat closes the cooling circuit from the engine block via the transmission fluid heat generator thermostat. The transmission fluid is thus cooled by this process.

Non-return valve

The non-return valve that the engine oil channels and the oil filter housing does not run empty during engine standstill. It opens the inlet from the oil pump at 0.1 bar ± 0.03 bar.

Heat generator thermostat for transmission fluid

A heat generator thermostat is integrated into the oil filter housing to warm up the transmission fluid faster. The transmission fluid heat generator thermostat remains closed up to an engine coolant temperature of < 80 °C (176° F). There is no coolant flow through the transmission fluid-to-coolant heat exchanger below this temperature.

If the engine coolant temperature reaches ≥ 80 °C (176 °F), then the transmission fluid heat generator thermostat opens and releases the coolant flow from the engine via the transmission fluid thermostat.

The heat generator thermostat has the following advantages for the transmission:

- Is warmed up with excess engine heat
- Faster warm-up
- Lower friction losses
- Optimum shifting comfort is available faster

Heat exchanger by-pass valve

The heat exchanger by-pass valve has the same function as the filter by-pass valve. If the oil pressure increases in the event of a plugged oil-to-coolant heat exchanger, the heat exchanger by-pass valve opens at a pressure of 2.5 ± 0.3 bar and the oil can still get to the lubricating points (by-passing the cooler).

Discharge valve

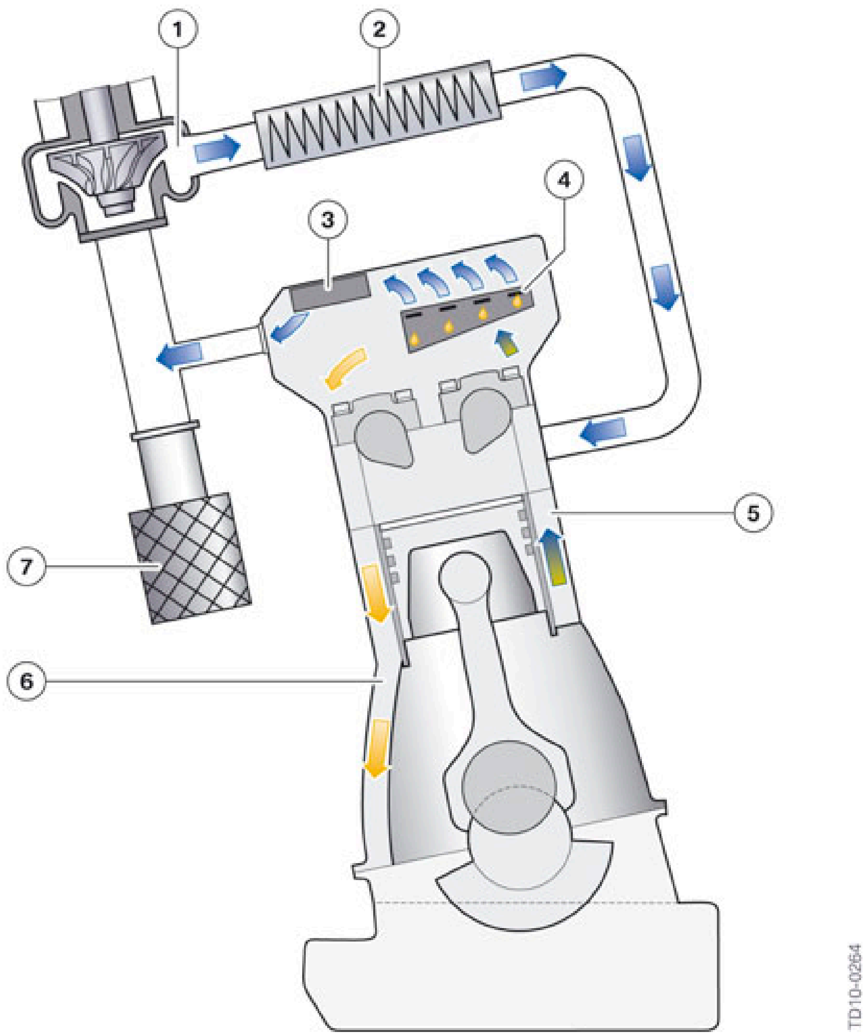
The discharge valve is integrated into the oil filter and is replaced when the oil filter is replaced.

4.5. Crankcase ventilation

With vacuum-controlled crankcase ventilation, a pressure control valve ensures that the vacuum pressure in the crankcase is limited to a defined level. An excessively high vacuum pressure in the crankcase could cause the crankshaft seals to fail. Fresh air would be inducted into the crank space, resulting in oil sludge. The total quantity of oil would not be separated in view of the large quantity of blow-by gases.

4. Oil Supply

The N47TU crankcase ventilation uses a "spring tab" separator system. There are four of these installed in the engine cover. The cleaned blow-by gas (free from oil) is sent via the pressure control valve to the clean air pipe in front of the turbocharger.



Crankcase ventilation diagram

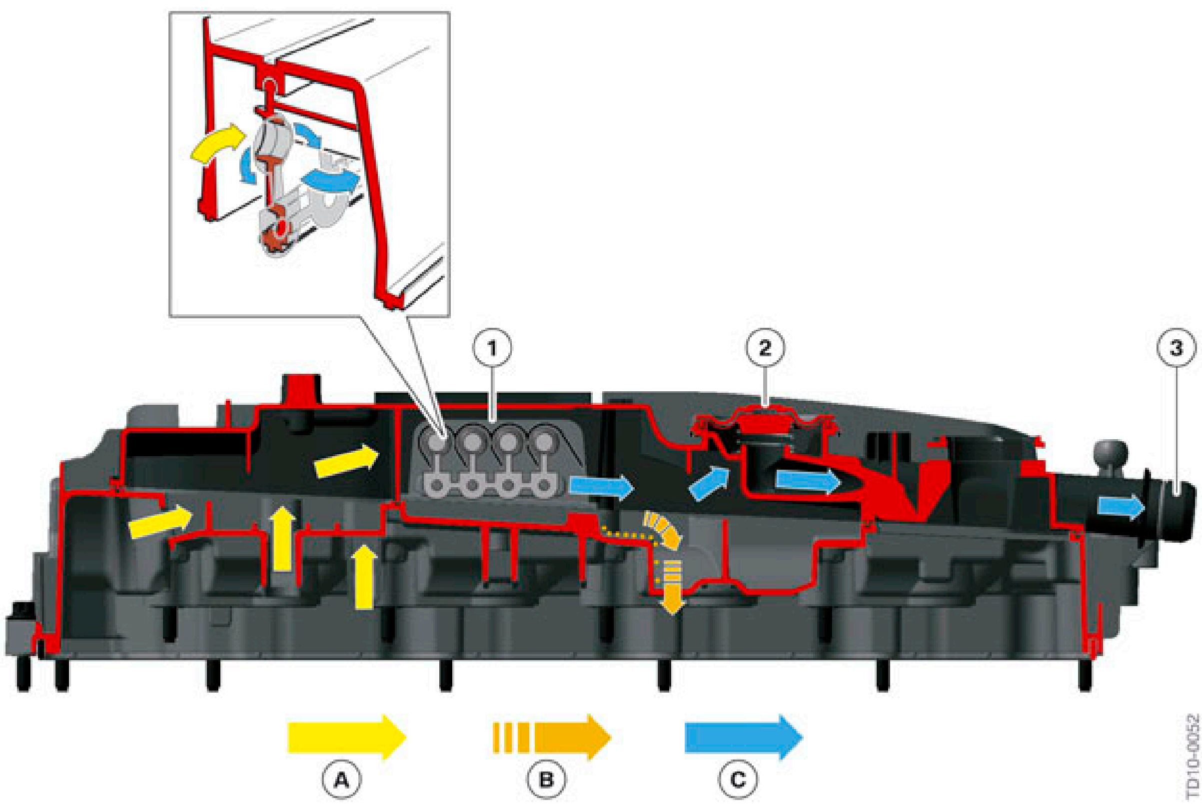
Index	Explanation
1	Turbocharger
2	Charge air cooler
3	Pressure control valve
4	Spring tab separator
5	Blow-by duct
6	Oil return duct
7	Air filter

4. Oil Supply

The engine is equipped with a vacuum controlled crankcase ventilation system with approximately 38 mbar of (regulated) vacuum. Pre-tensioned (metal) spring tabs (referred to as gap separators) regulate the speed of the air mass flow and thus ensure an optimum oil separation of blow-by gas in all operating conditions. A vacuum exists in the clean air pipe due to the suction power created by the turbocharger. Due to the pressure difference in the crankcase, the blow-by gas is sucked into the cylinder head.

The blow-by gas first flows into the calming chamber of the cylinder head. The calming chamber makes sure that no oil spray, e.g. from the camshafts, gets into the crankcase ventilation. An initial “pre” oil separation is done in the calming chamber. The oil coats the walls of the calming chamber and flows back into the cylinder head. The blow-by gas flows from the calming chamber to the spring tab separator. These spring tabs are pressed down by the blow-by gas flow allowing the blow-by gas to flow by. Since the opening cross-section is relatively small, the blow-by gas flowing by is accelerated. The blow-by gas is then diverted 180° which causes the liquid contained in the blow-by gas to be hurled onto the surrounding walls. It then flows along these via a drain hole back into the oil sump. Depending on the quantity of blow-by gas the spring tabs are opened with more or less force, whereby there is an optimum oil separation independent of blow-by gas volume flow.

The spring tab separator has made it possible to increase the separation quality under all operating conditions, but above all when the blow-by gas volume is low. The cleaned blow-by gas is sent through the pressure control valve into the clean air pipe in front of the turbocharger.

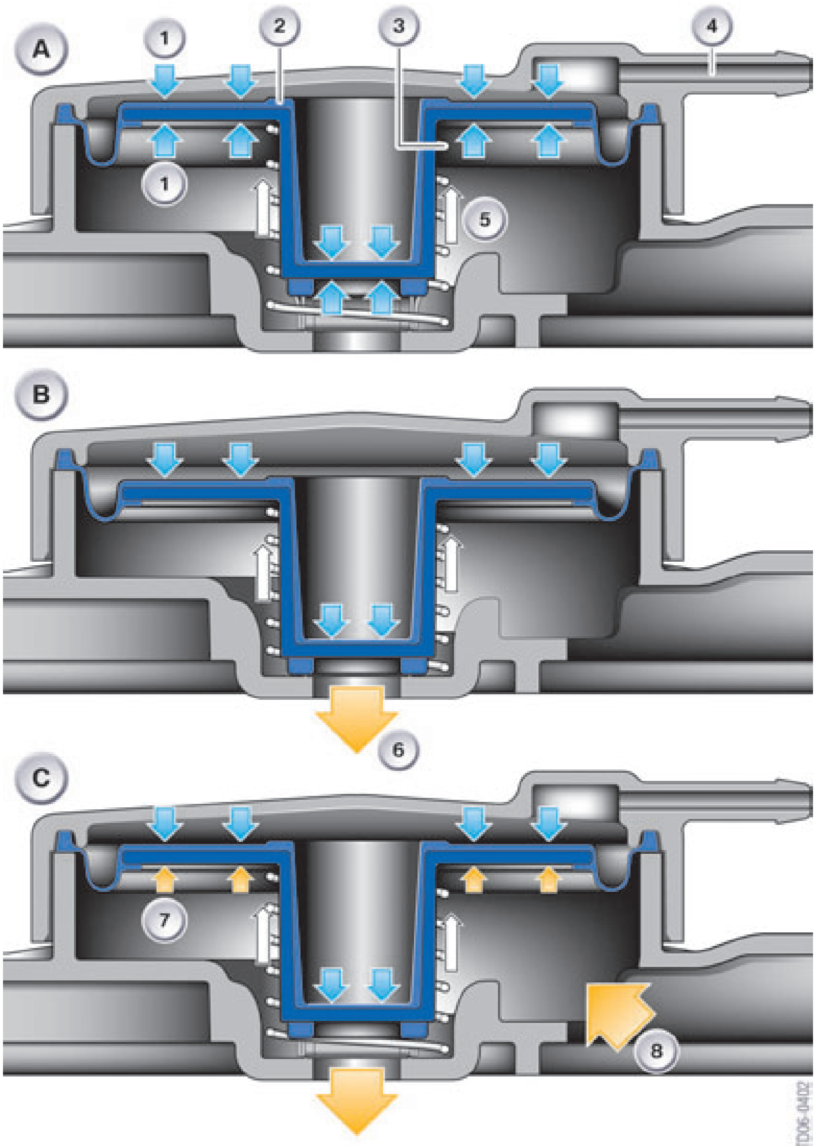


N47TU engine, timing diagram

Index	Explanation
A	Blow-by gas mixed with oil
B	Oil dripping
C	Blow-by gas cleaned of oil
1	Spring tab separator
2	Pressure control valve
3	Blow-by gas inlet to clean air pipe

4.5.1. Pressure control valve

The function of the pressure control valve is to ensure as constant a vacuum as possible in the crankcase. The following graphic depicts the pressure control valve in three different operating states. In control mode the restoring force of the compression spring (3) is in a state of equilibrium with the rolling diaphragm (2) pressurised by the crankcase vacuum. The reverse side of the rolling diaphragm is connected to atmospheric pressure by way of a bore in the crankcase (4). As the crankcase pressure rises, so too the opening cross-section in the pressure control valve increases. Blow-by gases are drawn off by the vacuum in the clean air pipe until the pressure in the crankcase drops to the point where the rolling diaphragm seals the opening cross-section. When the air filter is clogged or for example there is snow in the intake snorkel, the increased vacuum closes the pressure control valve. This prevents oil from being drawn into the intake area.



Pressure control valve in the crankcase ventilation

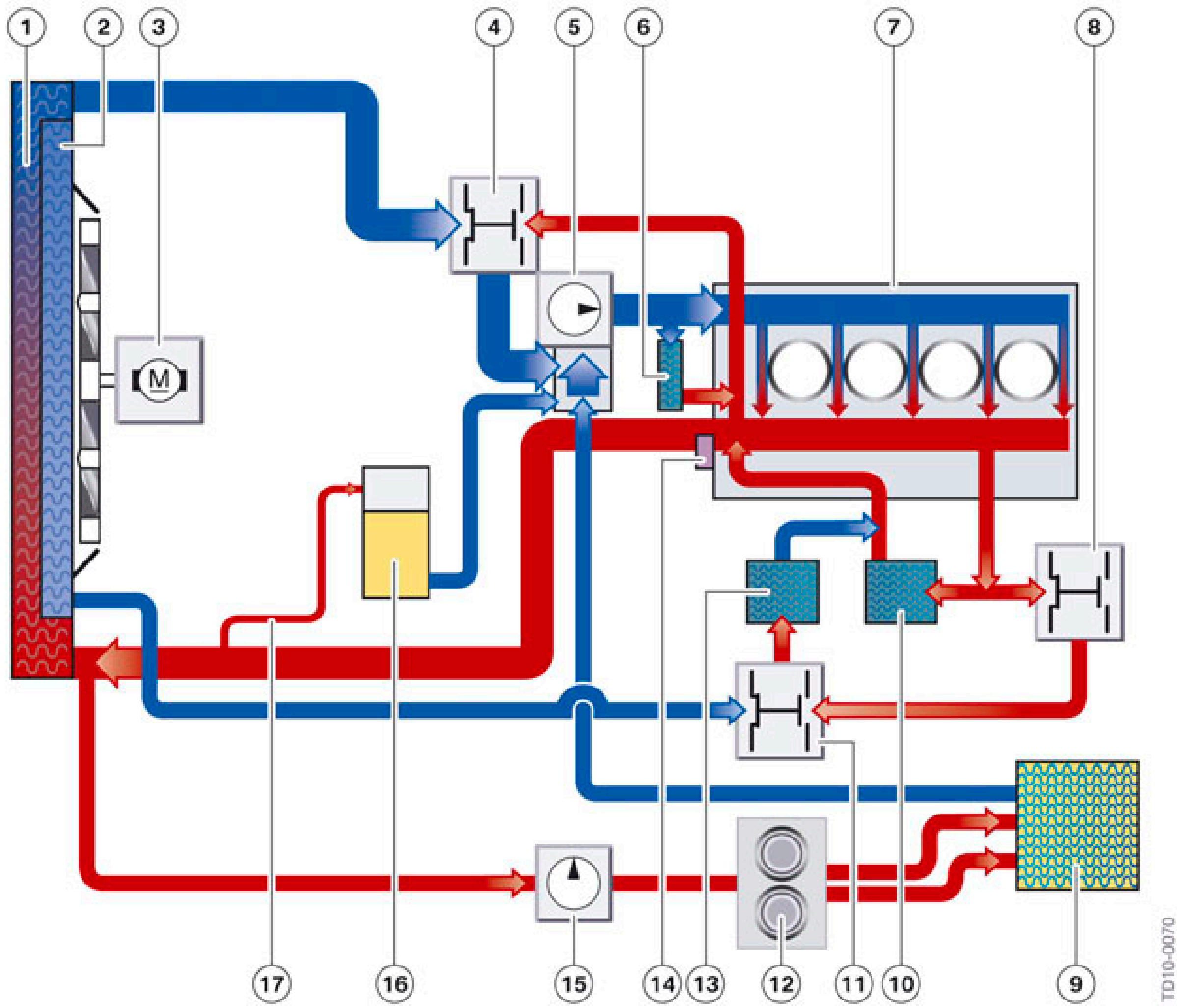
Index	Explanation
A	Pressure control valve **open** with engine off
B	Pressure control valve **closed** with maximum vacuum in crankcase
C	Pressure control valve **open** with vacuum in crankcase too low
1	Ambient pressure
2	Rolling diaphragm
3	Compression spring
4	Connection to ambient pressure

Index	Explanation
5	Spring force of compression spring
6	Intake manifold vacuum
7	Effective vacuum in crankcase
8	Blow-by gas from crankcase

Control operation

When the engine is off the pressure control valve is open (state A). Ambient pressure is applied on both sides of the rolling diaphragm, i.e. the rolling diaphragm is fully opened by means of spring force. When the engine is started, the vacuum in the intake pipe increases and the pressure control valve closes (state B). This state is obtained primarily at idle or in coasting (overrun) mode, since only minimal or no blow-by gas is produced here. A high relative vacuum (to the ambient pressure) is therefore applied on the inside of the rolling diaphragm. In this way the ambient pressure which is applied on the outside of the rolling diaphragm closes the valve against spring force. The blow-by gas (8) reduces the relative vacuum acting on the rolling diaphragm. The compression spring is able to open the valve to allow blow-by gas to be drawn in. The valve continues to open until an equilibrium between ambient pressure and crankcase vacuum plus spring force is obtained (state C). The more blow-by gases are produced, the lower the relative vacuum acting on the inside of the rolling diaphragm and the wider the pressure control valve opens. In this way a fixed vacuum (about 38 mbar) is maintained in the crankcase.

Vacuum in crankcase	Response of the rolling diaphragm
> 38 mbar	Rolling diaphragm moves in the “Closed” direction
< 38 mbar	Rolling diaphragm moves in the “Open” direction



N47TU engine cooling system

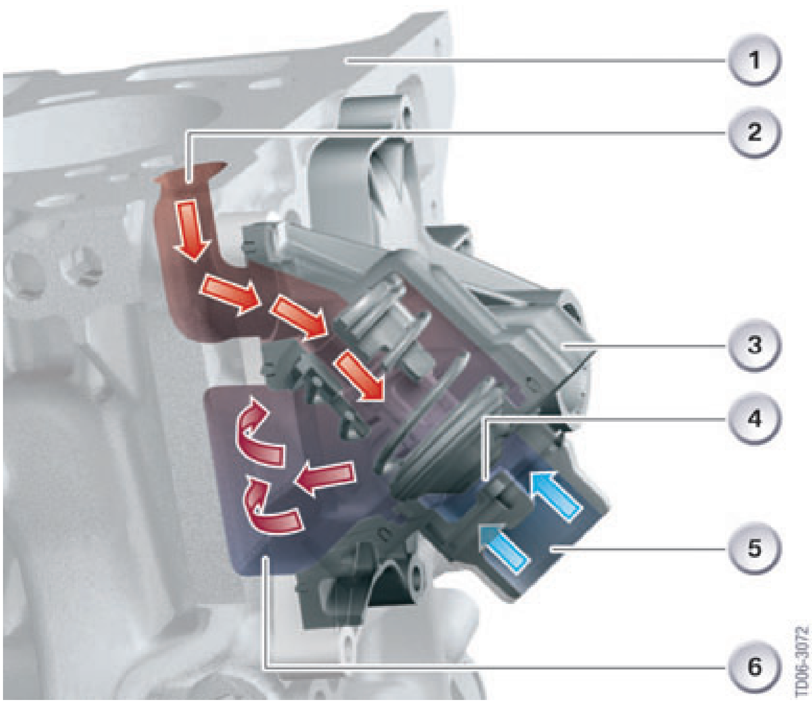
Index	Explanation
1	Radiator
2	Radiator low temperature range
3	Electric fan motor
4	Thermostat
5	Coolant pump
6	Exhaust-gas recirculation cooler
7	Engine housing
8	Transmission fluid heat generator thermostat
9	Heater matrix
10	Engine oil-to-coolant heat exchanger
11	Thermostat for transmission fluid

N47TU Engine
5. Coolant Circuit

Index	Explanation
12	Coolant valve
13	Transmission fluid-to-coolant heat exchanger
14	Coolant temperature sensor
15	Auxiliary water pump
16	Expansion tank
17	Ventilation line

5.1. Thermostat

In the N47TU engine, the engine temperature is regulated by a conventional thermostat. This means that only the coolant temperature determines regulation of engine temperature.

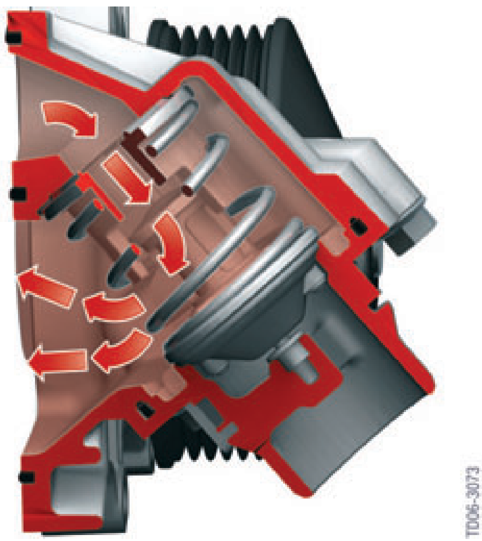


N47TU Thermostat

Index	Explanation
1	Crankcase
2	Hot coolant from the cylinder head
3	Thermostat housing
4	Wax element
5	Radiator return
6	Supply to the coolant pump

5.1.1. Thermostat closed

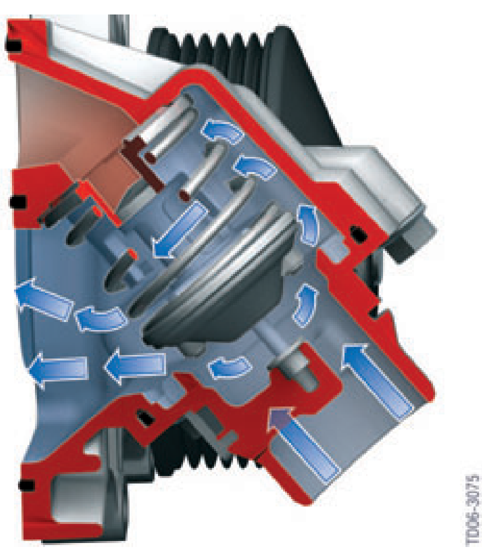
The coolant temperature is below the opening temperature of the thermostat. The coolant circuit is blocked. The coolant only flows inside the engine and not through the coolant radiator. Opening point: approximately 88 °C (190 ° F)



Thermostat closed

5.1.2. Thermostat open

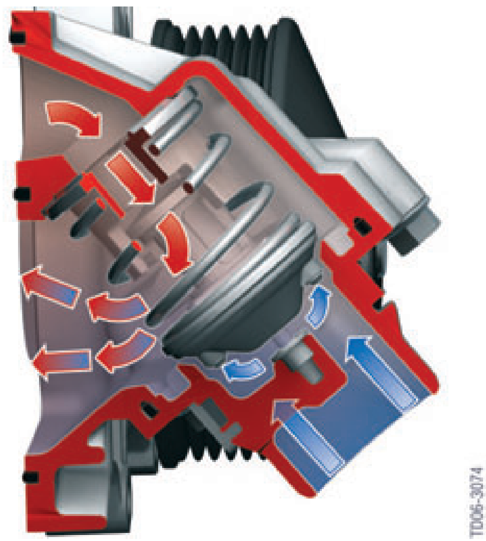
The coolant temperature is above the full opening temperature of the thermostat. All the coolant flows through the coolant radiator. This makes use of the maximum cooling output. Full opening temperature: 100 °C (212 ° F)



Thermostat open

5.1.3. Thermostat regulation range

The coolant temperature is between the opening point and the full opening temperature. The extent to which the coolant is divided depends on the coolant temperature. One part flows through the coolant radiator, the rest remains in the engine.

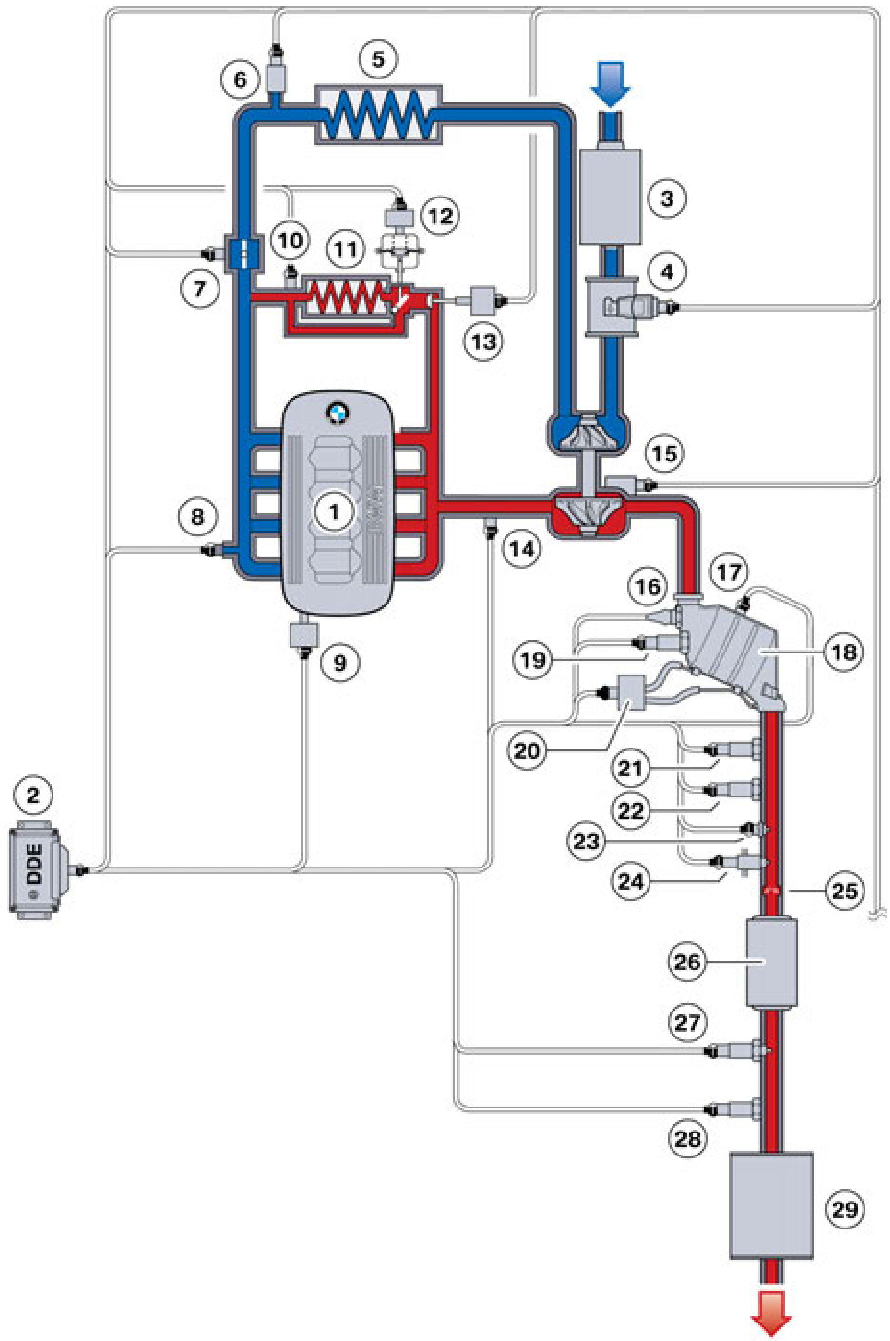


Thermostat regulating range

N47TU Engine

6. Intake and Exhaust Emission System

The basic design of the intake and exhaust emission system is very similar to previous BMW diesel engines. However, there are some modifications especially with regard to the exhaust after treatment systems and components. These special measures and components apply exclusively to the US market versions with the second generation diesel engines (N47TU and N57TU). These components are illustrated in the following graphic.



N47TU engine intake air and exhaust emission system (US)

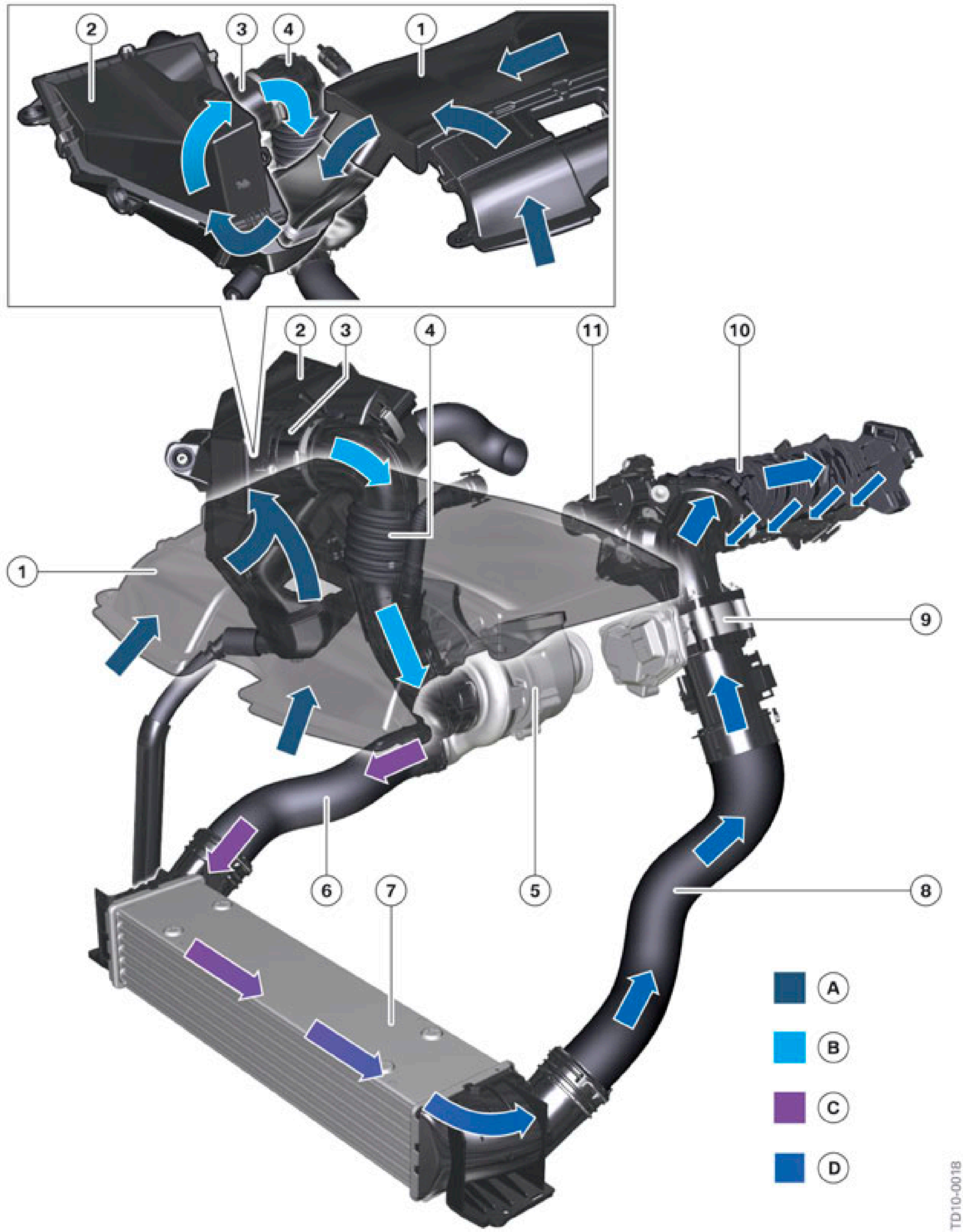
6. Intake and Exhaust Emission System

Index	Explanation
1	N47TU Engine
2	Digital Diesel Electronics (DDE)
3	Intake silencer
4	Hot film air mass meter
5	Charge air intercooler
6	Charge-air temperature sensor
7	Throttle valve
8	Boost pressure sensor
9	Swirl-flap actuator
10	Exhaust-gas recirculation temperature sensor
11	Exhaust-gas recirculation cooler
12	EGR cooler bypass plate
13	Exhaust-gas recirculation valve with position sensor
14	Exhaust back pressure sensor before the exhaust turbocharger
15	Boost pressure actuator
16	Exhaust-gas temperature sensor upstream NO_x storage catalytic converter (NSC)
17	Exhaust-gas temperature sensor downstream NO_x storage catalytic converter (NSC)
18	NO_x storage catalytic converter and diesel particulate filter (NSC/DPF)
19	Oxygen sensor upstream the NO_x storage catalytic converter (NSC)
20	Differential exhaust pressure sensor before and after the diesel particulate filter (DPF)
21	Oxygen sensor downstream diesel particulate filter (NSC/DPF)
22	NO_x sensor upstream selective catalyst reduction (SCR)
23	Exhaust-gas temperature sensor upstream of the Selective Catalyst Reduction (SCR)
24	Dosing valve
25	Mixer for (SCR)
26	Selective Catalyst Reduction (SCR)
27	Particulate matter (soot) sensor
28	NO_x sensor downstream Selective Catalyst Reduction (SCR)
29	Rear silencer

6. Intake and Exhaust Emission System

6.1. Intake plenum

The intake plenum was modified to relocate the throttle valve much more forward on the intake (when compared to previous engines). This modification of the intake plenum allows the use of shorter inlet pipe, since the charge air from the intercooler is now fed directly ahead of the engine via the throttle valve (2) and the mixing tube (3) in the differentiated air intake system (4).



N47TU engine, intake plenum

Index	Explanation
A	Raw air
B	Clean air
C	Warmed charge air
D	Cooled charge air
1	Intake snorkel
2	Intake silencer
3	Hot film air mass meter
4	Clean air pipe
5	Exhaust turbocharger
6	Charge air pipe
7	Charge air cooler
8	Charge air pipe
9	Throttle valve
10	Differentiated air intake system
11	Swirl-flap actuator

6.1.1. Intake silencer

The intake silencer incorporates a “snow valve” and a “drainage line”. The snow valve is designed to open and supply air to the engine in the event that the intake to the air filter is completely blocked with ice or snow.

6. Intake and Exhaust Emission System

N47TU engine, timing diagram

Index	Explanation
1	Intake silencer
2	Snow valve
3	Drainage line for water

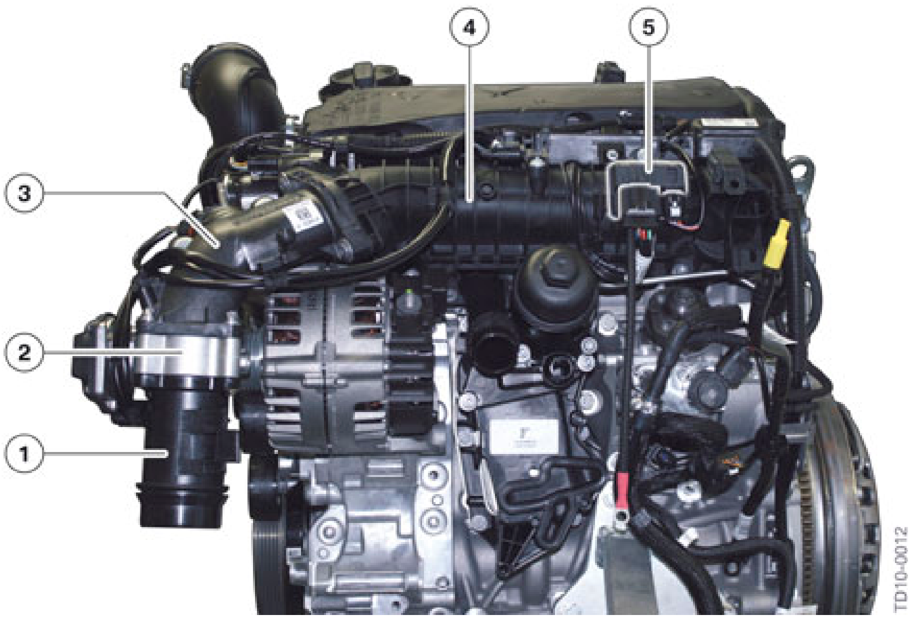
Snow valve

The snow valve is opened by a vacuum in the intake silencer and enables fresh air supply even with ice and snow clogged intake openings in the radiator grill.

Water drainage line

During strong rainfall or during spray water loading testing, some water may be drawn into the intake. A water drainage line is integrated into the bottom of the intake silencer to drain any water collected in the intake silencer. So that no air or water can be drawn in via the drainage line (when there is a vacuum in the intake silencer) it is closed at the lower end with a diaphragm valve.

6.1.2. Differentiated air intake system



N47TU engine, intake plenum

Index	Explanation
1	Charge air pipe
2	Throttle valve
3	Mixing tube
4	Differentiated air intake system
5	Preheating control unit

The differentiated air intake system is a new development designed to meet the requirements of the modified charge air inlet. The exhaust-gas recirculation cooler is now directly connected to the differentiated air intake system. The exhaust-gas recirculation is still fed via the cylinder head in the differentiated air intake system.

The swirl flaps were previously integrated in the differentiated air intake system. In the case of faults or damage of the swirl flaps or the swirl flap mechanism, the entire differentiated air intake system had to be replaced.

The swirl flaps are now integrated in the gasket between the differentiated air intake system and the cylinder head. The gasket is designed in three-dimensions and is clipped onto the differentiated air intake system.

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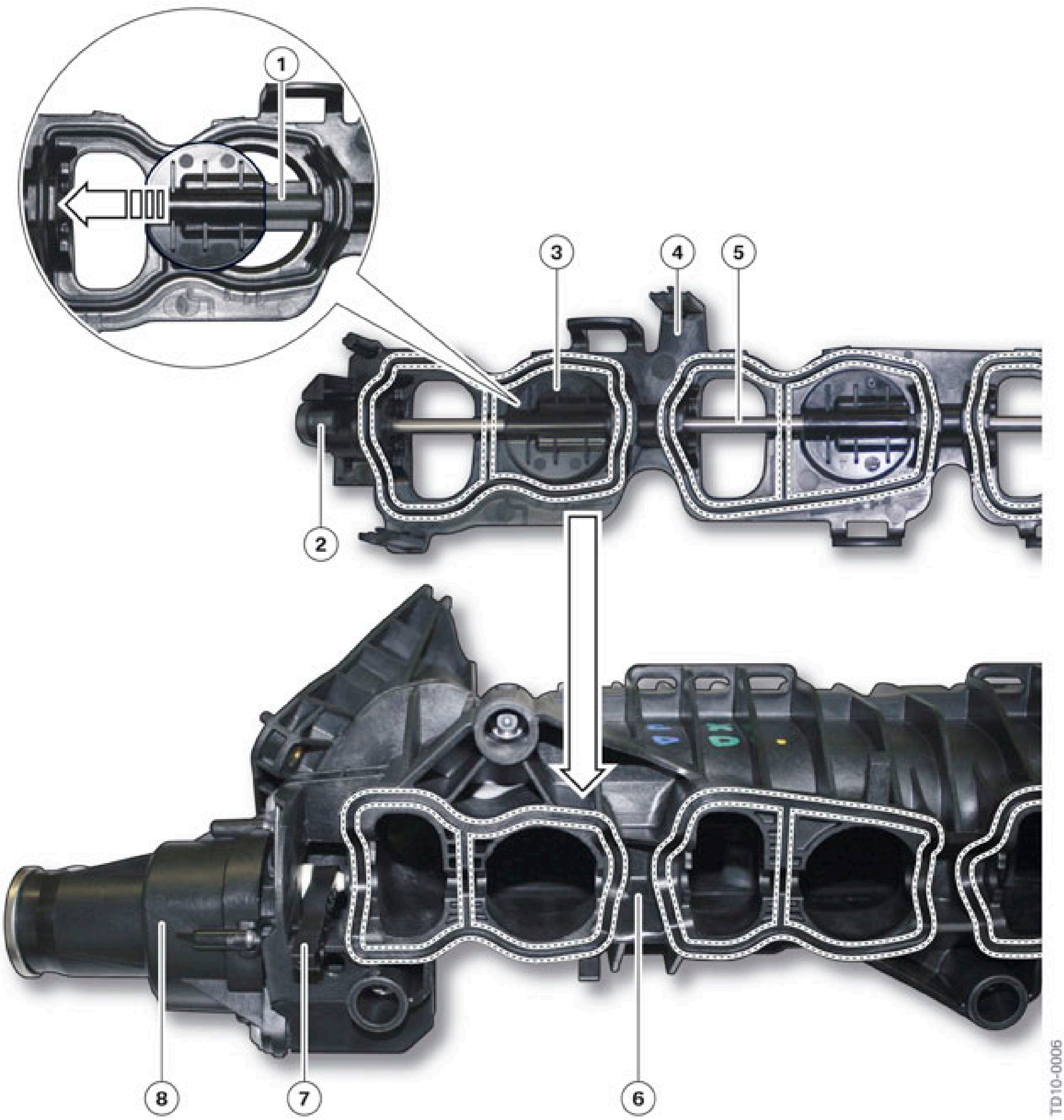
When installing the gasket the swirl flaps must be in the correct position, otherwise these will be damaged during the mounting of the intake plenum on the cylinder head.

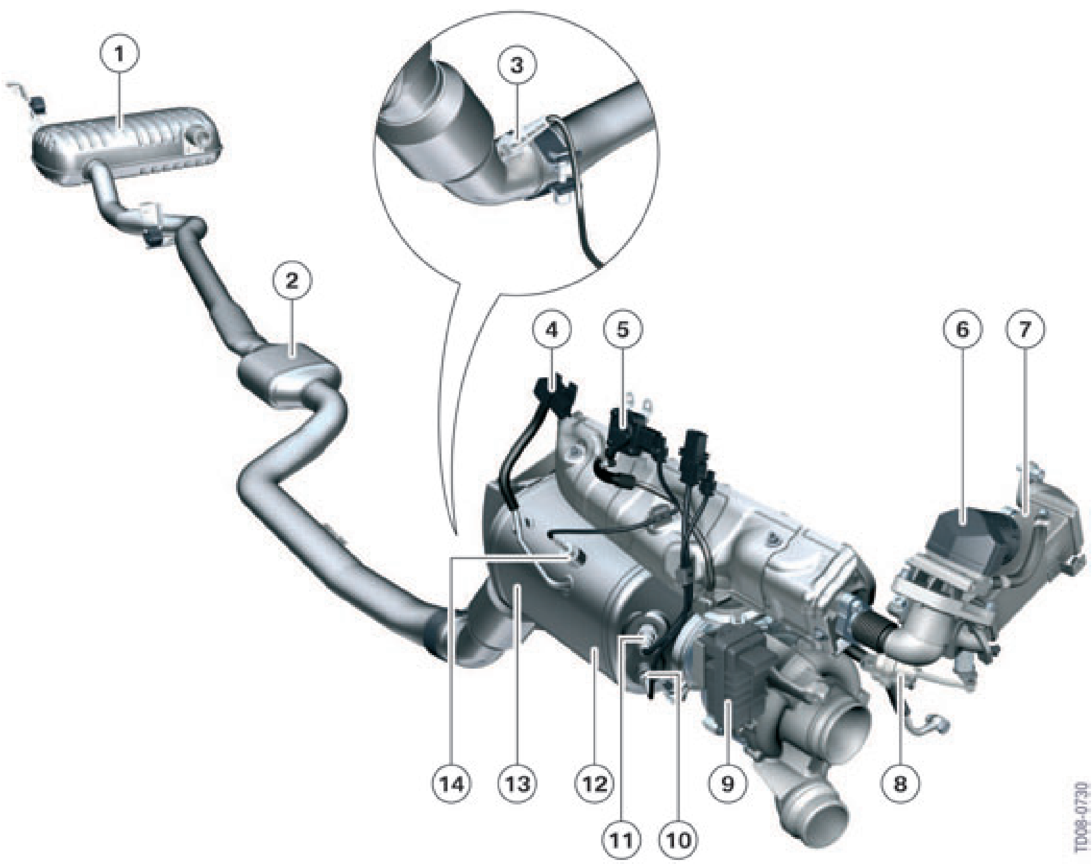


N47TU engine differentiated air intake system with gasket

6. Intake and Exhaust Emission System

Index	Explanation
1	Flap support (visible when the loose swirl flap is moved)
2	Lever
3	Swirl-flap
4	Gasket support
5	Shaft
6	Differentiated air intake system
7	Connection lever
8	Swirl-flap actuator

6.2. Exhaust Emission System



N57 EURO 6 exhaust after-treament components shown (not for U.S.)

Index	Explanation
1	Rear silencer
2	SCR catalyst (Not all SCR shown here)
3	Oxygen sensor downstream of the diesel particulate filter
4	Exhaust back-pressure sensor downstream of the NOx storage catalytic converter
5	Exhaust back-pressure sensor upstream of the turbocharger
6	EGR valve
7	EGR cooler
8	EGR cooler bypass valve vacuum unit
9	Boost pressure control valve
10	Exhaust temperature sensor upstream of the NOx storage catalytic converter
11	Oxygen sensor upstream of the NOx storage catalytic converter
12	NOx storage catalytic converter
13	Diesel particulate filter
14	Exhaust temperature sensor downstream of the NOx storage catalytic converter

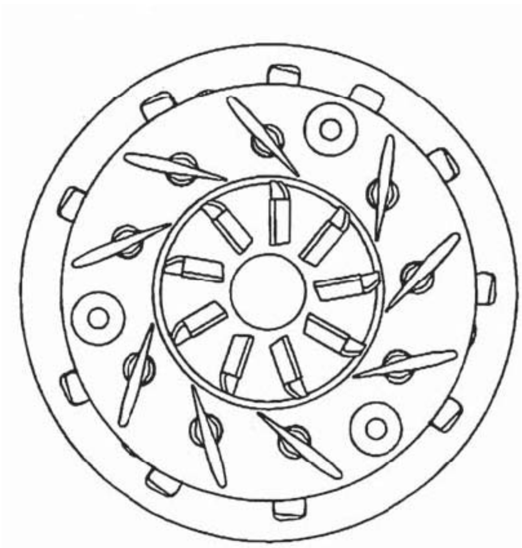
Note: In the U.S. market the back-pressure sensors (4 and 5) are combined into one differential pressure sensor.

⚠

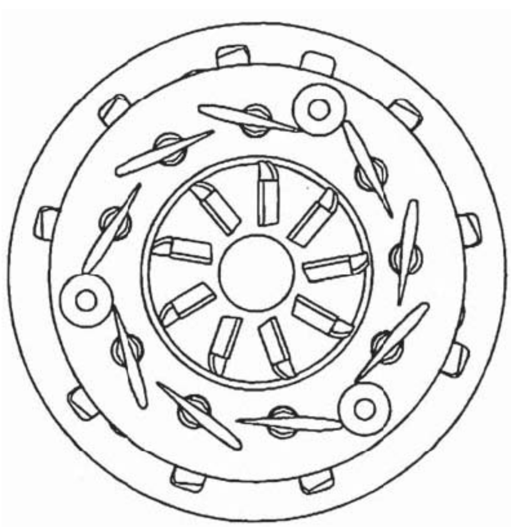
The N57 engine exhaust illustration shown above is NOT for the U.S. market and only used as an example.

6.2.1. Exhaust turbocharger (VNT)

The variable geometry exhaust turbocharger of the N47TU is referred to as a Variable Nozzle Turbine (VNT). The variable nozzle turbine makes it possible to alter the gas flow that drives the turbine wheel in relation to the engine operating point by varying the cross-flow section in the turbine wheel inlet housing using variable guide vanes.



VNT vanes open

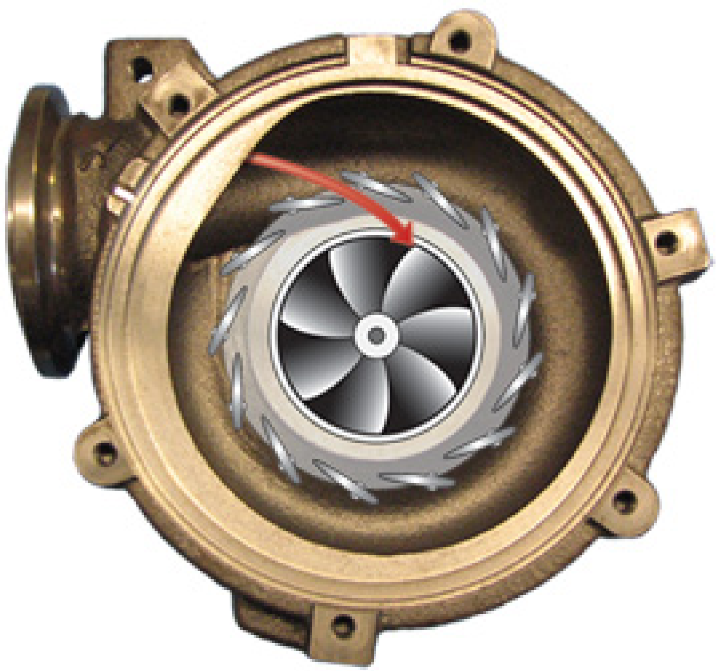


VNT vanes closed

The variable nozzle vanes (located inside the turbine housing) are arranged completely around the turbine wheel. These VNT actuator vanes move in unison to vary the cross-flow section (see graphic below) directing the exhaust gas flow and angle of attack to turn the turbine wheel. As the flow rate of the exhaust gas and the exhaust gas pressure acting on the turbine wheel increases, the transfer of energy to the turbine wheel and compressor is therefore increased, enhancing efficiency particularly at low engine speeds.

These vanes are adjusted by the (electrically controlled) boost pressure regulator (VNT actuator). As the turbine speed and boost pressure are directly dependent on the position of the actuator vanes and this is regulated by the DDE via the boost pressure regulator (VNT actuator) there is no need for a wastegate valve.

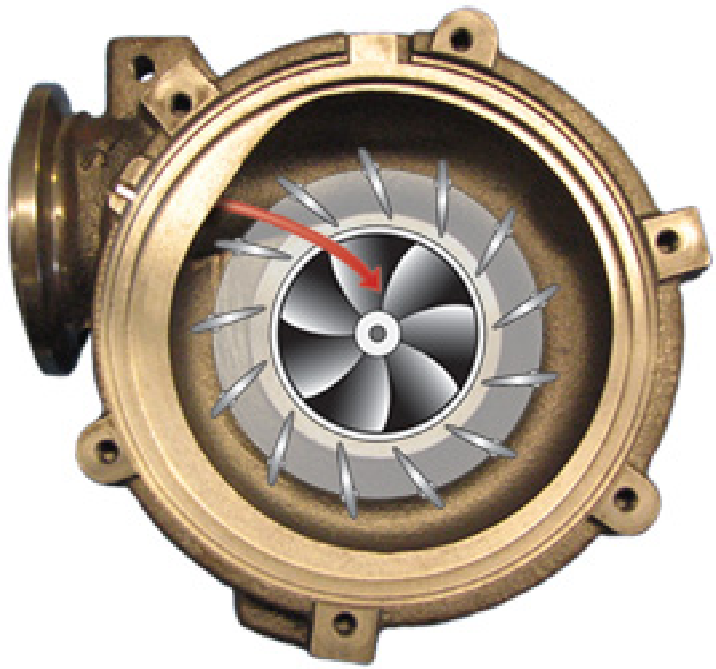
When the VNT vanes are in the **"closed"** position (see graphic below) the transfer of energy to the turbine wheel and compressor is increased due to an increase in exhaust gas pressure and an optimum angle of attack. This results in maximum turbine speed and boost pressure (beginning at low engine speeds). This increase in boost pressure allows for a higher injection rate to be authorized by the DDE.



VNT vane mechanism "closed"

When the VNT vanes are in the **"open"** position (see the next graphic) the transfer of energy to the turbine wheel and compressor is decreased as the flow rate and exhaust gas pressure driving the turbine decreases. This is due to a reduction in exhaust gas pressure and a less than optimum angle of attack which results in a decrease in turbine speed and boost pressure.

Therefore as the engine speed increases, the vanes are gradually opened so that the energy transfer always remains in equilibrium at the desired boost-pressure depending on engine speed and load requirements.



VNT vane mechanism “open”

The boost-pressure regulator (VNT actuator) is controlled by the DDE by means of a pulse-width modulated signal.

A control rod turns the adjustment ring, which in turn moves the VNT actuator vanes.

The VNT provides an additional degree of freedom in the optimization of thermodynamic behavior by comparison with a conventional exhaust turbocharger (which has a permanently constant flow cross section) with the additional benefit that the VNT turbocharger does not need a wastegate valve.

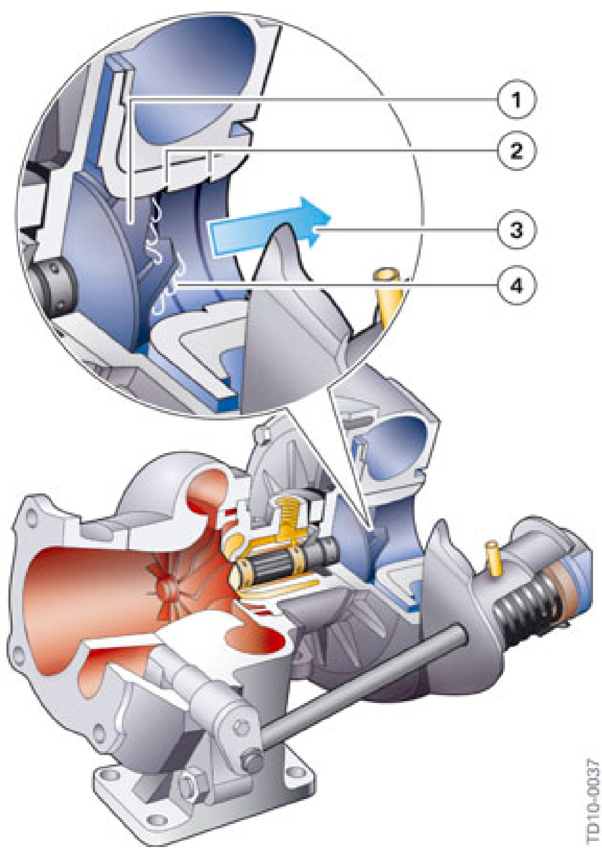
The control of the boost-pressure regulator is described in more detail in the “Engine electrical system” section of this training material.

Advantages of VNT system:

- High torque at both high and low engine speeds.
- Continuous and optimum adjustment for all engine speeds.
- No "wastegate valve" required.
- The exhaust energy is better utilized, less back-pressure in conjunction with the same compressor work.
- Low thermal and mechanical load facilitates improved optimization of engine power output.
- Low emission values also at very low engine speeds.
- Optimized fuel consumption over the entire engine speed spectrum.

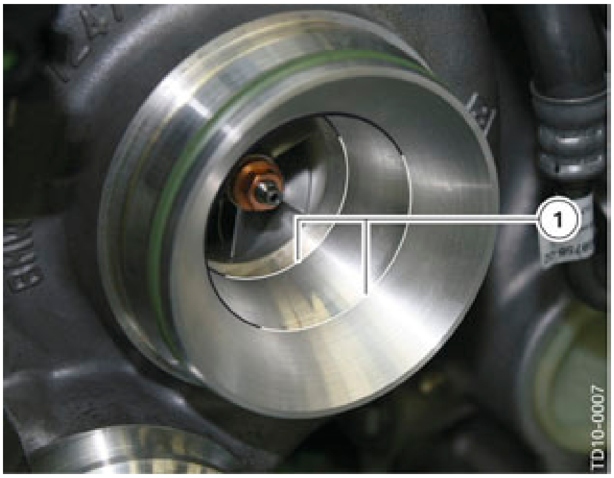
Fresh air inlet

One of the physical limitations of an exhaust turbocharger is the pumping limit. This occurs when the air flow across the compressor blades stalls due to reduced volumetric flow and too high pressure ratio. This creates a stall condition which results in interrupted delivery. Due to the vacuum in the intake side, the air flows in reverse through the compressor until a stable pressure ratio is adjusted and the air can again flow forwards. Two machined ridges (referred to as "Gills") in the exhaust turbocharger inlet counteract these "pumping" losses. These "Gills" maintain pressure on the compressor blade surface which limits stalling while having no influence on the normal (forward) flow of the intake air.



"Pumping" losses in an exhaust turbocharger with "Gills"

Index	Explanation
1	Impeller
2	Machined ridges (Gills)
3	Air flow in reverse
4	Stall



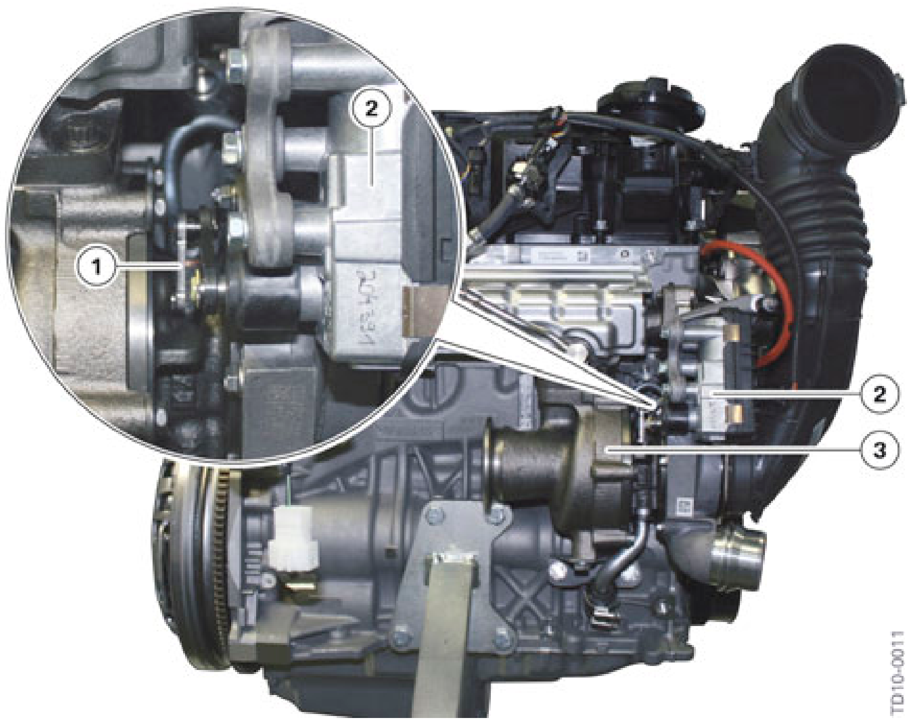
N47TU engine, gills in exhaust turbocharger inlet fresh air side

Index	Explanation
1	Machined ridges (Gills)

Boost pressure control

The variable nozzle vanes of the (VNT) are adjusted electrically via the boost pressure regulator also referred to as VNT actuator. This achieves a more accurate regulation of the boost pressure in comparison with vacuum regulated systems. The VNT boost pressure regulator controls the boost pressure up to 2.2 bar absolute pressure. The servomotor is controlled by the DDE via a PWM signal. The position regulator and the diagnostics function are integrated in the servomotor. In the event of a malfunction, the PWM signal from the internal position regulation of the servomotor is directed to ground for 0.5 to 2 seconds (depending on the fault message). From this, the DDE detects a fault with the electrical vane adjustment.

The control rod is not designed to be adjustable. The control rod is installed on the shaft of the adjustment lever for the VNT vanes and the VNT actuator.



N47TU engine, VNT actuator control mechanism

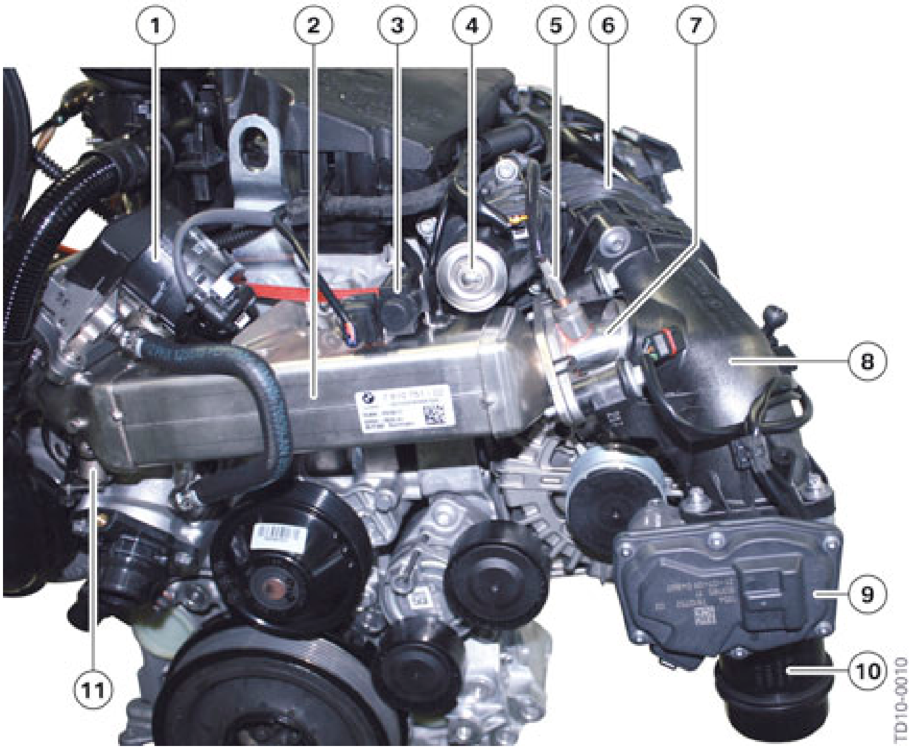
Index	Explanation
1	Control rod
2	Variable nozzle turbine (VNT) actuator
3	Exhaust turbocharger

6.2.2. Exhaust-gas recirculation

The exhaust-gas recirculation is a measure to reduce the formation of nitrogen oxide (NOx). Nitrogen oxides are created in great quantities when combustion runs lean (excess air) and at very high temperature. Here, the oxygen combines with the nitrogen of the combustion air to form nitrogen monoxide (NO) and nitrogen dioxide (NO_2). On the diesel engine, exhaust-gas recirculation is sometimes required at idle speed and always in the part-load range (cruising), because a particularly high air surplus is used there. The recirculated exhaust gas, to which fresh air is added and which has the same properties as inert gas, takes up space in the cylinder and achieves the following:

- Lower residual oxygen content in the cylinder
- Lowering of the maximum combustion temperature by up to 500 °C (932 °F).
  This effect is enhanced further if the recirculated exhaust gases are cooled.

6. Intake and Exhaust Emission System



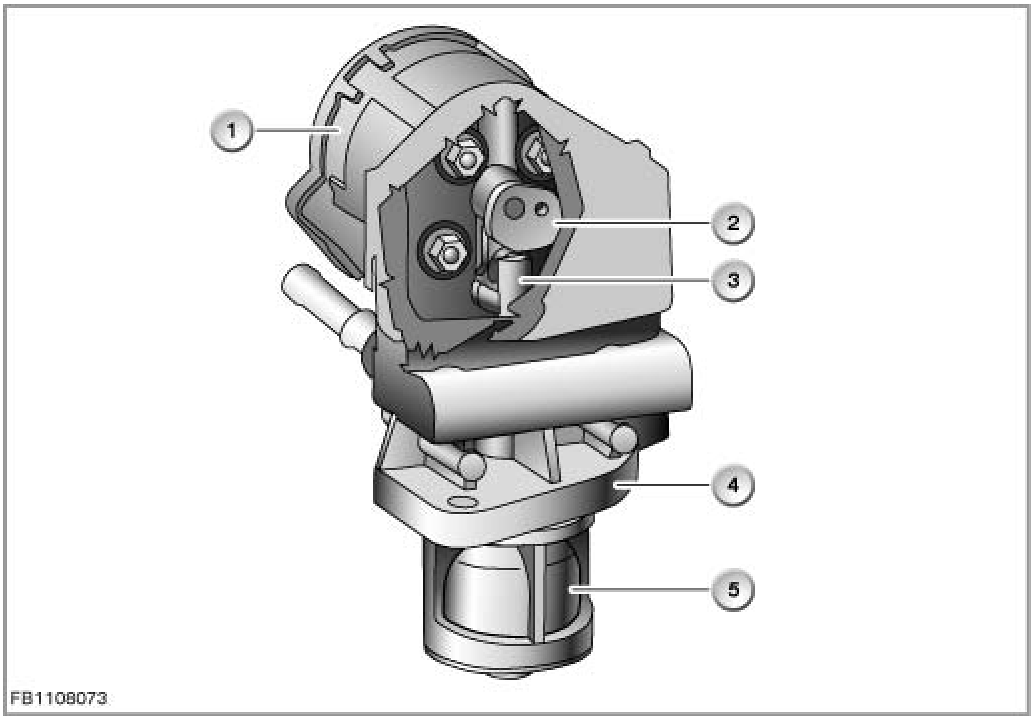
N47TU engine, exhaust gas recirculation

Index	Explanation
1	Coolant cooled exhaust-gas recirculation valve
2	Exhaust-gas recirculation cooler with integrated bypass
3	Electro-pneumatic changeover valve for bypass plate
4	Swirl-flap actuator
5	Exhaust-gas recirculation temperature sensor
6	Differentiated air intake system
7	Exhaust-gas recirculation pipe
8	Mixing tube
9	Throttle valve
10	Charge air pipe
11	Bypass plate

The exhaust-gas recirculation was optimized and adapted to the engine requirements. Thus the exhaust will be fed into the differentiated air intake system either cooled or un-cooled as with other BMW engines. Feeding into the differentiated air intake system is done via an exhaust-gas recirculation pipe, which extends into the mixing tube and is provided at the end with a plate, so that hot exhaust gas does not damage the mixing tube.

6.2.3. EGR valve/actuator

The exhaust-gas recirculation valve actuator is opened or closed electrically by the DDE control unit. To ensure optimized control of the exhaust-gas recirculation rate, the exact position must be continuously detected. The position of the exhaust-gas recirculation actuator is monitored by a non-contact hall effect sensor. The servomotor for the exhaust-gas recirculation actuator is a direct current motor. The position sensor is a hall effect sensor. The hall effect sensor determines the revolutions of the servomotor. This is used to calculate the position of the exhaust-gas recirculation actuator.



Electronic EGR valve/actuator

Index	Explanation
1	Exhaust gar recirculation actuator
2	Cam disc
3	Bucket tappet
4	Housing
5	Valve seat

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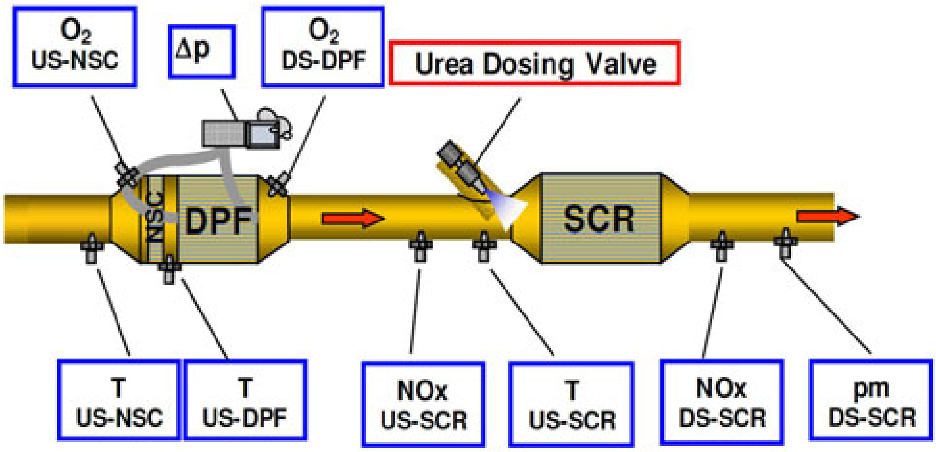
For further information regarding the N47TU Exhaust gas recirculation (EGR) system refer to the “Engine Control Functions” section of this training material.

6.2.4. Exhaust after-treatment



N47TU exhaust after-treatment components for the US market.

Index	Explanation
T US-NSC	Temperature sensor up stream of the NOx Storage Catalyst
O_2 US-NSC	O_2 sensor up stream of the NOx Storage Catalyst
NSC	NOx Storage Catalyst
Ap	Differential pressure sensor
T US-DPF	Temperature sensor up stream of the Diesel Particulate Filter
O_2 DS-DPF	O_2 sensor down stream of the Diesel Particulate Filter
NOx US-SCR	NOx sensor up stream of the Selective Catalyst Reduction
UDV	Urea Dosing Valve
T US-SCR	Temperature sensor up stream of the Selective Catalyst Reduction
SCR	Selective Catalyst Reduction
NOx DS-SCR	NOx sensor down stream of the Selective Catalyst Reduction
pm DS-SCR	Particulate matter sensor down stream of the Selective Catalyst Reduction

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The exhaust after-treatment systems and components of the N47TU and the N57TU have been especially design to comply with current (ULEV II) US market emission regulations and thus are different from those used with the previous US diesel (M57D30T2) engine.

A more powerful system for exhaust gas treatment is required to meet increasingly stringent emissions regulations in spite of lower exhaust temperatures with high efficiency diesel engines.

Where the pervious system used an oxidation catalyst there is now a NOx Storage Catalyst (NSC) installed. The NSC is a NOx adsorption (storage) catalyst which incorporates the precious metals Platinum, Palladium and Rhodium and is installed in the same housing as the Diesel Particulate Filter (DPF).

6. Intake and Exhaust Emission System

There is also now an additional O_2 sensor (downstream of the DPF). It is used to monitor the function of the NSC and to determine whether it needs to be regenerated.

The combination of a NOx Storage Catalyst (NSC) and SCR catalyst has significant advantages for the exhaust gas after-treatment due to the efficiency of the NSC especially under lean conditions.

The new system also incorporates the second generation SCR system (SCR 2). The system now uses a dosing control unit (DCU) to monitor and deliver the AdBlue fluid into the SCR system and several redesigned components.

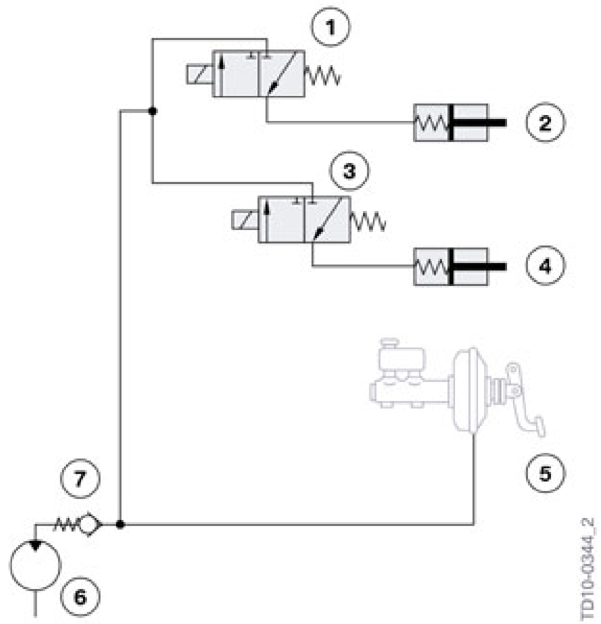
In addition, for the first time there is also a particulate matter sensor (located down stream of the SCR) to monitor the actual particulate matter (soot) that escapes the system at all times. This sensor is used to determine and manage the efficiency of the diesel particulate filter (DPF) in order to maintain the soot emission levels well below the mandated guidelines.

See the “Sensor” section of this training material and the Advance Diesel Technology training material available on TIS and ICP for more information regarding the new generation exhaust after treatment system.

7. Vacuum System

The negative pressure system is another system in addition to the electrical system for activating various components.

7.1. System overview



N47TU vacuum system

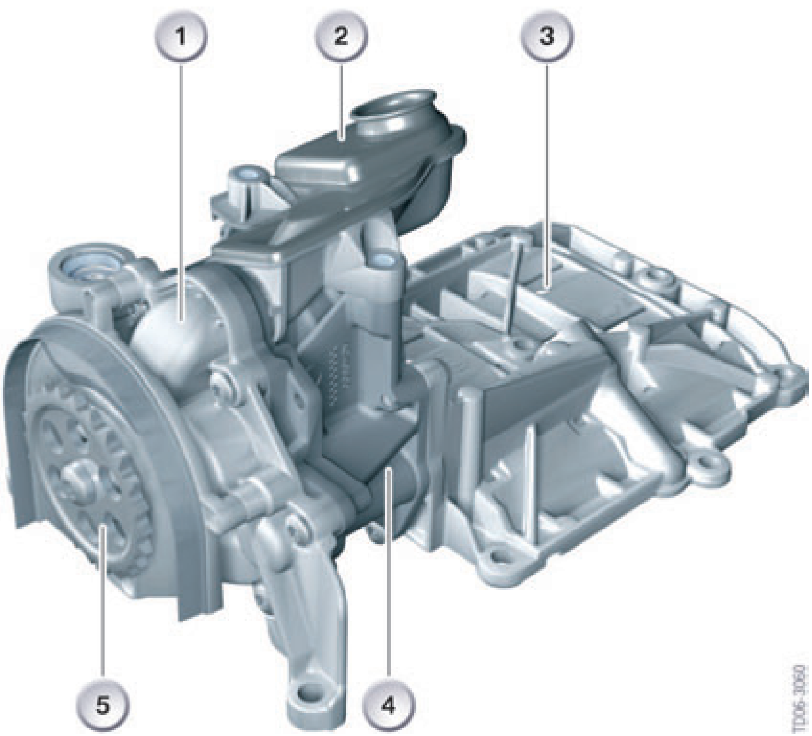
Index	Explanation
1	Electro-pneumatic changeover valve (EUV)
2	Motor mount vacuum unit
3	Electro-pneumatic changeover valve (EUV)
4	EGR bypass valve vacuum unit
5	Brake booster
6	Vacuum pump
7	Non-return valve

The vacuum pump creates the negative pressure and makes it available to the system. The negative pressure is sent to a vacuum unit for the control of components. The vacuum unit converts the negative pressure into motion. Electro-pneumatic changeover valves (EUV) are used to connect the negative pressure to the vacuum units for the EGR bypass valve and the vacuum controlled motor mounts. These changeover valves are controlled electrically. A non-return valve is installed in the circuit which prevents the negative pressure from collapsing through the vacuum pump while the engine is switched off.

7. Vacuum System

7.1.1. Vacuum pump

The vacuum pump of the N47TU engine is fitted inside the sump and forms a single unit together with the oil pump and the reinforcement shell (see oil pump section). The reason for the unusual installation location is to reduce the engine height dimension. It was designed in this manner with passive pedestrian safety in mind. The pump is a vane-type pump with aluminium housing (AlSi9Cu3) with a steel rotor and a plastic vane. It is chain-driven together with the oil pump by the crankshaft. The vacuum pump evacuates down to a negative pressure of 500 mbar (absolute) in fewer than 5 s. The negative pressure duct passes through the oil pump housing and the crankcase. The main negative pressure line exits the crankcase on the left side of the engine and is connected to the brake booster and the other consumers. A non-return valve is therefore installed at this connection.



N47TU oil/vacuum pump

Index	Explanation
1	Oil pump
2	Intake pipe
3	Reinforcement shell
4	Vacuum pump
5	Oil/vacuum pump sprocket

7.1.2. Electro-pneumatic changeover valve (EUV)

The electro-pneumatic changeover valve (EUV) operates in a similar way to the EPDW. The difference being that it does not set a pressure but merely forwards on the negative pressure in the system to the vacuum unit. As a result, there is no infinitely variable regulation possible, but rather a open/closed control. In the N47TU engine, the EGR cooler bypass valve and vacuum controlled motor mounts are switched by an electro-pneumatic changeover valve.

Electro-pneumatic changeover valve

8. Fuel Preparation

The fuel preparation system is the system which provides and meters the correct amount of fuel for combustion.

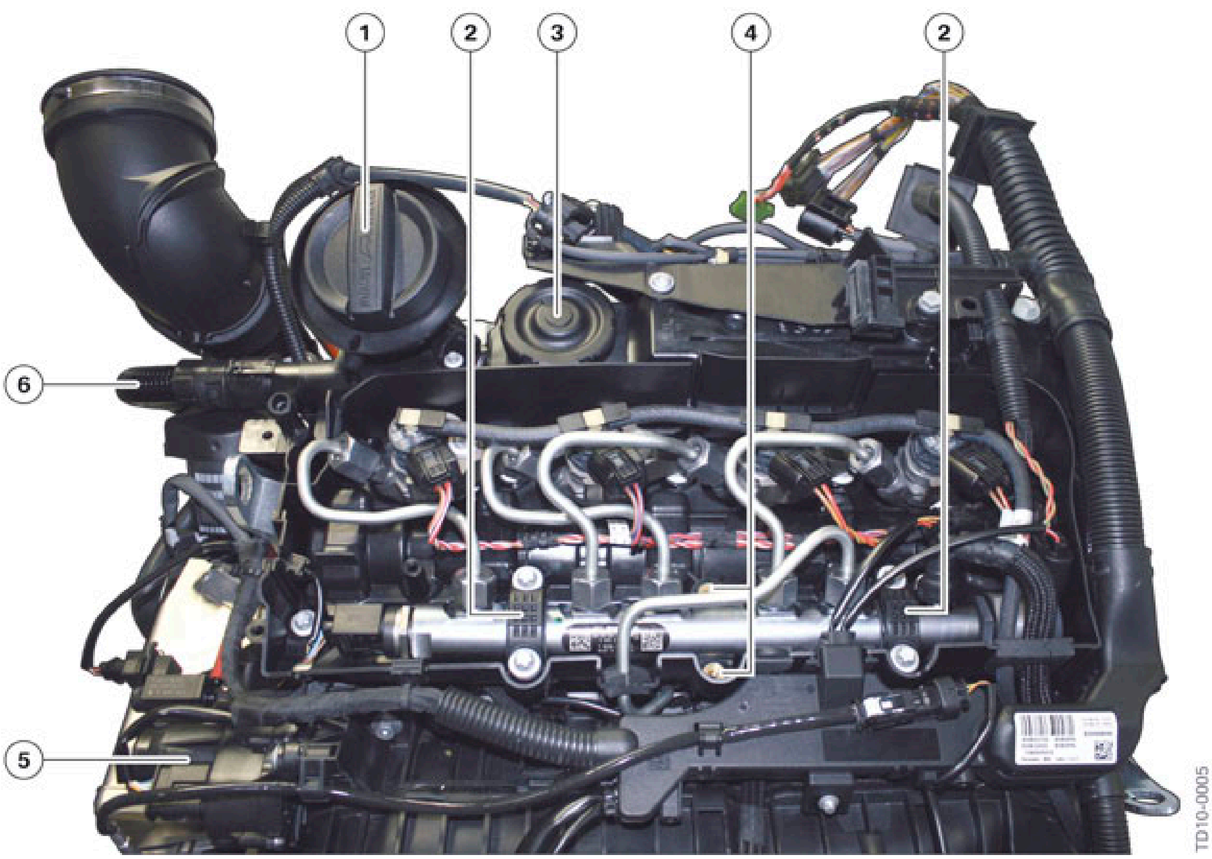
The main functions of the fuel preparation system are:

- Providing the required pressure
- Injecting the required fuel quantity (fuel quantity control)
- Setting the required start of injection (injection start control)

In order to comply with the more stringent emission limits for diesel engines, modern injection systems inject with ever higher pressures and with ever greater precision. The common rail system satisfies these requirements to optimum effect. In the common rail system the fuel is stored in the rail under high pressure and is injected via injectors on a map-controlled basis into the combustion chambers.

The fuel preparation system is comprised of the fuel rail with the following main components:

- Leakage oil line
- High pressure pump
- Injectors

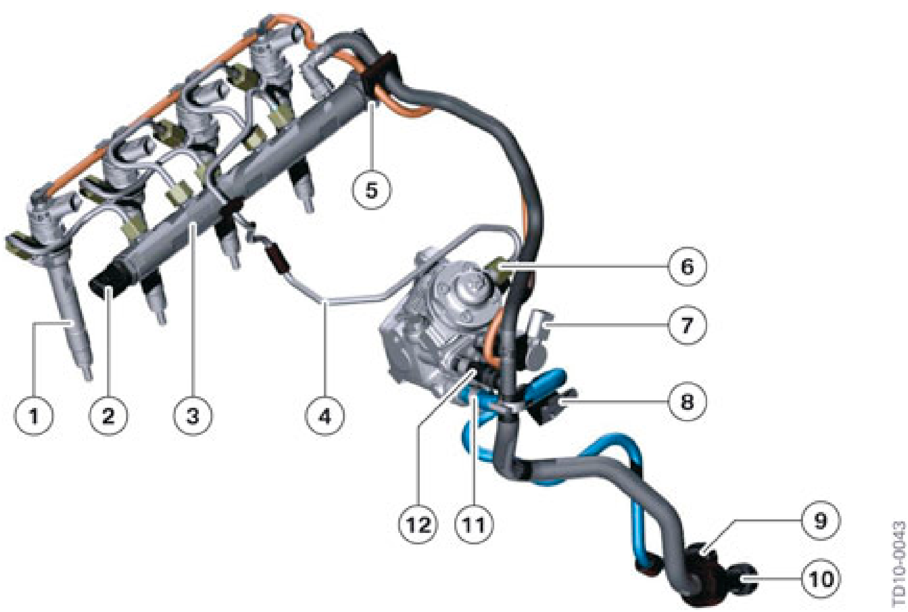


N47TU engine fuel preparation components

Index	Explanation
1	Uniform oil filler cap
2	High-pressure accumulator (rail) bracket
3	Crankcase ventilation valve
4	Bolting points for center high pressure accumulator bracket
5	Swirl-flap actuator
6	Blow-by pipe

The injection system is primarily comprised of the:

- **Low-pressure area:** The low-pressure area is divided into the fuel feed and the fuel return.
- **High-pressure area:** The high-pressure area contains the high-pressure pump, the high pressure lines, the rail and the injectors.
- **Electronic control:** The electronic control comprises the sensors and actuators such as the fuel filter heating, the fuel pressure/temperature sensor, the rail pressure sensor, the fuel quantity control valve and the injectors.



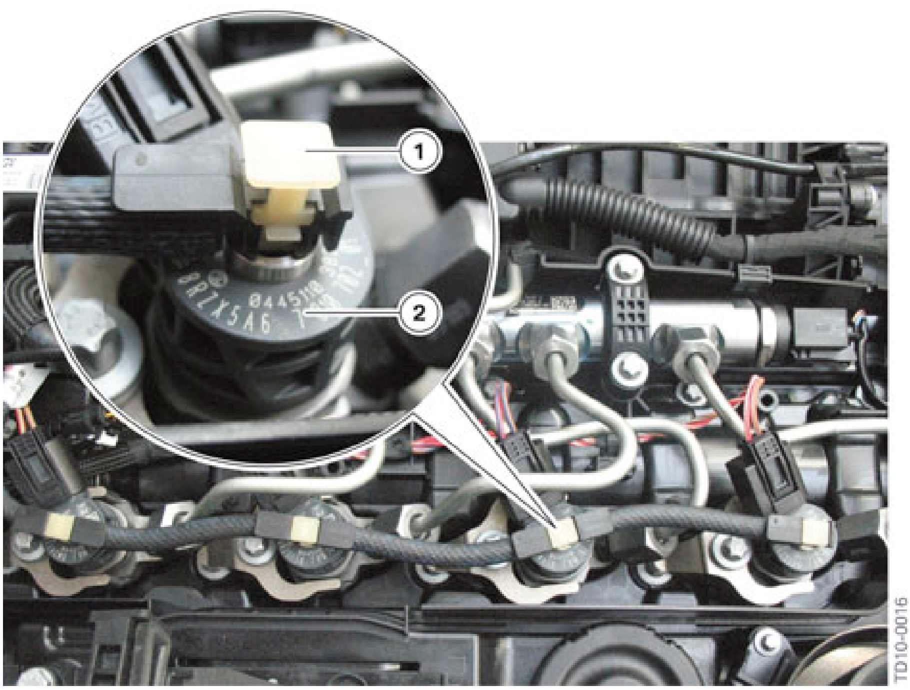
N47TU engine, high pressure pump and connection

Index	Explanation
1	Solenoid injector
2	Rail pressure sensor
3	Rail
4	High pressure line
5	Rail pressure regulating valve
6	High pressure line connection from the high pressure pump

Index	Explanation
7	Fuel quantity control valve
8	Fuel pressure temperature sensor
9	Fuel supply line from the fuel filter
10	Fuel return line
11	Fuel supply inlet connection at the high pressure pump
12	Fuel return outlet connection at the high pressure pump

8.1. Leakage oil line

The leakage oil line and the return connection of the engine are new compared to previous engines. In order to connect the leakage oil line with the injectors the return connection must be in the open position. The connector is then plugged in the injector return and the latch mechanism pressed in. With this, the return connector is secured against being pushed out. To open it the return connector must be opened (see illustration).



N47TU engine fuel return line

Index	Explanation
1	Return connector opened
2	Injector

N47TU Engine

8. Fuel Preparation

8.2. High pressure pump

The function of the high-pressure pump is to bring the fuel from the fuel supply to the required pressure level in line with the current demand. This must be performed in all operating ranges and over the entire service life. The high-pressure pump permanently generates the system pressure for the rail (high-pressure accumulator).

The CP4.1 single-plunger high-pressure pump is used in the N47TU engine. The CP4.1 delivers fuel with a double cam so that the injections are accompanied by delivery to the rail. This also reduces pressure fluctuations, as fuel is simultaneously delivered to the rail and withdrawn from the rail for injection.

The high-pressure pump is located on the flywheel side (rear) of the engine and is driven by the timing chain with a ratio of 1:1 from the crankshaft and is capable of generating a pressure of 1,800 bar.

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When work is carried out on the chain drive, the high-pressure pump in the N47TU engine must be positioned in relation to the crankshaft. Refer to the repair instructions for the exact procedure.

When compared to the N47 engine the camshaft of the N47TU high pressure pump was modified in order to increase the fuel delivery rate and the high pressure outlet was adapted to the modified high pressure line.

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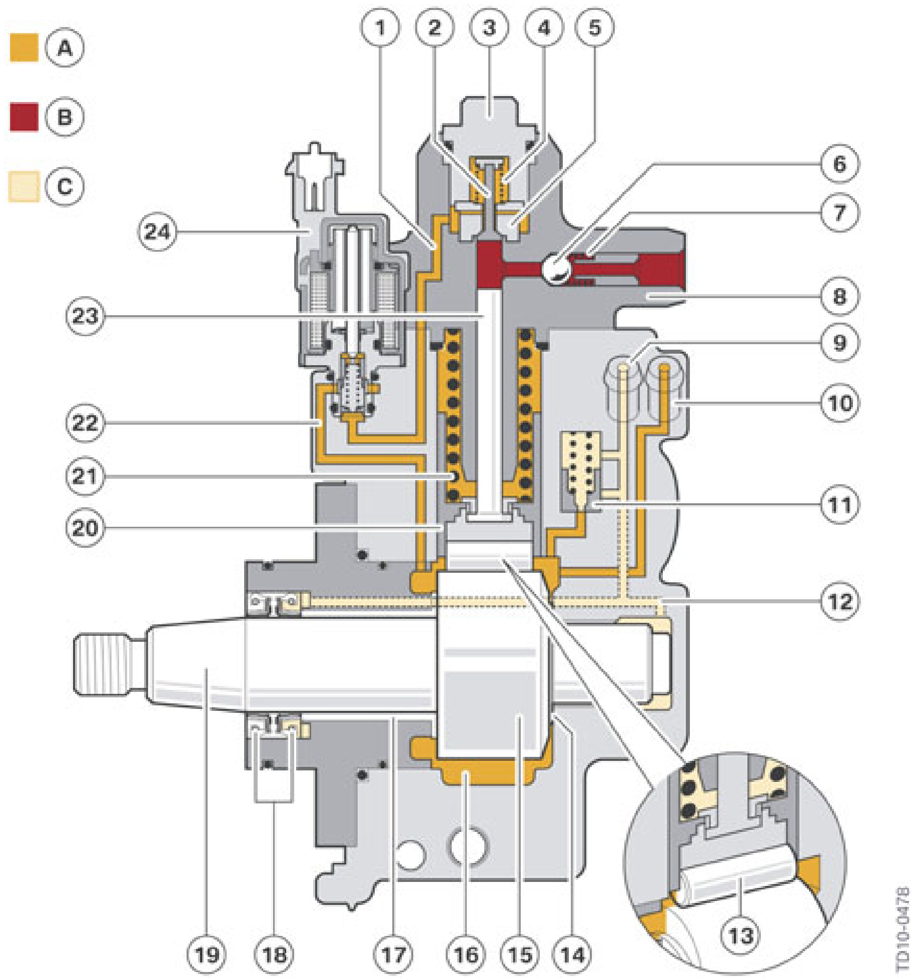
The pump is lubricated by the fuel. For this reason gasoline must not be used as a fuel flow enhancer in the winter months. The high-pressure pump and eventually the engine may otherwise be damaged.



N47TU high pressure injection pump CP4.1

Index	Explanation
A	Fuel supply
B	Fuel high pressure
C	Fuel return
1	Low-pressure channel
2	Valve plunger
3	Screw plug
4	Spring
5	Valve plate
6	Ball
7	Spring
8	Connecting branch
9	Connecting branch

Index	Explanation
10	Connecting branch
11	Fuel overflow valve
12	Return channel
13	Roller
14	Thrust washer
15	Double cam
16	Camshaft space
17	Bearing bushing
18	Radial shaft seal
19	Camshaft
20	Tappet
21	Spring
22	Low-pressure channel
23	Plunger
24	Fuel quality control valve (flow regulating valve)

To lubricate the high-pressure pump, fuel flows through the connecting branch (10) from the fuel supply (A) into the camshaft space (16). The fuel flows via the bearing bushing (17) through return channels (12) to the connecting branch (9) into the fuel return (C).

A fuel overflow valve (11) likewise discharges the excess fuel delivered to the connecting branch (9) into the fuel return (C).

From the camshaft space fuel flows through the low-pressure channel (22) to the fuel quantity control valve (24) and from there in a controlled state through the low-pressure channel (1) to the valve plate (5). The plunger (23) is pressed by the spring (21) via the tappet (20) and the roller (13) onto the double cam (15). The spring force is so high that the tappet rests with the roller on the double cam in all operating states.

When the tappet and the plunger move downwards in response to spring force, the valve plunger (2) is pressed by the applied fuel against the spring (4) or drawn upwards by the plunger moving downwards. The fuel can now flow into the cylinder.

When the plunger moves upwards, the valve is closed again and a pressure is built up. When the pressure in the cylinder exceeds the fuel high pressure (B), the ball (6) is pressed against the spring (7) and the rail pressure. The fuel can be delivered through the connecting branch (8) to the rail.

8.2.1. Fuel quantity control valve

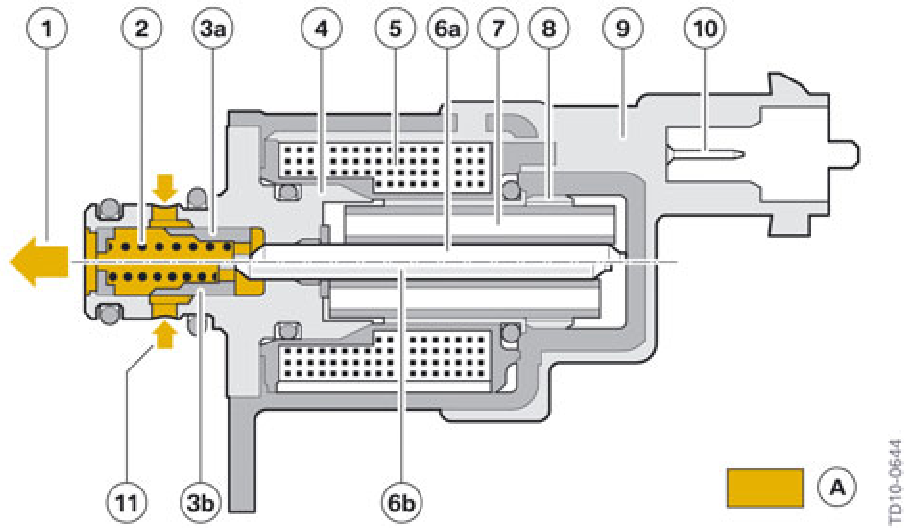
Fuel quantity control valve CP4.1

The fuel-quantity control valve (also known as flow regulating valve) is mounted on the high-pressure pump (CP4.1). The fuel-quantity control valve is controlled using a pulse-width modulated signal. The DDE controls the fuel-quantity control valve at various pulse-duty factors while the fuel-quantity control system is active. The system adjust rail pressure to the specified level as calculated by the DDE. The fuel-quantity control valve regulates the fuel flow from the low-pressure side to the high-pressure side of the high-pressure pump. This is how the desired fuel-rail pressure is achieved. Progressive reductions in the amount of fuel that the fuel-quantity control valve allows to flow to the high-pressure side produce corresponding reductions in the level to which the high-pressure pump charges the cylinders. The consequence is that less rail pressure is built up. The high-pressure pump generates pressure to maintain a constant level in the rail.

Two valves are employed to maintain the pressure within the fuel rail at the required level:

- Fuel quantity control valve
- Rail-pressure control valve (see corresponding description of operation)

When volumetric flow regulation is active, the DDE controls the fuel-quantity control valve (flow regulating valve) by means of a variable pulse duty factor in order to set the rail pressure to the level calculated by the DDE. The fuel-quantity control valve controls the flow of fuel into the high pressure pump from the low-pressure side, thereby controlling fuel-rail pressure as required. The less fuel the flow regulating valve allows to flow into the high pressure side, the less the radial cylinder of the high-pressure pump is filled. The consequence is that less rail pressure is built up.



Fuel quantity control valve cutaway CP4.1

Index	Explanation
A	Fuel supply (feed)
1	Fuel to pump element
2	Spring
3a	Plunger (in open state)
3b	Plunger (in closed state)
4	Ferro-magnet core
5	Solenoid coil
6a	Tappet (in the opened state)
6b	Tappet (in the closed state)
7	Armature
8	Bearing
9	Housing
10	Electrical connection
11	Fuel supply (feed)

The fuel quantity control valve is activated by the Digital Diesel Electronics with pulse-width modulation according to the calculated fuel requirement. On activation the tappet (6) is moved by the armature (7) actuated by magnetic force. The plunger (3) is displaced by the tappet. The plunger is pressed by the spring (2) against the tappet. The plunger, depending on its position, opens the fuel supply (11). This fuel quantity control reduces the power demand of the high-pressure pump. It delivers only that amount of fuel needed to generate the rail pressure determined from a characteristic map. The graphic below shows the plunger in its closed state (3b) and the associated tappet (6b). Also shown are the plunger in its opened state (3a) and the associated tappet (6a).

8.2.2. Volumetric flow regulation functional description

Depending upon conditions, one of the following 3 available closed-loop control strategies is used to adjust the rail pressure to the correct level:

- Volumetric flow regulation by the quantity control valve: The quantity control valve only allows the amount of fuel to flow into the high pressure pump from the low-pressure side that is required in order to generate the required fuel rail pressure. The high-pressure pump cylinder is not completely filled with fuel. The higher the control signal current, the lower the rail pressure that is generated. The rail-pressure regulating valve is not supplied with current for the maximum pressure. The rail-pressure regulating valve is supplied with slightly higher current than would be necessary for setting the target pressure.
- Pressure regulation by the rail pressure control valve: The high-pressure pump provides a constant supply of highly-pressurised fuel to the rail. The rail pressure regulating valve diverts excess fuel arriving in the rail into the return line. The higher the control signal current, the higher the rail pressure that is maintained. The flow regulating valve is set to maximum flow.
- Combined closed-loop control with simultaneous regulation from the rail pressure regulating valve and the quantity control valve: At extremely low fuel-injection quantities of less than roughly 4 mg (on trailing throttle/overrun) the rail pressure regulating valve must discharge a certain amount of fuel from the high-pressure system. The reason is that the high-pressure pump cannot run with zero delivery. This means that the high-pressure pump supplies fuel to the high-pressure system even when the quantity control valve (flow regulating valve) is closed. This would lead to excessive rail pressure and thus to a control deviation.

The two control methods are used under the following engine operating conditions:

- During engine starts: Pressure regulation is always active.
- When the engine is running: At a coolant temperature below 1 °C (34 °F), the pressure regulation is always active. Once the coolant temperature rises above 15 °C (59 °F) the combined closed-loop control system assumes operation.

Fault handling

If activation of the flow regulating valve is interrupted or has a short circuit to ground, the flow regulating valve switches to full delivery. The DDE detects the fault, limits the fuel injection rate and switches to pressure regulation. As of a fuel temperature of 60 °C (140 °F), the DDE reduces the fuel injection rate and the rail pressure to protect the rail-pressure regulating valve against overheating. In the event of a short circuit to positive, the engine shuts down.

8.3. Fuel rail

The rail (high-pressure accumulator) is a thick-walled pipe containing the connections for the high pressure lines and the rail pressure sensor. The rail is made from case harden steel. The volume in the rail is filled with fuel and makes the fuel available for injection. The fuel pressure of up to 1800 bar brings about a kind of spring action by the fuel and the rail which enables the fuel injection pressure to be kept virtually constant. Likewise, pressure fluctuations are damped or compensated by the delivery of the high-pressure pump.

8.3.1. Rail pressure sensor

Rail pressure sensor

A diaphragm with strain resistors is integrated in a metal housing. The measuring range of the sensor is dependent on the thickness of the diaphragm. The thicker the diaphragm, the higher the measurable pressure. The rail pressure sensor detects the current pressure in the rail. The pressure in the rail is of crucial importance to fuel injection. This measurement must be performed with great precision and within a suitably short period of time. If the rail pressure sensor fails, a fault is stored in the Digital Diesel Electronics and pressure regulation is activated "blind" by means of default values.

For more information regarding the rail pressure sensor see the “Sensor section” of this training manual or refer to the repair instructions in ISTA.

8.4. Injectors

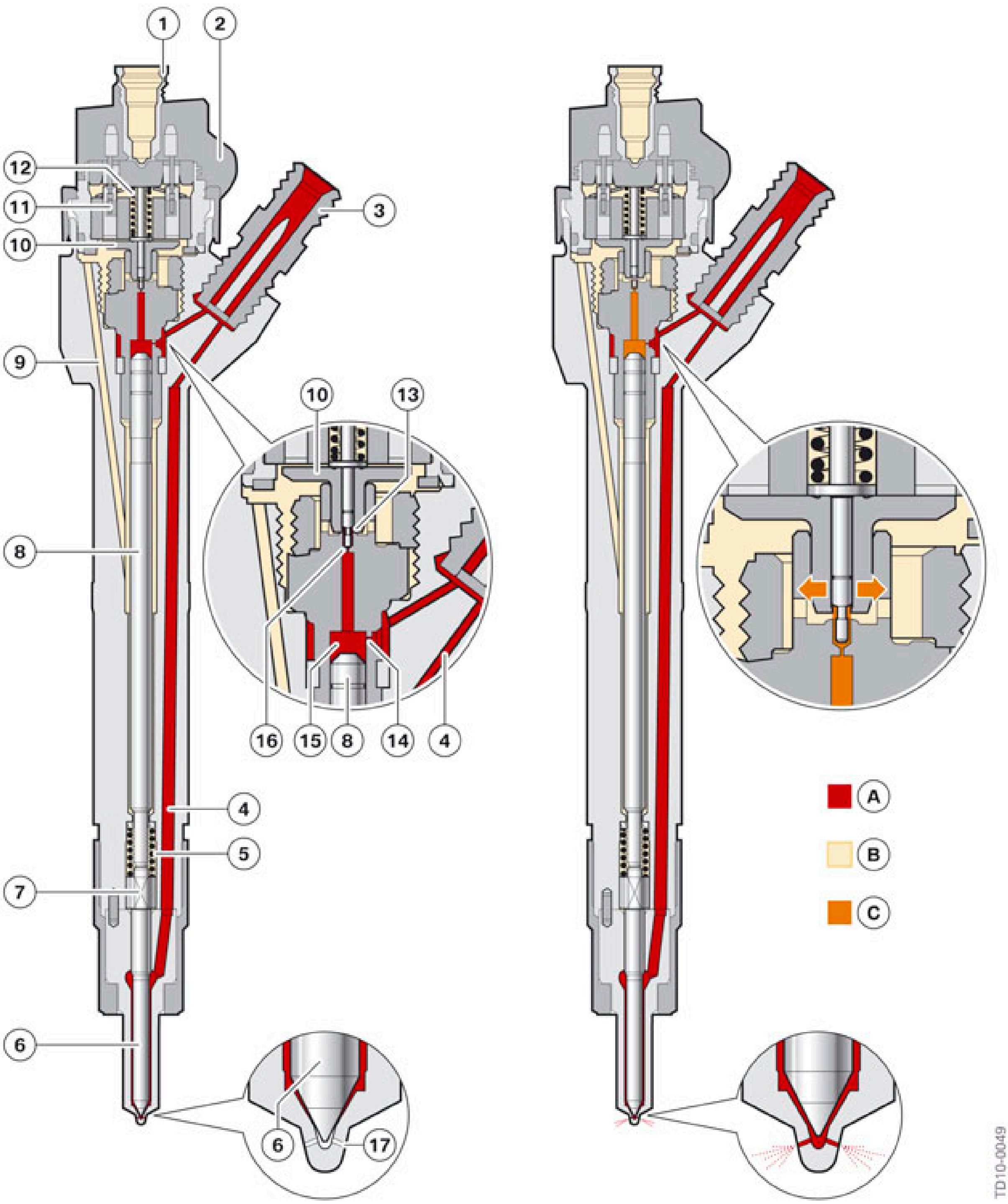
The new solenoid injectors (common rail injector CRI2.5) installed on the N47TU are produced by Bosch and operated with up to 1800 bar fuel pressure. Along with the increased maximum pressure, the number of possible switching actuations over the service life was also increased by 50%. It has multiple injection capability and also allows the implementation of very short switching times. The new solenoid injector delivers improved HC and CO emissions with the same power and consumption data as the 1800 bar piezo injector. An additional advantage of the solenoid type injector is the low manufacturing costs.

The nozzle geometry was adapted to meet increased emission regulation requirements.

8.4.1. Solenoid injector CRI2.5

Design

Important modifications were done on the solenoid valve injector when compared with the N47 engine (not available in the US). Instead of a ball shaped control valve a ring design is now used. The main concern is the permanent leakage of the pressure compensated valve. With the new shape a larger valve lift is achieved with a low opening cross-section.



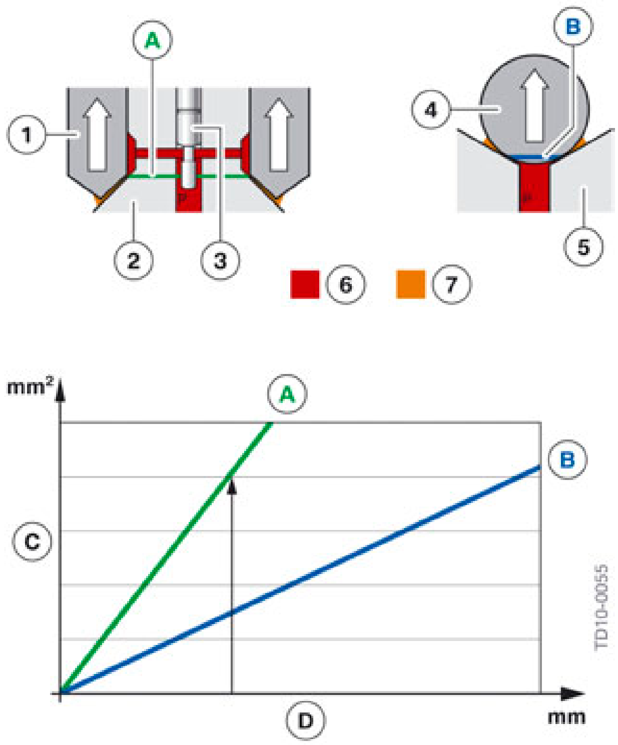
Solenoid injector CRI2.5

Index	Explanation
A	Fuel high pressure
B	Fuel return line
C	Reduced fuel high pressure
1	Fuel return line connection
2	Electrical connector
3	High-pressure connection with filter
4	Fuel delivery line
5	Nozzle needle spring
6	Nozzle needle
7	Coupler
8	Valve control piston
9	Leakage oil line
10	Armature
11	Solenoid coil
12	Armature spring
13	Control valve
14	Inlet throttle
15	Control chamber
16	Outlet throttle
17	Perforated nozzle

The behavior of the CRI2.5 injector is determined decisively by the control valve (13). The new injector should enable higher valve dynamics and simultaneously higher pressures. With the conventional ball valve this was not possible, because a reduction of the valve seat diameter to increase the operating pressure resulted in lower valve opening cross-sections for the control of the nozzle needle. Therefore the valve lift must be enlarged (at the cost of dynamics) which is not favorable with regards to injection rate and multiple fuel injection.

So that higher fuel injection pressure with simultaneously increased dynamics (multiple fuel injections) can be achieved, a pressure compensating valve was developed. Through this design the hydraulic forces within the seat diameter are captured by a fixed element. The advantage of this valve is an opening cross-section three times as large with the same valve lift.

Very short switching times can therefore be implemented with a small valve lift and simultaneously multiple fuel injections in very short time intervals. These modifications were necessary, since up to three pre-injections are required for emissions and noise reduction. However with regard to exhaust re-treatment there are currently up to four post-injections being used.



Comparison of valve opening cross-section for CRI2.2 and CRI2.5 injectors.

Index	Explanation
A	Pressure compensating valve CRI2.5
B	Ball valve CRI2.2 (previously used injector)
C	Opening cross-section
D	Valve lift
1	Control valve
2	Valve seat
3	Anchor bolts
4	Ball
5	Valve seat
6	Fuel high pressure
7	Reduced fuel high pressure (discharged fuel)

8.4.2. Injection volume calibration

Due to the tolerance during manufacturing of the injectors, the actual injected fuel volume deviates only slightly from the calculated fuel volume. This deviation is determined afterwards for each injector by taking measurements in several operating conditions. For each injector an adjustment value (code) is generated from these measurements. For vehicle assembly the compensation value of each injector is stored in the control unit after the installation of the Digital Diesel Electronics. The compensation values are assigned to the individual cylinders according to the installation of the injectors. The DDE corrects the calculated injection quantities slightly with these compensation values and so reduces the cylinder specific deviations of the injection volume.

Injection volume calibration, injector CRI2.5

Index	Explanation
1	Seven digit code (compensation value)

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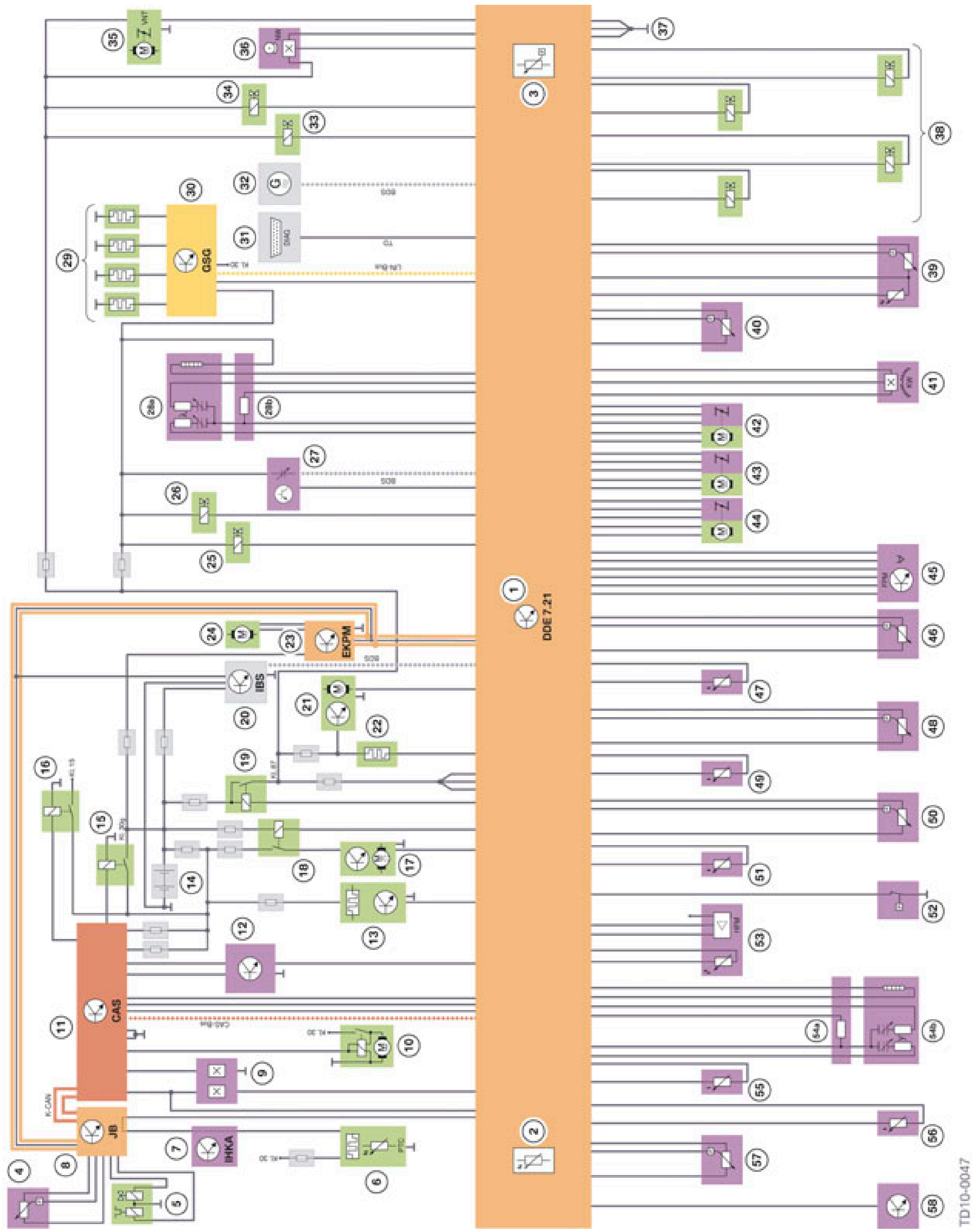
If injectors are replaced, the imprinted alphanumeric code of each injector must be assigned to the correct cylinder in the Digital Diesel Electronics.

9. Engine Electrical System

Although some new components are used the overall DDE IPO overview corresponds to the previous BMW diesel engines in their function and operating principle. The following system overview shows the components of the EURO 6 version which also directly corresponds with the US ULEVII version. The IPO also includes components for the automatic engine start-stop function. The DDE7.21 takes over the activation and evaluation of the sensors and actuators.



N47TU engine, DDE7.21 system wiring diagram with EURO 6 and ULEVII version

N47TU Engine
9. Engine Electrical System

Index	Explanation
1	Digital Diesel Electronics (DDE)
2	Temperature sensor in the DDE control unit
3	Ambient pressure sensor in the DDE control unit
4	Refrigerant pressure sensor
5	Air conditioning compressor
6	Electric auxiliary heater
7	Integrated automatic heating / air conditioning system
8	Junction box
9	Brake light switch
10	Starter
11	Car Access System
12	Clutch module (Not for U.S.)
13	Fuel filter heating
14	Battery
15	Terminal 30 switched relay
16	Terminal 15 relay
17	Electric fan
18	Electric fan relay
19	DDE main relay
20	Intelligent battery sensor
21	Air flap
22	Blow-by heater
23	Electronic fuel pump control
24	Electronic fuel pump
25	Electro-pneumatic changeover valve engine mounts
26	Electro-pneumatic changeover valve bypass flap exhaust-gas recirculation
27	Oil level sensor
28a	Oxygen sensor before the NO_x storage catalytic converter [control sensor with constant characteristic curve]
28b	Oxygen sensor connector
29	Glow plug
30	Preheating control unit
31	Diagnostic socket
32	Alternator
33	Rail pressure regulating valve

N47TU Engine
9. Engine Electrical System

Index	Explanation
34	Fuel quantity control valve
35	Charging pressure actuator
36	Camshaft sensor
37	Ground connection
38	Solenoid injectors
39	Fuel pressure temperature sensor
40	Rail pressure sensor
41	Crankshaft sensor
42	Exhaust-gas recirculation valve and exhaust recirculation sensor
43	Bypass controller and throttle valve sensor
44	Swirl-flap actuator and swirl-flap sensor
45	Accelerator pedal module
46	Exhaust back pressure sensor before the exhaust turbocharger
47	Coolant temperature sensor
48	Exhaust gas differential pressure sensor upstream and downstream of diesel particulate filter
49	Charge-air temperature sensor
50	Boost pressure sensor
51	Exhaust-gas temperature sensor before NO_x storage catalytic converter
52	Oil pressure switch
53	Hot film air mass meter
54 a	Oxygen sensor after the diesel particle filter (control sensor with constant characteristic curve)
54b	Oxygen sensor connector
55	Exhaust-gas temperature sensor after NO_x storage catalytic converter
56	Exhaust-gas recirculation temperature sensor
57	Brake vacuum-pressure sensor (for automatic engine start-stop function)
58	Zero-gear sensor (for automatic engine start-stop function)

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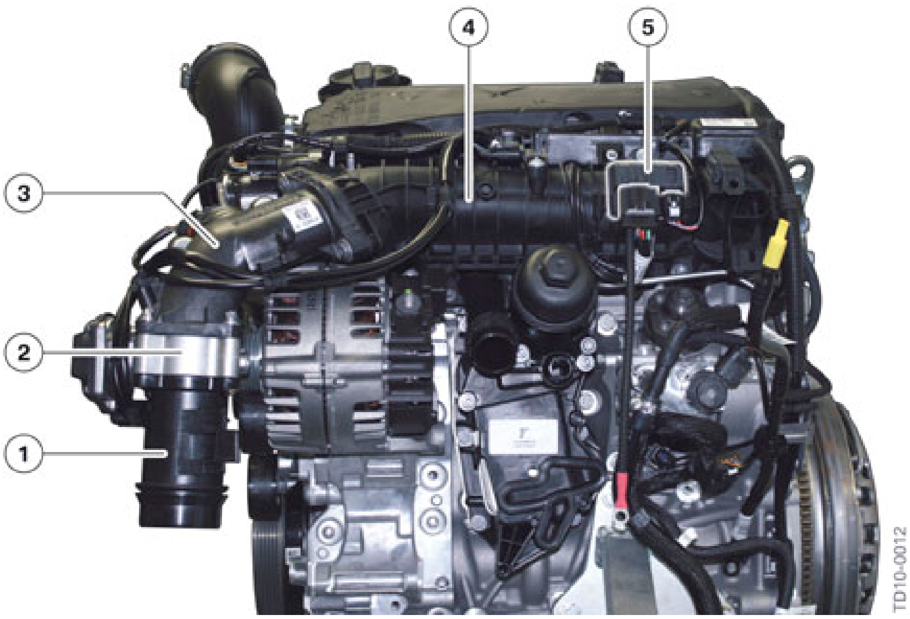
The two NOx sensors and the PM sensor are not shown in the DDE system wiring (IPO) illustration above because they have their own control units which communicate with the DDE via Lo-CAN.

9. Engine Electrical System

9.1. Preheating control unit

The preheating control unit is attached to the differentiated air intake system.



N47TU engine, belt drive variants

Index	Explanation
1	Charge air pipe
2	Throttle valve
3	Mixing tube
4	Differentiated air intake system
5	Preheating control unit

9.1.1. Glow plugs

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The glow plug detection must be performed after replacing the preheating control unit or glow plugs.

The service function offers two functions, which are necessary during repairs on the preheating system:

- Before replacing glow plug: **Activate safety data record.**
  Before replacing glow plugs the service function of the safety data record must be activated. This is necessary to ensure that the preheating control unit during terminal change controls the new glow plugs for safety reasons with the safety data record.
- After replacing glow plugs or the preheating control unit: **Perform glow plug detection.**
  After replacing the glow plugs or preheating control unit, the glow plug detection must be performed with the service function.

During this service function the following is checked:

- Does the preheating control unit detect all glow plugs?
- Are the correct glow plugs installed?
- Is the correct data record activated in the preheating control unit?

Reasons

Different glow plug types are used for the engines depending on power variations.

So that the different glow plug types can be activated with the correct respective voltage profile, there are different data records for the preheating control unit. In addition to the data records for the correct operation of the glow plugs there are also the so-called safety data record contained in the preheating control unit. The safety data record is laid out so that in case of a fault or with incorrect installation, all glow plug types can be supplied with current without danger of damage. There are two methods for detecting the glow plug type in the preheating control unit:

1. For each full heating cycle after a terminal change the detection is automatically initiated. During this the preheating control unit can only differentiate between metallic and ceramic glow plugs. If the preheating control unit detects a voltage fluctuation that is too large or if the signal for the starter intervention is active, the detection is aborted. If more than one glow plug of the wrong type is detected, the preheating control unit activates the safety data record. If only one glow plug of the wrong type is detected, the preheating control unit takes this glow plug from further preheating processes in the current driving cycle and does not activate the safety data record.
2. A special test preheating can be activated via the service function. During this the safety data record is always activated with unclear detection of all glow plugs.

9.2. Sensors

9.2.1. Crankshaft sensor

The crankshaft sensor informs the DDE of the position of the crankshaft. The signal from the engine speed sensor is one of the most important variables in the engine management.

The N47TU engine is equipped with a sensor that is able to detect reversed rotation. This is necessary for the automatic engine start-stop. The operation is identical to the conventional crankshaft sensor.

9. Engine Electrical System

N47TU Active crankshaft sensor

Index	Explanation
1	Active crankshaft sensor
2	Multipolar sensor wheel
3	Pole pair as "tooth gap"

The sensor is what is known as an active speed sensor, also functioning in accordance with the Hall principle. The sensor has its own evaluation logic.

With this speed sensor, pairs of magnetic poles assume the function of the teeth of an incremental gear. It can therefore be referred to as a multipolar sensor wheel, as already used in gasoline engines. On the multipolar sensor wheel, the tooth gap of the incremental gear is represented by a pair of poles twice as long.

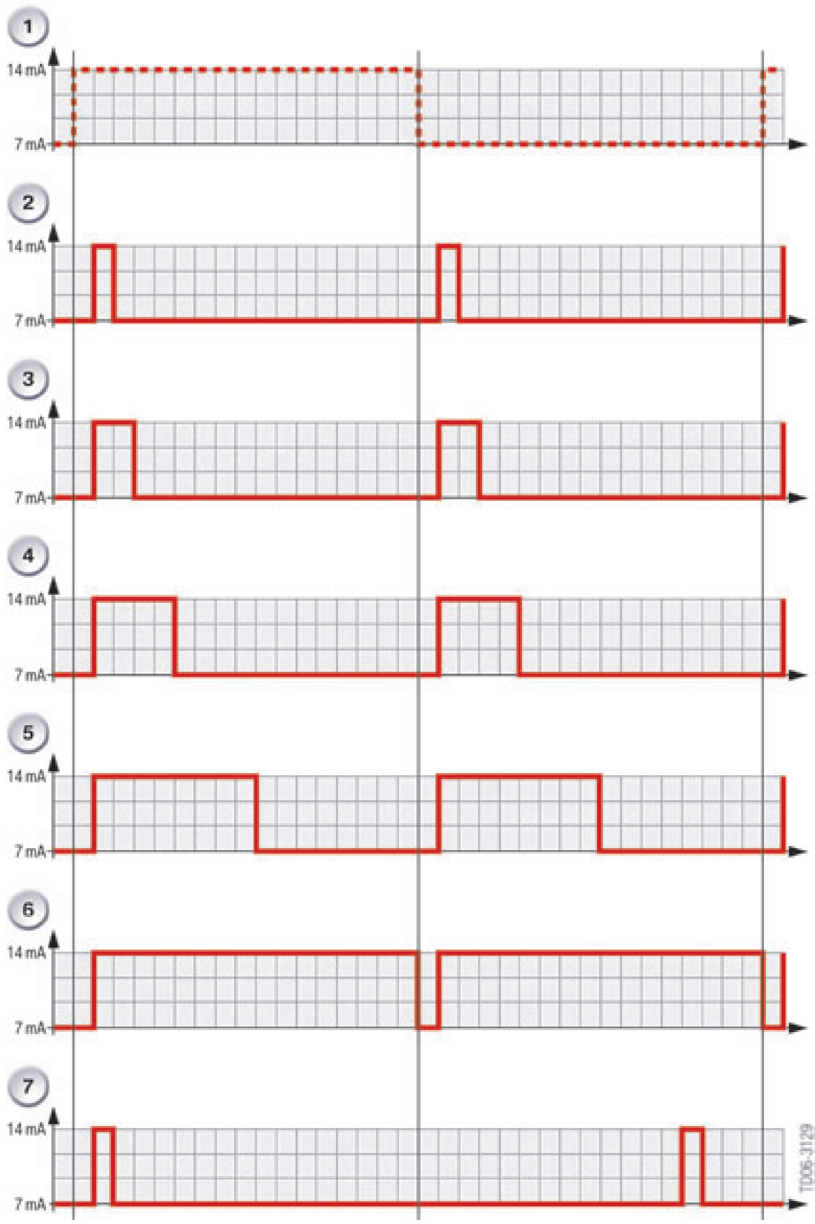
There are three Hall elements in the sensor, arranged next to each other in a housing. The signals of the first and third Hall element produce a differential signal for determining the signal frequency and the air gap to the sensor wheel. A clockwise or anti-clockwise direction of rotation can be detected thanks to the time offset between the signal of the center element and the differential signal.

The additional signals of the air gap and the direction of rotation are output using the pulse width of the digital signal.

The signals processed in the sensor are sent to the control unit on the combined ground and data line. On the data line, it is not the voltage level that is decisive but the current flow. There is a self-repeating data telegram that uses two different currents.

The 14 mA level contains the information about the speed, direction of rotation and the air gap. The 7 mA level acts as the evaluation current for the fault code memory.

Unlike the sensors used to date, a pulse indicating sensor availability is sent approximately every 740 ms when the vehicle is stationary.



N47TU crankshaft sensor with multipolar sensor wheel

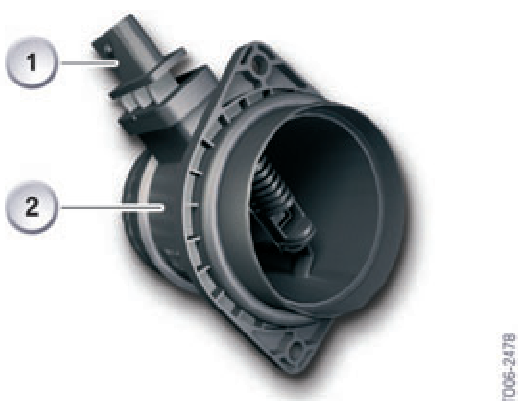
Index	Explanation
1	Maximum signal length of the sensor
2	Speed signal
3	Speed, direction of rotation: counterclockwise
4	Speed, direction of rotation: clockwise
5	Speed, counterclockwise direction of rotation + air gap width
6	Speed, clockwise direction of rotation + air gap width
7	Basic signal with engine stopped (740 ms)

9.2.2. Camshaft sensor

The N47TU camshaft sensor operates according to the Hall principle as with all BMW engines. The camshaft sensor is installed on the cylinder head cover above the intake camshaft. A camshaft sensor trigger wheel is mounted on the intake camshaft for this purpose. The Digital Diesel Electronics uses the camshaft sensor to detect whether the 1st cylinder is in the compression phase or the exhaust phase. This assignment cannot be made from the crankshaft position. Assignment is necessary so that fuel injection can be regulated accordingly. The DDE supplies the sensor with 5 V and ground. The sensor supplies a digital signal via the signal line to the DDE. A special pattern allows emergency operation if the crankshaft sensor fails. The resolution of the camshaft sensor signal is, however, too inaccurate to replace the crankshaft sensor during normal operation.

9.2.3. Hot-film air mass meter

The HFM 6 hot-film air mass meter is located downstream of the intake silencer and is fitted directly to its cover. The HFM measures the air mass taken in by the engine. This is used to record the actual air mass, which in turn is used to calculate the exhaust gas recirculation rate and the fuel limit volume.



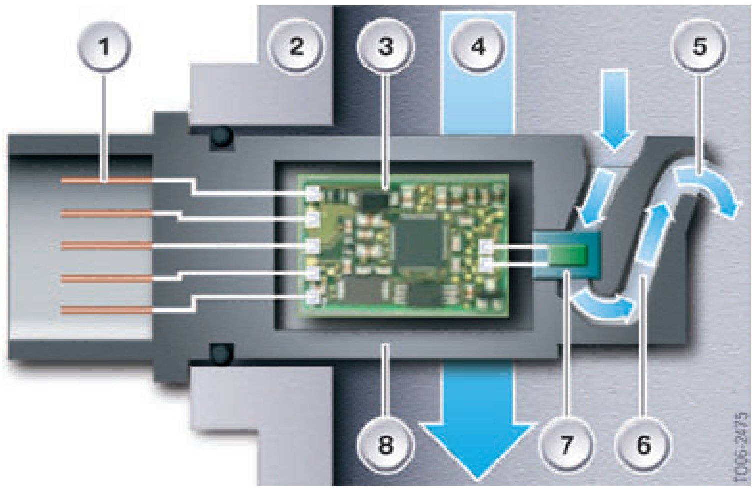
Hot-film air mass meter

Index	Explanation
1	HFM
2	Measurement tube

There is also an intake air temperature sensor in the HFM. The temperature evaluated by the HFM and sent to the DDE as a PWM signal. A pulse width of 22% equates to a temperature of -20 °C (-4 °F) and a pulse width of 63% equates to a temperature of 80 °C (176 °F).

Measurement method

A labyrinth (6) makes sure that only the actual air mass is recorded. Thanks to the labyrinth, back-flow and pulsation are not registered. In this way, the HFM determines the actual air mass irrespective of the air pressure and back-flow.

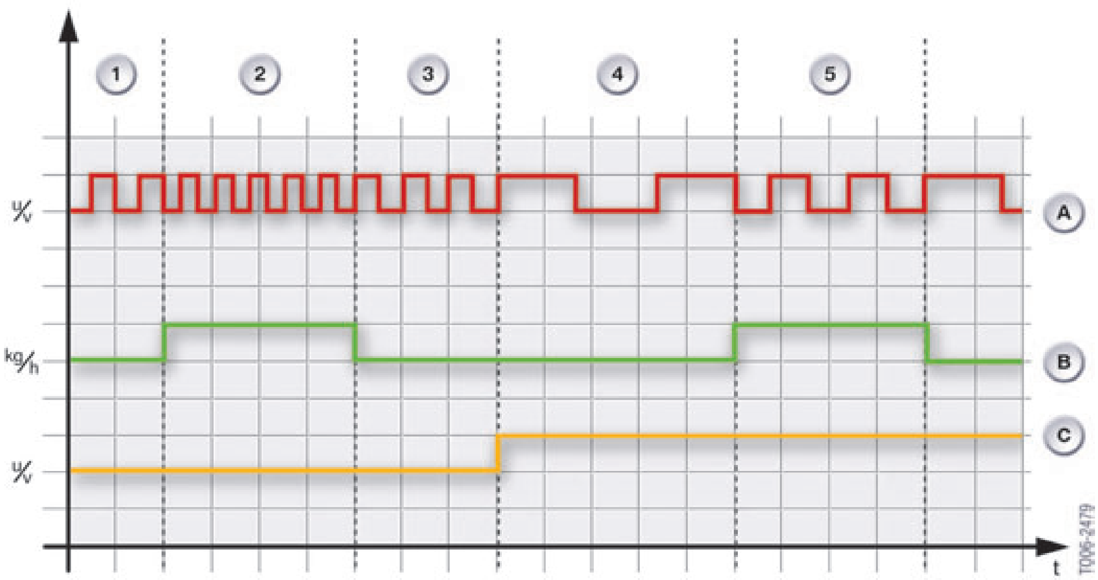


HFM measurement method

Index	Explanation
1	Electrical connections
2	Measuring tube housing
3	Evaluation electronics
4	Air mass flow
5	Partial measurement flow outlet
6	Labyrinth
7	Sensor measuring cell
8	Sensor housing

An electrically heated sensor measuring cell (7) protrudes into the air flow (4). The sensor measuring cell is always kept at a constant temperature. The air flow absorbs air from the measuring cell. The greater the mass air flow, the more energy is required to keep the temperature of the measuring cell constant.

The evaluator electronics (3) digitizes the sensor signals. This digitized sensor signal is then transferred frequency-modulated to the DDE. In order to be able to compensate for temperature influences, the air mass signal is referred to the variable temperature signal. The HFM is supplied with on-board voltage and connected to ground by the DDE.



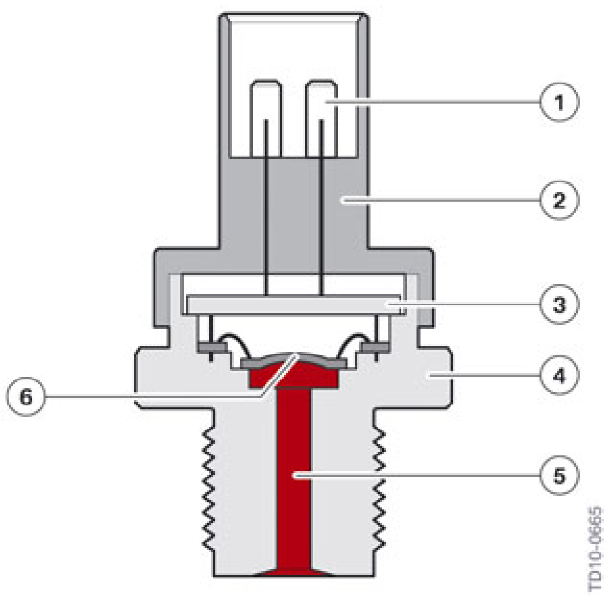
HFM signal

A	Air mass signal
B	Air mass
C	Temperature signal
1	Air mass signal (A) referred to air mass (B) and temperature signal (C)
2	With increased air mass (B) the period duration of the air mass signal (A) is shortened
3	With reduced air mass (B) the period duration of the air mass signal (A) is lengthened
4	With temperature increase (C) and air mass (B) staying the same the period duration of air mass signal (A) is lengthened to compensate for temperature influences
5	With increased air mass (B) the period duration of air mass signal (A) is shortened taking temperature signal (C) into account

9.2.4. Rail pressure sensor

Rail pressure sensor

The rail pressure sensor consists of strain resistors which are incorporated on a diaphragm (6). One side of this diaphragm is in contact with the fuel high pressure (5), with the fuel pressure acting on the diaphragm. The diaphragm is deflected depending on the extent of the pressure. The resistors on the diaphragm alter their resistance under the mechanical strain created. The bridge voltage is amplified, temperature influences compensated and the pressure characteristic line arise by a bridge circuit and electronics (3) for signal processing in the sensor. The output voltage for the Digital Diesel Electronics ranges between 0 and 3.3 V. As is the case with the temperature sensor the Digital Diesel Electronics stores a characteristic curve which assigns a corresponding pressure to each voltage value. The accuracy is ±2% of the end value.



Rail pressure sensor, sectional view

Index	Explanation
1	Electrical connection
2	Plastic housing
3	Electronics
4	Metal housing
5	Fuel high pressure
6	Diaphragm

9.2.5. Boost-pressure sensor

The boost-pressure sensor is located on the intake manifold and measures the pressure (absolute) inside it. It is supplied with 5 Volts and connected to ground by the DDE.

Boost pressure sensor

The boost pressure information is sent to the DDE on a signal line. The useful signal for the boost pressure fluctuates depending on the pressure.

The measuring range of approximately 0.1 - 0.9 V corresponds to a boost pressure of 50 kPa (0.5 bar) to 300 kPa (3 bar). The sensor serves the purpose of controlling the boost pressure.

9.2.6. Charge-air temperature sensor

The charge-air temperature sensor is located in the air duct downstream of the charge-air cooler, directly upstream of the throttle valve.

Charge-air temperature sensor

The DDE connects the charge-air temperature sensor to ground. A further connection is made to a voltage divider circuit in the DDE.

The intake temperature sensor contains a temperature-dependent resistor that protrudes into the flow of intake air and assumes the temperature of the intake air.

The resistor has a negative temperature coefficient (NTC). This means that the resistance decreases as temperature increases.

The resistor is part of a voltage divider circuit that receives 5 Volts from the DDE. The electrical voltage at the resistor is dependent on the air temperature. There is a table stored in the DDE that specifies the corresponding temperature for each voltage value; the table is therefore a solution to compensate for the non-linear relationship between voltage and temperature.

The resistance changes in relation to temperature from 149 kΩ to 161 Ω, corresponding to a temperature of -40 °C to 130 °C (-40 °F to 266 °F).

Note: These specifications may vary. Please refer to the appropriate repair information for up to date repair instructions.

9.2.7. Coolant temperature sensor

The coolant temperature sensor is located on the front of the cylinder head. It records the temperature of the coolant at the engine outlet. This value is used for the engine temperature. It is connected to ground by the DDE. The second connection is connected to a voltage divider circuit in the DDE.

The functional principle of the coolant temperature sensor is identical to that of the intake temperature sensor. The resistor has a negative temperature coefficient (NTC). This means that the resistance decreases as temperature increases.

The resistor is part of a voltage divider circuit that receives 5 Volts from the DDE. The electrical voltage at the resistor is dependent on the air temperature. There is a table stored in the DDE that specifies the corresponding temperature for each voltage value; the table is therefore a solution to compensate for the non-linear relationship between voltage and temperature.

The resistance changes in relation to temperature from 216 kΩ to 41.7 Ω, corresponding to a temperature of -55 °C to 150 °C (-58 °F to 302 ° F).

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These specifications may vary. Please refer to the appropriate repair information for the most up to date repair instructions.

9.2.8. Oxygen sensor

The oxygen sensor is an indispensable component for controlling and measuring the composition of exhaust gas with the aim of conforming to legally stipulated emission values. This is achieved by measuring the residual oxygen content in the exhaust gas.

For optimum combustion, a diesel engine is operated with a fuel-air ratio of $\lambda > 1$, i.e. rich in oxygen. $\lambda = 1$ signifies a mixture of 1 kg fuel with 14.7 kg air.

The oxygen sensor is located at the inlet to the shared housing of the diesel particulate filter (DPF) and NOx storage catalytic converter.

The control sensor with rising characteristic is a type LSU 4.9 broadband oxygen sensor supplied by Bosch. This broadband oxygen sensor is installed upstream of the NOx storage catalytic converter close to the engine.

The oxygen concentration in the exhaust gas can be determined over a large range with the broadband oxygen sensor. The broadband oxygen sensor is capable of providing accurate measurements not only at $\lambda = 1$ but also at $\lambda < 1$ (rich) and $\lambda > 1$ (lean). The broadband oxygen sensor supplies a distinct, steady-state electrical signal from $\lambda = 0.7$ to $\lambda = \infty$ ($\lambda\ \infty$ = air).

The DDE corrects the mixture composition through fuel injection based (in part) on the feedback of the O_2 sensor and the air mass (HFM). For optimum combustion, a diesel engine is operated with a fuel-air ratio of Lambda > 1, i.e. rich in oxygen. Lambda = 1 signifies a mixture of 1 kg fuel with 14.7 kg air.

The DDE also compares this information to data points in a characteristic map that refers to the mean quantity value adaptation (MMA). The mean quantity adaptation serves to adapt the exhaust-gas recirculation more precisely to tolerance in the fuel injection rates.

The Lambda oxygen sensor measures the fuel-air ratio. In the event of deviations, the DDE adapts the exhaust-gas recirculation rate to suit the change in air/fuel ratio. The mean quantity adaptation is not a rapid control operation, but is instead an adaptive learning procedure. An oxygen sensor deviation is ”learned” in a characteristic map and stored for a sustained period in the DDE control unit.

The exhaust after-treatment system also incorporates a second O_2 sensor located downstream of the diesel particulate filter. It is also an LSU 4.9 broadband oxygen type sensor. This second oxygen sensor enables the system to monitor detect whether the NOx storage catalytic converter needs to be regenerated.

The new system uses the two oxygen sensors and the two NOx sensors of the SCR system to monitor the entire exhaust after-treatment system for plausibility and fault detection.

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For more information regarding the exhaust after-treatment refer to the “Second generation diesel engine emission controls” in the ST1210 Diesel Technology training material available on TIS and ICP.

9.2.9. NOx sensors

As with the M57D30T2 engine the N47TU also uses Selective Catalyst Reduction system (SCR) for reducing NOx emissions.

As with the previous SCR system SCR 2 also incorporates two NOx sensor (one upstream and one downstream of the SCR Catalyst)

The nitrogen oxide sensor consists of the actual measuring probe and its own corresponding control unit. The control unit communicates via the Lo-CAN with the engine control unit.

In terms of its operating principle, the nitrogen oxide sensor can be compared with a broadband oxygen sensor. The measuring principle is based on the idea of basing the nitrogen oxide measurement on oxygen measurement.

Functional description

The sensor system of the nitrogen oxide sensor consists of a solid electrolyte made of ceramic based zirconium dioxide. Above a temperature of approximately 300°C, this material becomes conductive for oxygen ions. The installed heating element provides for the necessary operating temperature. The mixture of O_2 and nitrogen oxide in the exhaust gas reaches the nitrogen oxide sensor after the nitrogen oxide catalyst storage. The nitrogen oxide sensor consists of two chambers. A pump cell regulates the oxygen concentration to a specific value by pumping oxygen out of or into the first chamber. Through the application of a voltage, the oxygen molecules are split into ions and diverted through the solid electrolyte. The remaining nitrogen oxide then goes on to the second chamber. The oxygen concentration is then further reduced with a second pump cell in the second chamber. The remaining nitrogen oxide is split into oxygen and nitrogen at a catalytic element at the third pump cell. The released oxygen leads to a pump current which is proportional to the concentration of nitrogen oxide in the exhaust gas. The evaluation electronics generate the output signals based on the physical measured values. The control unit communicates via the Lo-CAN with the engine control unit.

9.2.10. Particulate matter sensor

Diesel particulate filter is an essential component of the exhaust after-treatment system for all current BMW diesel engines. Monitoring and diagnosis of the DPF (as with all emission systems) is required in order to insure its efficiency. This was done (in the previous system) via a differential pressure measurement which determines the pressure drop in the DPF. As the regulatory mandates regarding the OBD diagnosis of the DPF are constantly being updated the pressure method is not sufficient to meet the tighter regulations.

The particulate matter sensor was installed for the first time in combination with the second generation BMW diesel engines (N47TU and N57TU) which were introduced to the US market as of 7/2013. This sensor is in compliance with much more stringent US emission OBD diagnosis regulations and is a further enhancement to BMW Efficient Dynamics strategy.

Particulate matter sensor

The particulate matter sensor is integrated into the exhaust system downstream of the DPF and enables a constant diagnosis of the particulate filter (DPF).

In vehicles with the N47TU and N57TU the PM sensor is located after the SCR. Due to its location the sensor needs to stand up to many exhaust hazards including ammonia and urea from the SCR system. This location also affects the sensor's ability to reach its necessary dew point. During this time the sensor sits idle and cannot be used to detect particulates.

The PM sensor is very similar to a NOx sensor with regard to the construction of the body and that it also uses its own control unit. It has a 24 mm spin nut and an upper assembly to protect the wiring. Its internal sensing element is installed in the sensing tube and protected by a outer heat shield tube which helps to guide exhaust gas flow to the sensing element.

The evaluation electronics generate the output signals based on the physical measured values. The control unit communicates via the Lo-CAN with the engine control unit.

PM sensor operation

The sensor function is based on resistance measurements. Soot particles in the exhaust gas are absorbed into the sensor and collect on the sensing element. These soot particles are electrically conductive and form a conductive path between the electrodes of the sensing element through which an electric current is flowing. This decreases the resistance across the electrodes and increases the current flow. The increase in current flow is measured against a baseline threshold current. The amount of time that the current takes to reach this threshold current is then compared. The PM sensor control unit forwards this measured current feedback via the Lo-CAN to the DDE. The DDE then compares the amount of time that the signal takes to reach the specified threshold current and based on this evaluates the efficiency of the DPF.

Therefore if the current signal reaches the pre-set threshold before the predetermined time the DPF has failed.

The sensing element is regenerated regularly by heating to burn off the (conductive) soot accumulated on the sensor element. This is done via an integrated heater to restore the initial resistance across the electrodes in order to “zero” the baseline and prepare the sensor to test another soot sample.

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For more information regarding the exhaust after-treatment refer to the “Second generation diesel engine emission controls” in the ST1210 Diesel Technology training material available on TIS and ICP.

9.2.11. Exhaust gas temperature sensor

The exhaust gas after-treatment system of the N47TU engine uses three exhaust temperature sensors (besides the EGR temperature sensor). One located directly next to the oxygen sensor at the inlet to the NSC/DPF, a second is bolted to the NSC/DPF housing (down stream of the NSC just before the DPF). The third is located just before the SCR near the dosing valve. The first two exhaust temperature sensors are used by the DDE to monitor the efficiency of the NSC and to regulate regeneration of the DPF. The third sensor is used to send exhaust temperature feed back to the DDE with regard to the SCR system.

All three exhaust temperature sensors are of the same type and operate as on previous engines: they contain a temperature-sensitive resistor with a negative temperature coefficient (NTC). This means that the resistance decreases as temperature increases. The resistor is part of a voltage divider circuit that receives 5 Volts from the DDE. The electrical voltage at the resistor is dependent on the air temperature. There is a table stored in the DDE that specifies the corresponding temperature for each voltage value; the table is therefore a solution to compensate for the non-linear relationship between voltage and temperature.

The resistance changes in relation to temperature from 96 kΩ to 32 Ω, corresponding to a temperature of -40 °C to 800 °C (-40 °F to 1472 °F).

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These specifications may vary. Please refer to the appropriate repair information for the most up to date repair instructions.

9.2.12. Fuel temperature and pressure sensor

Fuel temperature and pressure are monitored by a combination sensor that is located in the fuel supply directly upstream of the high-pressure pump. The combination sensor has four connections: The ground connection is shared by the individual sensors. The fuel-pressure sensor has a power supply and each sensor has one signal output.

Fuel temperature sensor

The fuel temperature sensor measures the fuel temperature upstream of the high-pressure pump. It is used for engine overheating protection and calculating the injection volume. The fuel temperature sensor is connected to ground by the DDE. The second connection is connected to a voltage divider circuit in the DDE. It contains a temperature-dependent resistor that protrudes into the fuel and assumes its temperature. The resistor has a negative temperature coefficient (NTC). This means that the resistance decreases as temperature increases. The resistor is part of a voltage divider circuit that receives 5 Volts from the DDE. The electrical voltage at the resistor is dependent on the fuel temperature. There is a table stored in the DDE that specifies the corresponding temperature for each voltage value; the table is therefore a solution to compensate for the non-linear relationship between voltage and temperature. The resistance changes in relation to temperature from 75.5 kΩ to 87.6 Ω, corresponding to a temperature of -40 °C to 120 °C (-40 ° F to 248 ° F).

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These specifications may vary. Please refer to the appropriate repair information for the most up to date repair instructions.

Fuel pressure sensor

The fuel temperature sensor measures the pressure in the low-pressure fuel system, upstream of the high-pressure pump. The fuel pressure is used by the DDE as a basis for the on-demand control of the electric fuel pump. The DDE connects the fuel pressure sensor to ground and supplies with a voltage of 5 V. It delivers a voltage signal to the DDE. A sheet diaphragm converts the fuel pressure into a path dimension. This path is converted into a voltage signal by four pressure-sensitive resistors.

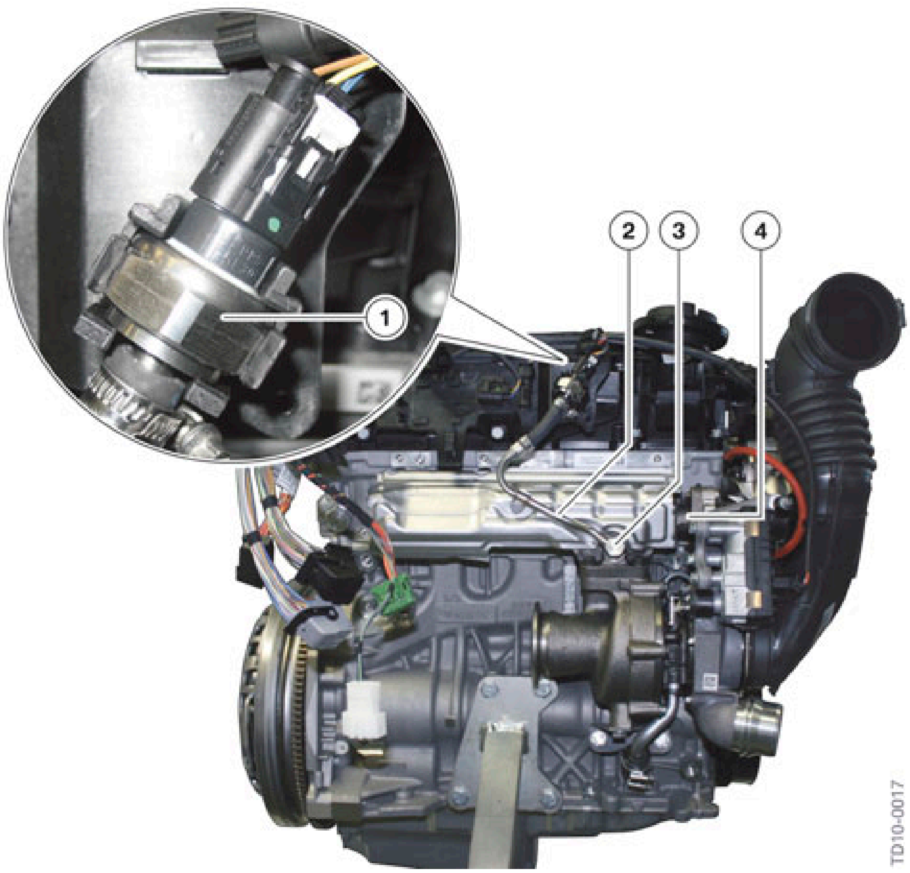
9.2.13. Exhaust back pressure sensor before the exhaust turbocharger

The exhaust back pressure sensor before the exhaust turbocharger is new.

The exhaust back pressure sensor measures the pressure in the exhaust system before the turbocharger. This information is necessary for optimum control of the exhaust-gas recirculation rate. Using the exhaust back pressure sensor and the exhaust-gas temperature sensor, the Digital Diesel Electronics (DDE) can regulate the exhaust-gas recirculation rate even more precisely and efficiently.

The exhaust back pressure sensor is connected to the exhaust manifold via a pipe and a hose. The reason for the clearance to the exhaust manifold is the possible high temperature of the exhaust emission system and dirt contamination, which otherwise could get onto the sensor element. The connection to the hose must point downward. The exhaust back pressure sensor is connected to the Digital Diesel Electronics (DDE) with three pins. The DDE supplies them with ground and a voltage of 5 Volt. The voltage signal gets to the DDE via the third pin.

Absolute pressure	Voltage
100 kPa (1.0 bar)	about 1.0 volt
500 kPa (5.0 bar)	about 4.5 volt



Exhaust back pressure sensor

Index	Explanation
1	Exhaust back pressure sensor
2	Connecting pipe
3	Connection to the exhaust manifold
4	Exhaust manifold

9.2.14. Throttle valve actuator

The throttle valve actuator is mounted on the intake manifold.

The DDE control unit calculates the position of the throttle valve from the position of the accelerator pedal and from the torque requirement of other control units. The throttle valve actuator is opened and closed electrically by the DDE control unit.

Throttle valve actuator

It is controlled by the DDE by means of a PWM signal with a pulse duty factor of 5 to 95%.

The throttle valve is also used for diesel particulate filter regeneration and to counteract shaking during engine switch-off.

Position sensor

To achieve optimum control of the throttle valve, its exact position must be recorded on a continual basis. The throttle valve position is monitored contactlessly in the throttle valve actuator by 2 Hall sensors. The position sensor is supplied with 5 Volts and connected to ground by the DDE. Two data lines guarantee redundant feedback of the throttle valve position to the DDE. The second signal output is the inverse of the first signal. The DDE evaluates the plausibility of the signal through subtraction.

Actuator motor

The actuator motor for operating the throttle valve is designed as a DC motor. It is driven by the DDE on demand. An H-bridge is used for activation which makes it possible to drive the motor in the opposite direction. The H-bridge in the DDE is monitored by the diagnostics system. When no power is applied to the drive unit, the throttle valve is set, spring-loaded, to an emergency operation position.

N47TU Engine
10. Engine Control Functions

10.1. Air supply

In the diesel engine, the DDE requires information about the air mass taken in so that it can control various functions. The mass flow rate of the intake air is measured by the hot-film air mass flow sensor (HFM).

The measured air mass flow rate is the basis for calculating the exhaust recirculation rate.

The air mass is also used in the calculation of the limit volume. The limit volume is the maximum permissible volume of fuel that may be injected under full load before smoke development would occur.

Swirl flaps provide a better air swirl effect. The result is to improve exhaust emission values.

The electrically controlled swirl flaps are located in the tangential ducts of the intake manifold (integrated in the gasket between the differentiated air intake system and the cylinder head). They are closed or opened depending on the operating condition. The electrically controllable swirl flaps are opened by the swirl flap actuator with increasing engine speed.

The swirl flaps are closed under the following conditions:

- At low engine speeds and
- low injection volumes (data-map controlled).

The swirl flaps generally remain open if:

- The coolant temperature is < 15 °C
- The intake air temperature is < 15 °C

The swirl flap actuator is a stepper motor that is controlled by the DDE control unit by means of a PWM signal. The stepper motor operates the connection lever and the swirl flaps close. An integrated sensor signals the position of the swirl flaps to the DDE control unit.

10.1.1. Boost-pressure control

The N47TU engine is boosted by an exhaust turbocharger. Adjustable guide vanes are pivoted on the outside around the turbine wheel on the exhaust side. The driving power which the exhaust gas exerts on the turbine is influenced by these guide vanes and thereby the desired boost pressure is set.

A boost pressure actuator on the turbine housing actuates the adjustable guide vanes via a control rod.

The Digital Diesel Electronics sends a pulse-width modulated signal to the boost pressure actuator. The operating range of the signal is between 10% and 95%, where 10% means “guide vanes open” and 95% “guide vanes closed”. The electronics in the boost pressure actuator converts the pulse-width modulated signal into a setting angle and activates the servomotor.

A feedback of the set position is detected via the integrated travel feedback in the boost pressure actuator by the DDE. The boost pressure actuator itself is capable of self diagnosis and signals an existing fault to the DDE.

10.2. Fuel supply

10.2.1. Fuel injection

The N47TU engine is equipped with high-pressure fuel injection with common rail pressure accumulator.

The common rail has the following advantages:

- Optimum fuel preparation for each individual cylinder.
- Adaptation of injection time to engine operating conditions (engine speed, load, temperature).
- Cylinder-selective injection correction in response to load change (the injection time can be corrected by post-injection, extending or shortening the time during the induction stroke).
- Cylinder-selective switch-off possible.
- Diagnostics of each individual injector is possible

Common rail injection offers these advantages due to the fact that all cylinders are supplied with fuel independently of each other.

10.2.2. High-pressure control

The fuel quantity (flow) control valve establishes the fuel supply from the low pressure side to the high pressure side of the high-pressure pump, thus achieving the required rail pressure. The fuel quantity control valve is forced open hydraulically as from a defined pressure on the high pressure side of the high-pressure pump. The less fuel that the fuel quantity control valve allows into the high-pressure side, the less the radial cylinder/cylinders of the high-pressure pump will be filled. This results in a reduction in rail pressure. The signal from the rail pressure sensor is an important input signal for the DDE for the control of the volume control valve. During a cold start, the pressure in the rail is not controlled by the fuel quantity control valve but by the rail-pressure regulating valve in the rail.

The high-pressure pump therefore always generates maximum pressure, which causes the fuel to heat up. The rail-pressure regulating valve also relieves excess pressure in the rail if the accelerator pedal is suddenly released.

In the event of the rail pressure sensor failing, the DDE controls the volume control valve in emergency mode.

See “Volumetric flow regulation functional description” and the “Fuel quantity control” section of this training manual for more information.

10.2.3. Injector volume calibration

At the end of the injector manufacturing process, measuring data is recorded for each individual injector. This is how the tolerance ranges of their hydraulic properties are determined.

A correction value is then defined for the pre-injection and main injection. This correction value is printed on the injector as a seven-digit numerical code. In the event of an injector replacement, this correction value must be programmed into the DDE using the diagnostic system.

10.2.4. Volume calibration control

The DDE control unit detects fluctuations in engine speed. The control duration of the injectors is corrected based on these engine speed fluctuations. The volume calibration control equalizes the injection volume of all cylinders.

10.2.5. Zero volume calibration

The zero-volume calibration is a continual learning process. This learning process is required to enable precise pre-injection for each individual injector. Compliance with exhaust emission requirements demand precise metering of the very low pre-injection volume. Due to the injector volume drift, zero volume calibration has to be carried out constantly.

A small amount of fuel is injected into each cylinder when the engine is overrunning. That quantity is gradually increased until the DDE control unit detects a slight increase in engine speed. That change enables the DDE control unit to detect when each cylinder starts to work. The volume of fuel injected during the zero-volume calibration sequence is used by the DDE control unit as the base figure for the pre-injection data map.

10.2.6. Mean volume adaptation

Mean volume adaptation is a learning process whereby the fuel/air ratio (lambda value) is corrected by adjusting the air mass flow rate or exhaust recirculation rate. Unlike the other processes, this process affects all injectors equally rather than the individual injector.

An injection volume averaged across all cylinders is calculated from the lambda value measured by the oxygen sensor and the air mass flow rate measured by the hot-film air mass flow sensor. That figure is compared with the injection volume specified by the DDE control unit.

If a discrepancy is identified, the air mass flow rate is adjusted to match the actual injection volume by adjusting the EGR valve. The correct lambda value is set in turn.

The mean volume adaptation is not an "instantaneous" regulation but an adaptive learning process. In other words, the injection volume error is taught into an adaptive characteristic map that is permanently stored in the EEPROM of the control unit.

A replacement of the following components requires a reset (delete) of this characteristic map:

- HFM
- Injector(s)
- Rail-pressure sensor

The characteristic map is reset by a function in the BMW diagnostic system.

Mean volume adaptation has to be reset if one of the following components has been replaced:

- Air-mass sensor
- Fuel-rail pressure sensor
- Oxygen sensor (upstream of the NSC)

10.3. Exhaust emission system

10.3.1. Oxygen control

An optimum fuel-air mixture is necessary for complete and problem-free combustion.

Modern catalytic converters therefore achieve a conversion rate of 98% up to virtually 100%, i.e. the percentage of converted pollutants. The optimum composition of the fuel-air mixture is controlled by the DDE. The required information relating to the composition of the exhaust gas is supplied by the oxygen sensors.

The broadband oxygen sensor upstream of the catalytic converter constantly measures the residual oxygen in the exhaust gas. The fluctuating residual oxygen levels are passed to the DDE control unit as voltage signals.

The DDE control unit uses them as the basis for adjusting the mixture composition.

Second generation diesel engines (N47TU and N57TU) use a Nox storage catalyst in place of (the previously used) oxidation catalyst. Both oxidation and reduction processes occur in the NSC catalytic converter. Oxygen (O_2) is required for oxidation while carbon monoxide CO is required for reduction. The pollutants CO, HC, NOx and the reduction catalysts O_2 and CO must be present in a certain ratio in order to facilitate the highest possible conversion rate.

The system uses a second oxygen sensor located downstream of the diesel particulate filter. This second oxygen sensor enables the system to detect whether the NOx storage catalytic converter needs to be regenerated. (For more information regarding the NOx storage catalytic converter see “Second generation diesel engine emission controls” training material available on TIS and ICP)

10.3.2. Lambda adaptation

Lambda adaptation (mixture adaptation) serves the purpose of adjusting component tolerances and ageing phenomena that have an influence on the fuel-air mixture. Factors such as secondary air and fuel pressure also affect lambda adaptation (partial adjustment). For these reasons, no exact control limits can be specified for a specific fault.

The following distinctions are made in terms of lambda adaptation:

- Additive mixture adaptation
- Multiplicative mixture adaptation

Additive mixture adaptation is effective at idle speed or the near idle speed range. Its influence decreases as the engine speed increases. Multiplicative mixture adaptation is effective over the entire characteristic map. One of the main factors is the fuel pressure.

The service function "Reset adaptation data" can be used to reset the adaptation data and the equipment option settings to their factory settings. It will then be necessary to relearn the adaptation values. A longer period of vehicle operation between idle speed and partial load is required in order to learn the values for mixture adaptation.

10.3.3. Exhaust gas recirculation (EGR)

As with previous BMW diesels the N47TU also uses an Exhaust Gas Recirculation System.

A calculated volume of exhaust gas based on the prevailing operating condition is fed back to the intake manifold by the EGR valve to reduce emissions.

Under certain engine operating conditions, a certain amount of exhaust is fed back into the intake manifold by the EGR valve for the purposes of reducing exhaust emissions.

The volume of the recirculated exhaust gas influences the mass of the intake fresh air. The more exhaust gas is recirculated, the less fresh air is taken in. It is known how much fresh air mass the engine takes in at any given operating point with EGR switched off. The reduction in the intake fresh air mass caused by the exhaust gas recirculation is therefore a measure of the volume of the recirculated exhaust gas. The system is controlled in such a way that the specified air mass flow rate for the operating situation is drawn in.

The DDE control unit calculates a target fresh air mass for each operating point from the following influencing variables:

- Engine speed
- Injected quantity
- Coolant temperature
- Atmospheric pressure
- Intake air temperature
- Reduction in the exhaust gas recirculation caused by idling for longer than 5 minutes

The DDE control unit can not precisely determine the mass flow rate of the recirculated exhaust because the hot-film air mass-flow sensor only measures the flow rate of the intake air and has a wide tolerance band for system design reasons.

The exhaust recirculation rate is controlled by operating the EGR valve relatively imprecisely even without an exhaust recirculation sensor. The oxygen sensor (upstream of the NSC) detects whether too much or too little exhaust is being recirculated. The exhaust recirculation rate is then readjusted according to the information from the oxygen sensor.

The EGR temperature sensor and the exhaust back-pressure sensor upstream of the turbocharger in conjunction with the boost pressure sensor make it possible to exactly control the exhaust recirculation rate. Therefore substantially improved control of the quantity of recirculated exhaust and, therefore, of the NOx content of the exhaust is possible.

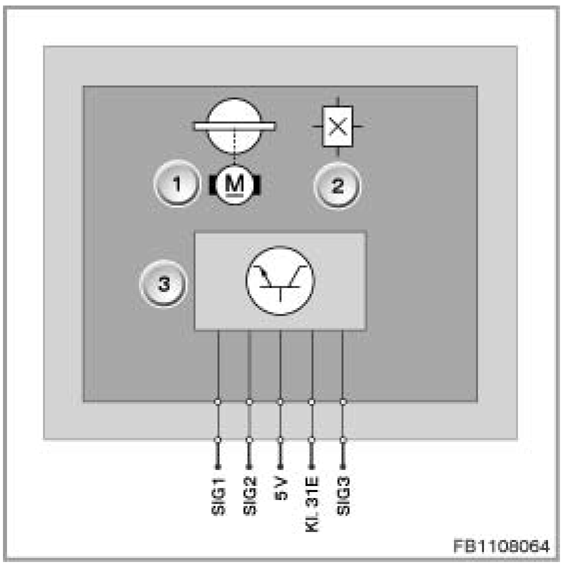
Function

The exhaust-gas recirculation actuator is opened or closed electrically by the DDE control unit. To ensure optimized control of the exhaust-gas recirculation rate, the exact position must be continuously detected. The position of the exhaust-gas recirculation actuator is monitored by a non-contact hall effect sensor.

The mean quantity adaptation (MMA) serves to adapt the exhaust-gas recirculation more precisely to tolerance in the fuel injection rates. The air ratio measured by the oxygen sensor and the air mass measured by the hot-film air-mass meter are used to determine a mean fuel injection rate across all cylinders. This value is compared with the fuel injection rate specified by the DDE control unit. If there is a deviation, the air mass is adapted to the actual fuel injection rate by adjusting the exhaust-gas recirculation actuator in such a way that the correct air ratio is set.

The mean quantity adaptation is not a rapid control operation, rather an adaptive learning procedure. That means that the fuel injection rate error is learned in an adaptive characteristic map that is stored permanently in the DDE control unit.

The servomotor for the exhaust-gas recirculation actuator is a direct current motor. The position sensor is a hall effect sensor. The hall effect sensor determines the revolutions of the servomotor. This is used to calculate the position of the exhaust-gas recirculation actuator.



N47TU Electronic EGR valve

Index	Explanation
1	Exhaust gas recirculation actuator
2	Electronic component with evaluation electronics
3	Hall effect sensor
SIG 1	Activation of EGR actuator, positive terminal
SIG 2	Activation of EGR actuator, negative terminal
5 V	Hall effect sensor voltage
Terminal 31E	Hall effect sensor ground
SIG 3	Hall effect sensor signal

Diagnosis

Observe the following nominal values for the exhaust-gas recirculation actuator:

10. Engine Control Functions

Variable	Value
Servomotor supply voltage	12 Volts
Activation frequency for servomotor	1300 hz
Servomotor blocking current	5 A
Hall effect sensor supply voltage	4.5 to 5.5 V
Hall effect sensor power consumption	20 mA
Temperature range of the Hall effect sensor and servomotor	-40 °C to 140 °C (-40 °F to 284 °F)

If the hall effect sensor fails, the following behavior is to be expected:

- Fault entry in the engine control unit
- Emergency operation with substitute value (limited engine torque)
- Check Control message

If the servomotor fails, the following behavior is to be expected:

- Fault entry in the engine control unit
- No exhaust-gas recirculation
- Check Control message

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If the exhaust-gas recirculation (EGR) valve is replaced, the adaptation of exhaust-gas recirculation actuator service function must be run in ISTA.

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For more information regarding exhaust emission systems please refer to ST1210 "Diesel Technology" training material available on TIS and ICP.

10.4. Glow system

The glow system ensures reliable cold start characteristics and smooth engine operation when the engine is cold.

The glow system comprises the following components:

- Pre-heater control unit
- New ceramic, rapid-start glow plugs
- LIN-bus and electrical lines

10. Engine Control Functions

The rapid-start glow plugs are designed for operation at a voltage of 5.3 to 7.8 V. During the glow-plug start-assist stage, there may even be a voltage equivalent to the on-board supply voltage for a short time.

The pre-heater control unit communicates with the DDE control unit via the LIN-bus.

The DDE control unit sends the request for heating output to the pre-heater control unit via the LIN-bus.

The pre-heater control unit implements the request and controls the glow plugs with a pulse-width modulated signal. Additionally, the pre-heater control unit feeds back diagnostics and status information to the DDE.

The necessary heat output is determined by the DDE control unit as a function of the following operational values:

- Coolant temperature
- On-board supply voltage

Two further operational values influence the activation and deactivation of the glow function:

- Engine speed
- Injection volume

Each one of the four glow circuits is individually compatible with diagnostics.

Pre-glow

This takes place for 0.5 seconds at a coolant temperature of below 25 °C (77 °F). As the temperature falls, the pre-glow time increases to a maximum of 2.7 seconds at coolant temperatures of below -25 °C (-13 °F).

The glow indication in the instrument cluster is only controlled at coolant temperatures of below 0 °C (32 °F).

Post-glow

To improve idling and emissions characteristics, a temperature-sensitive post-glow takes place after an engine start with the coolant temperature below 30 °C (86 °F).

Start-standby glow function

A start-standby glow function is activated for approximately 10 seconds if the engine has not started by the time the pre-glow time has elapsed and the ignition remains switched on.

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