Service

Engine

Engine Models:

KG2204 Naturally Aspirated
KG2204T Turbocharged
Liquefied Petroleum Gas (LPG)/Propane/ Natural Gas (NG) Fueled

rehlko

TP-6902 2/26c

⚠ **WARNING:** This product can expose you to chemicals, including carbon monoxide and benzene, which are known to the State of California to cause cancer and birth defects or other reproductive harm. For more information go to www.P65warnings.ca.gov

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INTRODUCTION

This manual provides operating and maintenance instructions for REHLKO Engines. Keep this manual with the equipment for future reference. Refer to the Service Manual for detailed information on adjusting and servicing the engine.

Information in this publication represents data available at the time of print. Discovery Energy, LLC and its affiliates dba Rehlko reserves the right to change this publication and the products represented without notice and without any obligation or liability whatsoever.

This engine operates on either Propane, Liquefied Petroleum Gas (LPG) or Natural Gas (NG), which are extremely flammable and explosive. Installation and repair of LPG/NG systems must be performed only by qualified LPG/NG technicians. Read this manual and carefully follow all procedures and safety precautions to ensure proper equipment operation and to avoid bodily injury.

Regular maintenance is necessary for safe and efficient operation. Inspect the engine often and perform required maintenance at prescribed intervals. Service work must be performed by appropriately skilled and suitably trained maintenance personnel who are familiar with engine diagnostics and repair.

Unless otherwise specified, all units of measurement are metric, followed by the Imperial (U.S.) equivalent.

IMPORTANT

Read all safety precautions and instructions carefully before operating or servicing equipment. Refer to operating instruction of equipment that this engine powers. Ensure engine is stopped and level before performing any maintenance or service.

For professional advice and conscientious service, please contact your nearest authorized distributor or dealer.

- Visit the company website at powersystems.rehlko.com.
- Look at the labels and decals on your product or review the appropriate literature or documents included with the product.
- Call toll free in the US and Canada 1-800-544-2444.
- Outside the US and Canada, call the nearest regional office.

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1.1 Safety Alerts

⚠ DANGER

DANGER indicates a hazardous situation which, if not avoided, will result in death or serious injury.

⚠ WARNING

WARNING indicates a hazardous situation which, if not avoided, could result in death or serious injury.

⚠ CAUTION

CAUTION indicates a hazardous situation which, if not avoided, could result in minor or moderate injury.

NOTICE

NOTICE is used to address practices not related to physical injury.

Note:

A Note is used to inform you of important installation, operation, or maintenance information.

1.2 Safety Information for this Engine

⚠ WARNING	**Carbon monoxide.** **Can cause severe nausea, fainting, or death.** Avoid inhaling exhaust fumes.
	

Engine Operation. Carbon monoxide can cause severe nausea, fainting, or death. Engine exhaust gases contain poisonous carbon monoxide. Carbon monoxide is an odorless, colorless, tasteless, nonirritating gas that can cause death if inhaled for even a short time. Avoid breathing exhaust fumes when working on or near the engine. Never operate the engine inside a building. Never operate the engine where exhaust gas could seep inside or be drawn into a potentially occupied building through windows, air intake vents, or other openings.

⚠ WARNING	**Risk of fire.** **Can cause severe injury or death.** Do not smoke or permit flames or sparks near fuels or the fuel system.
	

⚠ WARNING	**Pinch and entanglement hazards.** **Can cause severe injury and possible death.** Never check drive belt tension while the engine is running.
	

⚠ CAUTION	**Hazardous voltage.** **Electrical shock can cause injury.** Do not touch wires while the engine is running. Stop the engine and disconnect the battery leads, negative (-) lead first, before servicing the engine.
	

⚠ WARNING	**Moving parts.** **Can cause severe injury or death.** Operate the engine only when all guards and electrical enclosures are in place. Stay away from moving parts while the engine is in operation.
	

Servicing the engine when it is operating. Exposed moving parts can cause severe injury or death. Keep hands, feet, hair, clothing, and test leads away from the belts and pulleys when the engine is running. Replace guards, screens, and covers before operating the engine.

⚠ WARNING	**Hot engine and exhaust system.** **Can cause severe injury or death.** Do not work on the engine until it cools.
	

Hot engine components. Can cause severe injury or death. Never operate the engine with heat shields or guards removed.

⚠ WARNING	**Hot coolant and steam.** **Can cause severe injury or death.** Before removing the pressure cap, stop the engine and allow it to cool. Then loosen the pressure cap to relieve pressure.
	

Liquid coolant can be extremely hot from operation. Turning radiator cap when engine is hot can allow steam and scalding liquid to blow out and burn you severely. Shut off machine. Only remove radiator cap when cool enough to touch with bare hands. Slowly loosen cap to the first stop to relieve pressure before removing completely.

⚠ WARNING	**Accidental starting.** **Can cause severe injury or death.** Disconnect the battery cables before working on the engine. Remove the negative (–) lead first when disconnecting the battery. Reconnect the negative (–) lead last when reconnecting the battery.
	

Disabling the engine. Accidental starting can cause severe injury or death. Before working on the engine or connected equipment, disable the engine as follows: 1) Disconnect the ignition coil. 2) Remove the battery cables, negative (–) lead first. Reconnect the negative (–) lead last when reconnecting the battery. Follow these precautions to prevent the accidental starting of the engine.

⚠ WARNING	**Explosive fuel vapors.** **Can cause fires and severe burns.** If a gaseous odor is detected, ventilate the area and contact an authorized service technician.
	

The fuel system. Explosive fuel vapors can cause severe injury or death. Vaporized fuels are highly explosive. Use extreme care when handling and storing fuels. Store fuels in a well-ventilated area away from spark-producing equipment and out of the reach of children. Never add fuel to the tank while the engine is running because spilled fuel may ignite on contact with hot parts or from sparks. Do not smoke or permit flames or sparks to occur near sources of spilled fuel or fuel vapors. Keep the fuel lines and connections tight and in good condition. Do not replace flexible fuel lines with rigid lines. Use flexible sections to avoid fuel line breakage caused by vibration. Do not operate the engine in the presence of fuel leaks, fuel accumulation, or sparks. Repair fuel systems before resuming engine operation.

⚠ WARNING	**Handling caustic engine fluids and chemical products.** **Can cause severe chemical burns, nausea, fainting, or death.** Most chemicals such as used engine oil, antifreeze/coolant, rustproofing agent, inhibiting oil, degreasing agent, spray paint, and adhesives are hazardous to health. Read and follow the user information found on the packaging. Avoid inhalation and skin contact. Use only in well-ventilated areas and use a protective mask when spraying. Store engine fluids and chemical products in a locked cabinet. Contact your local recycling center for disposal information and locations.
	

Fire-damaged or burned O-rings may cause the formation of hydrofluoric acid. Contact with hydrofluoric acid may cause severe skin irritation and chemical burns. O-rings and other fluoroelastomer seals exposed to fire or temperatures above 316°C (600°F) (i.e., during welding) may decompose forming hydrofluoric acid. Avoid inhalation or skin contact. Do not incinerate O-rings. Dispose of O-ring waste material in a responsible manner.

⚠ WARNING	**Spring-loaded parts.** **Can cause severe personal injury or property damage.** Wear protective goggles when servicing spring-loaded parts. Hold parts securely during disassembly.
	

⚠ WARNING	**Airborne particles.** **Can cause severe injury or blindness.** Wear protective goggles and clothing when using power tools, hand tools, or compressed air.
	

⚠ WARNING	**Explosive fuel vapors.** **Can cause severe injury or death.** Use extreme care when handling, storing, and using fuels.
	

Gas fuel leaks. Explosive fuel vapors can cause severe injury or death. Fuel leakage can cause an explosion. Check the LPG vapor or natural gas fuel system for leakage by using a soap and water solution with the fuel system test pressurized to 6–8 ounces per square inch (10–14 inches water column). Do not use a soap solution containing either ammonia or chlorine because both prevent bubble formation. A successful test depends on the ability of the solution to bubble.

Used engine oil. Contact with used engine oil may cause severe skin irritation. Repeated and prolonged skin exposure may have other health risks. Used engine oil is a suspected carcinogen. Avoid contact with skin. Thoroughly wash your hands and nails with soap and water shortly after handling used engine oil. Wash or dispose of clothing or rags containing used engine oil. Dispose of used engine oil in a responsible manner. Contact your local recycling center for disposal information and locations.

⚠ CAUTION	**Damaged harmonic balancer, crankshaft, or flywheel.** **Can cause personal injury.** Broken fragments from the harmonic balancer, crankshaft, and flywheel can be thrown from the engine. Do not use a hammer to install or remove. Inspect these parts for damage and replace if needed.
	

1.3 Know Your Engine

Product identification numbers determine service parts. Record the product identification numbers in the spaces below immediately after unpacking the products so that the numbers are readily available for future reference.

Engine Identification

Record the product identification information from the engine nameplate.

Model Designation: _____

Serial Number: _____

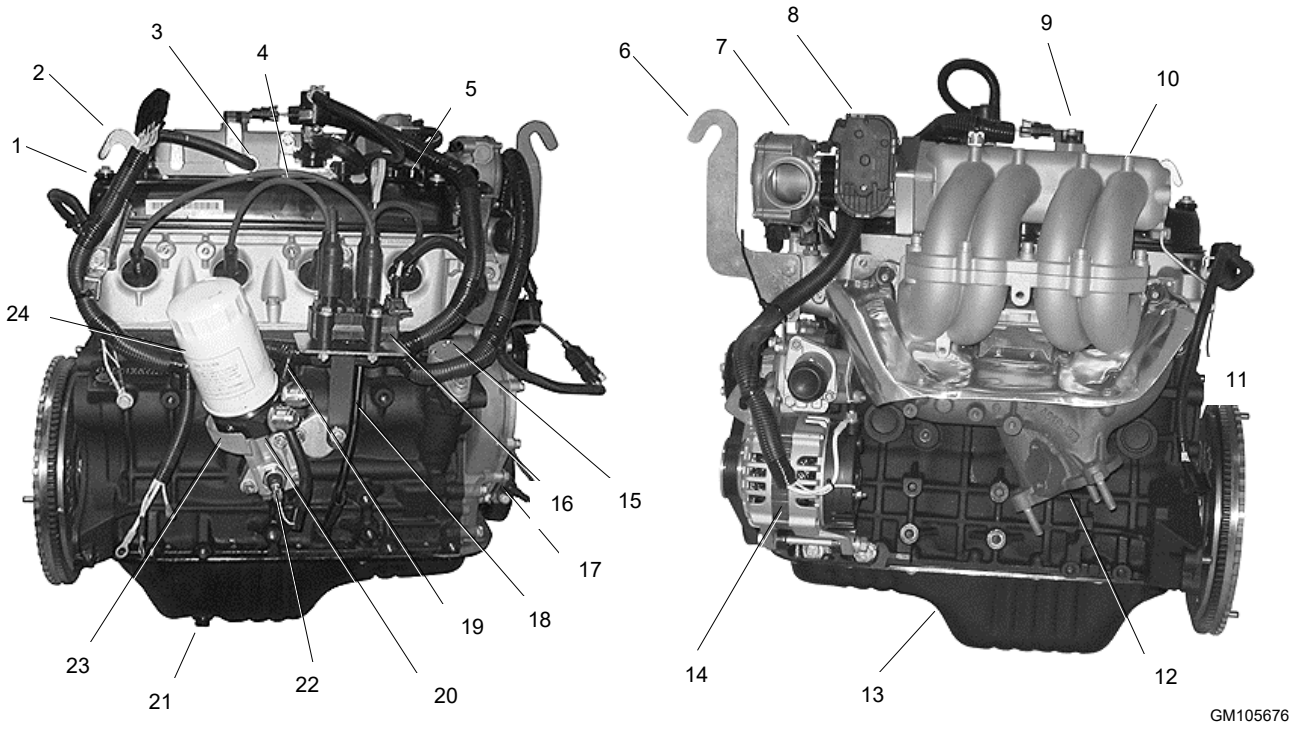
1.4 Related Literature

Literature Type	Part Number
REHLKO Models KG2204 and KG2204T Operation and Maintenance Manual	TP-6901
REHLKO Models KG2204 and KG2204T Service Manual/Troubleshooting/Diagnostics	TP-6903
REHLKO Models KG2204 and KG2204T Service Parts Manual	TP-6904

1.5 Service Parts

Contact an authorized distributor/dealer for all maintenance, service, and engine parts. To find an authorized distributor/dealer, visit powersystems.rehlko.com or call 1-800-544-2444 (U.S. and Canada).

1.6 Model KG2204 Engine Side Views

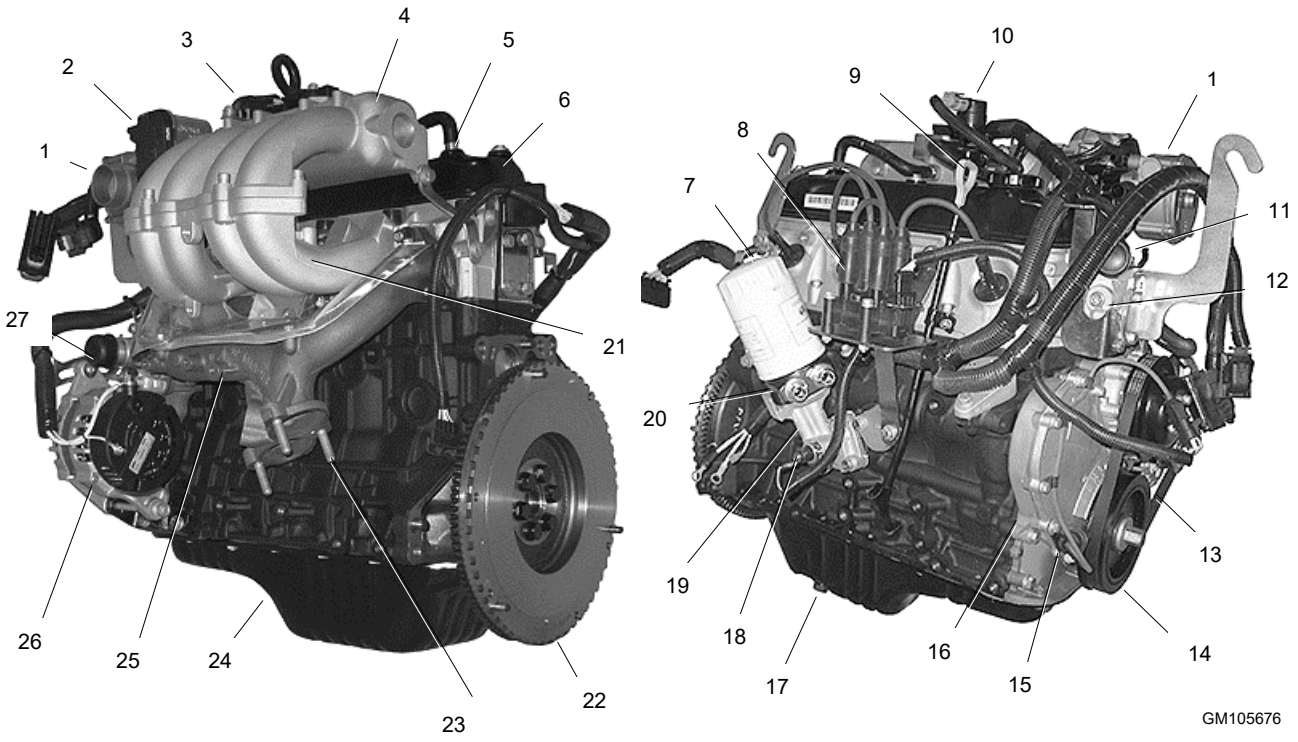


1. Rocker Arm Cover
2. Rear Hanger
3. Crankcase Breather
4. Spark Plug Wires
5. Oil Filler Cap
6. Front Hanger
7. Air-Fuel Mixer
8. Throttle Body
9. TMAP Sensor1
10. Intake Manifold
11. Flywheel
12. Exhaust Manifold
13. Oil Pan
14. Battery Charging Alternator
15. Oil Pump Drive
16. Ignition Coil
17. Crankshaft Position Sensor
18. Oil Dipstick and Tube
19. Knock Sensor (if equipped with turbocharger)
20. Oil Cooler Adapter (not included on all models)
21. Oil Pan Drain Plug
22. Oil Pressure Sender
23. Oil Filter Base
24. Oil Filter

[1]Air Temperature/Manifold Absolute Pressure (TMAP)

Figure 1 Naturally Aspirated 2.2L Engine Side Views (KG2204 Engine)

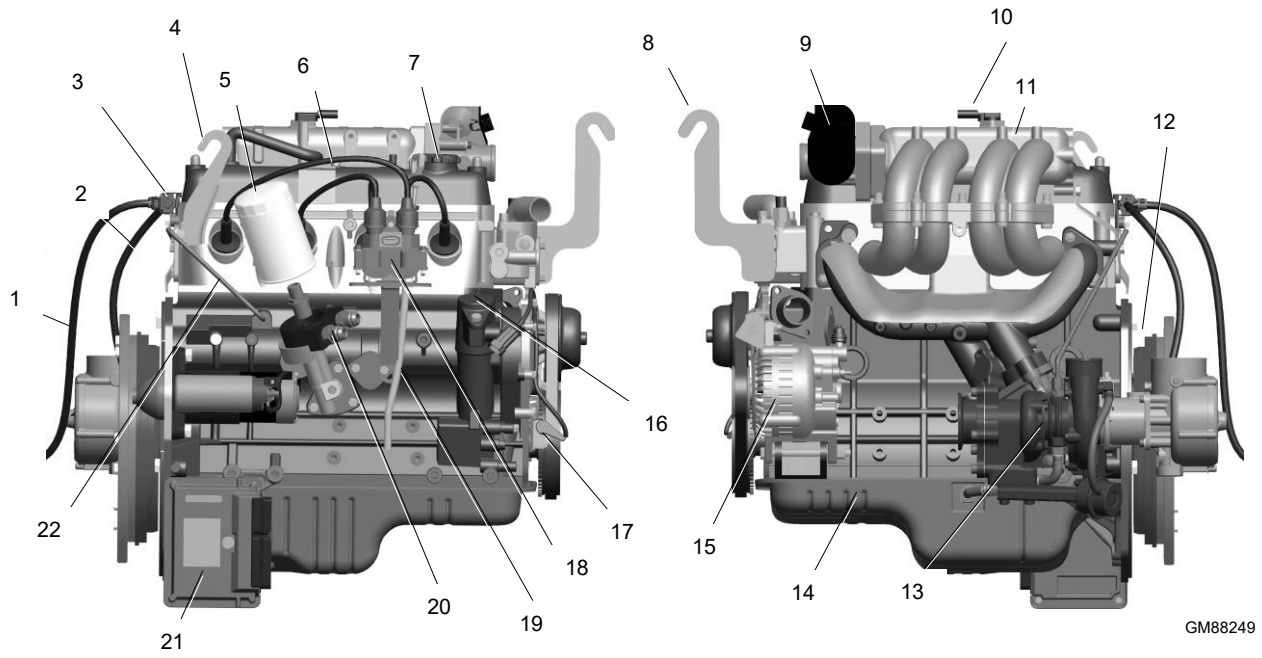
1.7 Model KG2204 Front and Rear Views



1. Air-Fuel Mixer
2. Throttle Body
3. TMAP Sensor
4. Upper Intake Manifold
5. PCV Valve
6. Rocker Arm Cover
7. Oil Filter
8. Ignition Coil
9. Oil Dipstick
10. Fuel Control Valve
11. Upper Coolant Outlet
12. Coolant Temperature Sensor
13. Drive Belt
14. Vibration Dampener
15. Crankshaft Position Sensor
16. Timing Cover
17. Oil Drain Plug
18. Oil Pressure Sensor (PGS)
19. Oil Filter Base
20. Oil Cooler Adapter (not included on all models)
21. Lower Intake Manifold
22. Flywheel
23. Exhaust Manifold Studs
24. Oil Pan
25. Exhaust Manifold
26. Battery Charging Alternator
27. Water Pump Inlet

Figure 2 Naturally Aspirated 2.2L Engine Front and Rear Views (KG2204 Engine)

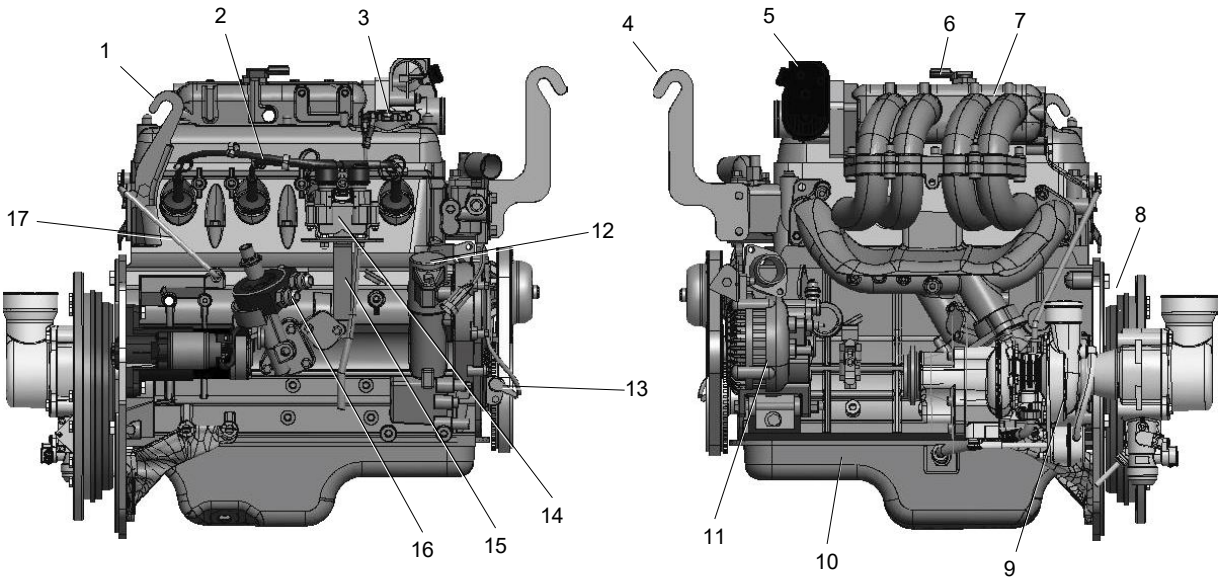
1.8 Model KG2204T Engine Side Views



1. Regulator to FCV Hose
2. FCV to Mixer Hose
3. Fuel Control Valve (FCV)
4. Rear Hanger
5. Oil Filter
6. Spark Plug Wires
7. Oil Filler Cap
8. Front Hanger
9. Throttle Body
10. TMAP Sensor[1]
11. Intake Manifold
12. Flywheel
13. Turbocharger
14. Oil Pan
15. Battery Charging Alternator
16. Oil Pump Drive
17. Crankshaft Position Sensor
18. Ignition Coil
19. Oil Dipstick and Tube
20. Oil Cooler Adapter and Stand-off
21. Engine Control Module
22. Turbo Oil Feed Line

[1] Air Temperature / Manifold Absolute Pressure (TMAP)

Figure 3 Turbocharged 2.2L Engine Side Views (KG2204T Engine)

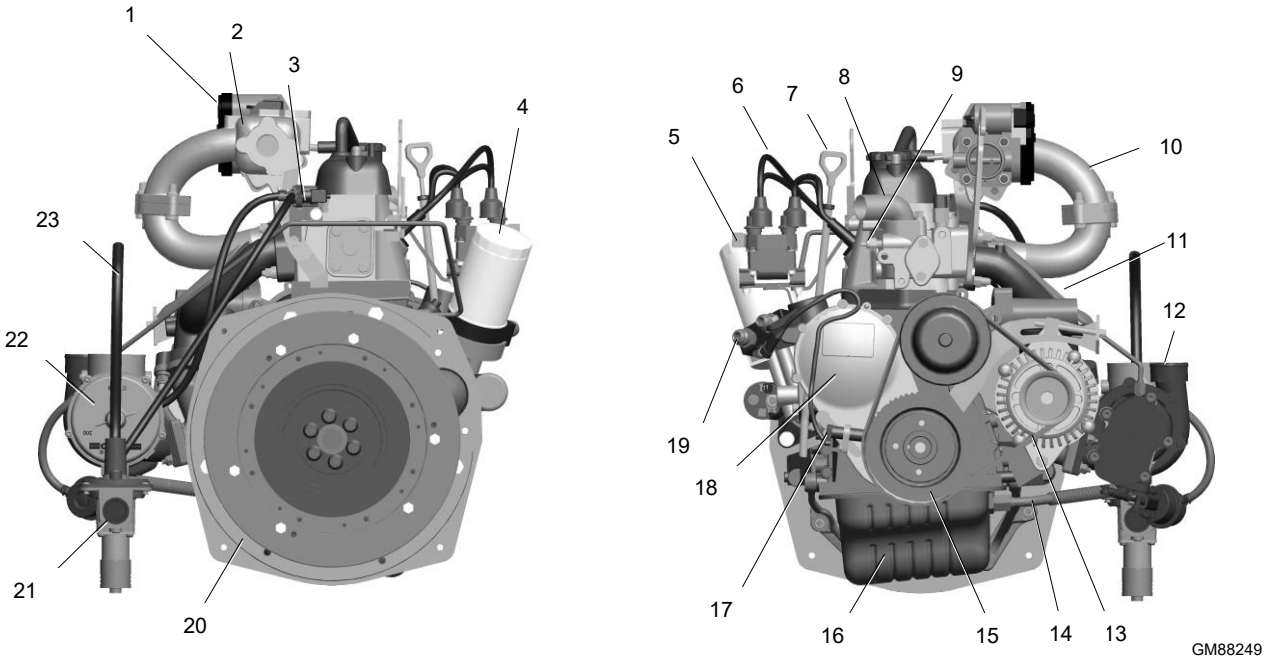


1. Rear Hanger
2. Spark Plug Wires
3. Oil Filler Cap
4. Front Hanger
5. Throttle Body
6. TMAP Sensor [1]
7. Intake Manifold
8. Flywheel
9. Turbocharger
10. Oil Pan
11. Battery Charging Alternator
12. Oil Pump Drive
13. Crankshaft Position Sensor
14. Ignition Coil
15. Oil Dipstick and Tube
16. Oil Cooler Adapter and Stand-off
17. Turbo Oil Feed Line

[1] Air Temperature / Manifold Absolute Pressure (TMAP)

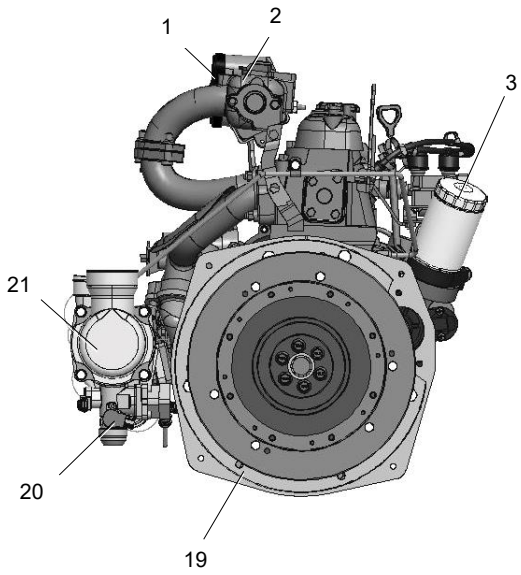
Figure 4 Turbocharged 2.2L Engine Side Views (KG02L04T Engine)

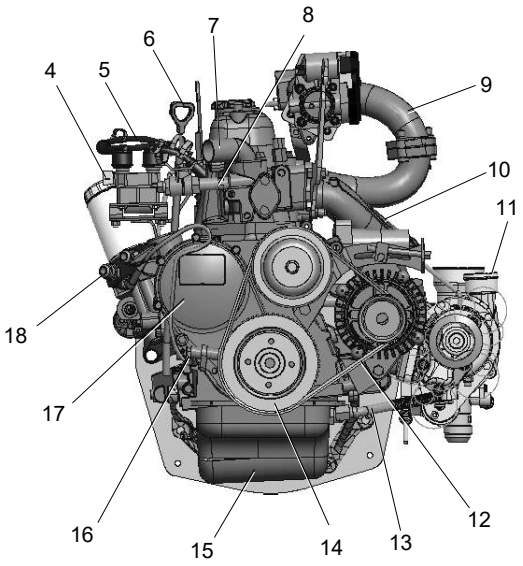
1.9 Model KG2204T Front and Rear Views



1. Throttle body
2. Upper intake manifold
3. Fuel control valve
4. Oil filter
5. Coil
6. Spark plug wires
7. Oil dipstick
8. Upper coolant outlet
9. Coolant temperature sensor
10. Lower intake manifold
11. Turbo oil feed line
12. Turbocharger
13. Drive belt
14. Turbo oil return line
15. Vibration dampener
16. Oil pan
17. Crankshaft position sensor
18. Timing cover
19. Oil pressure sensor
20. Flywheel
21. Dual fuel regulator (DFR)
22. Air-fuel mixer
23. DFR breather hose

Figure 5 Turbocharged 2.2L Engine Front and Rear Views (KG2204T Engine)





1. Throttle body
2. Upper intake manifold
3. Oil filter
4. Coil
5. Spark plug wires
6. Oil dipstick
7. Upper coolant outlet
8. Coolant temperature sensor
9. Lower intake manifold
10. Turbo oil feed line
11. Turbocharger
12. Drive belt
13. Turbo oil return line
14. Vibration dampener
15. Oil pan
16. Crankshaft position sensor
17. Timing cover
18. Oil pressure sensor
19. Flywheel
20. Dual fuel regulator (DFR)
21. Air-fuel mixer

Figure 6 Turbocharged 2.2L Engine Front and Rear Views (KG02L04T Engine)

2.1 Engine Specifications

Item	Specifications	
Engine Model	KG2204	KG2204T
Block Type	I-4	
Number of Cylinders	4	
Cylinder Bore	91 mm (3.5 in.)	
Piston Stroke	86 mm (3.4 in.)	
Displacement	2.2 L (134.25 $in.^3$)	
Rated Output @ 1800 rpm	30 kW (40 HP)	47.8 kW (64.1 hp)
Fuel Type	Propane, Liquid Petroleum Gas (LPG) or Natural Gas (NG).	
Oil Type/Weight	REHLKO synthetic engine oil, SAE Class or higher. Weight: Variable per ambient temperature. See “Fluid Specifications”	
Oil Dry Fill Capacity	4.2 L (4.4 qt.)	
Rotating Direction of Crankshaft	Counterclockwise (face to flywheel)	
Compression Ratio	10.5:1	
Cylinder Fire Order	1-3-4-2	
Lubricating Style	Pressurized	
Starting Style	Electric	
Net Weight (Dry)	145 kg (320 lb.)	
Overall Dimensions	826 mm x 547 mm x 647 mm (32.5 in. x 21.5 in. x 25.5 in.)	
Aspiration	Natural	Turbocharged
Charge Air Cooler	NA	Aluminum core

2.2 Specifications of Main Components

Item	Specifications	
	KG2204	KG2204T
Oil Filter/Breather	Paper, Rocker Arm Covers, Top Oil Filter	
Oil Pump	Rotor type	
Water Pump	Centrifugal type; no fan	
Flywheel	Flywheel with attachment provisions for flywheel adapter (REHLKO part number GM88832)	
Thermostat Settings	Valve open at 76°C (169°F) Valve lift fully open at 88°C (190°F)	
Alternator	Rated voltage 14 V, rated current 90 A	
Electric Starter	1.2 kW, speed reduction type	
Ignition System	Electronic	
Spark Plug	GM92785 Screw thread M14 x 1.25	GM100158 (use only genuine Rehlko service parts)

2.3 Adjustment Specifications

Item	Specifications	
	KG2204	KG2204T
Spark Plug Gap	0.9–1.0 mm (0.036–0.040 in.)	0.7–0.8 mm (0.028–0.031 in.)
Drive Belt Tension at pressure of 98 N (22 lb)	Deflection of a new belt is 5–7 mm (0.20–0.28 in.) Deflection of a used belt is 7–8 mm (0.28–0.31 in.)	
Fuel Pressure Regulator	Nonadjustable, LPG or NG selectable	
Throttle	Nonadjustable, ECM controlled	
Air–Fuel Mixer	Tamper-proof; nonadjustable	
Fuel Control Valve	Nonadjustable	

2.4 Fluid Specifications

2.4.1 Oil Recommendations

Note:

- *Do not mix different brands or types of oil.*
- *Do not overfill or underfill the engine's lubrication system. See "Engine Specifications."*

Use oil that displays the American Petroleum Institute (API) Starbrust certification mark for "Gasoline Engine" on the container. Do not use straight-weight oils recommended for industrial or stationary engines. CC or CD classification oils, even when labeled "Heavy Duty" or For Natural Gas Engines are not acceptable.

Synthetic oil is recommended for use in LPG/NG fueled engines. We recommend the use of REHLKO engine oils for best performance.

In colder climates such as the United States and Canada, use SAE-30. For warmer climates, select oil viscosity based on the ambient air temperature at the time of operation. See Figure 7.

Ambient Temperature	Engine Oil Type
-18°C (0°F) and above	SAE 10W-30
Below -18°C (0°F)	SAE 5W-30

Figure 7 Engine Oil Selection

2.4.2 Grease Recommendations

The alternator and starter bearings on this engine must be lubricated with high-quality lithium-based automotive grease.

2.4.3 Coolant Recommendations

Use only a mixture of 50% long life coolant and 50% clean, softened water to inhibit rust/corrosion and prevent freezing.

A solution of 50% long life coolant provides freezing protection to –37°C (–34°F) and overheating protections to 149°C (300°F). A coolant solution with less than 50% long life coolant may not provide adequate freezing and overheating protection. Do not mix long life coolants and conventional coolants. **Do not mix different types and/or colors of long life coolants.**

Note:
Fuel system components are not adjustable and cannot be serviced. Contact your authorized REHLKO authorized distributor/dealer for replacements.

2.5 Standard Torque Specifications

American Standard Fasteners Torque Specifications										
Size	Assembled into Cast Iron or Steel									Assembled into Aluminum
	Grade 2			Grade 5			Grade 8			
8-32	2.0	Nm	(18 in. lb.)	3.1	Nm	(27 in. lb.)	-			See Note 3
10-24	3.2	Nm	(28 in. lb.)	4.9	Nm	(43 in. lb.)	-			
10-32	3.6	Nm	(32 in. lb.)	5.5	Nm	(49 in. lb.)	-			
12-24	5.0	Nm	(44 in. lb.)	7.7	Nm	(68 in. lb.)	-			
1/4-20	7.6	Nm	(67 in. lb.)	11.6	Nm	(103 in. lb.)	16.5	Nm	(146 in. lb.)	
1/4-28	8.6	Nm	(76 in. lb.)	13.2	Nm	(117 in. lb.)	18.8	Nm	(166 in. lb.)	
5/16-18	15.5	Nm	(137 in. lb.)	24.0	Nm	(212 in. lb.)	33.9	Nm	(300 in. lb.)	
5/16-24	17.1	Nm	(151 in. lb.)	26.4	Nm	(234 in. lb.)	40	Nm	(28 ft. lb.)	
3/8-16	27	Nm	(243 in. lb.)	42	Nm	(31 ft. lb.)	60	Nm	(44 ft. lb.)	
3/8-24	31	Nm	(274 in. lb.)	47	Nm	(35 ft. lb.)	68	Nm	(50 ft. lb.)	
7/16-14	43	Nm	(32 ft. lb.)	68	Nm	(50 ft. lb.)	96	Nm	(71 ft. lb.)	
7/16-20	49	Nm	(36 ft. lb.)	76	Nm	(56 ft. lb.)	107	Nm	(79 ft. lb.)	
1/2-13	66	Nm	(49 ft. lb.)	103	Nm	(76 ft. lb.)	146	Nm	(108 ft. lb.)	
1/2-20	75	Nm	(55 ft. lb.)	117	Nm	(86 ft. lb.)	164	Nm	(121 ft. lb.)	
9/16-12	96	Nm	(71 ft. lb.)	149	Nm	(110 ft. lb.)	210	Nm	(155 ft. lb.)	
9/16-18	107	Nm	(79 ft. lb.)	165	Nm	(122 ft. lb.)	235	Nm	(173 ft. lb.)	
5/8-11	133	Nm	(98 ft. lb.)	206	Nm	(152 ft. lb.)	290	Nm	(214 ft. lb.)	
5/8-18	150	Nm	(111 ft. lb.)	232	Nm	(171 ft. lb.)	328	Nm	(242 ft. lb.)	
3/4-10	-			365	Nm	(269 ft. lb.)	515	Nm	(380 ft. lb.)	
3/4-16	-			405	Nm	(299 ft. lb.)	572	Nm	(422 ft. lb.)	
1-8	-			881	Nm	(650 ft. lb.)	1245	Nm	(918 ft. lb.)	
1-12	-			961	Nm	(709 ft. lb.)	1357	Nm	(1001 ft. lb.)	

Metric Fasteners Torque Specifications, Measured in Nm (ft. lb.)									
Size (mm)	Assemblies into Cast Iron or Steel								Assembled into Aluminum
	Grade 5.8		Grade 8.8		Grade 10.9		Grade 12.9		
Mxxx-04xxx-xx	1.9	(1.4)	2.9	(2.1)	4.3	(3.2)	4.3	(3.2)	See Note 3
Mxxx-05xxx-xx	3.8	(2.8)	5.8	(4.3)	8.5	(6.3)	8.5	(6.3)	
Mxxx-06xxx-xx	6.5	(4.8)	10.4	(7.7)	14.7	(11)	17.6	(13)	
Mxxx-08xxx-xx	16	(12)	25	(17)	36	(26)	43	(31)	
Mxxx-08xxx-xxF	17	(13)	27	(20)	38	(28)	46	(34)	
Mxxx-10xxx-xx	31	(23)	50	(37)	70	(52)	85	(62)	
Mxxx-10xxx-xxF	33	(24)	53	(39)	74	(55)	89	(66)	
Mxxx-12xxx-xx	55	(40)	87	(64)	123	(91)	147	(109)	
Mxxx-12xxx-xxF	60	(44)	95	(70)	134	(99)	161	(119)	
Mxxx-14xxx-xx	87	(64)	135	(103)	196	(145)	236	(174)	
Mxxx-14xxx-xxF	94	(69)	151	(111)	212	(156)	254	(188)	
Mxxx-16xxx-xx	135	(100)	217	(160)	305	(225)	365	(270)	
Mxxx-16xxx-xxF	145	(107)	231	(171)	325	(240)	390	(288)	
Mxxx-18xxx-xx	187	(138)	299	(221)	421	(310)	505	(373)	
Mxxx-18xxx-xxF	210	(155)	336	(248)	473	(349)	567	(419)	
Mxxx-20xxx-xx	264	(195)	423	(312)	595	(439)	714	(526)	
Mxxx-20xxx-xxF	293	(216)	469	(346)	660	(487)	792	(584)	
Mxxx-22xxx-xx	360	(266)	576	(425)	811	(598)	973	(718)	
Mxxx-22xxx-xxF	396	(292)	633	(467)	890	(657)	1068	(788)	
Mxxx-24xxx-xx	457	(337)	731	(539)	1028	(758)	1233	(910)	
Mxxx-24xxx-xxF	498	(367)	797	(588)	1121	(827)	1345	(992)	
Mxxx-27xxx-xx	-		1072	(790)	1507	(1112)	1809	(1334)	
Mxxx-27xxx-xxF	-		1156	(853)	1626	(1199)	1952	(1439)	
Mxxx-30xxx-xx	-		1453	(1072)	2043	(1507)	2452	(1809)	

Notes:

1. The torque values above are general guidelines. Always use the torque values specified in the service manuals and/or assembly drawings when they differ from the above torque values.
2. The torque values above are based on new plated threads. Increase torque values by 15% if non-plated threads are used.
3. At minimum, hardware threaded into aluminum must have two diameters of thread engagement. Hardware threaded into steel and cast iron must have 1.25 diameters of thread.
4. Torque values are calculated as equivalent stress loading on American hardware with an approximate preload of 75% of proof strength and a friction coefficient of 0.2.

3.1 Introduction

These four-stroke internal combustion engines are certified to operate on either Propane, Liquid Petroleum Gas (LPG) or Natural Gas (NG). System configuration is factory preset for NG. Instructions for switching to LPG are provided within this section.

The fuel system on this engine is a closed loop design. As the engine runs, sensors located at various points within the system provide continuous operating feedback to the Engine Control Module (ECM). The ECM adjusts the engine speed, ignition timing, and fuel supply in response to changes in the applied load, surrounding air temperature, operating temperature of the engine, and amount of oxygen present in the exhaust.

Refer to the equipment Operation Manual for specific information on how fault codes are displayed.

3.2 Repair Specifications

Item	Specification
Compression Pressure	Standard 1379 kPa (200 psi) Limit 1241 kPa (180 psi)
Thermostat Specifications	Start to Open 76°C (169°F). Fully Open 88°C (190°F)
Ignition Wire Resistance	25k Ohms (Maximum)
Drive Belt Tension	Applied Test Pressure 98 N (22 lbf.) Belt Deflection - New 5–7 mm (0.20–0.28 in.) Belt Deflection - Used 7–8 mm (0.28–0.31 in.)
Spark Plug Gap	KG2204: 0.9–1.0 mm (0.036–0.040 in.) KG2204T: 0.7–0.8 mm (0.028–0.031 in.)
Intake Manifold Distortion Limit	0.40 mm (0.0157 in.)
Exhaust Manifold Distortion Limit	0.40 mm (0.0157 in.)
Cylinder Head Warpage—Maximum	Combustion Chamber Surface 0.15 mm (0.0059 in.) Intake/Exhaust Manifold Surface 0.10 mm (0.0039 in.)
Cylinder Block Warpage—Maximum	0.05 mm (0.0019 in.)
Rocker Arm Specifications	Rocker Arm—Inside Diameter (Bore) 18.500–18.513 mm (0.7283–0.7288 in.) Rocker Arm Shaft—Outside Diameter 18.467–18.482 mm (0.7270–0.7276 in.) Rocker Arm—Standard Oil Clearance 0.018–0.046 mm (0.0007–0.0018 in.) Rocker Arm—Maximum Oil Clearance 0.08 mm (0.0031 in.)
Valve Specifications	Valve Guide Bushing—Inside Diameter 8.010–8.030 mm (0.3153–0.3161 in.) Intake Valve—Valve Stem Diameter 7.970–7.985 mm (0.3137–0.3143 in.) Exhaust Valve—Valve Stem Diameter 7.965–7.98 mm (0.3135–0.3141 in.) Intake Valve—Standard Oil Clearance 0.025–0.060 mm (0.0009–0.0023 in.) Exhaust Valve—Standard Oil Clearance 0.030–0.065 mm (0.0011–0.0025 in.) Intake Valve—Maximum Oil Clearance 0.10 mm (0.0039 in.) Exhaust Valve—Maximum Oil Clearance 0.12 mm (0.0047 in.)

Item	Specification
Valve Margin Specifications	Intake Valve—Standard Margin Thickness 1.0–1.4 mm (0.0393–0.0551 in.) Exhaust Valve—Standard Margin Thickness 1.3–1.7 mm (0.0511–0.0669 in.) Intake Valve—Minimum Margin Thickness 0.5 mm (0.0196 in.) Exhaust Valve—Minimum Margin Thickness 0.8 mm (0.0314 in.)
Valve Specifications	Intake Valve—Standard Overall Length 108.2 mm (4.2598 in.) Exhaust Valve—Standard Overall Length 108.5 mm (4.2716 in.) Intake Valve—Minimum Overall Length 107.7 mm (4.2401 in.) Exhaust Valve—Minimum Overall Length 108.0 mm (4.2519 in.)
Valve Seat—Contact Width	1.2–1.6 mm (0.0472–0.0629 in.)
Intake And Exhaust Valve Face Angle	44.5° Angle
Valve Spring—Free Length	46.75–47.25 mm (1.8208–1.8602 in.)
Valve Spring—Squareness Limit	<2.0 mm (0.0787 in.)
Valve Spring Specifications	Valve Spring—Installed Height 40.6 mm (1.5984 in.) Valve Spring—Tension 282–345 N (63.4–77.56 lbf.)
Pushrod—Maximum Runout	0.30 mm (0.0118 in.)
Valve Guide Specifications	Valve Guide Bore—Standard Valve Guide 13.000–13.027 mm (0.5118–0.5129 in.) Valve Guide Bore—Resize Dimensions 13.050–13.077 mm (0.5138–0.5148 in.) Valve Guide Bore—Oversize Valve Guide 13.050–13.077 mm (0.5129–0.5138 in.) Valve Guide Bore—Maximum Valve Guide Bore Size 13.077 mm (0.5129 in.)
Valve Guide—Installed Height	20.31 mm (0.080 in.)
Lifter Bore Inside Diameter	21.412–21.443 mm (0.843–0.844 in.)
Valve Lifter Outside Diameter	21.387–21.400 mm (0.8420–0.8425 in.)
Lifter Bore Oil Clearance	Standard 0.012–0.056 mm (0.0004–0.0022 in.) Maximum 0.10 mm (0.0039 in.)
Timing Chain Slack	Applied Test Pressure 98 N (72 lbf.) Maximum Chain Slack 13.5 mm (0.531 in.)
Tensioner Thickness	Standard Thickness 15.0 mm (0.59 in.) Minimum Thickness 12.5 mm (0.49 in.)
Damper Thickness	Standard Thickness 6.6 mm (0.259 in.) Minimum Thickness 5 mm (0.196 in.)
Sprocket Diameter (With Chain)	Crankshaft Chain Sprocket 59 mm (2.32 in.) Camshaft Chain Sprocket 114 mm (4.48 in.)
Chain Elongation—Maximum	Test Tension 49 N (36 lbf.) Chain Length 291.4 mm (11.47 in.)
Camshaft Runout—Maximum	0.06 mm (0.0023 in.)

Item	Specification
Camshaft Lobe Height	Standard Intake 38.620–38.720 mm (1.5205–1.5244 in.) Exhaust 38.629– 38.729 mm (1.5208–1.5248 in.) Minimum Intake 38.26 mm (1.5062 in.) Exhaust 38.27 mm (1.5066 in.)
Camshaft Journal Diameter	Standard (from the front side) No. 1 46.459–46.475 mm (1.8291–1.8297 in.) No. 2 46.209–46.225 mm (1.8192–1.8199 in.) No. 3 45.959–45.975 mm (1.8094–1.8100 in.) No. 4 45.709–45.725 mm (1.7996–1.8002 in.) No. 5 45.459–45.475 mm (1.7897–1.7904 in.)
Camshaft Thrust Plate Clearance	Standard 0.07–0.22 mm (0.00270–0086 in.) Maximum 0.30 mm (0.0118 in.)
Camshaft Bearing Bore Specifications	Standard (from the front of the cylinder block) No. 1 46.500–46.540 mm (1.8307–1.8323 in.) No. 2 46.250–46.290 mm (1.8209–1.8224 in.) No. 3 46.000–46.040 mm (1.8110–1.8126 in.) No. 4 45.750–45.790 mm (1.8012–1.8028 in.) No. 5 45.500–45.540 mm (1.7913–1.7929 in.)
Camshaft Bearing Clearances	Standard 0.025–0.081 mm (0.0010–0.0032 in.) Maximum 0.10 mm (0.0039 in.)
Oil Pump Driven Rotor-to-Pump Body Clearance	Standard 0.1–0.15 mm (0.0039–0.0059 in.) Limit 0.2 mm (0.008 in.)
Oil Pump Rotor Side Clearance	Standard 0.03–0.07 mm (0.0012–0.0028 in.) Limit 0.15 mm (0.0059 in.)
Oil Pump Rotor Tip Clearance	Standard 0.07–0.12 mm (0.0028–0.0047 in.) Limit 0.2 mm (0.008 in.)
Connecting Rod Thrust Clearance	Standard 0.160–0.312 mm (0.006–0.012 in.) Maximum 0.35 mm (0.013 in.)
Crankshaft Thrust Clearance	Standard 0.020–0.220 mm (0.0007–0.0086 in.) Maximum 0.30 mm (0.011 in.)
Crankshaft Thrust Washer Thickness	2.044–2.490 mm (0.0804–0.0806 in.)
Crankshaft Main Journal Oil Clearance	Standard 0.020–0.051mm (0.0007–0.0020 in.) Maximum 0.10 mm (0.039 in.)
Connecting Rod Journal Oil Clearance	Standard Clearance 0.020–0.051 mm (0.0007–0.002 in.) Maximum Clearance 0.10 mm (0.0039 in.)
Connecting Rod Bend—Maximum	0.05 mm per 100 mm (0.0019 in. per 3.93 in.)

Item	Specification
Connecting Rod Twist—Maximum	0.05 mm per 100 mm (0.0019 in. per 3.93 in.)
Piston Ring-to-Piston Ring Land Clearance	0.030–0.070 mm (0.0011–0.0027 in.)
Piston Ring End Gap	Standard No. 1 0.22–0.51 mm (0.0086–0.020 in.) No. 2 0.15–0.47 mm (0.0059–0.018 in.) Oil (Side rail) 0.20–0.70 mm (0.0078-0.0027 in.) Maximum No. 1 1.11 mm (0.043 in.) No. 2 1.07 mm (0.042 in.) Oil (Side rail) 1.10 mm (0.043 in.)
Piston Pin Specifications	Piston Pin Bore—Diameter 22.010–22.016 mm (0.8665–0.08667 in.) Piston Pin—Diameter 22.003–22.006 mm (0.8662–0.8664 in.) Piston Pin Oil Clearance 0.004–0.013 mm (0.0002–0.0005 in.)
Piston Specifications—Diameter	Standard Group 1 90.938–90.948 mm (3.5802–3.5806 in.) Group 2 90.948–90.958 mm (3.5806–3.5810 in.) Group 3 90.958–90.968 mm (3.5810–3.5814 in.) Oversize Piston 91.425–91.955 mm (3.599–3.620 in.) Cylinder Bore-to-Piston—Clearance 0.065–0.085 mm (0.0025–0.0033 in.)
Main Journal And Crank Pin Diameter	Main Journal Diameter 57.985–58.000 mm (2.282–2.283 in.) Crank Pin Diameter 47.985–48.000 mm (1.8891–1.8897 in.)
Main Journal And Crank Pin Taper And Runout—Maximum	0.02 mm (0.0007 in.)
Crankshaft Circle Runout—Maximum	0.06 mm (0.0023 in.)
Cylinder Deck Warpage—Maximum	0.05 mm (0.002 in)
Standard Cylinder Bore Diameter	Standard Group 1 91.000–91.010 mm (3.5820–3.5830 in.) Group 2 91.010–91.020 mm (3.5830–3.5834 in.) Group 3 91.020–91.030 mm (3.5834–3.5838 in.) Maximum Diameter 91.23 mm (3.591 in.) Oversize Cylinder Bore Diameter +0.50 mm Piston Diameter
Oversize Cylinder Bore Diameter	+0.50 mm Piston Diameter 91.50–92.24 mm (3.602–3.631 in.) Maximum Diameter 92.24 mm (3.631 in.)

3.3 Repair torque Specifications

Item	Nm	ft.lb.
Water Pump Bolt And Nut	18	13.3
Spark Plugs KG2204 KG2204T	 18 25	 13.3 18.4
Intake Manifold Flange Nut	20	15
Exhaust Manifold Flange Nut	20	15
Flywheel Bolt	85	63
Crankshaft Vibration Dampener Bolt	160	118
Rear Crankshaft Seal Retainer Bolt	12	9
Oil Pan Bolt And Nut	13	10
Oil Drain Plug	20-25	15-18
Oil Pump Drive Bolt	13	10
Cylinder Head Bolt M12 Bolts (10 Used) M8 Bolts (3 Used)	 88–98 19–25	 64.90–72.28 14.01–18.44
Rocker Arm Shaft Bolts	25–32	18.5–23.6
Camshaft Sprocket Bolt	90	66
Camshaft Thrust Plate Bolt	18	13
Camshaft Timing Gear Bolt	91	67
Chain Tensioner Bolt	18	13
Chain Damper Bolt	18	13
Timing Cover Bolt	18	13
Oil Pump Cover Bolt	8	5.8
Connecting Rod Cap	49	36
Main Bearing Cap Bolt	79	58
Turbocharger Exhaust Flange Adapter Stud Exhaust Flange Adapter to Turbo Nut Ex. Flange Adapter to Ex. Manifold Nut	 20 ± 3 28 ± 3 70 ± 5	 15 ± 2 21 ± 2 52 ± 3
Oil Drain Line Fitting to Oil Sump Fitting Oil Drain Line to Turbo Bearing Housing	62 ± 3 10 ± 1	46 ± 2 7 ± 1
Oil Feed Line Fitting to Turbo Bearing Housing	16 ± 1	12 ± 1

3.4 Troubleshooting

Problem	Possible Cause	Solution
Will Not Start	No fuel	Check fuel supply.
	Incorrect fuel	Make sure fuel system is configured properly for LPG or NG supply.
	Dirty/restricted fuel system	Check fuel system and clean components as needed.
	Incorrect oil level	Check engine oil level; add as needed.
	Engine overloaded	Disconnect or reduce loads.
	Faulty spark plug	Inspect, adjust, or replace as needed.
Black smoke from exhaust	Clogged air filter	Replace air filter.
	Overloaded engine	Reduce engine load.
	Idle low	Increase idle speed. Replace rings.
	Bad valve seal	Replace valve seals..
White smoke from exhaust	Worn or stuck rings	Replace rings and/or rebuild engine.
	Worn out cylinders	Rebore cylinders/rebuild engine.
	Defective thermostat	Check and/or replace thermostat.
Oil pressure too low	Bearing shells of bearing cap—piston rod—rocker worn out.	Replace defective parts and/or rebuild engine.
	Low oil level	Add oil to crankcase as needed.
	Defective oil pressure gauge or sending unit.	Replace oil pressure gauge and/or oil pressure sending unit
	Excessively diluted oil	Change oil and filter with correct viscosity oil.
Excessive oil consumption	Worn out or stuck rings	Replace rings.
	Worn out cylinders	Rebore/rebuild engine
	Worn out valve guides Replace valve	Replace valve guides, Refurbish cylinder heads.
	Bad valve seals	Replace valve seals
	Bearing shells of bearing cap—piston rod—rocker worn out	Replace defective parts and/or rebuild engine.
	Cylinder head gasket damage	Replace cylinder head gasket.
	High oil level	Drain excess oil from oil pan.
	Low idle	Adjust idle.
Engine overheats	Insufficient engine coolant	Add engine coolant.
	Defective fan, radiator, radiator cap, and/or thermostat	Inspect and/or replace defective parts.
	Defective or worn water pump	Replace water pump.
	Accessory drive belt loose or worn	Replace or adjust accessory drive belt.
	Heat exchange surface of the radiator blocked/clogged	Properly clean radiator.
	Cylinder head gasket damaged	Replace cylinder head gasket.
High noise level	Excessive valve clearances	Adjust valve clearances.
	Bearing shells of bearing caps—piston rod—rocker worn out	Replace defective parts and/or rebuild engine.
	Cylinder head gasket damage	Replace cylinder head gasket.

Turbo engine-specific potential problems

Knocks or Pings	Boost pressure too high	Check for stuck wastegate, check for leak in wastegate boost line.
	Excessive intake manifold temperature	Check charge air cooler for debris and clean as needed.
	Cylinder head gasket damage	Replace cylinder head gasket.
Lacks power	Air induction system leak	Inspect air induction system.
	Damaged turbocharger	Inspect turbocharger compressor and turbine blades for damage and/or contact against housing.
Erratic operation	Air induction system leak	Inspect air induction system

3.5 Test and Adjustments

3.5.1 Cylinder Compression Test

Note:
If output reduction, excessive oil consumption, or extremely bad fuel consumption is observed, measure the cylinder compression pressure.

1. Run the engine until it is warm, and then turn the engine off.

Standard coolant temperature
80°C (176°F) or more

2. Remove all spark plugs from cylinder head.
3. Disconnect electrical connections at coil pack.
4. Compression test measurement:

NOTICE
Run the starter motor to discharge foreign matters from cylinders before the compression pressure measurement. Always use a fully charged battery to keep the engine speed at 250 rpm or above.

   a. Insert the compression gauge into the spark plug hole.
   b. Use the diagnostic software to fully open the throttle.
   c. Crank the engine over by using the starter motor and measure the compression pressure.

Compression pressure	
Standard	1379 kPa (200 psi)
Limit	1241 kPa (180 psi)

   d. Repeat steps 1 through 3 (above) for all cylinders and inspect the pressure differences.
   e. If the compression pressure is below the limit (See “Repair Specifications”) or if the compression pressure in any cylinder is deviated beyond the pressure difference limit, add a small amount of engine oil through the spark plug hole, and repeat steps 1 through 3.
      i. If the pressure rises after the addition of engine oil, the piston rings and/or cylinder bore may be worn or damaged.
      ii. If the pressure is still low after the addition of engine oil, a valve seizure, valve contact defect, or pressure leak from the gasket may be the reason.
   f. Connect electrical connectors at coil pack.
   g. Install spark plugs to cylinder head.

3.6 Engine Disassembly and Assembly

3.6.1 Engine Disassembly

The following sequence is suggested when a complete disassembly for overhaul is required. Refer to the appropriate section for removal, inspection and repair of the individual engine components.

Procedure	Reference
Drain coolant and oil.	See “Engine Specifications” for capacities.
Mount engine on an appropriate repair stand.	See “Engine Specifications” for weight of engine.
Remove drive belt and alternator.	See “Drive Belt Removal and Installation” and See “Alternator Removal and Installation”.
Remove thermostat and water pump.	See “Thermostat Removal and Installation” and “Water Pump Removal and Installation”.
Remove spark plugs and spark plug tubes.	See “Spark Plug Removal and Installation” and “Remove and Install Spark Plug Tubes”.
Remove ignition wire harness, ignition coil and ignition coil mounting bracket.	See “Ignition Wire Removal and Installation”, “Ignition Coil Removal and Installation” and “Ignition Coil Mounting Bracket Removal and Installation”.
Remove the air-fuel mixer and throttle body.	See “Air-Fuel Mixer and Throttle Body Removal and Installation”.
Remove turbocharger (KG2204T engine only).	See “Turbocharger Removal and Replacement (KG2204T only)”.
Remove upper and lower intake manifold.	See “Upper Intake Manifold Removal and Installation” and “Intake Manifold Removal and Installation”.
Remove exhaust manifold.	See “Exhaust Manifold Removal and Installation”.
Remove flywheel.	See “Remove and Install Flywheel”.
Remove vibration dampener.	See “Remove and Install Crankshaft Vibration Dampener”.
Remove crankshaft position sensor.	See “Remove and Install Crankshaft Position Sensor”.
Remove front and rear crankshaft seals.	See “Remove and Install Front Crankshaft Seal” and “Remove and Install Rear Crankshaft Seal”.
Remove rocker arm cover.	See “Remove and Install Rocker Arm Cover”.
Remove oil pump drive, oil filter and oil filter base.	See “Oil Pump Drive Removal and Installation”, “Oil Filter Removal and Installation” and “Oil Filter Base Removal and Installation”.
Remove rocker arm assembly and push rods.	See “Rocker Arm Assembly—Removal and Installation”.
Remove cylinder head.	See “Cylinder Head Removal and Installation”.
Disassemble cylinder head.	See “Valves—Removal and Installation” and “Valve Guides—Removal and Installation”.
Remove camshaft and related components.	See appropriate procedure in “Cylinder Block”: • Remove valve lifters. • Remove timing chain cover. • Remove timing chain tensioner and dampener. • Remove timing chain and gears. • Remove thrust plate and camshaft. • Remove timing chain gear housing. • Remove camshaft bearings.
Remove oil pan.	See “Remove and Install Oil Pan”.
Disassemble cylinder block and components.	Use the appropriate procedure. See “Cylinder Block” in the Engine section. • Remove oil pump and oil pump pick-up. • Remove connecting rod bearing caps and bearings. • Remove connecting rods and pistons. • Remove main bearing caps. • Remove crankshaft. • Inspect crankshaft. • Measure crankshaft journals and bearing ID. • Measure crankshaft circle runout. • Remove main bearings from main caps and block. • Check cylinder block deck for warpage. • Inspect cylinder bore. • Check cylinder taper. • Remove oil and coolant galley plugs.
Disassemble connecting rods and piston assemblies.	Use the appropriate procedure. See “Cylinder Block” in the Engine section. • Disassemble connecting rods from pistons. • Check connecting rods for bend or twist. • Clean pistons. • Check piston ring grooves. • Check piston ring gap. • Check piston pins. • Check piston skirts.

3.6.2 Engine Assembly

The following assembly sequence is suggested when engine has been completely disassembled. Be sure to check runout specifications, clearance tolerances, torques, etc., as engine is assembled. Refer to the appropriate repair section when assembling engine components.

Note:
Refer to the torque and adjustment specifications for the corresponding components throughout the assembly.

Procedure	Reference
Assemble connecting rods and pistons.	Use the appropriate procedure. See “Cylinder Block” in the Engine section. • Assemble connecting rods, piston pins and pistons. • Install piston rings.
Assemble cylinder block and components.	Use the appropriate procedure. See “Cylinder Block” in the Engine section. • Install oil and coolant galley plugs. • Install upper main bearings in cylinder block. • Install lower main bearings into caps. • Install thrust washers. • Install crankshaft. • Install piston and connecting rod assemblies. • Install oil pump and oil pump pick-up.
Install rear crankshaft seal.	See “Remove and Install Rear Crankshaft Seal”. .
Install oil pan.	See “Remove and Install Oil Pan”.
Install camshaft and related components.	See appropriate procedure in “Cylinder Block” . • Install camshaft bearings. • Install timing chain gear housing. • Install camshaft and thrust plate. • Install timing chain and gears. • Install timing chain tensioner and dampener. • Install timing chain cover. • Install valve lifters.
Install front crankshaft seal.	See “Remove and Install Front Crankshaft Seal”.
Install valve guides.	See “Valve Guides—Removal and Installation”.
Install valves.	See “Valves—Removal and Installation”.
Install cylinder head.	See “Cylinder Head Removal and Installation”.
Install push rods and rocker arm assembly.	See “Rocker Arm Assembly—Removal and Installation” .
Install rocker arm cover.	See “Remove and Install Rocker Arm Cover”.
Install oil pump drive and oil filter base.	See “Oil Pump Drive Removal and Installation” and “Oil Filter Base Removal and Installation”.
Install crankshaft position sensor.	See “Remove and Install Crankshaft Position Sensor”.
Install water pump and thermostat.	See “Water Pump Removal and Installation” and “Thermostat Removal and Installation”.
Install crankshaft vibration dampener.	See “Remove and Install Crankshaft Vibration Dampener”.
Install flywheel.	See “Remove and Install Flywheel”.
Install exhaust manifold.	See “Exhaust Manifold Removal and Installation”.
Install intake manifold.	See “Intake Manifold Removal and Installation” and “Upper Intake Manifold Removal and Installation” .
Install turbocharger (KG2204T only).	See “Turbocharger Removal and Replacement (KG2204T only)”.
Install air-fuel mixer and throttle body.	See “Air-Fuel Mixer and Throttle Body Removal and Installation”.
Install coil mounting bracket, ignition coil, and ignition wire harness.	See “Ignition Coil Mounting Bracket Removal and Installation”, “Ignition Coil Removal and Installation” , and “Ignition Wire Removal and Installation”.
Install spark plug tubes and spark plugs.	See “Spark Plug Removal and Installation” and “Remove and Install Spark Plug Tubes” .
Install alternator and drive belt.	See “Alternator Removal and Installation” and “Drive Belt Removal and Installation”.
Install oil filter.	See “Oil Filter Removal and Installation” .
Remove from engine repair stand and install.	See appropriate instructions.
Refill coolant and engine oil.	See “Fluid Specifications” .

3.7 External Components

⚠ WARNING	
	**Carbon monoxide.** **Can cause severe nausea, fainting, or death.** Avoid inhaling exhaust fumes.

Engine Operation. Carbon monoxide can cause severe nausea, fainting, or death. Engine exhaust gases contain poisonous carbon monoxide. Carbon monoxide is an odorless, colorless, tasteless, nonirritating gas that can cause death if inhaled for even a short time. Avoid breathing exhaust fumes when working on or near the engine. Never operate the engine inside a building. Never operate the engine where exhaust gas could seep inside or be drawn into a potentially occupied building through windows, air intake vents, or other openings.

⚠ WARNING	
	**Risk of fire.** **Can cause severe injury or death.** Do not smoke or permit flames or sparks near fuels or the fuel system.

⚠ WARNING	
	**Pinch and entanglement hazards.** **Can cause severe injury and possible death.** Never check drive belt tension while the engine is running.

⚠ CAUTION	
	**Hazardous voltage.** **Electrical shock can cause injury.** Do not touch wires while the engine is running. Stop the engine and disconnect the battery leads, negative (-) lead first, before servicing the engine.

⚠ WARNING	
	**Moving parts.** **Can cause severe injury or death.** Operate the engine only when all guards and electrical enclosures are in place. Stay away from moving parts while the engine is in operation.

Servicing the engine when it is operating. Exposed moving parts can cause severe injury or death. Keep hands, feet, hair, clothing, and test leads away from the belts and pulleys when the engine is running. Replace guards, screens, and covers before operating the engine.

⚠ WARNING	
	**Hot engine and exhaust system.** **Can cause severe injury or death.** Do not work on the engine until it cools.

Hot engine components. Can cause severe injury or death. Never operate the engine with heat shields or guards removed.

⚠ WARNING	**Hot coolant and steam.** **Can cause severe injury or death.** Before removing the pressure cap, stop the engine and allow it to cool. Then loosen the pressure cap to relieve pressure.
	

Liquid coolant can be extremely hot from operation. Turning radiator cap when engine is hot can allow steam and scalding liquid to blow out and burn you severely. Shut off machine. Only remove radiator cap when cool enough to touch with bare hands. Slowly loosen cap to the first stop to relieve pressure before removing completely.

⚠ WARNING	**Accidental starting.** **Can cause severe injury or death.** Disconnect the battery cables before working on the engine. Remove the negative (–) lead first when disconnecting the battery. Reconnect the negative (–) lead last when reconnecting the battery.
	

Disabling the engine. Accidental starting can cause severe injury or death. Before working on the engine or connected equipment, disable the engine as follows: 1) Disconnect the ignition coil. 2) Remove the battery cables, negative (–) lead first. Reconnect the negative (–) lead last when reconnecting the battery. Follow these precautions to prevent the accidental starting of the engine.

⚠ WARNING	**Explosive fuel vapors.** **Can cause fires and severe burns.** If a gaseous odor is detected, ventilate the area and contact an authorized service technician.
	

The fuel system. Explosive fuel vapors can cause severe injury or death. Vaporized fuels are highly explosive. Use extreme care when handling and storing fuels. Store fuels in a well-ventilated area away from spark-producing equipment and out of the reach of children. Never add fuel to the tank while the engine is running because spilled fuel may ignite on contact with hot parts or from sparks. Do not smoke or permit flames or sparks to occur near sources of spilled fuel or fuel vapors. Keep the fuel lines and connections tight and in good condition. Do not replace flexible fuel lines with rigid lines. Use flexible sections to avoid fuel line breakage caused by vibration. Do not operate the engine in the presence of fuel leaks, fuel accumulation, or sparks. Repair fuel systems before resuming engine operation.

⚠ WARNING	**Handling caustic engine fluids and chemical products.** **Can cause severe chemical burns, nausea, fainting, or death.** Most chemicals such as used engine oil, antifreeze/coolant, rustproofing agent, inhibiting oil, degreasing agent, spray paint, and adhesives are hazardous to health. Read and follow the user information found on the packaging. Avoid inhalation and skin contact. Use only in well-ventilated areas and use a protective mask when spraying. Store engine fluids and chemical products in a locked cabinet. Contact your local recycling center for disposal information and locations.
	

Fire-damaged or burned O-rings may cause the formation of hydrofluoric acid. Contact with hydrofluoric acid may cause severe skin irritation and chemical burns. O-rings and other fluoroelastomer seals exposed to fire or temperatures above 316°C (600°F) (i.e., during welding) may decompose forming hydrofluoric acid. Avoid inhalation or skin contact. Do not incinerate O-rings. Dispose of O-ring waste material in a responsible manner.

⚠ WARNING	**Spring-loaded parts.** **Can cause severe personal injury or property damage.** Wear protective goggles when servicing spring-loaded parts. Hold parts securely during disassembly.
	

WARNING	
	**Airborne particles.** **Can cause severe injury or blindness.** Wear protective goggles and clothing when using power tools, hand tools, or compressed air.

WARNING	
	**Explosive fuel vapors.** **Can cause severe injury or death.** Use extreme care when handling, storing, and using fuels.

Gas fuel leaks. Explosive fuel vapors can cause severe injury or death. Fuel leakage can cause an explosion. Check the LPG vapor or natural gas fuel system for leakage by using a soap and water solution with the fuel system test pressurized to 6–8 ounces per square inch (10–14 inches water column). Do not use a soap solution containing either ammonia or chlorine because both prevent bubble formation. A successful test depends on the ability of the solution to bubble.

Used engine oil. Contact with used engine oil may cause severe skin irritation. Repeated and prolonged skin exposure may have other health risks. Used engine oil is a suspected carcinogen. Avoid contact with skin. Thoroughly wash your hands and nails with soap and water shortly after handling used engine oil. Wash or dispose of clothing or rags containing used engine oil. Dispose of used engine oil in a responsible manner. Contact your local recycling center for disposal information and locations.

CAUTION	
	**Damaged harmonic balancer, crankshaft, or flywheel.** **Can cause personal injury.** Broken fragments from the harmonic balancer, crankshaft, and flywheel can be thrown from the engine. Do not use a hammer to install or remove. Inspect these parts for damage and replace if needed.

3.7.1 Water Pump Removal and Installation

3.7.1.1 Removal

1. Drain cooling system.
2. Remove alternator. See “Alternator Removal and Installation”.

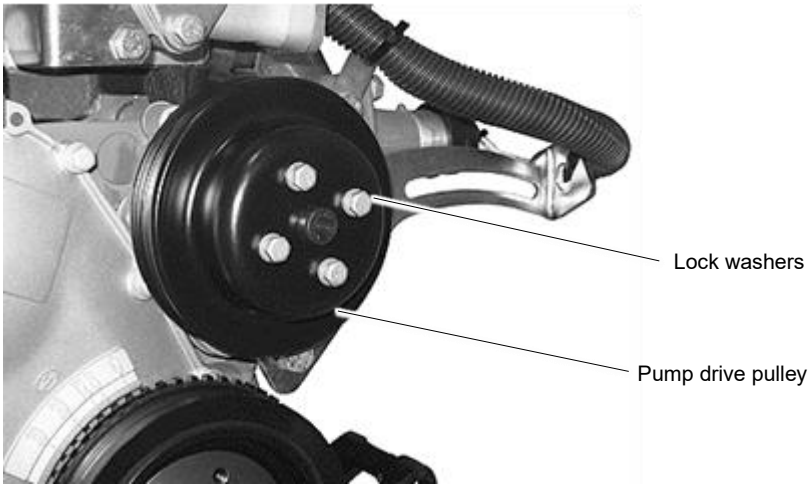


Figure 8 Water Pump Drive Pulley

3. Remove four water pump drive pulley mounting bolts, flat washers, and lock washers. See Figure 8.
4. Remove water pump drive pulley from water pump.

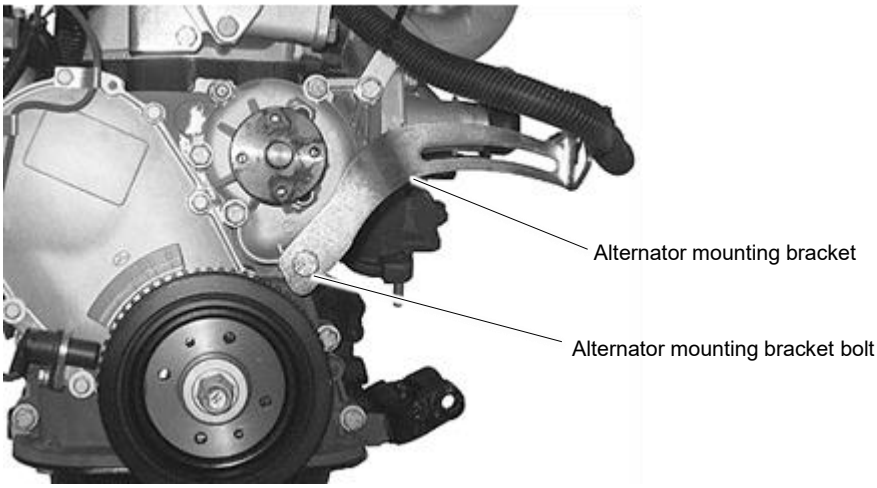


Figure 9 Alternator Mounting Bracket

5. Remove upper alternator mounting bracket bolt and remove upper alternator mounting bracket from water pump. See Figure 9.

   Note:
   Take notice of water pump bolt length differences during removal.

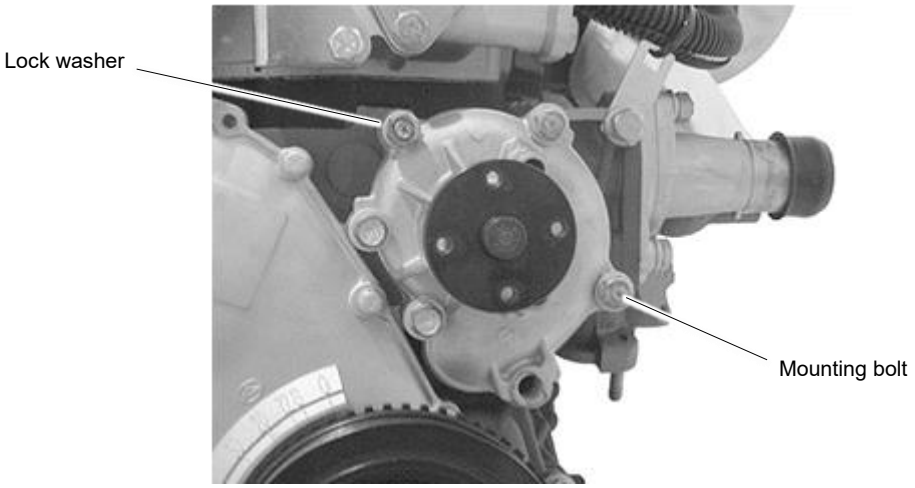


Figure 10 Water Pump

6. Remove four water pump mounting bolts. See Figure 10.
7. Remove water pump mounting nut, flat washer, and lock washer from water pump.
8. Lightly tap water pump with a soft face hammer and remove water pump from engine.

3.7.1.2 Inspection

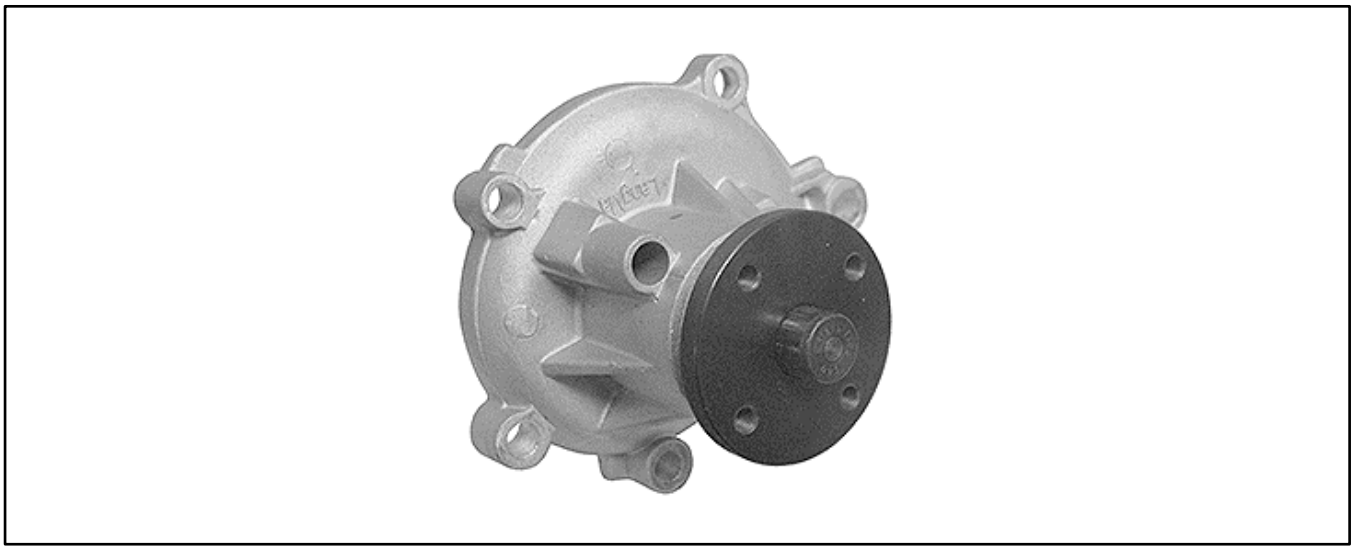


Figure 11 Water Pump Bearing

1. Inspect water pump bearing for excess play by pulling upward on water pump pulley hub and rotate side to side. The bearing should feel smooth and rotate freely. See Figure 11.
2. Inspect impeller. Impeller should not be bent or show signs of rubbing, or corrosion.
3. Inspect weep hole for leakage of coolant.
4. Inspect gasket sealing flange for cracks or distortion.
5. Clean water pump housing and water pump of old gasket material.
6. If inspection reveals damage, leakage, or wear, replace water pump.

3.7.1.3 Installation

1. If installing new water pump, check new water pump gasket sealing surface for nicks or burrs. Remove nicks or burrs if needed.
2. Install new water pump gasket to cylinder block.
3. Install water pump to cylinder block.

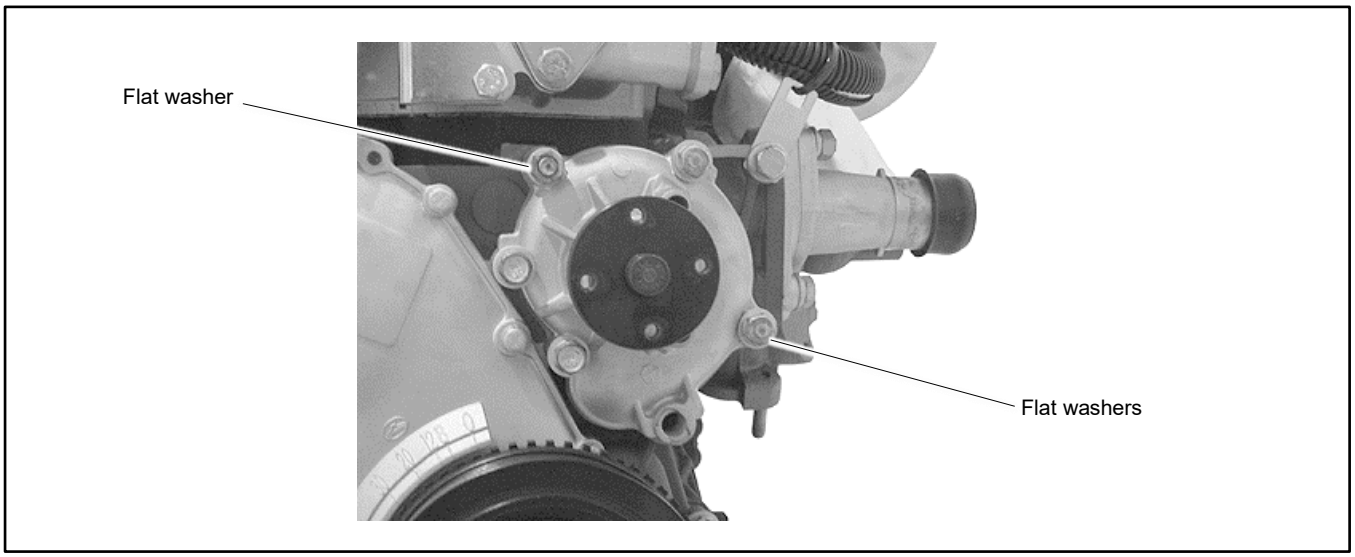


Figure 12 Water Pump

4. Install water pump mounting nut, lock washer, and flat washer to water pump. Do not tighten at this time. See Figure 12.

5. Install four water pump mounting bolts, lock washers, and flat washers (B) to water pump as noted during removal. Torque mounting bolts and nut to specification.

Water Pump Bolt and Nut Torque
18 Nm (13 ft.lb.)

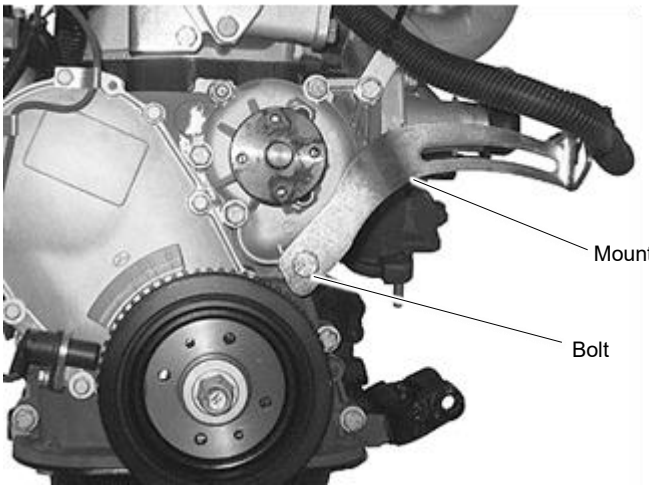


Figure 13 Alternator Mounting Bracket

6. Install upper alternator mounting bracket with bolt. Do not tighten bolt at this time. See Figure 13.

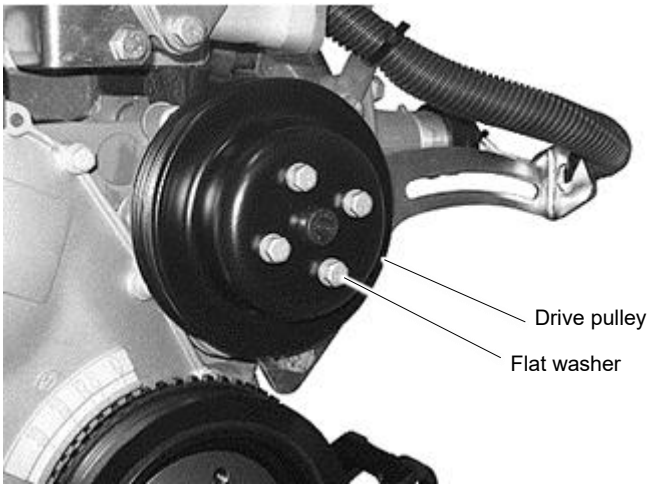


Figure 14 Water Pump Dive Pulley

7. Install water pump drive pulley to water pump with four mounting bolts, lock washers, and flat washers. Tighten bolts. See Figure 14.

8. Install alternator. See “Alternator Removal and Installation”.

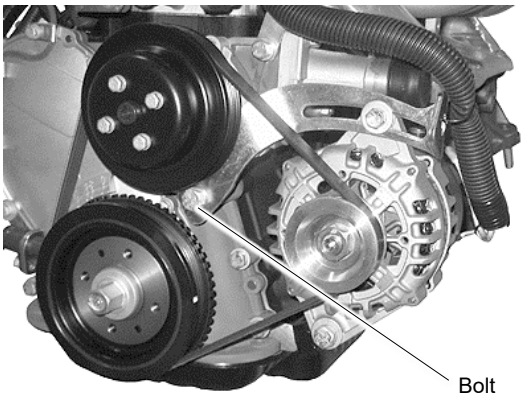


Figure 15 Water Pump Mounting Bolt

NOTE:
Bolt (G) securing the upper alternator bracket is also a water pump mounting bolt and must be torqued to specification. See Figure 15.

9. Torque upper alternator mounting bracket bolt (G).

Water Pump Bolt and Nut Torque
18 Nm (13 ft.lb.)

10. Fill cooling system.
11. Run engine and check for leaks.

3.7.2 Thermostat Removal and Installation

3.7.2.1 Removal

1. Drain cooling system.

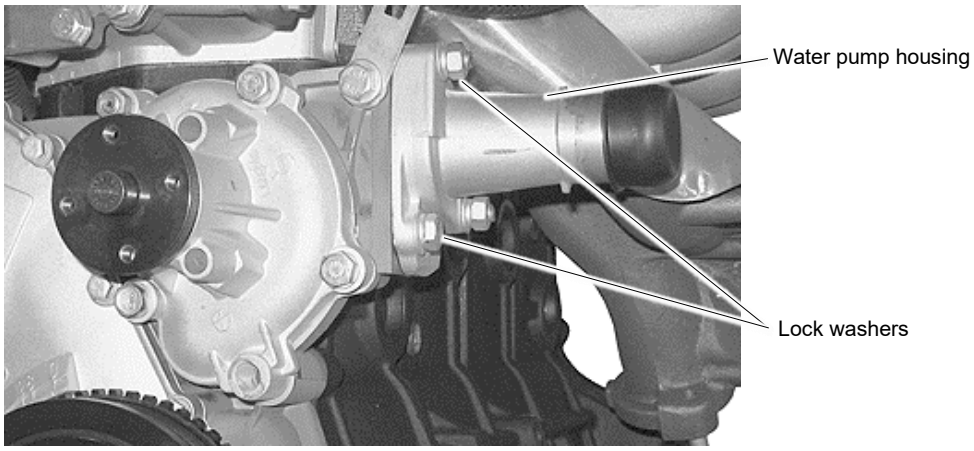


Figure 16 Water Pump Housing Location

2. Remove thermostat housing mounting nuts, flat washers, and lock washers. See Figure 16.
3. Remove thermostat housing from water pump housing.

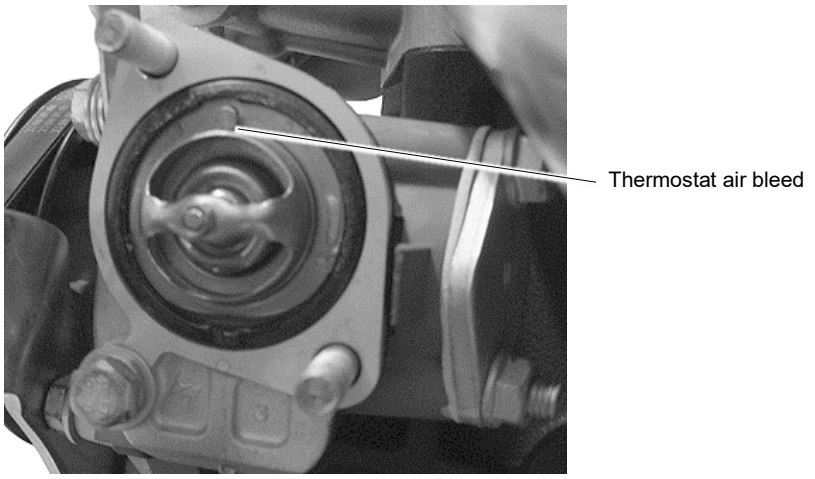


Figure 17 Thermostat Air Bleed

NOTE:
Take notice of thermostat air bleed (C) orientation. Air bleed hole must be positioned at approximately the ten to eleven o'clock position. See Figure 17.

4. Remove thermostat from water pump housing.
5. Thoroughly clean water pump housing.

3.7.2.2 Thermostat Check

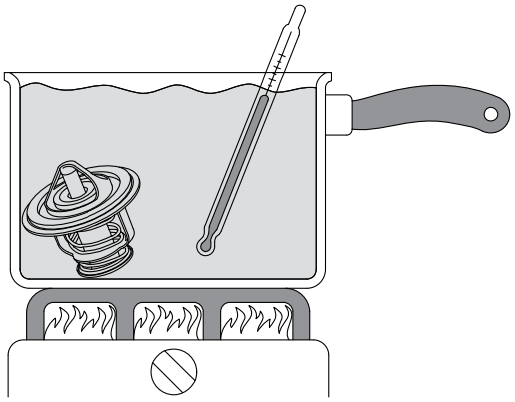


Figure 18 Testing Thermostat

1. Place thermostat in a pot of water along with a thermometer. See Figure 18.
2. Apply heat and observe the opening temperature on thermometer.

THERMOSTAT SPECIFICATIONS	
Start to Open	76 °C (169 °F).
Fully Open	88 °C (190 °F)

3. If thermostat does not open as specified, replace thermostat.

3.7.2.3 Installation

NOTICE
Ensure O-ring is installed to thermostat.

NOTE:
Thermostat MUST be installed “spring” end first. Air bleed must be positioned at approximately the ten to eleven o’clock position. See Figure 19.

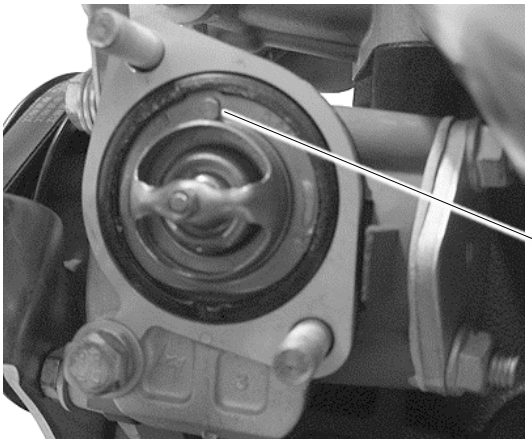


Figure 19 Thermostat Air bleed

1. Install thermostat into water pump housing. See Figure 19.

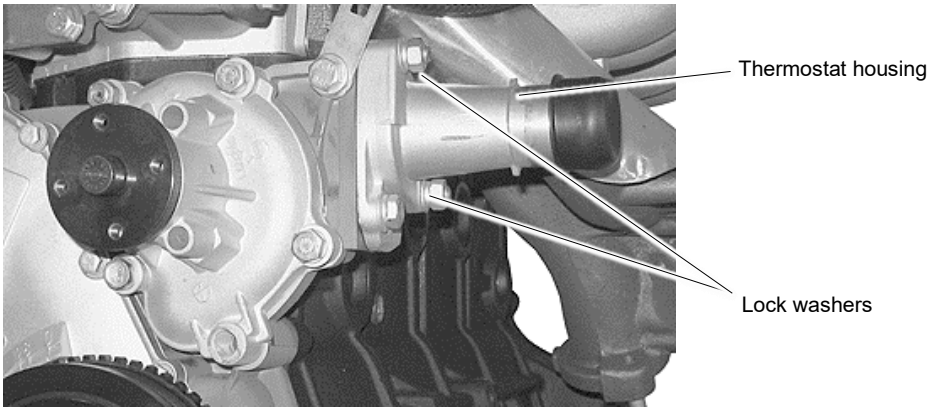


Figure 20 Thermostat housing

2. Install thermostat housing over thermostat. See Figure 20.
3. Install thermostat housing mounting nuts, flat washers, and lock washers.
4. Fill cooling system.
5. Run engine and check for leaks.

3.7.3 Ignition Wire Removal and Installation

CAUTION	
	**Hazardous voltage.** **Electrical shock can cause injury.** Do not touch wires while the engine is running. Stop the engine and disconnect the battery leads, negative (-) lead first, before servicing the engine.

3.7.3.1 Removal

NOTICE
Identify and tag ignition wires for reference during installation. Ignition wires MUST be installed correctly.

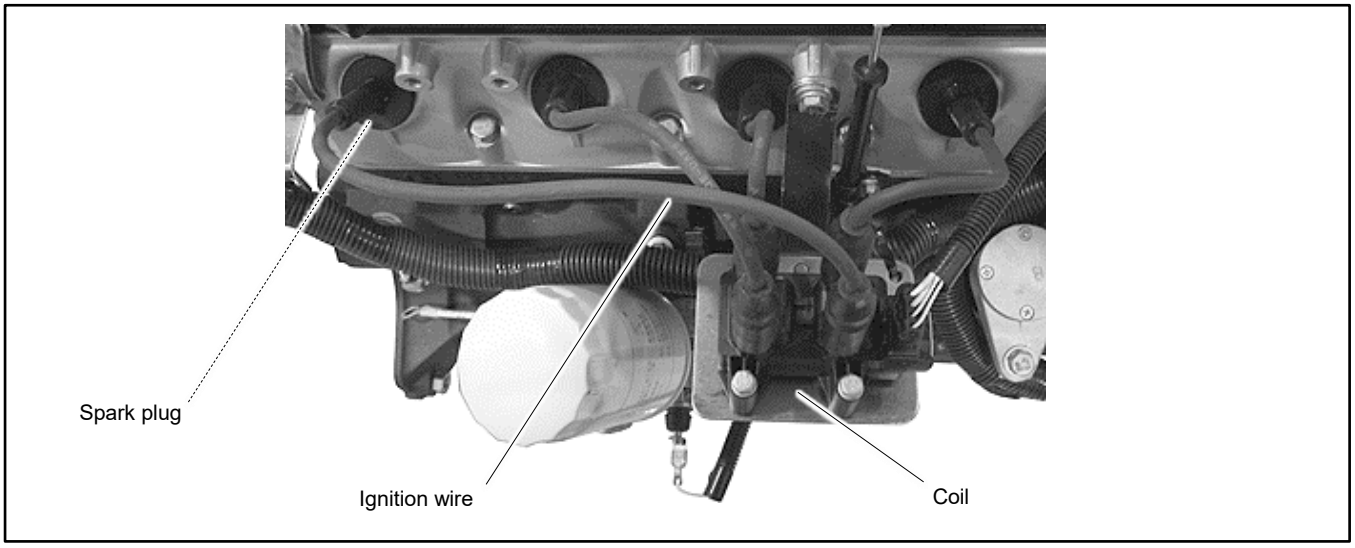


Figure 21 Ignition Wire Location

1. Clean dirt and debris away from ends of ignition wires.
2. Firmly grasp ends of ignition wire at spark plug and coil. Using a twisting motion, remove wire from spark plug and coil. See Figure 21.
3. Repeat for remaining ignition wires.

3.7.3.2 Inspection

1. Inspect ignition wires or cuts, abrasions, burning or missing boots.
2. If inspection reveals damage or wear, replace ignition wire.
3. Inspect the resistance of each ignition wire using an ohmmeter set to read a minimum of 25k Ohms. Attach ohmmeter leads to spark plug and ignition coil ends of ignition wire. If reading exceeds specification, replace ignition wire.

Ignition Wire Resistance
25k Ohms (Maximum)

3.7.3.3 Installation

NOTICE
Ignition wires MUST be installed correctly. Use identification on ignition wires from removal.

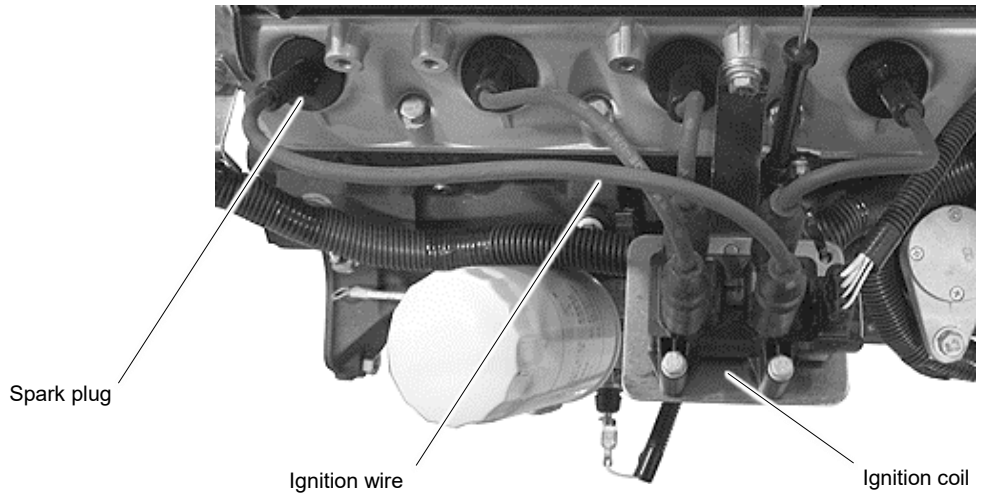


Figure 22 Ignition Wire Installation

1. Connect ignition wire to ignition coil and spark plug by firmly pressing ignition wire onto terminals. See Figure 22.
2. Repeat for remaining ignition wires.

3.7.4 Drive Belt Removal and Installation

3.7.4.1 Removal

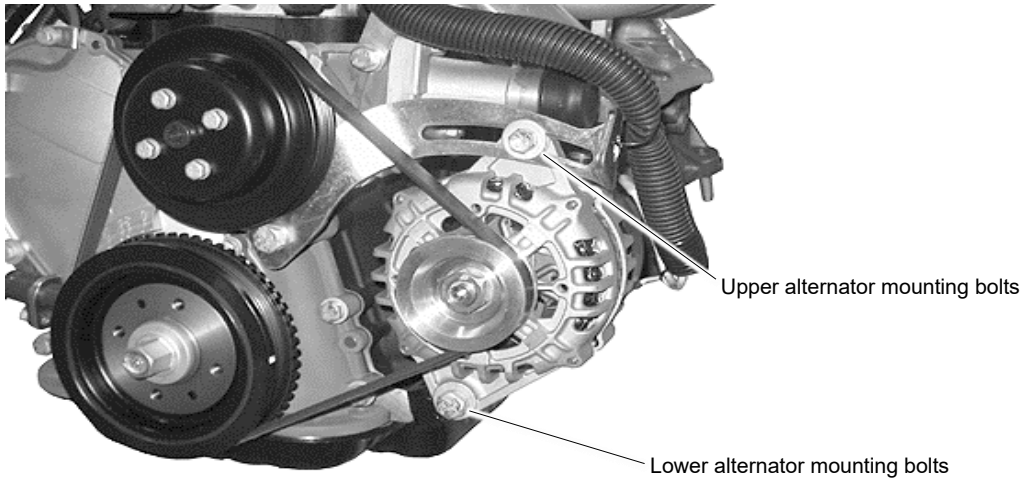


Figure 23 Drive Belt Location

1. Loosen upper and lower alternator mounting bolts and rotate alternator towards cylinder block. See Figure 23.
2. Remove drive belt from drive pulleys.

3.7.4.2 Inspection

1. Inspect drive belt for cracks or stretching. If inspection reveals cracks or stretching, replace drive belt.
2. Inspect drive pulleys for defects and wear. If inspection reveals defective or worn drive pulleys, replace drive pulleys.

3.7.4.3 Installation

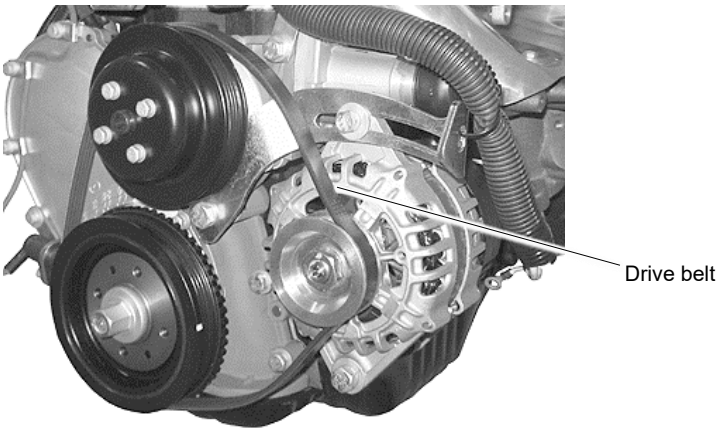


Figure 24 Drive Belt Location

1. Install drive belt as shown. See Figure 24.



Figure 25 Drive Belt Alignment

2. Check drive belt for correct alignment. If alignment is incorrect, severe damage to drive belt may occur. See Figure 25.
3. Rotate alternator away from cylinder block to remove slack in drive belt.

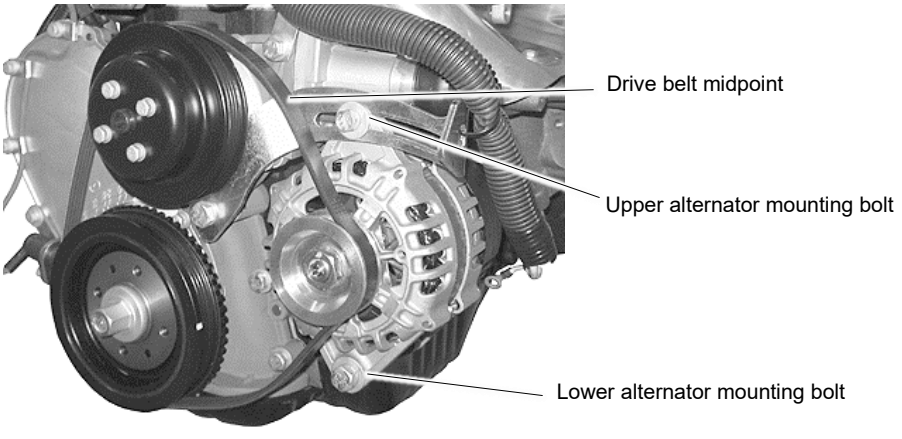


Figure 26 Drive Belt

4. Tighten upper alternator mounting bolt, then tighten lower alternator mounting bolt. See Figure 26.
5. Check the drive belt tension at the midpoint between the pulleys.
    a. Apply specified force to the drive belt at its midpoint. At the same time, measure the amount of deflection of the drive belt at its midpoint. Deflection should be within specification.

DRIVE BELT TENSION	
Applied Test Pressure	98 N (22 lbf.)
Belt Deflection - New	5–7 mm (0.20–0.28 in.)
Belt Deflection - Used	7–8 mm (0.28–0.31 in.)

6. If the amount of deflection is out of specification, adjust the drive belt tension.

3.7.5 Alternator Removal and Installation

3.7.5.1 Removal

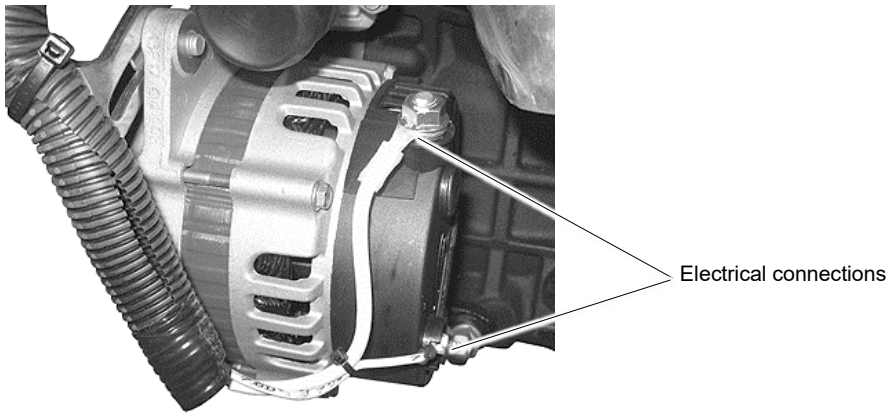


Figure 27 Electrical Connections

1. Disconnect negative battery cable from battery.
2. Disconnect all electrical connections from alternator. See Figure 27.
3. Remove drive belt. See “Drive Belt Removal and Installation”.

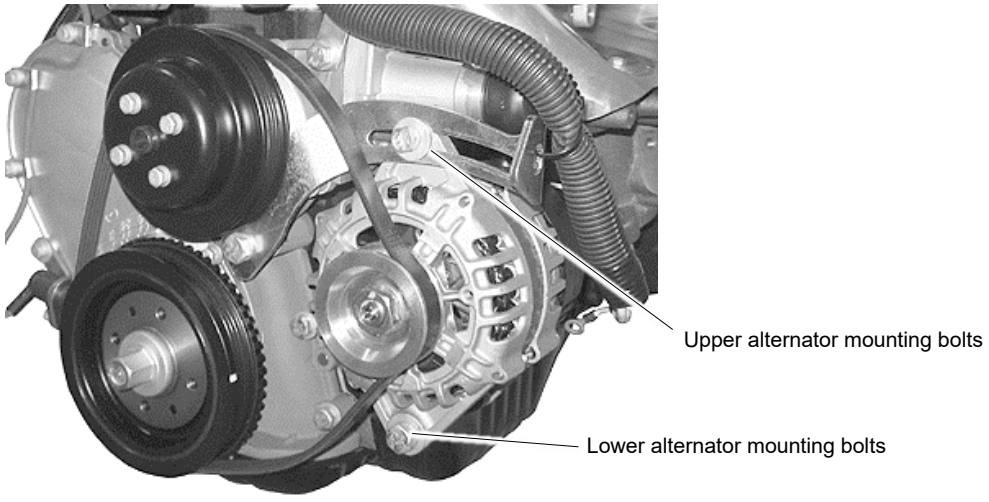


Figure 28 Alternator Mounting Bolts

4. Support alternator and remove upper and lower alternator mounting bolts. Remove alternator from alternator mounting brackets. See Figure 28.

3.7.5.2 Inspection

1. Inspect alternator drive pulley for defects and wear. Damaged or worn drive pulleys must be replaced.
2. Inspect alternator bearing for excess play by pulling upward on alternator pulley and rotate side to side. The bearing should feel smooth and rotate freely.
3. Inspect all electrical connections for corrosion or damage.
4. Replace alternator if needed.

3.7.5.3 Installation

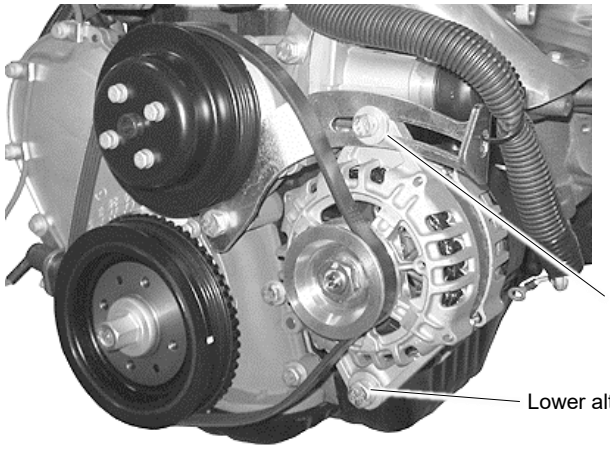


Figure 29 Mounting Bolts

1. Install alternator to alternator mounting brackets and install two mounting bolts. Do not tighten bolts at this time. See Figure 29.
2. Install drive belt. See “Drive Belt Removal and Installation”. Disconnect negative battery cable from battery.

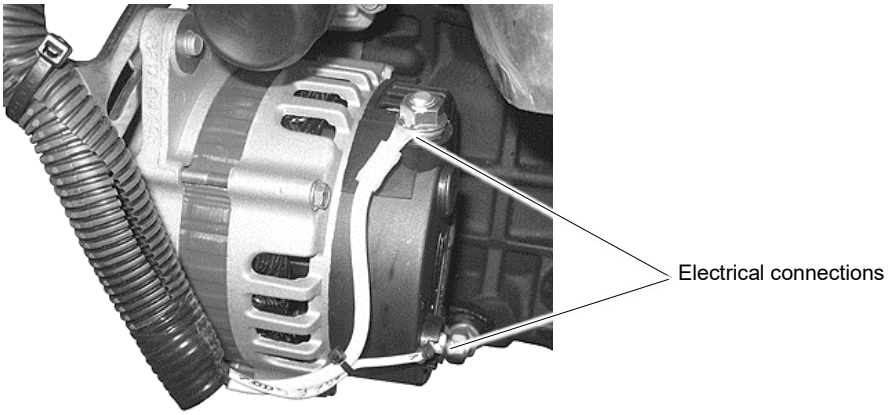


Figure 30 Electrical Connections

3. Connect all electrical connections to alternator. See Figure 30.
4. Connect negative battery cable to negative battery terminal.

3.7.6 Spark Plug Removal and Installation

CAUTION	
	**Hazardous voltage.** **Electrical shock can cause injury.** Do not touch wires while the engine is running. Stop the engine and disconnect the battery leads, negative (-) lead first, before servicing the engine.

3.7.6.1 Removal

1. Disconnect ignition wires from spark plugs. See “Ignition Wire Removal and Installation”.

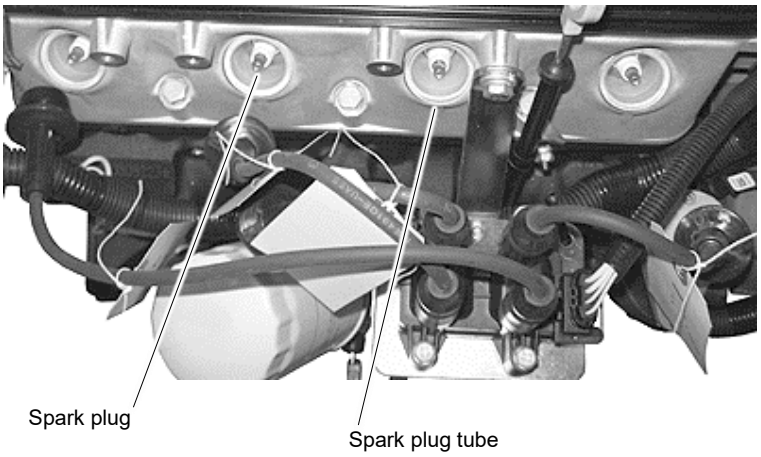


Figure 31 Spark Plug Location

2. Clean the inside of the spark plug tubes. See Figure 31.
3. Using a spark plug socket, remove spark plugs from cylinder head by rotating spark plug counterclockwise.

3.7.6.2 Inspection

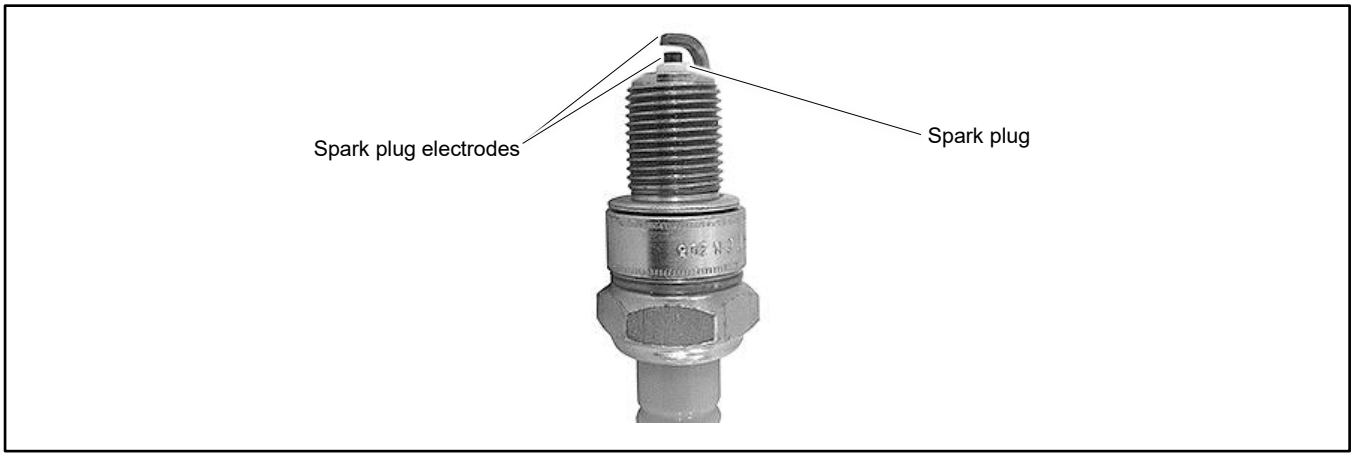


Figure 32 Spark Plug Location

1. Inspect spark plug electrodes for wear. See Figure 32.
   - Spark plug electrodes should have sharp pronounced edges.
   - Rounded or missing electrodes are indications that spark plugs must be replaced.
2. Check color of the deposits on spark plug.
   - Tan to brown is normal deposit color.
   - Dark brown to black is an overfueling or cold engine operating deposit color.
   - Very light tan to white is an underfueling or overheating engine operating deposit color.

3.7.6.3 Installation

1. Replace worn spark plugs with exact replacement spark plugs. Use Rehlko genuine service parts.

Spark Plugs	
KG2204	GM92785
KG2204T	GM100158

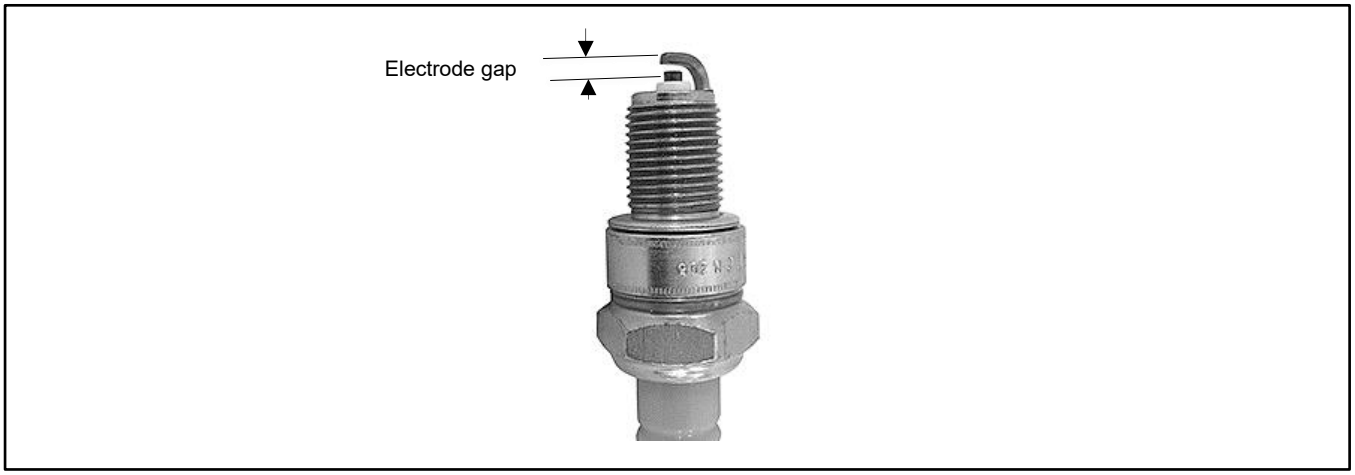


Figure 33 Installation of Spark Plug

2. Check electrode gap using a wire feeler gauge and adjust electrode gap to specification before installation. See Figure 33.

Spark Plug Electrode Gap	
KG2204	0.9–1.0 mm (0.036–0.040 in.)

KG2204T	0.7–0.8 mm (0.028–0.031 in.)

3. Install spark plug and torque spark plug to specification.

Spark Plug Torque	
KG2204	18 Nm (13 ft.lb.)
KG2204T	25 Nm (18.4 ft.lb.)

4. Connect ignition wire to spark plug. See “Ignition Wire Removal and Installation”.
5. Repeat procedure for remaining spark plugs.

3.7.7 Remove and Install Spark Plug Tubes

3.7.7.1 Removal

1. Remove spark plug wires from cylinder head.
2. Remove spark plugs from cylinder head.

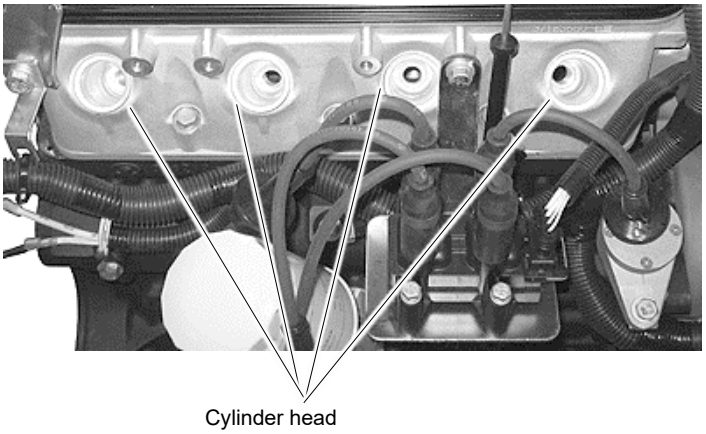


Figure 34 Spark Plug Tubes Removal

3. Remove spark plug tubes from cylinder head. See Figure 34.

3.7.7.2 Installation

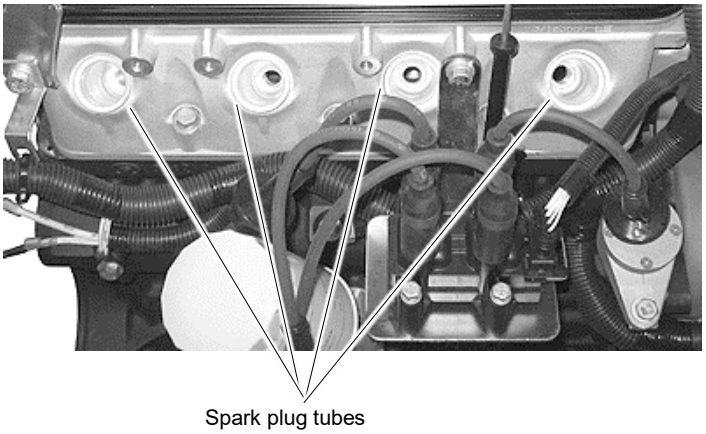


Figure 35 Spark Plug Tubes Installation

1. Install spark plug tubes to cylinder head. See Figure 35.
2. Install spark plugs to cylinder head.
3. Install spark plug wires to cylinder head.

3.7.8 Ignition Coil Removal and Installation

CAUTION	
	**Hazardous voltage.** **Electrical shock can cause injury.** Do not touch wires while the engine is running. Stop the engine and disconnect the battery leads, negative (-) lead first, before servicing the engine.

3.7.8.1 Removal

1. Disconnect ignition wires from ignition coil. See “Ignition Wire Removal and Installation”.

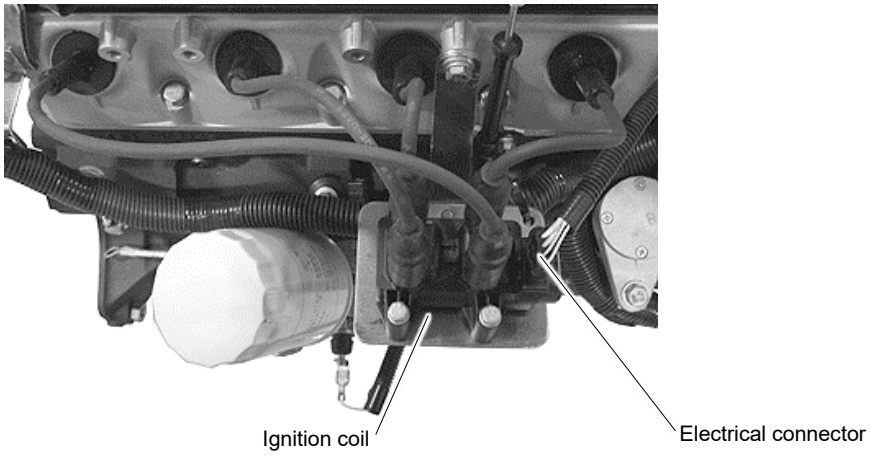


Figure 36 Electrical Connector

2. Disconnect electrical connector from ignition coil. See Figure 36.

NOTE:
Record orientation of coil, flat washers, and lock washers for assembly.

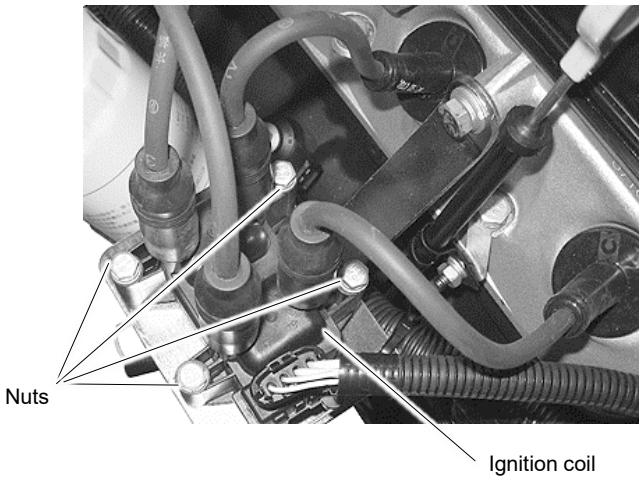


Figure 37 Ignition Coil Removal

3. Remove four ignition coil mounting bolts, flat washers, lock washers, and nuts from ignition coil. See Figure 37.
4. Remove ignition coil from ignition coil mounting bracket.

3.7.8.2 Installation

NOTE:
Ensure that coil is positioned as noted previously during the removal process.

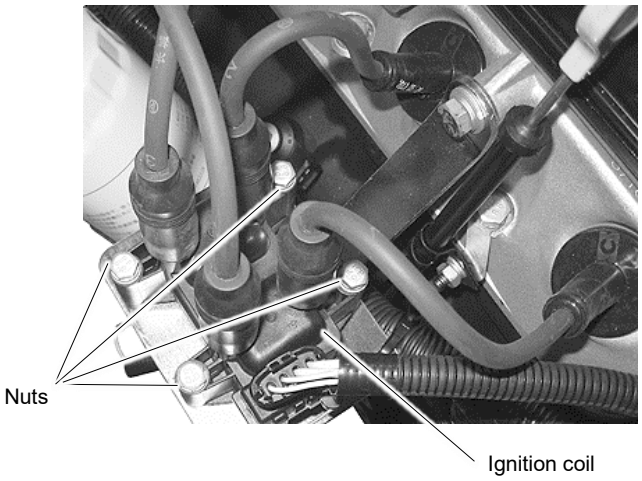


Figure 38 Ignition Coil Installation

1. Install ignition coil to ignition coil mounting bracket using four ignition coil mounting bolts, flat washers, lock washers, and nuts (A). See Figure 38.

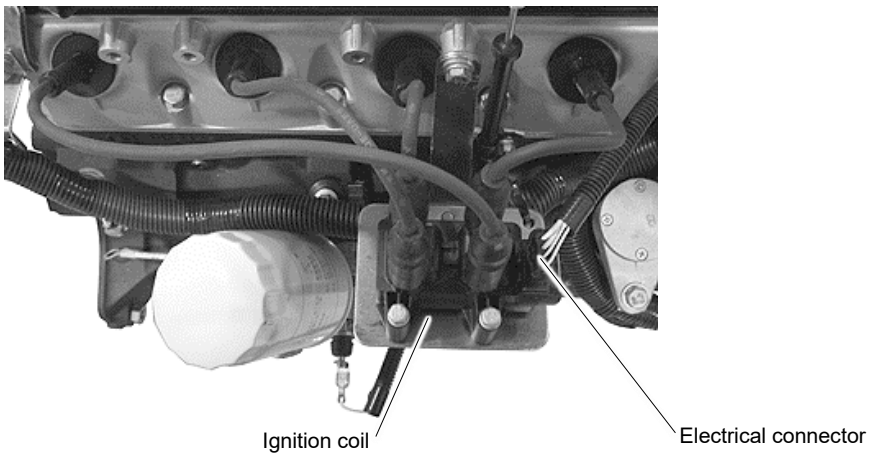


Figure 39 Electrical Connector

2. Connect electrical connector to ignition coil. See Figure 39.
3. Connect ignition wires to ignition coil. See “Ignition Wire Removal and Installation”.

3.7.9 Ignition Coil Mounting Bracket Removal and Installation

CAUTION	
	**Hazardous voltage.** **Electrical shock can cause injury.** Do not touch wires while the engine is running. Stop the engine and disconnect the battery leads, negative (-) lead first, before servicing the engine.

3.7.9.1 Removal

1. Remove ignition coil. See “Ignition Coil Removal and Installation”.

NOTE:
Take notice and record coil mounting bracket bolt length and wire tie location during removal.

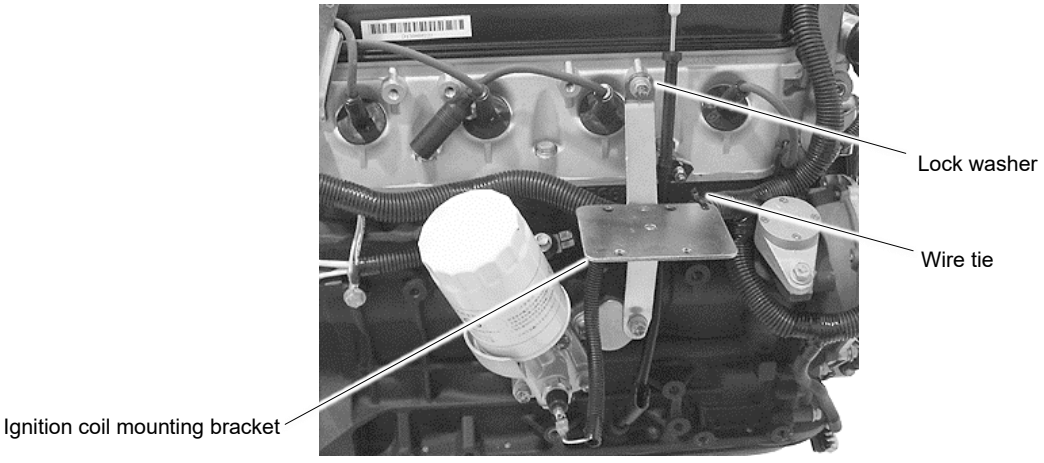


Figure 40 Ignition Coil Mounting Bracket

2. Remove wire tie holding engine harness to coil bracket. See Figure 40.
3. Remove ignition coil mounting bracket bolts, flat washers, and lock washers from ignition coil mounting bracket. Remove ignition coil mounting bracket from cylinder block.

3.7.9.2 Installation

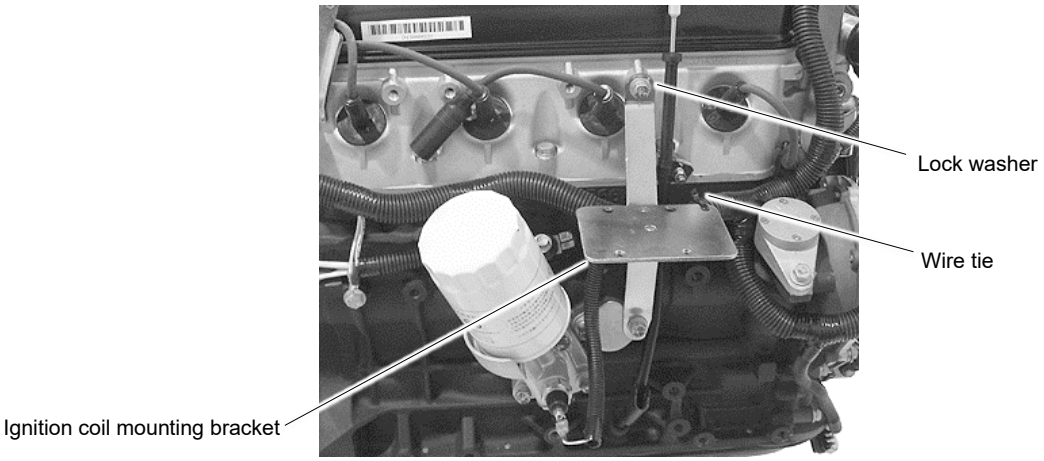


Figure 41 Ignition Coil Mounting Bracket Installation

1. Install ignition coil mounting bracket to engine with mounting bolts, flat washers, and lock washers as noted during removal. See Figure 41.
2. Install wire tie.
3. Install ignition coil to ignition coil mounting bracket. See “Ignition Coil Removal and Installation”.

3.7.10 Air-Fuel Mixer and Throttle Body Removal and Installation

⚠ WARNING	**Explosive fuel vapors.** **Can cause fires and severe burns.** If a gaseous odor is detected, ventilate the area and contact an authorized service technician.
	

LPG fuel leaks. Explosive fuel vapors can cause severe injury or death. Fuel leakage can cause an explosion. Check the LPG vapor fuel system for leakage by using a soap and water solution with the fuel system test pressurized to 6-8 ounces per square inch (10-14 inches water column). Do not use a soap solution containing either ammonia or chlorine because both prevent bubble formation. A successful test depends on the ability of the solution to bubble.

Natural Gas—Adequate ventilation is mandatory. Because natural gas rises, install natural gas detectors high in a room. Inspect the detectors per the manufacturer’s instructions.

3.7.10.1 Removal

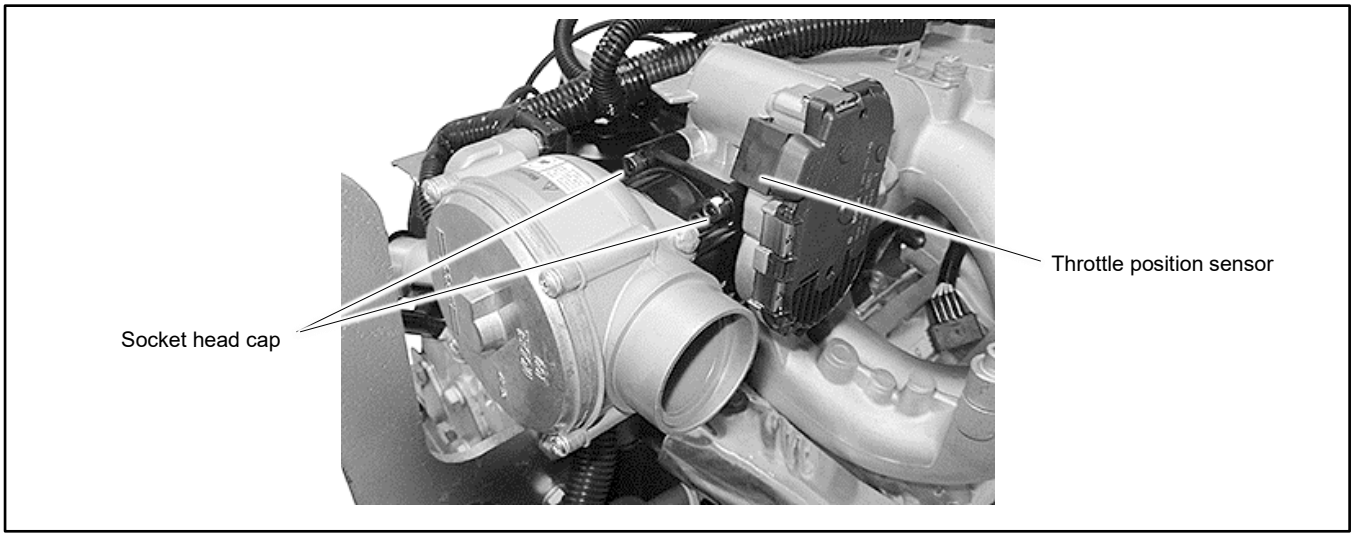


Figure 42 Throttle Body Connection Removal

NOTE:
On turbocharged engines, the air-fuel mixer is located on the turbocharger. See TP-6903 for instructions to remove and replace the air-fuel mixer on turbocharged engines, if necessary.

1. Remove electrical connection at throttle body from throttle position sensor. See Figure 42.
2. Loosen four socket head cap screws securing the air-fuel mixer valve and throttle body assembly to the upper intake manifold. Remove air-fuel mixer valve and throttle body as a unit from the upper intake manifold. See Figure 42.

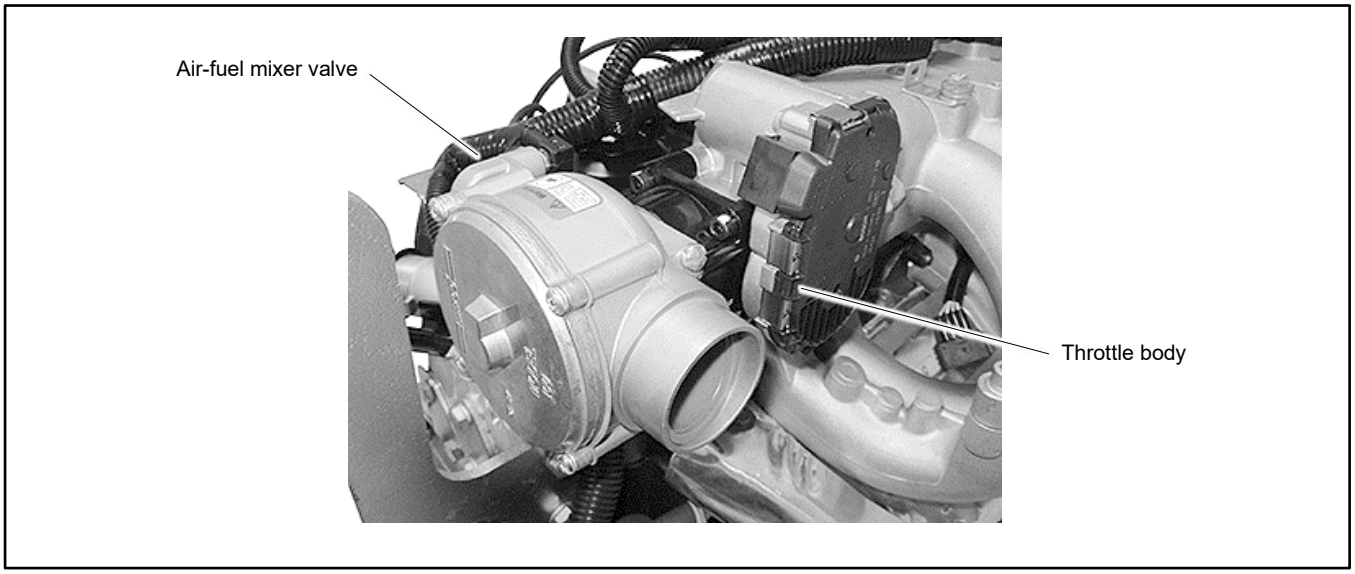


Figure 43 Air-fuel Mixer Valve Location

3. Separate the air-fuel mixer valve from the throttle body by using a rotational motion as pulling apart. Use caution not to damage O-rings. See Figure 43.

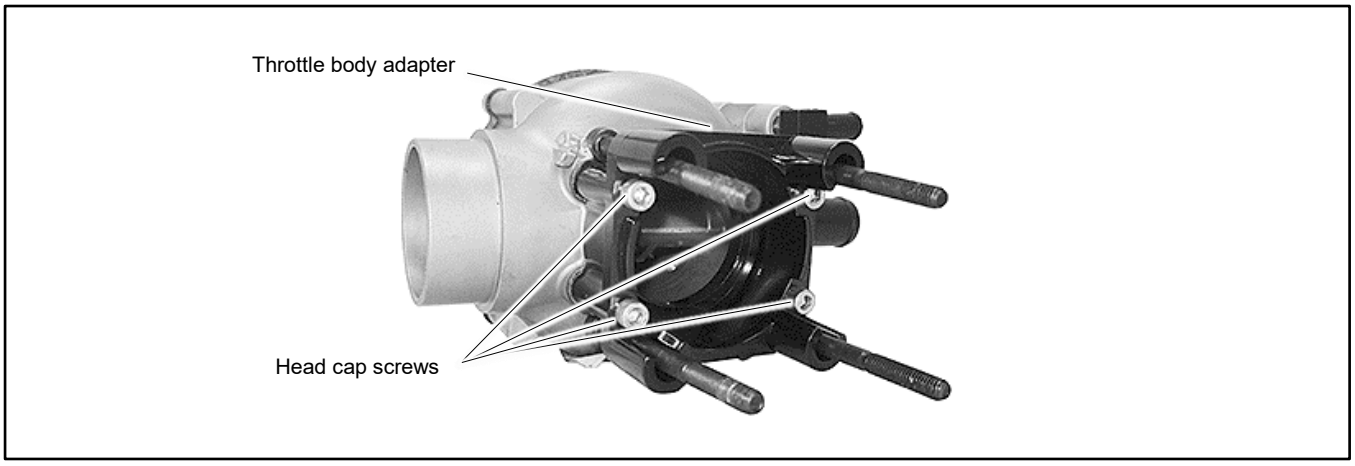


Figure 44 Throttle Body Adapter Location

4. Remove four socket head cap screws securing air-fuel mixer to throttle body adapter and remove adapter. See Figure 44.

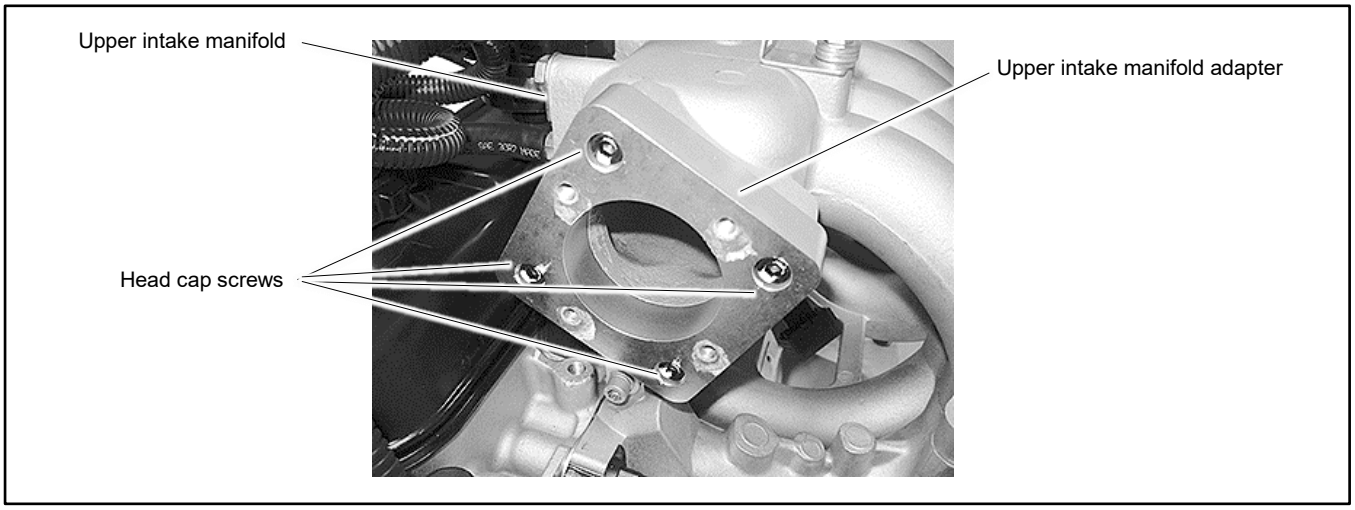


Figure 45 Upper Intake Manifold Location

5. Remove four socket head cap screws securing throttle body to upper intake manifold adapter and remove adapter from the upper intake manifold. See Figure 45.

3.7.10.2 Installation

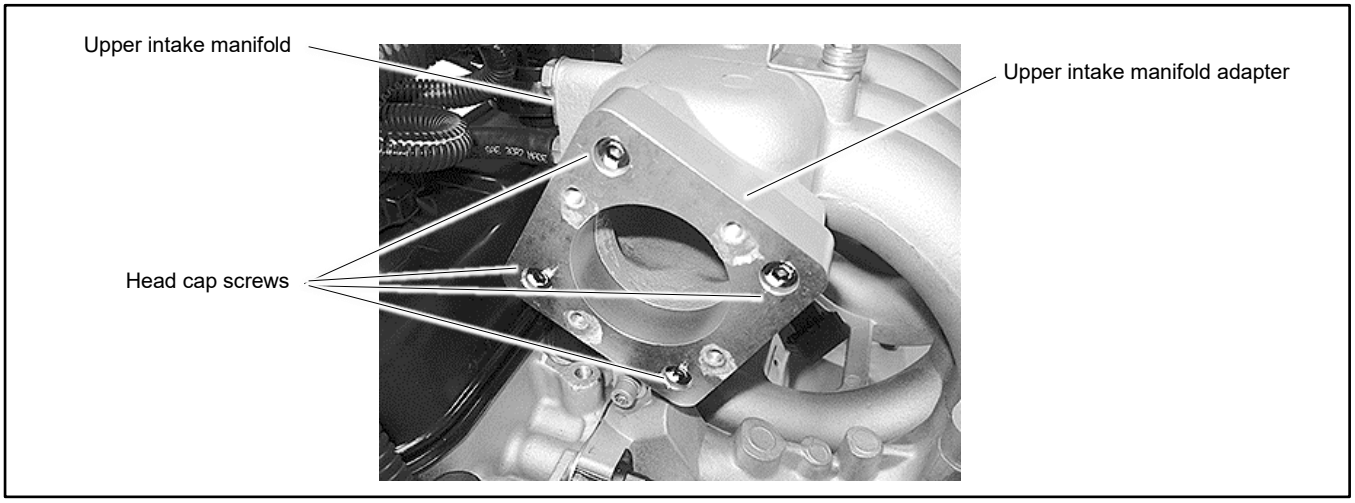


Figure 46 Upper Intake Manifold Location

1. Install the throttle body upper intake manifold adapter to the upper intake manifold. Secure with four socket head cap screws. See Figure 46.

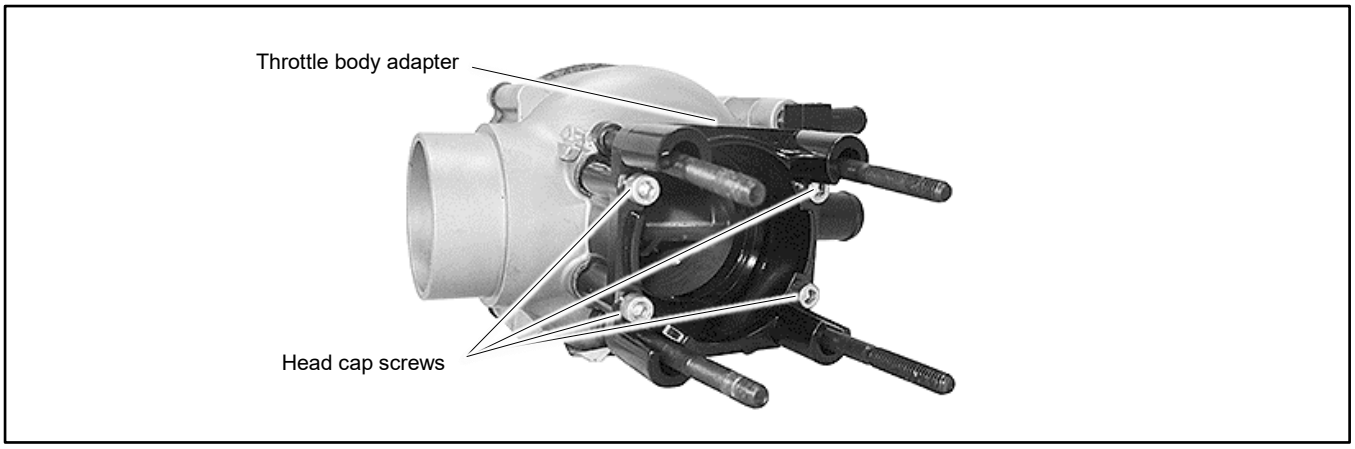


Figure 47 Throttle Body Adapter Location

2. Install the air-fuel mixer and throttle body adapter to the air-fuel mixer valve. Secure with four socket head cap screws. See Figure 47.
3. Use a lubricant on O-rings. Install the throttle body into the air-fuel mixer valve adapter. Use caution not to damage O-rings.

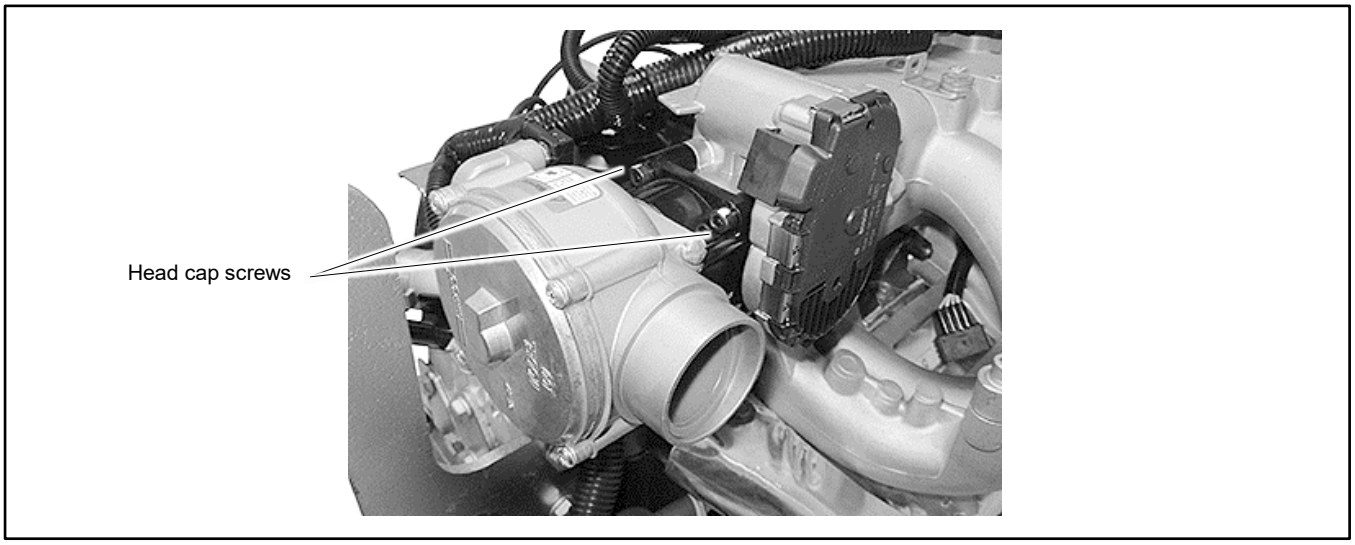


Figure 48 Air-fuel Mixer Valve Installation

4. Install the air-fuel mixer valve and throttle body to the upper intake manifold as a unit. Secure with four socket head cap screws. See Figure 48.

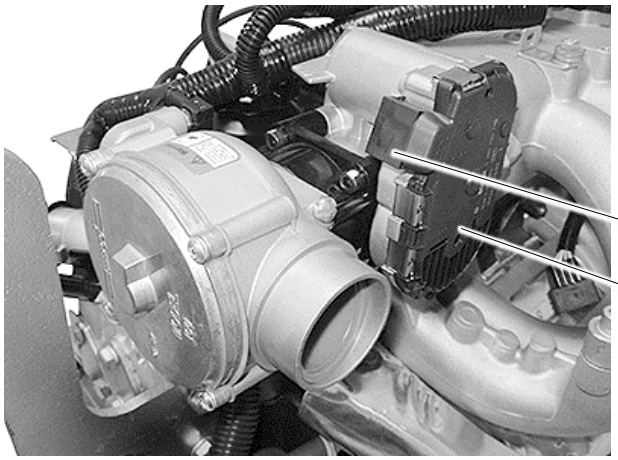


Figure 49 Throttle Body Location

5. Install electrical connection at throttle body to throttle position sensor. See Figure 49.

3.7.11 Turbocharger Removal and Replacement (KG2204T Only)

3.7.11.1 Turbocharger Removal



Figure 50 Oil Feed Line Location

1. Drain the oil from the engine.
2. Disconnect the nut on the turbocharger oil feed line fitting. Pull the oil feed line slightly away from the fitting. See Figure 50.



Figure 51 Turbocharger Oil Drain Line Fitting Location

3. Using a wrench to hold the oil drain fitting in place, loosen and disconnect the nut on the turbocharger oil drain line fitting. Pull the turbocharger oil drain line away from the fitting. See Figure 51.



Figure 52 Turbocharger Compressor Discharge

4. Loosen the hose clamp on the turbocharger compressor discharge. Disconnect the hose from the turbocharger compressor discharge. See Figure 52.

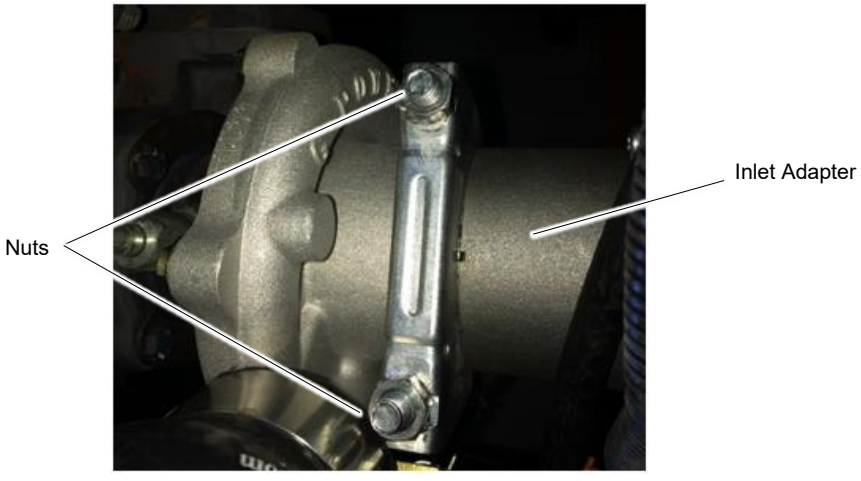


Figure 53 Inlet Adapter Location

5. Remove the two nuts on the clamp on the turbocharger compressor inlet adapter. Remove the clamp and disconnect the inlet adapter. See Figure 53.

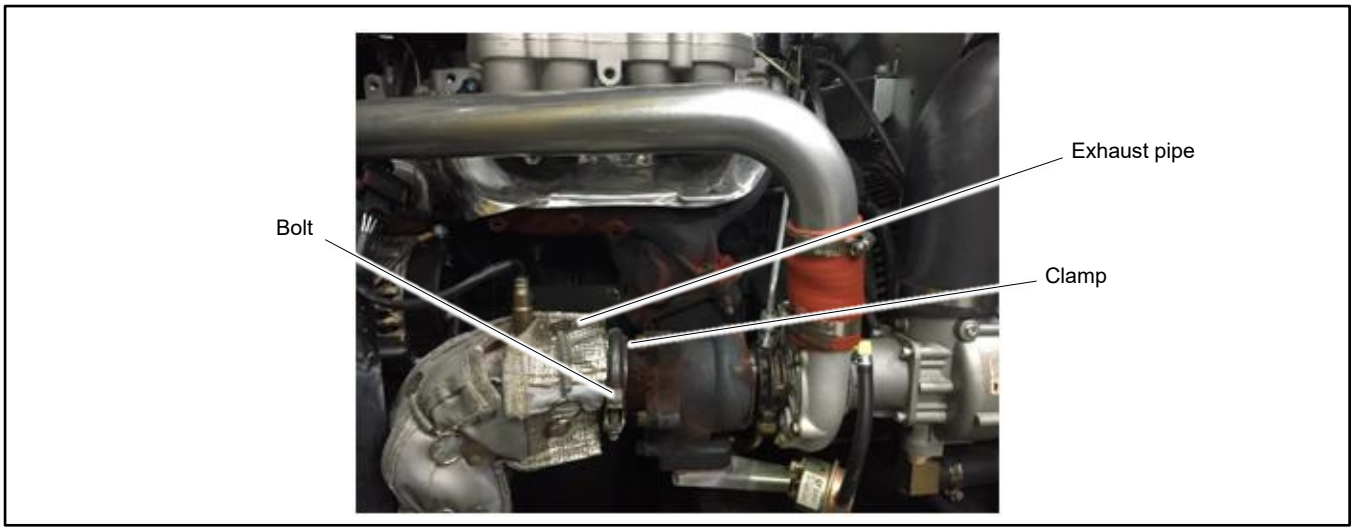


Figure 54 Exhaust Pipe Location

6. Remove the bolt on the v-band clamp on the turbocharger outlet adapter. Remove the clamp and then remove the exhaust pipe from the turbocharger outlet adapter. See Figure 54.

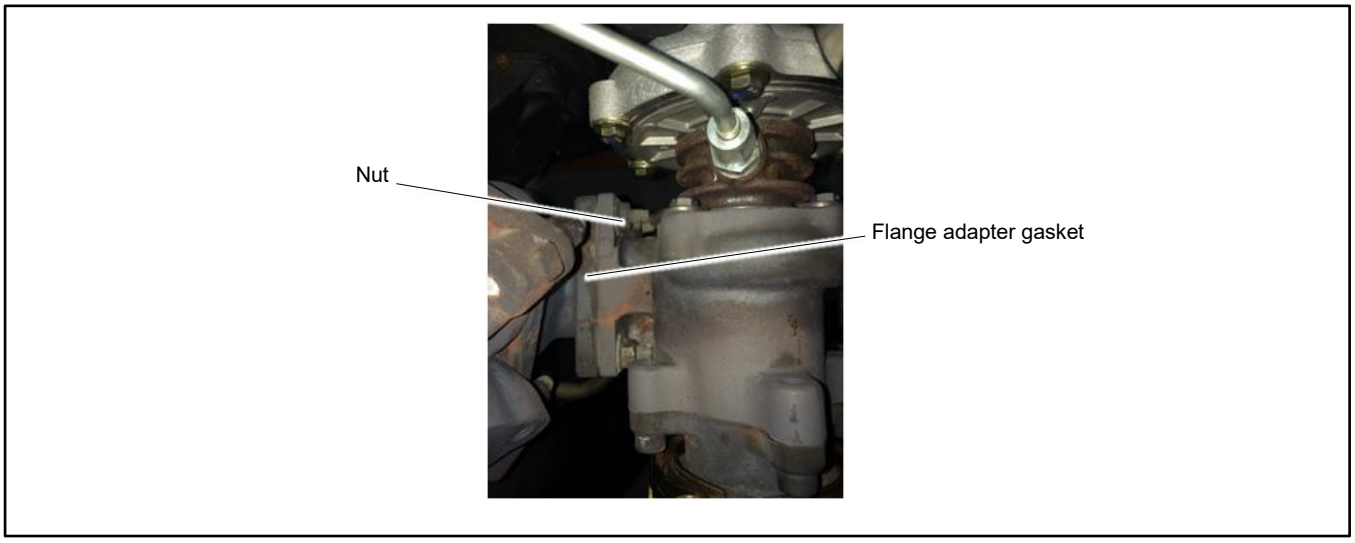


Figure 55 Flange Adapter Gasket Location

7. Remove the four nuts on the turbocharger exhaust adapter flange. Remove the turbocharger from the exhaust adapter flange and remove the flange adapter gasket. See Figure 55.

3.7.11.2 Turbocharger Installation

Note:
See the engine parts catalog for replacement part numbers as needed.

Reverse steps of the removal process.

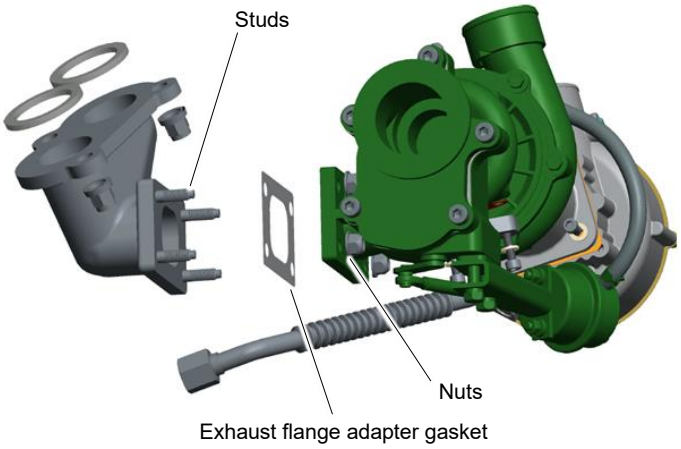


Figure 56 Exhaust Flange Adapter

1. Remove the existing exhaust studs and install four new studs into the exhaust flange adapter. Tighten to 20 ± 3 Nm (14.8 ± 2 ft.lb.). Install the new exhaust flange adapter gasket. Install the turbocharger onto the exhaust flange adapter. Assemble four new nuts onto exhaust flange adapter studs and tighten to 28 ± 3 Nm (21 ± 2 ft.lb.). See Figure 56.



Figure 57 V-Band Clamp Location

2. Connect the exhaust pipe to the turbocharger outlet and install the v-band clamp. Install the clamp bolt and tighten to 20 Nm (14.8 ± 2 ft.lb.). See Figure 57.

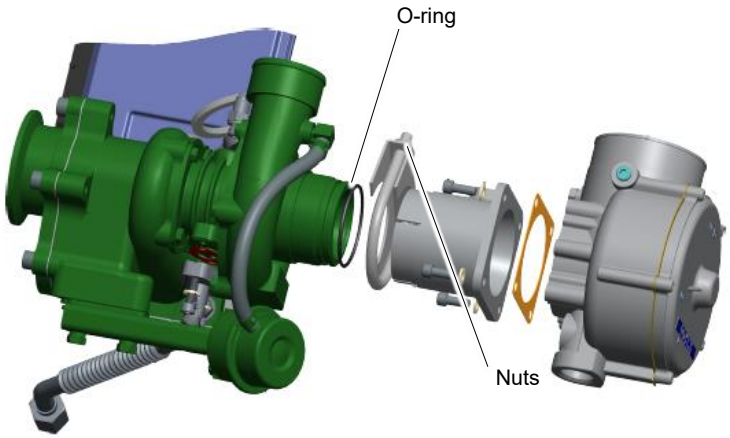


Figure 58 O-Ring Location

3. Inspect the O-ring on the turbocharger compressor inlet and replace if damaged. Connect the inlet adapter to the turbocharger compressor inlet. Install the clamp onto the inlet adapter using two nuts. Tighten the nuts to 14 ±1 Nm (10 ±1 ft.lb.). See Figure 58.



Figure 59 Turbocharger Compressor Discharge Location

4. Connect the turbocharger compressor discharge hose to the turbocharger compressor outlet. Tighten the hose clamp onto the hose (4.5 Nm [3.3 ft.lb.]). See Figure 59.



Figure 60 Turbocharger Oil Drain Line Fitting Location

5. Connect the turbo oil drain line to the fitting in the oil pan. Apply a light coating of engine oil to the fitting thread. Thread the nut onto the fitting by hand. Use a wrench to hold the fitting adjacent to the oil pan in place while tightening the nut onto the fitting to 62 ± 3 Nm (46 ± 2 ft.lb.). See Figure 60.



Figure 61 Fitting and Nut Location

6. Connect the turbo oil feed line onto the fitting on the turbocharger. Apply a light coating of engine oil to the fitting thread. Tighten the nut onto the fitting to 16 ± 1 Nm (11.8 ± 1 ft.lb.). See Figure 61.

3.7.12 Intake Manifold Removal and Installation

WARNING	**Hot engine and exhaust system.** **Can cause severe injury or death.** Do not work on the engine until it cools.

Hot engine components. Can cause severe injury or death. Never operate the engine with heat shields or guards removed.

3.7.12.1 Removal

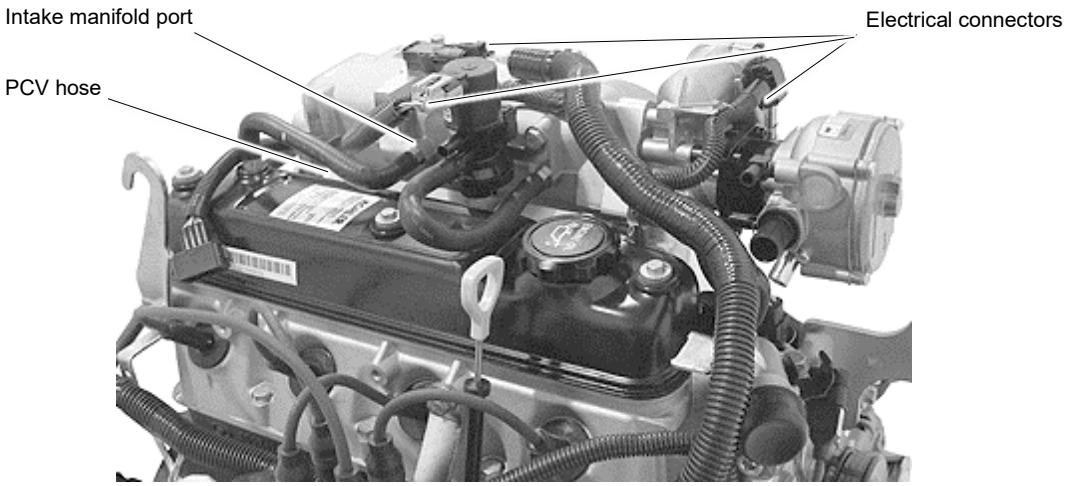


Figure 62 PCV Hose Location

1. Disconnect three electrical connectors from intake manifold sensors. See Figure 62.
2. Disconnect PCV hose from intake manifold port. Close all openings.

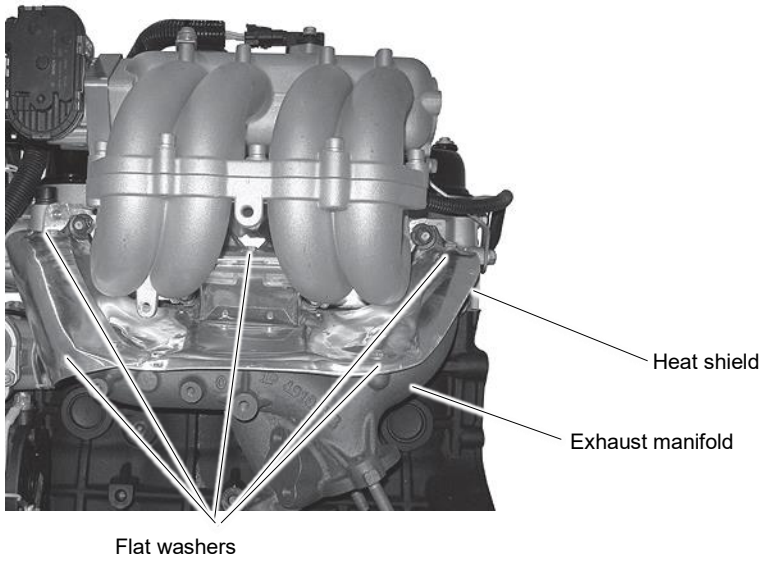


Figure 63 Heat Shield Location

3. Remove five heat shield mounting bolts and flat washers from heat shield. See Figure 63.
4. Remove heat shield from exhaust manifold.

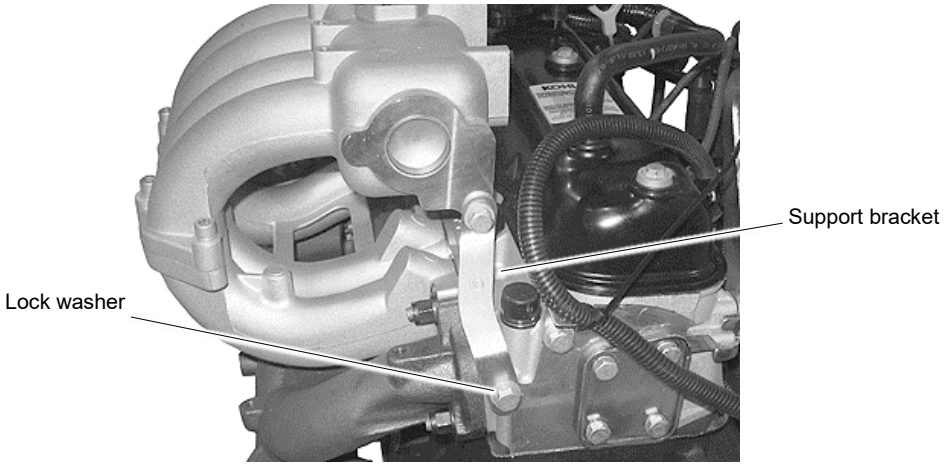


Figure 64 Support Bracket Location

5. Remove bolt, flat washer, and lock washer from intake manifold-to-cylinder head support bracket. See Figure 64.

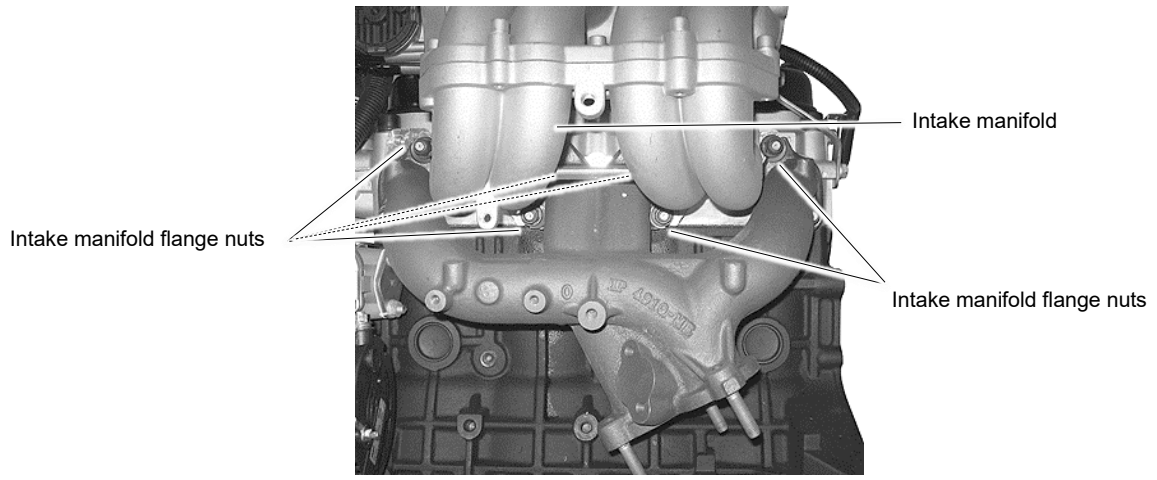


Figure 65 Intake Manifold Location

6. Remove six intake manifold flange nuts and remove intake manifold from cylinder head. See Figure 65.

NOTICE
Do not use harsh cleaning operations to clean intake manifold or cylinder head. Use of air buffers and steel scrapers may remove intake manifold or cylinder head material damaging intake manifold and/or cylinder head.

3.7.12.2 Inspection

1. Inspect intake manifold for cracks, corrosion holes, or erosion around the gasket area.
2. If inspection reveals any damage, replace intake manifold.

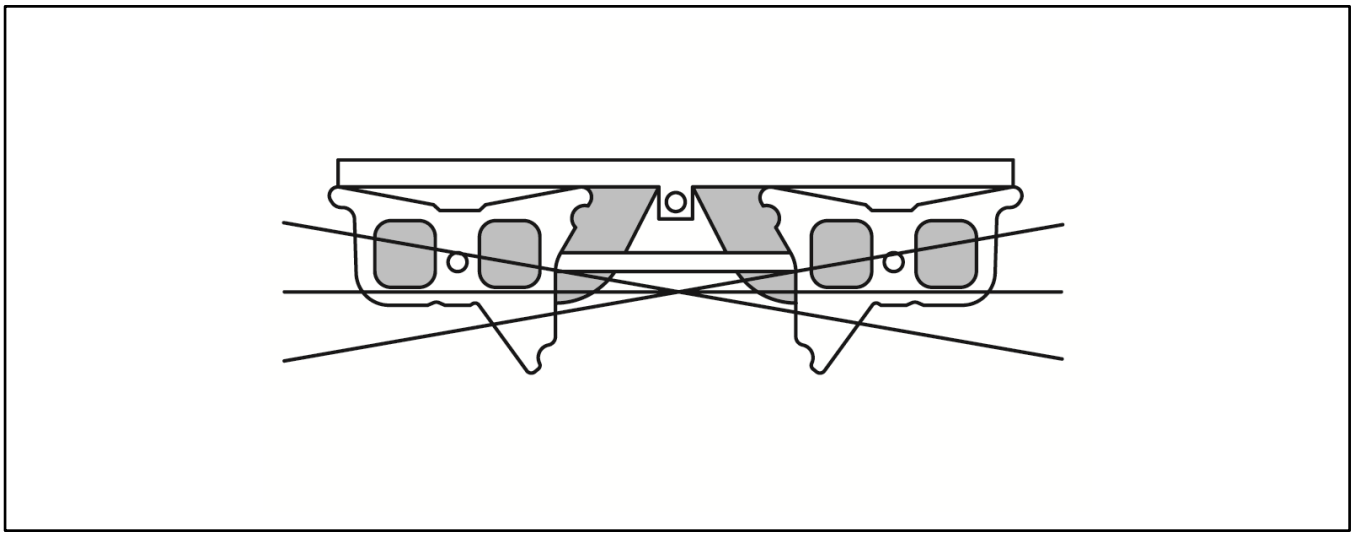


Figure 66 Intake Manifold Inspection

3. Inspect intake manifold for distortion using a straight edge and feeler gauge as shown. See Figure 66.
4. If intake manifold distortion exceeds specification, resurfacing or replacement of intake manifold is required.

Intake Manifold Distortion Limit
0.40 mm (0.0157 in.)

5. Inspect intake/exhaust manifold gasket for damage. If inspection reveals damage, remove exhaust manifold and replace intake/exhaust manifold gasket. See “Exhaust Manifold Removal and Installation”.

3.7.12.3 Installation

NOTE:
If exhaust manifold was removed, it must be installed before installation of intake manifold. See “Exhaust Manifold Removal and Installation”.

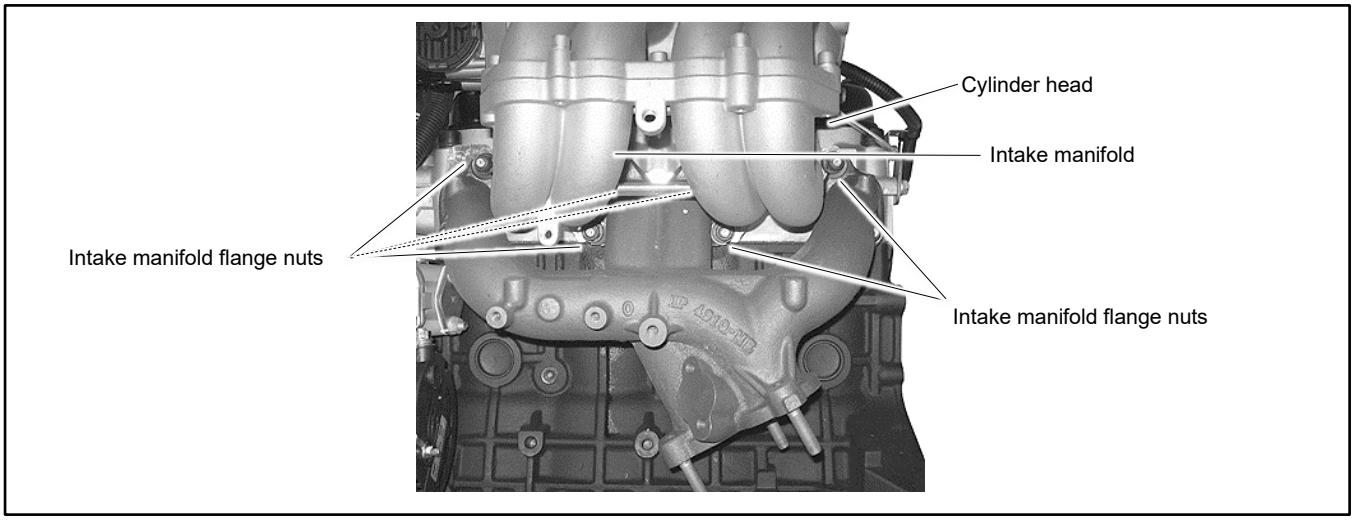


Figure 67 Intake Manifold Location

1. Install intake manifold to cylinder head with six flange nuts. See Figure 67.

2. Torque intake manifold flange nuts to specification.

Intake Manifold Flange Nut Torque
20 Nm (15 ft.lb.)

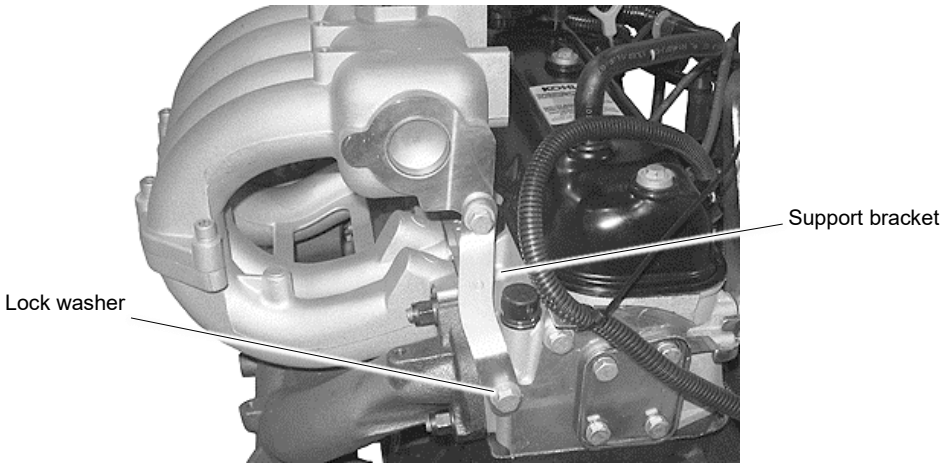


Figure 68 Support Bracket Location

3. Install bolt, flat washer, and lock washer to intake manifold-to-cylinder head support bracket. Tighten bolt. See Figure 68.

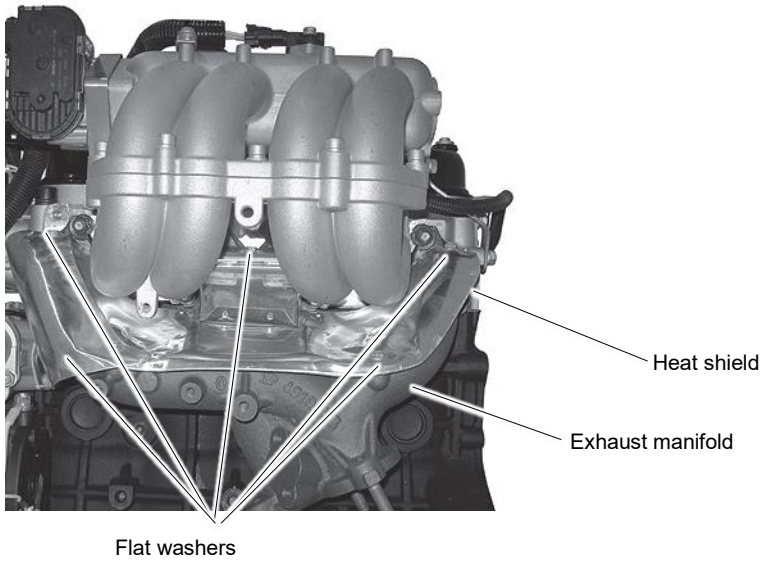


Figure 69 Heat Shield Location

4. Install heat shield to exhaust manifold with five mounting bolts and flat washers. Tighten bolts. See Figure 69.

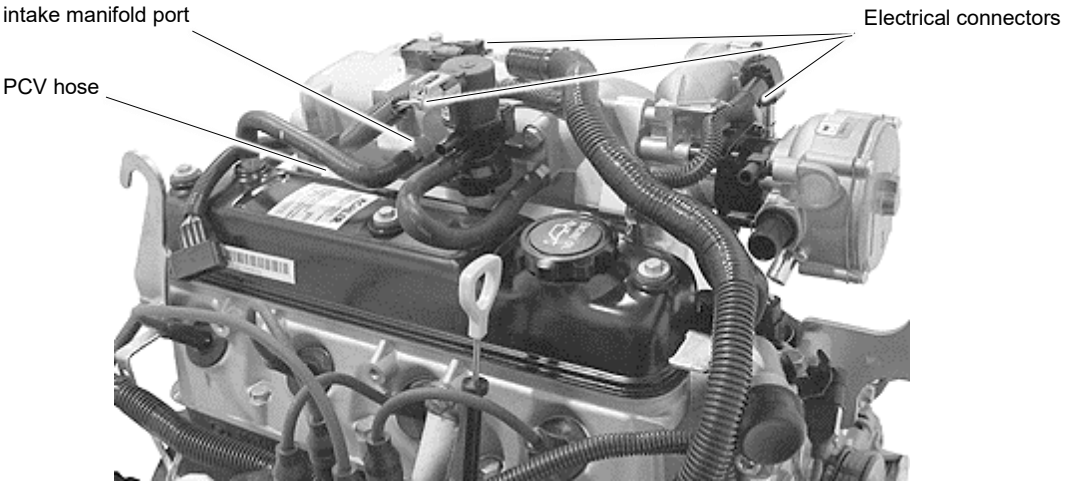


Figure 70 PCV Hose Location

5. Connect PCV hose to intake manifold port. See Figure 70.
6. Connect three electrical connectors to intake manifold sensors.

3.7.13 Upper Intake Manifold Removal and Installation

WARNING	**Hot engine and exhaust system.** **Can cause severe injury or death.** Do not work on the engine until it cools.

Hot engine components. Can cause severe injury or death. Never operate the engine with heat shields or guards removed.

3.7.13.1 Removal

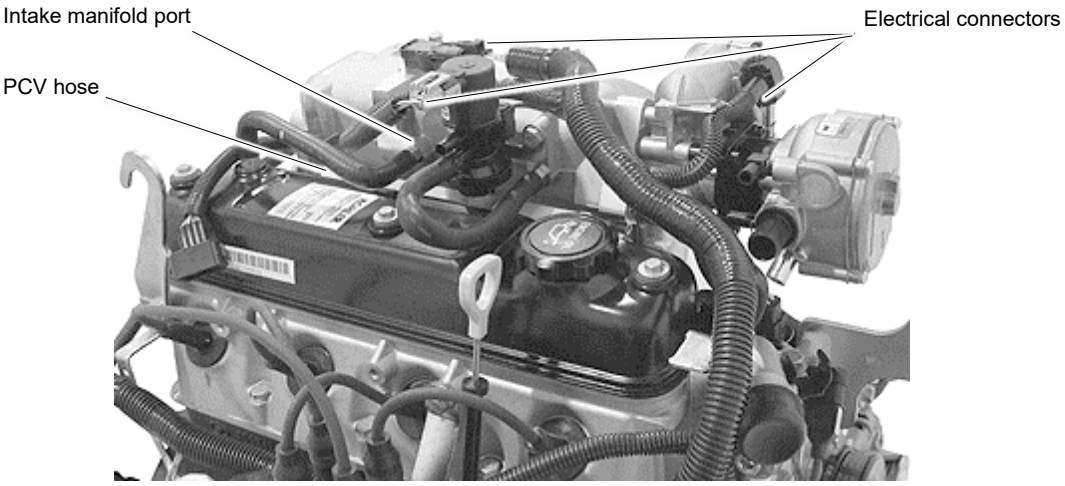


Figure 71 PCV Hose Location

1. Disconnect three electrical connectors from intake manifold sensors. See Figure 71.
2. Disconnect PCV hose from intake manifold port. Close all openings.

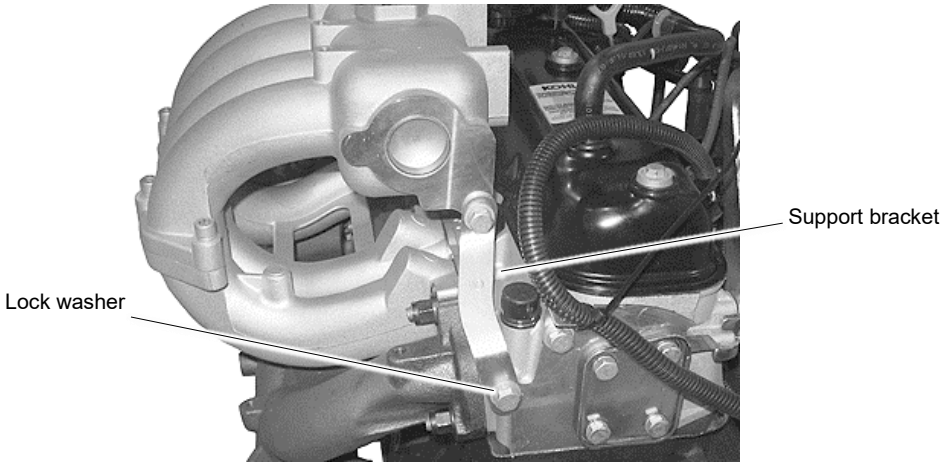


Figure 72 Support Bracket Location

3. Remove bolt, flat washer, and lock washer from intake manifold-to-cylinder head mounting bracket. See Figure 72.

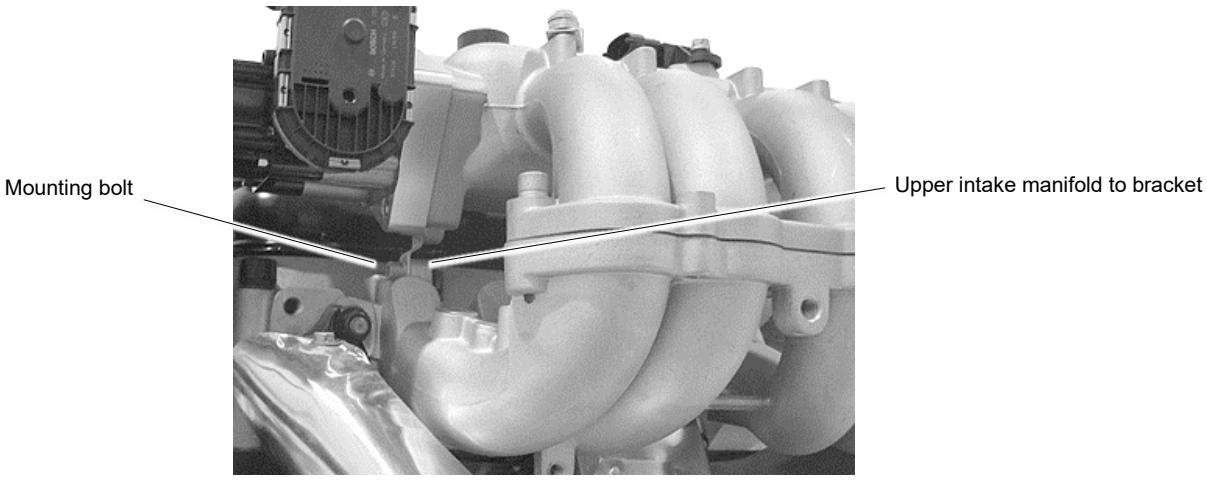


Figure 73 Upper Intake Manifold to Bracket Location

4. Remove mounting bolt securing upper intake manifold to bracket. See Figure 73.

Note:
Take notice of upper intake mounting bolt length differences during removal for reference during installation.

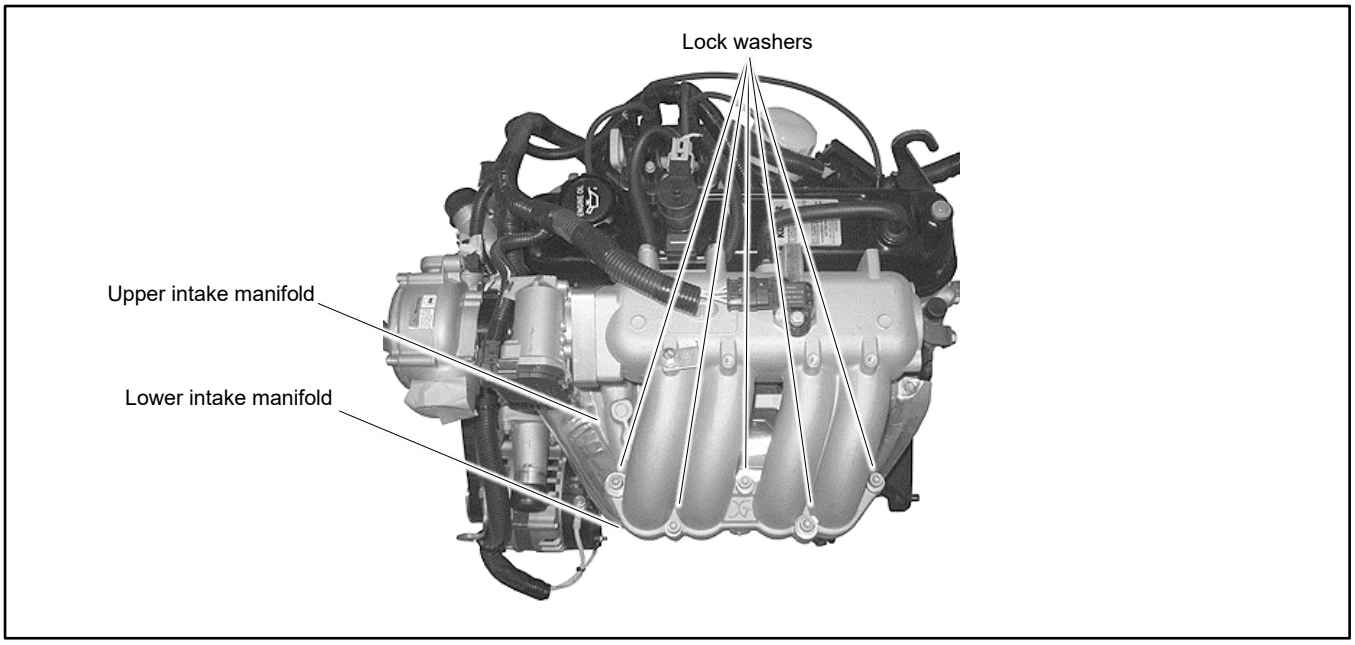


Figure 74 Upper/Lower Manifold Location

5. Remove five bolts, flat washers, and lock washers securing upper intake to lower intake manifold. See Figure 74.
6. Remove upper intake manifold from lower intake manifold. Cap/plug all openings.



Figure 75 Intake Manifold Gasket Location

7. Remove old intake manifold gasket from lower intake manifold. See Figure 75.

NOTICE
Do not use harsh cleaning operations to clean upper and lower intake manifolds. Use of air buffers and steel scrapers can remove intake manifold material very quickly, damaging intake manifolds.

8. Clean gasket surfaces.

3.7.13.2 Inspection



Figure 76 Alignment Pins Inspection

1. Inspect alignment pins for distortion or looseness. See Figure 76.
   a. If inspection reveals distortion, replace alignment pins.
   b. If inspection reveals loose alignment pins, lightly tap alignment pins back into lower intake manifold with a soft faced hammer.
2. Inspect mounting bolt holes for cracks or stripped threads. See Figure 76.
3. If inspection of bolt holes reveals cracks, replace lower intake manifold. If inspection reveals stripped bolt hole threads, repair bolt hole threads.

3.7.13.3 Installation

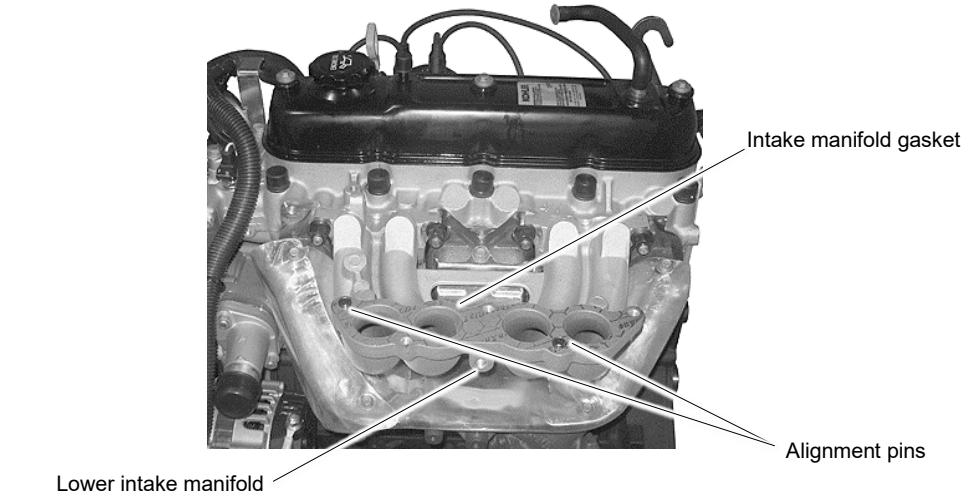


Figure 77 Intake Manifold Gasket Location

1. Install new upper-to-lower intake manifold gasket to lower intake manifold. See Figure 77.

NOTICE
Ensure upper intake is properly positioned on lower intake alignment pins (C) or damage may occur.

2. Install upper intake to lower intake.

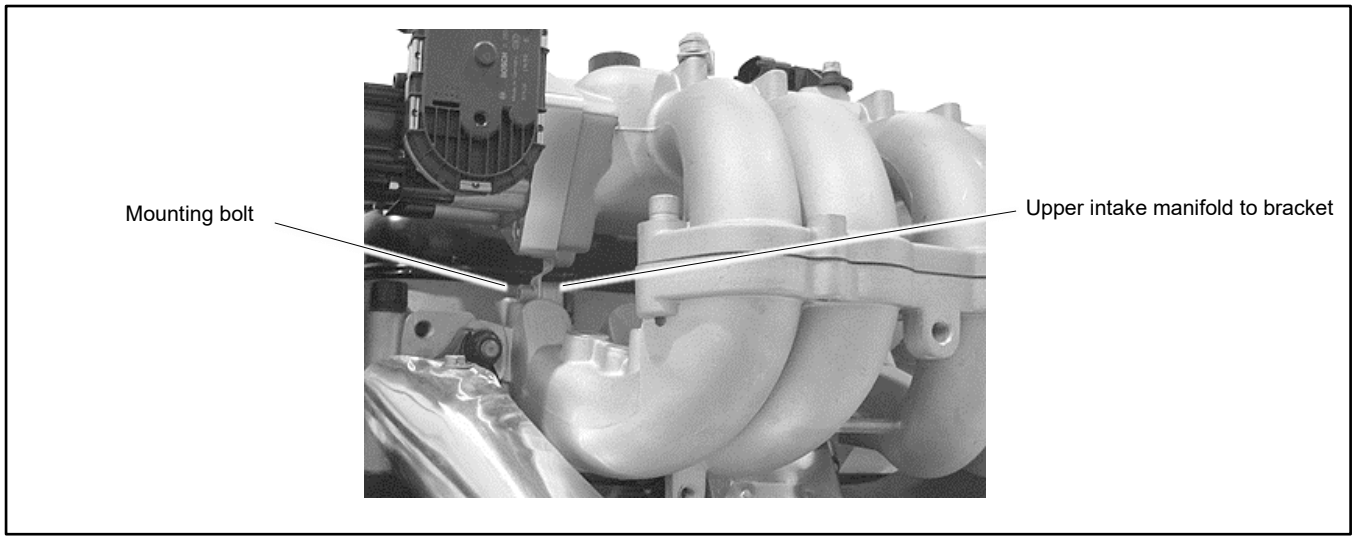


Figure 78 Upper Intake Manifold to Bracket Location

3. Install mounting bolt (D) securing upper intake manifold to bracket (E). Do not tighten bolt at this time. See Figure 78.

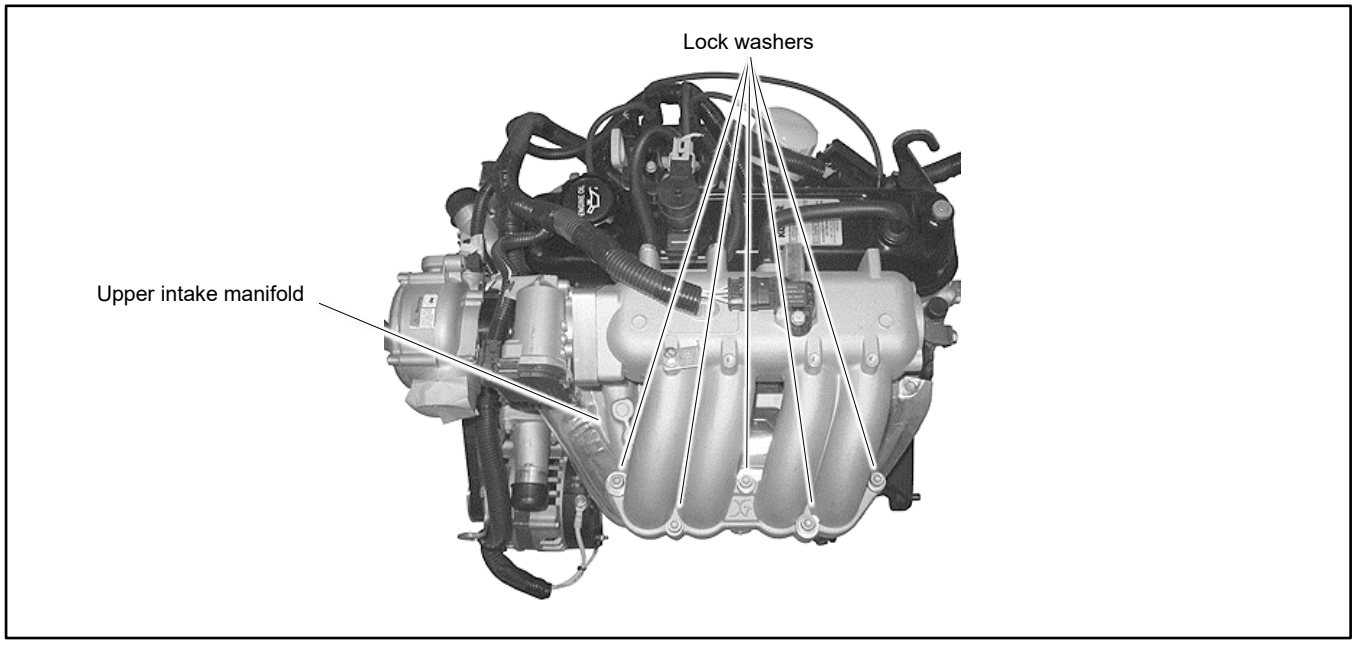


Figure 79 Upper Intake Manifold Location

4. Install five bolts, flat washers, and lock washers to upper intake manifold as noted during removal. Tighten bolts. See Figure 79.

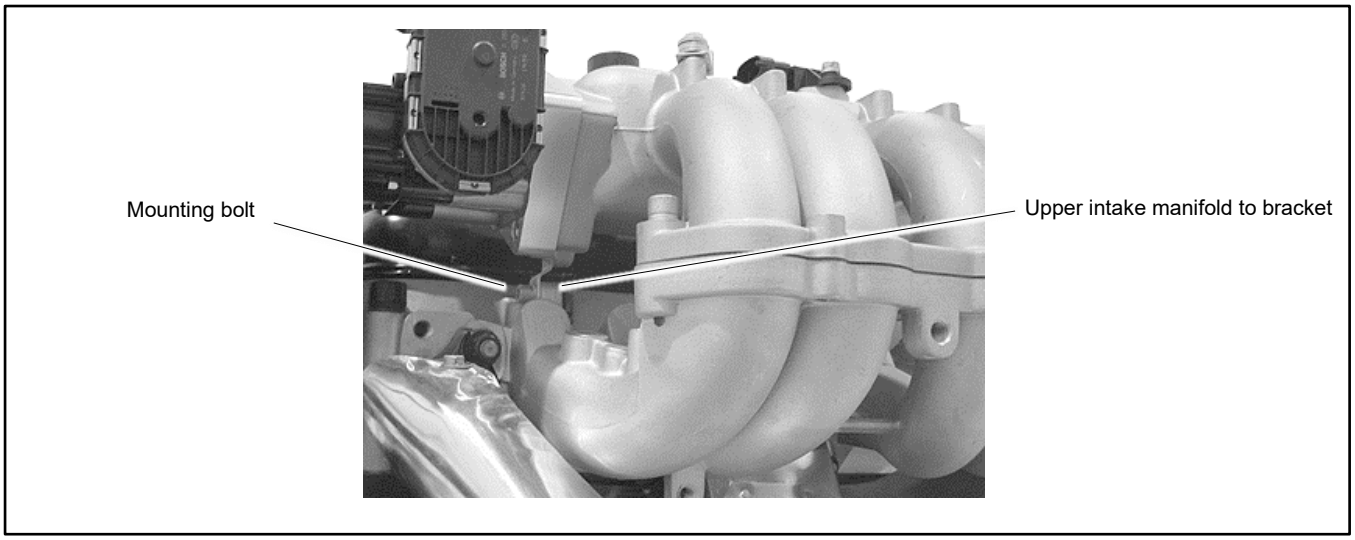


Figure 80 Upper Intake Manifold to Bracket Location

5. Tighten mounting bolt securing upper intake manifold to bracket. See Figure 80.

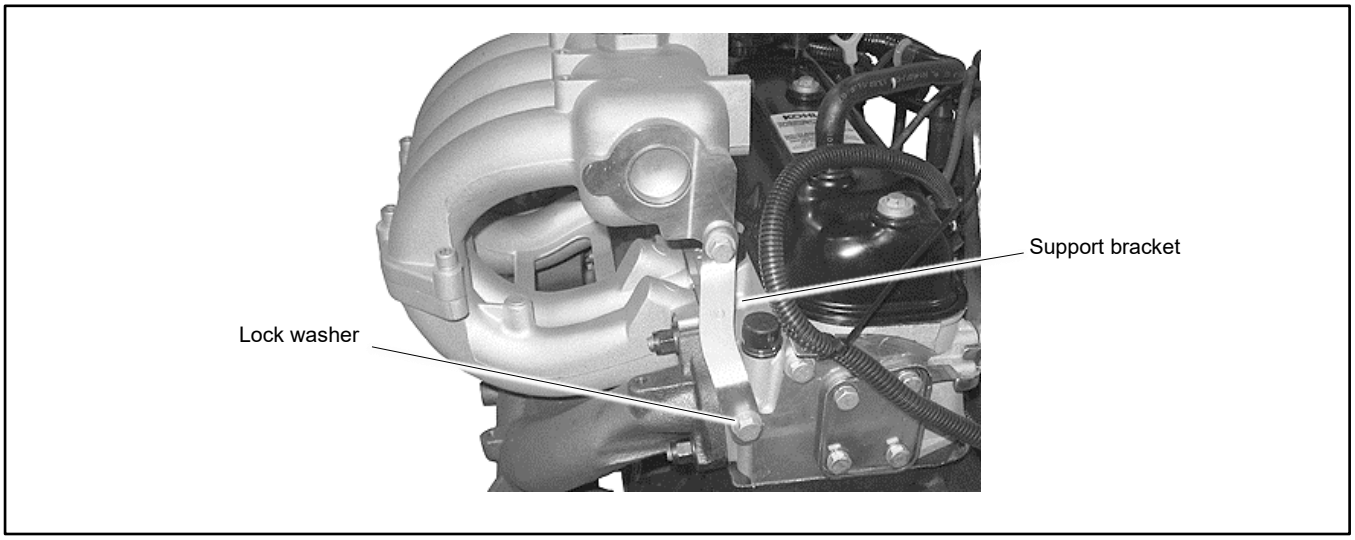


Figure 81 Cylinder Head Bracket Location

6. Install rear intake manifold-to-cylinder head mounting bracket bolt, flat washer, and lock washer to manifold-to-cylinder head mounting bracket. Tighten bolt. See Figure 81.

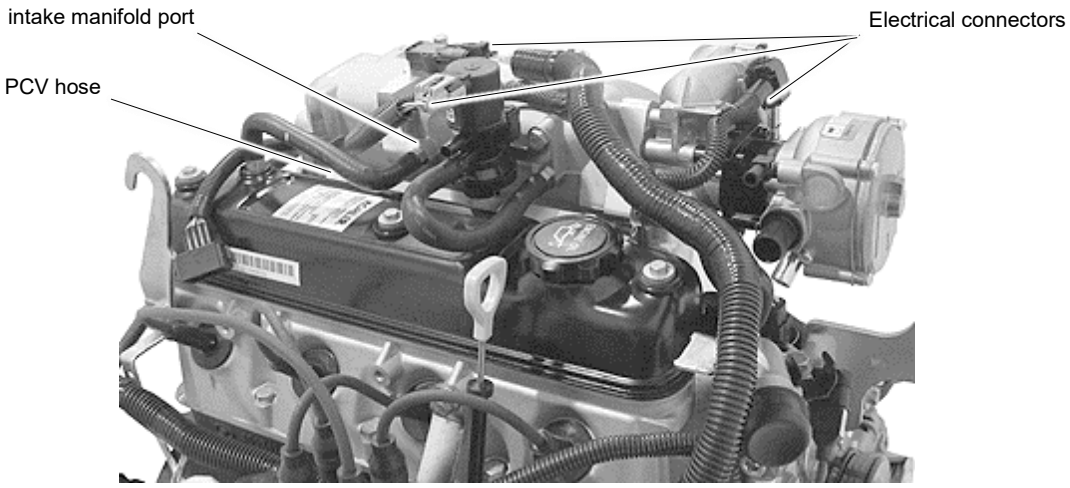


Figure 82 PCV Hose Location

7. Connect PCV hose to intake manifold port. See Figure 82.
8. Connect three electrical connectors to intake manifold sensors.

3.7.14 Exhaust Manifold Removal and Installation

⚠ WARNING	**Hot engine and exhaust system.** **Can cause severe injury or death.** Do not work on the engine until it cools.
	

Hot engine components. Can cause severe injury or death. Never operate the engine with heat shields or guards removed.

3.7.14.1 Removal

1. Remove intake manifold. See “Intake Manifold Removal and Installation”.

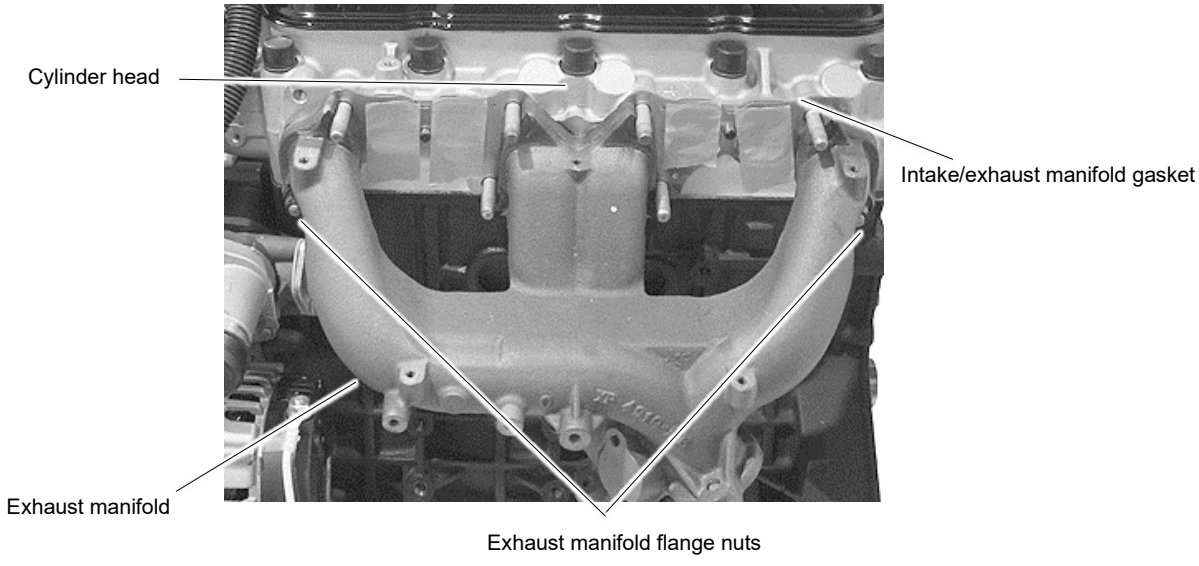


Figure 83 Exhaust Manifold Location

2. Remove two exhaust manifold flange nuts and remove exhaust manifold from cylinder head. See Figure 83.
3. Remove intake/exhaust manifold gasket from cylinder head. Close all openings.

NOTICE
Do not use harsh cleaning operations to clean intake manifold or cylinder head. Use of air buffers and steel scrapers may remove intake manifold and cylinder head material, damaging intake manifold and cylinder head.

4. Remove intake/exhaust manifold gasket from intake/exhaust manifolds and cylinder head. Close all openings.

3.7.14.2 Inspection

1. Inspect exhaust manifold for cracks, rust holes, or erosion around the gasket area.
2. If inspection reveals cracks, rust holes or erosion around gasket area, replace intake manifold.

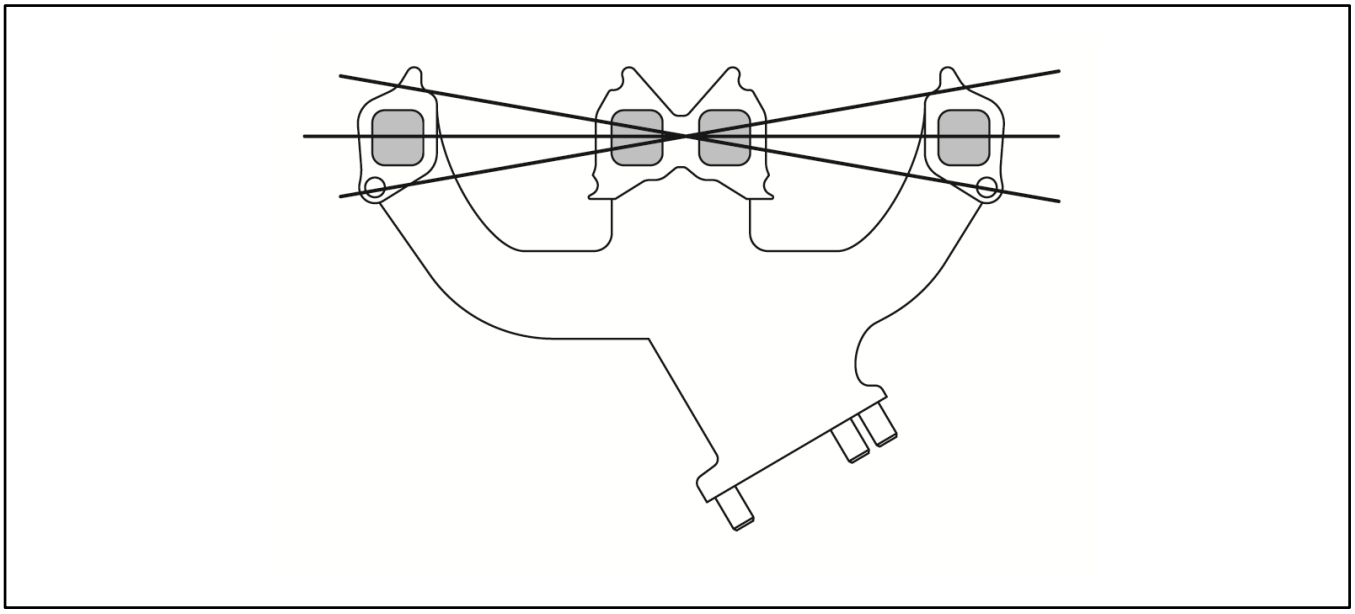


Figure 84 Exhaust Manifold Inspection

3. Inspect exhaust manifold for distortion using a straightedge and feeler gauge as shown. See Figure 84.
4. If exhaust manifold distortion exceeds specification, resurfacing or replacement of exhaust manifold is required.

Exhaust Manifold Distortion Limit
0.40 mm (0.0157 in.)

5. Inspect exhaust manifold to pipe mounting studs for being loose, broken, or have stripped threads.
6. If exhaust pipe mounting studs are loose, broken, or have stripped threads, tighten or replace manifold to pipe mounting studs.

3.7.14.3 Installation

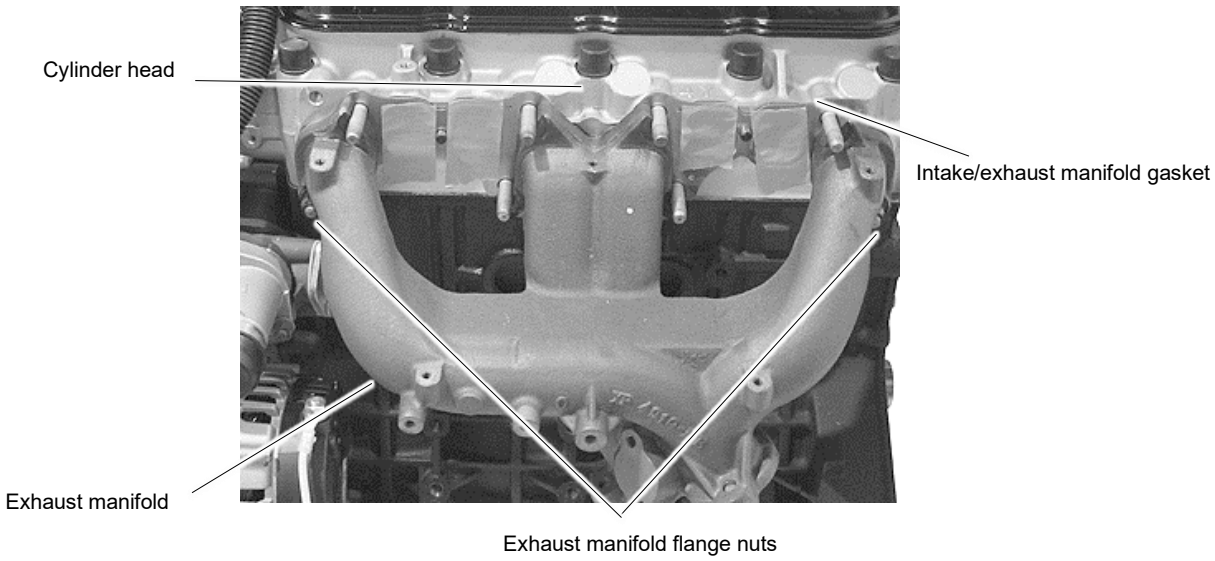


Figure 85 Exhaust Manifold Location

1. Install new intake/exhaust manifold gasket to cylinder head. See Figure 85.
2. Install exhaust manifold to cylinder head with two flange nuts.
3. Torque exhaust manifold flange nuts.

Exhaust Manifold Flange Nut Torque
20 Nm (15 ft.lb.)

4. Install intake manifold to cylinder head. See “Intake Manifold Removal and Installation”.

3.7.15 Remove and Install Flywheel

CAUTION	
	**Damaged harmonic balancer, crankshaft, or flywheel.** **Can cause personal injury.** Broken fragments from the harmonic balancer, crankshaft, and flywheel can be thrown from the engine. Do not use a hammer to install or remove. Inspect these parts for damage and replace if needed.

3.7.15.1 Removal

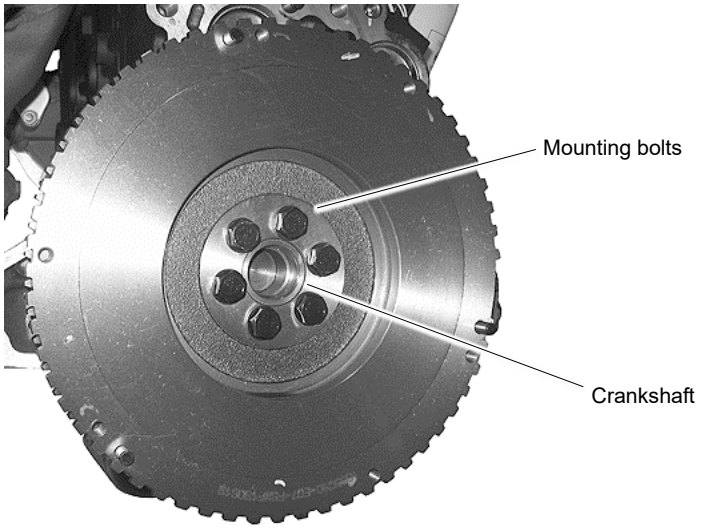


Figure 86 Crankshaft Location

1. Mark flywheel to crankshaft for proper indexing during assembly. See Figure 86.
2. Remove six flywheel mounting bolts from flywheel.
3. Remove flywheel from crankshaft.

3.7.15.2 Installation

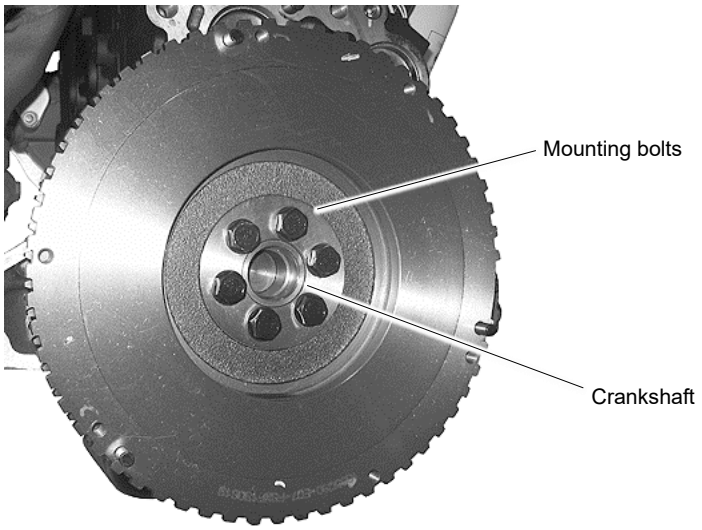


Figure 87 Crankshaft Location

1. Install flywheel to crankshaft as marked during removal. See Figure 87.
2. Install six flywheel mounting bolts. Torque bolts to specification.

Flywheel Bolt Torque
85 Nm (63 ft.lb.)

3. Run engine and check for leaks.

3.7.16 Remove and Install Crankshaft Position Sensor

3.7.16.1 Removal

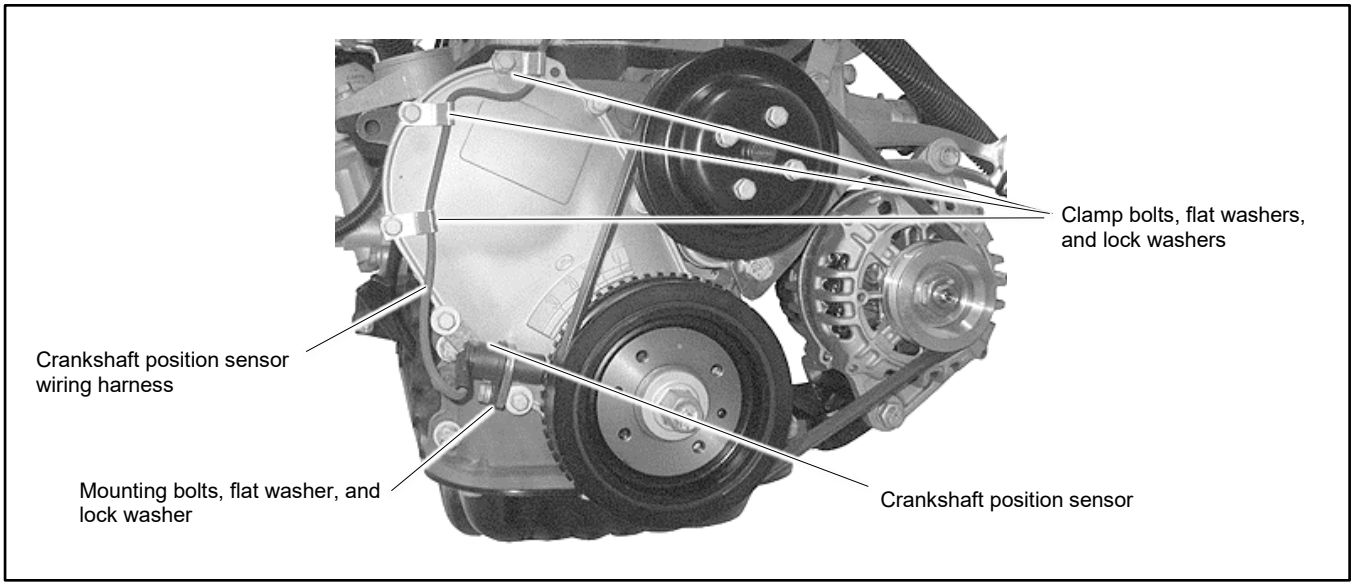


Figure 88 Crankshaft Position Sensor Location

1. Remove three electrical harness clamp bolts, flat washers, and lock washers from crankshaft position sensor wiring harness. See Figure 88.
2. Remove mounting bolt, flat washer, and lock washer from crankshaft position sensor and remove sensor.

3.7.16.2 Installation

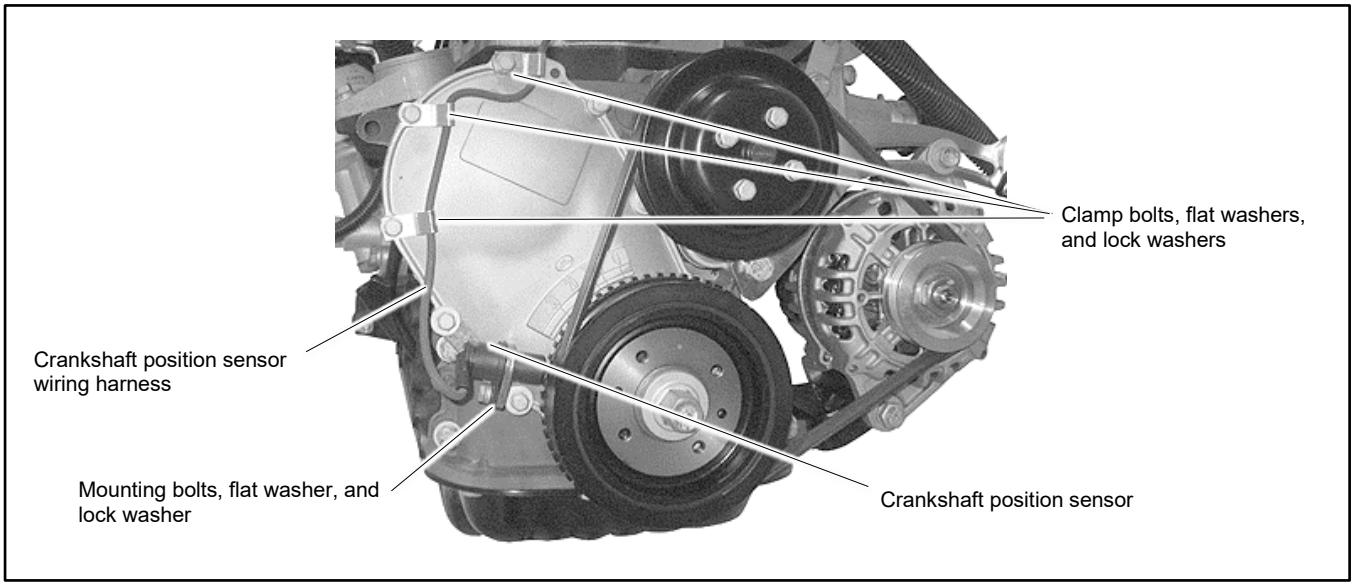


Figure 89 Crankshaft Position Sensor Location

1. Install crankshaft position sensor to mounting bracket. See Figure 89.
2. Install mounting bolt, flat washer, and lock washer to crankshaft position sensor.
3. Install three electrical harness clamp bolts, flat washers, and lock washer to crankshaft position sensor wiring harness.

3.7.17 Remove and Install Crankshaft Vibration Dampener

3.7.17.1 Removal

1. Remove drive belt. See “Drive Belt Removal and Installation”.

   NOTE:
   Use care not to damage crankshaft position sensor when removing crankshaft vibration dampener.

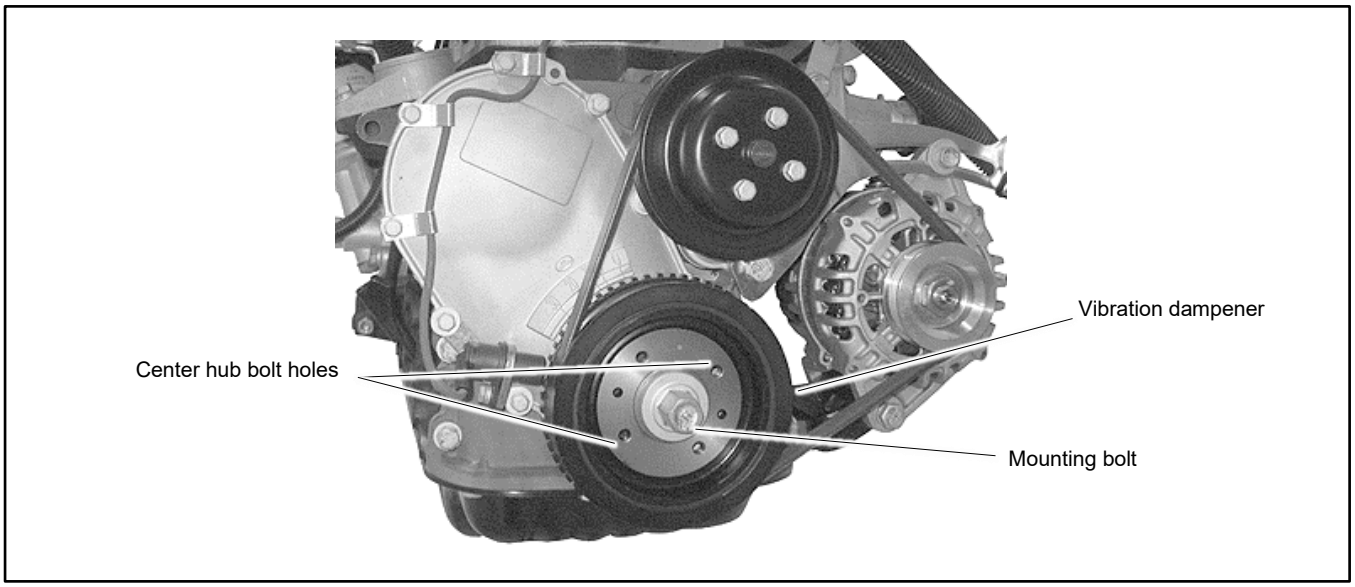


Figure 90 Crankshaft Vibration Dampener Location

2. Remove mounting bolt from crankshaft vibration dampener. See Figure 90.

NOTICE
Do not use a jaw puller on the outside of the crankshaft vibration dampener. Damage will occur to the crankshaft vibration dampener if jaw puller is used. Failure to use a center pilot to protect threads in crankshaft end will result in damage to crankshaft.

3. Install a puller with center pilot to the center hub bolt holes of crankshaft vibration dampener.
4. Remove crankshaft vibration dampener from crankshaft.

3.7.17.2 Inspection

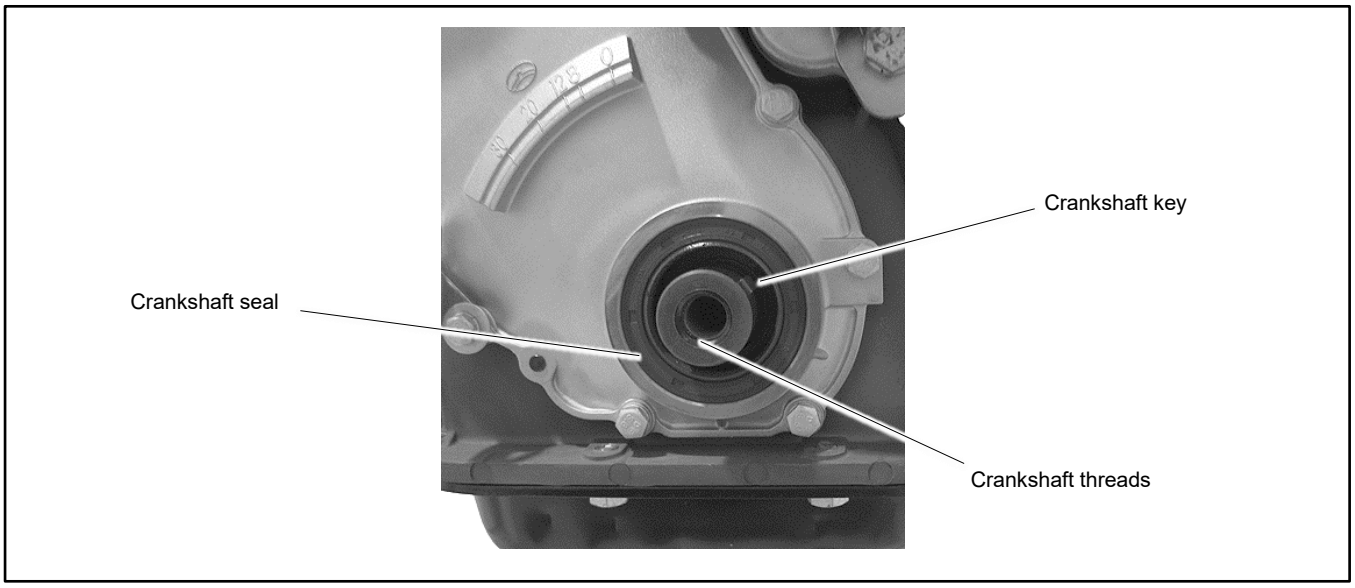


Figure 91 Crankshaft Key Location

1. Inspect crankshaft key for wear or damage. If crankshaft key is worn or damaged, replace crankshaft key. See Figure 91.
2. Inspect front crankshaft seal. If seal lip is damaged or worn, replace front crankshaft seal. See “Remove and Install Front Crankshaft Seal”.
3. Inspect crankshaft threads. If inspection reveals threads are damaged, repair threads.
4. Inspect crankshaft vibration dampener mounting bolt threads. If inspection reveals threads are damaged, replace crankshaft vibration dampener mounting bolt.

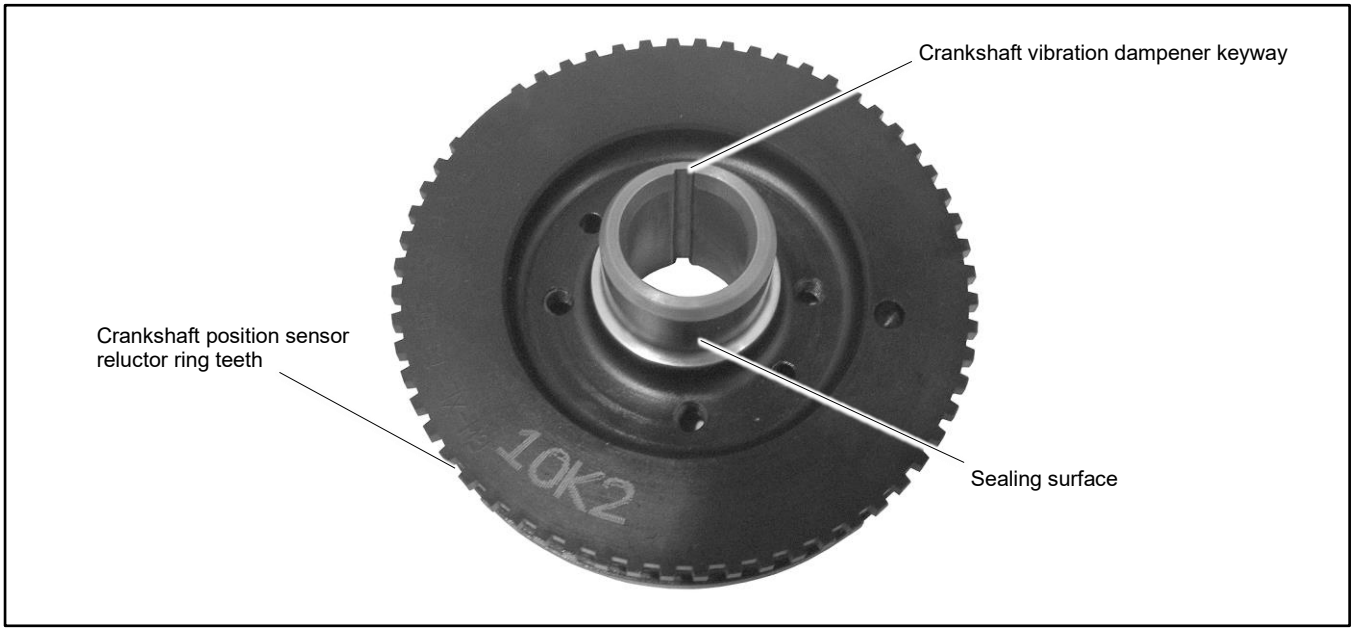


Figure 92 Crankshaft Vibration Dampener Keyway Location

5. Inspect condition of crankshaft vibration dampener keyway for wear or damage. See Figure 92.
6. Inspect condition of sealing surface of crankshaft vibration dampener for seal cutting.
7. Inspect condition of crankshaft position sensor reluctor ring teeth.
8. Inspect the rubber ring of crankshaft vibration dampener for separation from center hub.

9. Inspect condition of drive belt pulley.
10. If inspection reveals wear or damage, replace crankshaft vibration dampener.

3.7.17.3 Installation

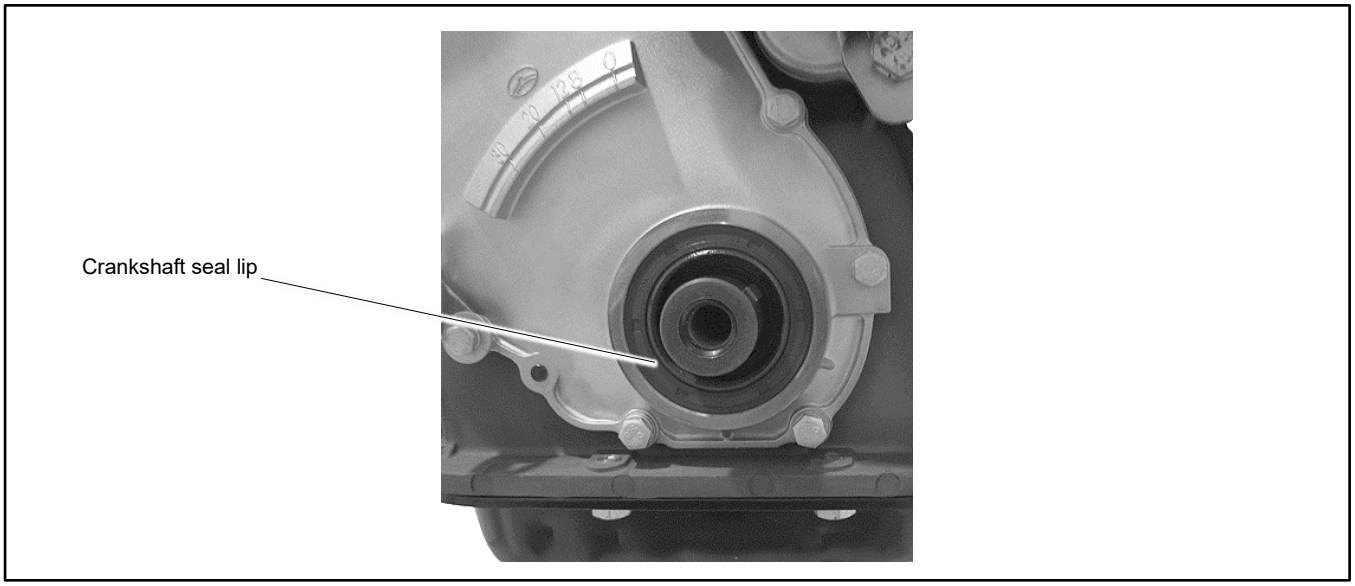


Figure 93 Crankshaft Seal Lip Location

1. Lubricate front crankshaft seal lip and sealing surface of crankshaft vibration dampener with clean engine oil. See Figure 93.

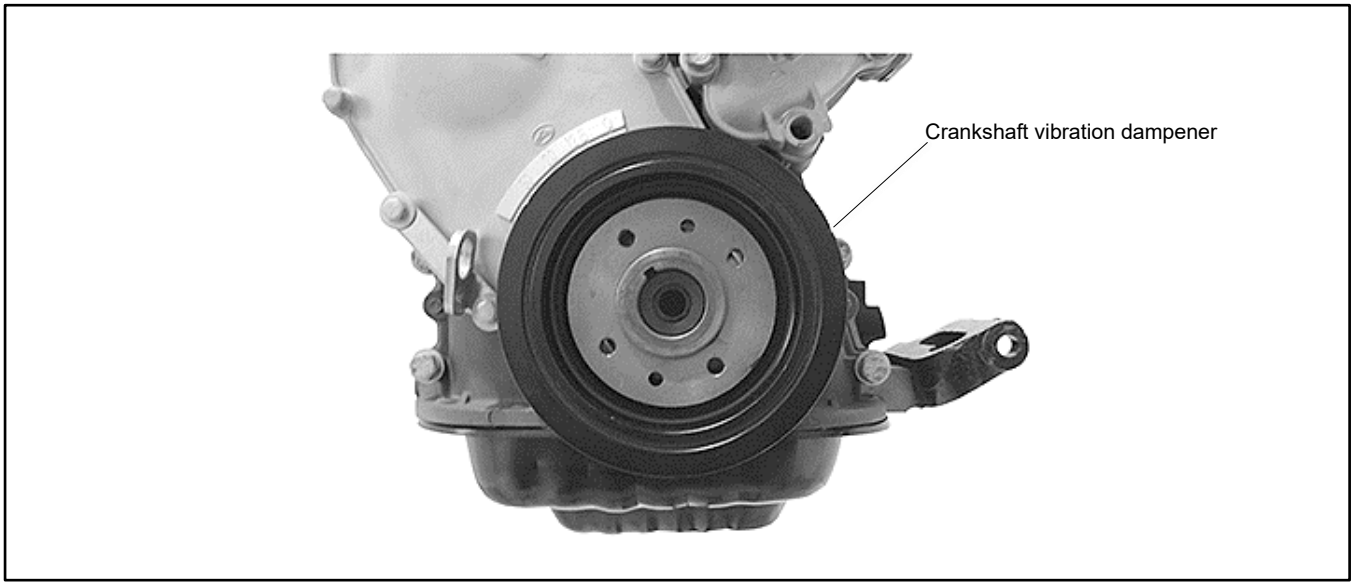


Figure 94 Crankshaft Vibration Dampener Location

2. Carefully install crankshaft vibration dampener to crankshaft so as not to damage front crankshaft seal. Tap crankshaft vibration dampener with a soft face hammer to seat dampener to crankshaft. See Figure 94.

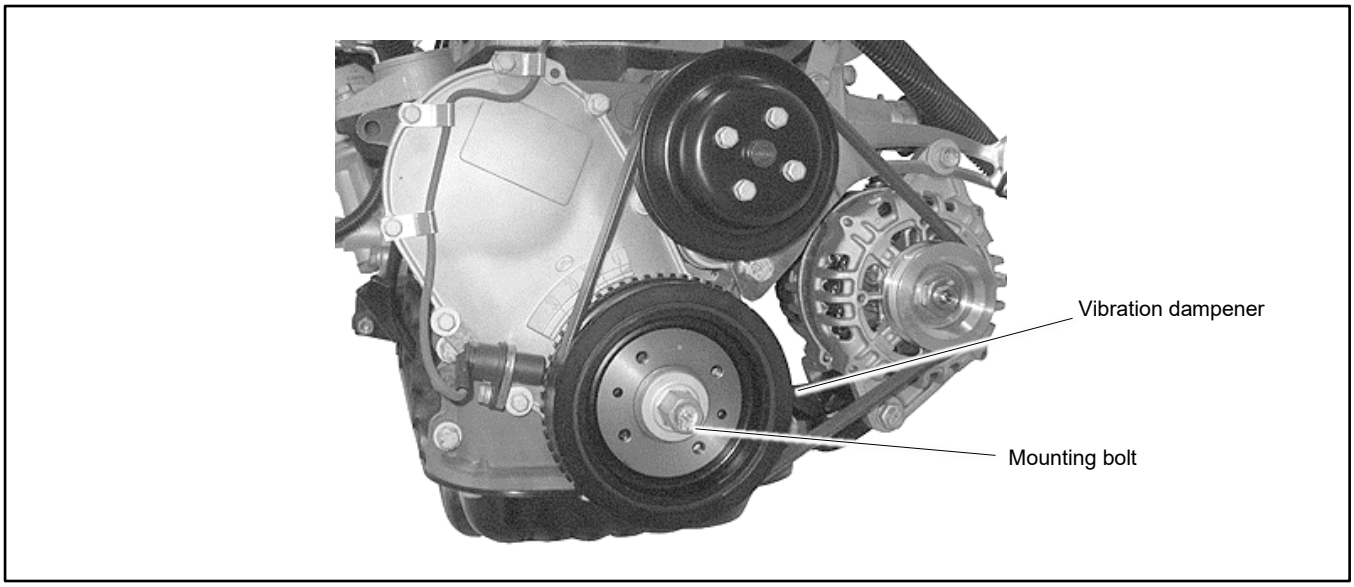


Figure 95 Crankshaft Vibration Dampener Location

3. Install crankshaft vibration dampener mounting bolt to crankshaft and dampener. See Figure 95.
4. Torque crankshaft vibration dampener mounting bolt to specification.

Crankshaft Vibration Dampener Bolt Torque
160 Nm (118 ft.lb.)

5. Install drive belt. See “Drive Belt Removal and Installation”.

3.7.18 Remove and Install Front Crankshaft Seal

3.7.18.1 Removal

1. Remove drive belt. See “Drive Belt Removal and Installation”.
2. Remove crankshaft vibration dampener. See “Remove and Install Crankshaft Vibration Dampener”.

NOTICE
Failure to use a center pilot to protect threads in crankshaft end will result in damage to crankshaft. Timing chain cover damage will occur if puller is inserted past the front crankshaft seal and is allowed to hook on timing chain cover. Do not nick or scratch crankshaft with seal puller. Note orientation of seal lip.

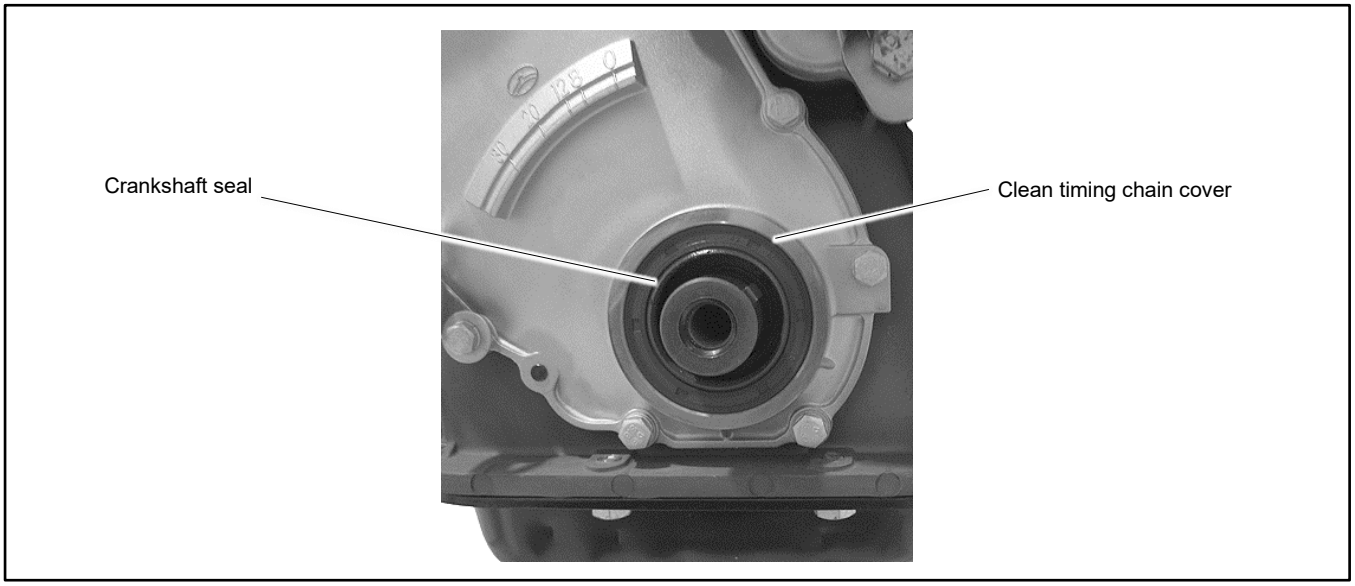


Figure 96 Crankshaft Seal Location

3. Remove front crankshaft seal using a seal puller or equivalent tool. See Figure 96.
4. Clean timing chain cover of any sealer or old crankshaft seal.

3.7.18.2 Installation

NOTE:
Install new front crankshaft seal oriented as noted during removal.

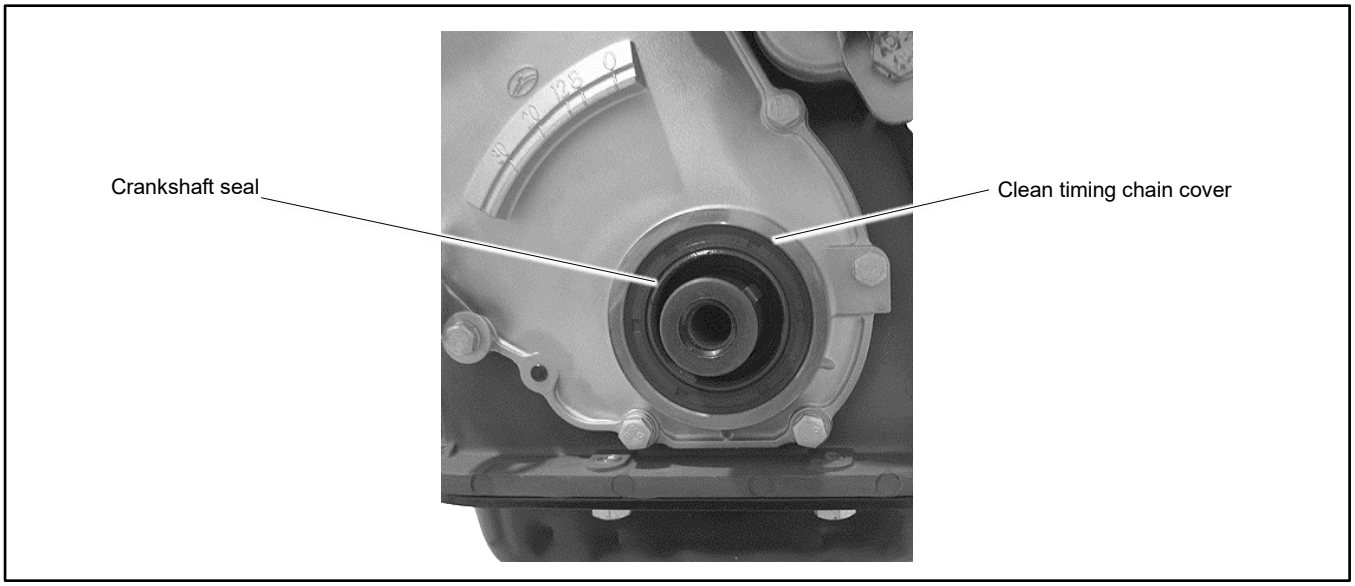


Figure 97 Crankshaft Seal Location

1. Drive front crankshaft seal into timing chain cover with seal driver or equivalent tool until seal is flush with timing chain cover. See Figure 97.
2. Install crankshaft vibration dampener. See “Remove and Install Crankshaft Vibration Dampener”.
3. Install drive belt. See “Drive Belt Removal and Installation”.
4. Run engine and check for leaks.

3.7.19 Remove and Install Rear Crankshaft Seal

3.7.19.1 Removal

1. Remove flywheel. See “Remove and Install Flywheel”.

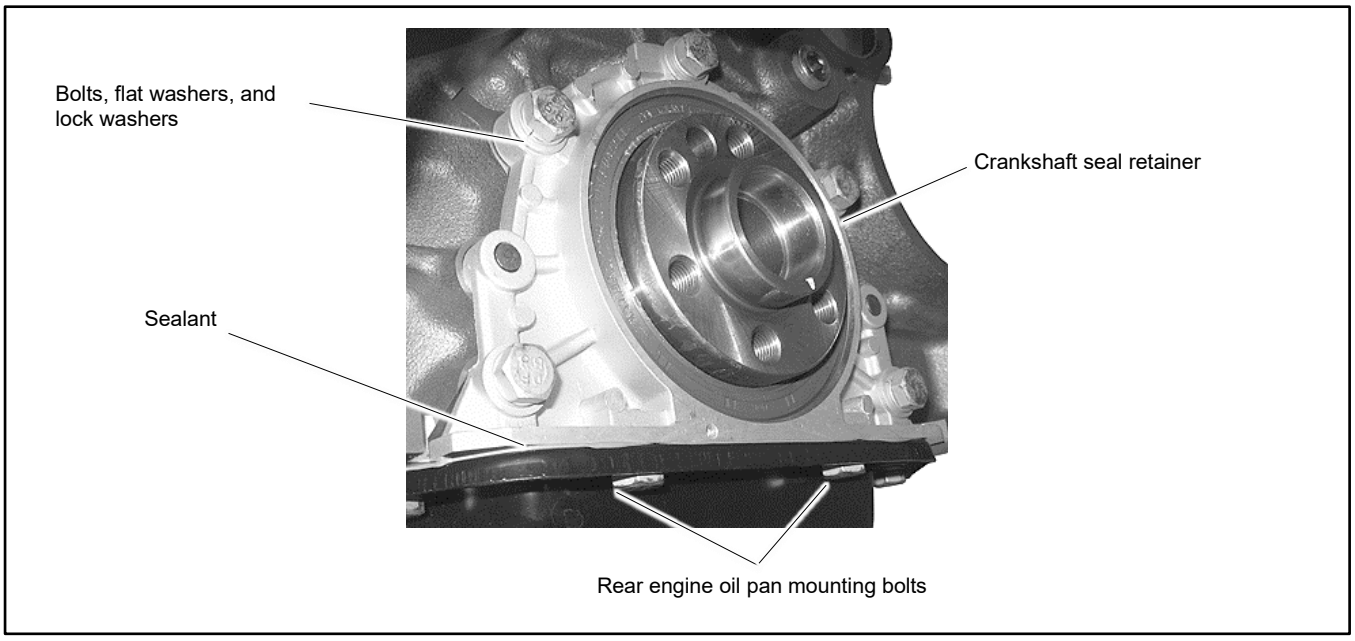


Figure 98 Rear Crankshaft Seal Retainer Location

2. Remove two rear engine oil pan mounting bolts. See Figure 98.
3. Using a sharp blade, cut sealant between engine oil pan and rear crankshaft seal retainer.
4. Remove five rear crankshaft seal retainer-to-cylinder block mounting bolts, flat washers, and lock washers from rear crankshaft seal retainer.
5. Remove rear crankshaft seal retainer from cylinder block.

   NOTE:
   Take notice of seal lip orientation for installation.
6. Remove rear crankshaft seal from seal retainer using a seal driver or equivalent tool.
7. Clean rear crankshaft seal retainer and cylinder block of old gasket.
8. Clean engine oil pan of old sealant.
9. Check crankshaft for any burrs or imperfections that may damage new seal. Remove with emery paper if necessary.

3.7.19.2 Installation

NOTE:
Install new rear crankshaft seal oriented as noted during removal.

1. Using a seal driver or equivalent tool, install rear crankshaft seal into rear crankshaft seal retainer until flush with outer face of rear crankshaft seal retainer.

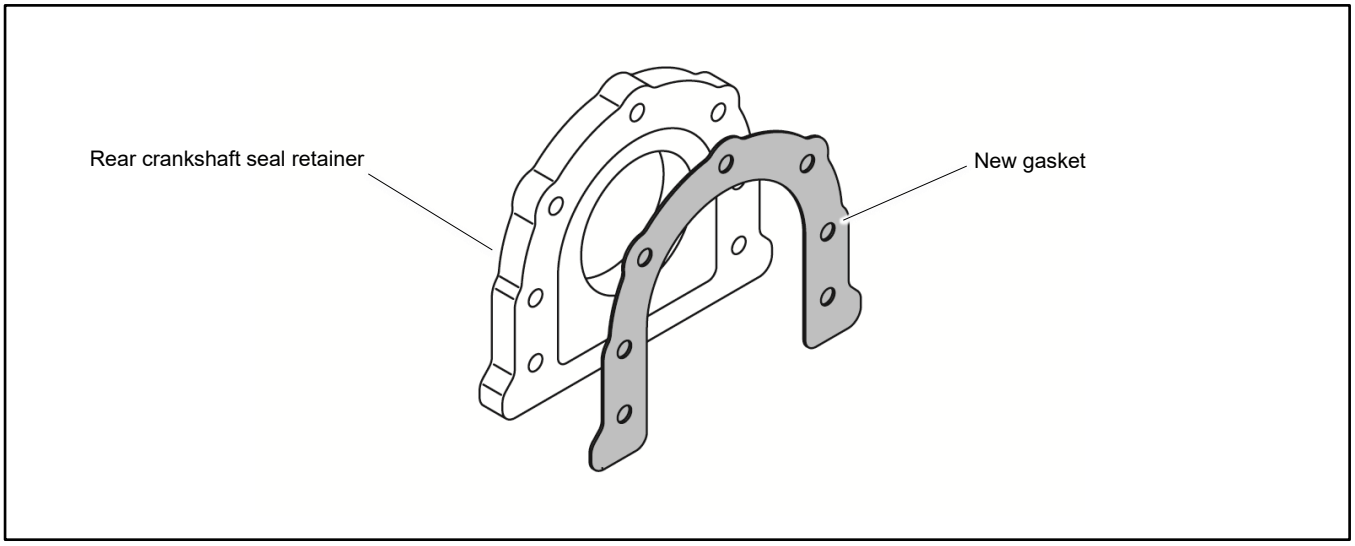


Figure 99 Gasket Location

2. Install new gasket between rear crankshaft seal retainer and cylinder block. See Figure 99.

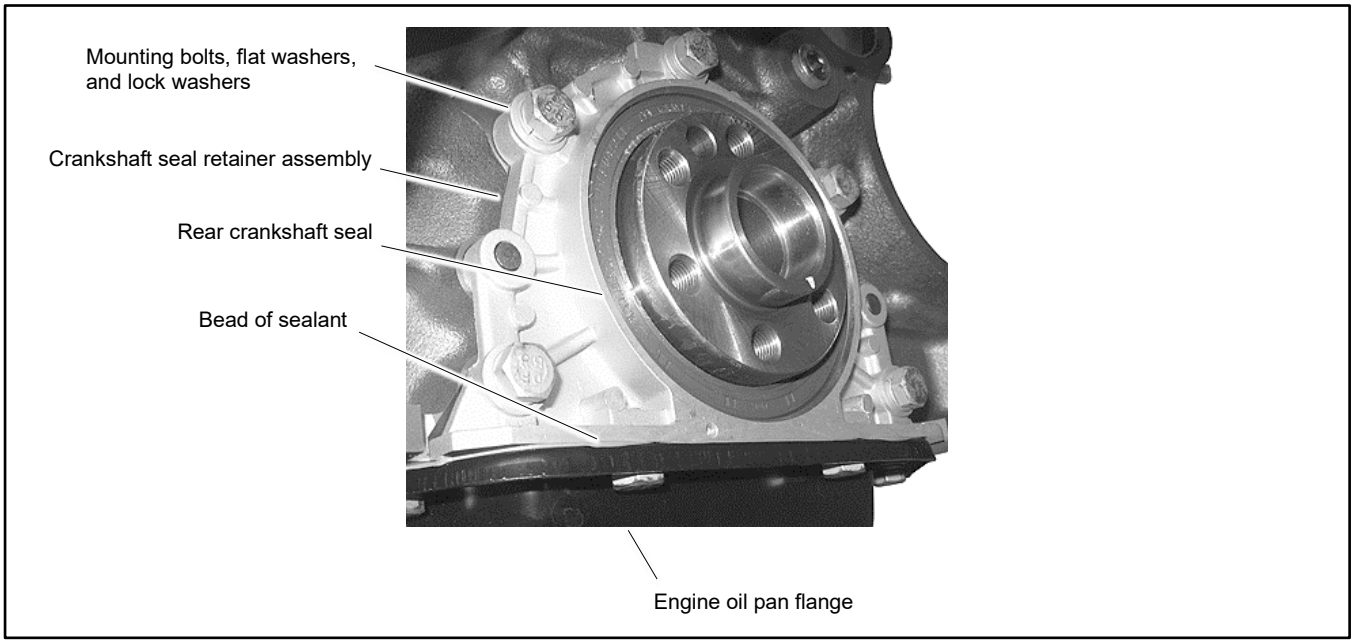


Figure 100 Rear Crankshaft Seal Retainer Location

3. Run a 3 mm bead of sealant along the top center of the engine oil pan flange. See Figure 100.
4. Lubricate lip of rear crankshaft seal and crankshaft with clean engine oil.
5. Carefully install rear crankshaft seal retainer assembly over crankshaft.
6. Secure rear crankshaft seal retainer to cylinder block with five mounting bolts, flat washers, and lock washers. Torque bolts to specification.

Rear Crankshaft Seal Retainer Bolt Torque
12 Nm (9 ft.lb.)

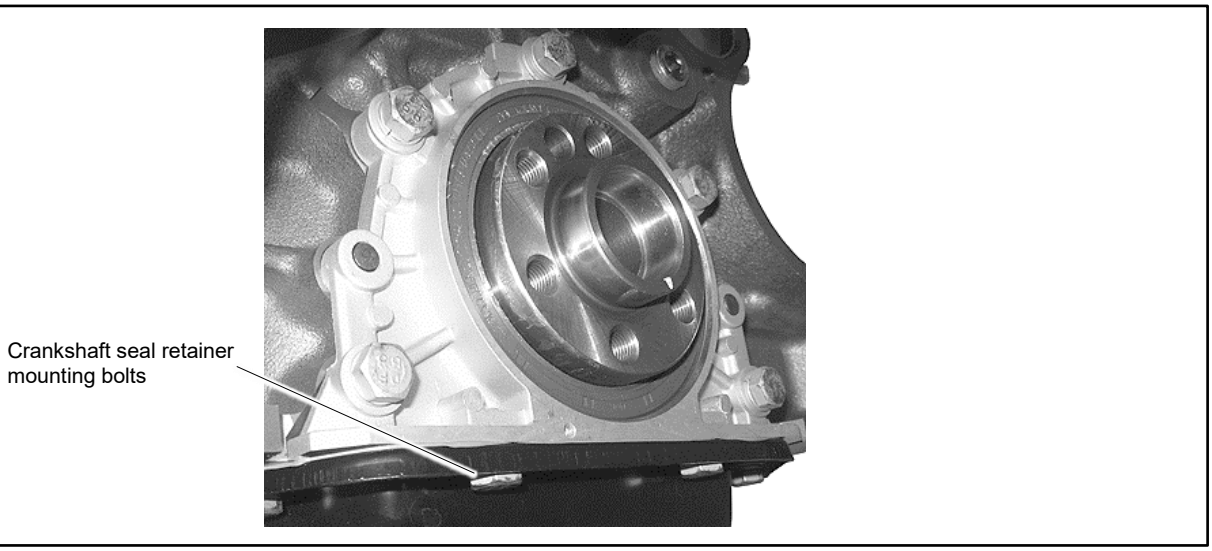


Figure 101 Rear Crankshaft Seal Retainer Mounting Bolts

7. Install two rear engine oil pan-to-rear crankshaft seal retainer mounting bolts. See Figure 101.
8. Install flywheel. See “Remove and Install Flywheel”.

3.7.20 Remove and Install Rocker Arm Cover

3.7.20.1 Removal

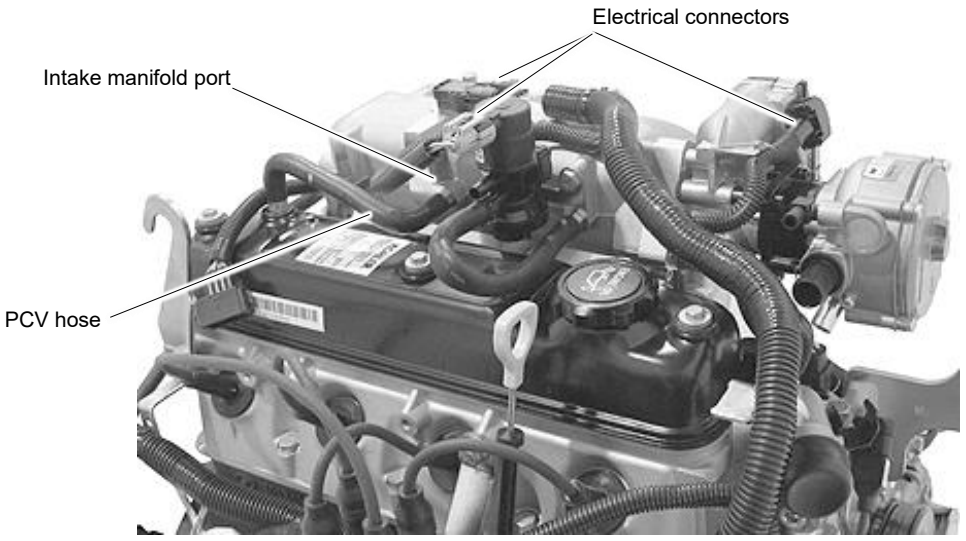


Figure 102 PCV Hose Location

1. Disconnect three electrical connectors from intake manifold sensors and set wiring harness aside. See Figure 102.
2. Disconnect PCV hose from intake manifold port. Close all openings.

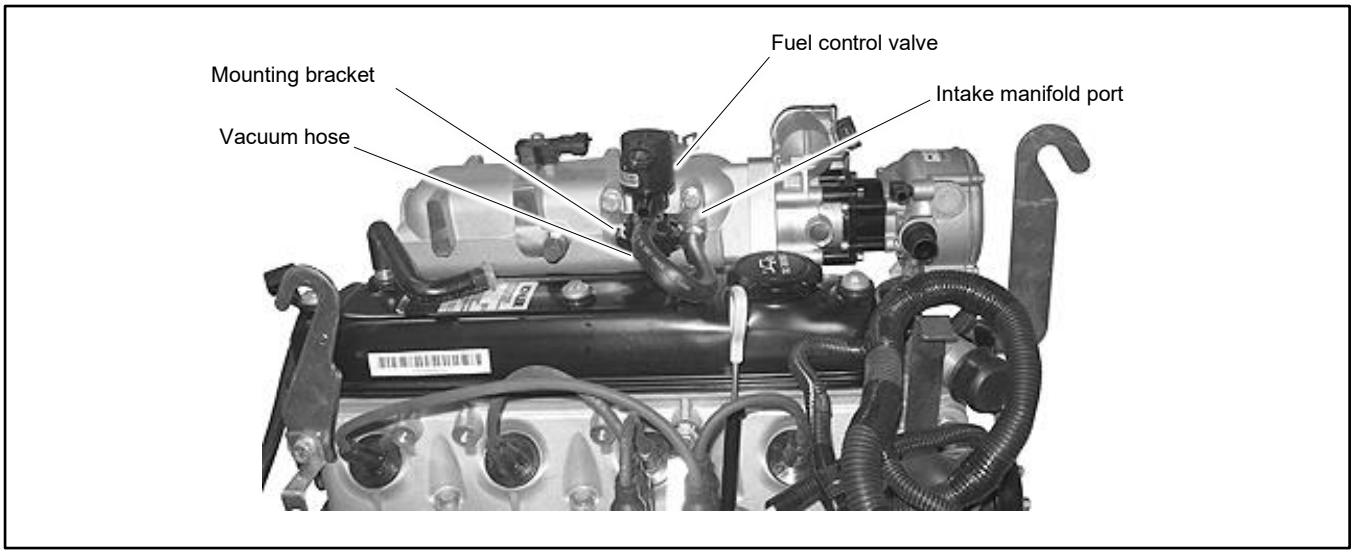


Figure 103 Fuel Control Valve Location

3. Disconnect fuel control valve vacuum hose from intake manifold port. Close all openings. See Figure 103.
4. Pull fuel control valve straight up to remove from fuel control valve mounting bracket.

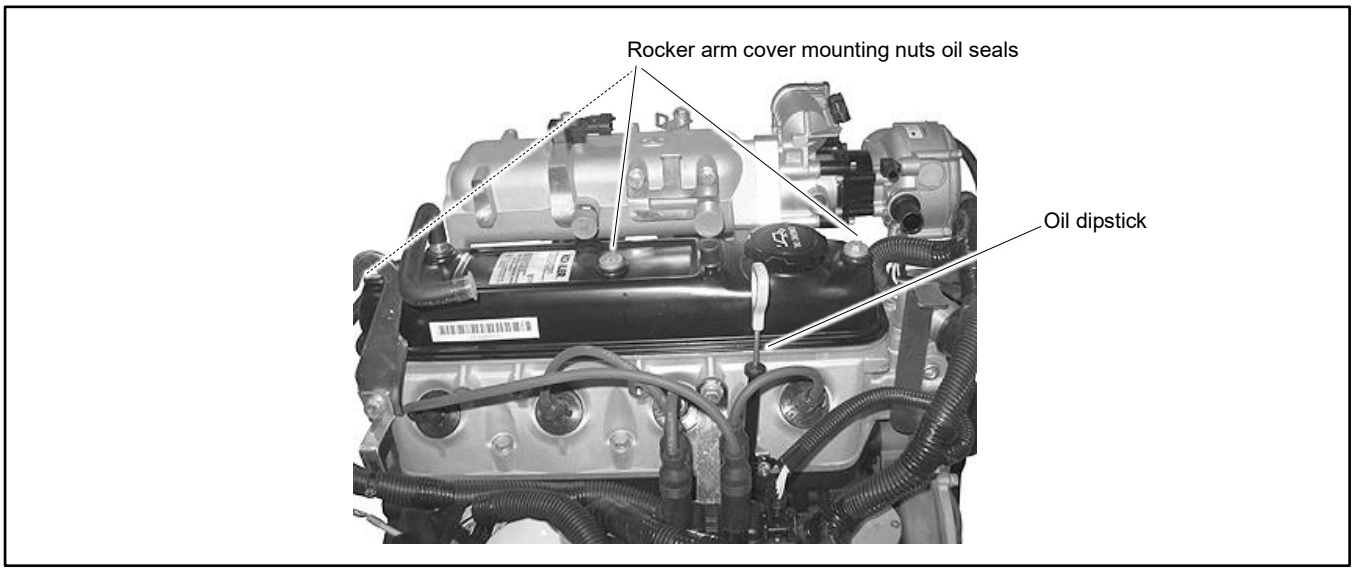


Figure 104 Rocker Arm Cover Mounting Nuts Removal

5. Remove three rocker arm cover mounting nuts and oil seals. See Figure 104.
6. Remove engine oil dipstick.

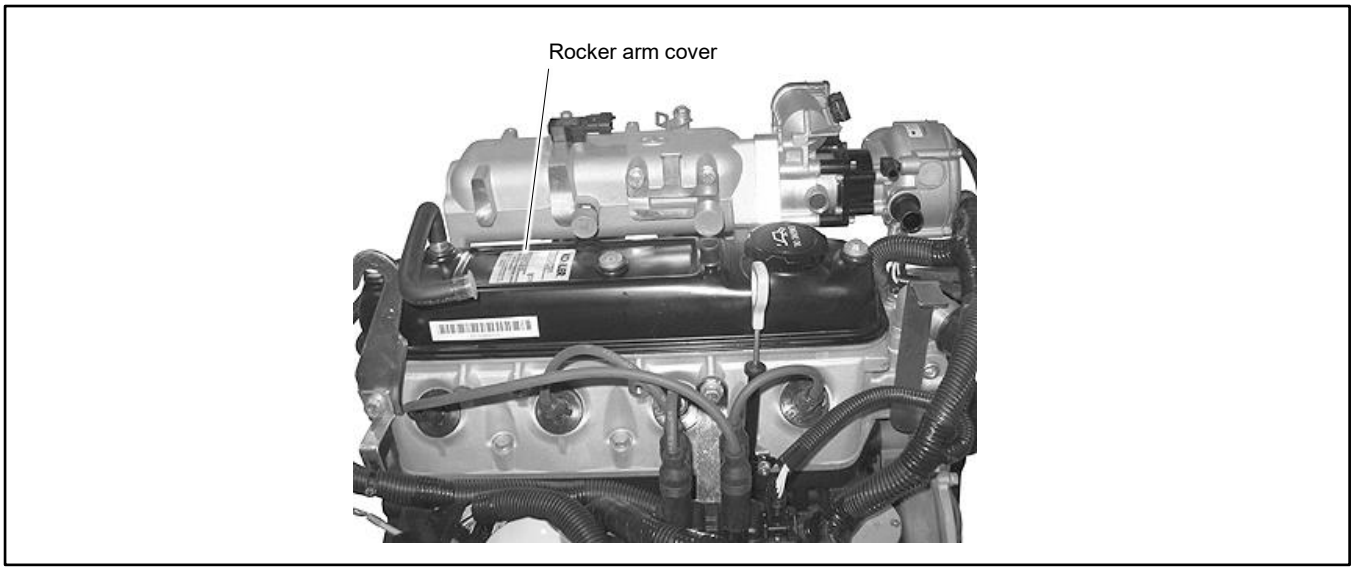


Figure 105 Rocker Arm Cover Removal

7. Remove rocker arm cover from cylinder head. See Figure 105.

3.7.20.2 Inspection

1. Inspect rocker arm cover gasket and mounting nut seals for hardness, cracks, and splits.
2. Replace rocker arm cover gasket or seals if inspection reveals damage.

3.7.20.3 Installation

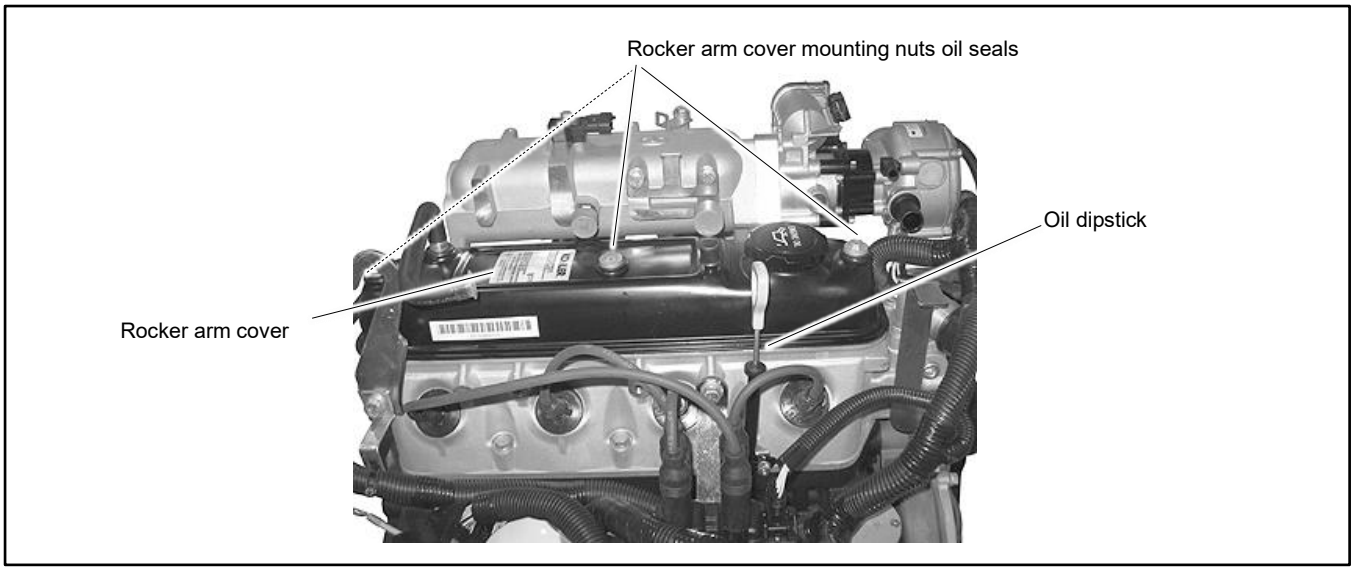


Figure 106 Rocker Arm Cover Mounting Nuts Installation

1. Install rocker arm cover to cylinder head. See Figure 106.
2. Install engine oil dipstick.
3. Install three seals and mounting nuts. Tighten rocker arm cover nuts.

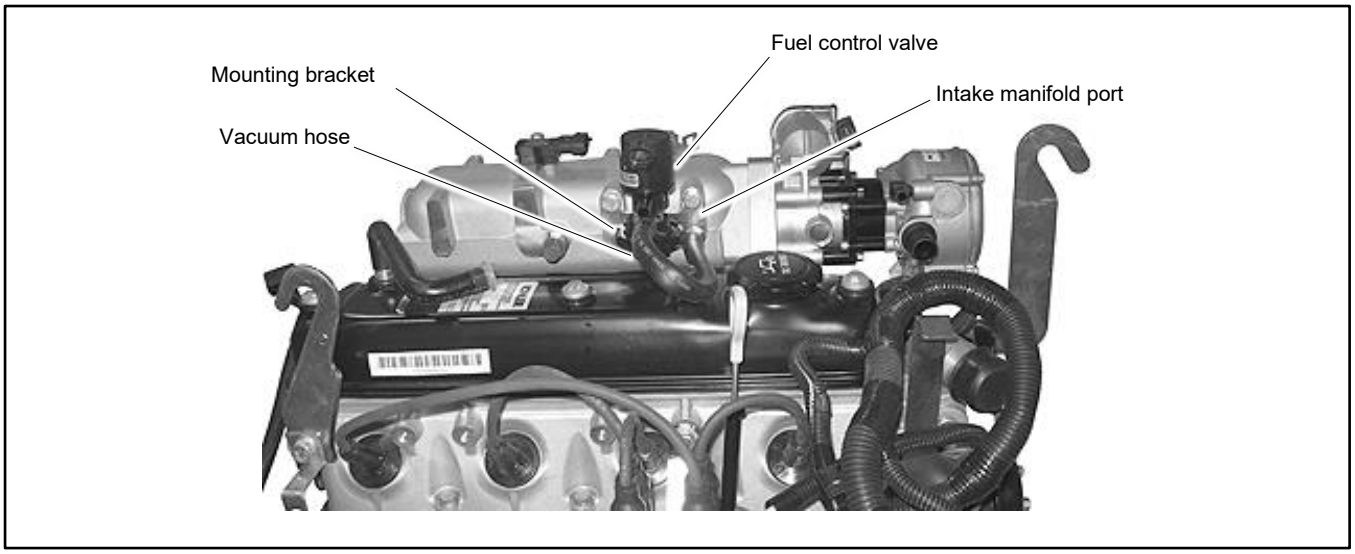


Figure 107 Fuel Control Valve Connection

4. Push fuel control valve straight down onto fuel control valve mounting bracket. See Figure 107.
5. Connect fuel control valve vacuum hose to intake manifold port.

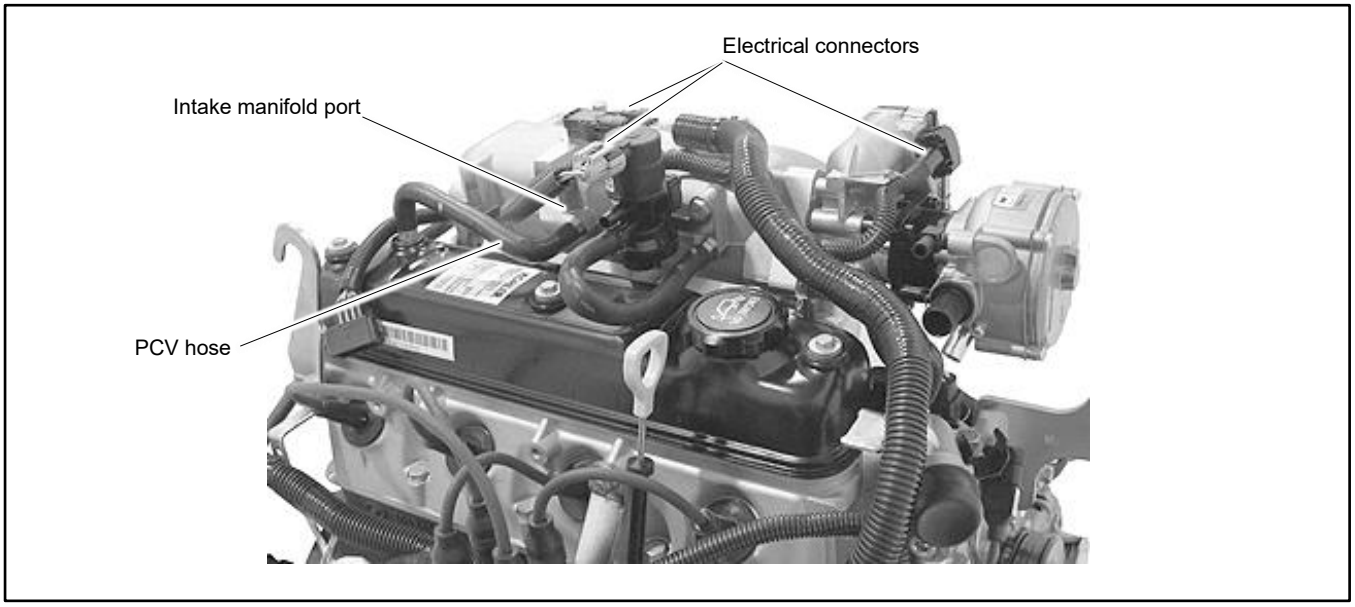


Figure 108 Electrical Connection

6. Connect PCV hose to intake manifold port. See Figure 108.
7. Connect three electrical connectors to intake manifold sensors.

3.7.21 Remove and Install Oil Pan

3.7.21.1 Removal

1. Drain engine oil.

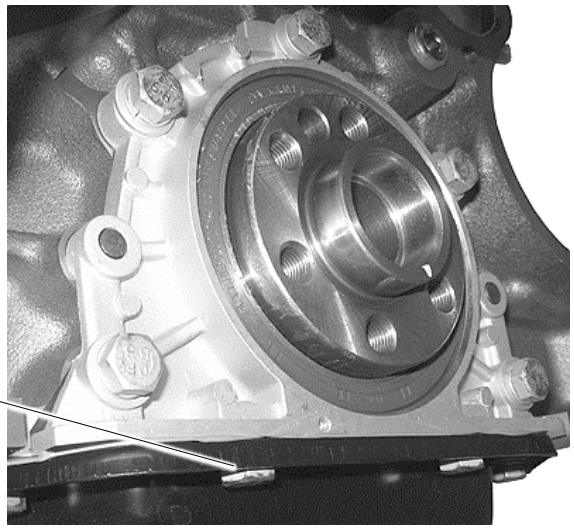


Figure 109 Oil Pan Location

2. Remove 16 oil pan mounting bolts, flat washers, and lock washers from oil pan. See Figure 109.
3. Remove two oil pan mounting nuts, flat washers, and lock washers from oil pan.

NOTICE
Do not pry oil pan loose from cylinder block. Damage will occur to sealing flange of oil pan if sealant is not cut.

4. To remove oil pan from cylinder block, cut sealant with a sharp blade or equivalent tool.
5. Clean old sealant from oil pan and cylinder block.
6. Clean any debris from inside oil pan and engine.

3.7.21.2 Installation

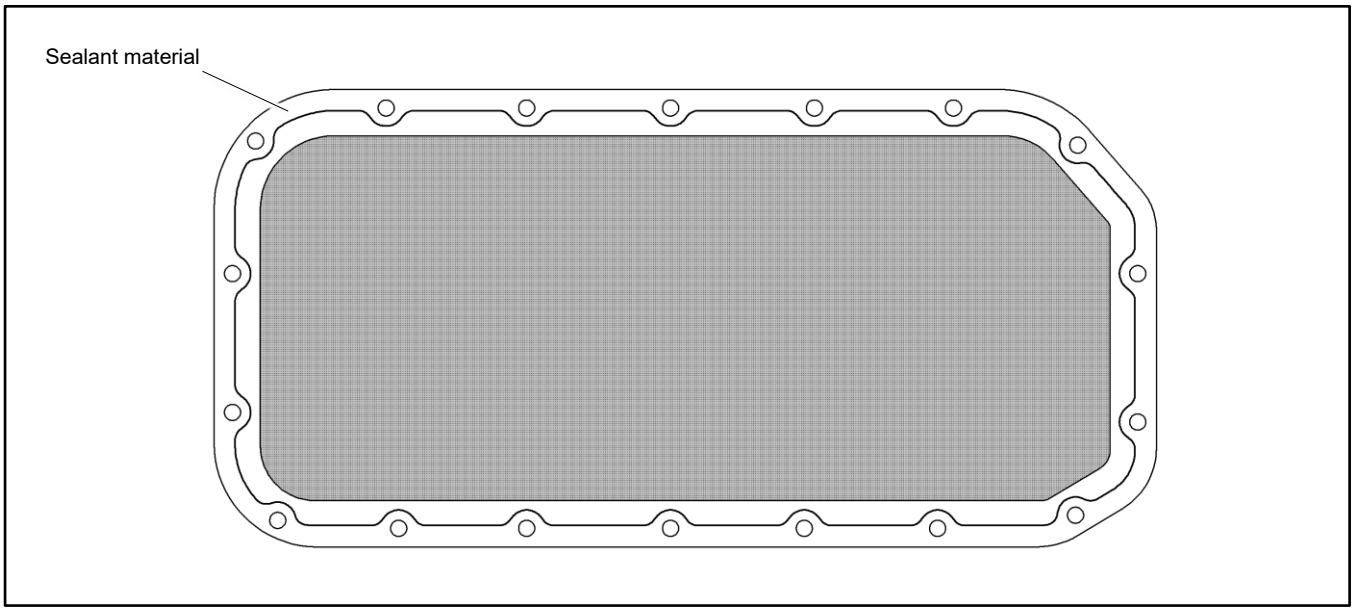


Figure 110 Oil Pan Sealant Location

1. Install new sealant material to oil pan in a 3 mm (0.12 in.) bead. Overlap starting and ending points of application. See Figure 110.
2. Install oil pan to cylinder block with two nuts, flat washers, and lock washers. Lightly tighten nuts.
3. Install 16 oil pan mounting bolts, flat washers, and lock washers to oil pan. Torque oil pan bolts and nuts to specification.

Oil Pan Bolt and Nut Torque
13 Nm (10 ft.lb.)

4. Install oil pan drain plug to oil pan. Torque oil drain plug to specification.

Oil Drain Plug Torque
20-25 Nm (15–18 ft.lb.)

5. Fill engine oil to specification See “Fluid Specifications”.

3.7.22 Oil Pump Drive Removal and Installation

3.7.22.1 Removal

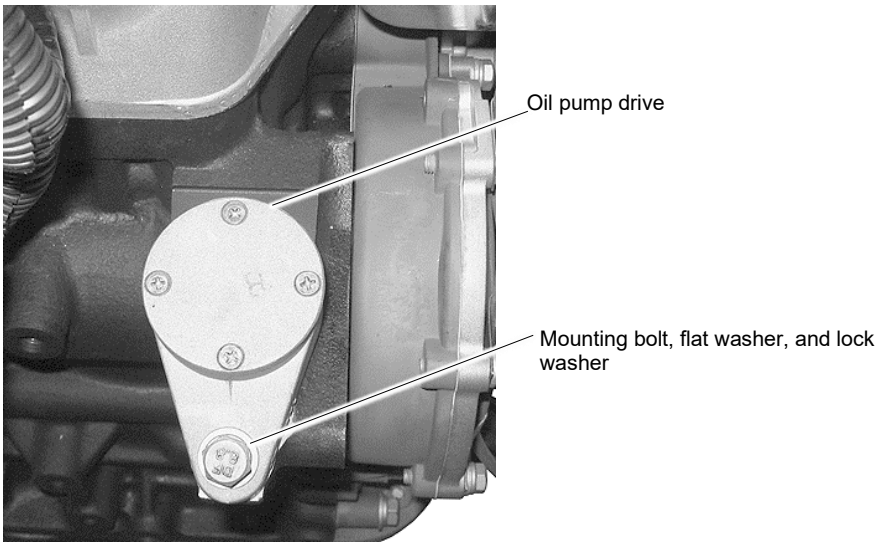


Figure 111 Oil Pump Drive Location

1. Remove mounting bolt, flat washer, and lock washer from oil pump drive. See Figure 111.
2. Pull oil pump drive from cylinder block. Cover opening.

3.7.22.2 Inspection

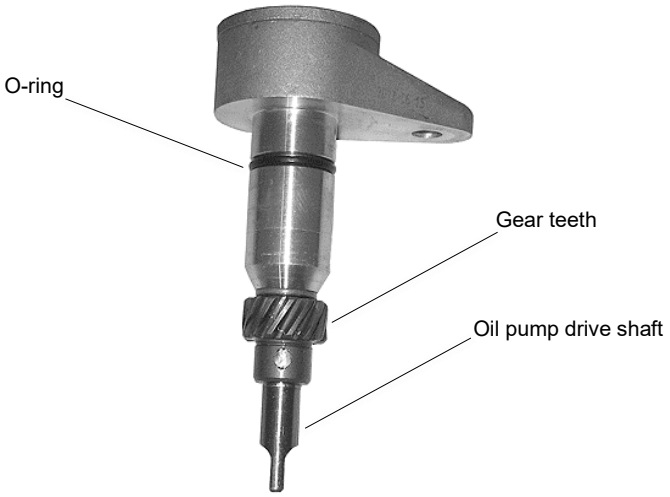


Figure 112 Oil Pump Drive

1. Inspect condition of oil pump drive sealing O-ring. See Figure 112.
2. Inspect condition of gear teeth for wear or damage.
3. Inspect condition of oil pump drive shaft for wear or damage.
4. If inspection reveals wear or damage, replace oil pump drive assembly.

3.7.22.3 Installation

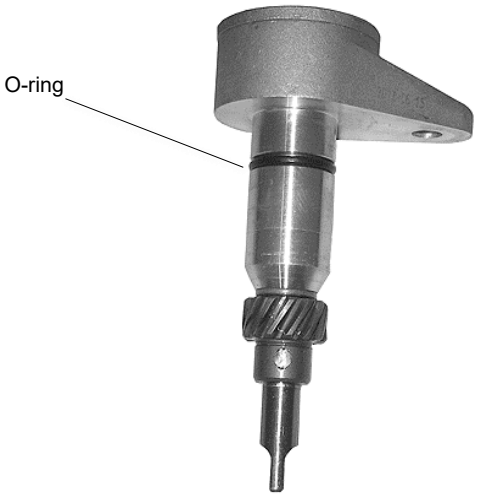


Figure 113 O-Ring Location

1. Lubricate oil pump drive sealing O-ring with clean engine oil. See Figure 113.

NOTICE
When installing oil pump drive to oil pump, do not force oil pump drive into cylinder block. Oil pump drive will set flush with cylinder block when fully engaged to oil pump.

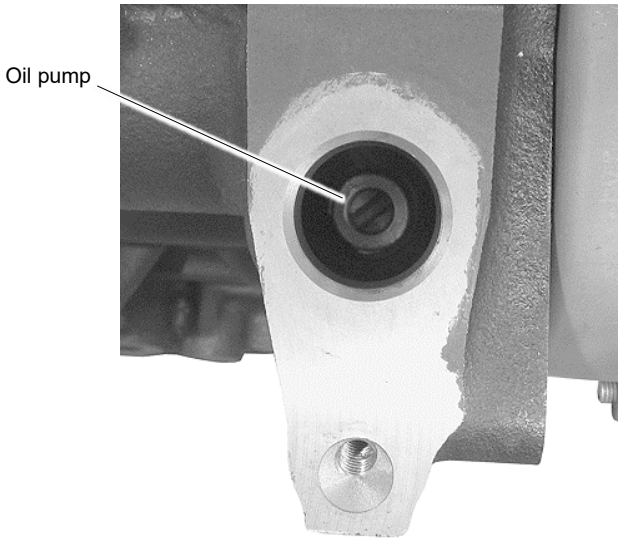


Figure 114 Oil Pump Location

2. Install oil pump drive to cylinder block and align slot in oil pump with tab on bottom of pump drive. See Figure 114.

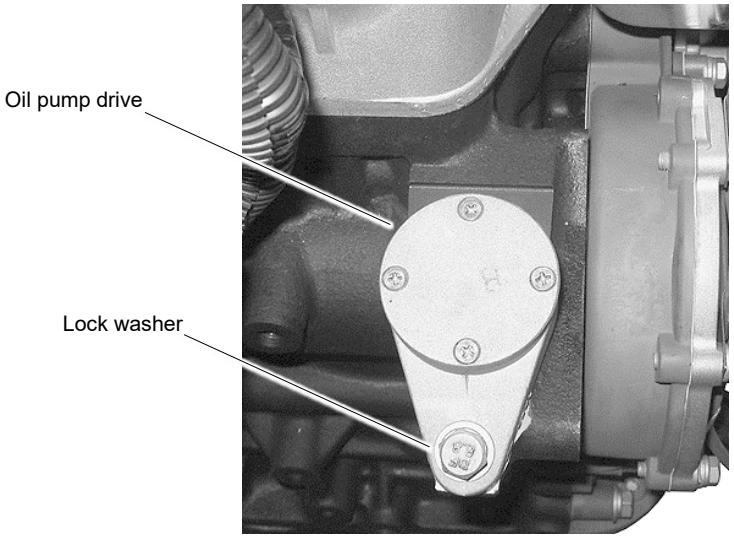


Figure 115 Oil Pump Drive Location

3. Secure oil pump drive to cylinder block using bolt, flat washer, and lock washer. Tighten bolt to specification. See Figure 115.

Oil Pump Drive Bolt Torque
18 Nm (13 ft.lb.)

3.7.23 Oil Filter Removal and Installation

3.7.23.1 Removal

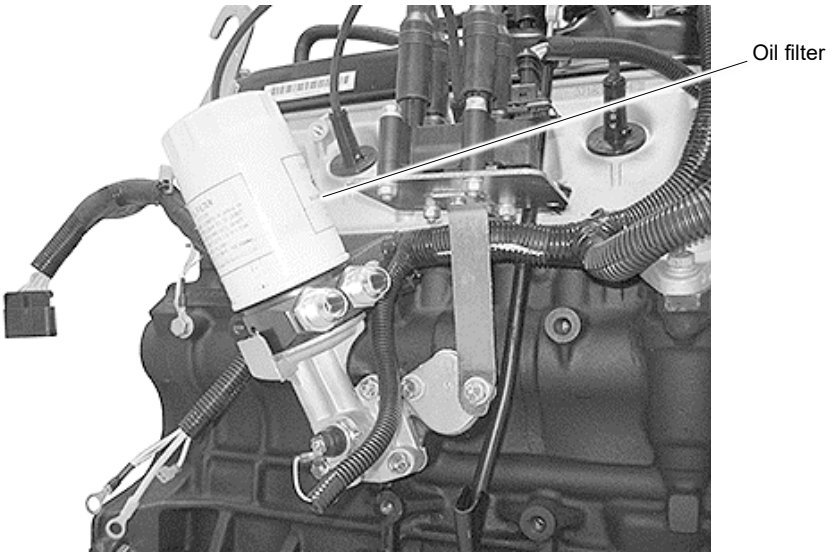


Figure 116 Oil Filter Location

1. Using an oil filter wrench or equivalent tool, turn oil filter counter clockwise and remove from oil filter base. See Figure 116.

3.7.23.2 Inspection

1. Ensure old oil filter gasket is not stuck to oil filter base.
2. Clean oil filter base gasket sealing area with a clean shop towel.
3. If equipped, tighten oil cooler adapter center standoff nut.

Oil Cooler Adapter Center Standoff Nut Torque
40 Nm (29.5 ft.lb.)

3.7.23.3 Installation

1. Replace oil filter with exact replacement or equivalent new oil filter.
2. Lubricate oil filter gasket with clean engine oil.

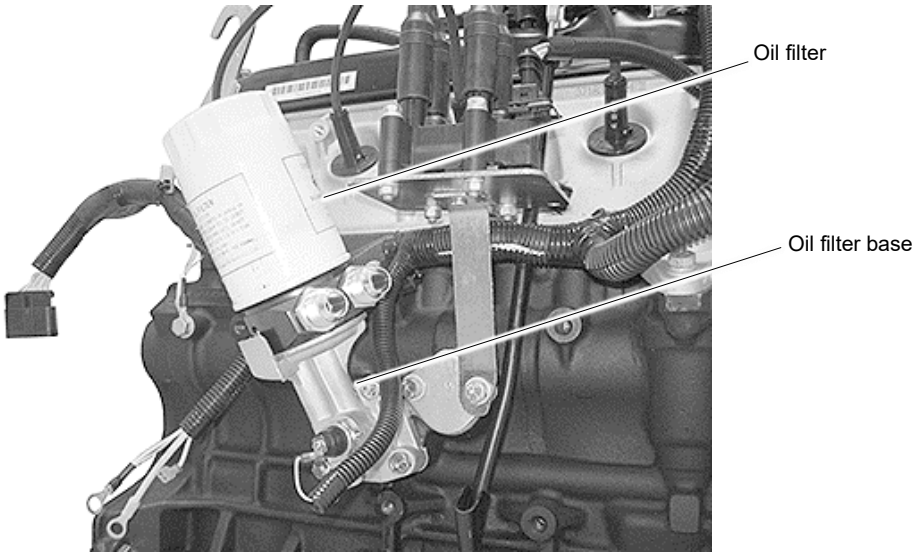


Figure 117 Oil Filter Installation

3. Install oil filter to oil filter base by turning clockwise until oil filter gasket makes contact with oil filter base. See Figure 117.

   Note:
   See oil filter manufacturer's specifications for proper tightening of oil filter. Do not overtighten oil filter.

3.7.24 Oil Filter Base Removal and Installation

3.7.24.1 Removal

1. Remove oil filter. See “Oil Filter Removal and Installation”.

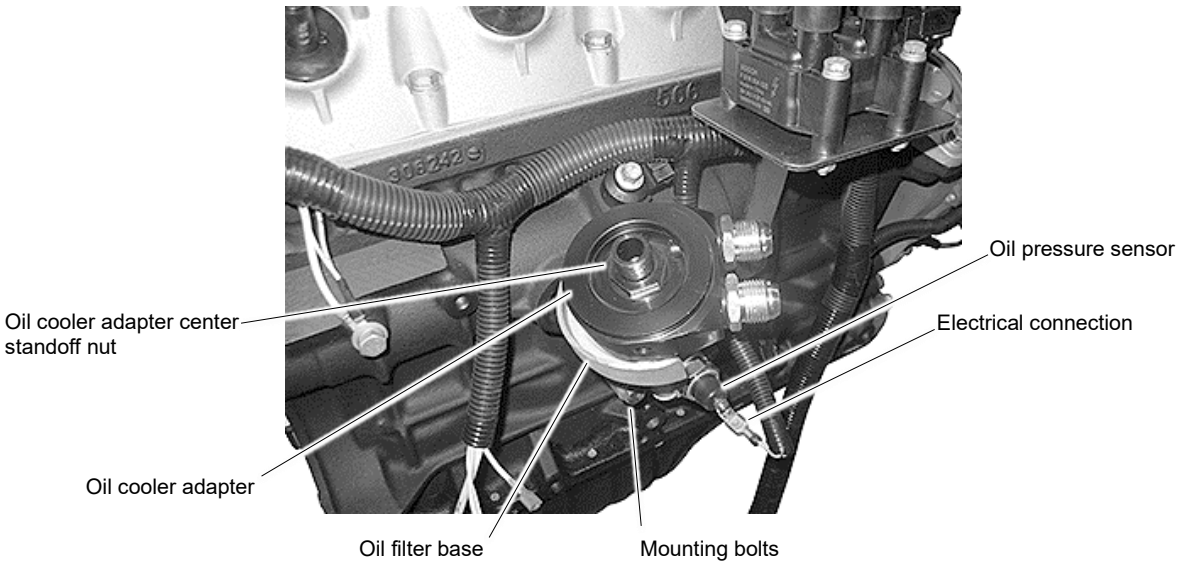


Figure 118 Oil Filter Base Location

2. Disconnect electrical connection from oil pressure sensor. See Figure 118.
3. If equipped: Remove oil cooler adapter center standoff nut and oil cooler adapter.
4. Remove three mounting bolts from oil filter base and remove oil filter base from cylinder block. Close all openings.

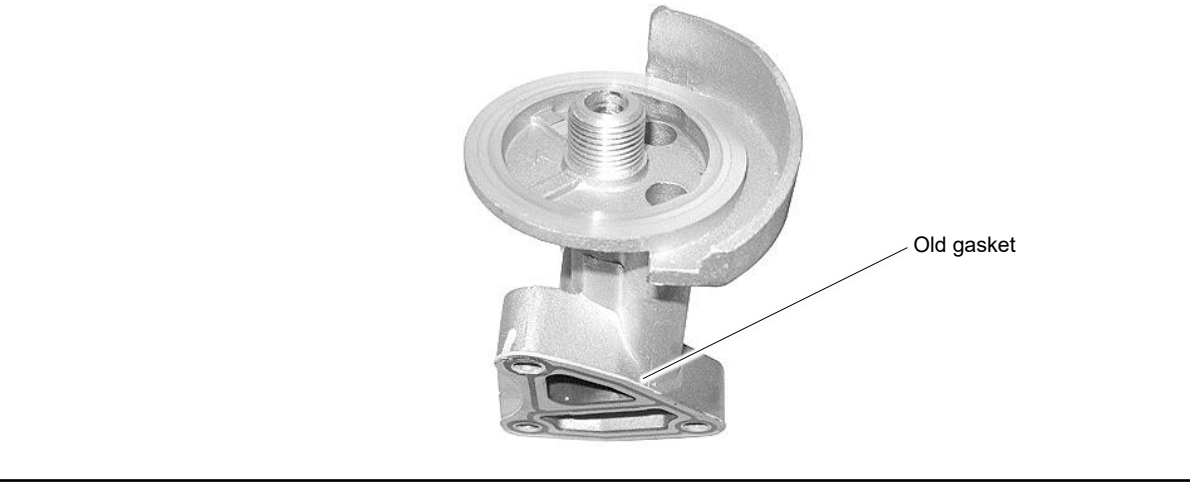


Figure 119 Old Gasket Location

5. Remove old gasket from oil filter base. See Figure 119.

3.7.24.2 Inspection

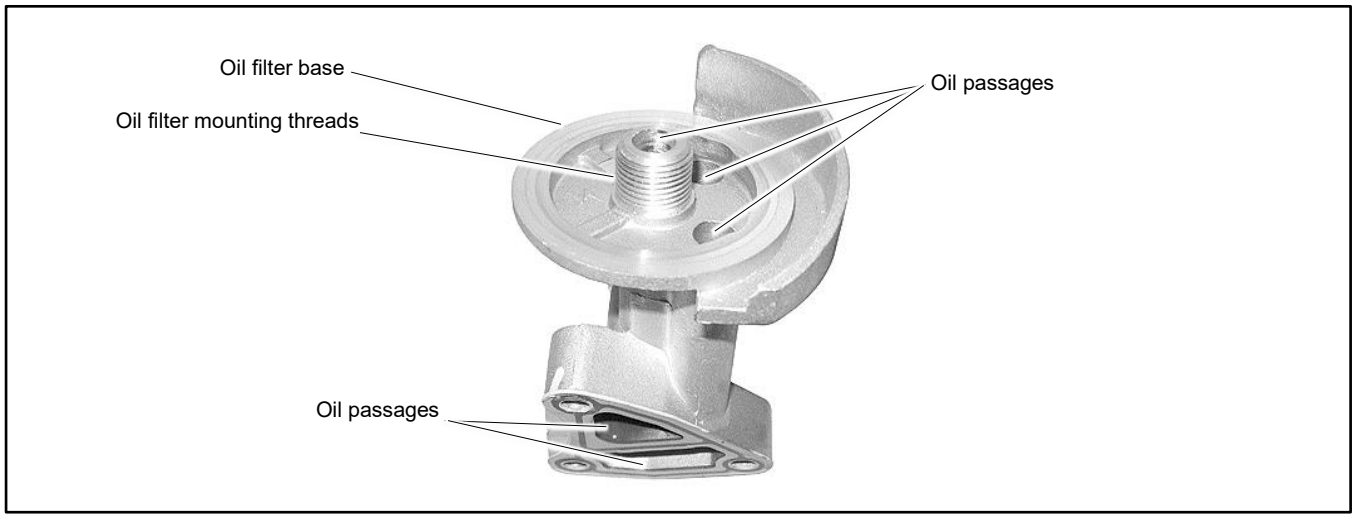


Figure 120 Oil Filter Base Inspection

1. Inspect oil filter base for cracks. See Figure 120.
2. Inspect oil filter mounting threads for damage.
3. If inspection reveals cracks or damaged threads, replace oil filter base.
4. Clean oil filter base oil passages.

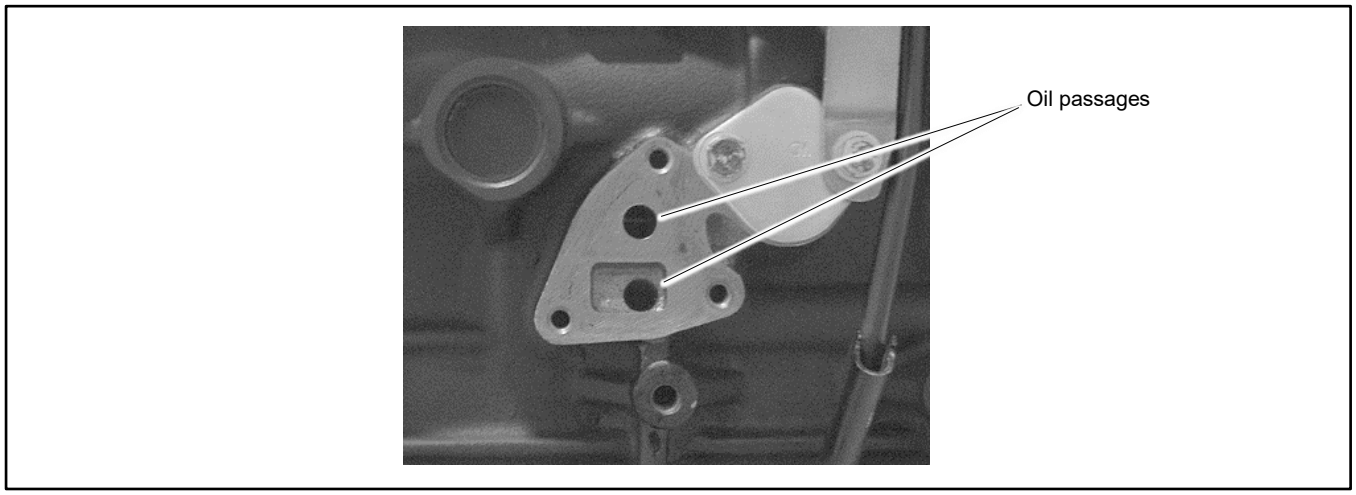


Figure 121 Oil Passages

5. Ensure oil passages of cylinder block are clean. See Figure 121.

3.7.24.3 Installation

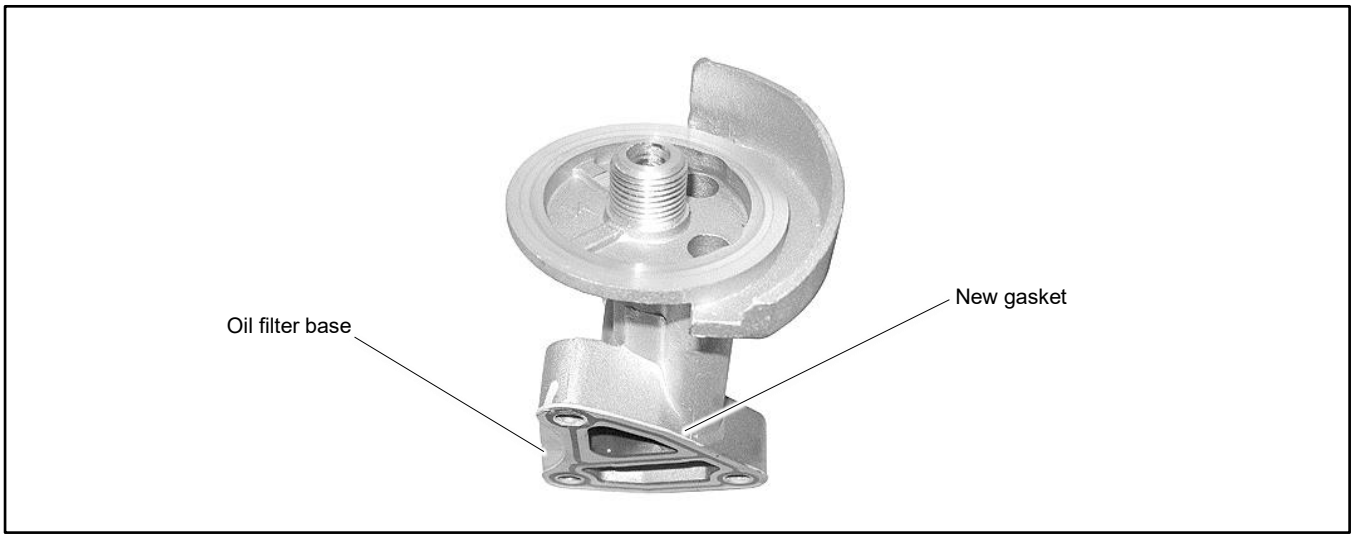


Figure 122 New Gasket Installation

1. Install new gasket on oil filter base. See Figure 122.

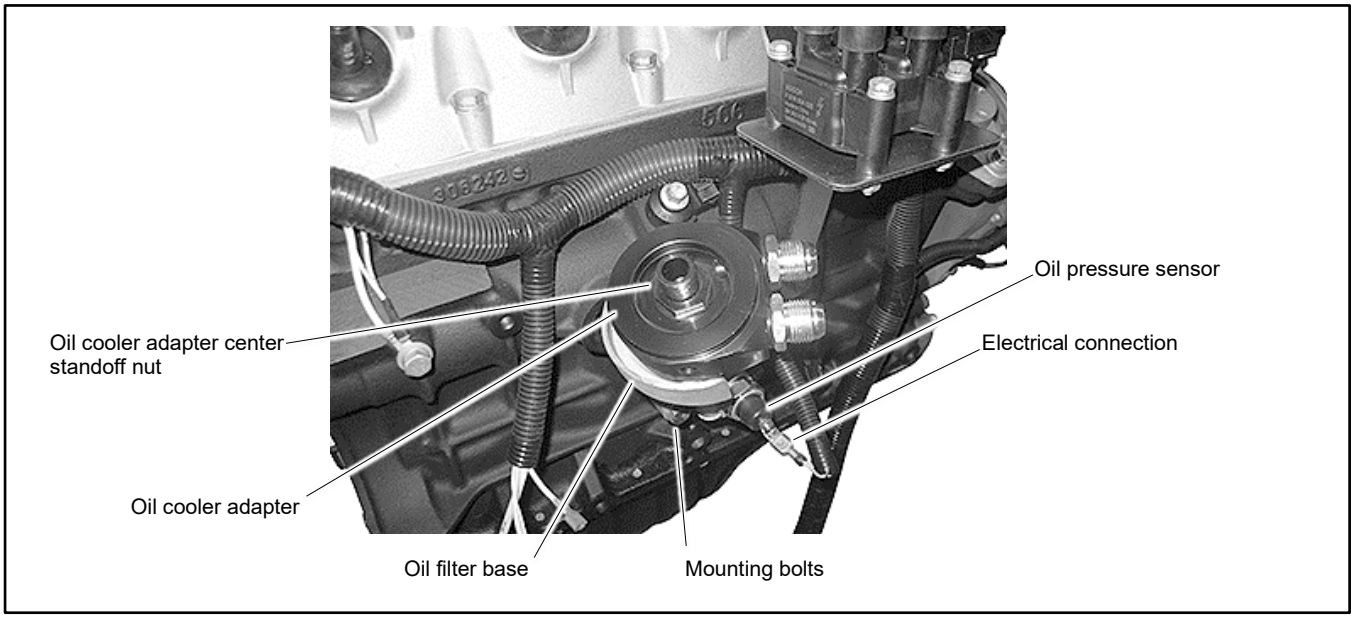


Figure 123 Oil Filter Base Installation

2. If equipped: Install oil cooler adapter and tighten center standoff nut. See Figure 123.

Oil Cooler Adapter Center Standoff Nut Torque
40 Nm (29.5 ft. lb.)

3. Install oil filter base to cylinder block with three bolts, flat washers, and lock washers. Tighten bolts.
4. Connect electrical connection to oil pressure sensor.
5. Install oil filter. See “Oil Filter Removal and Installation”.
6. Start engine and check for leaks.

3.8 Cylinder Head

Engine Operation. Carbon monoxide can cause severe nausea, fainting, or death. Engine exhaust gases contain poisonous carbon monoxide. Carbon monoxide is an odorless, colorless, tasteless, nonirritating gas that can cause death if inhaled for even a short time. Avoid breathing exhaust fumes when working on or near the engine. Never operate the engine inside a building. Never operate the engine where exhaust gas could seep inside or be drawn into a potentially occupied building through windows, air intake vents, or other openings.

⚠ WARNING 	**Carbon monoxide.** **Can cause severe nausea, fainting, or death.** Avoid inhaling exhaust fumes.

⚠ WARNING 	**Risk of fire.** **Can cause severe injury or death.**

⚠ WARNING 	**Pinch and entanglement hazards.** **Can cause severe injury and possible death.** Never check drive belt tension while the engine is running.

⚠ WARNING 	**Moving parts.** **Can cause severe injury or death.** Operate the engine only when all guards and electrical enclosures are in place. Stay away from moving parts while the engine is in operation.

⚠ CAUTION 	**Hazardous voltage.** **Electrical shock can cause injury.** Do not touch wires while the engine is running. Stop the engine and disconnect the battery leads, negative (-) lead first, before servicing the engine.

Servicing the engine when it is operating. Exposed moving parts can cause severe injury or death. Keep hands, feet, hair, clothing, and test leads away from the belts and pulleys when the engine is running. Replace guards, screens, and covers before operating the engine.

⚠ WARNING 	**Risk of fire.** **Can cause severe injury or death.** Do not smoke or permit flames or sparks near fuels or the fuel system.

WARNING	
	**Hot engine and exhaust system.** **Can cause severe injury or death.** Do not work on the engine until it cools.

Hot engine components. Can cause severe injury or death. Never operate the engine with heat shields or guards removed.

WARNING	
	**Hot coolant and steam.** **Can cause severe injury or death.** Before removing the pressure cap, stop the engine and allow it to cool. Then loosen the pressure cap to relieve pressure.

Liquid coolant can be extremely hot from operation. Turning radiator cap when engine is hot can allow steam and scalding liquid to blow out and burn you severely. Shut off machine. Only remove radiator cap when cool enough to touch with bare hands. Slowly loosen cap to the first stop to relieve pressure before removing completely.

WARNING	
	**Accidental starting.** **Can cause severe injury or death.** Disconnect the battery cables before working on the engine. Remove the negative (–) lead first when disconnecting the battery. Reconnect the negative (–) lead last when reconnecting the battery.

Disabling the engine. Accidental starting can cause severe injury or death. Before working on the engine or connected equipment, disable the engine as follows: 1) Disconnect the ignition coil. 2) Remove the battery cables, negative (–) lead first. Reconnect the negative (–) lead last when reconnecting the battery. Follow these precautions to prevent the accidental starting of the engine.

WARNING	
	**Explosive fuel vapors.** **Can cause fires and severe burns.** If a gaseous odor is detected, ventilate the area and contact an authorized service technician.

The fuel system. Explosive fuel vapors can cause severe injury or death. Vaporized fuels are highly explosive. Use extreme care when handling and storing fuels. Store fuels in a well-ventilated area away from spark-producing equipment and out of the reach of children. Never add fuel to the tank while the engine is running because spilled fuel may ignite on contact with hot parts or from sparks. Do not smoke or permit flames or sparks to occur near sources of spilled fuel or fuel vapors. Keep the fuel lines and connections tight and in good condition. Do not replace flexible fuel lines with rigid lines. Use flexible sections to avoid fuel line breakage caused by vibration. Do not operate the engine in the presence of fuel leaks, fuel accumulation, or sparks. Repair fuel systems before resuming engine operation.

WARNING	
	**Handling caustic engine fluids and chemical products.** **Can cause severe chemical burns, nausea, fainting, or death.** Most chemicals such as used engine oil, antifreeze/coolant, rustproofing agent, inhibiting oil, degreasing agent, spray paint, and adhesives are hazardous to health. Read and follow the user information found on the packaging. Avoid inhalation and skin contact. Use only in well-ventilated areas and use a protective mask when spraying. Store engine fluids and chemical products in a locked cabinet. Contact your local recycling center for disposal information and locations.

Fire-damaged or burned O-rings may cause the formation of hydrofluoric acid. Contact with hydrofluoric acid may cause severe skin irritation and chemical burns. O-rings and other fluoroelastomer seals exposed to fire or temperatures above 316°C (600°F) (i.e., during welding) may decompose forming hydrofluoric acid. Avoid inhalation or skin contact. Do not incinerate O-rings. Dispose of O-ring waste material in a responsible manner.

⚠ WARNING	**Spring-loaded parts.** **Can cause severe personal injury or property damage.** Wear protective goggles when servicing spring-loaded parts. Hold parts securely during disassembly.
	

⚠ WARNING	**Airborne particles.** **Can cause severe injury or blindness.** Wear protective goggles and clothing when using power tools, hand tools, or compressed air.
	

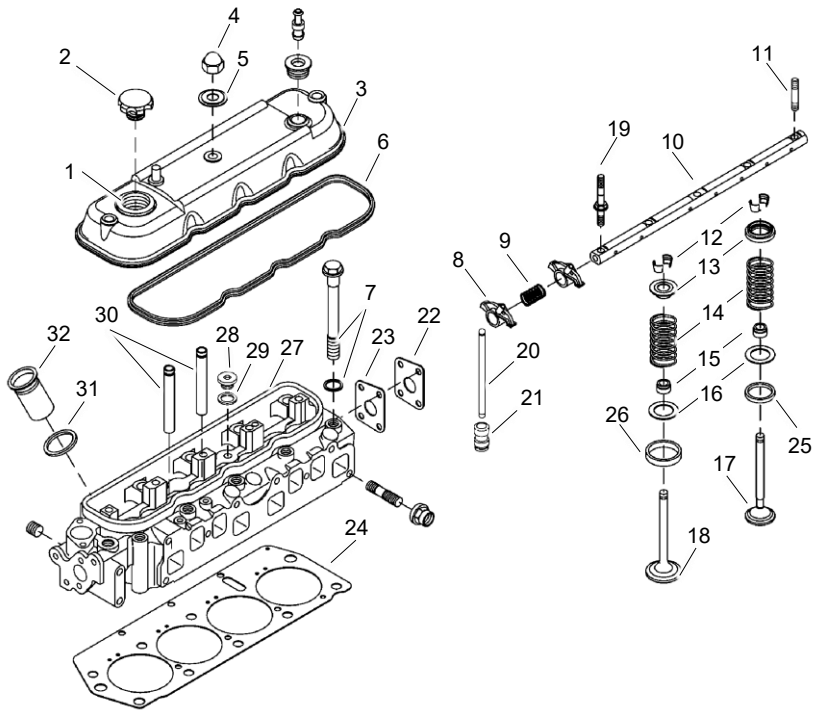
⚠ WARNING	**Explosive fuel vapors.** **Can cause severe injury or death.** Use extreme care when handling, storing, and using fuels.
	

Gas fuel leaks. Explosive fuel vapors can cause severe injury or death. Fuel leakage can cause an explosion. Check the LPG vapor or natural gas fuel system for leakage by using a soap and water solution with the fuel system test pressurized to 6–8 ounces per square inch (10–14 inches water column). Do not use a soap solution containing either ammonia or chlorine because both prevent bubble formation. A successful test depends on the ability of the solution to bubble.

Used engine oil. Contact with used engine oil may cause severe skin irritation. Repeated and prolonged skin exposure may have other health risks. Used engine oil is a suspected carcinogen. Avoid contact with skin. Thoroughly wash your hands and nails with soap and water shortly after handling used engine oil. Wash or dispose of clothing or rags containing used engine oil. Dispose of used engine oil in a responsible manner. Contact your local recycling center for disposal information and locations.

⚠ CAUTION	**Damaged harmonic balancer, crankshaft, or flywheel.** **Can cause personal injury.** Broken fragments from the harmonic balancer, crankshaft, and flywheel can be thrown from the engine. Do not use a hammer to install or remove. Inspect these parts for damage and replace if needed.
	

3.8.1 Cylinder Head Components



1.	Oil Fill Cap Seal	12.	Spring Retainer Locks	23.	Cylinder Head Rear Plate Gasket
2.	Oil Fill Cap	13.	Valve Spring Retainers	24.	Cylinder Head Gasket
3.	Rocker Arm Cover	14.	Valve Springs	25.	Valve Seat Exhaust
4.	Nut	15.	Oil Seal	26.	Valve Seat Intake
5.	Seal Washer	16.	Valve Spring Seat	27.	Cylinder Head
6.	Rocker Cover Gasket	17.	Intake Valve	28.	Plug
7.	Head Bolt Assembly	18.	Exhaust Valve	29.	Seal
8.	Rocker Arm	19.	Stud Bolt	30.	Valve Guide
9.	Spring	20.	Pushrod	31.	Spark Plug Tube Seal
10.	Rocker Arm Shaft	21.	Hydraulic Valve Lifter	32.	Spark Plug Tube
11.	Stud	22.	Cylinder Head Rear Plate		

Figure 124 Cylinder Head Component Location

3.8.2 Cylinder Head Removal and Installation

3.8.2.1 Removal

1. Drain cooling system.
2. Remove intake manifold. See “Intake Manifold Removal and Installation”.
3. Remove exhaust manifold. See “Exhaust Manifold Removal and Installation”.
4. Remove rocker arm cover. See “Remove and Install Rocker Arm Cover”.
5. Remove rocker arm shaft. See “Rocker Arm Assembly—Removal and Installation”.

   Note:
   Identify and tag push rods for correct order and orientation during installation.

6. Remove push rods from lifters.

   Note:
   Arrow points to front of engine assembly.

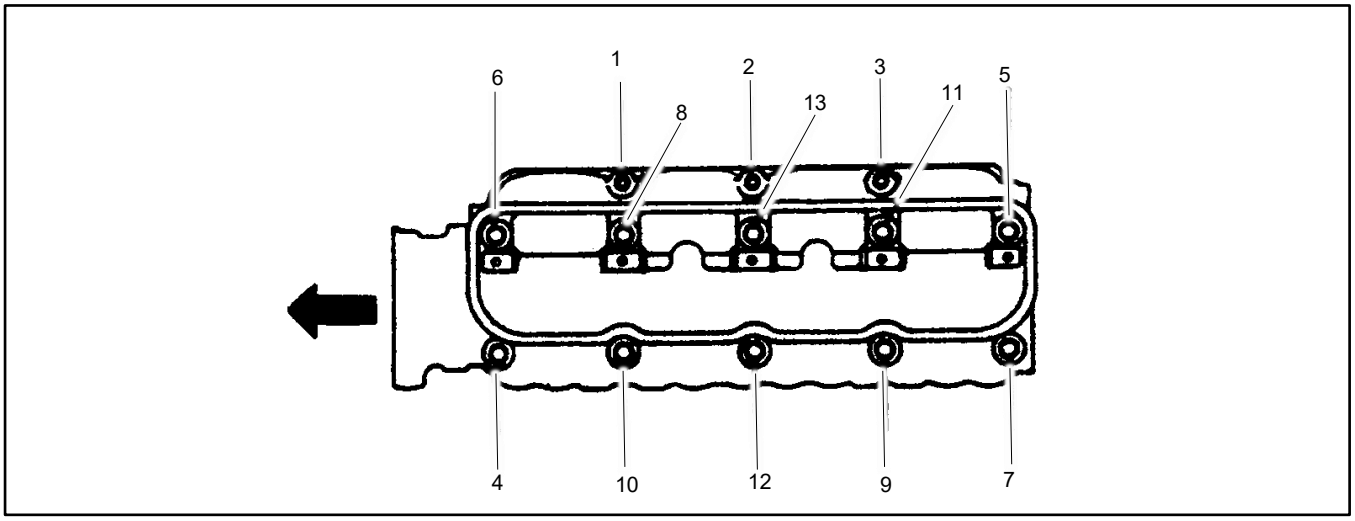


Figure 125 Cylinder Head Mounting Bolts Location

7. Loosen cylinder head mounting bolts in three steps in sequence as shown. See Figure 125.
8. Lightly tap cylinder head with a soft face hammer to loosen cylinder head from cylinder block.

NOTICE
Do not set cylinder head down on machined surfaces unless precautions are taken to avoid scratching machined surfaces.

9. Remove cylinder head from cylinder block.

NOTICE
Do not use harsh cleaning operations to clean cylinder head or block. Use of air buffers and steel scrapers may remove material damaging head or block.

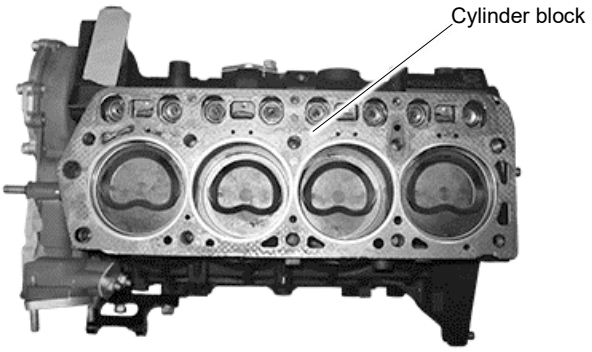


Figure 126 Cylinder Block Location

10. Clean old head gasket from cylinder block. Avoid getting gasket material into lifter bores, water jackets and bolt holes. See Figure 126.
11. Clean old head gasket from cylinder head.

3.8.2.2 Inspection

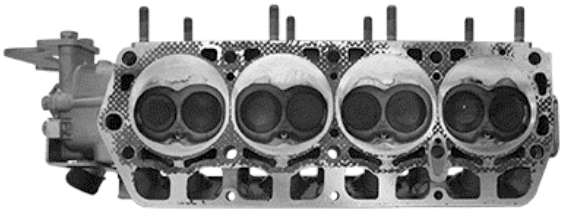


Figure 127 Cylinder Head

1. Using a wire brush, completely remove all carbon deposits from cylinder head. See Figure 127.

NOTICE
Cracks may develop in areas between cylinders and between valves commonly.

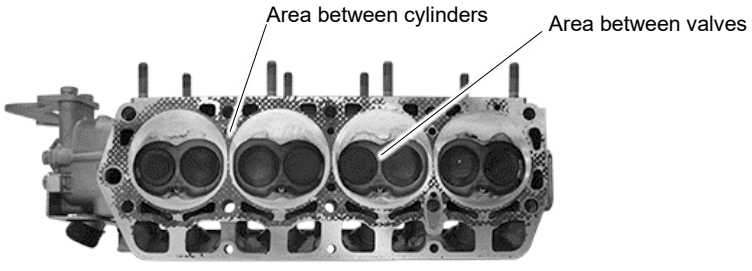


Figure 128 Cylinder Head Valves

2. Inspect cylinder head for cracks. If any cracks are found, replace cylinder head. See Figure 128.
3. Inspect spark plug hole threads. If spark plug hole threads are damaged, repair threads.

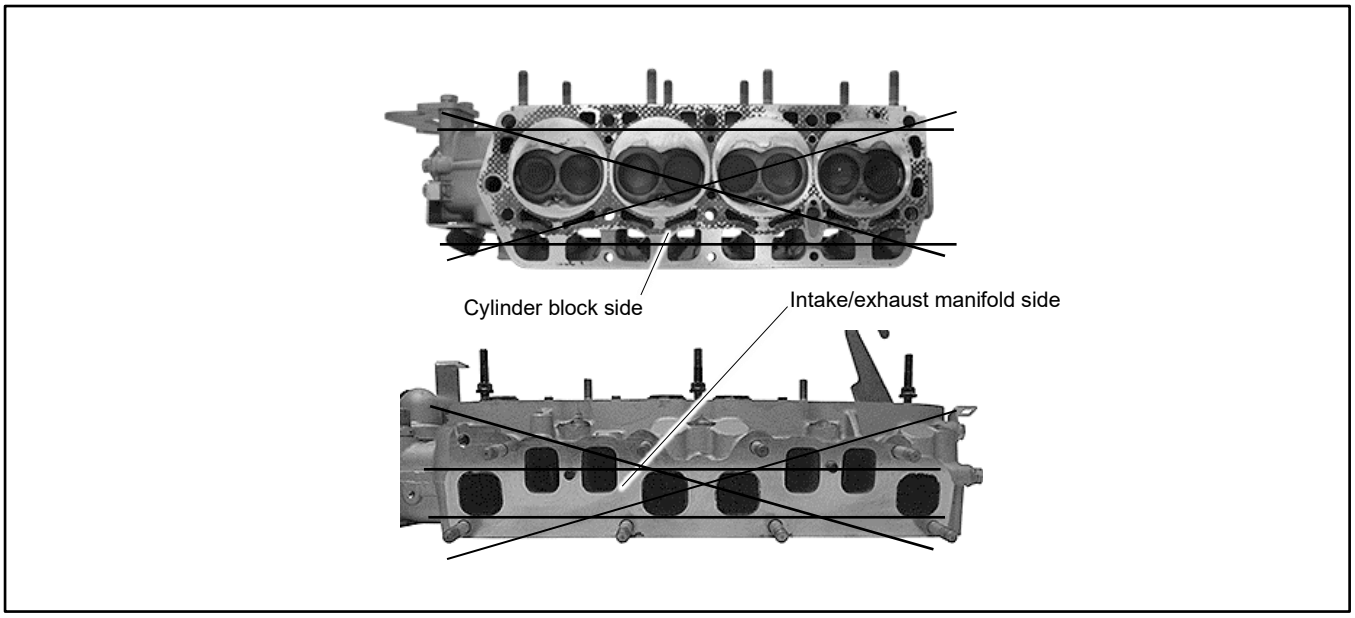


Figure 129 Cylinder Head Inspection

4. Inspect cylinder head for warpage at cylinder block side and at intake/exhaust manifold side using a straightedge and feeler gauge. See Figure 129.

CYLINDER HEAD WARPAGE—MAXIMUM	
Combustion Chamber Surface	Intake/Exhaust Manifold Surface
0.15 mm (0.0059 in.)	0.10 mm (0.0039 in.)

5. If cylinder head is not within specification, cylinder head must be replaced.
6. Install new cylinder head bolts. Do not reuse old cylinder head bolts.
7. Inspect cylinder head bolt holes in cylinder block for obstructions and damaged threads by running a thread chaser down the bolt holes.

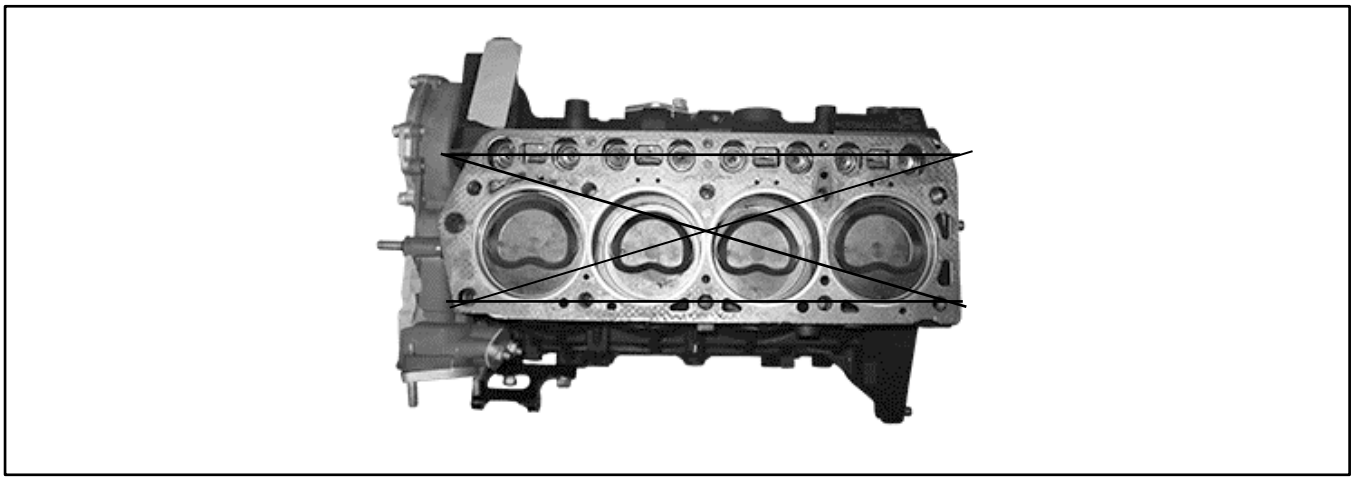


Figure 130 Cylinder Block Deck

8. Inspect cylinder block deck for warpage using a straightedge and feeler gauge as shown. See Figure 130.

CYLINDER BLOCK WARPAGE—MAXIMUM
0.05 mm (0.0019 in.)

9. If cylinder block deck is out of specification, cylinder block deck must be machined or cylinder block must be replaced.

3.8.2.3 Installation

Note:
Arrow points to front of engine assembly. Ensure head gasket is positioned as noted during removal.

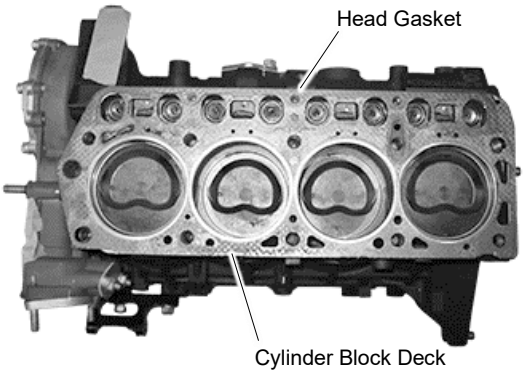


Figure 131 Head Gasket Location

1. Install new head gasket to a clean cylinder block deck. See Figure 131.

NOTICE
Use caution when installing cylinder head. Do not drag cylinder head over head gasket, or head gasket damage will occur.

2. Install cylinder head to cylinder block.
3. Lightly lubricate head bolts with clean engine oil.
4. Install cylinder head mounting bolts to cylinder head.

NOTE:
Arrow points to front of engine assembly.

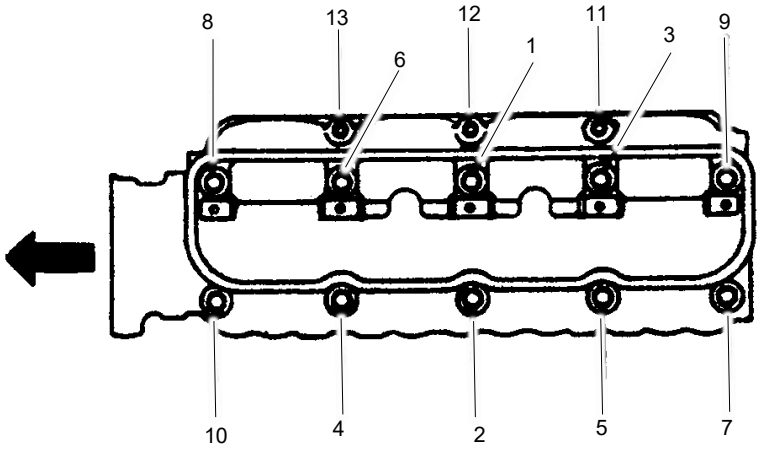


Figure 132 Cylinder Head Mounting Bolts Location

5. Torque cylinder head mounting bolts to specification in three steps in sequence shown. See Figure 132.

CYLINDER HEAD BOLT—TORQUE	
M12 Bolts (10 used)	**M8 Bolts (3 used)**
88–98 Nm (64.90–72.28 ft.lb.)	19–25 Nm (14.01–18.44 ft.lb.)

6. Install push rods to lifters as noted during removal.
7. Install rocker arm shaft. See “Rocker Arm Assembly—Removal and Installation”.

8. Install rocker arm cover. See “Remove and Install Rocker Arm Cover”.
9. Install exhaust manifold. See “Exhaust Manifold Removal and Installation”.
10. Install intake manifold. See “Intake Manifold Removal and Installation”.
11. Fill cooling system. See “Fluid Specifications”.

3.8.3 Rocker Arm Assembly—Removal and Installation

⚠ WARNING	**Spring-loaded parts.** **Can cause severe personal injury or property damage.** Wear protective goggles when servicing spring-loaded parts. Hold parts securely during disassembly.
	

3.8.3.1 Removal

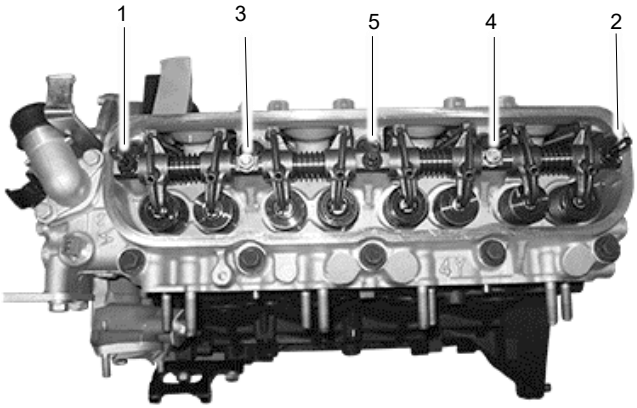


Figure 133 Rocker Arm Fastener Sequence

1. Loosen the rocker arm shaft fasteners in steps using sequence shown. Repeat this sequence until the pressure from the valve springs has been released. See Figure 133.

   Note:
   The rocker arms have light spring pressure applied to keep them in place over the valves. Use care when removing the rocker arm shaft from the cylinder head.

2. Remove the fasteners and then remove the rocker arm shaft from the cylinder head.

3.8.3.2 Inspection

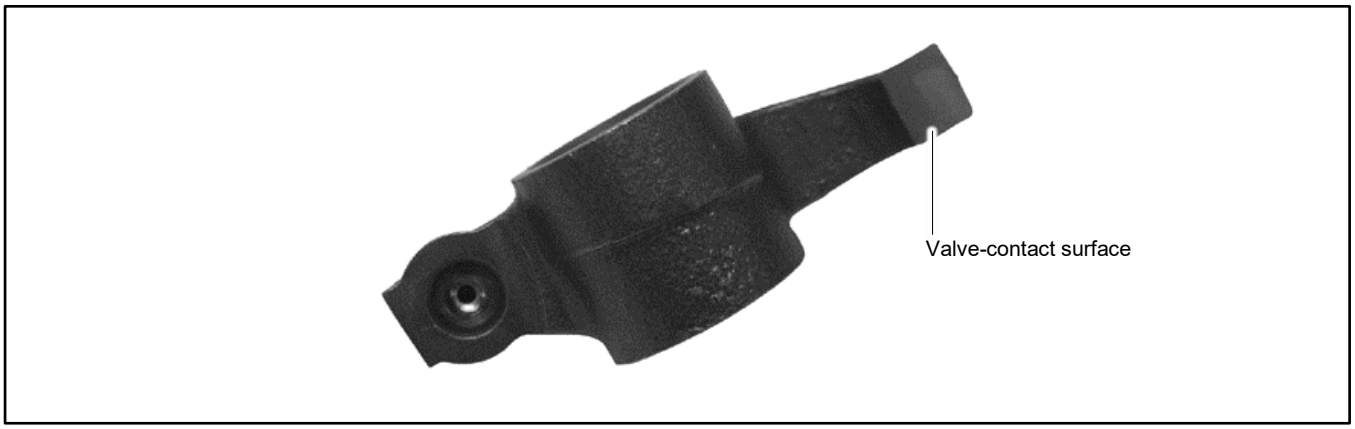


Figure 134 Valve-Contact Surface

1. Inspect the valve-contact surface of the rocket arm for wear. Grind this surface or replace arm rocker if necessary. See Figure 134.

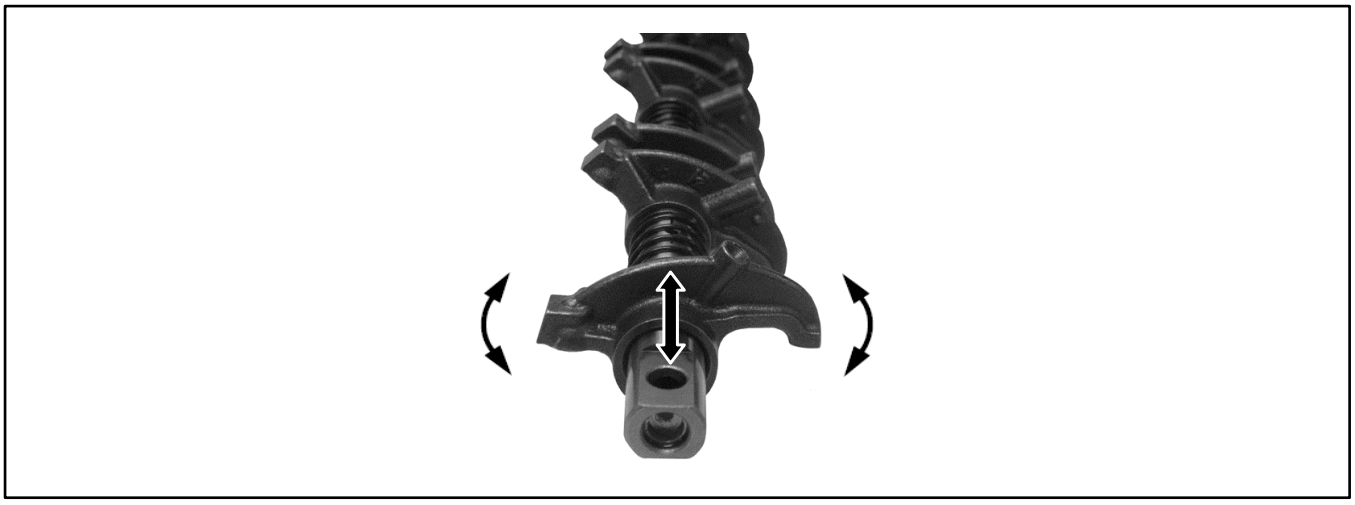


Figure 135 Checking the Rocker Arm-to-Shaft Clearance

2. Inspect the rocker arm-to-shaft clearance by moving each rocker arm as shown, checking for movement. See Figure 135.

   Note:
   During disassembly, arrange the rocker arm shaft components in the correct sequence for assembly.

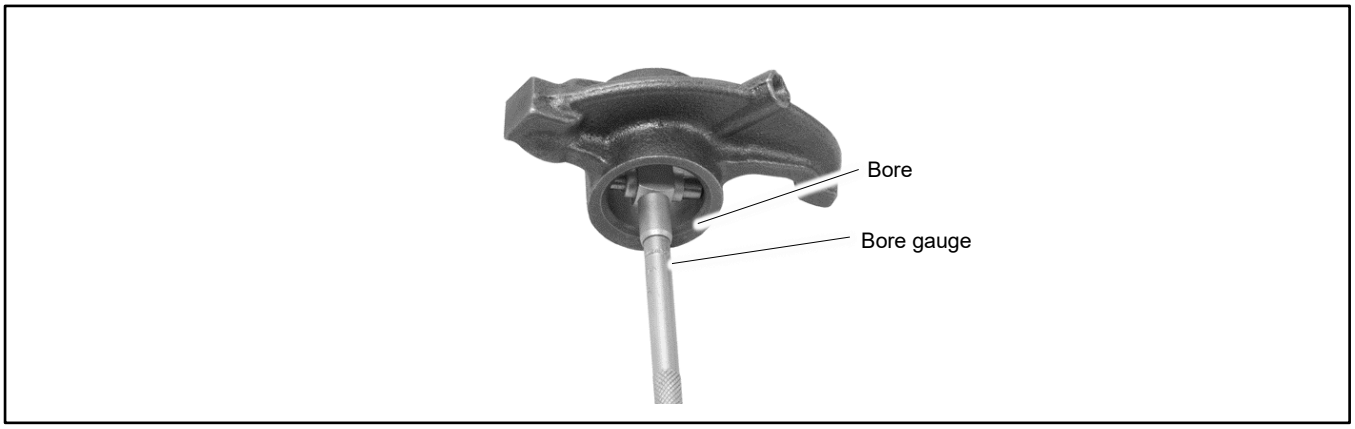


Figure 136 Measuring the Rocker Arm Shaft Bore

3. If movement is felt, disassemble and measure the inside diameter (bore) of the rocker arm, using the appropriate bore gauge. See Figure 136.

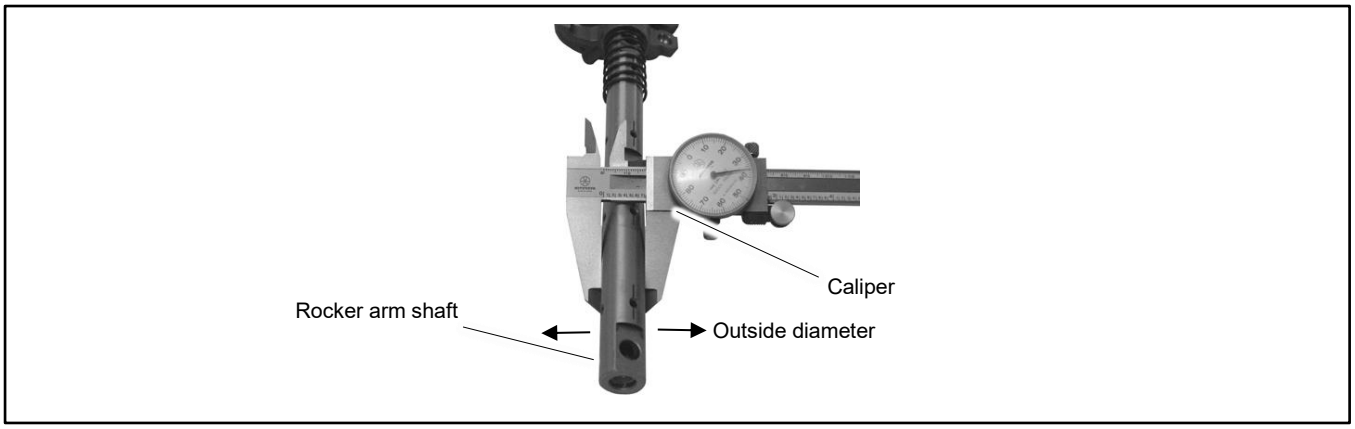


Figure 137 Measuring the Rocker Arm Shaft Outside Diameter

4. Measure the rocker arm shaft outside diameter using a caliper. Two measurements should be taken, the second at 90° from the first measurement. Use the larger measurement for calculations. See Figure 137.

ROCKER ARM SPECIFICATIONS	
Rocker Arm—Inside Diameter (Bore)	18.500–18.513 mm (0.7283–0.7288 in.)
Rocker Arm Shaft—Outside Diameter	18.467–18.482 mm (0.7270–0.7276 in.)
Rocker Arm—Standard Oil Clearance	0.018–0.046 mm (0.0007–0.0018 in.)
Rocker Arm—Maximum Oil Clearance	0.08 mm (0.0031 in.)
If the oil clearance is not within specification, replace rocker arm and rocker arm shaft.	

If the oil clearance is not within specification, replace rocker arm and rocker arm shaft.

3.8.3.3 Installation

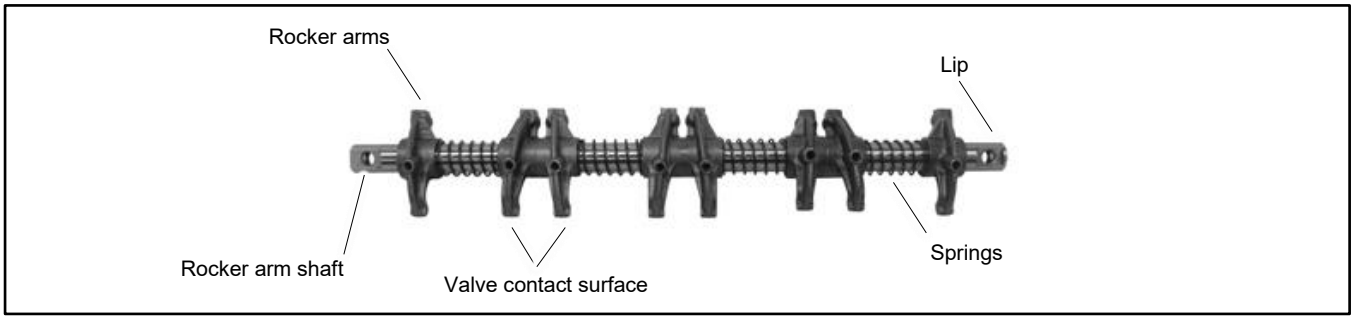


Figure 138 Rocker Arms Assembly and Installation

1. Arrange the rocker arms into pairs with the valve contact surface angled in. See Figure 138.
2. Compress the springs with the rocker arms and install the rocker arm support tool to hold the rocker arms and springs in place during assembly.
3. When installing the rocker arm assembly on the cylinder head, the raised lip on the rocker arm shaft must be to the rear and facing up as shown.

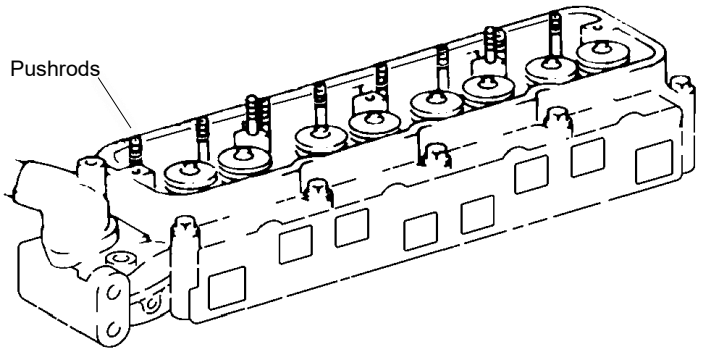


Figure 139 Pushrod Location

NOTICE
When installing the pushrods, make sure the pushrod is fully seated in the hydraulic valve lifter.

4. Install the pushrods into the hydraulic valve lifters. See Figure 139.
5. Install the rocker arm assembly on the cylinder head, aligning the pushrods with the rocker arms, and install the fasteners.

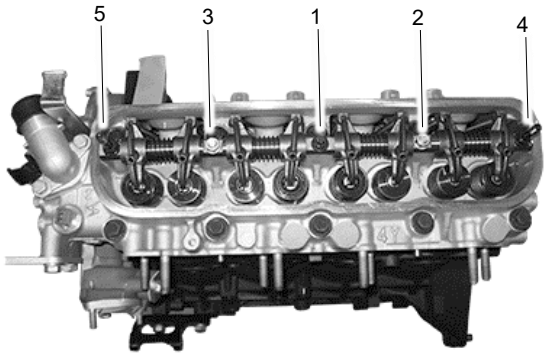


Figure 140 Rocker Arm Assembly Tightening Sequence

NOTICE
The following step must be done to evenly distribute spring pressure to the components and prevent damage to rocker arm assembly and pushrods.

6. Tighten the rocker arm fasteners in the sequence shown in several steps to specification. See Figure 140.

ROCKER ARM SHAFT ASSEMBLY—TORQUE
25–32 Nm (18–24 ft.lb.)

7. Remove the rocker arm support tools and the pushrod alignment tools.

3.8.4 Valves—Removal and Installation

⚠ WARNING	**Spring-loaded parts.** **Can cause severe personal injury or property damage.** Wear protective goggles when servicing spring-loaded parts. Hold parts securely during disassembly.
	

3.8.4.1 Removal

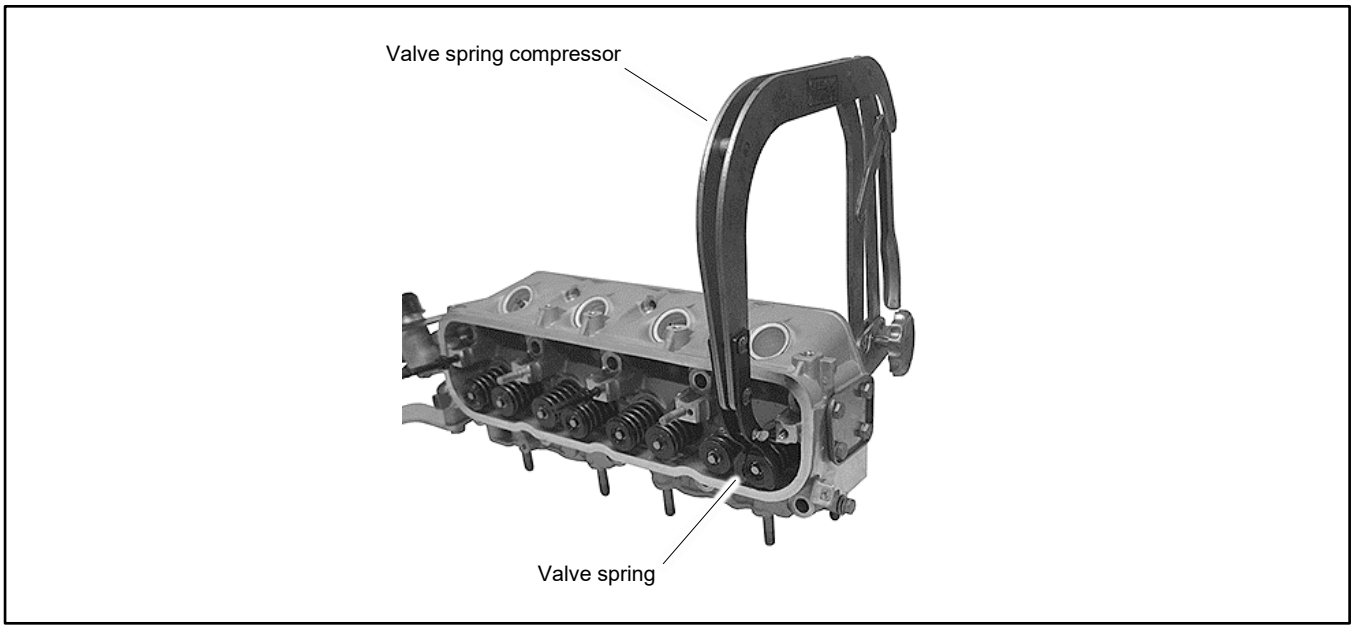


Figure 141 Valve Spring Compressor

1. Remove the valves from the cylinder head using a valve spring compressor to compress the valve spring to remove the valve retainers. See Figure 141.

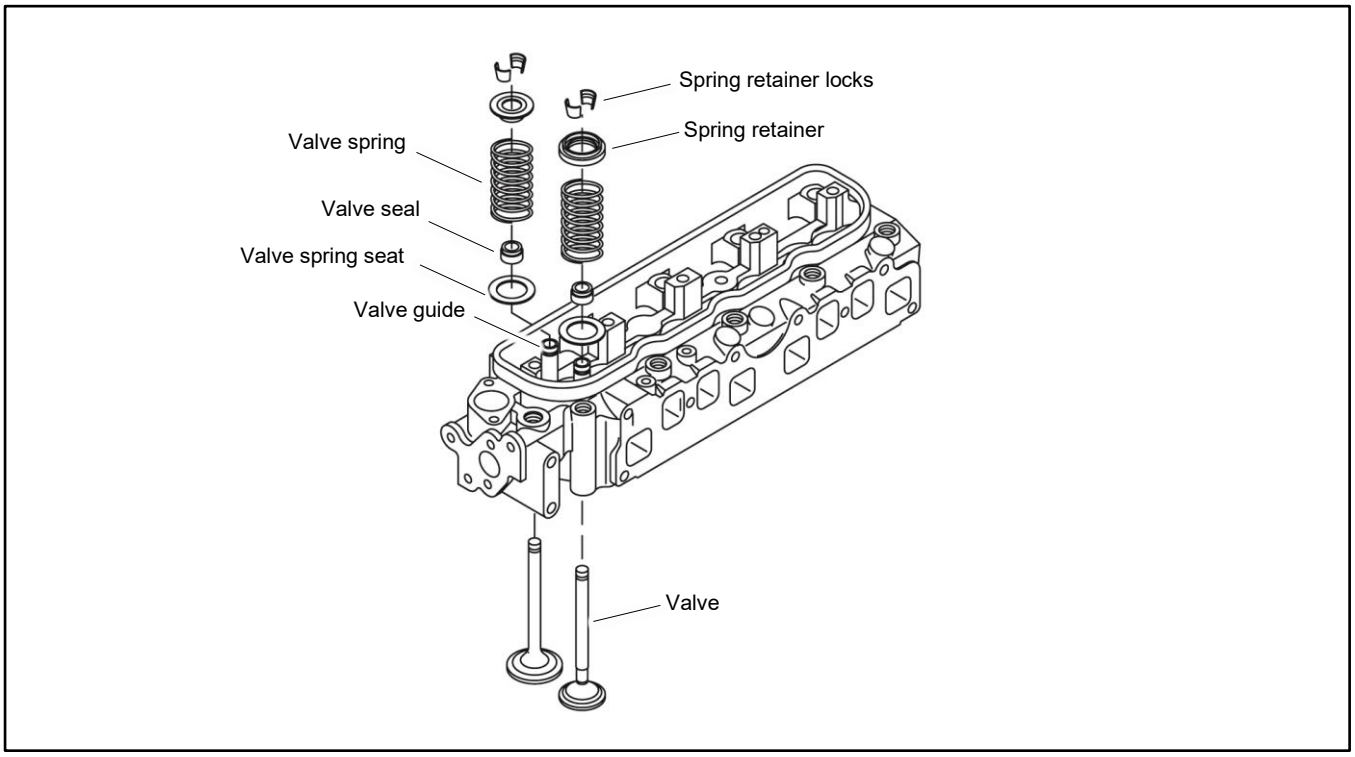


Figure 142 Valve Component Location

2. Compress the valve spring enough to remove the spring retainer locks. See Figure 142.
3. Remove the spring retainer locks.
4. Remove the tension on the valve spring and remove the spring retainer, the valve spring, and the valve spring seat.
5. Remove the valve.
6. Remove the valve seal and discard.

3.8.4.2 Installation

NOTICE
The exhaust valve assemblies utilize a rotating spring retainer that is not compatible with the intake valves. Engine damage can occur if rotating spring retainers are used with the intake valves.

1. Clean out the valve guide with a brush before installing the valves.

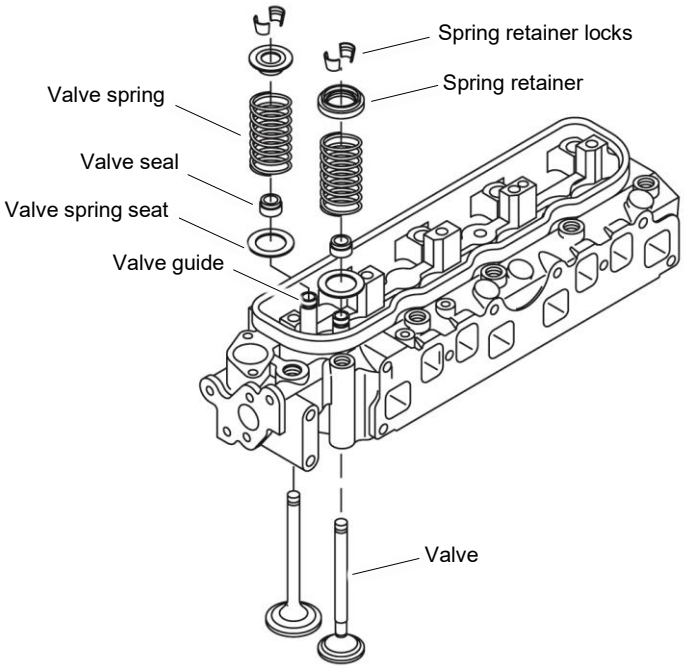


Figure 143 Valve Component Location

2. Apply a light layer of assembly lubricant to the valve stem before inserting into the valve guide. See Figure 143.
3. Install the valve into the valve guide.
4. Place the oil seal installation sleeve (if provided) over the valve stem. Apply a thin layer of assembly lubricant to the top of the sleeve and install the oil seal over the sleeve until it reaches the top of the valve guide. Press the oil seal into place using the appropriate oil seal installation tool.
5. Apply a light coat of assembly lubricant and install the valve spring seat.

NOTICE
The painted portion of the valve spring MUST face the head.

6. Install the valve spring with the painted end facing the cylinder head.

NOTICE
The exhaust valve assembly uses a rotating valve spring retainer that allows the exhaust valve to rotate. **Do not install this retainer on the intake valve assembly, or engine failure may result.**

7. Apply a thin layer of assembly lubricant to the spring retainer and install over the valve spring.

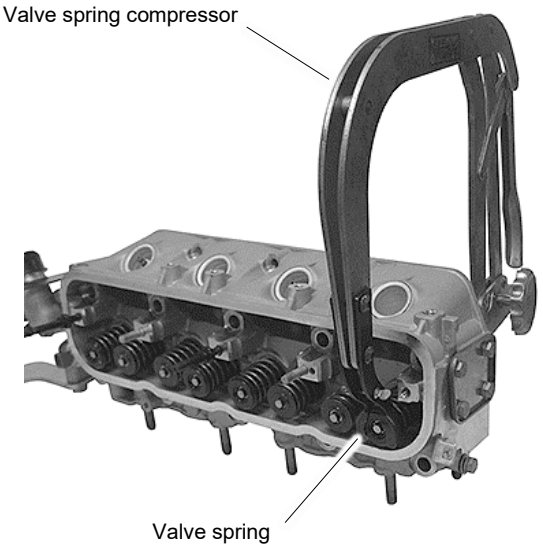


Figure 144 Valve Spring Compressor

⚠ WARNING	**Spring-loaded parts.** **Can cause severe personal injury or property damage.** Wear protective goggles when servicing spring-loaded parts. Hold parts securely during disassembly.
	

NOTE:
Apply a small amount of assembly lubricant to the insides of the valve spring retainer locks to aid in assembly and to hold in place during the release of the valve spring.

8. Using an appropriate valve spring compressor, compress the valve spring to gain enough clearance, and install the valve spring retainer locks. See the Valve Spring Compressor figure.
9. Slowly release the valve spring compressor, making sure that the valve spring retainer locks remain seated.
10. Using a soft-faced hammer, tap the top of the valve stem to seat the valve spring retainer locks into the locking grooves of the valves. Clean out the valve guide with a brush before installing the valves.

3.8.5 Cylinder Head Component Inspection

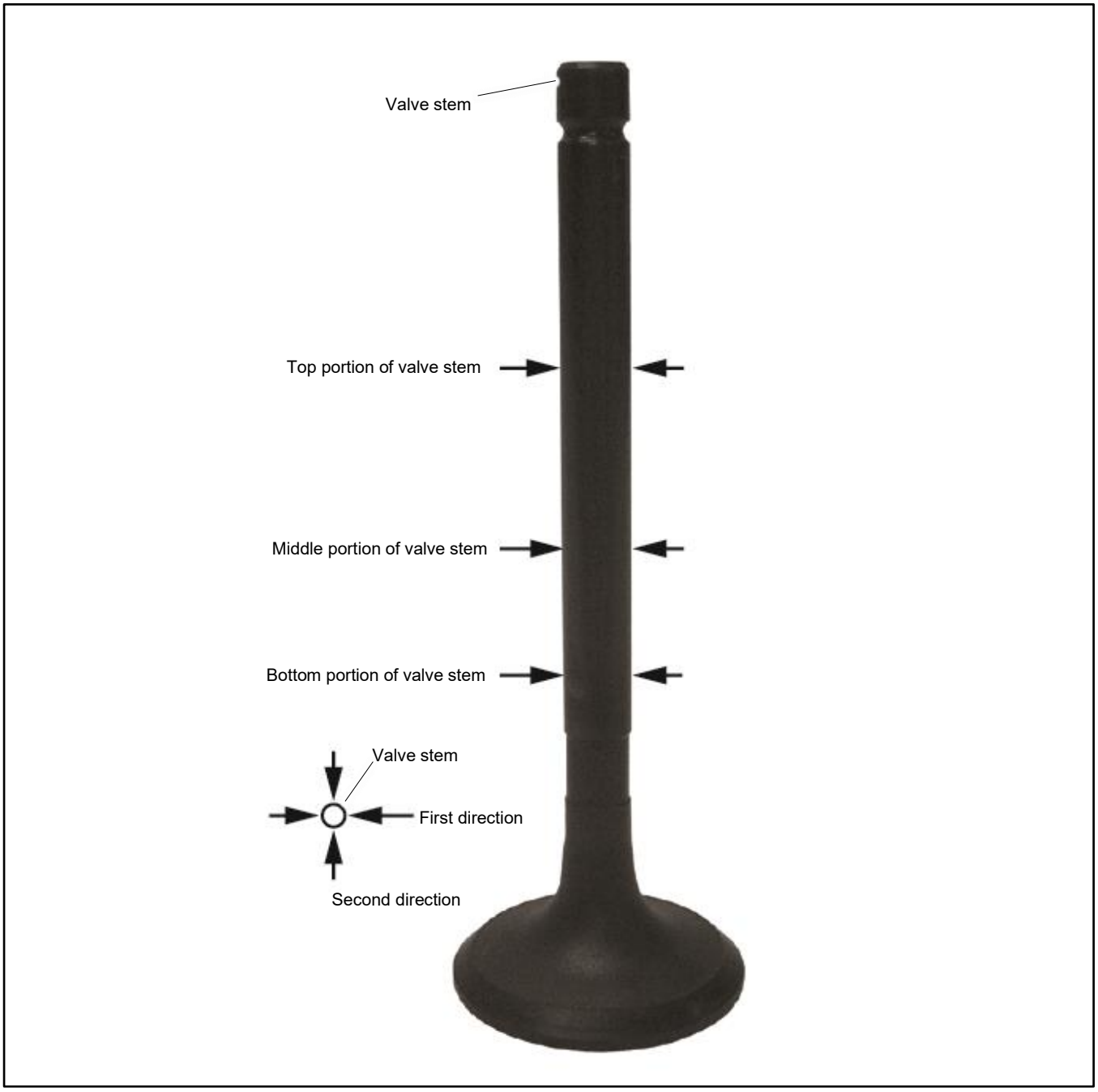


Figure 145 Valve Stem

1. Measure the valve stem at the top, middle, and bottom of the valve stem. Record the measurement from the first direction. See Figure 145.
2. Rotate the valve 90° and measure the valve stem a second time, beginning again at the top, then middle, and bottom of the valve stem. Record the measurements from the second direction. If the valve stem measurements do not meet specifications, shown on the following page, replace the valve.

   Note:
   Valve guide shown removed from cylinder head for clarity only.

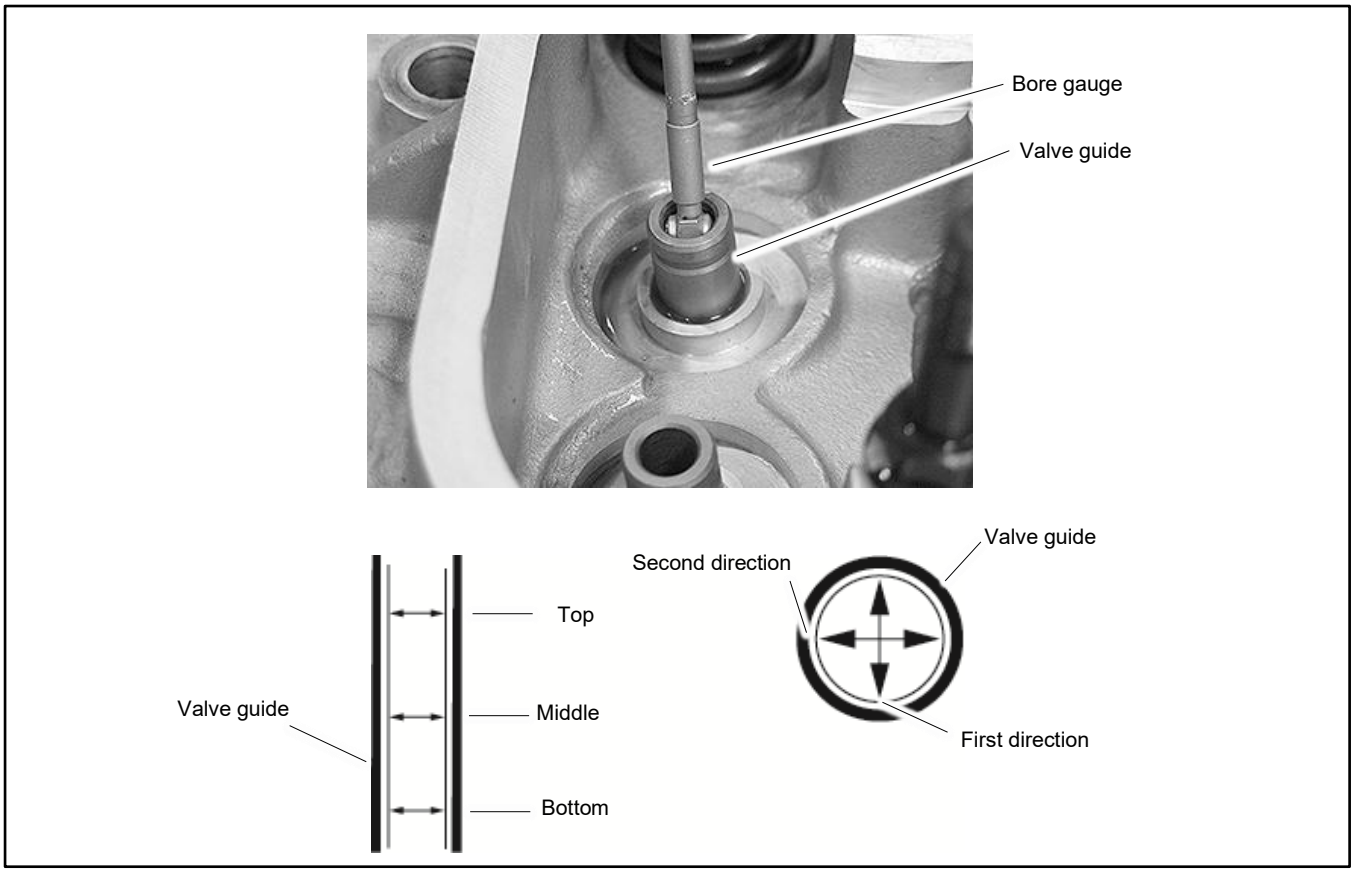


Figure 146 Measure the Inside Diameter of the Valve Guide

3. Measure the inside diameter of the valve guide at the top, middle, and bottom in the first direction. See Figure 146.
4. Measuring in the second direction, rotating 90°, measure the top, middle, and bottom of the valve guide.
5. Check the oil clearance between the valve stem and the valve guide. The oil clearance must be within specification.

VALVE SPECIFICATIONS	
Valve Guide Bushing—Inside Diameter	8.010–8.030 mm (0.3153–0.3161 in.)
Intake Valve—Valve Stem Diameter	7.970–7.985 mm (0.3137–0.3143 in.)
Exhaust Valve—Valve Stem Diameter	7.965–7.98 mm (0.3135–0.3141 in.)
Intake Valve—Standard Oil Clearance	0.025–0.060 mm (0.0009–0.0023 in.)
Exhaust Valve—Standard Oil Clearance	0.030–0.065 mm (0.0011–0.0025 in.)
Intake Valve—Maximum Oil Clearance	0.10 mm (0.0039 in.)
Exhaust Valve—Maximum Oil Clearance	0.12 mm (0.0047 in.)

6. If valves or valve guides do not meet specification, replace the valve and the valve guide.
7. Clean and inspect valve for pits, grooves, and carbon buildup.

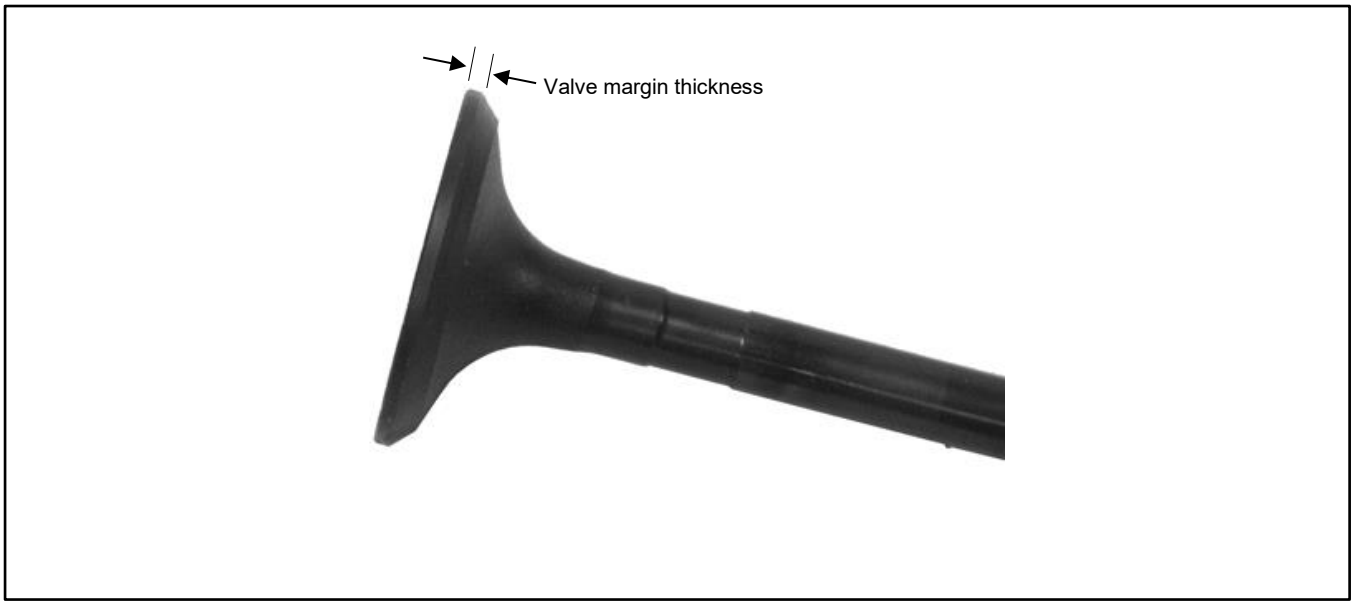


Figure 147 Valve Margin Thickness

8. Check the valve margin thickness. See Figure 147.

VALVE MARGIN SPECIFICATIONS	
Intake Valve—Standard Margin Thickness	1.0–1.4 mm (0.0393–0.0551 in.)
Exhaust Valve—Standard Margin Thickness	1.3–1.7 mm (0.0511–0.0669 in.)
Intake Valve—Minimum Margin Thickness	0.5 mm (0.0196 in.)
Exhaust Valve—Minimum Margin Thickness	0.8 mm (0.0314 in.)

If the margin thickness specification is less than the minimum value, replace the valve.

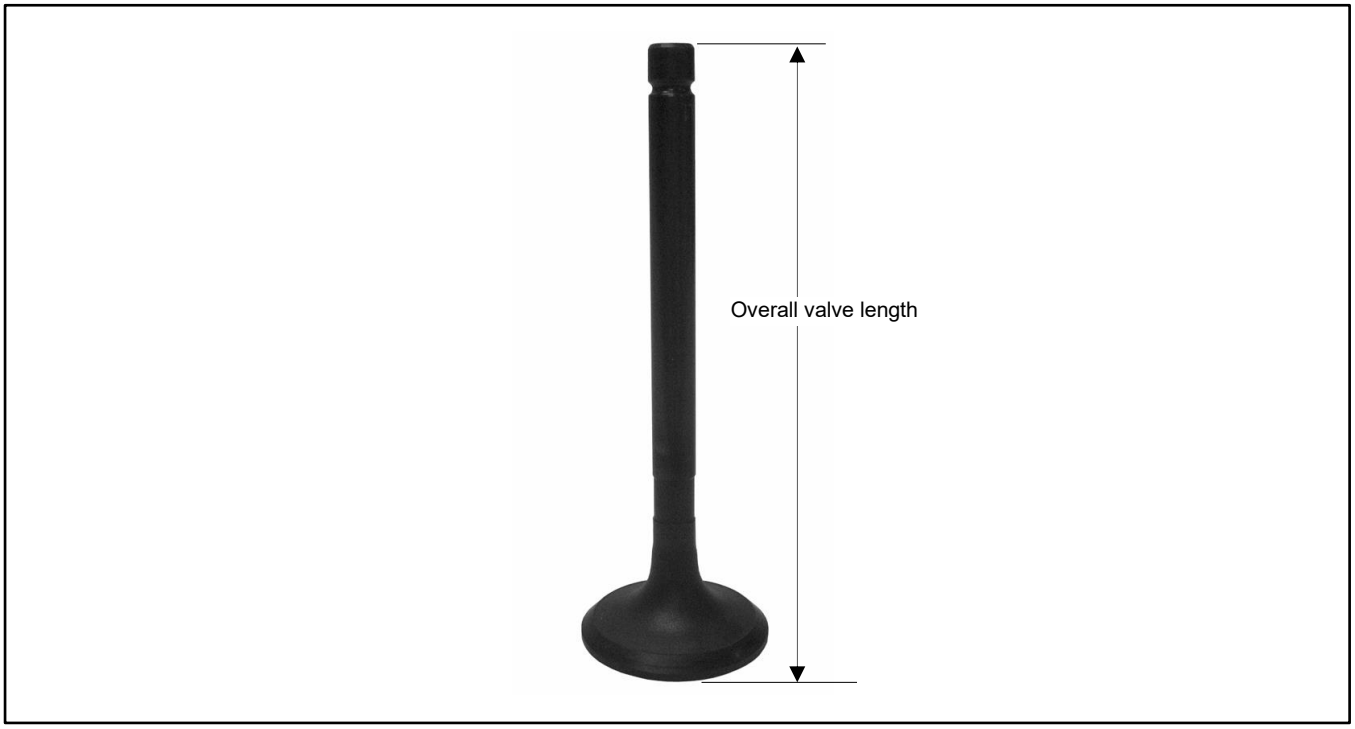


Figure 148 Overall Valve Thickness

9. Measure the overall valve length. See Figure 148.

VALVE SPECIFICATIONS	
Intake Valve—Standard Overall Length	108.2 mm (4.2598 in.)
Exhaust Valve—Standard Overall Length	108.5 mm (4.2716 in.)
Intake Valve—Minimum Overall Length	107.7 mm (4.2401 in.)
Exhaust Valve—Minimum Overall Length	108.0 mm (4.2519 in.)

If the valve length does not meet the minimum length specification, replace the valve.

3.8.5.1 Valve and Valve Seat—Contact Check

Check valve seats for wear, damage, and carbon buildup. Only grind the valve seat, if necessary, enough to remove pits, grooves, and carbon buildup.

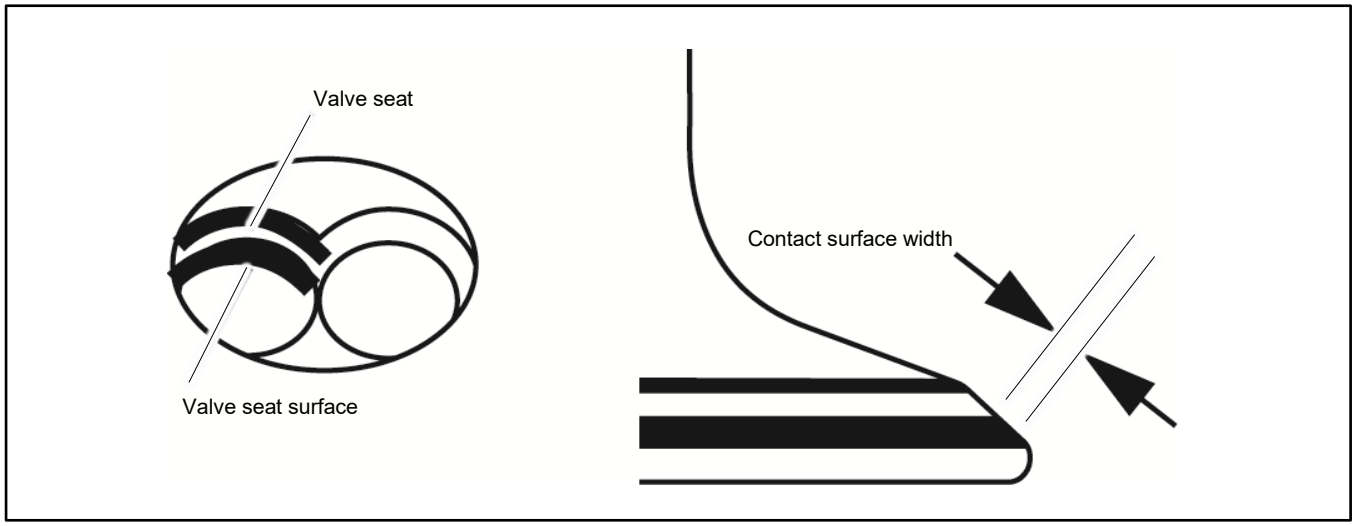


Figure 149 Valve Seat

1. Apply a thin layer of layout dye to the valve seat surface. See Figure 149.
2. Install the valve and lightly apply pressure to the valve. Check the valve contact pattern with the valve seat.
3. The valve face surface must show blue in the middle all the way around the seat, with a contact surface width that is within specification.

VALVE SEAT—CONTACT WIDTH
1.2–1.6 mm (0.0472–0.0629 in.)

If the seat circle from the previous steps does not produce results within specification, an adjustment is needed.

3.8.5.2 Valve Seat Grinding and Lapping

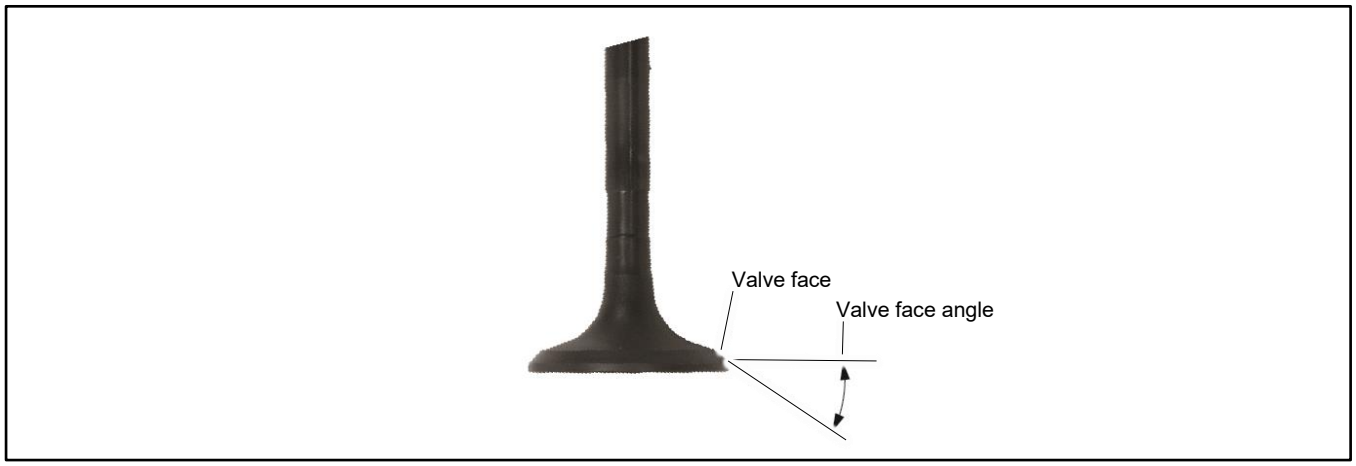


Figure 150 Valve Face

1. Check to make sure the valve face meets the specified valve face angle. Grind the valve only enough to remove pits and carbon from the valve face if necessary. See Figure 150.

INTAKE AND EXHAUST VALVE FACE ANGLE
44.5° Angle

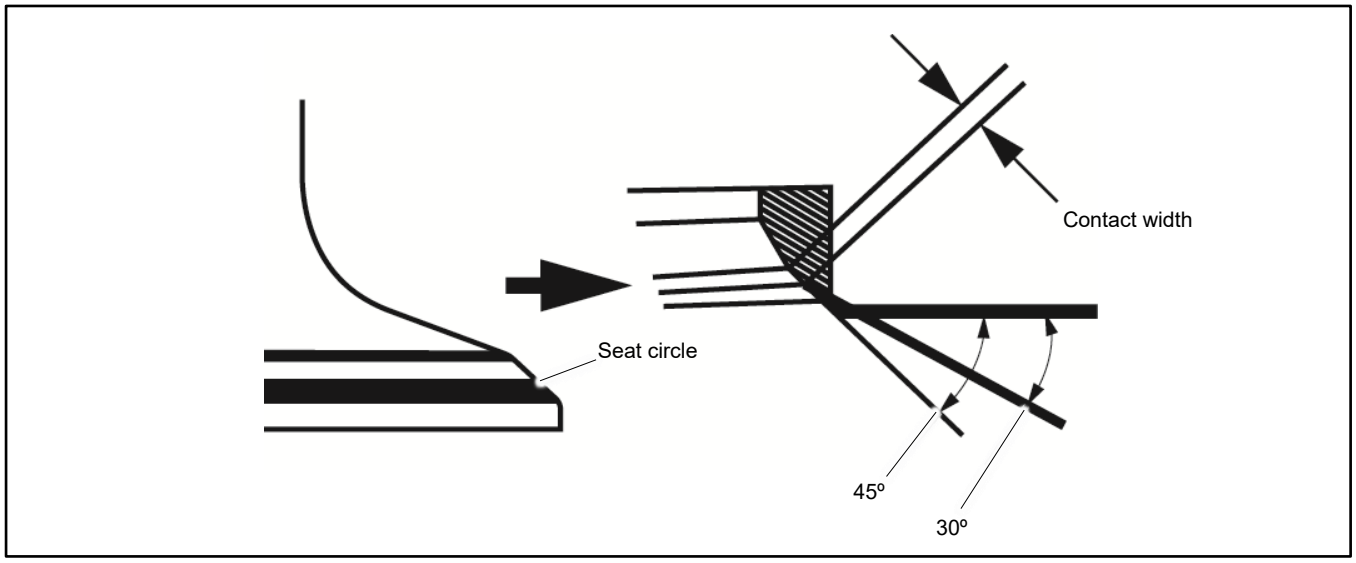


Figure 151 Valve Seat Position Closer to the Top Surface

2. If the seat circle is closer to the top side of the valve face, grind seat with 30° and 45° milling cutter, while maintaining the contact width. See Figure 151.

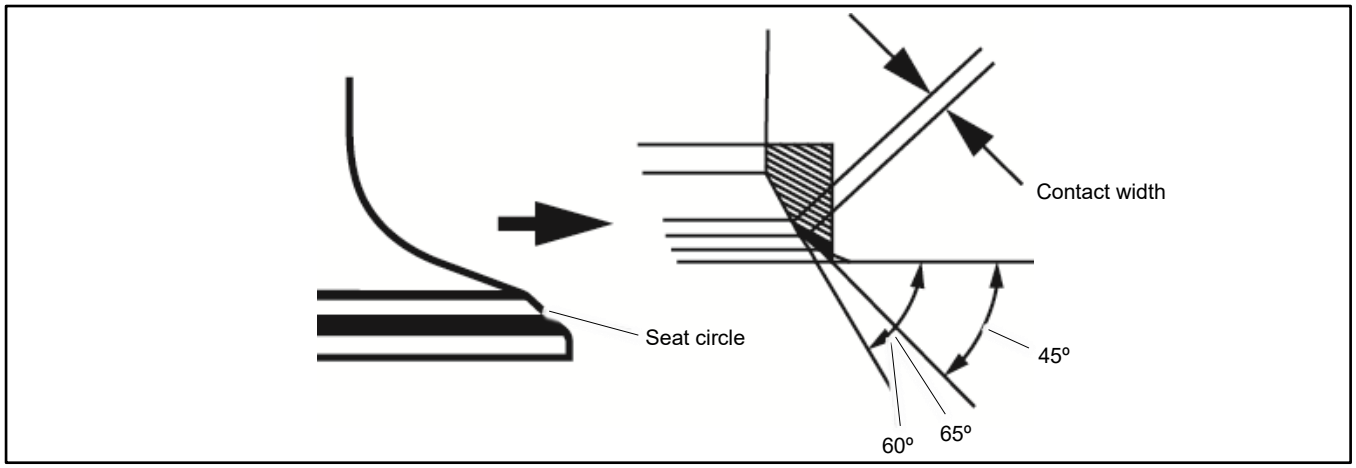


Figure 152 Valve Seat Position Closer to the Bottom Surface

3. If seat circle is closer to the lower side of the valve face surface, grind the seat with a 60° and 45° milling cutter for the intake seats. For the exhaust, grind the seat with a 65° and 45° milling cutter, while maintaining the contact width. See Figure 152.

4. Using a valve lapping tool and lapping compound, lap the valve into the seat by hand and check that there is no leakage between the valve and the seat. Clean the valve, valve guide, and valve seat completely before assembly.

3.8.5.3 Valve Spring—Inspection

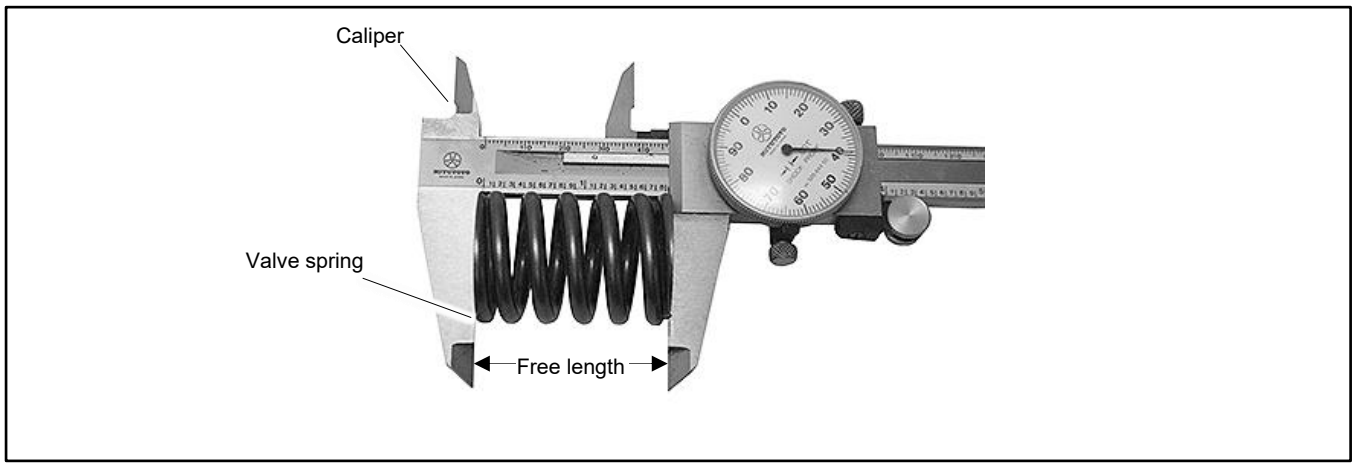


Figure 153 Caliper

1. Using a caliper, measure the free length of the valve spring. The free length should be within specification. See Figure 153.

VALVE SPRING—FREE LENGTH
46.75–47.25 mm (1.8208–1.8602 in.)

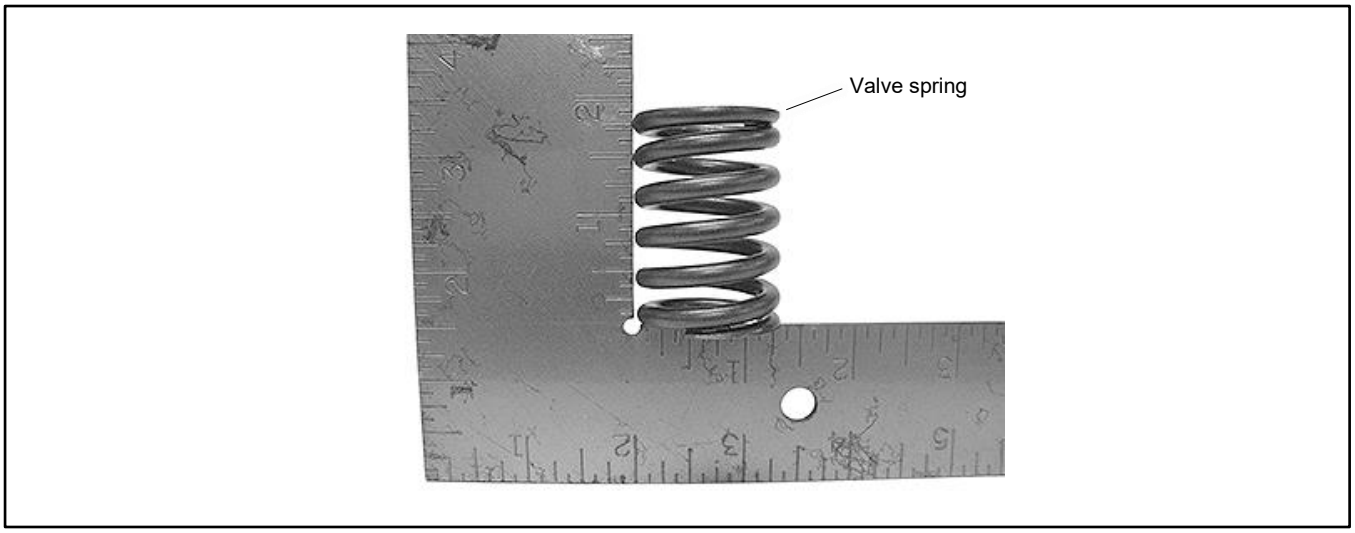


Figure 154 Valve Spring

2. Using a steel square, check the valve spring for squareness on a flat surface. The valve spring should be within specification. See Figure 154.

VALVE SPRING—SQUARENESS LIMIT
<2.0 mm (0.0787 in.)

3. Measure the tension of the valve spring at the specified installed height.

VALVE SPRING SPECIFICATIONS	
Valve Spring—Installed Height	40.6 mm (1.5984 in.)
Valve Spring—Tension	282–345 N (63.4–77.56 lbf.)

If any of the valve spring specifications are not met, replace the valve spring.

3.8.5.4 Pushrods—Inspection

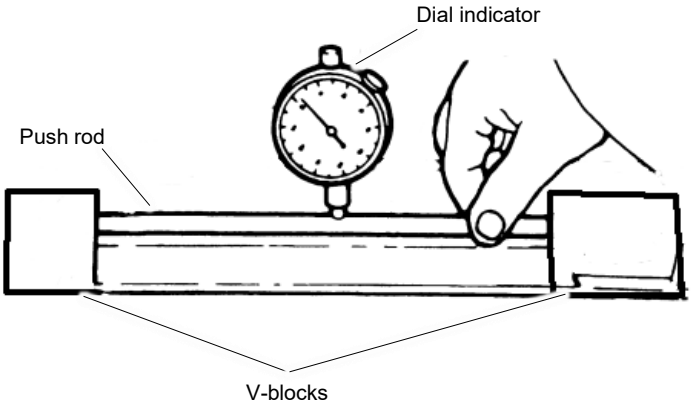


Figure 155 Pushrods

1. Place the push rod on a pair of V-blocks. Using a dial indicator, measure the runout on the dial indicator gauge by slowly rotating the pushrod and observing the reading on the dial indicator. See Figure 155.

PUSHROD—MAXIMUM RUNOUT
0.30 mm (0.0118 in.)

If the measured runout is greater than the specified maximum runout, replace the push rod.

⚠ WARNING	**Airborne particles.** **Can cause severe injury or blindness.** Wear protective goggles and clothing when using power tools, hand tools, or compressed air.
	

1. Check push rod oil hole for obstructions. Clean as needed.

3.8.6 Valve Guides—Removal and Installation

3.8.6.1 Removal

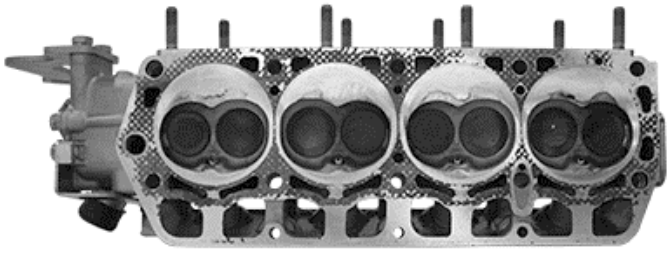


Figure 156 Intake and Exhaust Ports of the Cylinder Head

1. Before removing valve guides, clean any carbon deposits from inside the intake and exhaust ports of the cylinder head. See Figure 156.

Servicing the exhaust system. Hot parts can cause severe injury or death. Do not touch hot engine parts. The engine and exhaust system components become extremely hot during operation.

2. To remove damaged valve guides, gradually heat the cylinder head to 80–100°C (176–212°F).

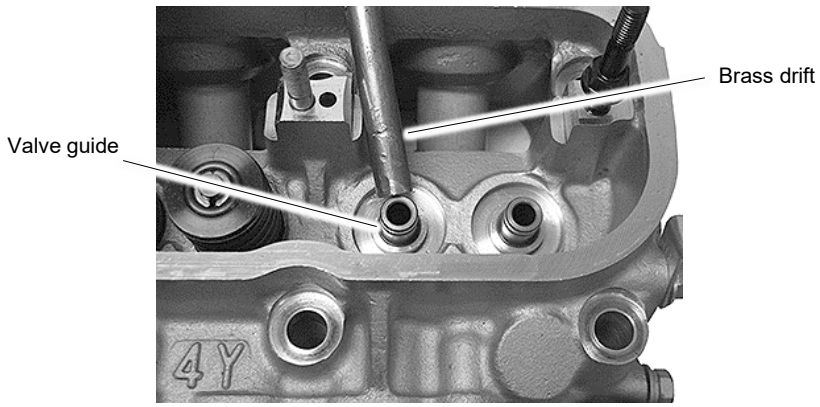


Figure 157 Break Off the Top of the Valve Guide

3. Using a brass drift, break off the top of the valve guide. See Figure 157.

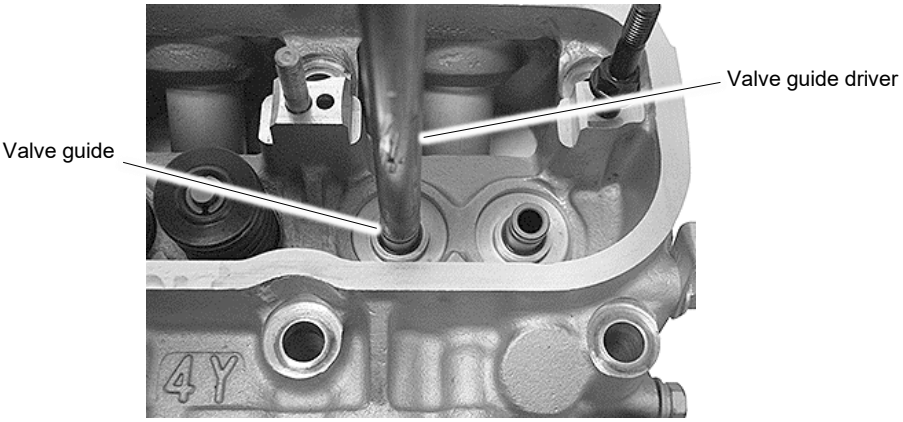


Figure 158 Removing the Valve Guide

4. Remove the valve guide using a hammer with the proper valve guide driver. See Figure 158.

3.8.6.2 Installation

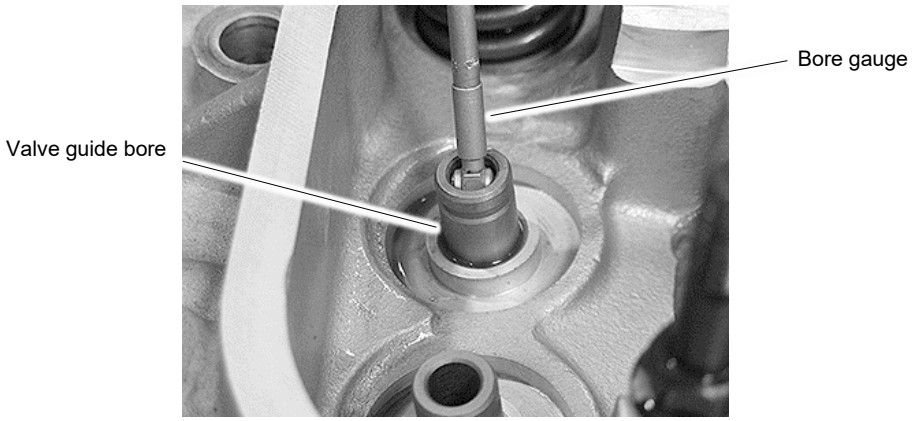


Figure 159 Valve Guide Bore Location

1. Using a bore gauge, measure the valve guide bore in the cylinder head to determine valve guide size. See Figure 159.

   a. If the valve guide bore is within the standard valve guide bore specification, use a standard size valve guide.

   b. If the valve guide bore exceeds oversize valve guide bore specification, use a reamer to correct the valve guide bore to specification and install an oversize valve guide.

   c. If the valve guide bore exceeds the maximum specified bore dimension, replace the cylinder head.

VALVE GUIDE SPECIFICATIONS	
Valve Guide Bore—Standard Valve Guide	13.000–13.027 mm (0.5118–0.5129 in.)
Valve Guide Bore—Resize Dimensions	13.050–13.077 mm (0.5138–0.5148 in.)
Valve Guide Bore—Oversize Valve Guide	13.050–13.077 mm (0.5129–0.5138 in.)
Valve Guide Bore—Maximum Valve Guide Bore Size	13.077 mm (0.5129 in.)

Hot engine components. Can cause severe injury or death. Never operate the engine with heat shields or guards removed.

2. Before installing valve guides, gradually heat the cylinder head to 80–100°C (176–212°F).

NOTICE
The valve guides must be installed to align with the valve guide bore. Improperly installed valve guides can damage the valve guide and the cylinder head.

Note:
To aid in valve guide installation, the valve guides may be placed in a freezer or other cold environment prior to installation.

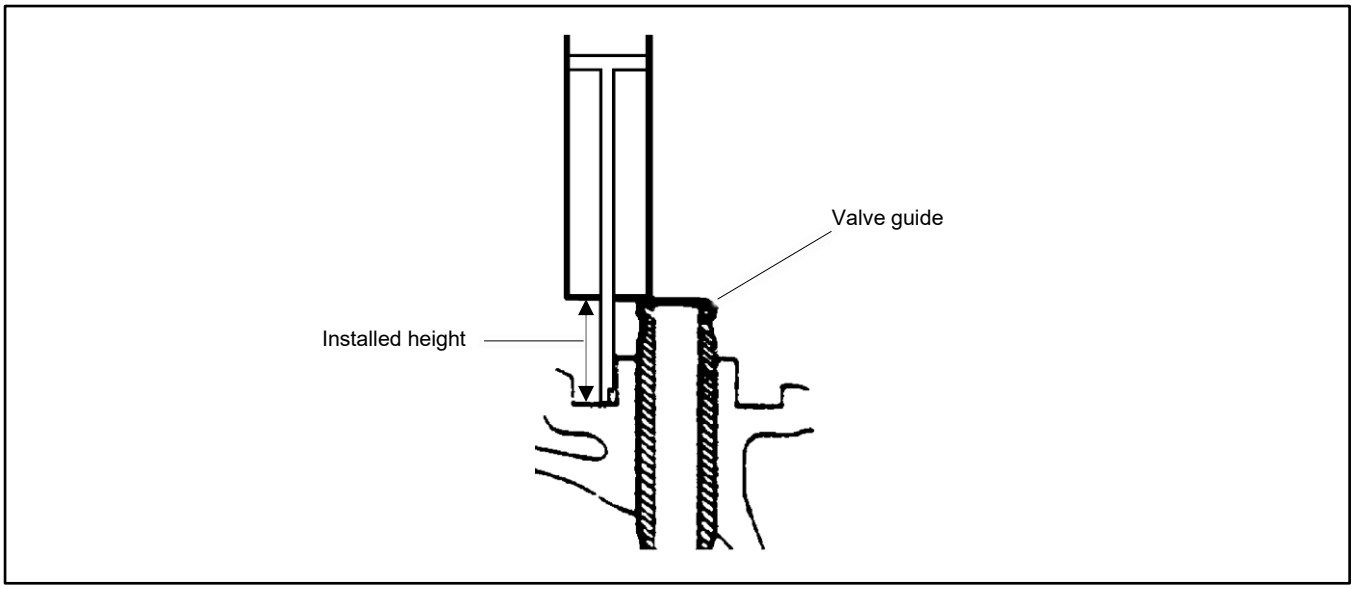


Figure 160 Installing the Valve Guides

3. Apply a light layer of assembly lubricant to the valve guide and install the valve guide into the valve guide bore using the valve guide drive and a hammer. See Figure 160.
4. Drive the valve guide into the cylinder head until it has reached proper installed height.

VALVE GUIDE—INSTALLED HEIGHT
20.31 mm (0.080 in.)

3.9 Cylinder Block

WARNING	
	**Carbon monoxide.** **Can cause severe nausea, fainting, or death.** Avoid inhaling exhaust fumes.

Engine Operation. Carbon monoxide can cause severe nausea, fainting, or death. Engine exhaust gases contain poisonous carbon monoxide. Carbon monoxide is an odorless, colorless, tasteless, nonirritating gas that can cause death if inhaled for even a short time. Avoid breathing exhaust fumes when working on or near the engine. Never operate the engine inside a building. Never operate the engine where exhaust gas could seep inside or be drawn into a potentially occupied building through windows, air intake vents, or other openings.

WARNING	
	**Pinch and entanglement hazards.** **Can cause severe injury and possible death.** Never check drive belt tension while the engine is running.

WARNING	
	**Risk of fire.** **Can cause severe injury or death.** Do not smoke or permit flames or sparks near fuels or the fuel system.

⚠ CAUTION	**Hazardous voltage.** **Electrical shock can cause injury.** Do not touch wires while the engine is running. Stop the engine and disconnect the battery leads, negative (-) lead first, before servicing the engine.
	

⚠ WARNING	**Moving parts.** **Can cause severe injury or death.** Operate the engine only when all guards and electrical enclosures are in place. Stay away from moving parts while the engine is in operation.
	

Servicing the engine when it is operating. Exposed moving parts can cause severe injury or death. Keep hands, feet, hair, clothing, and test leads away from the belts and pulleys when the engine is running. Replace guards, screens, and covers before operating the engine.

⚠ WARNING	**Hot engine and exhaust system.** **Can cause severe injury or death.** Do not work on the engine until it cools.
	

Hot engine components. Can cause severe injury or death. Never operate the engine with heat shields or guards removed.

⚠ WARNING	**Hot coolant and steam.** **Can cause severe injury or death.** Before removing the pressure cap, stop the engine and allow it to cool. Then loosen the pressure cap to relieve pressure.
	

Liquid coolant can be extremely hot from operation. Turning radiator cap when engine is hot can allow steam and scalding liquid to blow out and burn you severely. Shut off machine. Only remove radiator cap when cool enough to touch with bare hands. Slowly loosen cap to the first stop to relieve pressure before removing completely.

⚠ WARNING	**Accidental starting.** **Can cause severe injury or death.** Disconnect the battery cables before working on the engine. Remove the negative (–) lead first when disconnecting the battery. Reconnect the negative (–) lead last when reconnecting the battery.
	

Disabling the engine. Accidental starting can cause severe injury or death. Before working on the engine or connected equipment, disable the engine as follows: 1) Disconnect the ignition coil. 2) Remove the battery cables, negative (–) lead first. Reconnect the negative (–) lead last when reconnecting the battery. Follow these precautions to prevent the accidental starting of the engine.

⚠ WARNING	**Explosive fuel vapors.** **Can cause fires and severe burns.** If a gaseous odor is detected, ventilate the area and contact an authorized service technician.
	

The fuel system. Explosive fuel vapors can cause severe injury or death. Vaporized fuels are highly explosive. Use extreme care when handling and storing fuels. Store fuels in a well-ventilated area away from spark-producing equipment and out of the reach of children. Never add fuel to the tank while the engine is running because spilled fuel may ignite on contact with hot parts or from sparks. Do not smoke or permit flames or sparks to occur near sources of spilled fuel or fuel vapors. Keep the fuel lines and connections tight and in good condition. Do not replace flexible fuel lines with rigid lines. Use flexible sections to avoid fuel line breakage caused by vibration. Do not operate the engine in the presence of fuel leaks, fuel accumulation, or sparks. Repair fuel systems before resuming engine operation.

⚠ WARNING	**Handling caustic engine fluids and chemical products.** **Can cause severe chemical burns, nausea, fainting, or death.** Most chemicals such as used engine oil, antifreeze/coolant, rustproofing agent, inhibiting oil, degreasing agent, spray paint, and adhesives are hazardous to health. Read and follow the user information found on the packaging. Avoid inhalation and skin contact. Use only in well-ventilated areas and use a protective mask when spraying. Store engine fluids and chemical products in a locked cabinet. Contact your local recycling center for disposal information and locations.
	

Fire-damaged or burned O-rings may cause the formation of hydrofluoric acid. Contact with hydrofluoric acid may cause severe skin irritation and chemical burns. O-rings and other fluoroelastomer seals exposed to fire or temperatures above 316°C (600°F) (i.e., during welding) may decompose forming hydrofluoric acid. Avoid inhalation or skin contact. Do not incinerate O-rings. Dispose of O-ring waste material in a responsible manner.

⚠ WARNING	**Spring-loaded parts.** **Can cause severe personal injury or property damage.** Wear protective goggles when servicing spring-loaded parts. Hold parts securely during disassembly.
	

⚠ WARNING	**Airborne particles.** **Can cause severe injury or blindness.** Wear protective goggles and clothing when using power tools, hand tools, or compressed air.
	

⚠ WARNING	**Explosive fuel vapors.** **Can cause severe injury or death.** Use extreme care when handling, storing, and using fuels.
	

Gas fuel leaks. Explosive fuel vapors can cause severe injury or death. Fuel leakage can cause an explosion. Check the LPG vapor or natural gas fuel system for leakage by using a soap and water solution with the fuel system test pressurized to 6–8 ounces per square inch (10–14 inches water column). Do not use a soap solution containing either ammonia or chlorine because both prevent bubble formation. A successful test depends on the ability of the solution to bubble.

Used engine oil. Contact with used engine oil may cause severe skin irritation. Repeated and prolonged skin exposure may have other health risks. Used engine oil is a suspected carcinogen. Avoid contact with skin. Thoroughly wash your hands and nails with soap and water shortly after handling used engine oil. Wash or dispose of clothing or rags containing used engine oil. Dispose of used engine oil in a responsible manner. Contact your local recycling center for disposal information and locations.

⚠ CAUTION	**Damaged harmonic balancer, crankshaft, or flywheel.** **Can cause personal injury.** Broken fragments from the harmonic balancer, crankshaft, and flywheel can be thrown from the engine. Do not use a hammer to install or remove. Inspect these parts for damage and replace if needed.
	

3.9.1 Camshaft

3.9.1.1 Remove Valve Lifters

1. Remove the valve lifter with a piece of metal wire from the top of the cylinder block.

NOTICE
Always keep the valve lifters upright and in correct order.

3.9.1.2 Inspect Valve Lifters

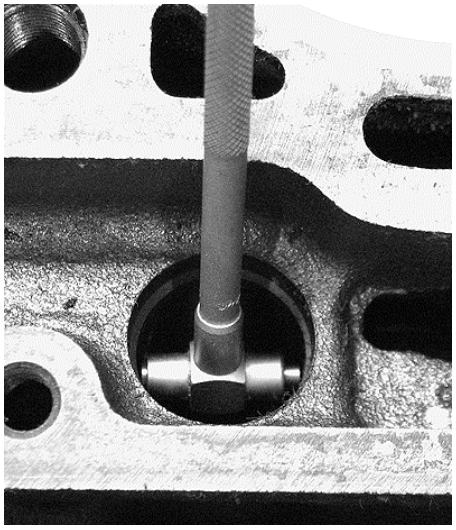


Figure 161 Valve Lifter Location

1. Use a snap gauge to measure the valve lifter bore diameter. See Figure 161.

LIFTER BORE INSIDE DIAMETER
21.412–21.443 mm (0.843–0.844 in.)

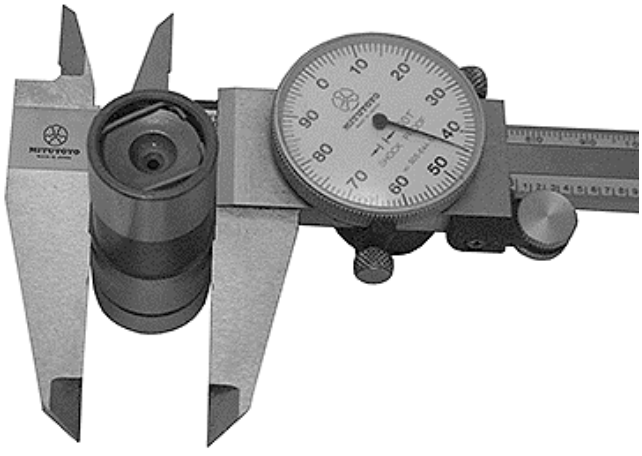


Figure 162 Micrometer

2. Use a micrometer to measure the valve lifter outside diameter. See Figure 162.

VALVE LIFTER OUTSIDE DIAMETER
21.387–21.400 mm (0.8420–0.8425 in.)

3. Calculate the difference between the valve lifter hole inside diameter and valve lifter outside diameter.

LIFTER BORE OIL CLEARANCE	
Standard	0.012~0.056 mm (0.0004–0.0022 in.)
Maximum	0.10 mm (0.0039 in.)

4. If the clearance is greater than maximum specification, replace the valve lifters.

3.9.1.3 Remove Timing Chain Cover

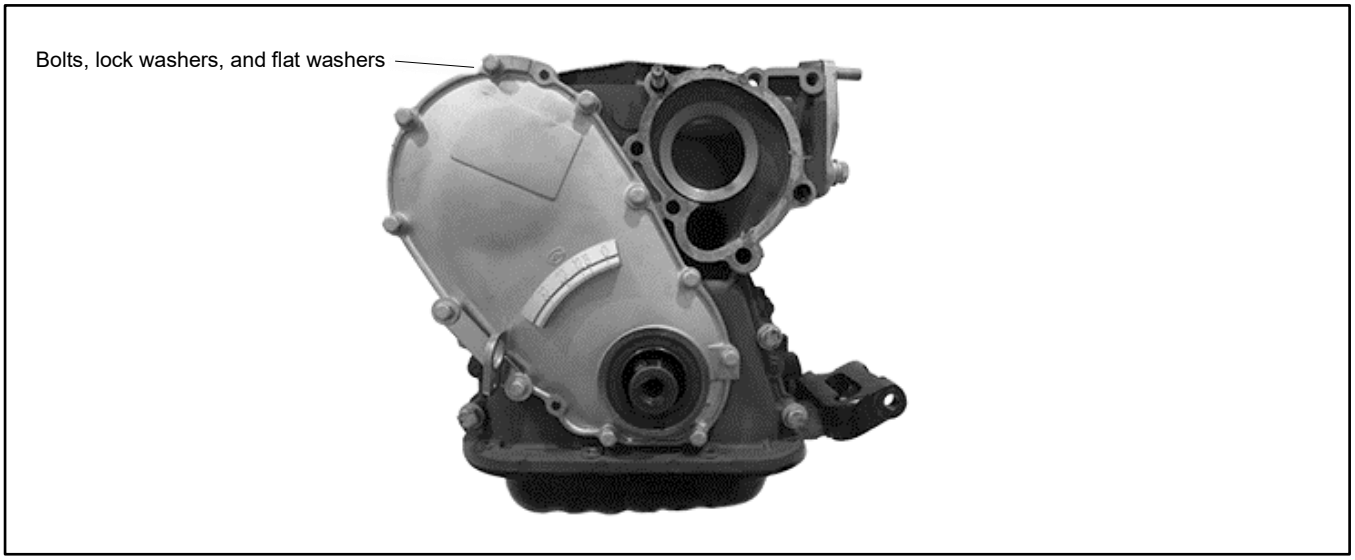


Figure 163 Timing Chain Cover

1. Remove eleven bolts, lock washers, and flat washers. Leave the timing pick-up sensor bracket attached to timing chain cover. See Figure 163.
2. Remove timing chain cover from engine.

3.9.1.4 Check Timing Chain Slack

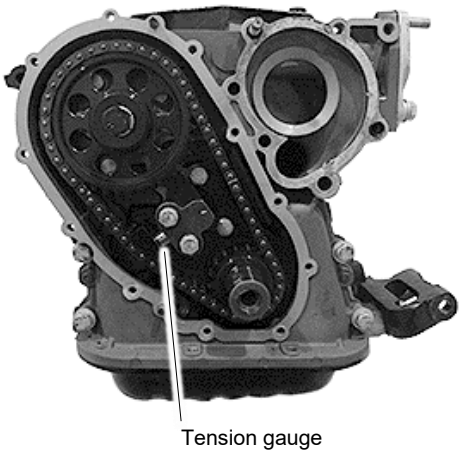


Figure 164 Timing Chain Cover

1. Using a tension gauge, measure the slack of the timing chain. See Figure 164.

TIMING CHAIN SLACK	
Applied Test Pressure	98 N (72 lbf.)
Maximum Chain Slack	13.5 mm (0.531 in.)

2. If the slack is greater than maximum specification, replace the timing chain and sprockets.

3.9.1.5 Remove Timing Chain Tensioner and Damper

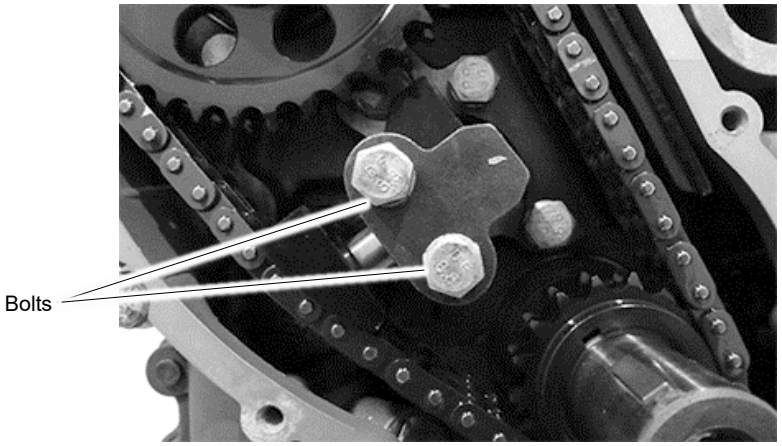


Figure 165 Timing Chain Tensioner

1. Remove two bolts securing timing chain tensioner to cylinder block and remove tensioner. See Figure 165.

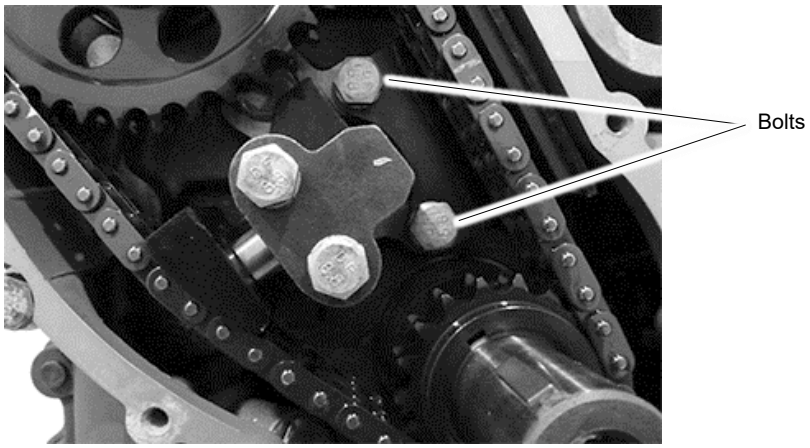


Figure 166 Timing Chain Damper

2. Remove two bolts securing timing chain damper to cylinder block and remove damper. See Figure 166.

3.9.1.6 Check Timing Chain Tensioner and Damper

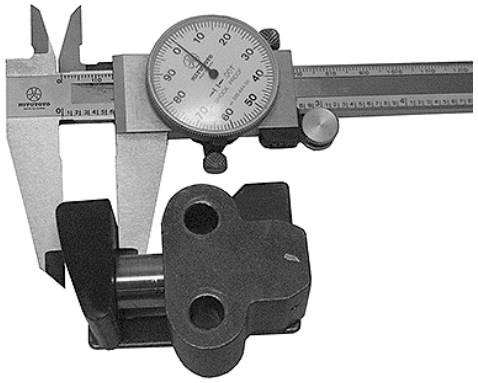


Figure 167 Measurement of the Tensioner Thickness

1. Using calipers, measure the tensioner thickness. See Figure 167.

TENSIONER THICKNESS	
Standard Thickness	15.0 mm (0.59 in.)
Minimum Thickness	12.5 mm (0.49 in.)

2. If the thickness is less than minimum specification, replace the tensioner or its parts. When replacing or reinstalling tensioner, fill tensioner body with oil.

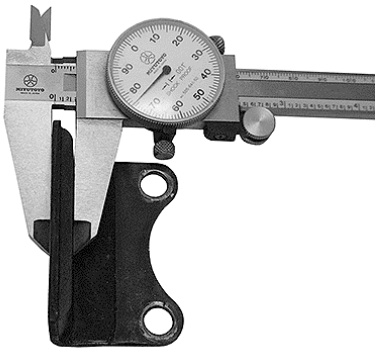


Figure 168 Measurement of the Damper Thickness

3. Using a caliper, measure the damper thickness. See Figure 168.

Damper THICKNESS	
Standard Thickness	6.6 mm (0.259 in.)
Minimum Thickness	5 mm (0.196 in.)

4. If damper thickness is less than minimum specification, replace damper.

3.9.1.7 Remove Timing Chain and Gears

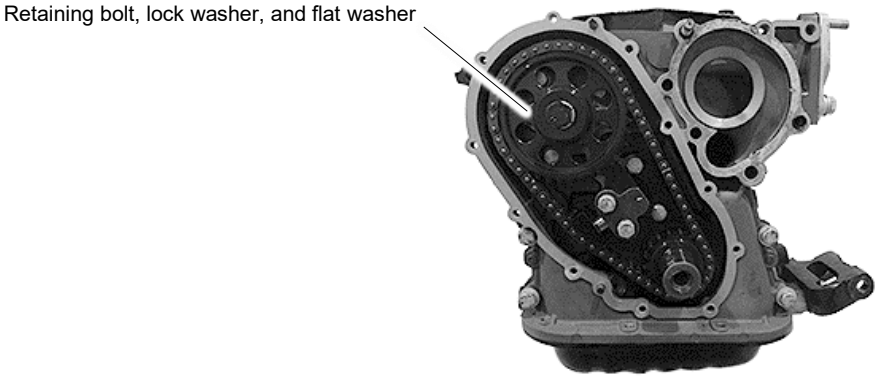


Figure 169 Timing Chain Cover

1. Remove one retaining bolt, lock washer, and flat washer fastening camshaft sprocket to camshaft. See Figure 169.
2. Remove timing chain tensioner and damper. See “Remove Timing Chain Tensioner and Damper”.
3. Using an appropriate gear puller, remove the camshaft sprocket. Do not damage the camshaft or sprocket.
4. Using an appropriate gear puller, remove the crankshaft timing chain gear. Do not damage crankshaft or sprocket.

3.9.1.8 Inspect Timing Chain and Gear

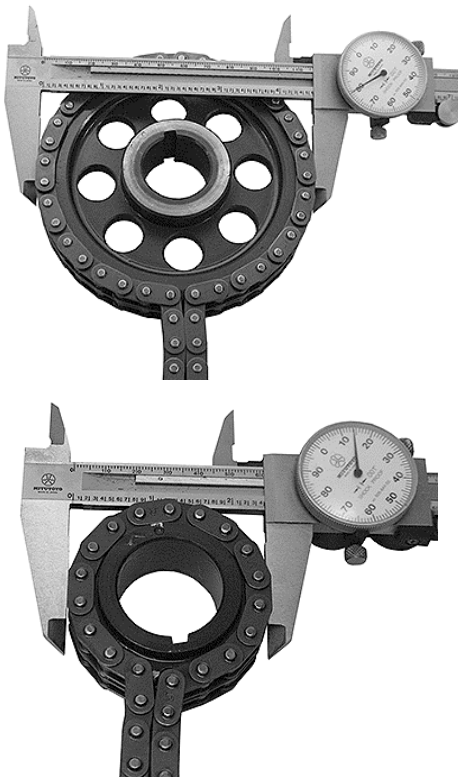


Figure 170 Timing Chain and Gear Inspection Using a Caliper

1. Using a caliper, measure the sprocket diameter with the chain installed to the sprocket. See Figure 170.

SPROCKET DIAMETER (WITH CHAIN)	
Crankshaft Chain Sprocket	59 mm (2.32 in.)
Camshaft Chain Sprocket	114 mm (4.48 in.)

2. If the diameter is less than minimum specification, replace the chain and two sprockets.

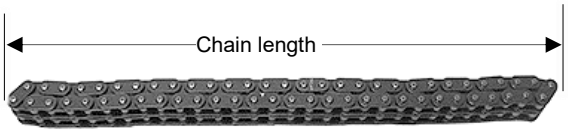


Figure 171 Timing Chain

3. Measure the chain length with the chain fully stretched. See Figure 171.
4. Make the same measurements pulling at three or more places selected at random.

CHAIN ELONGATION—MAXIMUM	
Test Tension	49 N (36 lbf.)
Chain Length	291.4 mm (11.47 in.)

5. If the elongation is greater than maximum specification, replace the chain.

3.9.1.9 Remove Thrust Plate and Camshaft

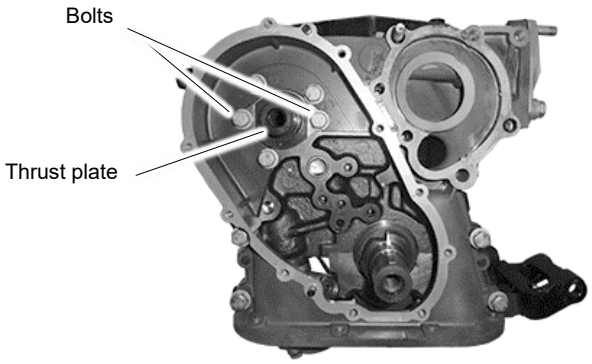


Figure 172 Thrust Plate Location

1. Remove two bolts, and remove the thrust plate. Note direction of thrust plate to camshaft. See Figure 172.

NOTICE
Do not damage the camshaft bearings, camshaft lobes, or camshaft journals when removing camshaft.

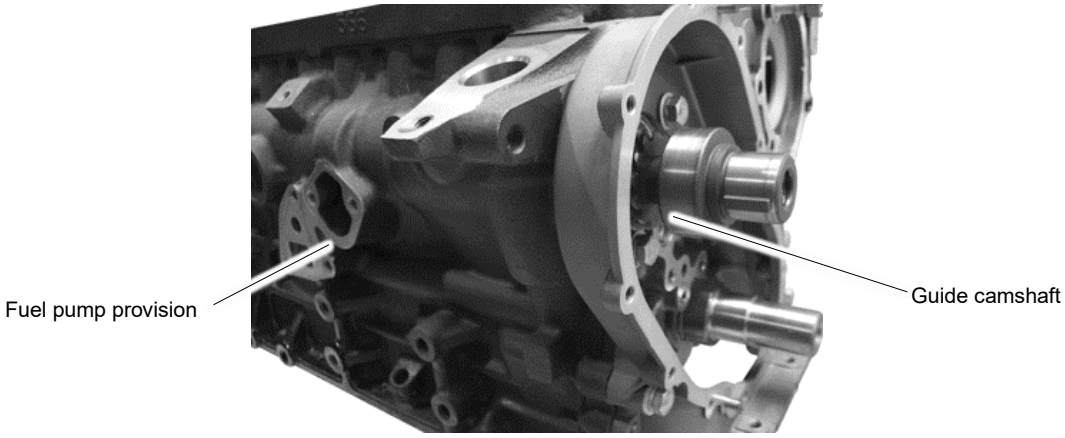


Figure 173 Camshaft Location

2. Guide camshaft from cylinder block through front of engine, also using mechanical fuel pump provision on the side of cylinder block to prevent damage to camshaft or camshaft bearings. See Figure 173.

3.9.1.10 Inspect Camshaft

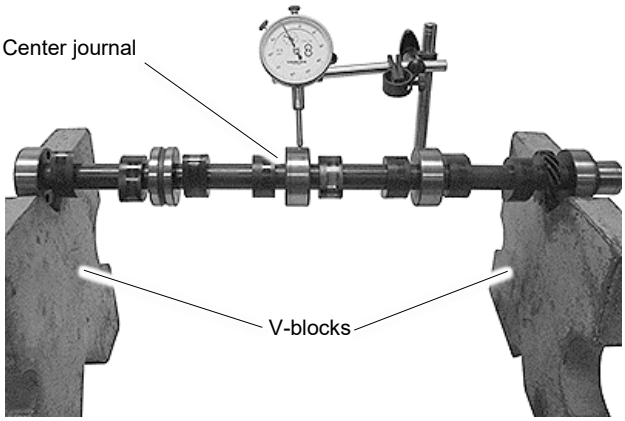


Figure 174 Camshaft

1. Place the camshaft on V-blocks and measure the runout at the center journal. See Figure 174.

CAMSHAFT RUNOUT—MAXIMUM
0.06 mm (0.0023 in.)

2. If the circle runout is greater than maximum specification, replace the camshaft.



Figure 175 Measurement of Cam Lobe Height Using a Micrometer

3. Using a micrometer, measure the cam lobe height at the large end with the bevel. See Figure 175.

CAMSHAFT LOBE HEIGHT	
Standard	
Intake	38.620–38.720 mm (1.5205–1.5244 in.)
Exhaust	38.629–38.729 mm (1.5208–1.5248 in.)
Minimum	
Intake	38.26 mm (1.5062 in.)
Exhaust	38.27 mm (1.5066 in.)

4. If the lobe height is less than minimum specification, replace the camshaft.

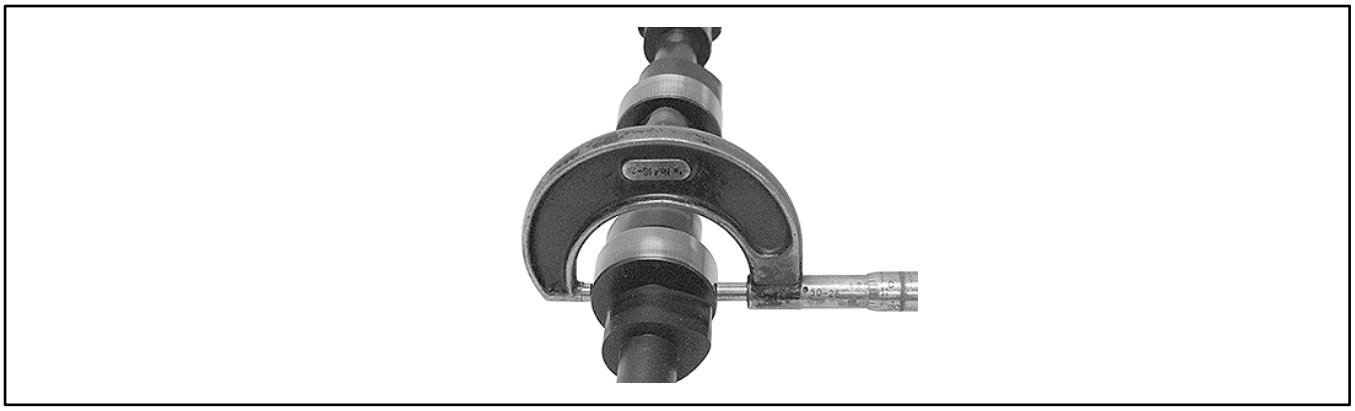


Figure 176 Measurement of Camshaft Journal Outside Diameter Using a Micrometer

5. Use a micrometer and measure the camshaft journal outside diameter. Record measurements for reference. See Figure 176.

CAMSHAFT JOURNAL DIAMETER	
Standard (from the front side)	
No. 1	46.459–46.475 mm (1.8291–1.8297 in.)
No. 2	46.209–46.225 mm (1.8192–1.8199 in.)
No. 3	45.959–45.975 mm (1.8094–1.8100 in.)
No. 4	45.709–45.725 mm (1.7996–1.8002 in.)
No. 5	45.459–45.475 mm (1.7897–1.7904 in.)

6. If the camshaft journal diameter is not within specification, check the oil clearance of the bearings. See “Inspect Camshaft Bearings”.

3.9.1.11 Checking Camshaft Thrust

1. Install the thrust plate and camshaft sprocket to the camshaft.
2. Install and torque the camshaft sprocket mount bolt to specification.

CAMSHAFT SPROCKET BOLT—TORQUE
90 Nm (66 ft.lb.)

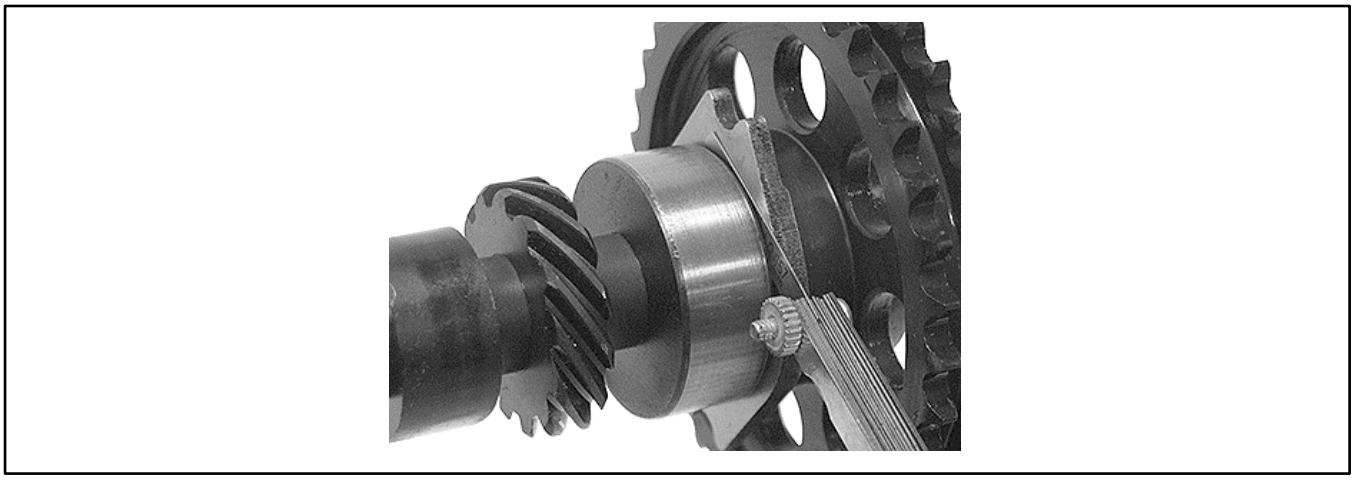


Figure 177 Thrust Clearance Measurement

3. Using a feeler gauge, measure the thrust clearance between the thrust plate and camshaft. See Figure 177.

CAMSHAFT THRUST PLATE CLEARANCE	
Standard	0.07–0.22 mm (0.00270–0086 in.)
Maximum	0.30 mm (0.0118 in.)

4. If the clearance is greater than maximum specification, replace the thrust plate, if necessary, replace the camshaft.

3.9.1.12 Remove Timing Chain Gear Housing

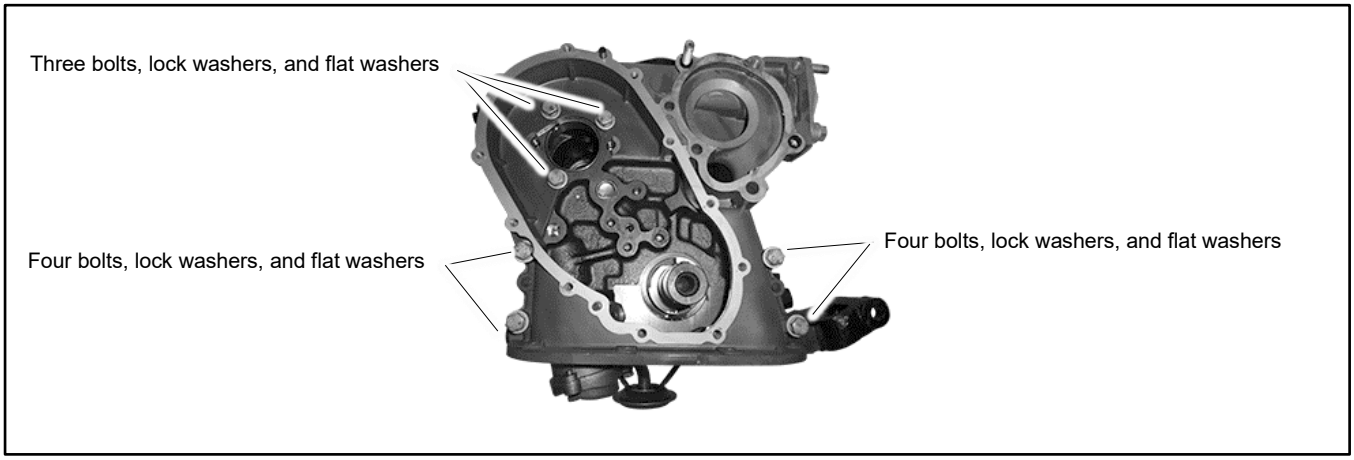


Figure 178 Timing Chain Gear Housing

1. Remove three bolts, lock washers, and flat washers, from the inside of the timing chain housing. See Figure 178.
2. Remove four bolts, lock washers, and flat washers, from the outside of the timing chain housing.
3. Remove the timing chain housing.

3.9.1.13 Inspect Camshaft Bearings

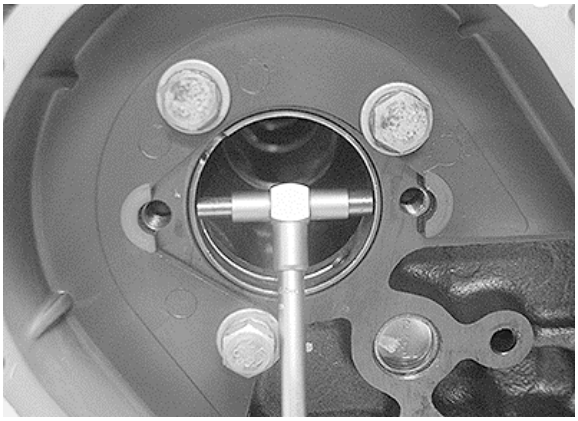


Figure 179 Inside Diameter of the Camshaft Bearing

1. Using a dial bore micrometer, measure the inside diameter of the camshaft bearing with the bearing installed in cylinder block. See Figure 179.

CAMSHAFT BEARING BORE SPECIFICATIONS	
Standard (from the front of the cylinder block)	
No. 1	46.500–46.540 mm (1.8307–1.8323 in.)
No. 2	46.250–46.290 mm (1.8209–1.8224 in.)
No. 3	46.000–46.040 mm (1.8110–1.8126 in.)
No. 4	45.750–45.790 mm (1.8012–1.8028 in.)
No. 5	45.500–45.540 mm (1.7913–1.7929 in.)

2. Replace camshaft if not within specification.
3. Calculate the difference between the measured bearing inside diameter and camshaft journal outside diameter.

CAMSHAFT BEARING CLEARANCE SPECIFICATIONS	
Standard	0.025–0.081 mm (0.0010–0.0032 in.)
Maximum	0.10 mm (0.0039 in.)

4. If the maximum specification is exceeded, regrind or replace the camshaft.

3.9.1.14 Remove Camshaft Bearings

NOTICE
All camshaft bearings have different outside diameter.

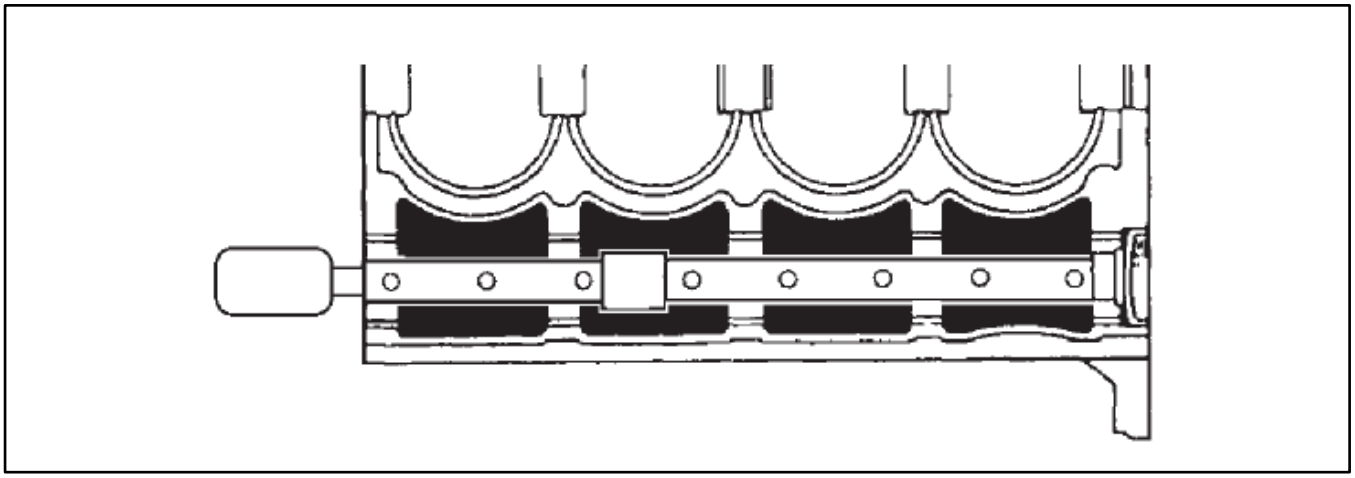


Figure 180 Plug Removal from the Cylinder Block

1. Use a block plug removal tool to remove the tight plug from the rear of the cylinder block behind number five camshaft bearing. See Figure 180.

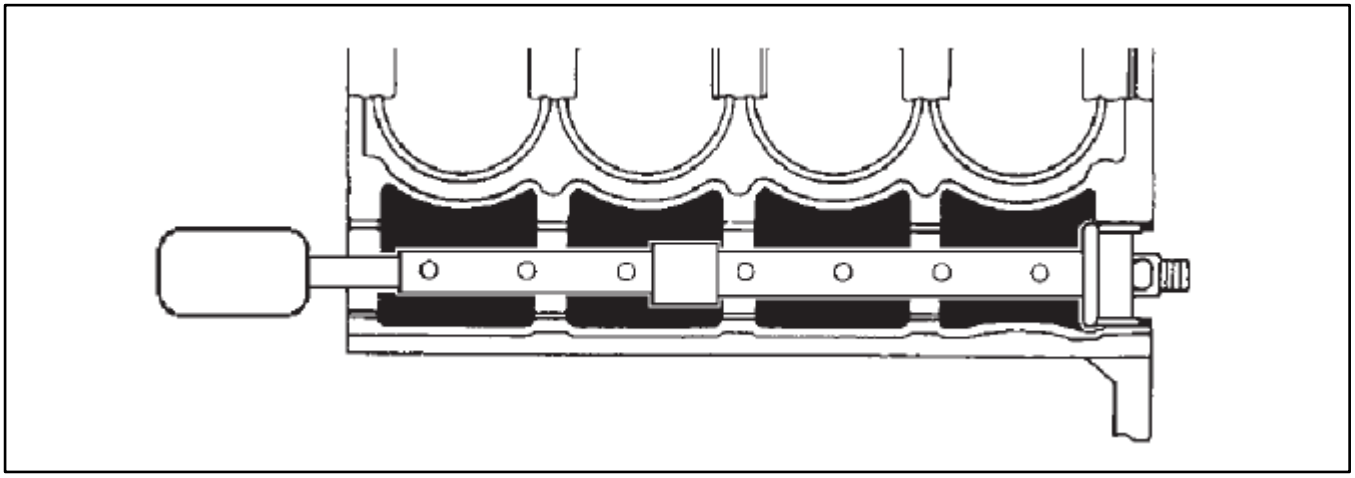


Figure 181 Crankshaft Bearing Removal

2. Using a camshaft bearing removal tool, remove the camshaft bearings. See Figure 181.

3.9.1.15 Install Camshaft Bearings

NOTICE
Oil holes in cam bearings MUST be aligned with oil holes in cylinder block or engine damage will occur.

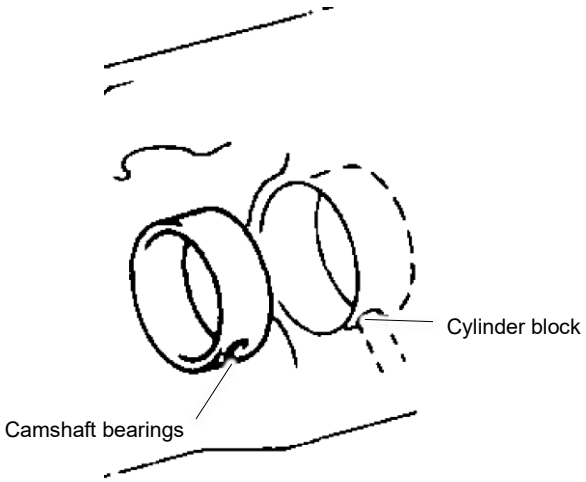


Figure 182 Alignment of Camshaft Bearings and Cylinder Block

1. Align oil holes of the cylinder block and camshaft bearings. See Figure 182.

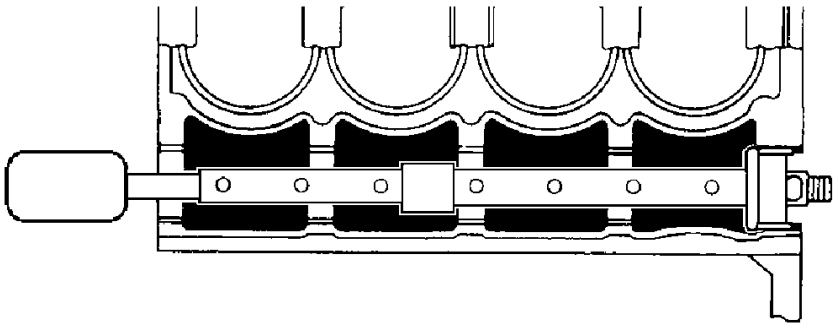


Figure 183 Camshaft Bearings

2. Using a camshaft bearing installation tool, install the camshaft bearings. See Figure 183.
3. Coat sealant on the tight plug installation surface of the cylinder block.

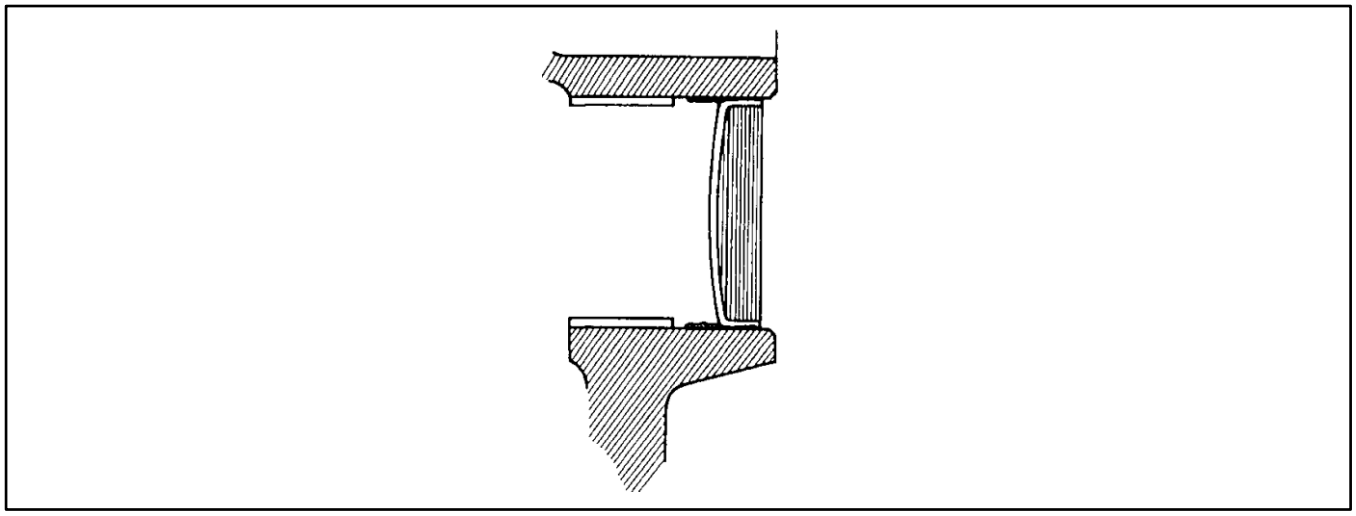


Figure 184 Cylinder Block End Surface

4. Use a hammer to drive in the tight plug until it is flush with the cylinder block end surface. See Figure 184.

3.9.1.16 Install Timing Chain Gear Housing

NOTICE
Do not damage the camshaft bearings, camshaft lobes, or camshaft journals when installing camshaft.

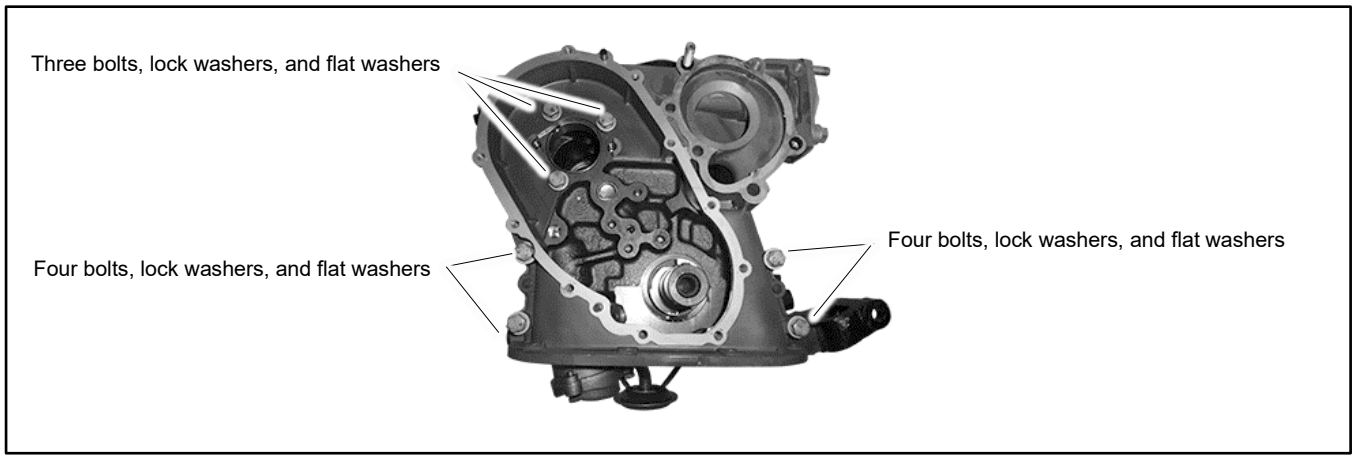


Figure 185 Timing Chain Gear Housing

1. Install new gasket and timing chain gear housing to cylinder block.
2. Install four outer housing bolts, lock washers, and flat washers. See Figure 185.
3. Install three inner housing bolts, lock washers, and flat washers.

3.9.1.17 Install Camshaft and Thrust Plate

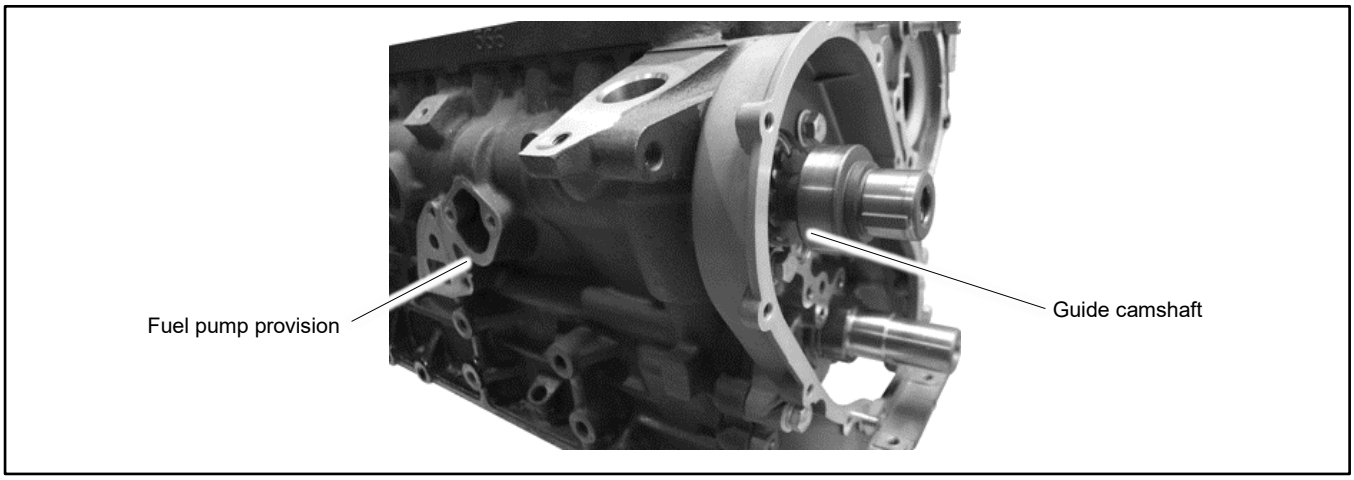


Figure 186 Camshaft Location

1. Guide camshaft in to cylinder block through front of engine, also using mechanical fuel pump provision on the side of cylinder block to prevent damage to camshaft or camshaft bearings.

NOTICE
Thrust plate must be installed facing proper direction. Dimples must face front of engine. See Figure 187.

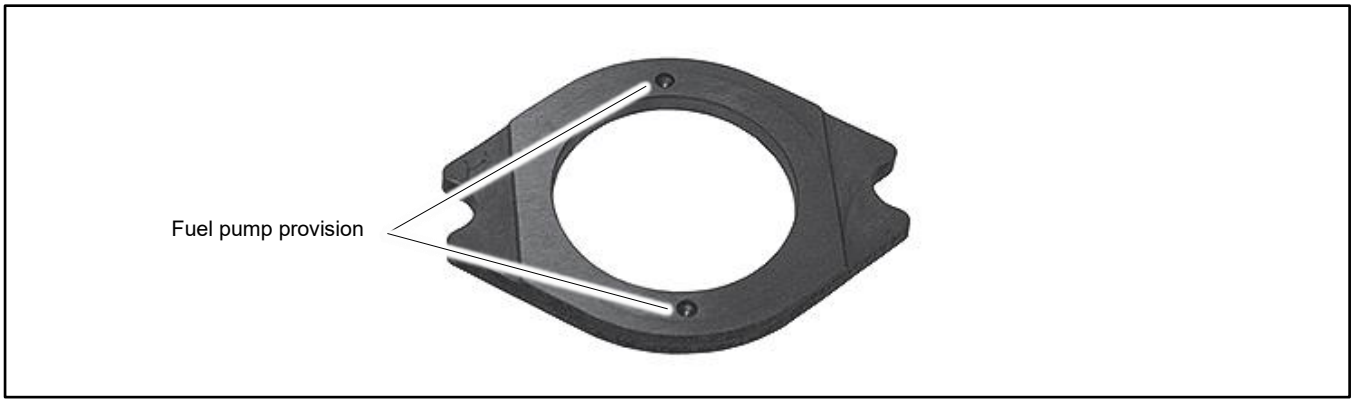


Figure 187 Front of Engine

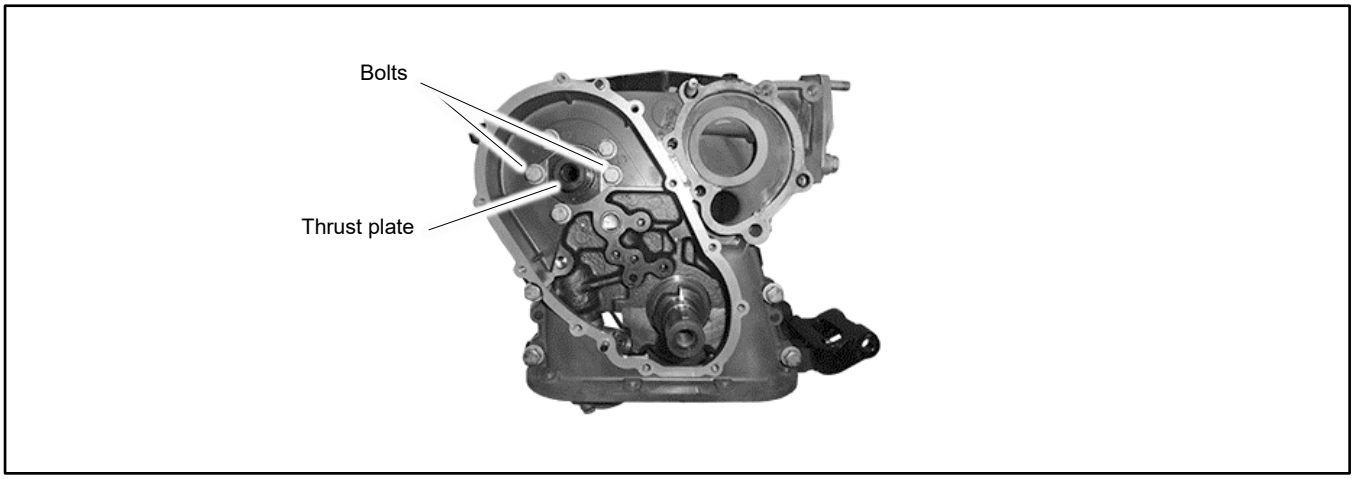


Figure 188 Thrust Plate Location

4. Install the camshaft thrust plate to the cylinder block, using two bolts, lock washers, and flat washers. See Figure 188.
5. Torque camshaft thrust plate bolts to specification.

CAMSHAFT THRUST PLATE BOLT—TORQUE
17.6 Nm (13 ft.lb.)

3.9.1.18 Install Timing Chain and Gears

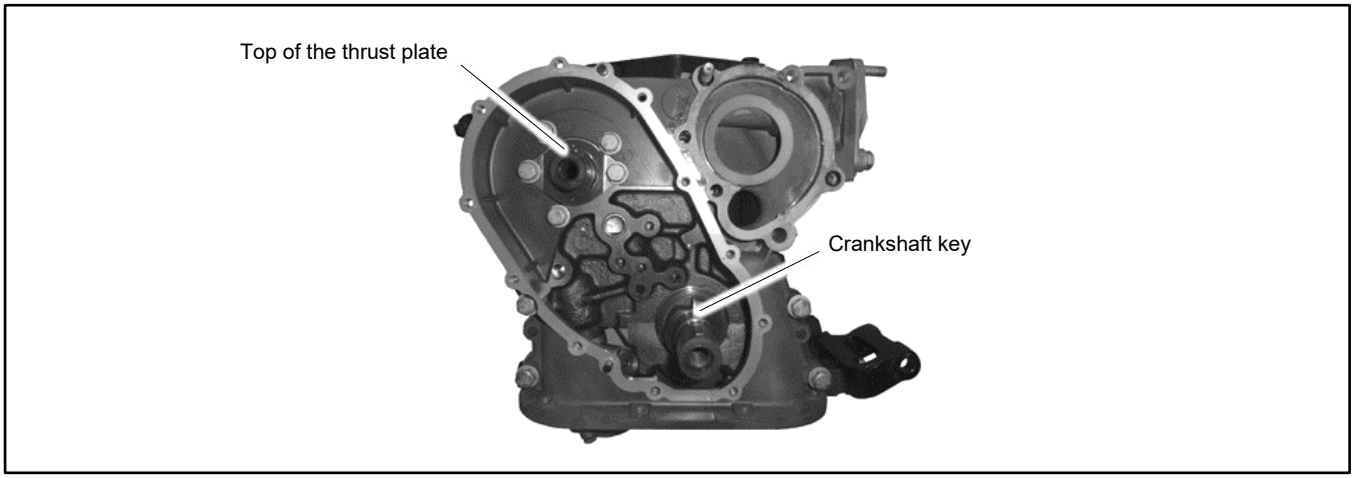


Figure 189 Thrust Plate Location

1. Rotate the crankshaft to bring the crankshaft key to the top position. See Figure 189.
2. Rotate the camshaft to align the camshaft key with the timing mark at the top of the thrust plate.

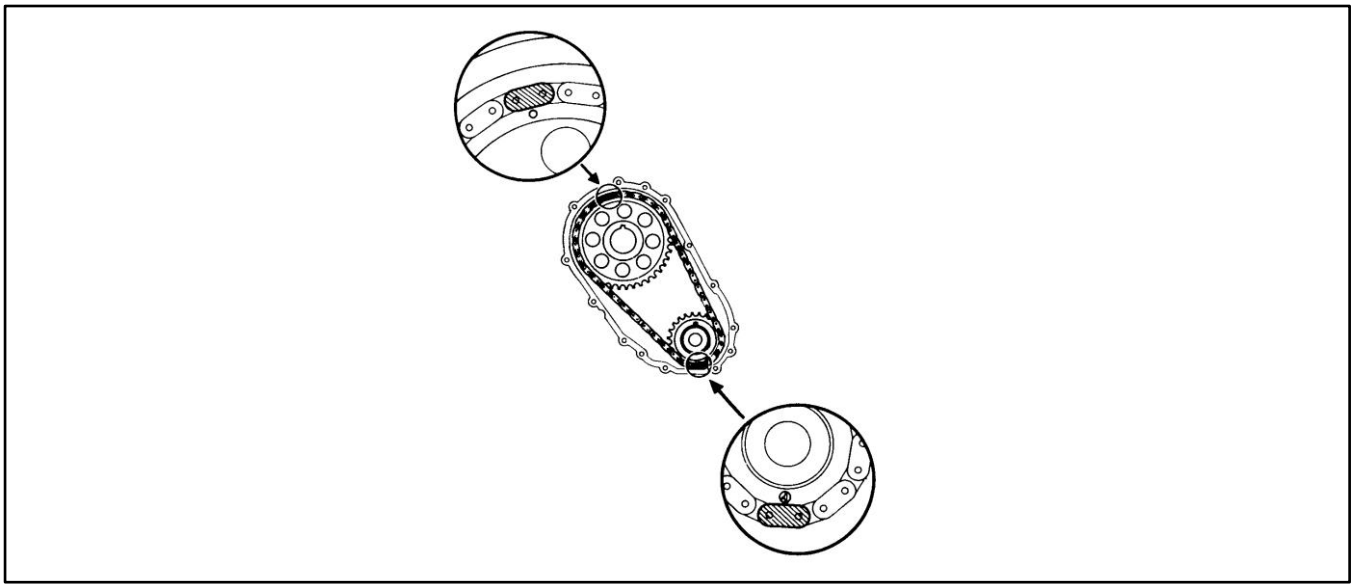


Figure 190 Assembly of crankshaft timing gear, camshaft timing gear, and timing chain

NOTICE
Match the mark on each timing gear with the corresponding timing mark on the timing chain.

3. Assemble the crankshaft timing gear, camshaft timing gear, and timing chain. See Figure 190.
4. Install the timing chain and timing gears at the same time.
5. Coat the thread and seat surface of the camshaft timing gear bolt with clean engine oil.
6. Install the camshaft timing gear bolt securing the camshaft timing gear to the camshaft.



Figure 191 Camshaft Timing Gear Bolt

7. Holding the crankshaft from rotating, torque the camshaft timing gear bolt to specification. See Figure 191.

CAMSHAFT TIMING GEAR BOLT—TORQUE
90.2 Nm (67 ft.lb.)

3.9.1.19 Install Timing Chain Tensioner and Damper

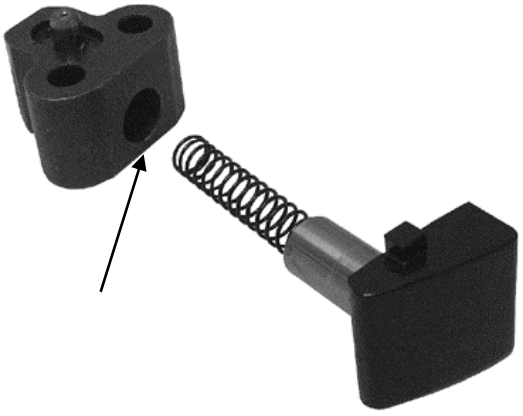


Figure 192 Timing Chain Tensioner Body

1. Fill timing chain tensioner body with clean engine oil prior to installing to the cylinder block. See Figure 192.

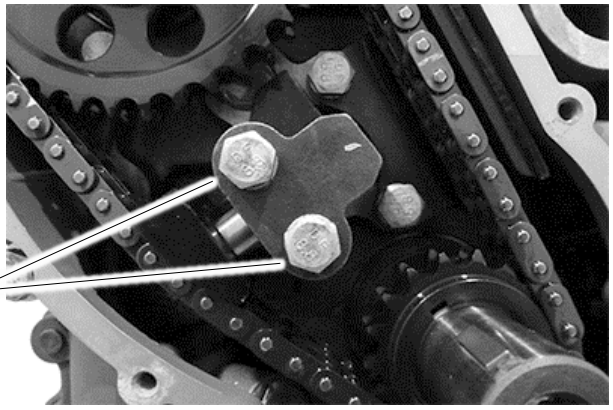


Figure 193 Installation of Timing Chain Tensioner

2. Install the timing chain tensioner to the cylinder block secure with two bolts, lock washers, and flat washers. See Figure 193.

3. Torque bolts to specification.

CHAIN TENSIONER BOLT—TORQUE
17.6 Nm (13 ft.lb.)

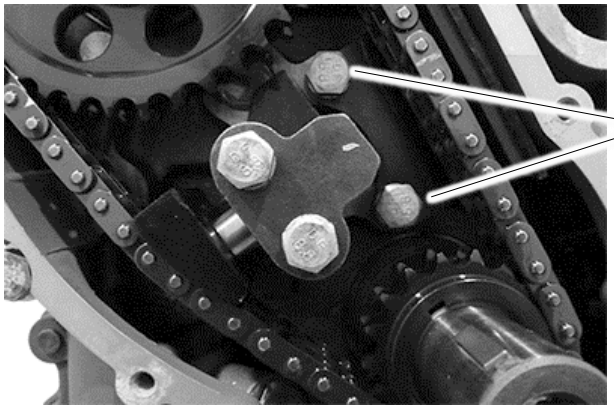


Figure 194 Installation of Timing Chain Vibration Damper

4. Install the timing chain vibration damper to the cylinder block with two bolts, lock washers, and flat washers. See Figure 194.

5. Torque damper bolts to specification.

CHAIN DAMPER BOLT—TORQUE
17.6 Nm (13 ft.lb.)

3.9.1.20 Install Timing Cover

1. Install a new timing chain cover gasket to the timing chain housing.

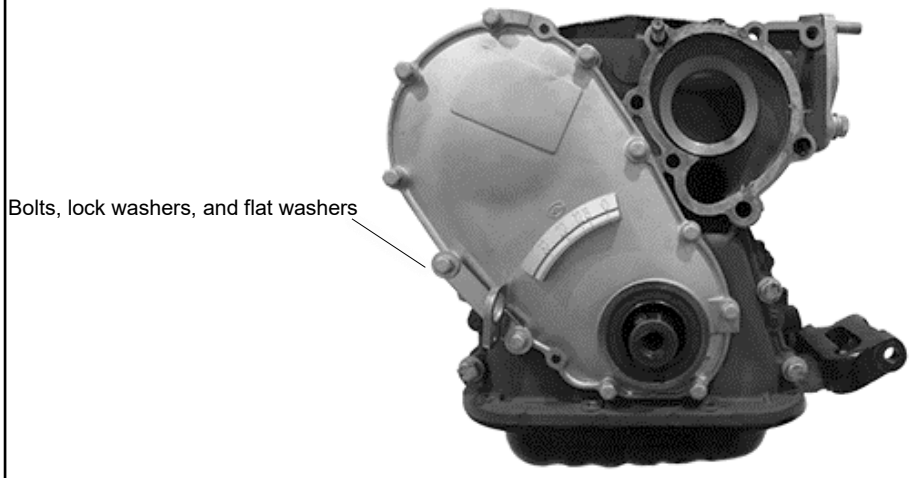


Figure 195 Timing Chain Cover

2. Install the timing chain cover to the timing chain housing and secure with eleven bolts, lock washers, and flat washers. See Figure 195.

3. Torque bolts to specification.

TIMING COVER BOLT—TORQUE
17.6 Nm (13 ft.lb.)

3.9.1.21 Install Lifters

1. Prior to installing the valve lifters to the cylinder block, bleed the air from the valve lifter body. Place the valve lifter into a container of clean engine oil, compress the piston of the lifter to release any air in the lifter body and filling with engine oil.
2. Use a wire with its tip bent to an “L” shape. Carefully insert the valve lifter into the valve lifter hole.

3.9.2 Cylinder Block, Crankshaft, Connecting Rods, and Pistons

3.9.2.1 Remove Oil Pump and Oil Pump Pick-up

Oil pump installs at the bottom and front of cylinder block, driven by oil pump drive device.

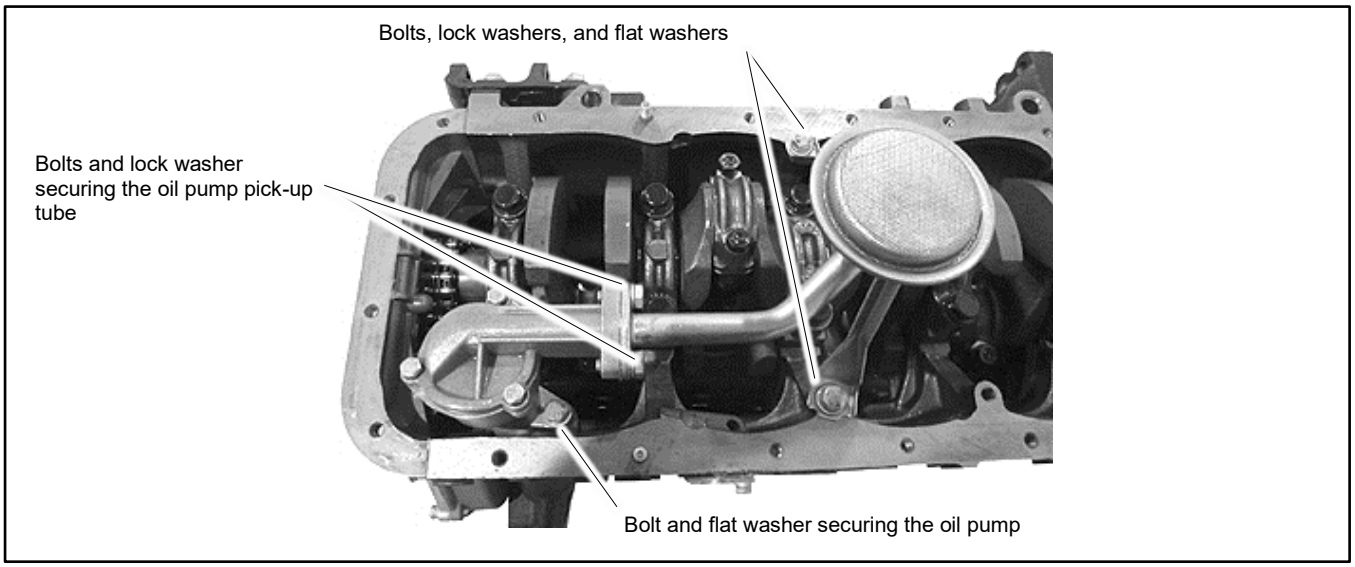


Figure 196 Oil Pump

1. Remove two bolts, lock washers, and flat washers securing the oil pump pick-up tube to the cylinder block. See Figure 196.
2. Remove two bolts and lock washers securing the oil pump pick-up tube at the suction side of the oil pump housing.
3. Remove the oil pump pick-up tube from the oil pump housing.
4. Remove one bolt and flat washer securing the oil pump to the cylinder block.
5. Remove the oil pump from the cylinder block.

3.9.2.2 Disassemble and Inspect Oil Pump

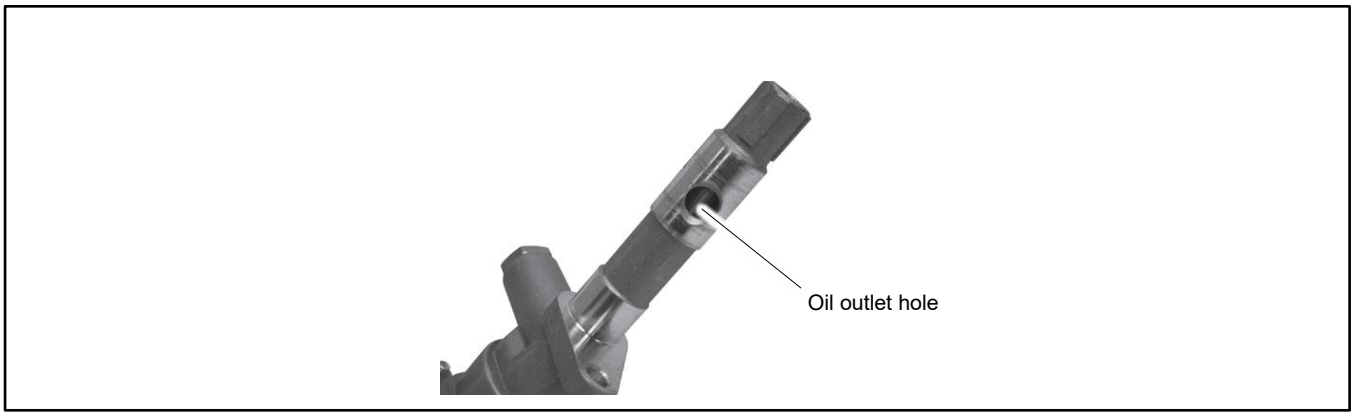


Figure 197 Oil Outlet Hole

1. Using a screwdriver, immerse the oil strainer in oil and turn the oil pump shaft clockwise. Oil should come out of the oil outlet hole. See Figure 197.
2. Close the oil outlet hole with your thumb and turn the oil pump shaft as before. The oil pump shaft should be difficult to turn.

   If there is very little to no resistance, replace the oil pump.
3. Remove the three oil pump cover bolts and then remove the oil pump cover.

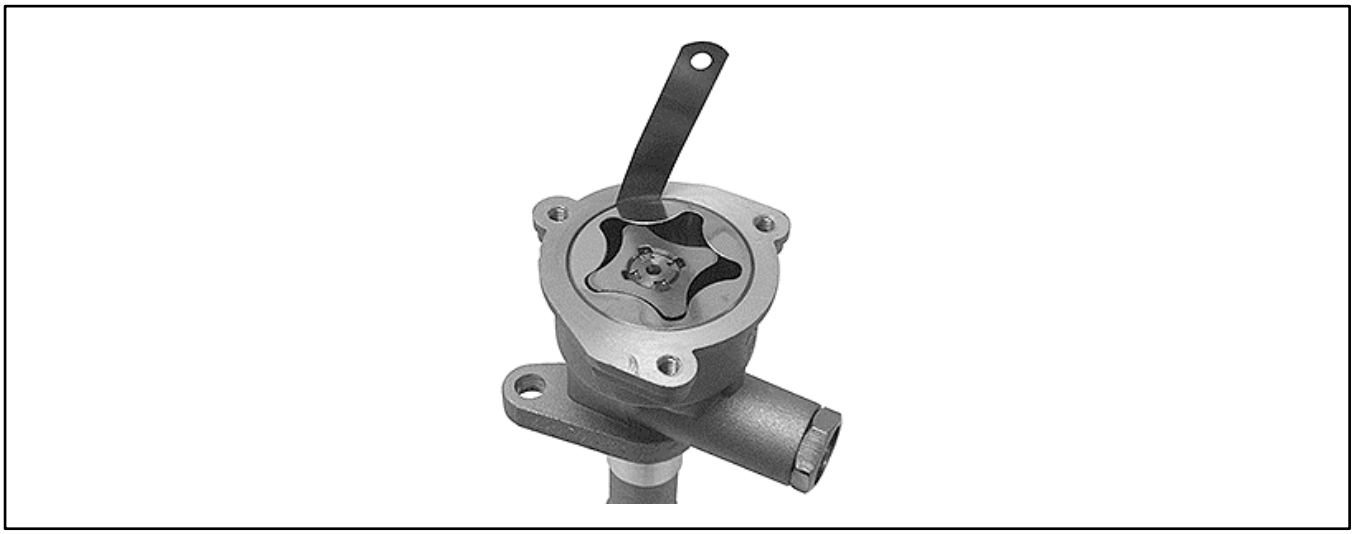


Figure 198 Oil Pump Body and Driven Rotor

4. Use a thickness gauge to measure the clearance between the driven rotor and pump body. See Figure 198.

OIL PUMP DRIVEN ROTOR-TO-PUMP BODY CLEARANCE	
Standard	0.1–0.15 mm (0.0039–0.0059 in.)
Limit	0.2 mm (0.008 in.)

If the clearance exceeds the limit, replace the rotors as a set.

If necessary, replace the whole oil pump assembly.

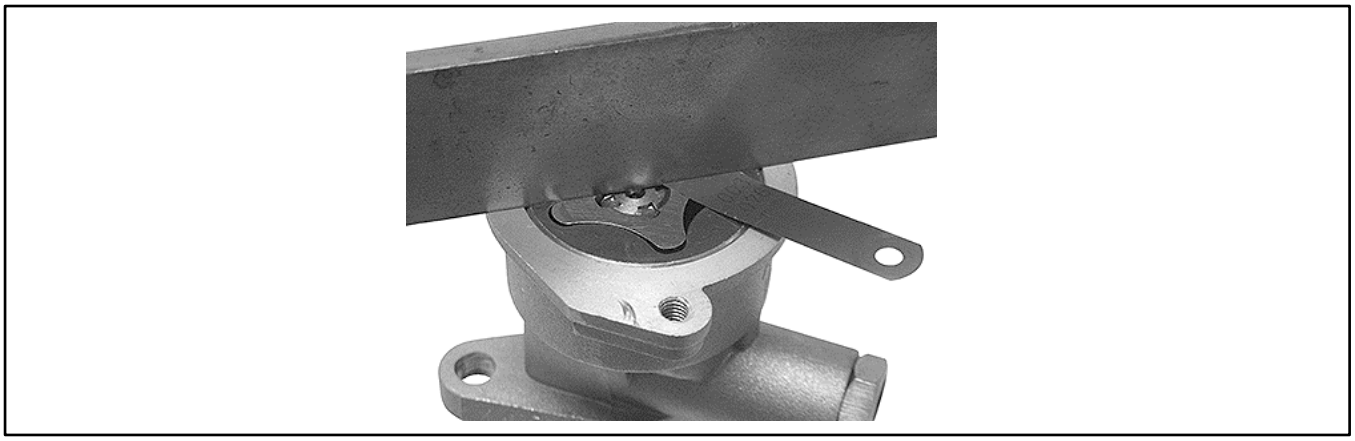


Figure 199 Oil Pump Body and Driven Rotor

5. Use a straight edge and thickness gauge to measure the rotor side clearance. See Figure 199.

OIL PUMP ROTOR SIDE CLEARANCE	
Standard	0.03–0.07 mm (0.0012–0.0028 in.)
Limit	0.15 mm (0.0059 in.)

If the clearance exceeds the limit, replace the rotors as a set.

If necessary, replace the whole oil pump assembly.

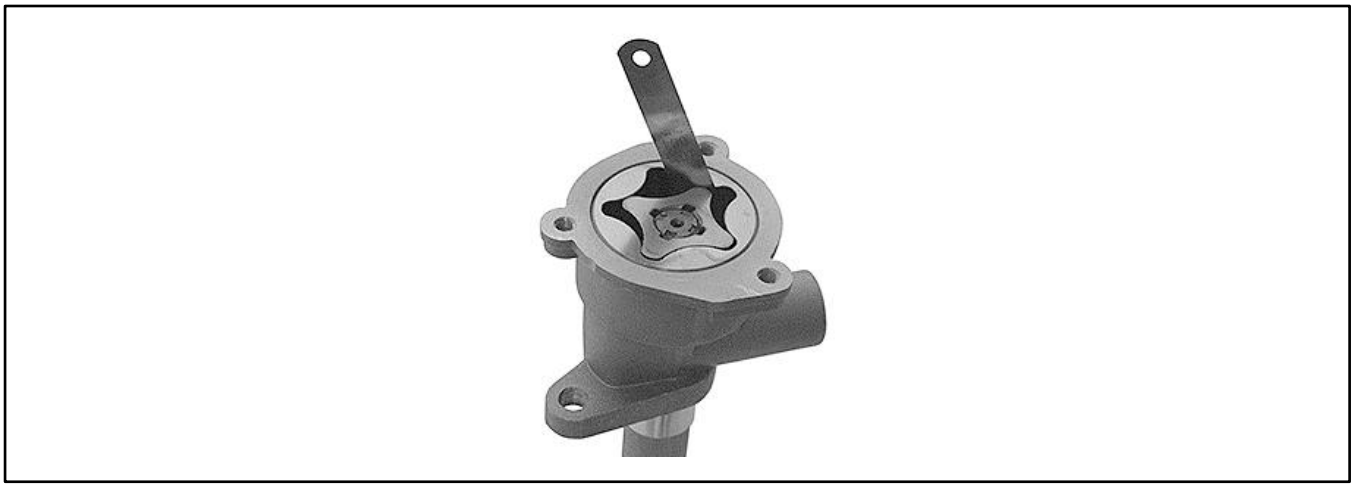


Figure 200 Drive and Driven Rotor Tip Clearance

6. Use the thickness gauge and measure the tip clearance between the drive and driven rotors. See Figure 200.

OIL PUMP ROTOR TIP CLEARANCE	
Standard	0.07–0.12 mm (0.0028–0.0047 in.)
Limit	0.2 mm (0.008 in.)

If the clearance exceeds the limit, replace the rotors as a set.

If necessary, replace the whole oil pump assembly.

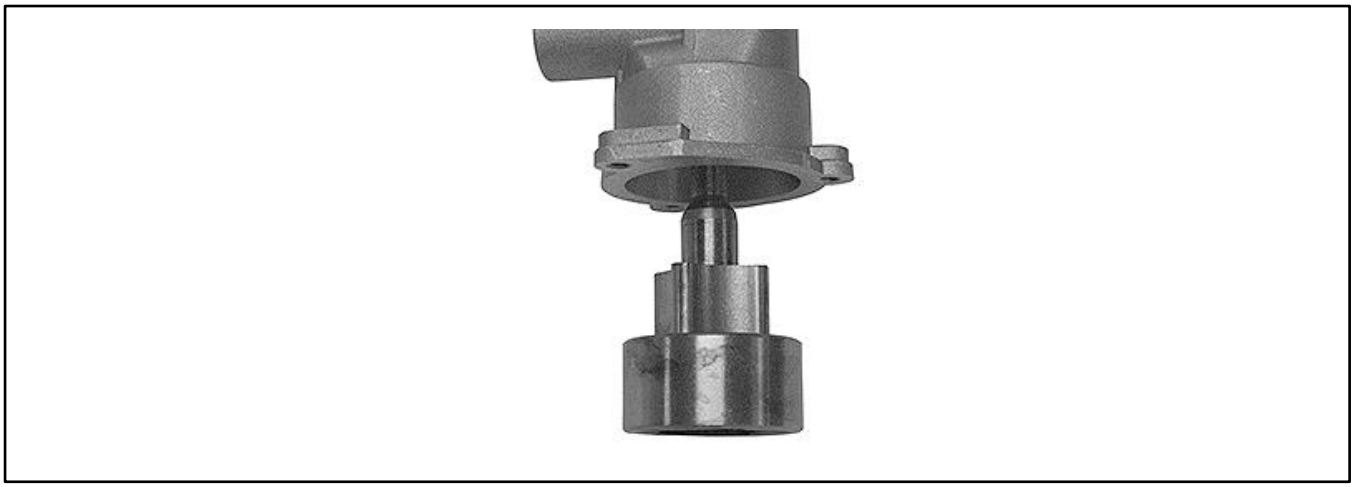


Figure 201 Oil Pump Body

7. Remove the drive and driven rotors from the pump body. See Figure 201.

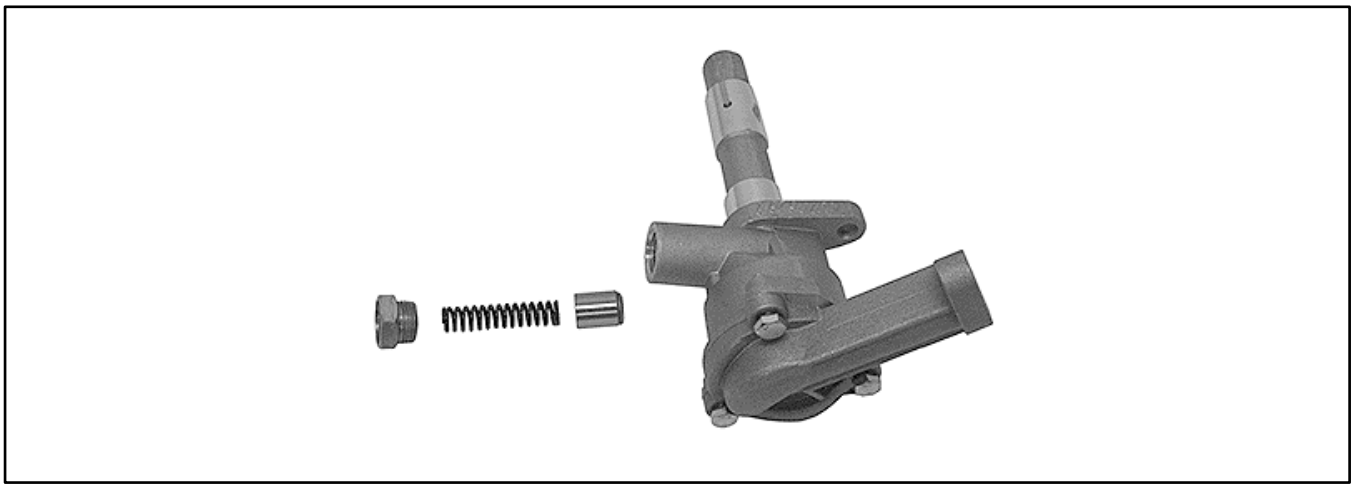


Figure 202 Plug, Spring and Relief Valve

8. Remove the plug, spring, and relief valve from the oil pump body. See Figure 202.

3.9.2.3 Assemble Oil Pump

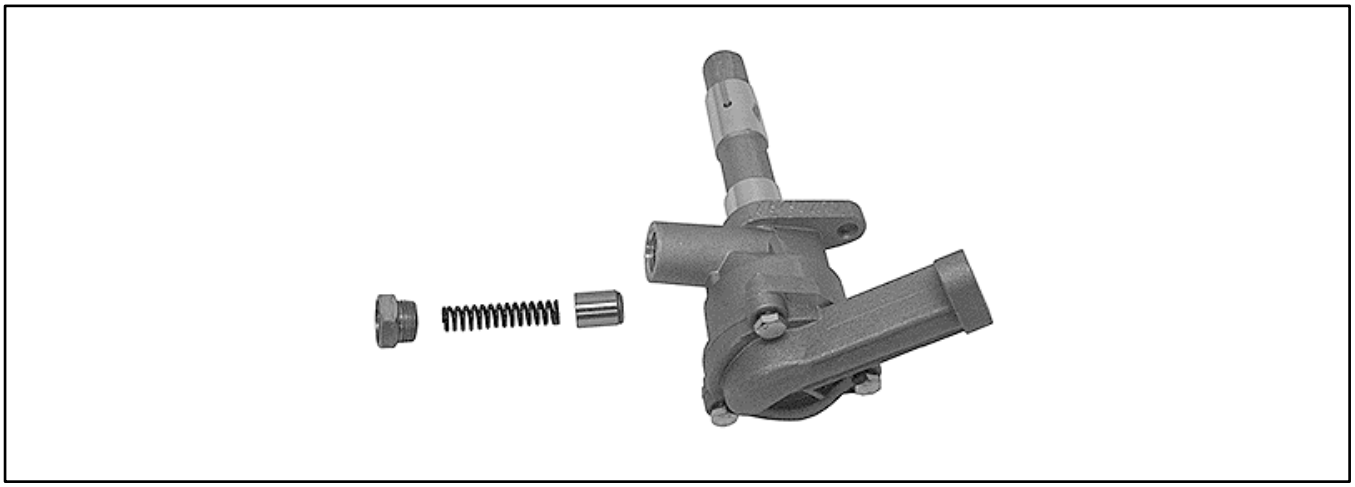


Figure 203 Plug, Spring and Relief Valve

1. Install the relief valve, spring, and plug into the oil pump body. See Figure 203.



Figure 204 Oil Pump Body

2. Install the driven and drive rotors to the pump body. See Figure 204.
3. Install oil pump cover and three bolts.
4. Torque bolts to specification.

OIL PUMP COVER BOLT—TORQUE
8 Nm (5.8 ft.lb.)

3.9.2.4 Install Oil Pump

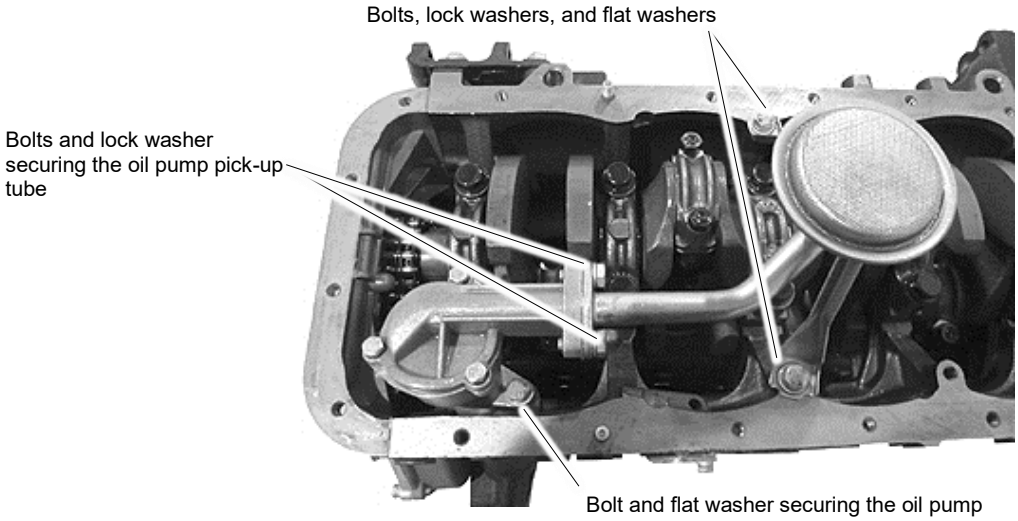


Figure 205 Oil Pump

1. Install the oil pump to the cylinder block.
2. Install one bolt and flat washer securing the oil pump to the cylinder block. See Figure 205.
3. Install the oil pump pick up tube to the oil pump housing.
4. Install two bolts and lock washers securing the oil pump pick up tube at the suction side of the oil pump housing.
5. Install two bolts, lock washers, and flat washers securing the oil pump pick up tube to the cylinder block.

3.9.2.5 Check Connecting Rod Thrust Clearance

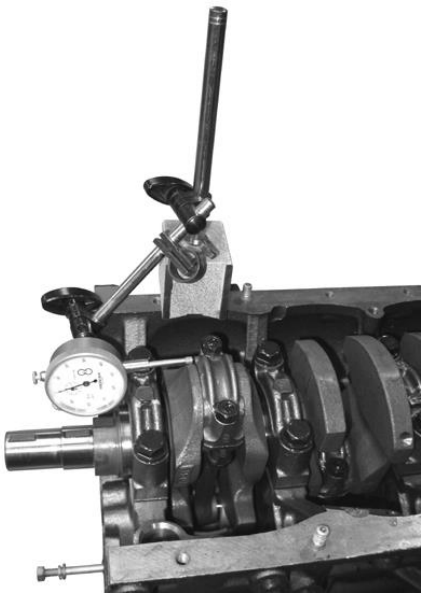


Figure 206 Dial Indicator

1. Using a dial indicator, measure the thrust clearance while moving the connecting rod back and forth. See Figure 206.

CONNECTING ROD THRUST CLEARANCE	
Standard	0.160–0.312 mm (0.006–0.012 in.)
Maximum	0.35 mm (0.013 in.)

2. If the clearance is greater than maximum, replace the connecting rod assembly.

3.9.2.6 Check Crankshaft Thrust Clearance

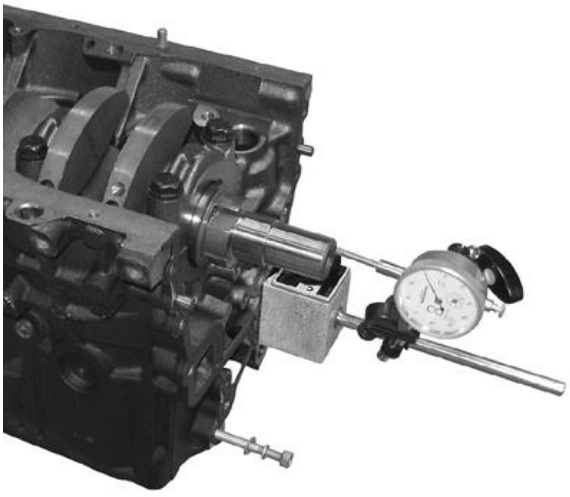


Figure 207 Thrust Clearance Measurement Using Dial Indicator

1. Using micrometer or dial indicators measure the thrust clearance between the crankshafts back and forth with a screwdriver. See Figure 207.

CRANKSHAFT THRUST CLEARANCE

Standard	0.020–0.220 mm (0.0007–0.0086 in.)
Maximum	0.30 mm (0.011 in.)

2. If the clearance is greater than maximum, replace the thrust washers.

CRANKSHAFT THRUST WASHER TICKNESS
2.044–2.490 mm (0.0804–0.0806 in.)

3.9.2.7 Check Bearing Oil Clearance

3.9.2.7.1 Main Bearings

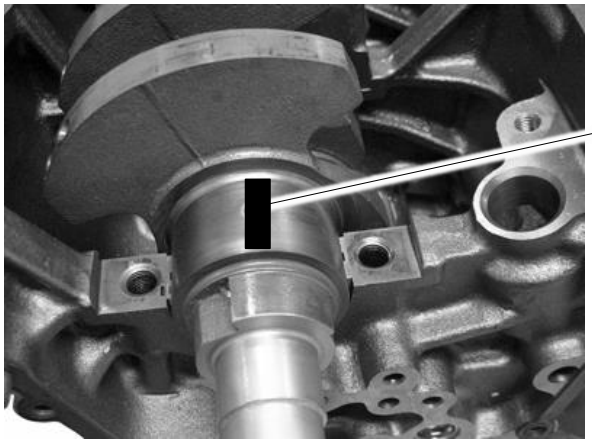


Figure 208 Oil Clearance Between Crankshaft Main Journal/Main Bearing

1. Check oil clearance between crankshaft main journal and main bearing using a plastic indicator strip. See Figure 208.

CRANKSHAFT MAIN JOURNAL OIL CLEARANCE	
Standard	0.020–0.051 mm (0.0007–0.0020 in.)
Maximum	0.10 mm (0.039 in.)

2. If the clearance is greater than maximum specification, replace the main bearings. If necessary, grind or replace the crankshaft.

3.9.2.7.2 Connecting Rod Bearings

NOTICE
There are matching marks on the side of connecting rod body and cap, do not exchange with others.

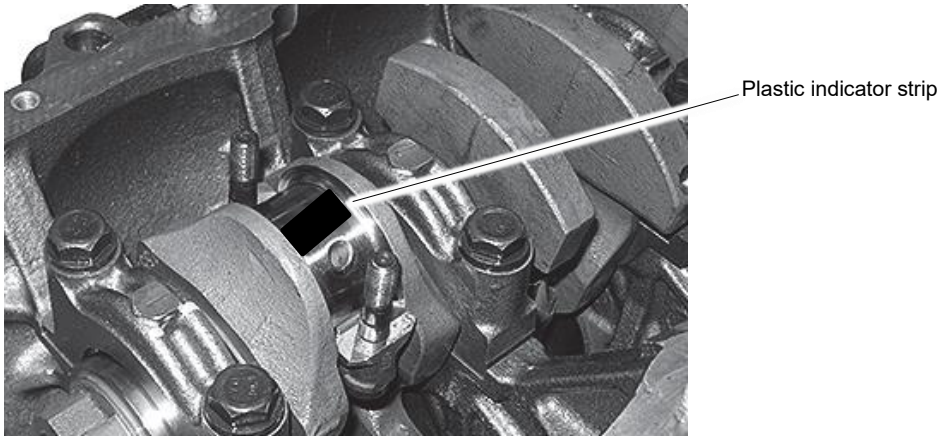


Figure 209 Oil Clearance Between Connecting-rod Bearing and Crank Pin

1. Check oil clearance between connecting-rod bearing and crank pin using a plastic indicator strip. See Figure 209.

CONNECTING ROD JOURNAL OIL CLEARANCE	
Standard	0.020–0.051 mm (0.0007–0.002 in.)
Maximum	0.10 mm (0.0039 in.)

2. If the clearance is greater than the maximum specification, replace the bearings. If necessary, grind or replace the crankshaft.

3.9.2.8 Remove Connecting Rods and Pistons

1. Remove carbon from the top of cylinder bore with a scraper or ridge reamer. Remove loose material from cylinders.

NOTICE
There are matching marks on the side of connecting rod body and cap, do not exchange with others.

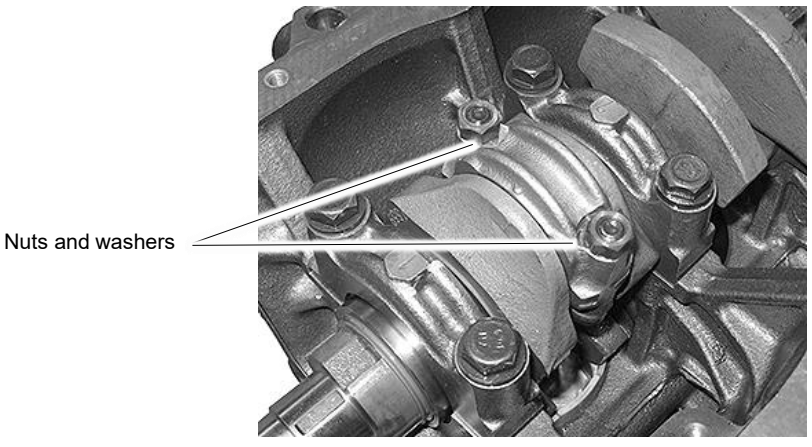


Figure 210 Connecting-rod Bearing Location

2. Remove two nuts and washers securing connecting rod cap to connecting rod with bearing in place. See Figure 210.
3. Remove connecting rod cap from connecting rod and crankshaft.

4. Cover the connecting rod bolts with vinyl hoses. Gently tap piston through top of cylinder block from the bottom as not to damage the crank pin.
5. Remove pistons and rods from engine.

NOTICE
The removed pistons, connecting rod caps, and bearings should be arranged in the order of corresponding cylinders.

3.9.2.9 Remove Connecting Rod Bearings from Connecting Rods

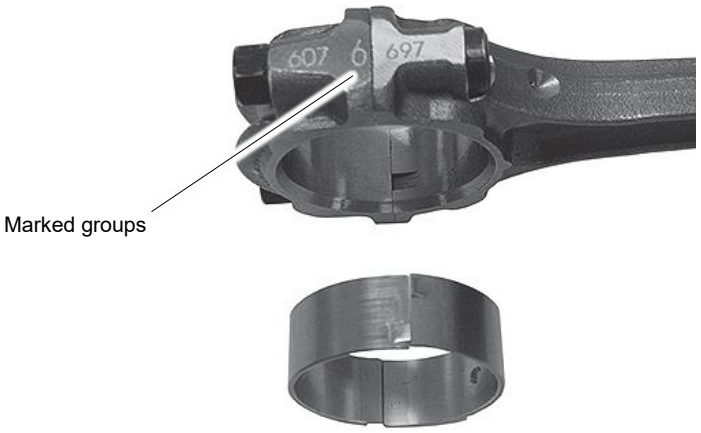


Figure 211 Connecting-rod Big Hole Diameter and Bearing

Connecting-rod big hole diameter and bearing are divided into 3 groups, marked with “6”, “7”, and “8”. Keep bearings in pairs when removed. See Figure 211.

NOTICE
Replace the same number of connecting rod bearings as that of new connecting rod caps.



Figure 212 Remove Bearings From Connecting-rods

1. Remove bearings from connecting rods and connecting rod caps. See Figure 212.

3.9.2.10 Disassemble Connecting Rod and Piston Assembly

NOTICE
Removed pistons, piston rings, and piston pins shall be used in original combinations before removal.

Arrange the removed pistons, piston pins, piston rings, and connecting rods in order of the corresponding cylinders.

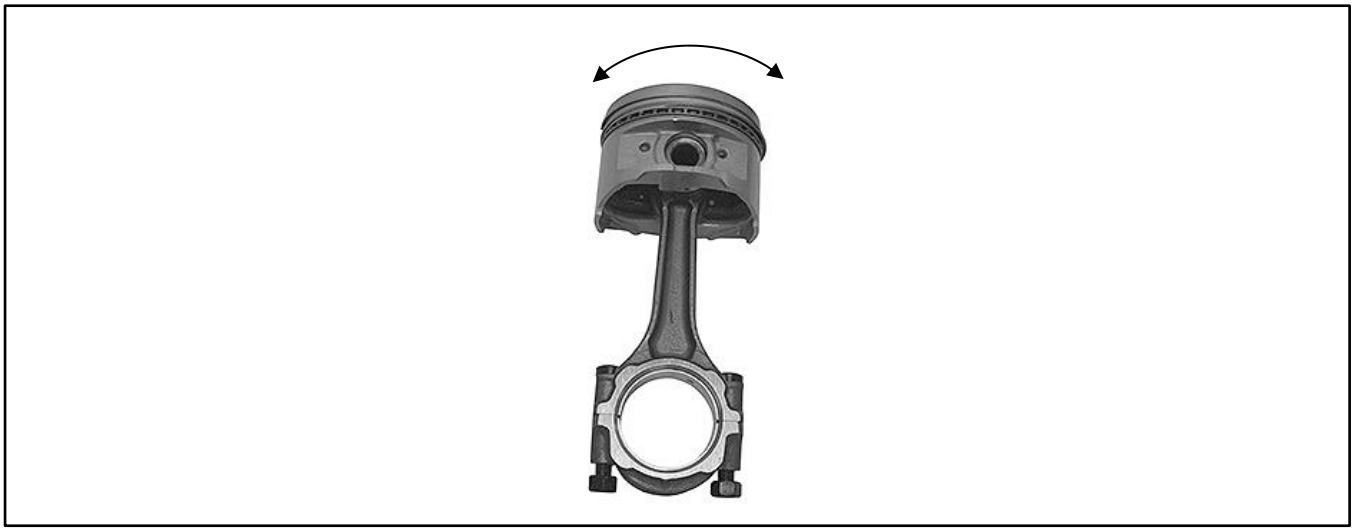


Figure 213 Piston View

1. Move the piston to check for smooth movement. See Figure 213.
2. If obstruction, looseness, or heavy movement is observed, replace the piston subassembly.

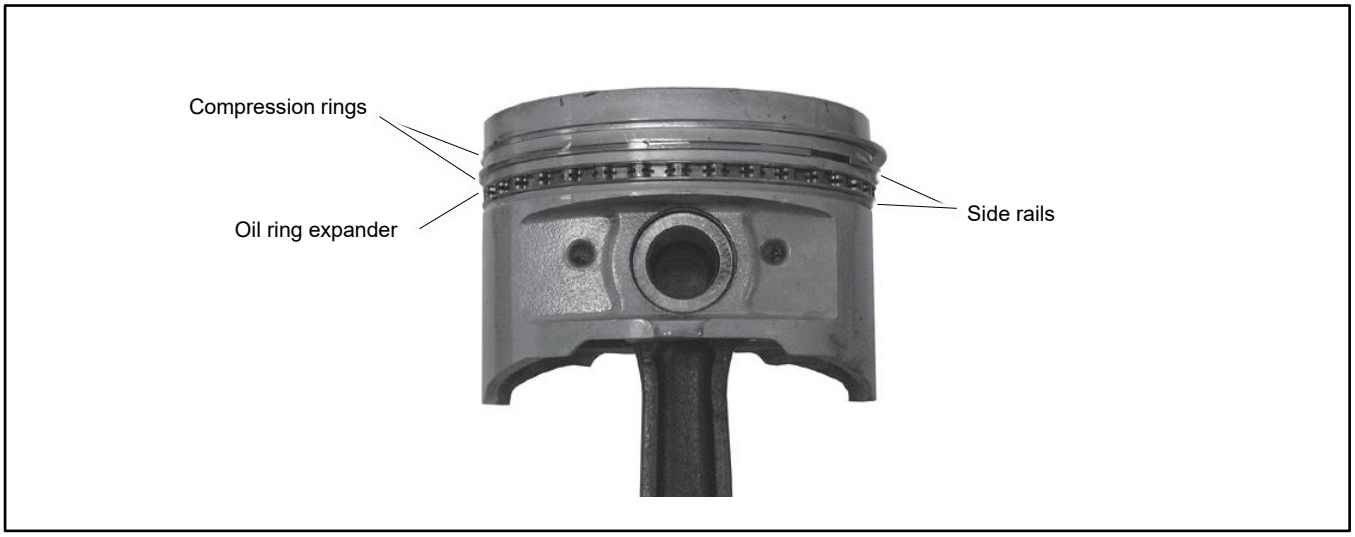


Figure 214 Compression Rings

3. Remove two compression rings from the piston using a piston ring expansion tool. See Figure 214.
4. Manually remove two side rails and oil ring expander.
5. Arrange the removed piston rings in the order of the corresponding cylinders.
6. Remove the piston pin from the piston rod assembly at room temperature, using the proper piston pin removal tool.

3.9.2.11 Check Connecting Rods for Bend or Twist

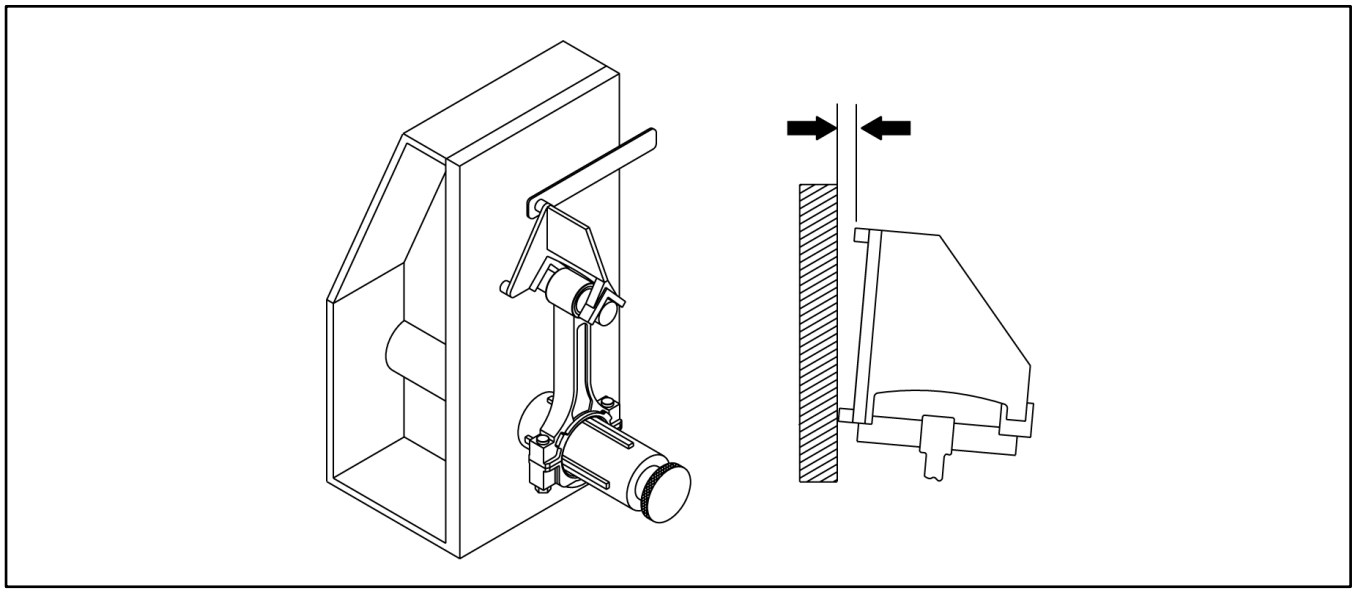


Figure 215 Connecting-rod Alignment Bend

1. Using a rod aligner, check the connecting rod alignment for bend or twist. See Figure 215.

CONNECTING ROD BEND—MAXIMUM
0.05 mm per 100 mm (0.0019 in. per 3.93 in.)

2. If bend is greater than maximum specification, replace the connecting rod assembly.

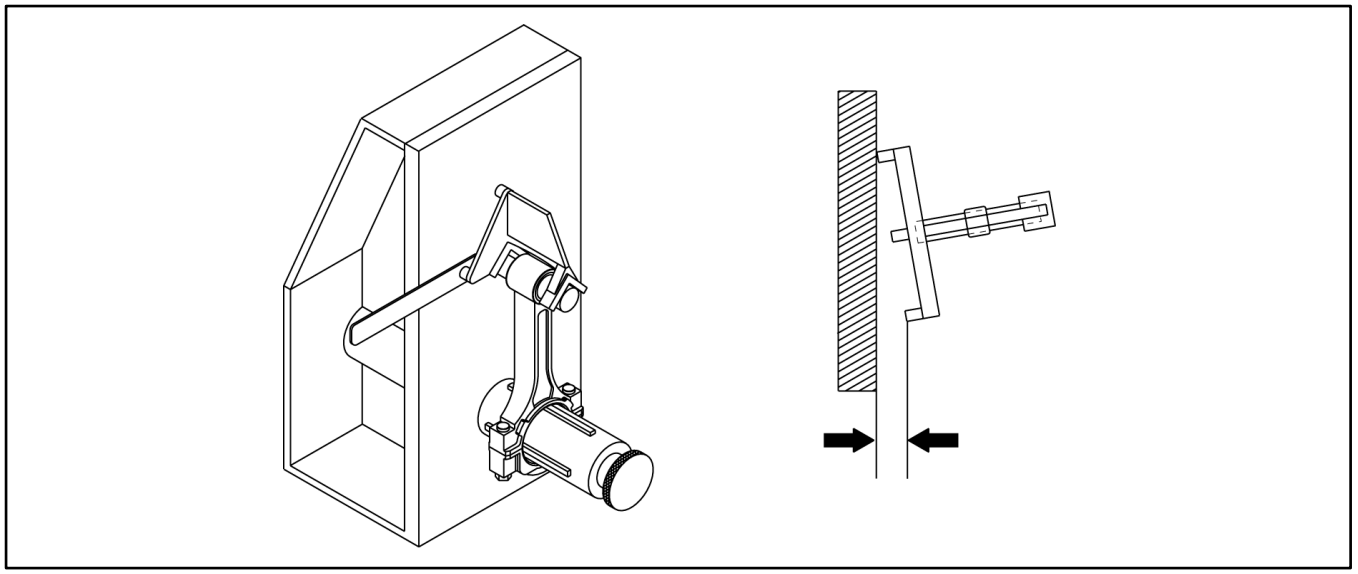


Figure 216 Connecting-rod Alignment Twist

CONNECTING ROD TWIST—MAXIMUM
0.05 mm per 100 mm (0.0019 in. per 3.93 in.)

3. If twist is greater than maximum specification, replace the connecting rod assembly.

3.9.2.12 Clean Pistons



Figure 217 Piston Ring Groves

1. Clean piston ring grooves using a piston ring groove cleaning tool or an old piston ring. See Figure 217.

NOTICE
When washing pistons, always use a stiff bristle brush–NOT A WIRE BRUSH–to loosen carbon residue. DO NOT bead blast ring groove area.

2. Clean pistons by any of the following methods:
   - Immersion-solvent “D-Part.”
   - Hydra-Jet Rinse Gun.
   - Hot water with liquid detergent soap.

   If cleaning with hot water and liquid detergent, soak pistons in a 50 percent solution of liquid household detergent and hot water for 30 to 60 minutes. Use a stiff bristle brush–NOT A WIRE BRUSH–to loosen carbon residue. Dry with compressed air.

3.9.2.13 Check Piston Ring Grooves



Figure 218 Inspection of Piston Rings

1. Inspect piston ring grooves and piston ring lands for wear. See Figure 218. If there is wear or damage, repair or replace piston as necessary.
2. Using a feeler gauge, measure the clearance between the piston ring land and piston ring.

PISTON RING-TO-PISTON RING LAND CLEARANCE
0.030–0.070 mm (0.0011–0.0027 in.)

3. If the clearance is not within specification, replace the piston.

3.9.2.14 Check Piston Ring Gap

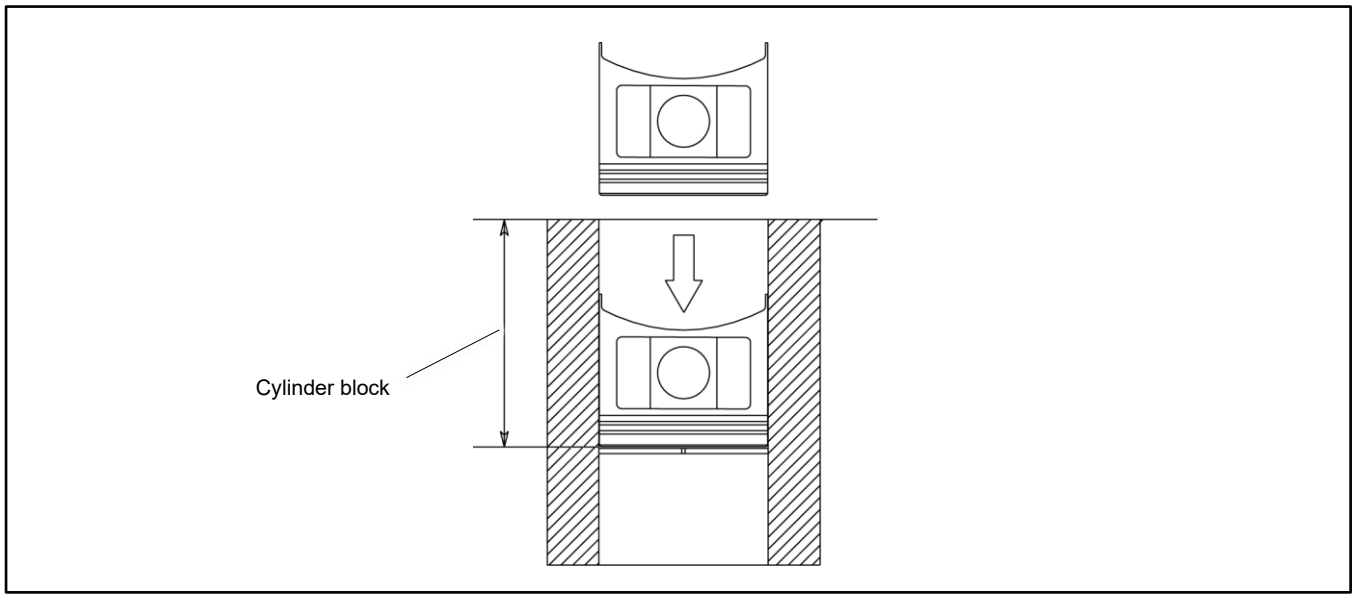


Figure 219 Cylinder Block

1. Insert the piston ring into the cylinder bore. Using a piston, push the piston ring a little beyond the bottom of the ring travel of the cylinder bore, 110 mm (4.33 in.) from the top of the cylinder block. See Figure 219.

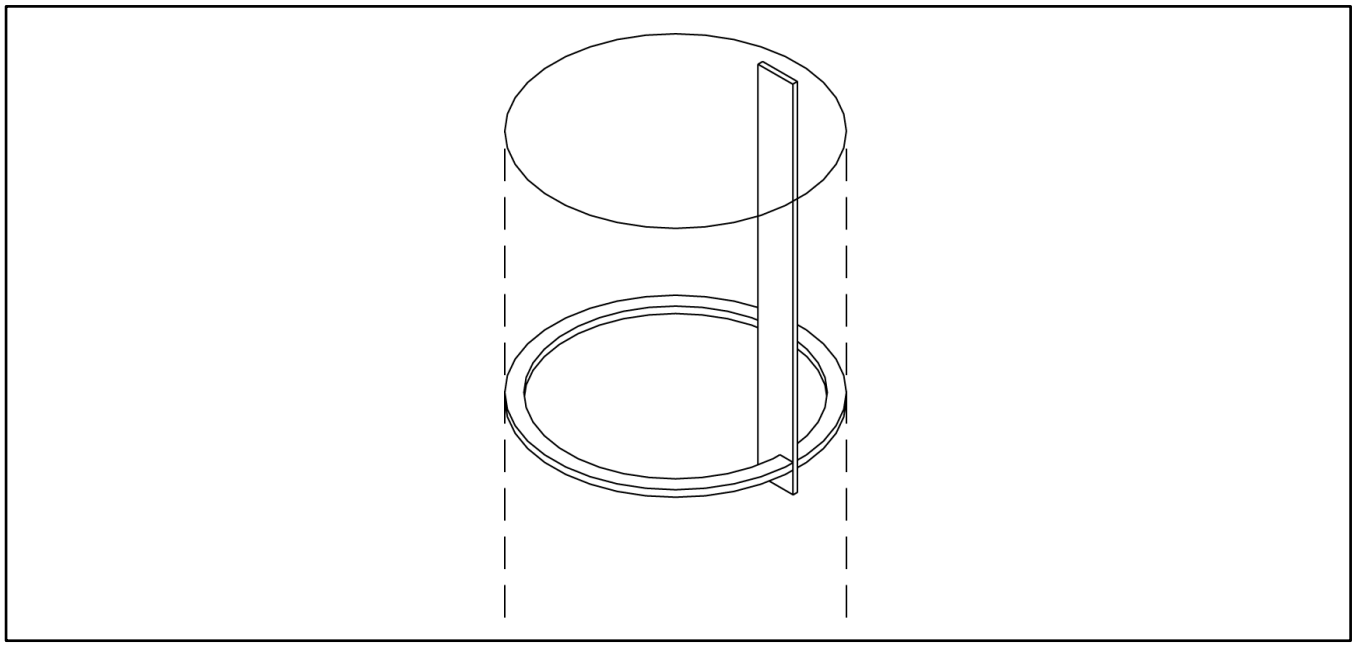


Figure 220 Piston Ring End Gap

2. Using a feeler gauge, measure the piston ring end gap. See Figure 220.

PISTON RING END GAP	
Standard	
No. 1	0.22–0.51 mm (0.0086–0.020 in.)
No. 2	0.15–0.47 mm (0.0059–0.018 in.)
Oil (Side rail)	0.20–0.70 mm (0.0078-0.0027 in.)
Maximum	
No. 1	1.11 mm (0.043 in.)
No. 2	1.07 mm (0.042 in.)
Oil (Side rail)	1.10 mm (0.043 in.)

3.9.2.15 Check Piston Pins

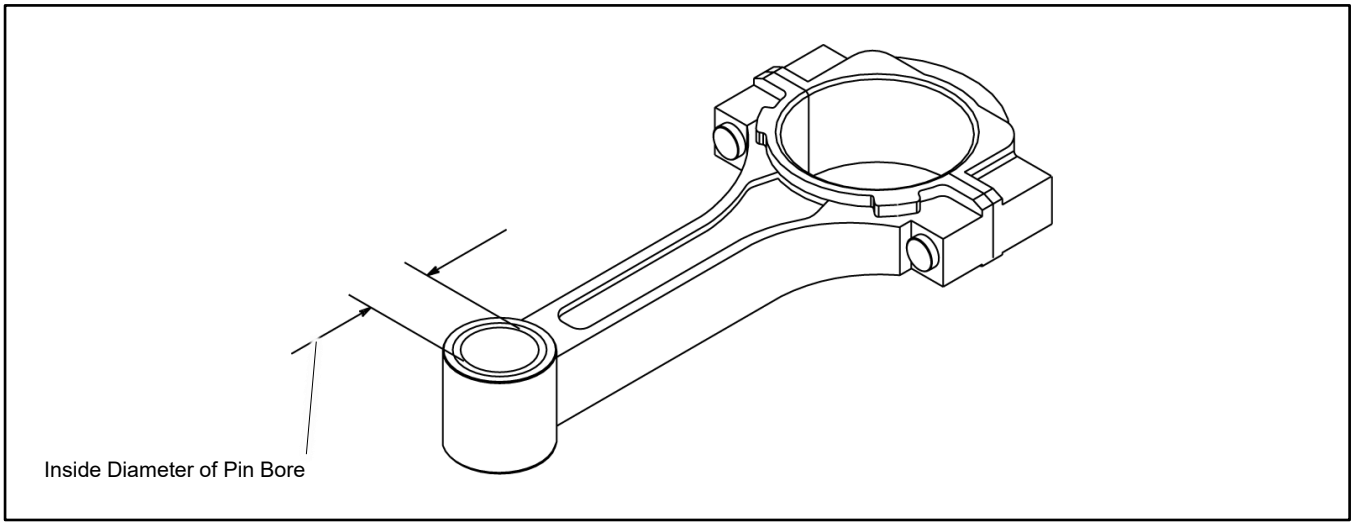


Figure 221 Pin Bore Inside Diameter

1. Check inside diameter of pin bore in piston with a bore gauge. See Figure 221.

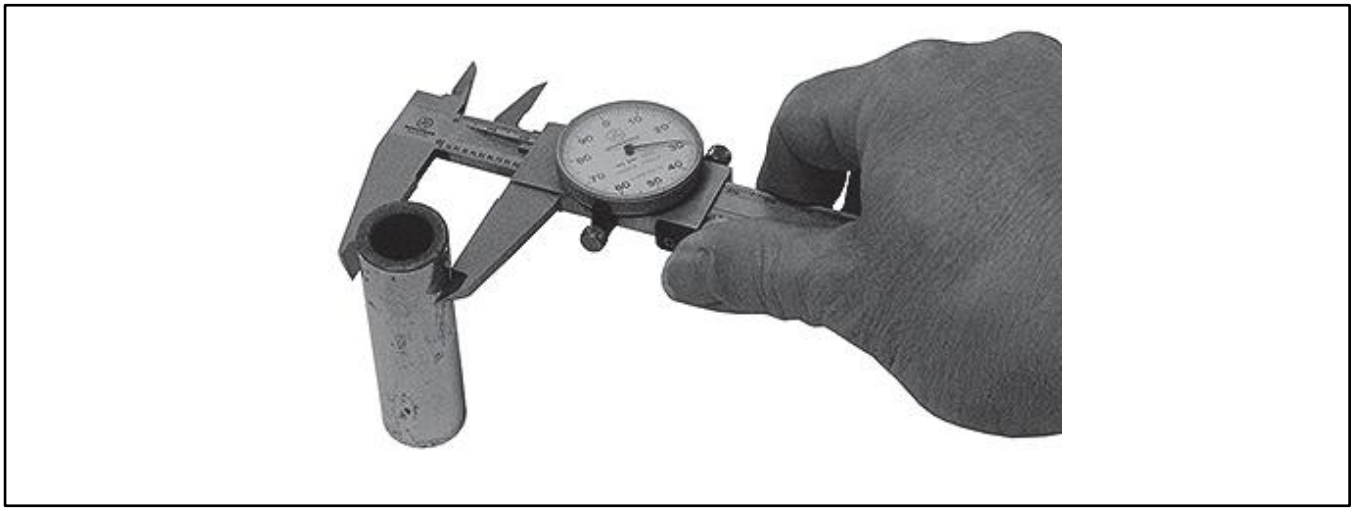


Figure 222 Piston Pin Diameter

2. Using a micrometer, check piston pin diameter. See Figure 222.

PISTON PIN SPECIFICATIONS
Piston Pin Bore—Diameter
22.010–22.016 mm (0.8665–0.08667 in.)
Piston Pin—Diameter
22.003–22.006 mm (0.8662–0.8664 in.)
PISTON PIN OIL CLEARANCE
0.004–0.013 mm (0.0002–0.0005 in.)

3.9.2.16 Check Piston Skirts

NOTICE
Piston diameter is grouped into three groups. Same as cylinder bore diameter. Grouping mark is located on top of piston.

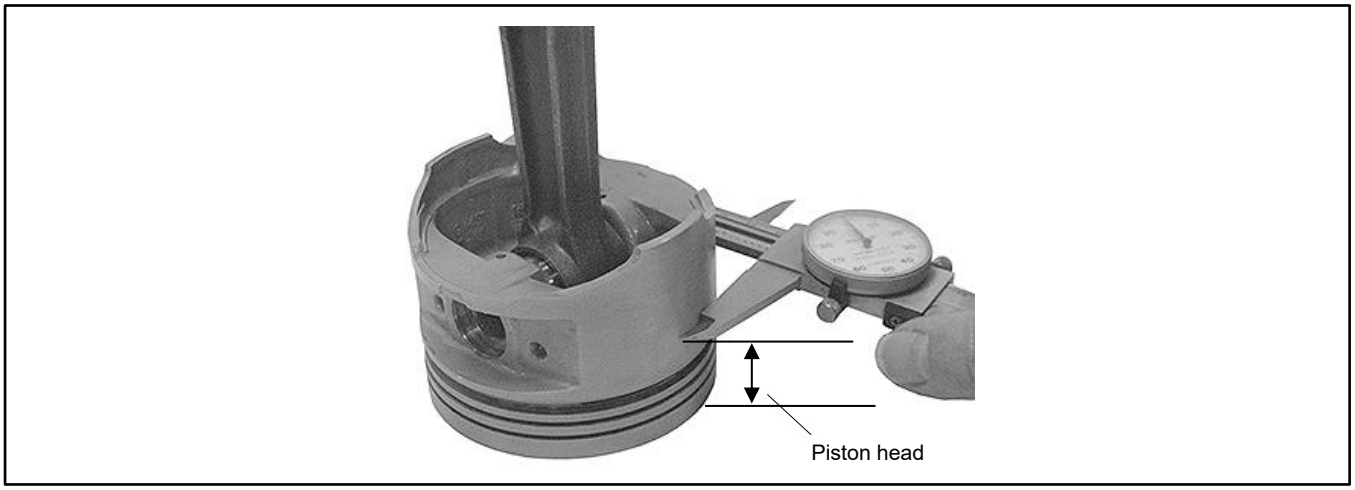


Figure 223 Piston Diameter Measurement

1. Using a micrometer, measure the piston diameter at plumb angles to the piston pin centerline, 24 mm (0.945 in.) from the piston head. See Figure 223.

PISTON SPECIFICATIONS—DIAMETER	
Standard	
Group 1	90.938–90.948 mm (3.5802–3.5806 in.)
Group 2	90.948–90.958 mm (3.5806–3.5810 in.)
Group 3	90.958–90.968 mm (3.5810–3.5814 in.)
Oversize Piston	91.425–91.955 mm (3.599–3.620 in.)
Cylinder Bore-to-Piston—Clearance	0.065–0.085 mm (0.0025–0.0033 in.)

2. If the clearance is not within specification, replace the piston, or re-bore all four cylinders and replace all four pistons.

3.9.2.17 Assemble Piston and Connecting Rods

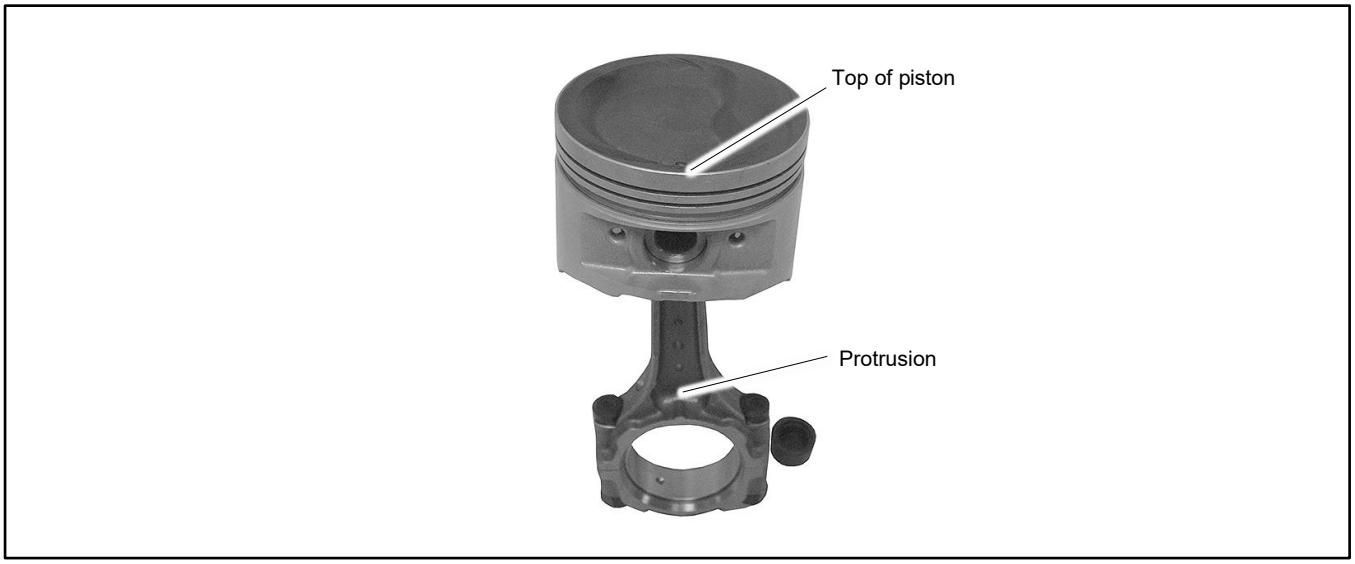


Figure 224 Assembling Piston and Connecting Rod Body

1. There are matching marks on the side of connecting rod body and cap, do not exchange with others. The protrusion on the connecting body and cap should be in the same side with concave point positioned on the top of piston, and towards front of engine. See Figure 224.
2. Coat engine oil on the piston pin and piston hole in piston.
3. Use an appropriate press to press the piston pin into the piston at room temperature.

3.9.2.18 Install Piston Rings

1. Manually install the oil ring expander and two side rails.

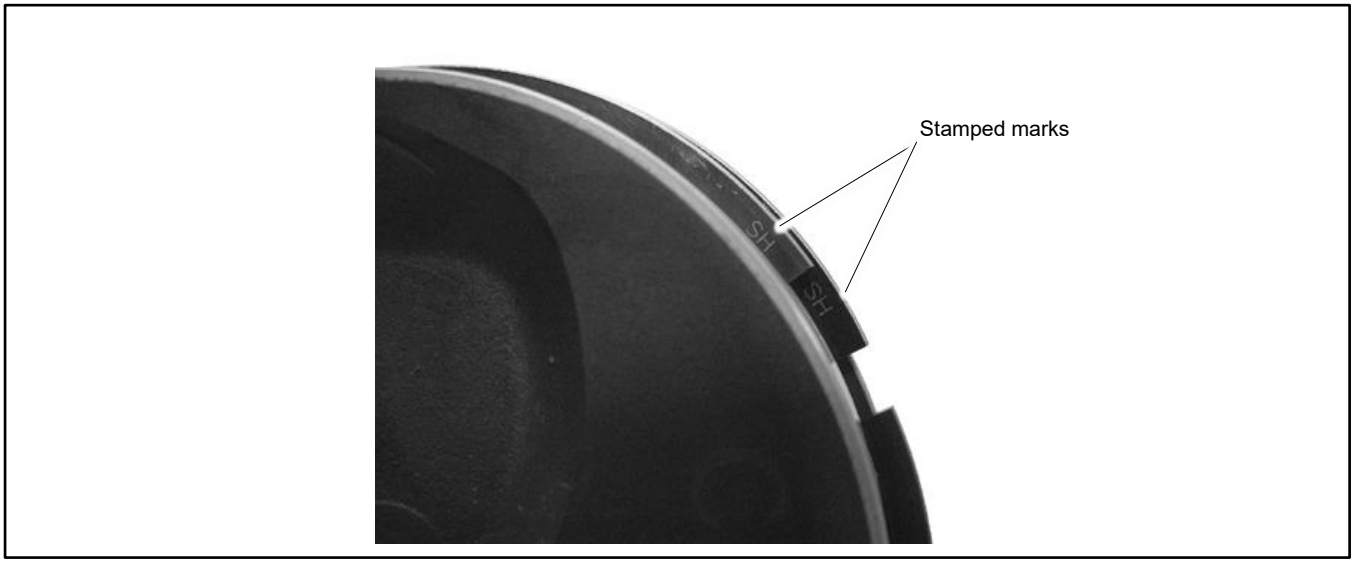


Figure 225 Piston Rings

2. Use a piston ring expansion tool and install two piston rings, with the stamped marks facing upward. See Figure 225.

   Note:
   Arrow points to front of engine assembly.

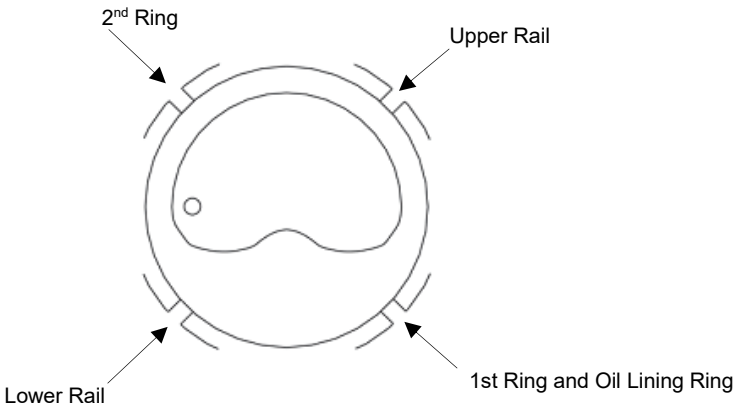


Figure 226 Piston Rings Ends

3. Position the piston ring ends as illustrated. See Figure 226.

3.9.2.19 Install Piston and Connecting Rod Assembly

1. Coat engine oil on the cylinder bores, piston outer circumferences, and bearing surfaces.
2. Cover connecting rod bolts with vinyl tubing to prevent damage of the cylinders and the crankshaft.
3. Check piston ring joint positions.

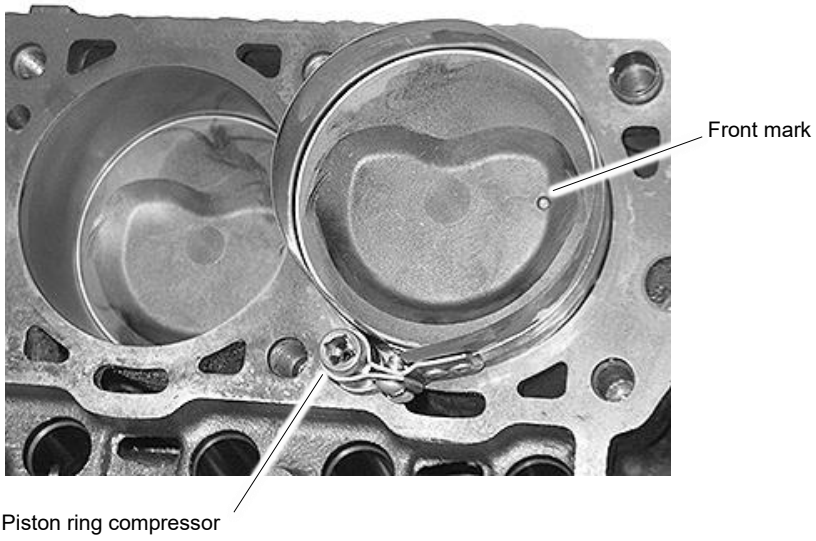


Figure 227 Piston Rings Compressor with Front Marks

4. Using a piston ring compressor, with the front marks facing the front side of engine, insert each piston connecting rod into the cylinder block. See Figure 227.

NOTICE
The piston and the block combination shall be the same as before disassembly.

5. Check the matching marks punched at the time of removal.

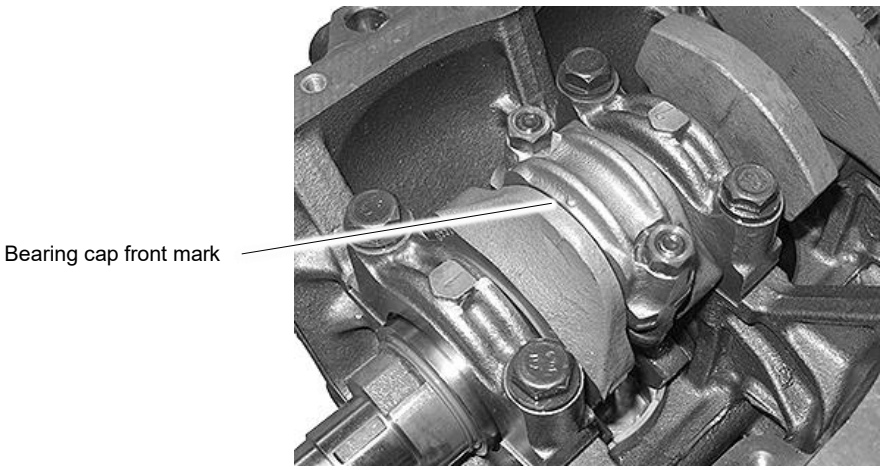


Figure 228 Bearing Cap Installation

6. Place the bearing cap front mark facing the front side, and install the bearing cap to the connecting rod. See Figure 228.
7. Slightly coat engine oil on the connecting rod threaded portion and nut bottom surface.
8. Alternately tighten the left and right nuts equally in several steps.

CONNECTING ROD CAP—TORQUE
49 Nm (36 ft.lb.)

NOTICE
Connecting rod thrust clearance can only be checked as connecting rod assemblies are installed as pairs.

9. Check the connecting rod thrust clearance.

3.9.2.20 Remove Main Bearing Caps

Main bearing bore is grouped in three groups, first to fifth main bearing bore-grouping marks are on the bottom surface of the cylinder block, rear end and right side.

Note:
Arrow points to front of engine assembly.

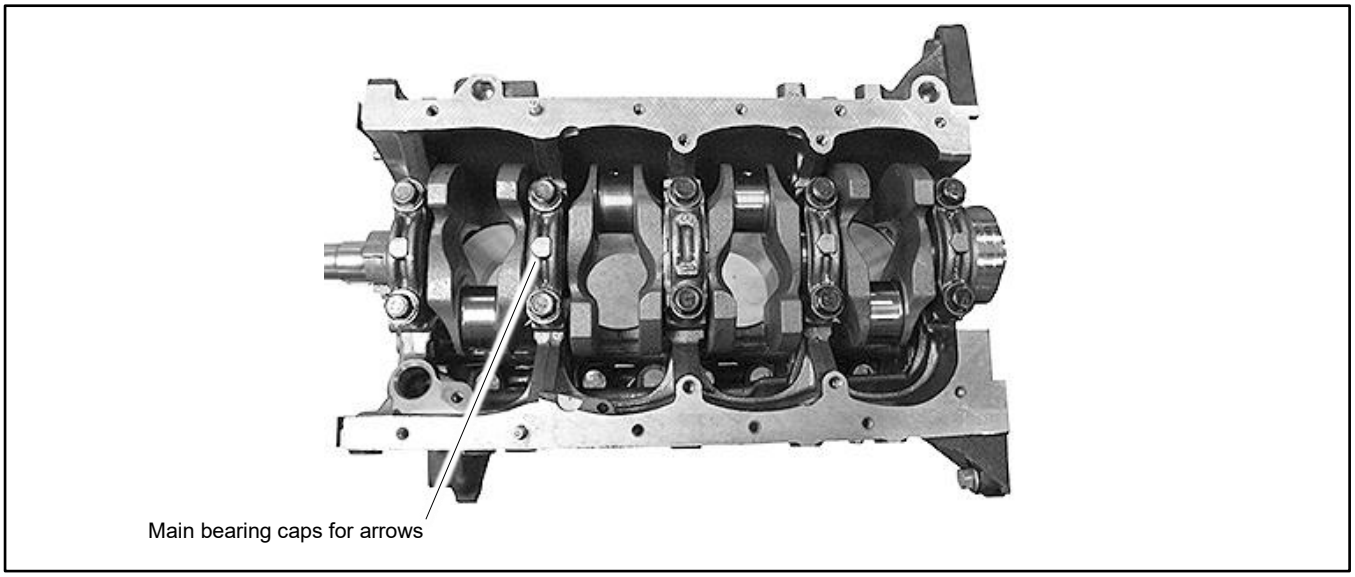


Figure 229 Main Bearing Cap

1. Check main bearing caps for arrows cast in main bearing cap, and numbers stamped on cap and oil pan rail. If there are no numbers, stamp corresponding numbers on cap and oil pan rail to ensure correct placement of bearing caps during reassembly. See Figure 229.
2. Loosen two main bearing cap bolts and washers.

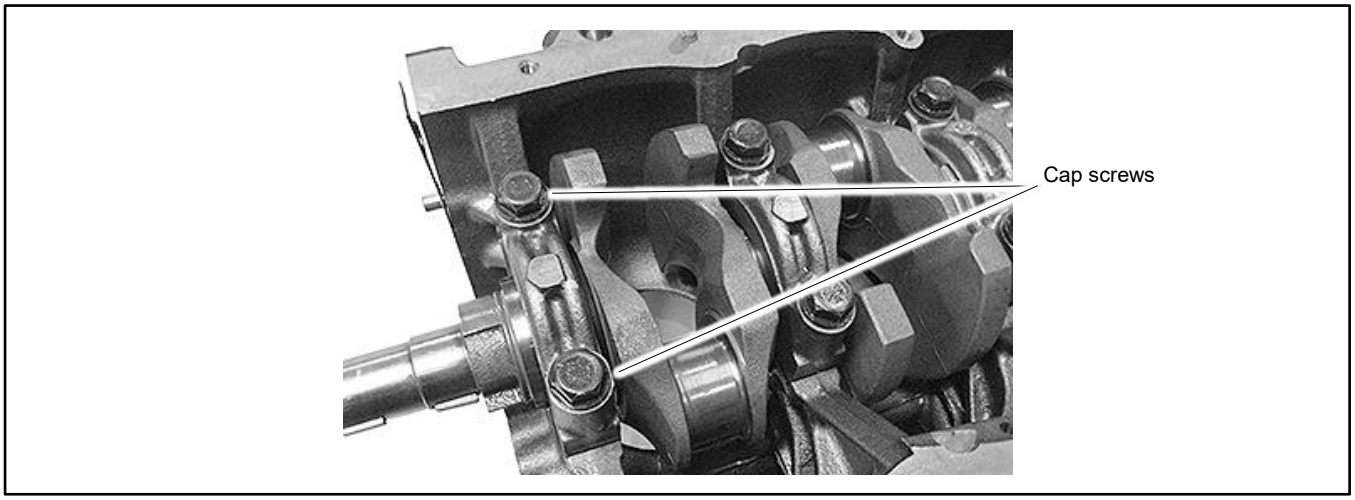


Figure 230 Removal of Main Bearing

3. Remove main bearing caps by extending cap screws and forcing heads of screws together. Wiggle bearing cap back and forth while applying an upward force with cap screws until free from main bearing cap support. See Figure 230.

3.9.2.21 Remove Crankshaft

CAUTION	
	**Damaged harmonic balancer, crankshaft, or flywheel.** **Can cause personal injury.** Broken fragments from the harmonic balancer, crankshaft, and flywheel can be thrown from the engine. Do not use a hammer to install or remove. Inspect these parts for damage and replace if needed.

1. Carefully raise crankshaft out of cylinder block.
2. Clean crankshaft, especially oil passages, using solvent and compressed air.
3. Place crankshaft on clean V-blocks.

3.9.2.22 Inspect Crankshaft

- Thoroughly clean and visually inspect crankshaft. Clear all restrictions from all oil passages.
- Inspect crankshaft for signs of load stress, cracks, scoring, or journal scratches. Replace crankshaft if cracks are found.
- Check each journal for excessive overheating or discoloration. If either condition exists, replace crankshaft since heat treatment has probably been destroyed.
- Inspect the keyway for evidence of cracks or wear. Replace crankshaft as necessary.
- Carefully inspect the rear hub of the crankshaft in the area of the wear sleeve contact surface for evidence of a rough or grooved condition. Any imperfections in this area will result in oil leakage. Slight ridges may be cleaned up with emery cloth or crocus cloth.
- Carefully check the crankshaft for cracks in the area of rod journal holes and at journal fillets. Replace crankshaft if any cracks are found.

3.9.2.23 Measure Crankshaft Journals and Bearing ID

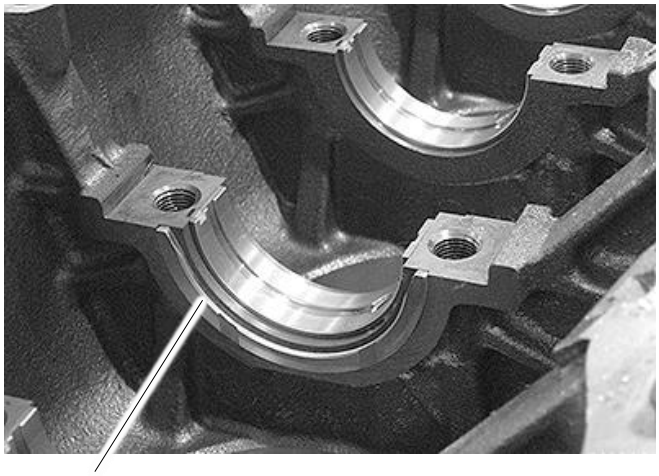


Figure 231 Cylinder Block

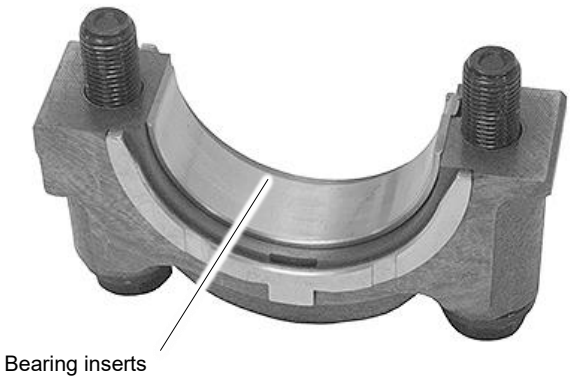


Figure 232 Bearing Inserts

1. With crankshaft removed from cylinder block, assemble main bearing caps with bearing inserts. Be sure inserts are installed correctly.
2. Install main bearing caps to the cylinder block.
3. Tighten main bearing caps screws to specification.

MAIN BEARING CAP BOLT—TORQUE
79 Nm (58 ft.lb.)

4. Measure main bearing assembled ID at several points with a inside micrometer.



Figure 233 Measure Main Bearing Journal



Figure 234 Measure Crank Pin

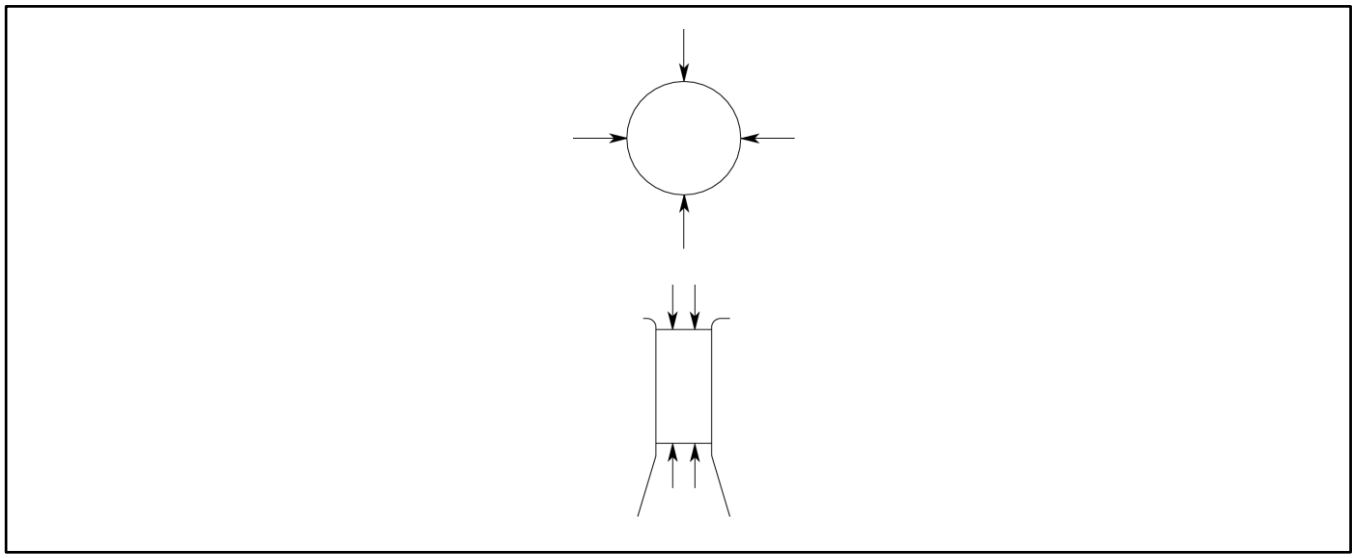


Figure 235 Measure Crankshaft and Connecting Rod OD

5. Using a micrometer, measure the diameter of each main journal and crank pin. See Figure 233, Figure 234, and Figure 235.

MAIN JOURNAL AND CRANK PIN DIAMETER	
Main Journal Diameter	57.985–58.000 mm (2.282–2.283 in.)
Crank Pin Diameter	47.985–48.000 mm (1.8891–1.8897 in.)

6. If the diameter is not within specification, check the oil clearance.
7. If taper and runout is greater than the maximum specification, grind or replace the crankshaft.

MAIN JOURNAL AND CRANK PIN TAPER AND RUNOUT—MAXIMUM
0.02 mm (0.0007 in.)

8. Measure crankshaft OD and connecting rod journal OD at several points around each journal.
9. Compare measurements with specifications given.

3.9.2.24 Check Crankshaft Circle Runout



Figure 236 Crankshaft Circle Runout

1. Inspect the crankshaft for circle runout.
2. Place the crankshaft on V-blocks. Using a dial indicator, measure the circle runout at the center main journal. See Figure 236.

CRANKSHAFT CIRCLE RUNOUT—MAXIMUM
0.06 mm (0.0023 in.)

3. If the circle runout is greater than maximum specification, replace the crankshaft.

3.9.2.25 Remove Main Bearings from Main Caps and Block



Figure 237 Bore Grouping Marks

Note:
Main bearing bore is grouped in three groups. First to fifth main bearing bore-grouping marks are on the bottom surface of the cylinder block, rear end and right side. Main bearings are divided into three groups also, matching the main bearing bore group.

Main bearing caps cannot interchange; direction cannot be reversed. There are arrows cast on top of the main cap, also sequence numbers on top of caps.

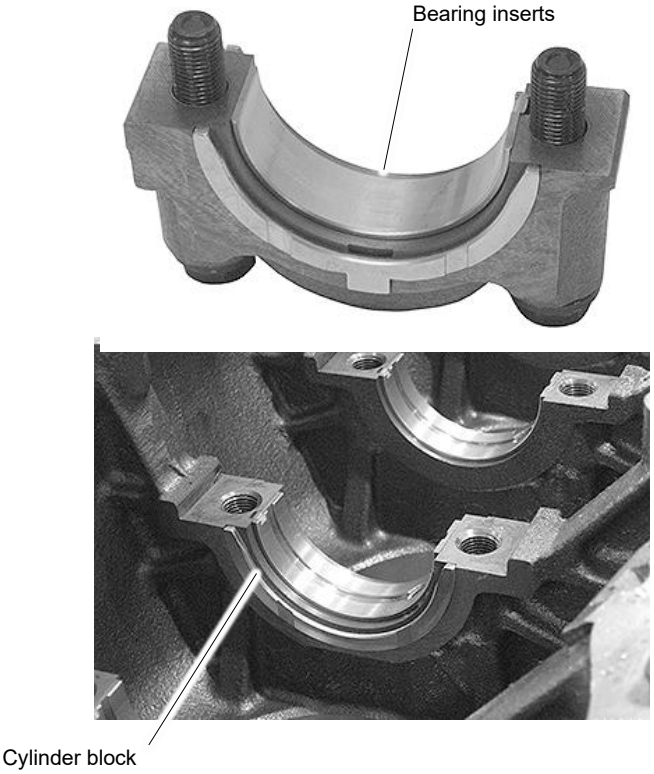


Figure 238 Main Bearing Inserts

1. If main bearing inserts are to be replaced, remove inserts from main bearing caps. Otherwise, leave bearing inserts in caps until assembled ID has been measured. See “Check Bearing Oil Clearance”.
2. If main bearing inserts are to be replaced, remove inserts from cylinder block. Otherwise, leave bearing inserts in block until assembled ID has been measured.

3.9.2.26 Check Cylinder Block Deck for Warpage

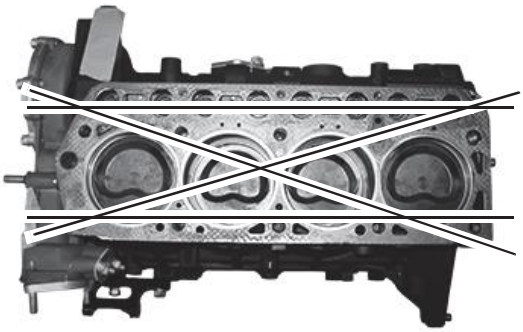


Figure 239 Cylinder Block Deck Warpage

1. Check cylinder block deck for warpage. Using a precision straight edge and feeler gauge, check the cylinder block deck surface connecting the cylinder head for warpage. See Figure 239.

CYLINDER DECK WARPAGE—MAXIMUM
0.05 mm (0.002 in)

2. If deck surface warpage is greater than the maximum specification, surface grind the deck with plane grinder toothful or replace the cylinder block.

NOTICE
If the limit is exceeded, regrind the top surface of the cylinder block or replace the cylinder block.

3.9.2.27 Cylinder Bore Visual Inspection

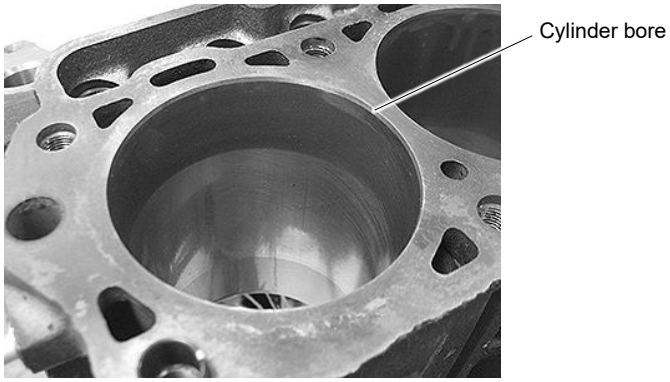


Figure 240 Cylinder Block Deck Warpage

- Check the cylinder bore for surface defects. If any excessive damage or cracks are found rebore cylinder or replace cylinder block. See Figure 240.
- If there are deep score marks lengthwise on the cylinder bores, all four cylinders will need to be rebored.

3.9.2.28 Check Cylinder Taper

Note:
Arrow points to front of engine assembly.

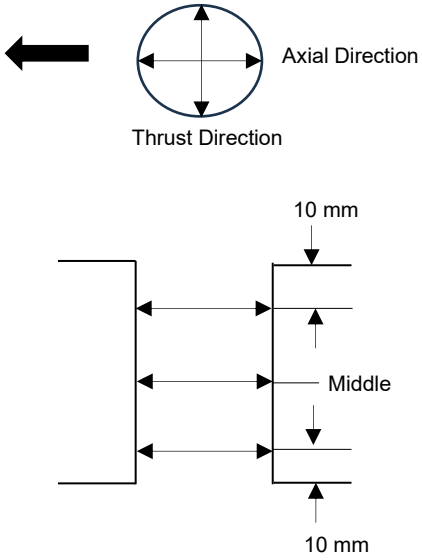


Figure 241 Cylinder Bore Diameter

- Using a dial bore gauge, measure the cylinder bore diameter at positions A, B and C in the thrust and axial directions. See Figure 241.

STANDARD CYLINDER BORE DIAMETER	
Standard	
Group 1	91.000–91.010 mm (3.5820–3.5830 in.)
Group 2	91.010–91.020 mm (3.5830–3.5834 in.)
Group 3	91.020–91.030 mm (3.5834–3.5838 in.)
Maximum Diameter	91.23 mm (3.591 in.)

- If the cylinder bore diameter is greater than maximum specification, rebore all four cylinders, if necessary, replace the cylinder block.

OVERSIZE CYLINDER BORE DIAMETER	
Standard	
+0.50 mm Piston Diameter	91.50–92.24 mm (3.602–3.631 in.)
Maximum Diameter	92.24 mm (3.631 in.)

- If diameter is greater than this maximum specification, replace cylinder block.

3.9.2.29 Disassemble Cylinder Block

1. Remove all water galley plugs from cylinder block.
2. Remove all oil galley plugs from cylinder block.

3.9.2.30 Cylinder Block Cleaning and Inspection

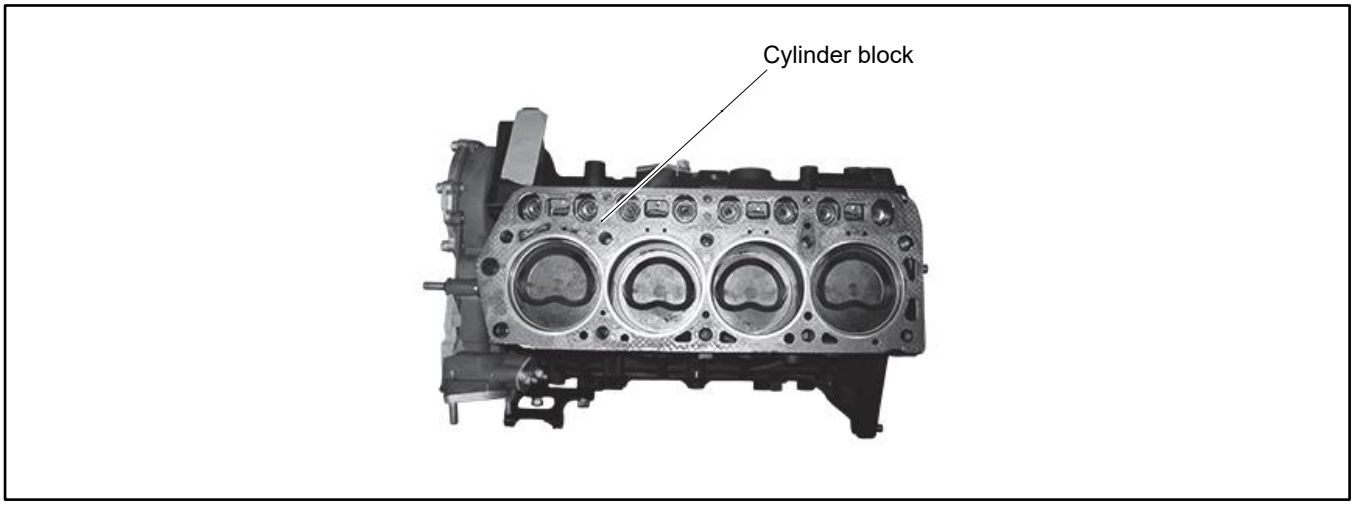


Figure 242 Cylinder Block

1. Use a scraper and remove any gasket material or sealant remaining on the cylinder block. See Figure 242.
2. Clean each part of the cylinder block with a solvent.

3.9.2.31 Install Main Bearings



Figure 243 Bore Grouping Marks

Main bearing bore is grouped in 3 groups. First to fifth main bearing bore-grouping marks are on the bottom surface of the cylinder block, rear end and right side. Main bearings are divided into 3 groups also, matching main bearing bore group. See Figure 243.

NOTICE
Keep the bearing outer surfaces (in contact with the cylinder block or bearing caps) free from oil.

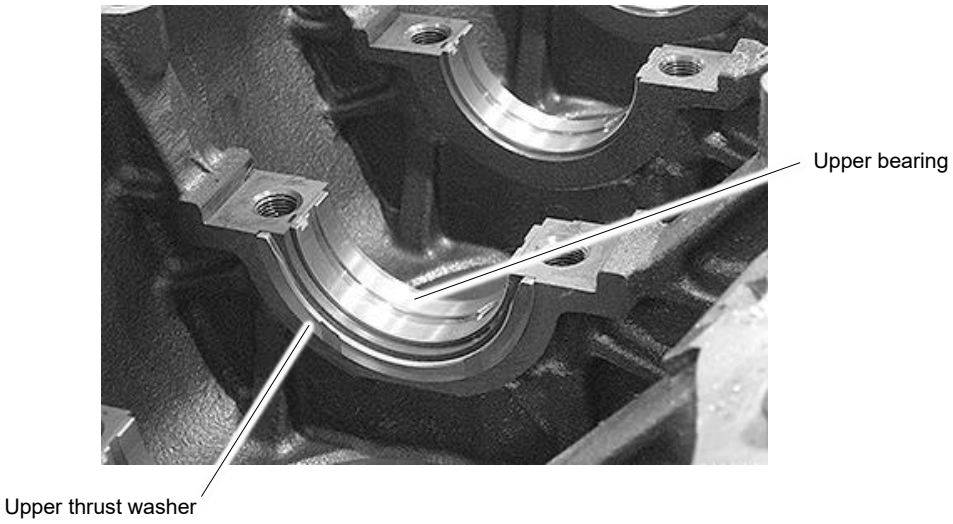


Figure 244 Upper Bearing Installation

1. Install the upper bearing which has an oil groove on the whole periphery, with the cylinder block oil hole and lock groove as the guide. See Figure 244.
2. Install the upper thrust washers to the No. 3 journal supporting portion, with the oil grooves facing outward.

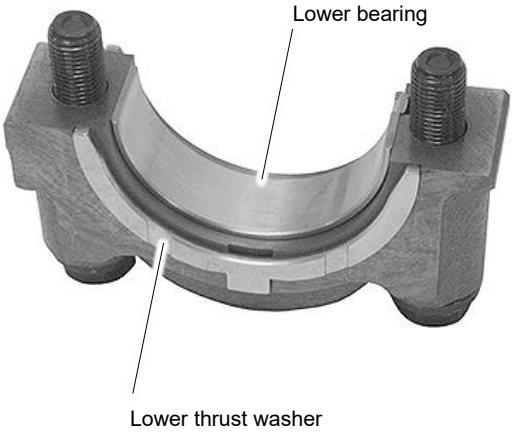


Figure 245 Lower Bearing Installation

3. Install the lower bearing by fitting with the bearing cap lock groove. See Figure 245.
4. Install the lower thrust washers to the No. 3 bearing cap, with the oil grooves facing outward.

NOTICE
Coat engine oil on the rear face of the thrust washer to prevent falling.

CAUTION	
	**Damaged harmonic balancer, crankshaft, or flywheel.** **Can cause personal injury.** Broken fragments from the harmonic balancer, crankshaft, and flywheel can be thrown from the engine. Do not use a hammer to install or remove. Inspect these parts for damage and replace if needed.

3.9.2.32 Install Crankshaft

1. Coat engine oil on the upper bearings and install the crankshaft.

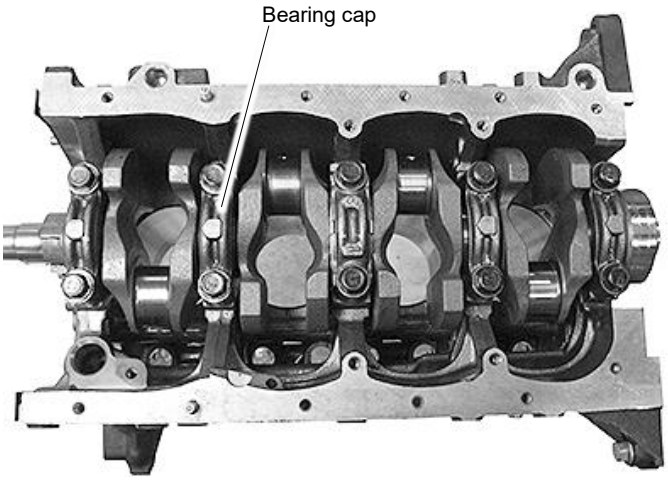


Figure 246 Bearing Cap

2. Coat engine oil on the lower bearing surfaces. Install the bearing caps to the corresponding code positions, with the front marks on the front side. See Figure 246.
3. Coat engine oil thinly on the bearing cap bolt threads and seat surfaces. Loosely install bearing cap bolts.

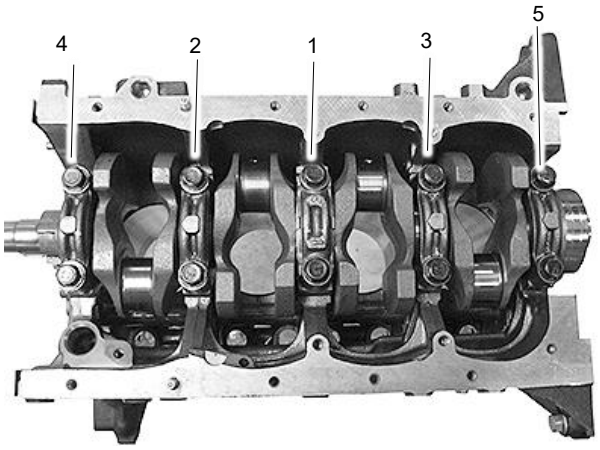


Figure 247 Bearing Cap Tightening Order

4. Evenly tighten ten bearing cap bolts on the left and right sides in the illustrated order little by little in several steps. See Figure 247.

MAIN BEARING CAP BOLT—TORQUE
8.00 kg-m (58 ft.lb.)

5. After tightening the bearing caps, check that the crankshaft rotates smoothly.
6. Inspect the crankshaft thrust clearance.

3.9.2.33 Complete Final Assembly

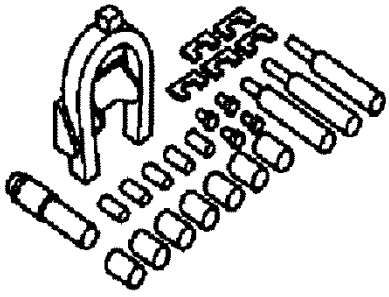
Install all fittings and plugs to engine as removed. Install all external components to engine. See the Engine Assembly section.

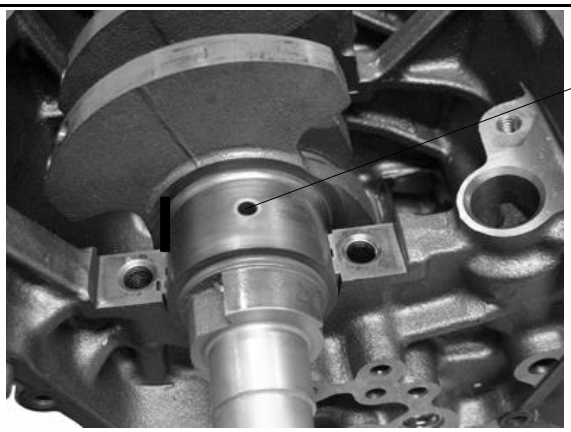
4.1 Tools and Equipment

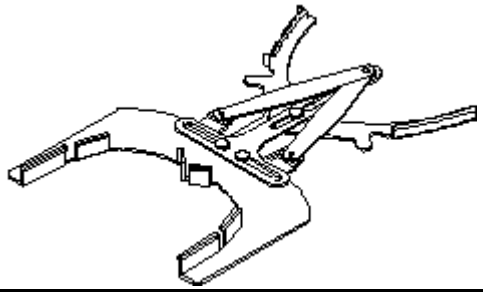
Special tools are listed and illustrated throughout this section. These tools (or their equivalents) are specially designed to quickly and safely accomplish the operations for which they are intended. The use of these special tools will also minimize possible damage to engine components. Some precision measuring tools are required for inspection of certain critical components. Torque wrenches and a torque angle meter are necessary for the proper tightening of various fasteners. To properly service the engine assembly, the following items should be readily available:

- Approved eye protection and safety gloves.
- A clean, well-lit work area.
- A suitable parts cleaning tank.
- A compressed air supply.
- Trays or storage containers to keep parts and fasteners organized.
- An adequate set of hand tools.
- Approved engine repair stand.
- An approved engine lifting device that will adequately support the weight of the components.

	Vibration Dampener Puller
	Valve Spring Compressor
	Cylinder Bore Gauge

	Valve Spring Tester
	Ridge Reamer
	Universal Seal Installer Set
	Piston Pin Remover Set

	Plastic Clearance Checking Strips (1)
	Micrometer Set
	Dial Indicator Set
	Piston Ring Compressor

	Camshaft Bearing Remover/Installer Set
	Piston Ring Groove Cleaner



TP-6902 2/26c

Original Instructions (English)

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