CATERPILLAR®

Asia Pacific Learning

"Provide leading edge learning solutions today for tomorrow's success"

Air Induction and Exhaust Systems

Student Guide

Caterpillar Service Technician Module
APLTCL001
Air Induction and Exhaust Systems

Published by Asia Pacific Learning
1 Caterpillar Drive
Tullamarine Victoria Australia 3043

Version 3.2, 2003

Acknowledgements

A special thanks to the Caterpillar Family for their contribution in reviewing the curricula for this program, in particular:

- Caterpillar engineers and instructors
- Dealer engineers and instructors
- Caterpillar Institutes.

MODULE INTRODUCTION

Module Title

Air Induction and Exhaust Systems.

Module Description

This module covers the knowledge and skills of Air Induction and Exhaust Systems. Upon satisfactory completion of this module students will be able to competently service and repair Air Induction and Exhaust Systems.

Pre-Requisites

The following module(s) must be completed prior to delivery of this module:

- APLBUS006 Follow Workplace Occupational Health and Safety Procedures
- APLTCL011 Mechanical Principles
- APLTCL035 Diesel Engine Fundamentals.

Learning & Development

Delivery of this facilitated module requires access to the Air Induction and Exhaust Systems Activity Workbook.

The successful completion of the curriculum provides the knowledge for competency assessment, on further learning outcomes, by an Accredited Workplace Assessor.

Suggested References

- APLTCL011 Facilitator Guide
- APLTCL001 Facilitator Guide.

Assessment Methods

Classroom and Workshop

To satisfactorily complete this module, students must demonstrate competence in all learning outcomes. Consequently, activities and assessments will measure all the necessary module requirements.

For this module, students are required to participate in classroom and practical workshop activities and satisfactorily complete the following:

- Activity Workbook
- Knowledge Assessments
- Practical Activities.

Workplace

To demonstrate competence in this module students are required to satisfactorily complete the Workplace Assessment(s).

KNOWLEDGE AND SKILLS ASSESSMENT

Learning Outcome 1: Identify the components and explain the operation of naturally aspirated air intake and exhaust systems on a Diesel Engine.

Assessment Criteria

1.1 Identify the components in the air intake and exhaust system

- 1.1.1 Pre-cleaner
- 1.1.2 Air cleaner
- 1.1.3 Intake manifold
- 1.1.4 Exhaust manifold
- 1.1.5 Muffler
- 1.1.6 Exhaust stack

1.2 Explain the purpose of components in a naturally aspirated air intake system

- 1.2.1 Purpose of the air intake system
- 1.2.2 Donaspin pre-cleaner
- 1.2.3 Cyclone tube
- 1.2.4 Donaldson cyclapac
- 1.2.5 Donaldson donacline
- 1.2.6 Dry element type air cleaners
  - 1.2.6.1 Vacuator valve
  - 1.2.6.2 Air cleaner service
    - – Air cleaner service indicator
- 1.2.7 Inlet manifold

1.3 Explain the purpose of the components in a naturally aspirated exhaust system

- 1.3.1 Purpose of the exhaust system
- 1.3.2 Exhaust manifold
- 1.3.3 Piping
- 1.3.4 Mufflers
  - 1.3.4.1 Straight through mufflers
  - 1.3.4.2 Reverse flow muffler
  - 1.3.4.3 Spark arrester muffler
  - 1.3.4.4 Muffler service
- 1.3.5 Exhaust stack
- 1.3.6 Catalytic converters
- 1.3.7 Australian Design Rules for noise pollution, gas emissions (Catalytic Converter).

Learning Outcome 2:

Identify the components and explain the operation of forced air intake and exhaust systems on a Diesel Engine.

Assessment Criteria

2.1 Demonstrate knowledge of an induction system on a diesel engine

- 2.1.1 Air volumes required of an engine are compared:
  - 2.1.1.1 Naturally aspirated
  - 2.1.1.2 Fitted with a turbocharger
  - 2.1.1.3 Fitted with a blower
  - 2.1.1.4 Volumetric efficiency

2.2 Identify the components of a turbocharger system

- 2.2.1 Air intake
- 2.2.2 Compressor
- 2.2.3 Turbine
- 2.2.4 Bearing housing assembly
- 2.2.5 Exhaust manifold
- 2.2.6 Wastegate
- 2.2.7 Oil supply
- 2.2.8 Intercooler

2.3 Describe the operating principles of a turbocharger

- 2.3.1 Types of turbochargers
  - 2.3.1.1 Constant pressure
  - 2.3.1.2 Pulse
- 2.3.2 Turbocharger location
- 2.3.3 Unfiltered air
  - 2.3.3.1 Damage to components
  - 2.3.3.2 Dusty operating conditions
  - 2.3.3.3 Air intake condition
- 2.3.4 Lubrication and cooling
  - 2.3.4.1 Oil as per manufacturer's specifications
  - 2.3.4.2 Oil and oil filter change recommendations
  - 2.3.4.3 Turbocharger oil requirements
- 2.3.5 Volumetric efficiency
- 2.3.6 Engine performance
- 2.3.7 Boost pressure
- 2.3.8 Exhaust gas circulation
- 2.3.9 Pressure control
  - 2.3.9.1 Pressure ratio control
  - 2.3.9.2 Electronic
  - 2.3.9.3 Altitude effect
- 2.3.10 Two stage turbocharging (series)
- 2.3.11 Compound turbocharging
- 2.3.12 Start up procedure

2.3.13 Shut down procedures

2.3.14 Turbine shut down timer delay

2.4 Describe the operating principles of a Rootes type blower

2.4.1 Blower location

2.4.2 Volumetric efficiency

2.4.3 Engine performance

2.4.4 Forced air pressure circulation

2.4.5 Lubrication and cooling

2.4.6 Pressure control.

Learning Outcome 3:

Determine faults and the requirements of disassembly, inspection procedures and assembly of a turbocharged forced induction and exhaust system.

Assessment Criteria

3.1 Determine faults and the requirements for disassembly, inspection procedures and assembly of a turbocharger

3.1.1 Determine faults

3.1.1.1 Hot and cold side oil leakage

3.1.1.2 Hot shutdown

3.1.1.3 Restricted air cleaner

3.1.1.4 Plugged engine crankcase breathers

3.1.1.5 Air leaks in intake system

3.1.1.6 Leaks in exhaust system

3.1.1.7 Overfuelling

3.1.1.8 High altitude operation

3.1.1.9 Failure to prelube:

- After service
- After oil filter change
- Long shutdown periods

3.1.1.10 Dirty air cleaners

3.1.1.11 Leaking oil lines

3.1.1.12 Loose or over torqued mounting bolts

3.1.2 Disassembly

3.1.2.1 Collection of fluids

3.1.2.2 Turbocharger disassembly

3.1.3 Inspection

3.1.3.1 Cleaning prior to inspection

3.1.3.2 Turbine wheels and shaft assemblies

- Blades
- Back face of turbine wheel
- Oil seal ring grooves
- Bearing journals
- Shaft areas
- Shaft bend

3.1.3.3 Compressor wheels

- Blades
- Nut face
- Back face
- Bore

3.1.3.4 Centre housing
- Snap rings and grooves
- Oil seal ring bore
- Bearing bore
- Flange area
- Thrust washer retaining pins.

3.1.3.5 Compressor housing
- Contour bore and vanes
- Turbine housing
  Cracks
  Bolt holes
  Contour bore
- Inlet flange
- Outlet bore

3.1.3.6 Thrust collar and ring

3.1.3.7 Wheel shroud

3.1.3.8 Finger sleeves and thrust spacer

3.1.3.9 Compressor end insert

3.1.3.10 Thrust plates

3.1.3.11 Thrust bearings

3.1.3.12 Bearings

3.1.4 Assembly

3.1.4.1 As per manufacturer's specifications

3.1.4.2 Tolerance checks
- End play
- Bearing and shaft play

3.1.5 Installation

3.1.5.1 Loose or foreign materials

3.1.5.2 Manifold bolt torques

3.1.5.3 Gaskets

3.1.5.4 Torques.

3.2 Determine the requirements for disassembly, inspection procedures and assembly of an exhaust system

3.2.1 Inspection prior to disassembly:

3.2.1.1 Locating leaks

3.2.1.2 Vibration

3.2.1.3 Back pressure

3.2.1.4 Exhaust noise

3.2.2 Disassembly

3.2.2.1 Hard to remove components

3.2.2.2 Decoking exhaust systems components

3.2.3 Manifold checks

3.2.3.1 Cracks

3.2.3.2 Mounting surface for warpage

3.2.3.3 Threaded bores

3.2.3.4 Studs

3.2.4 Assembly

3.2.4.1 Cylinder head surface

3.2.4.2 Gaskets

3.2.4.3 Multi-sectional manifolds

3.2.4.4 Connection to turbochargers

3.2.4.5 Torques

- Manufacturer's specifications
- Sequence
- Special requirements.

Learning Outcome 4: Explain boost pressure tests for the inlet manifold of a turbocharged Diesel engine.

Assessment Criteria

4.1 Explain the components used and the purpose of boost pressure tests conducted on the inlet manifold of a turbocharged Diesel Engine

4.1.1 Pressure gauge

4.1.2 Compound pressure gauges

4.1.3 Differential pressure gauges

4.1.4 Calibration of gauges

4.1.5 Water manometer

4.1.5.1 Filling

4.1.5.2 Cleaning

4.1.5.3 Reading

4.1.6 Conversion of kPa or PSI to inches of Mercury (inHG)

4.1.7 Inlet restrictions

4.2 Explain the procedure for conducting inlet manifold pressure tests on a turbocharged Diesel Engine

4.2.1 Inspect for intake and exhaust system blockages

4.2.2 Connection of the pressure groups to the engine

4.2.3 Running the engine

4.2.4 Recording the value and compare to manufacturer's specifications

4.2.5 Disconnection of test equipment

4.2.6 Exhaust back pressure

4.3 Explain the procedures for testing exhaust noise and emissions

4.3.1 Dba analyser

4.3.1.1 Components

4.3.1.2 Operation

4.3.1.3 Test procedure

4.3.2 Exhaust gas analyser

4.3.2.1 Components

4.3.2.2 Operation

4.3.2.3 Test procedure.

Learning Outcome 5: Inspect and test an exhaust system on a Diesel Engine.

Assessment Criteria

5.1 Visual inspect an exhaust systems and check for:

5.1.1 Pipework

5.1.2 Flanges

5.1.3 Mufflers

5.1.4 Spark arrestors

5.1.5 Mountings

5.1.6 Exhaust system restrictions are identified

5.2 Noise and emission control tests

5.2.1 Tests are conducted according to manufacturer's specifications

5.2.2 Results are recorded

5.3 Exhaust system faults are identified and recommended repair action is submitted

5.4 Facilitators are to ensure that the tasks are completed:

5.4.1 Without causing damage to components or equipment

5.4.2 Using appropriate tooling, techniques and materials

5.4.3 According to industry/enterprise guidelines, procedures and policies

5.4.4 Using and interpreting correct information from the manufacturer's specifications.

Learning Outcome 6:

Remove, disassemble, inspect, assemble and refit a turbocharger fitted to a Diesel Engine.

Assessment Criteria

6.1 Conduct

- 6.1.1 Visual checks on the air inlet and exhaust system
  - 6.1.1.1 Intake scoop
  - 6.1.1.2 Prefilters
  - 6.1.1.3 Filters
  - 6.1.1.4 Pipework
  - 6.1.1.5 Elements
  - 6.1.1.6 Hoses
  - 6.1.1.7 Clamps
  - 6.1.1.8 Mounts
- 6.1.2 Functional tests of turbocharger and exhaust system
  - 6.1.2.1 Test equipment used to determine inlet system restrictions
- 6.1.3 Removal of turbocharger
- 6.1.4 Disassemble turbocharger
- 6.1.5 Inspect turbocharger components
- 6.1.6 Repair action identified
- 6.1.7 Assemble turbocharger
- 6.1.8 Refit turbocharger to engine
- 6.1.9 Function test

6.2 Facilitators are to ensure that the tasks are completed:

- 6.2.1 Without causing damage to components or equipment
- 6.2.2 Using appropriate tooling, techniques and materials
- 6.2.3 According to industry/enterprise guidelines, procedures and policies
- 6.2.4 Using and interpreting correct information from the manufacturer's specifications.

TABLE OF CONTENTS

REVIEW MATERIAL

Intake and Exhaust Systems

REVIEW OF FOUR STROKE CYCLE

Intake Stroke

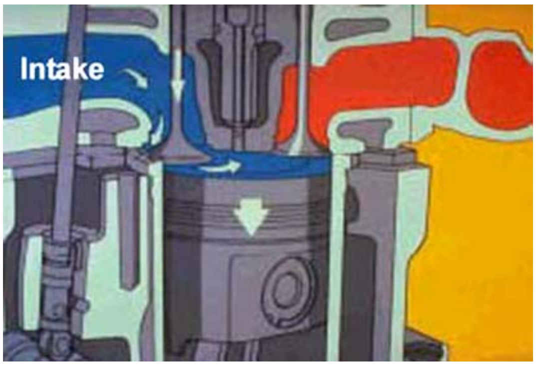

Figure 1

Air flows through the intake ports in the cylinder head. On the intake stroke (Figure 1), the inlet valve opens just before the piston starts to travel down the cylinder and air will then flow into the cylinder.

Compression Stroke

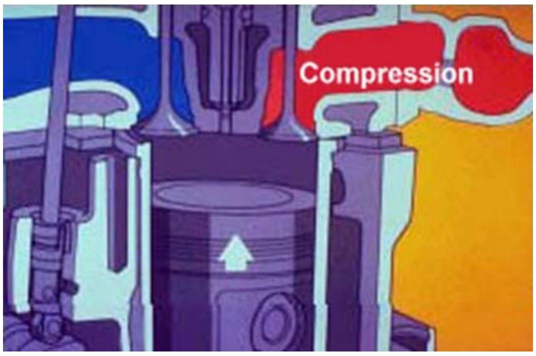

Figure 2

On the compression stroke (Figure 2), the piston is travelling upwards and both intake and exhaust valves are closed. The air that is trapped in the cylinder is therefore compressed. Compressing the air raises it's temperature to a level where the fuel will ignite when it is injected into the cylinder.

Power Stroke

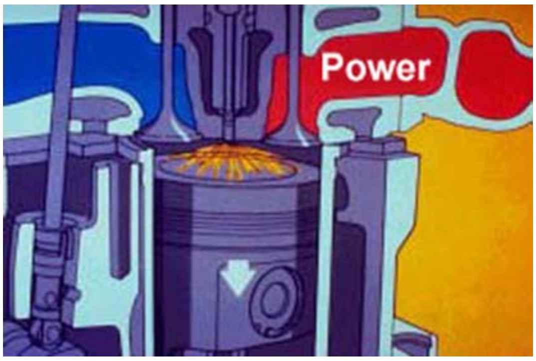

Figure 3

When the piston nears the top of it's travel (Figure 3), fuel is injected into the cylinder as a fine mist, as a result of the very high pressure developed in the injector. The fuel mixes with the hot air and ignites. This type of combustion process is the reason why the diesel engine is also referred to as a "compression ignition engine".

The energy produced by combustion forces the piston down to produce the power.

Exhaust Stroke

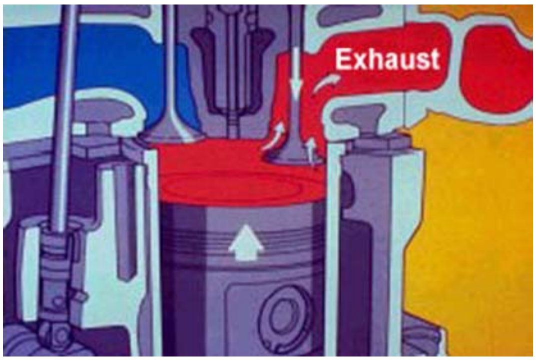

Figure 4

Near the end of the power stroke (Figure 4), the exhaust valve opens. The upward movement of the piston will force the hot gas into the exhaust manifold. Near the top of the exhaust stroke, the exhaust valve closes and the inlet valve opens in preparation for the cycle to be repeated.

It takes two crankshaft revolutions for the completion of the four stroke cycle, for each cylinder in the engine.

Purpose of intake and exhaust

Diesel engines require sufficient quantities of air to burn the fuel.

Air induction systems must provide enough clean air for combustion. The design of the air induction system must be adequate to prevent leakages into the systems & minimise restrictions. The exhaust system must remove heat and combustion gases, and provide for efficient operation of turbochargers, where used. Any reduction in the flow of air or combustion gases through the systems reduces engine performance. The exhaust system discharges spent gases to the atmosphere.

Internal combustion engines require sufficient quantities of air to burn the fuel. Air induction systems must provide enough clean air for combustion.

The design of the air intake system should ensure air leakage does not occur & ensure minimum restriction to air flow.

The purpose of the exhaust system is to remove the spent combustion gases from the engine & discharge them into the atmosphere. The design of the system must ensure that there is minimum restriction to gas flow & ensure that the noise level is reduced to satisfy appropriate standards.

Excessive exhaust pressure has a detrimental effect on engine performance in that more work has to be expended on pushing the exhaust out of the engine so less is available for useful work. This becomes apparent as a loss of power & an increase in fuel consumption. Another indication of increased exhaust back pressure is higher than normal coolant temperature because of increased cooling required due to higher pressure & temperature of the exhaust gases.

TYPES OF SYSTEM

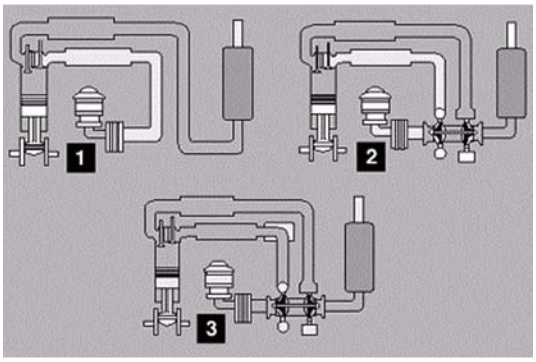

Figure 5

There are three types of air induction systems (Figure 5):

1. Naturally aspirated

   Air intake systems that have neither a tubocharge or aftercooler are known as naturally aspirated or “NA” systems. These types of systems are rarely used on present day diesel engines.

   The system relies on the downward movement of the piston, to draw in air through the air intake system.

2. Turbo-charged

   These systems are known as “T” systems. The exhaust gas drives a pump known as a tubocharger, which causes air to be forced into the engine under pressure.

3. Turbo-charged and after-cooled

   Presently in Caterpillar machine, these systems are the most common. These systems are known as “TA” systems and have a turbocharger & after cooler. Different types of aftercooler can be used.

TOPIC 1

Naturally Aspirated Intake and Exhaust Systems

COMPONENTS AIR INTAKE

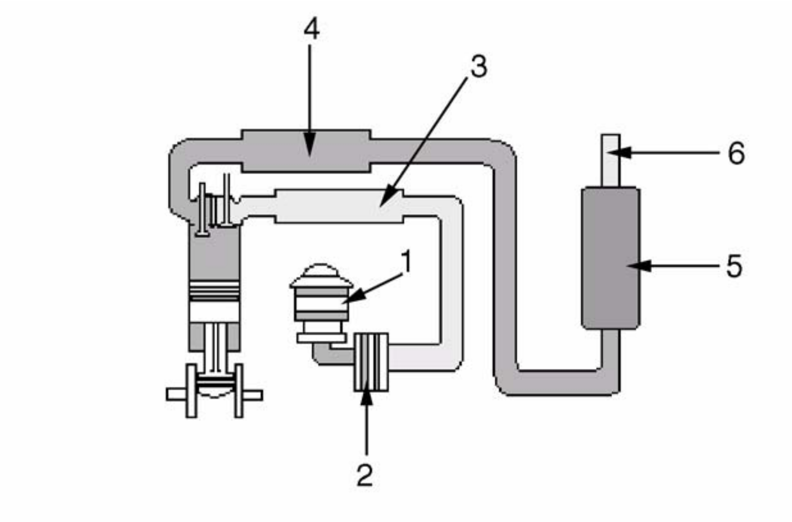

Figure 6

1. Pre cleaner
2. Air cleaner
3. Intake manifold
4. Exhaust manifold
5. Muffler
6. Exhaust stack.

PURPOSE OF INTAKE SYSTEM

Diesel engines require sufficient quantities of air to burn the fuel.

Air induction systems must provide enough clean air for combustion. The design of the air induction system must be adequate to prevent leakages into the system & minimise restrictions. Any reduction in the flow of air or combustion gases through the Air Intake system reduces engine performance.

Pre-cleaner

Figure 7

Many engines use a pre-cleaner. The pre-cleaner is located before the inlet to the main air cleaner (Figure 7). The purpose of the pre-cleaner is to collect much of the dirt or contaminants before the air cleaner. This increases the service life of the air cleaner.

The simplest type of pre-cleaner is a mesh cap at the top of the air filter housing inlet.

Donaspin Pre-cleaner

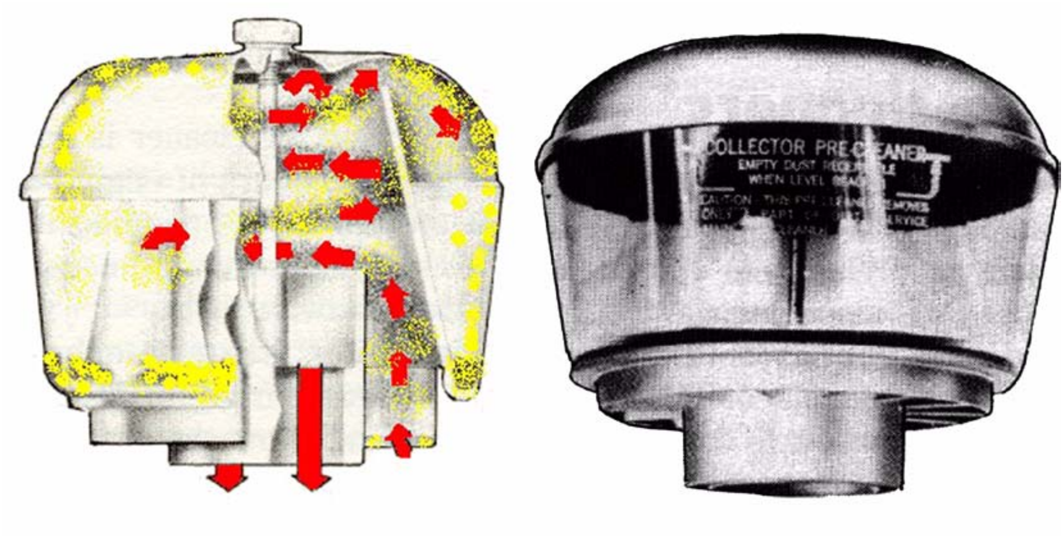

Figure 8

The Donaspin pre-clear (Figure 8) is designed to remove heavy containments from incoming air. The contaminants will then spiral out by centrifugal force, hitting the clear cover and falling to the bottom, where it builds up to the fill marker and will need to be emptied by the service personnel or operator.

Cyclone Tube Exhaust Dust Ejected Pre-cleaner

Figure 9 - Cyclone Tube Exhaust Dust Ejected Pre-cleaner

On earthmoving machinery pre-cleaners are often exhausted through the muffler using the pulsing pressure differences created by the exhaust system (Figure 9).

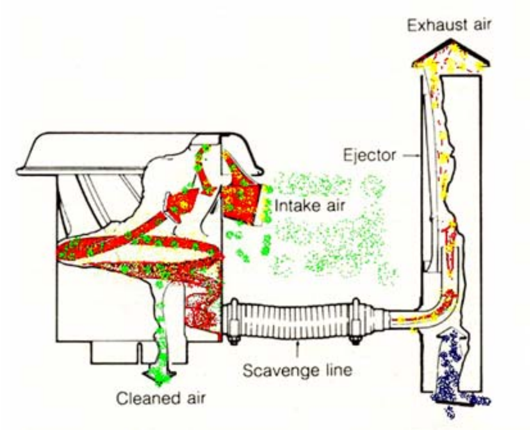

Figure 10

The advantage of this system over a conventional pre-cleaner includes the use of a low pressure scavenging line vented in the exhaust pipe (Figure 10). The particles are carried out into the exhaust, therefore no mechanical maintenance is needed to clean out the pre-cleaner system.

Donaldson Fin Cyclopac

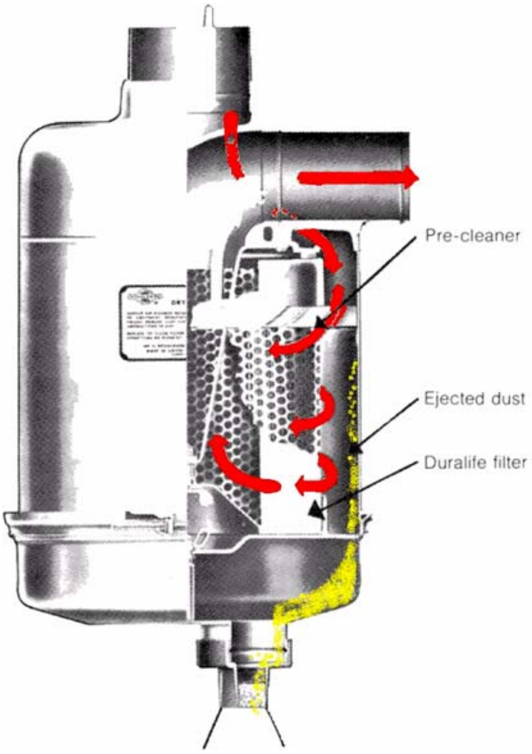

Figure 11

In the Donaldson Fin Cyclopac pre-cleaner (Figure 11), inducted air is forced to move around the steel casing of the filter assembly by the plastic fins of the filter element. This creates a swirling movement, forcing the heavy particles to the outside by centrifugal force. The heavy particles are forced out to the steel casing where they fall down to the base of the unit and are expelled via the lower flap.

Donaldson Donalcine SBG

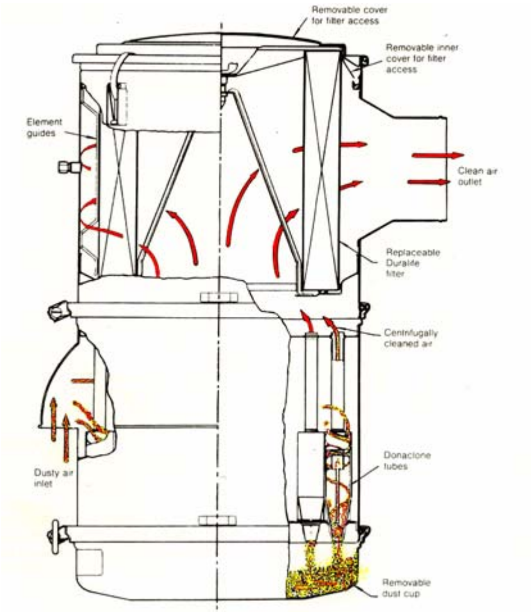

Figure 12

In a Donaldson Donacline SBG pre-cleaner (Figure 12) veins inside the tube impart a cyclonic twist inside the unit, causing the heavy particles to be thrown to the outside, which then fall to the bottom of the unit, known as the dust cup. This dust is expelled by the vacuum valve, or manually by opening the cover, i.e. like on 789 Off-Highway Trucks.

Dust Tubes

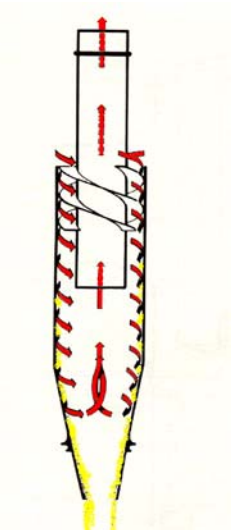

Figure 13

Here is a close-up view of how the dust tubes work (Figure 13). With the air coming in at the side, and being drawn down to the bottom, and then sucked up the middle intake tube with the heavy particles being cyclonically removed from the air and dropped to the bottom to be collected in the dust cup.

Another type of pre-cleaner that is used on Caterpillar equipment is a spirally fanned drum. The vanes cause the incoming air to spin.

Because the dirt that is drawn in is heavier than the air, the dirt is forced to the outside due to the spinning action. The dirt then falls into a collection bowl, and the partially cleaned air flows down the centre tube to the air cleaner.

Pre-cleaners should be inspected and emptied on a daily basis.

Vacuator Valve

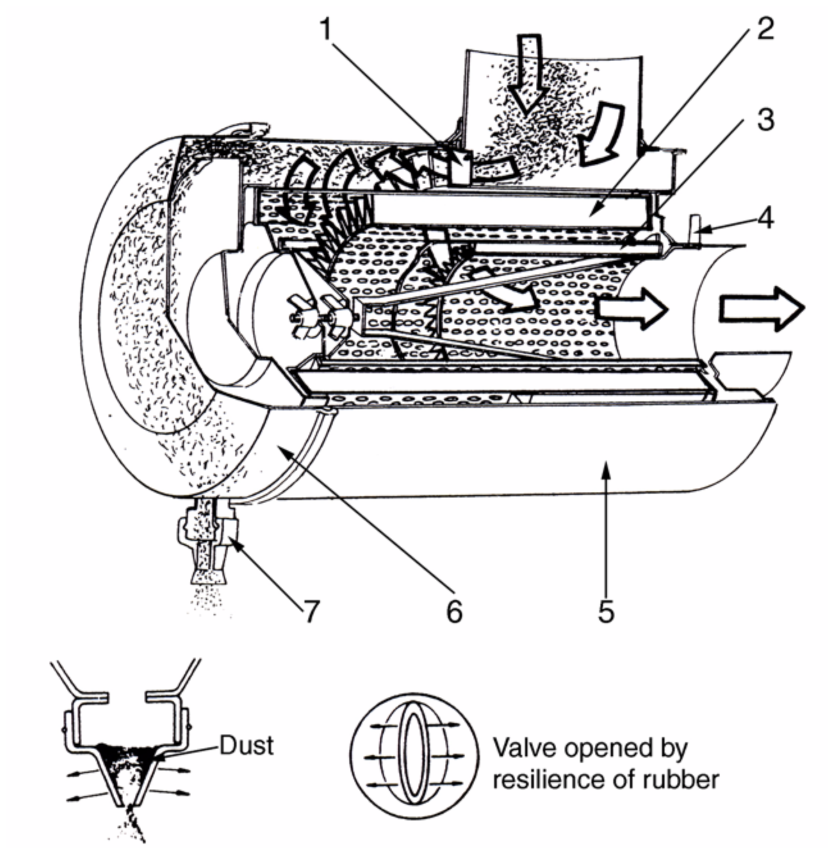

Figure 14

1. Pre-cleaner fins
2. Outer air cleaner element
3. Inner or safety air cleaner element
4. Connection for service indicator
5. Air cleaner housing
6. Dust cap
7. Vacuator valve.

The installation of a vacuator valve on the dust cup will eliminate the need for regular dust cup service, as this valve will automatically eject dust and water. The vacuator valve is made of rubber and fits on to the bottom of the dust cup, as shown in Figure 14. Even though the dust cup is normally under a slight vacuum when the engine is running, pulsing of the vacuum opens and closes the valve, expelling dust and water. The vacuator valve will also unload and expel dust when the engine is stopped.

Air Cleaner

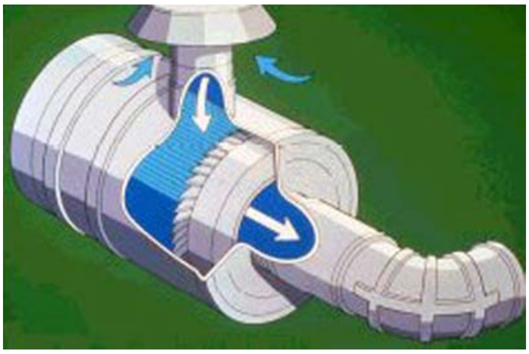

Figure 15

Air Cleaner or filter Air Cleaner Air is drawn into the engine through the Air Cleaner (Figure 15). The air cleaner houses a filter element that removes smaller foreign material from the air before it enters the engine. There are several different types of air cleaners currently available on Caterpillar engines.

The assembly shown in Figure 15 contains a simple vane structure that spins the air and ejects particles by cyclone effect to the bottom of the housing. A pulsating rubber assembly ejects the particles.

NOTE:
Always refer to the operation and maintenance manual of the engine for the most accurate maintenance procedures.

Dry Air Cleaner Element

Figure 16 - Dry Element Air Cleaner

Dry element air cleaners (Figure 16) are by far the most common type of air cleaners used on Caterpillar engines. Dry element air cleaners are typically composed of a pleated paper filter media that is used to remove the dirt from the incoming air.

Figure 17 - Dry Element Cleaning

Dry element air cleaners (Figure 17) can usually be cleaned with filtered, dry air with a maximum pressure of 207 kPa (30 psi). The element should be cleaned from the clean side out, holding the tip of the air nozzle parallel to the pleats of the air cleaner.

NOTE:
Most mine sites have banned the act of cleaning filters with an air blower. Some companies offer cleaning and / or exchange elements that have been serviced.

NOTE:
When conducting this operation, be sure to wear safety glasses and breathing mask.

Heavy-duty air cleaners, as used on construction machines, also contain a safety or secondary element inside the primary element, in case the primary fails and to increase air cleaning efficiency.

Without the use of a secondary element, major engine damage would result from dirt ingestion, should the primary element fail.

For this reason it is essential to ensure that the intake manifold is always sealed.

Caterpillar Air Filter with a New Radial Seal

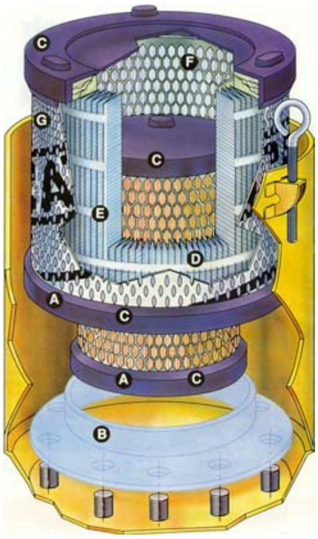

Figure 18

A. Radial seal design
B. All steel adapter ring
C. One-piece moulded urethane end caps with integral seal
D. Densely pleated filter paper
E. Built-in pleat support and positive pleat spacing
F. Heavy-duty metal inner and outer wrap
G. Baked-on enamel outer filter wrap.

Air Cleaner Service

Figure 19 - Typical Twin Air Cleaner, each with its own Service Indicator

Engine air cleaners should be serviced on a regular basis. Many air cleaners are equipped with a service indicator (Figure 19). The indicator monitors the amount of restriction through the air cleaners. The service indicator is the most accurate method to use to determine when the air cleaners are in need of service.

Dial Indicator

Figure 20

A dial indicator (Figure 20) can have colours of green and yellow for indication. Red indicates high vacuum reading in inches of water.

Filter Indicator

Figure 21

When the yellow indicator has reached the red zone of the filter indicator (Figure 21), it is time to replace the air cleaning element.

Operating Conditions

Figure 22

Operating conditions will dictate when the air filter service limit / period needs to be done either more or less regularly, depending upon conditions (Figure 22).

Figure 23

Before servicing the air system:

- turn the engine off, and place a danger tag on the ignition (Figure 23)
- remove the air cleaner element, blocking off the intake tube
- clean old element away from intake of engine
- check for any faults in filter element, i.e. by the way of a light
- reset the air filter indicator.

Engine air cleaner elements should be serviced, cleaned or replaced, when either the yellow diaphragm enters the red zone or the red piston locks into the visible position, which means that the service indicator has tripped. Cleaning entails washing with air, water or detergent.

Over-servicing can be bad too. Air cleaning can be an environmental issue, as silicon dust can be spread.

EXHAUST SYSTEM

Purpose of the Exhaust System

The purpose of the exhaust system is to remove the spent combustion gases from the engine & discharge them into the atmosphere. The design of the system must ensure that there is minimum restriction to gas flow & ensure that the noise level is reduced to satisfy appropriate standards.

COMPONENTS EXHAUST SYSTEM

Inlet Manifold

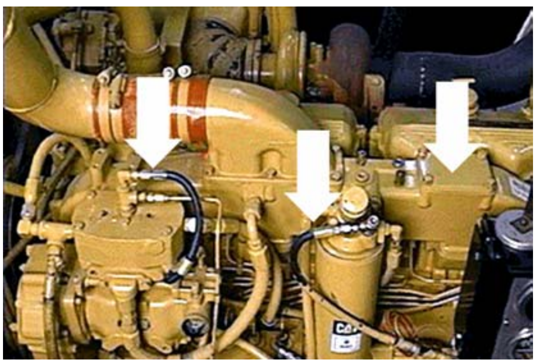

Figure 24

From the air cleaner and turbocharger/after-cooler, if equipped, the incoming air enters the inlet manifold (Figure 24) and is directed to the inlet ports for each cylinder.

Exhaust Manifold

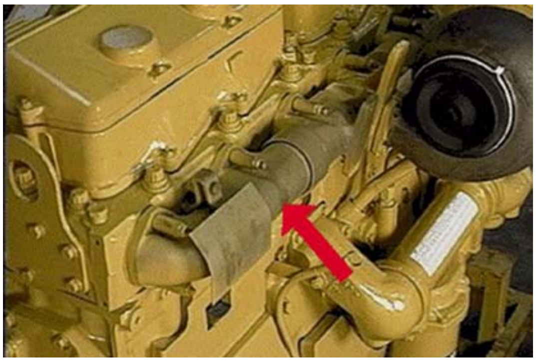

Figure 25

Exhaust gases, leaving the cylinder through the exhaust ports, enter the exhaust manifold (Figure 25) and are then routed to the exhaust system.

Mufflers

Mufflers or silencers are used in the exhaust system to reduce the level of exhaust noise by the use of internal baffling. Whenever gas flows through a muffler, its velocity decrease and pressure increase. The more effective the silencing, the greater the back-pressure in the system. Therefore, muffler selection by the engine manufacturer is a compromise between noise reduction and back-pressure increase.

The two most commonly used exhaust mufflers are the straight-through and reverse-flow types.

Straight-through muffler

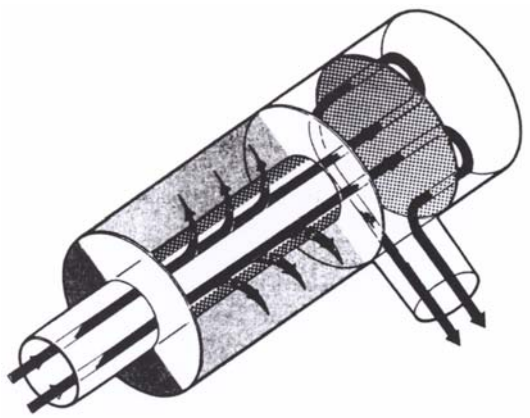

Figure 26

The straight-through muffler design, as shown in Figure 26, carries the exhaust gas straight through the muffler via a perforated tube, which is surrounded by a sound-absorbing material. The vibrating exhaust gas passes through the holes in the perforated tube and penetrates into the sound-absorbent material — generally metal shavings or glass wool. This process lowers the frequency of the gas vibrations, which lowers the pitch of the exhaust sound. There is very little back-pressure with this design of muffler, which makes it suitable for use on two-stroke diesel engines that operate on the Kadency principle of exhaust scavenging.

Reverse-flow muffler

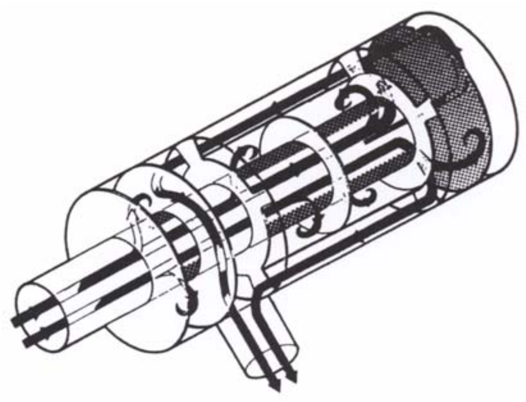

Figure 27

The reverse-flow muffler, as shown in Figure 27, helps to reduce sound levels by channelling the exhaust gas back and forth through expansion chambers within the muffler. The effect of this is to reduce the pressure and temperature of the gas as it passes through baffles and tubes where its turbulence dies out and noise levels are reduced. The degree of noise reduction in reverse-flow mufflers can be varied by the size of the expansion chambers within the muffler. When comparing the two muffler designs, the reverse-flow type can achieve the lowest noise levels.

Spark arrester muffler

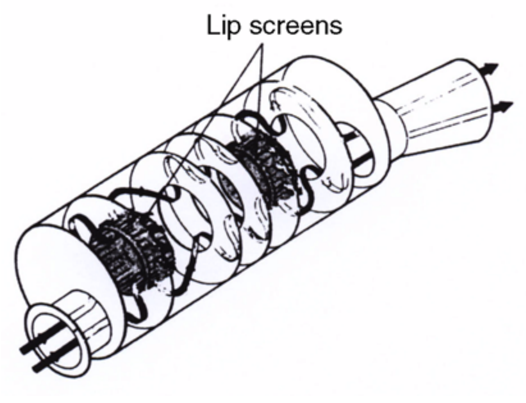

Figure 28

The reverse-flow muffler can be varied in its design so as to act as a spark arrester for engines operating near combustible material. This type of muffler is therefore dual purpose in that it acts as a sound-suppressing unit as well as extinguishing any burning pieces of carbon which may be present in the exhaust gas. With reference to Figure 28 the spark arrester inserts, so-called ‘lip screens’. When the exhaust gases flow through these screens, they cause the screens to rotate, thereby forcing any sparks towards the muffler outer jacket, where they are extinguished.

On some underground mining equipment, special provision is made to eliminate sparks in high fire-hazard areas. The design of muffler used on such equipment is a wet type which allows the exhaust gas to mix with water as it goes though the exhaust system and, in so doing, quench sparks, cool the exhaust and lower the sound levels.

Catalytic Converter

Catalytic converters are fitted in the exhaust system the same way as mufflers. They are used on petrol vehicles, which use unleaded fuels to reduce emissions. They are not used on diesel engines.

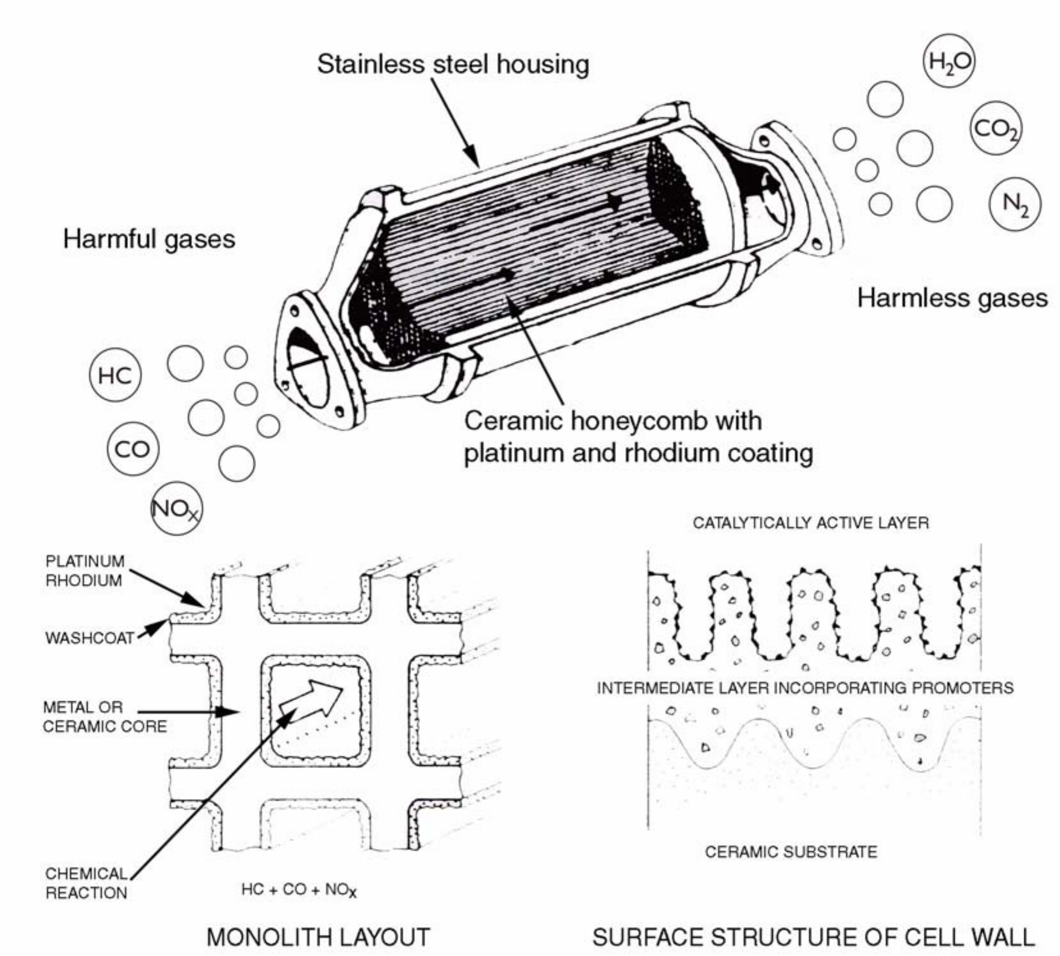

Figure 29

The converter (Figure 29) is a honeycomb structure chemically coated with thin deposits of Platinum and Rhodium. These elements act as a catalyst for a chemical reaction to take place that will convert harmful gases into harmless ones. The reaction has no effect on the materials in the converter during normal operation.

The converter must never be used with leaded fuels because the converter would become contaminated and rendered useless. To operate correctly, the converter must not be overheated with incorrect fuel ratios or misfires.

The converter converts three pollutant gases into harmless ones.

Carbon Monoxide is converted to Carbon Dioxide.

Hydrocarbons are converted to water.

Oxides of Nitrogen are converted to Nitrogen.

Exhaust Back Pressure

Exhaust back pressure is the pressure created in the exhaust manifold due to the restriction to the flow of the exhaust gases as they flow through the muffler and exhaust piping. Increased back pressure in the exhaust system can be caused by a partially blocked muffler, incorrect exhaust pipe sizing, too long an exhaust pipe, too many bends in the pipe or a restriction in the pipe.

The least amount of exhaust back pressure is desirable to maximise engine efficiency. Too much back pressure causes exhaust overheating and significant power loss.

To measure exhaust back pressure a water filled manometer is recommended for maximum accuracy or for a general guide, a low pressure gauge can be used. Measurement should be taken with the engine running at full load (maximum fuel) condition. The normal measurement point is in the elbow outlet from the turbocharger.

The general specified maximum amount for Caterpillar turbocharged diesel engines fitted to machines is 27 inches (686 mm) of water or 6.75 kpa and 34 inches water (864 mm) or 8.5 kpa.

Australian Design Rules (ADR)

There are laws covering the construction of heavy vehicles. These laws place responsibility on the vehicle and component manufacturers, vehicle dealers, mechanics and operators. The ADR's which relate to vehicle noise and emissions are identified below.

ADR 28 for motor vehicle noise.

The intention of this ADR is to define limits on external noise emitted from motor vehicles in order to limit the contribution by motor vehicles to community noise.

This ADR applies to diesel powered heavy vehicles.

ADR 28A for motor vehicle noise.

This ADR is a later revision of ADR 28A and reduces the noise emission requirements.

ADR 30 for diesel engine exhaust smoke emission.

The intention of this ADR is to limit the opacity (density and colour) of diesel engine smoke emissions.

ADR 36 for diesel engine pollution.

The intention of this ADR is to limit emissions from motor vehicles in order to reduce pollution.

Exhaust Stack

Figure 30

The exhaust stack (Figure 30) connects directly to the muffler & carries exhaust gases into the atmosphere, away from the operators compartment.

Some models use exhaust stacks that are fitted with a rain trap. This rain trap prevents rain entering the engine via the muffler & turbocharger when the machine is parked. Exhaust pressure forces the trap open when the machine is operating.

TOPIC 2

Forced Air Intake System

VOLUMETRIC EFFICIENCY

There are many ways to increase engine output. Engine output, for a given engine cylinder size, is determined by the amount of fuel mixture that is burnt during each combustion stroke. Therefore, the most effective method of increasing an engines output is to get more fuel/air mixture into the cylinders. An effective means of achieving this aim is by applying a positive pressure, or forcing the air into the combustion chamber. This is accomplished by turbocharging or supercharging, which increases the volumetric efficiency of the engine.

Volumetric efficiency can be defined with the following formula.

$$VE = \frac{\text{Airflow (metres cubed per minute) x 2000}}{\text{Displacement (litres) x rpm}}$$

A well designed, naturally aspirated, four stroke, overhead valve, diesel engine has a volumetric efficiency of approximately 85%.

A turbocharged or supercharged diesel engine has a volumetric efficiency of approximately 130%.

In other words, turbocharging or supercharging allows the designer to achieve more power output from a smaller engine. Additional benefits are increased fuel efficiency, a more complete combustion and reduction of the production of pollutants.

COMPONENTS

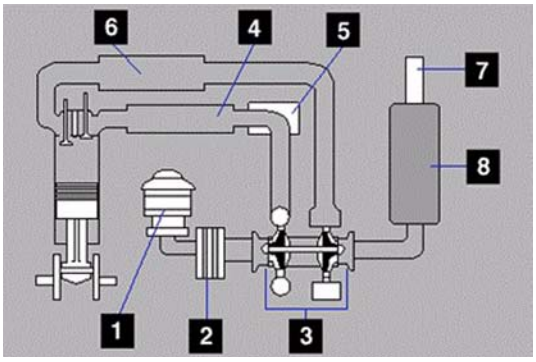

Figure 31

The air induction and exhaust system contains the following components (Figure 31), in addition to pipework:

1. Pre-cleaner

2. Air cleaner

3. Turbocharger

4. Intake manifold

5. After-cooler

6. Exhaust manifold

7. Exhaust Stack

8. Muffler.

FUNCTIONS

- Normalize air supply
- Boost air supply.

Turbo functions:

Turbochargers serve two functions, normalizing air supply and boosting air supply to engines.

Normalizing means keeping air supply the same as is normal for a naturally aspirated engine at sea level. When engines operate at altitudes above sea level, the air becomes less dense, and a turbocharger is needed to gather in more of the thinner air. If normalization is not maintained, the fuel settings must be decreased when the air becomes less dense to avoid over-fuelling the engine. Thus, normalizing allows engines to develop normal horsepower over a broad range of altitudes.

Some turbochargers have what is called a "waste gate", which bypasses exhaust gases around the turbo when boost reaches a specified pressure. This allows the engine to be operated at various altitudes and yet maintain a stable, normalized air supply.

The technician should be aware that while turbochargers can concentrate thinner air at higher altitudes to give normal oxygen supply and normal power, higher turbo speeds are required to do so. Thus, for operation above about 2,100 meters (7,000 feet) fuel de-rating is often suggested to avoid turbocharger overspeed.

Side benefits of using a turbocharger include quieter exhaust, better combustion, and cleaner emissions.

The second function of a turbocharger is boosting air supply to give the engine more than normal oxygen. This enables increased fuel settings while still providing better combustion and quieter exhaust. Improved combustion means not only better fuel economy, but also cleaner exhaust emissions.

Lubrication System

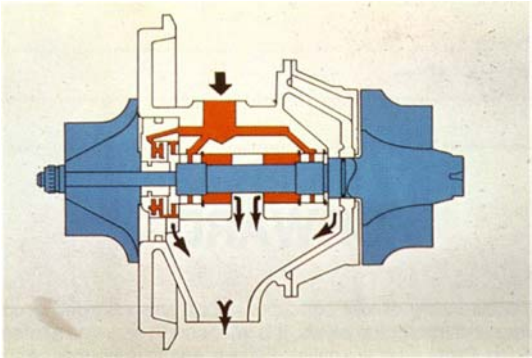

Figure 32

The lubrication system (Figure 32) is also vital to trouble free turbocharger operation because it performs three important functions: lubricating, cooling and cleaning. Interruptions of oil supply for only a few seconds can cause disastrous results. It is essential that sufficient quantity of oil continually flows through the turbocharger to provide suspension and stabilization of the full floating bearing system and to remove heat. There are many ways that lubricant can be restricted or lost before it reaches the turbocharger. The lubricant can contain large abrasive particles that can bridge the lubricant film and cause physical damage to rotating parts. Thus, not only must adequate lubricant quantity be present, but the lubricant quality must also be good. Before inspecting the failed turbo, gather basic quantity and quality facts about the lubrication system such as:

1. Type and viscosity of oil used

2. Oil level on the dipstick

3. Oil filter evaluation, includes opening and inspecting the paper

4. SOS oil sample

5. Operators comments about lube pressures or other problems prior to the failure.

Air Flow Restrictions

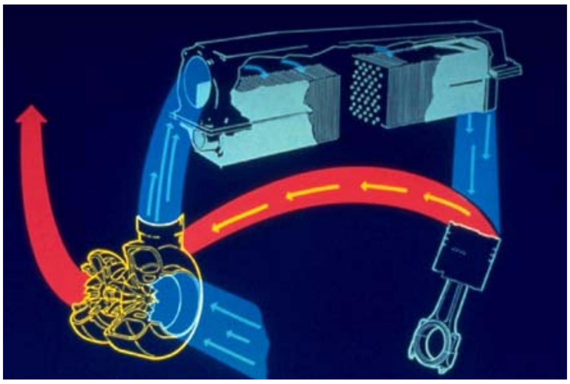

Figure 33

Air inlet and exhaust system problems account for many failures (Figure 33). For example, when air inlet restriction is too high:

1. Excessive end loading can occur and cause accelerated thrust bearing wear

2. Turbocharger RPM can increase significantly.

Abnormally high exhaust temperatures can cause marginal lubrication problems and metallurgical damage.

Foreign material can be introduced into the turbocharger from either the inlet or exhaust systems. Thus, the technician should always gather basic information about air inlet and exhaust systems when investigating turbo failures.

COMPONENTS

Turbochargers are free-spinning components, which often spin faster than 80,000 RPM. At peak RPM, journal bearing surface speeds can be greater than 30 meters (100 feet) per second, and the energy stored in rotating components can equal engine horsepower. These conditions demand near perfect balance and alignment of all moving parts, as well as proper operating and maintenance environments. Although problems with the turbo can cause failures, usually simple problems in the working environment, such as air inlet restriction, cause most failures.

Figure 34

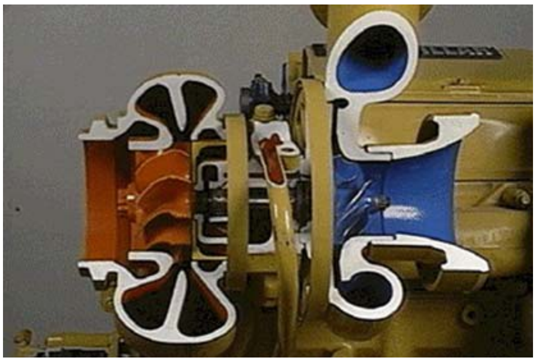

Figure 35

The turbocharger (Figure 34 & Figure 35) was invented by a Swiss named Buchi in 1906, and has been seen from time to time in various versions ever since. However, it is only in the past two decades that it has been developed to such a degree of reliability and performance that it is now being fitted to continually increasing percentage of new IC engines.

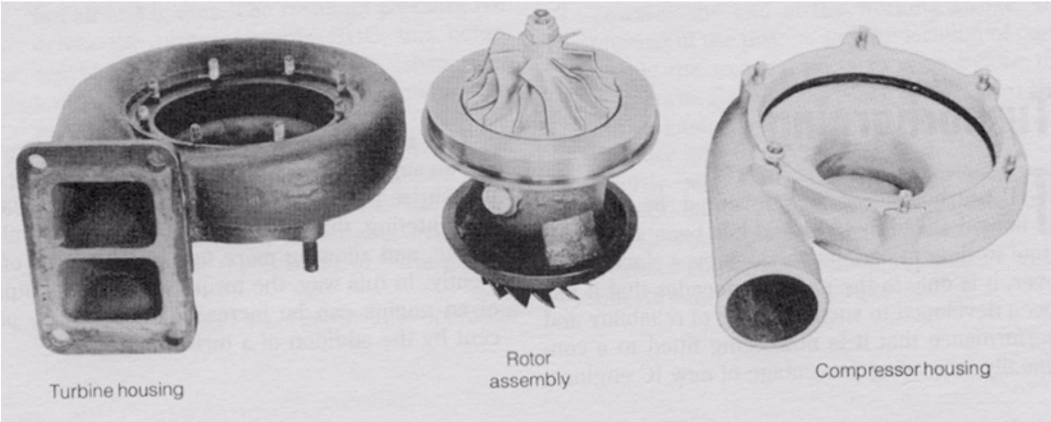

Figure 36 - Turbocharger sub-assemblies

The turbocharger is made up of three sections, the centre bearing housing assembly, the turbine housing (exhaust driven) and the compressor housing (intake side), as shown in Figure 36. The bearing housing contains two plain bearings, piston-ring-type seals, retainers and a thrust bearing. There are also passages for the supply and dumping of oil to and from the housing.

Cross Section

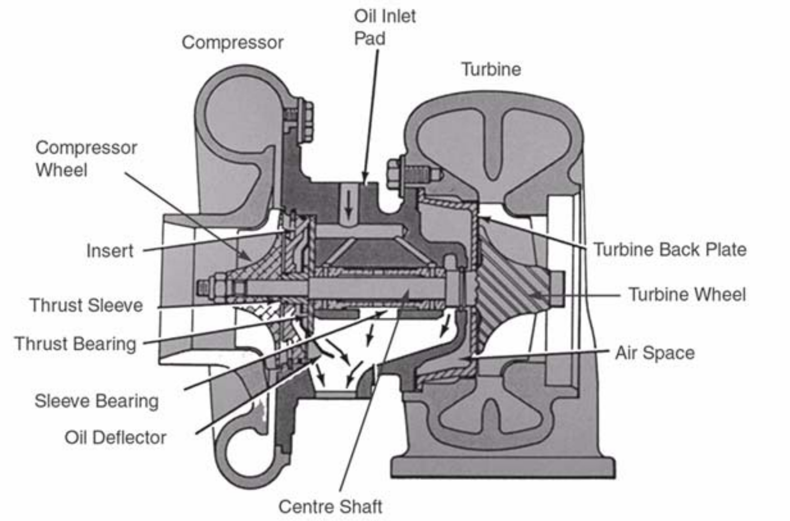

Figure 37 - Sectional view of a typical turbocharger

- Turbocharger structure is quite simple
  - Hot (exhaust) and cold (inlet) wheels are mounted on a shaft
  - The shaft is supported by journal bearings and thrust bearings
  - A heat shield keeps heat from the centre housing
  - Engine oil provides cooling as well as lubrication.

When assembled, the compressor wheel, the centre shaft, and the turbine wheel become one solid piece that turns in free-floating journal bearings. A stationary thrust bearing located near the compressor wheel controls endplay. Larger turbochargers have two separate journal bearings while some small ones have a single cartridge style bearing. Thrust washers are positioned on each side of the thrust bearing with a spacer in the middle. When the compressor wheel is installed, the retaining nut forces the wheel, the thrust washers and the spacer against the shoulder on the centre shaft, making all of the parts into a rotating assembly. All bearings ride on a cushion of oil during turbocharger operation.

The turbine back plate, or heat shield, and the air space behind it serve as insulators to keep high exhaust temperatures from penetrating the centre housing. Heat that is conducted into the centre shaft from the hot wheel is removed at the bearing near the turbine wheel by lubricating oil.

Thus, even though temperatures can be as high as 760 degrees C (1400°F) at the turbine wheel, normal temperatures are under 150 degrees C (300°F) at the journal bearing because of the cooling effect of the lubricating oil.

- Thrust bearings are quite easily damaged
- Good balance of parts is critical
- Perpendicularity and parallelism of parts is critical.

Rotating parts must be very carefully balanced. This means that both component balance and component assemblies must be correct. Component balance is the balance of each individual part about the part centreline. Component assemblies relates to the perpendicularity and parallelism of assembled components. Perpendicularity defines the squareness of surfaces relative to the bore, while parallelism defines the alignment of component end surfaces. If these two aspects are incorrect, when the compressor wheel nut is tightened the tensile load on the centre shaft will not be axial, bending of the shaft can occur, and serious unbalance can result. Thus, both individual component balance and component assembly must be very carefully controlled. During field reconditioning and repair these facts should be kept in mind and much care used when handling and assembling the rotating parts.

Welding and Hardening

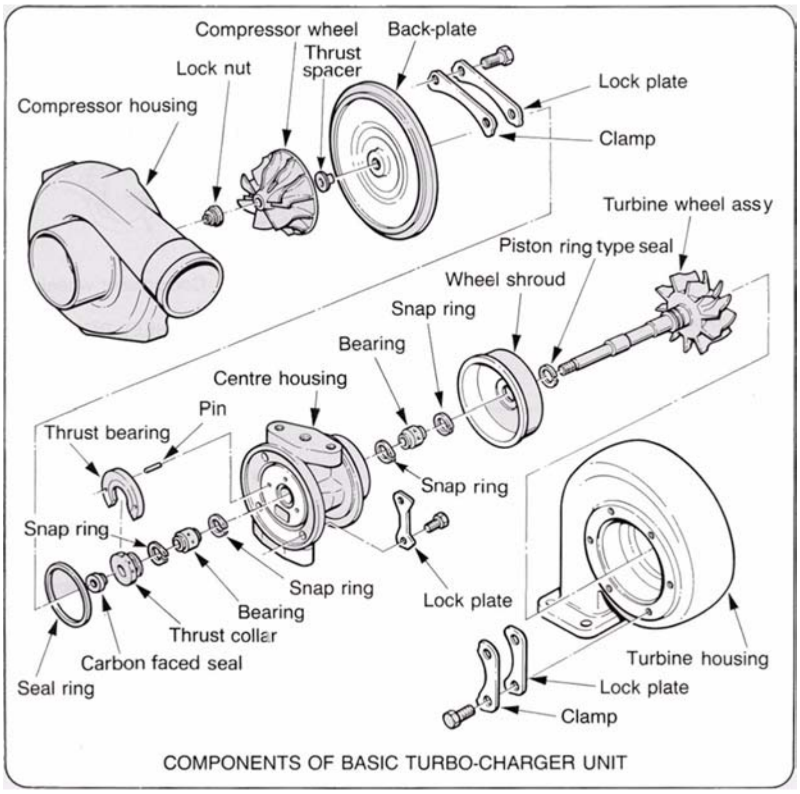

Figure 38

Centreshaft and Turbine Wheel

Turbo parts are made to withstand the heat and loads applied during operation. The shaft and turbine wheel may be welded together by:

- Inertial welds
- Electron beam welds.

  The centre shaft and turbine (hot wheel) are made separately and then welded together with one of two processes: friction welding or electron beam welding. The centre shaft and turbine wheel shown in Figure 38, are inertial welded (spin welded) together then straightened and balanced.

  Centre shafts are made from high strength steel that is very magnetic. After inertial welding to the hot wheel, the shaft is induction hardened where bearings fit to obtain about Rockwell C-55 hardness.

- Wheels are nonmagnetic and temperature resistant

  This shaft is not designed to withstand and should not be exposed to high temperatures.

  Turbine wheels are made of a cast nickel alloy containing over 10% chrome and less than 1% cast iron. This metal is essentially nonmagnetic and can withstand high temperatures without deterioration.

Compressor Wheels

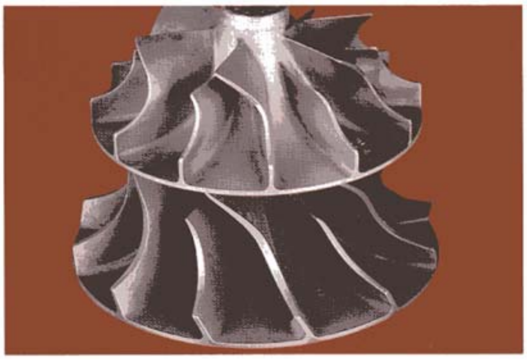

Figure 39

Compressor wheels are made from high quality, high strength aluminium alloys (Figure 39). Special care is taken in processing these alloys to prevent stringers and inclusions that could weaken the metal and cause cracks to start. This metal is not designed to withstand and should never be exposed to high temperatures.

Compressor wheel blade design can either be straight or back curved. Perhaps the easiest way to notice the difference is to compare the two (Figure 42). Notice the slope of the blades on the bottom wheel is more severe than the slope of the blades on the top wheel. The bottom wheel is a back curve design. When RPM increases, centrifugal force tries to straighten the back curved blades. Thus, as RPM increases and then decreases a cyclic bending load is placed on back curve blades, and the cyclic loading from centrifugal force is much more severe than the cyclic load from compressing air. It is cyclic loads that cause fatigue fractures. Blades must be designed to withstand these heavy cyclic bending loads as well as the lighter loading from compressing air.

The centre shaft hole is drilled using a special machine that calculates the precise location of the hole for the closest wheel balance. Sometimes material is removed from the nose of the wheel, near the drilled hole, for more exact balancing.

Journal Bearings

Figure 40

The free-floating journal bearings (Figure 40) can be made either from a copper/tin/lead alloy or from aluminium, depending on the turbo design. On older turbochargers, many bearings were completely saturated with lead, while newer bearings have a lower lead content. The lead acts as a lubricant during short periods of marginal lubrication (such as during startups). Some bearings have a thin tin flash over the copper/tin/lead alloy to increase lubricity on startups.

Bearing inside and outside diameters are carefully controlled to insure correct clearances and oil film thickness. Notice that some of the bearings have oil holes that are chamfered to remove any drilling irregularities and to allow free flow of oil as the bearing is spinning. Other bearings will have oil grooves on the sides.

Retaining Rings

Figure 41

Journal bearing retaining snap rings (Figure 41) are stamped from high strength steel. The stamping operation gives one side rounded edges, and the other side sharp edges. The smooth, rounded edge should always be installed toward the bearing to minimize abrasive contact.

Thrust Bearings

Figure 42

Thrust bearings (Figure 42) are made from copper/tin/lead and high strength aluminium alloys. Some are tin flashed to improve lubricity on startups, but most thrust surfaces bushings have a bronze appearance. Thrust bearings are stationary while adjacent thrust washers turn at full shaft RPM. Because of this, thrust bearings absorb more energy than any other turbo bearing and therefore are more sensitive to marginal lubrication, foreign material and abnormal end loading.

Some thrust bearings have drilled oil passageways as seen here to provide direct lubrication to the thrust contact surface.

Seal Rings

Figure 43

Hot side seal rings (Figure 43) are made from a high chrome alloy ductile iron that can resist high temperatures. Cold side seal rings are made from cast iron and should never be exposed to high temperatures. Both are carefully made to insure roundness, smooth surface finish, and adequate spring force. These aspects keep the seal ring from turning in the bore and from leaking. When seal rings are installed, end gap should be about 0.250 mm (0.010”) (refer to service manuals for exact specifications for a particular turbocharger).

Housings

Figure 44

The turbocharger housing (Figure 44) is made up of a compressor housing, centre housing and turbine housing.

Compressor housings are made of a cast aluminium alloy. Bore perpendicularity and parallelism are carefully controlled to insure uniform compressor wheel clearances (usually somewhat less than 0.250 mm (0.010”) refer to service manuals for exact specifications for each turbocharger). These housings are designed to withstand the forces of a high-speed compressor wheel separation.

Centre housings are made from cast iron and are normally not subjected to either high temperatures or high loads. Bore parallelism and perpendicularity are carefully controlled, as well as the inside diameter and surface finish where journal bushings fit.

Turbine housings are made of ductile irons or nickel alloyed ductile irons. These housings must withstand loads of any attachments at temperatures as high as 760^{o} C (1400°F) without creeping (permanently changing size or shape). The housings are also carefully machined to insure bore parallelism and perpendicularity and maintain uniform turbine wheel clearances.

Backing Plate

Figure 45

The turbine backing plate (Figure 45), or heat shield, acts as an insulator to protect the centre housing from high exhaust temperatures. The shield is made of ductile iron and provides insulation by creating a dead air space between the turbine wheel and the centre housing.

TURBOCHARGER LUBRICATION

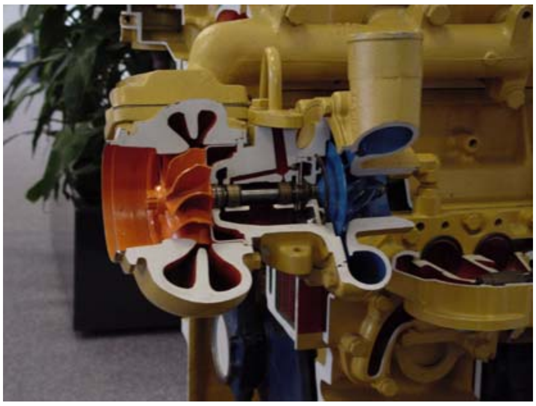

Figure 46

In most applications, turbochargers are lubricated by the lubrication system of the engine to which they are fitted (Figure 46). Oil under pressure from the engine oil pump enters the top of the bearing housing and flows around the shaft and to the thrust bearings and oil seals. The oil flows both inside and around the outside of the shaft bearings, which fully float in oil during operation. The oil also flows to the piston-ring-type oil seals at either end of the rotating shaft to aid in sealing and lubrication. The thrust bearing located at the compressor end of the rotating assembly is lubricated by the same oil before it leaves the bearing housing and flows back to the engine sump.

On large diesel engines such as those used in marine and power-generation applications, the turbocharger has its own oil reservoir in the main bearing housing and does not rely on engine oil for lubrication.

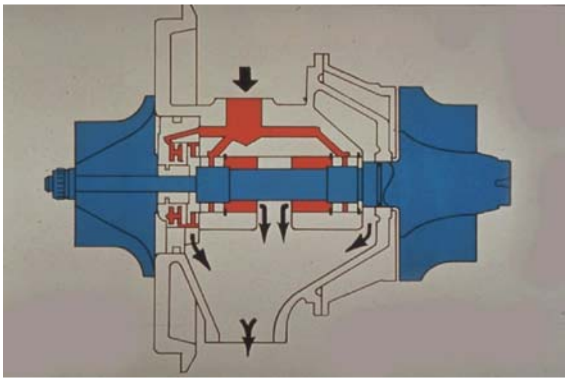

Figure 47

Continuous, clean oil supply is vital to good turbocharger performance.

The oil flow through the turbocharger is shown in Figure 47 above. Arrows show oil flow.

The lubrication system is also vital to trouble free turbocharger operation because it performs three important functions: lubricating, cooling and cleaning. Interruptions of oil supply for only a few seconds can cause disastrous results. It is essential that sufficient quantity of oil continually flows through the turbocharger to provide suspension and stabilization of the full floating bearing system and to remove heat. There are many ways that lubricant can be restricted or lost before it reaches the turbocharger. The lubricant can contain large abrasive particles that can bridge the lubricant film and cause physical damage to rotating parts. Thus, not only must adequate lubricant quantity be present, but the lubricant quality must also be good.

Exhaust Manifold

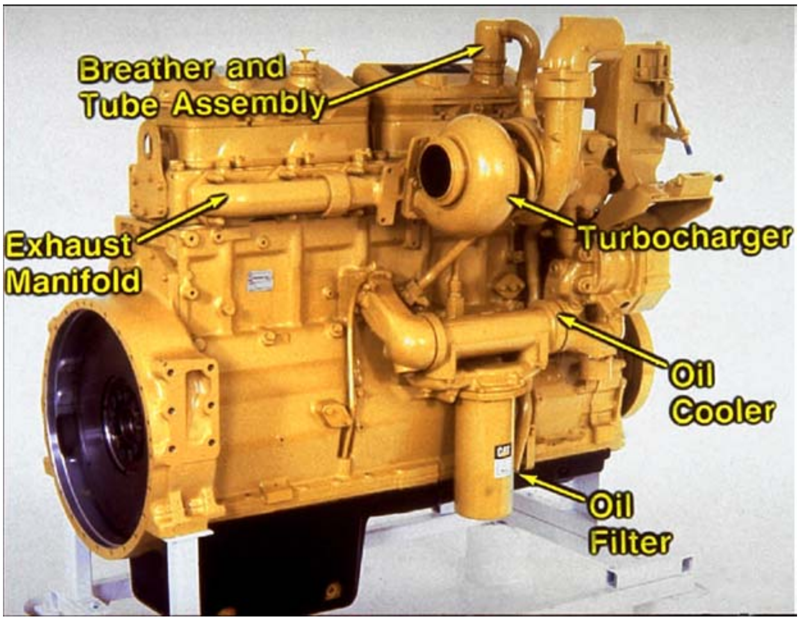

Figure 48

The exhaust manifold on turbochrged engines (Figure 51) is similar in construction to those on naturally aspirated engines. The significant difference on turbocharged engines is that the exhaust manifold is connected to the turbine housing of the turbocharger to direct the hot flowing gases to the turbine. The exhaust gases, are removed from the centre of the turbine housing via an elbow and then to the exhaust stack.

Wastegates

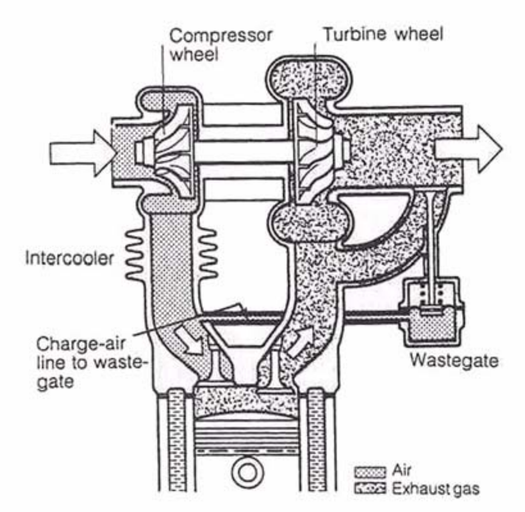

Figure 49

To control the boost pressure, the turbocharger is fitted with a wastegate, or bypass valve, which controls the turbocharger speed. The wastegate controls the flow of exhaust gas to the turbine wheel, and so controls the turbine speed. It can allow some gas to go to the turbine and some to go directly to the exhaust outlet. In this way, the turbine speed can be controlled.

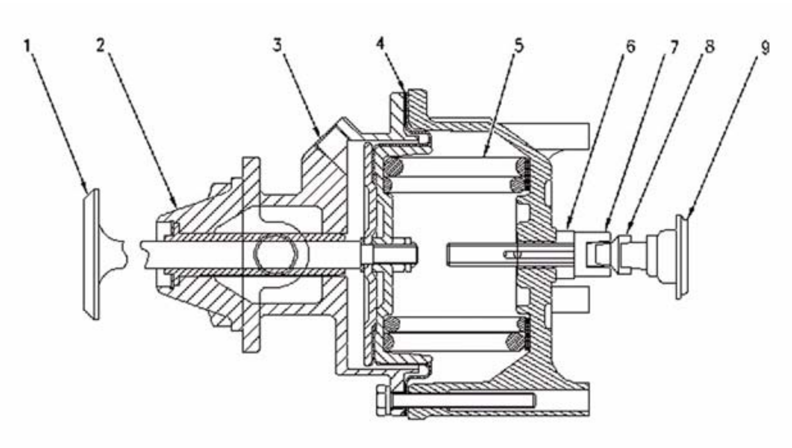

Figure 50

1 Valve
2 Water cooled base assembly with valve guide
3 Supply for inlet air
4 Diaphragm
5 Springs
6 Washers or spacer
7 Valve stop
8 Fitting
9 Breather.

A wastegate (Figure 50) primarily consists of a valve and a base assembly that is cooled by water from a cooler to the turbocharger. This base assembly contains the valve guide. When the valve is retracted into the base assembly, the wastegate is open. This allows exhaust gas to bypass the turbocharger. When the valve is extended to the normal position, the wastegate is closed. This prevents exhaust gas from bypassing the turbocharger.

Force from two springs extends the valve for the wastegate. Two forces try to open the valve. One force is based on the amount of air pressure behind the diaphragm. The second is the pressure of the spring.

After-Coolers

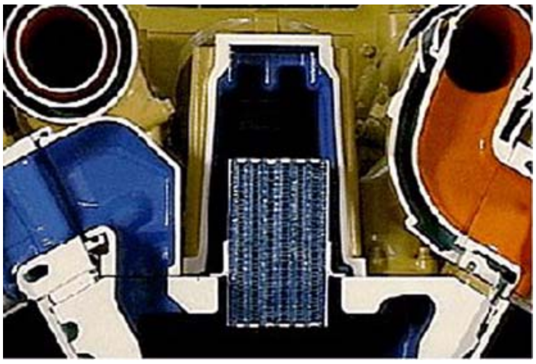

Figure 51

Aftercoolers (Figure 51) are fitted to high performance turbocharged or supercharged diesel engines and are in effect a heat exchanger.

After-coolers are used to cool the engine incoming air so that the volume of air available is increased.

Some engine manufacturers refer to the aftercooler as an intercooler.

Aftercoolers are required because intake air, which is compressed by either a turbocharger or supercharger, heats up due to the laws of physics.

Hot air occupies a larger space than cold air, therefore more air can be forced into the combustion chamber when colder.

Figure 52

There are two basic designs of after-cooler: one uses engine coolant for cooling of the intake air, (Figure 52) and the other uses the air flow by vehicle movement and cooling fan to create an air draft.

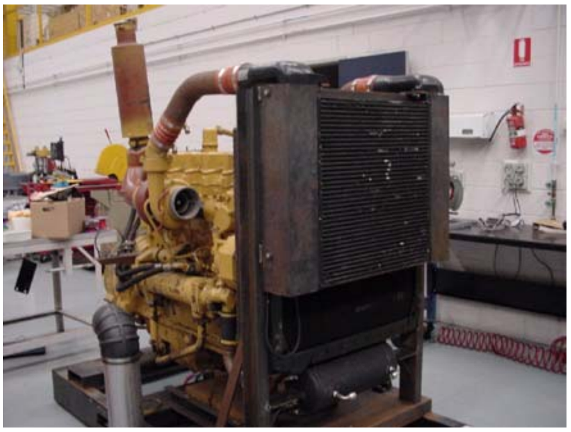

Figure 53

In the latter case, the after-cooler is positioned in front of the engine coolant radiator (Figure 53).

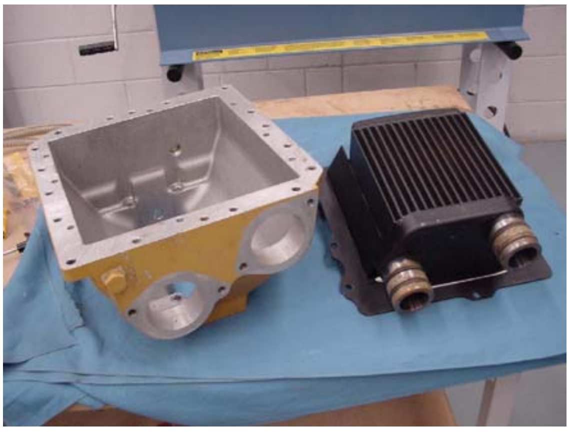

Figure 54

The core of the after-cooler, which uses engine coolant (Figure 54), appears similar to a compressed radiator core, with coolant flowing through the core and the intake air being blown across the fins, releasing heat to the coolant. Coolant taken from the bottom of the block enters the cooler core and then exits to the thermostat housing, where it will pass through the engine radiator. The core is a neat fit into the specially designed intake manifold.

Some machines use a separate aftercooler circuit, where a portion of the radiator is used only for aftercooler water. In this system, cooler water is normally available to cool the engine intake air.

TURBOCHARGER OPERATION

Figure 55

Turbochargers are free-spinning components, which often spin faster than 80,000 RPM. At peak RPM, journal bearing surface speeds can be greater than 30 meters (100 feet) per second, and the energy stored in rotating components can equal engine horsepower. These conditions demand near perfect balance and alignment of all moving parts, as well as proper operating and maintenance environments. Although problems with the turbo can cause failures, usually simple problems in the working environment, such as air inlet restriction, cause most failures.

In general terms, there are two types of turbocharger - the pulse type and the constant pressure type - each with its own operating characteristics. However, both operate in the same basic way.

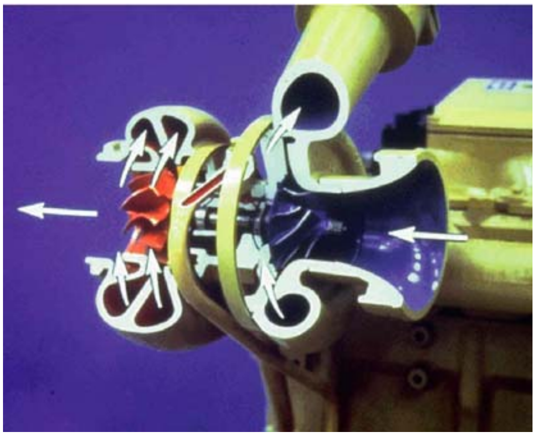

Figure 56 - Turbocharger Operation

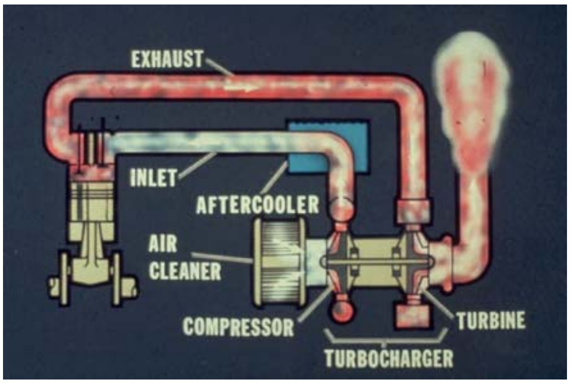

Figure 57

Exhaust gas from the engine passes through the exhaust manifold and into the turbocharger turbine housing, where it impinges on the turbine blades, causing the turbine, shaft and compressor wheel assembly to rotate.

The turbine wheel is connected by a shaft to the compressor wheel, and exhaust gases push the turbine and the compressor wheel to about 80,000 -130,000 RPM, depending on turbo design. This compresses the intake air.

When the load on an engine increases, more fuel is injected into the cylinders. The increased combustion generates more exhaust gases causing the turbine and compressor wheel to turn faster, forcing more air into the engine. The maximum RPM of the turbocharger is controlled by the fuel setting, high idle speed setting, height above sea level, and by the wastegate, where used (Figure 57).

As the compressor rotates, air is pressurised by centrifugal force and passes from the compressor housing to the engine inlet manifold, the quantity and/or pressure of the air being proportional to the speed of rotation.

Pulse Type

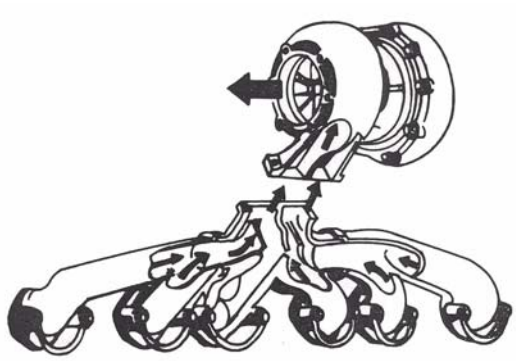

Figure 58 - Pulse-type exhaust manifold

The pulse-type turbocharger requires a specially designed exhaust manifold to delver high energy exhaust pulses to the turbocharger turbine. This design, with its individual branches as shown in Figure 58, prevents interference between the exhaust gas discharges from the separate cylinders, thus promoting a high-speed pulsing flow not achieved with other designs.

APLTCL001

Split Pulse

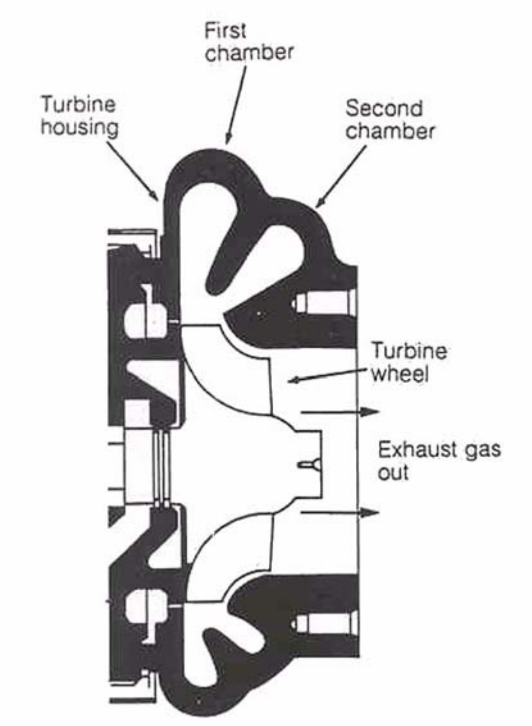

Figure 59 - Split-pulse turbine housing

In some applications, a split-pulse turbine housing can be used to further aid in the excitation of the rotating assembly. This design has two volute chambers instead of one. The term ‘volute chamber’ is used in reference to the spiral-shaped turbine housing, which decreases in volume towards its centre in the manner of a snail shell.

Each chamber receives half of the engine exhaust flow; for example, in a four-cylinder engine the front two cylinders are fed into the first chamber, while the back two are fed into the second chamber as shown in Figure 59.

Constant Pressure Type

With the constant pressure type of turbocharger, the exhaust gas from all cylinders flows into a common manifold, where the pulses are smoothed out, resulting in exhaust gas entering the turbine housing at an even pressure.

With both types of turbocharger, the exhaust gas then enters a volute-shaped annular ring in the turbine housing, which accelerates it radially inwards at reduced pressure and increased velocity on to the turbine blades. The blades are so designed that the force of the high-velocity gas drives the turbine and its shaft assembly.

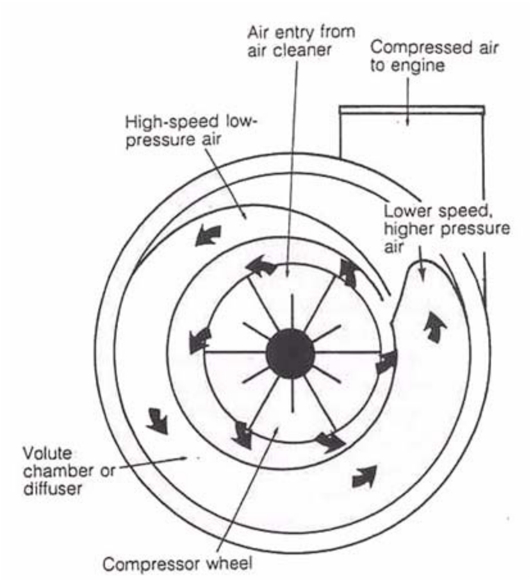

Figure 60 - Turbocharger compressor housing

The compressor assembly (in Figure 60) is of similar design and construction in both pulse and constant-pressure turbochargers. The compressor consists of a wheel and a housing incorporating a single volute or diffuser. Air in the compressor chamber mainly lies between the blades of the compressor wheel, and is thrown out radially by centrifugal force into the volute during rotation of the wheel. Here the air velocity decreases and a corresponding increase in air pressure results. As the air progresses around the volute, its velocity decreases further and the pressure increases as the cross-sectional diameter of the chamber increases.

Summary

In summary, the pulse-type turbocharger offers a quick excitation of the rotating assembly due to the rapid succession of the exhaust gas pulses on the turbine assembly. It is predominantly used in automotive applications, where acceleration response is important.

Constant-pressure turbochargers are used mainly on diesel engines in earth moving equipment and in marine applications. In these applications, acceleration response is not so critical.

Air Intake Condition

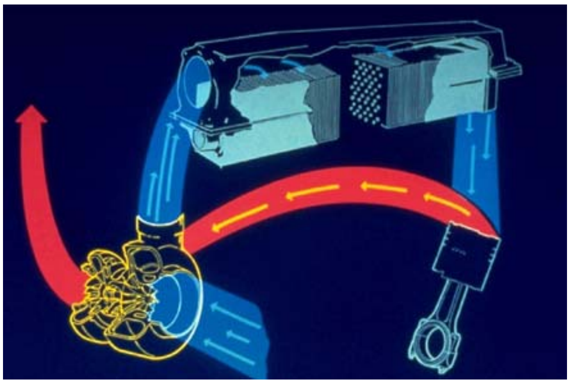

Figure 61

Air inlet and exhaust system problems account for many failures. For example, when air inlet restriction is too high:

- Excessive end loading can occur and cause accelerated thrust bearing wear, and
- Turbocharger RPM can increase significantly.

Abnormally high exhaust temperatures can cause marginal lubrication problems and metallurgical damage.

Foreign material can be introduced into the turbocharger from either the inlet or exhaust systems. Thus, the technician should always gather basic information about air inlet and exhaust systems when investigating turbo failures.

Lubrication

As discussed, turbochargers have extremely high rotational speeds and high energy factors and are lubricated with engine oil. To achieve reliable turbocharger operation and predictable life, the correct quality and viscosity oil is essential and the oil must be in good condition and clean:

- Oil and Filters **must** be changed on time and correct levels maintained on the dipstick at all times
- Oil filters should be cut open and examined at change interval
- Engine oil pressure should always be at specified levels.

Boost Pressure

Boost pressure is defined as the pressure existing in the inlet manifold when the engine is operating at nominal or rated power output. Boost pressure is specified for each engine model.

Boost pressure is measured at a location in the inlet manifold and the units used for boost pressure measurement are either mm Hg when a mercury manometer is used or kPa when a gauge is used.

When measuring boost pressure, this should always be compared with standard inlet and fuel conditions of:

- 99 kPa dry barometric pressure
- 29 degrees celsius
- 35 API rated fuel.

If the standard conditions are not present at the time of test, correction factors should be applied.

Pressure Control

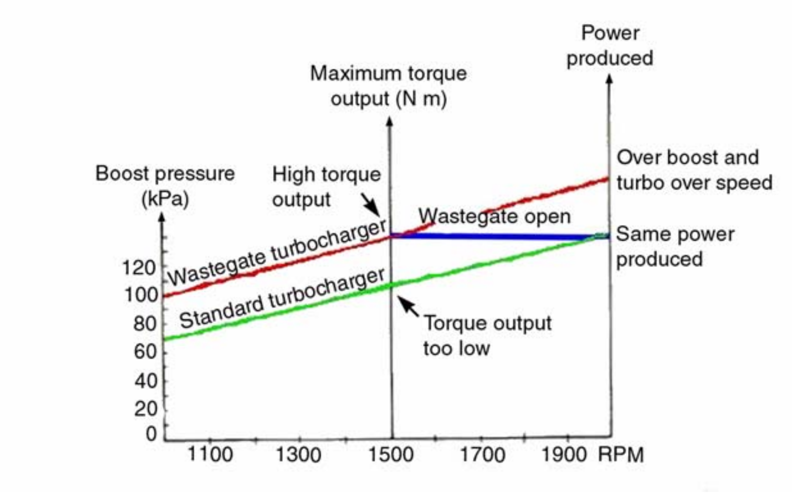

Figure 62

The chart shown in Figure 62 is a typical performance comparison between a standard turbocharger and a turbocharger fitted with a wastegate.

Problems with wastegates are normally reported as low power complaints. This will occur when the wastegate sticks open. If the wastegate diaphragm fails or the wastegate sticks in the closed position, over boosting and high exhaust temperatures will result.

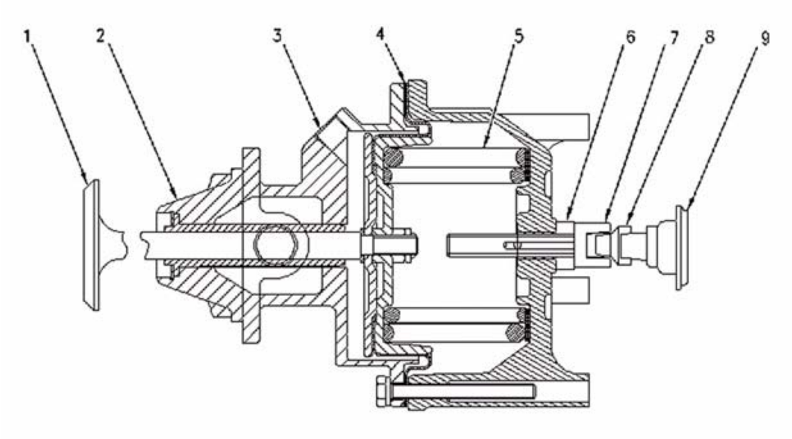

Figure 63

The wastegate (Figure 63) turbocharger is of a higher output capacity and capable of delivering sufficient charge air for complete combustion of the fuel during acceleration as well as in high-torque situations. As the engine speed and exhaust-gas energy increase, so the turbocharger speed increases and the charge-air pressure rises. Without the wastegate charge, pressure would continue to rise with considerable risk to both the engine and the turbocharger.

However, the increasing air pressure acts on the diaphragm in the wastegate until, at a predetermined pressure, the resulting force is sufficient to compress the spring and open the exhaust bypass passage. This allows sufficient exhaust gas to bypass the turbine to prevent any further rise in turbocharger speed and subsequent charge-air pressure.

Wastegate turbochargers are generally fitted to faster moving earthmoving equipment - for example, dump trucks and road scrapers - as well as high-performance automotive vehicles. They are also fitted to vehicles to achieve both low and high altitude capability without de-rating.

Electronically Controlled Wastegate

Air is supplied to the wastegate solenoid. If boost pressure exceeds a predetermined value a sensor will send a signal to the ECM and the ECM will open the wastegate solenoid. The open wastegate solenoid will allow air pressure to open the exhaust bypass valve. When the exhaust bypass valve is open, exhaust at the turbine side of the turbochargers is diverted through the muffler. When the exhaust at the turbine side of the turbochargers is diverted through the muffler the speed of the turbochargers will decrease. This will reduce the boost pressure to the cylinders.

The wastegate solenoid can be controlled with the ET service tool for diagnostic purposes. Connect a multimeter to the wastegate solenoid. Set the meter to read ‘DUTY CYCLE”. Overrise the wastegate solenoid with the electronic service tool. Use the multimeter to measure the corresponding duty cycle.

Application

Use of wastegates almost disappeared from Caterpillar engines, however, their use is now becoming more frequent. The use of wastegates is driven by emission requirements as well as a need for superior performance from the turbocharger over a wide speed range.

Wastegates are used on Caterpillar 3500 engines installed in the larger mining off-highway trucks and in the C9 to C16 on-highway truck engine. In addition, some smaller machines also use a wastegate. In the 793 off-highway truck, the wastegate is used to allow the vehicle to operate at high altitudes without engine derating.

The 793-off highway truck is the only current example of a rebuildable type of wastegate in the Caterpillar system. The 793 wastegate is similar in design to those used on earlier engines apart from the fact that the 793 wastegate is controlled electronically.

EFFECTS OF ALTITUDE ON TURBOCHARGED DIESEL ENGINES

When an internal combustion engine is operated at a high altitude where the air is less dense than at sea level, the quantity of air (and oxygen) entering the engine cylinder on the induction stroke is insufficient for combustion of the normal fuel charge. As a result, the performance of the engine falls in proportion to the altitude at which it is being operated.

Turbocharged engines are not affected to the same degree. As the air becomes less dense with altitude, the turbocharger spins faster due to the reduced pumping load, producing a compensating effect. However, there is still a decrease in engine performance, although this is much less than for naturally aspirated engines.

On turbocharged engines, power output is reduced by approximately 1% per 300m rise in altitude above sea level. When the operating altitude is in the vicinity of 2000m, the fuel delivery to the engine must be decreased according to engine specifications to prevent damage to the turbocharger due to over speeding.

Series Turbocharging

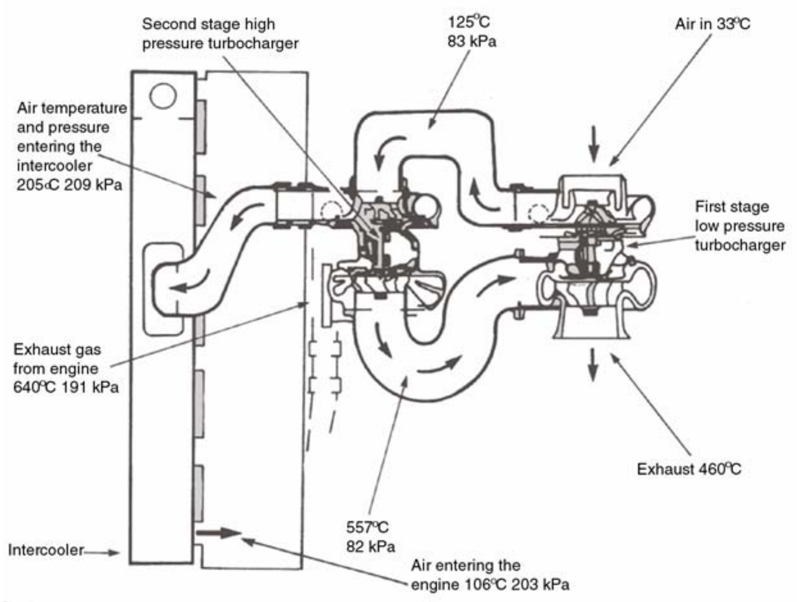

Figure 64

Series turbocharging (Figure 64) is used occasionally in high performance heavy duty diesel engines to improve the efficiency of the air intake system. It uses a large (low Pressure) turbocharger to provide a supply to a small (high pressure) turbocharger. This arrangement provides an air supply to the small turbocharger which is pressurised to a level above atmospheric pressure.

The 3516 engine fitted to the 793 off-highway truck was the first engine in the Caterpillar system to use series boosting.

The advantages of the series boost system are:

- improved fuel consumption
- reduced smoke especially on acceleration
- increased peak torque
- higher overall efficiency.

Compound Turbocharging

In an effort to increase engine efficiency and performance, some engine manufacturers are turbocompounding their engines. In a conventional turbocharged engine, the exhaust gas is directed to the turbine wheel and then exits into the atmosphere via the exhaust pipe.

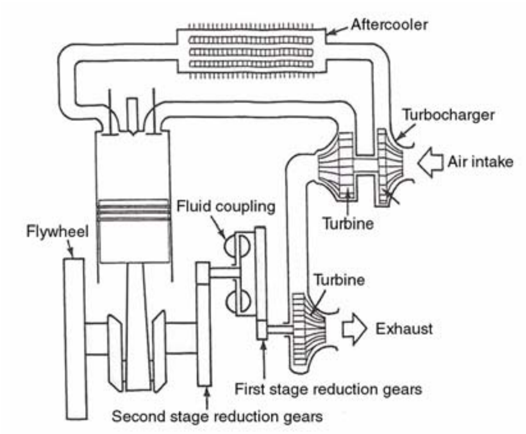

Figure 65 - Schematic diagram of a turbocompounded diesel engine

With turbocompounding, the exhaust gas leaves the turbocharger and is redirected through a second turbine assembly, which harnesses some of the remaining exhaust energy to help drive the engine's flywheel as seen in Figure 65.

This second turbine assembly directs its rotational force via a stepped-down gear reduction into a fluid coupling. A fluid coupling consists of a driving and driven member, which are connected to each other by a fluid. Since the coupling is through a fluid, it absorbs shock loadings and speed variations brought about by varying engine operating conditions. In this way, it protects the system from undue stress. The drive from the fluid coupling is further reduced in speed as it is geared down and coupled directly to the flywheel.

Overall, the drive through the fluid coupling and gear reductions combine to link a turbine spinning at a maximum of 55 000 RPM to a crankshaft, which runs at a speed of up to 2200 RPM.

Some of the advantages of using turbocompounding are lower specific fuel consumption, reduced exhaust emission, better power-to-weight ratio and increased thermal efficiency. Claims have been made by some manufacturers that, by using turbocompounding, the thermal efficiency of their engines has risen from 44% to 46%.

Engine Starting Procedure

A turbocharged engine should always be allowed to idle when it is started until the engine oil pressure has built up to normal operating pressure.

Starting an engine with the throttle wide open will result in the turbocharger operating at high speed with very little oil being circulated through its bearings, with resultant accelerated wear on the rotating assembly and bearings of the turbocharger.

Engine Shutdown

Before a turbocharged diesel engine is shut down, the engine should be run at idle speed for three to four minutes. This will allow the high-speed rotating assembly to slow down, allow the engine operating temperature to normalise, and allow excessive heat to be dissipated from the turbocharger.

If a turbocharged engine is shut down while operating at high speeds or under load, the turbocharger rotating assembly will continue to rotate for some time without oil for essential lubrication and cooling. Because the exhaust turbine shaft operates at high temperature during engine operation, once the oil flow to the bearing housing stops, the heat in the shaft and housing is sufficient to decompose the oil to form gums and varnish, leaving no lubricating residue and causing premature wear to the rotating shaft, its support bearings and the bearing housing.

There are now ways of protecting the turbocharger against sudden engine shutdown. An automatic timer unit can be fitted to the engine shutdown system, which overrides the stop control and allows the engine to idle for a number of minutes before stopping.

Another method utilises an oil accumulator mounted on the engine, which is charged by the engine lubrication system during operation. When the engine is shut down, oil is forced from the accumulator, via a check valve, to the turbocharger bearing housing, and lubricates the bearings for approximately 30 seconds.

ROOTES TYPE SUPERCHARGER

Function

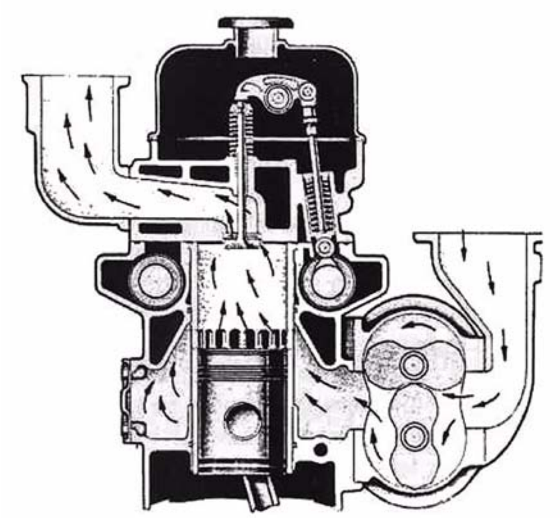

Figure 66 - Scavenge air flow through two-stroke diesel engine

Supercharging is the action of pressurisation of the air intake change for combustion. The term ‘blower’ is used to refer to the air supply pump that supplies the air under pressure to two-stroke engines, the primary purpose being to scavenge burnt gas from the engine cylinder. As a secondary function, blowers usually ensure that the cylinder is completely filled with fresh air by raising the cylinder pressure to above atmospheric pressure. The primary function is achieved by having both the inlet and exhaust ports open together, allowing the fresh air to sweep through the entire cylinder, while the secondary function is performed by closing the exhaust port (or valve) before the inlet port (or valve), thus allowing the pressure to build up in the engine cylinder before the air supply is shut off. Almost all engine manufacturers use Roots blowers for this purpose.

The supercharger can be fitted in any location where a drive is accessible.

Some installations are belt driven, however the superchargers used on ‘V’ configuration Detroit two stroke diesel engines are mounted on top of the engine and blow directly into the air intake system. This model uses a gear drive from the front timing gears.

SUPERCHARGER CONSTRUCTION

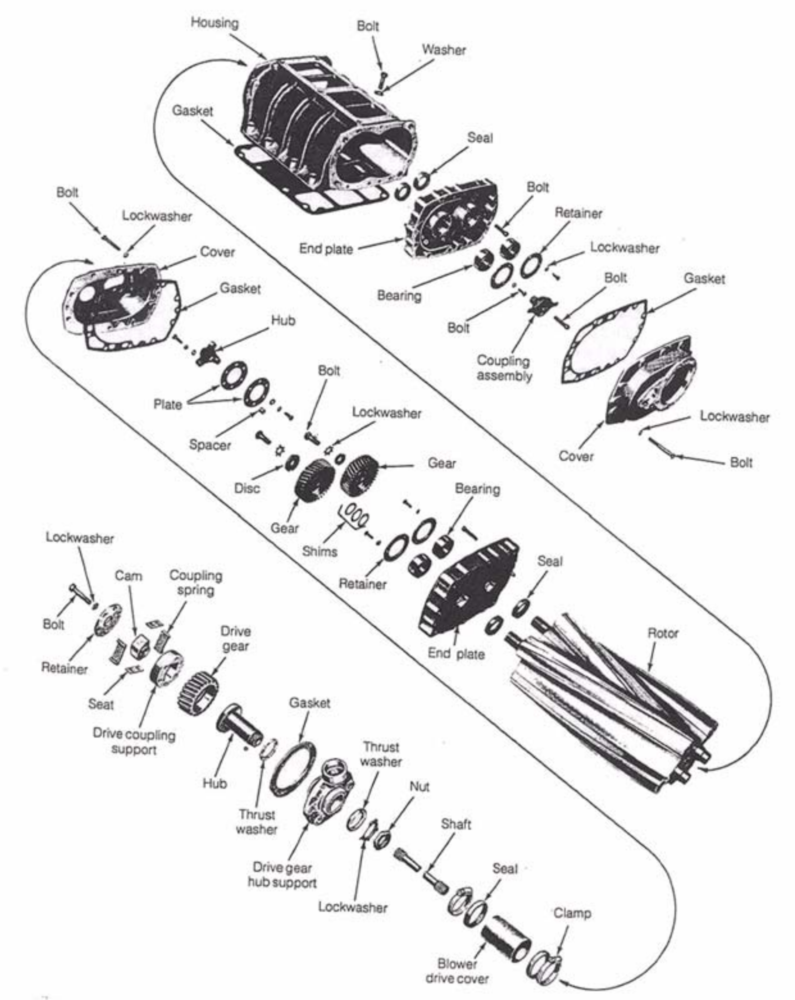

Figure 67 - Exploded view of blower assembly and drive

The basic Roots blower consists of three major sub-assemblies: an oval housing, a pair of rotors and associated bearings, gears and seals, and two end covers (Figure 67).

The rotors are geared, one to the other, and turn in opposite directions in the housing, supported in antifriction bearings in the end covers.

Each rotor consists of a steel shaft with (usually) three lobes surrounding it. These are generally twisted along their length and are known as helical rotors. Rotors with two lobes only are also used in some blowers.

Although designed to pump air, the blower rotors are not fitted with seals, but rely on the precise and limited clearances between the rotors themselves and between the rotors and the housing.

OPERATION

The operation of a blower is similar to that of a gear-type oil pump. The lobes on the rotors fit together like gears in mesh, and turn in opposite directions. As one lobe moves from the valley between the two lobes on the other rotor, it creates a void that is filled with air. This is the inlet action.

The air between adjacent lobes is carried to the outlet as the rotors turn; it is then forced from the valley by the re-entry of the meshing lobe. This creates the discharge and pressurisation of the air.

In order to eliminate the typical pulsating action associated with a gear or lobe pump, the helical rotors are used and provide a continuous and uniform air displacement from the blower. Blowers fitted to two-stroke diesel engines rotate at approximately twice engine speed.

The rotor gears have to be timed to each other, otherwise the required clearance between the rotor lobes will not be maintained and damage to the lobes and engine can occur. Due to normal wear, the running clearances will alter and may have to be adjusted during the blower’s service life. To alter this clearance, the helical drive gears are shim adjusted.

Because the rotor lobes turn within close tolerances and never contact one another, no form of lubrication is necessary within the blower housing. However, the support bearings and timing gears at the end of the rotors need constant lubrication from the engine lubrication system. To prevent engine oil from entering the rotor compartment, lip or piston ring-type oil seals are fitted within the blower end plates to separate the two sections of the blower and prevent the entry of oil into the air chamber.

The drive coupling used between the engine and the blower is a flexible or dampening type, which reduces the torsional twisting loads placed on the blower drive shaft during normal engine operation (Figure 67).

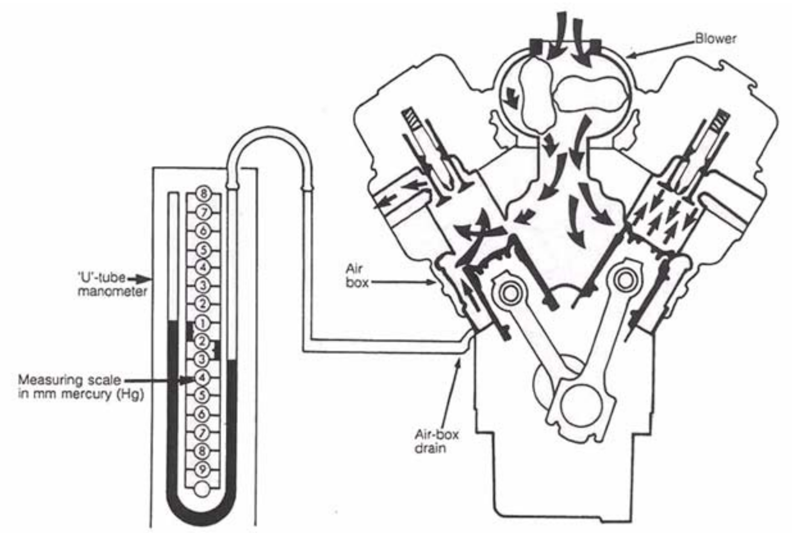

Figure 68 - Measuring blower pressure with ‘U’ tube manometer - schematic view

When in service, the efficiency of the blower is checked by measuring the discharge pressure by means of a mercury-filled manometer - a ‘U’-tube device that indicates pressure by means of the difference between fluid levels in the arms of the tube (Figure 68). To check blower output (or air-box pressure), connect the manometer to an air-box drain, usually located on the lower side of the cylinder block, just below inlet-port level. (The air box is the compartment that surrounds the tangential ports area of the cylinder liners).

To carry out a static inspection of the blower, the air inlet housing and safety screen leading into the blower inlet must be removed. The safety screen is a wire gauze screen located at the blower inlet to prevent the entry of foreign objects.

To detect a worn flexible drive coupling, hold the driving rotor and try to rotate it. The rotor should move, against the flexing of the coupling, from 10-16mm as measured at the lobe crown. On release, the rotor should spring back at least 6mm. If the rotors cannot be moved as described above, the drive coupling should be inspected and replaced if necessary. A faulty blower drive coupling can be detected by a rattling noise within the vicinity of the coupling during engine operation.

The rotors should be examined for evidence of contact by visually checking the edges of the rotor lobe crowns and mating rotor roots for signs of scoring or contact wear marks. At the same time, the drive gear backlash should be checked by mounting a dial indicator on the blower housing with the indicator probe perpendicular to, and in contact with, the side of the lobe. The backlash is measured by moving the rotor in one direction and then the other within the limits of the gear teeth clearance (the second rotor must not move). The allowable backlash is generally 0.1mm; if this is exceeded, the blower drive gears will have to be renewed.

During an inspection, oil on the blower rotors indicates leaking rotor shaft oil seals, which may be the result of worn rotor bearings, worn seals or lip-type seals that have been turned inside out due to the closure of the emergency shutdown flaps during high-speed engine operation. The emergency shutdown flap is a shutter mounted on the inlet to the blower, which, when operated, closes off the air supply to the blower (and engine), thereby stopping the engine. The emergency shutdown flap is to be used **only** in an emergency when the normal method of engine shutdown is inoperative.

Finally, the safety screen should be checked for signs of damage and, after the emergency shutdown flap has been refitted, the latch checked to ensure that the flap remains open during engine operation.

TOPIC 3

Causes of Failure, Inspection and Repair Procedures for Turbochargers

IDENTIFY CAUSES OF TURBOCHARGER FAILURE

Turbochargers fail in many different ways and for many different reasons. Some examples of failure causes are provided below.

Hot and Cold side oil leakage.

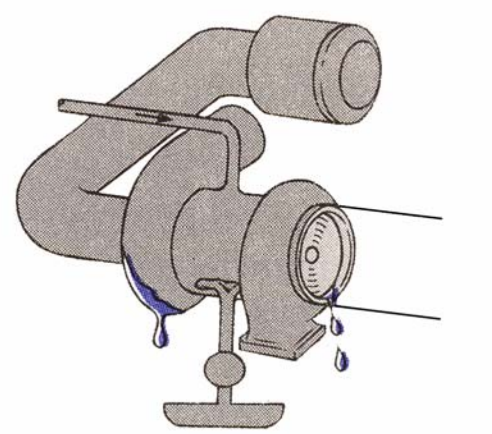

Figure 69 - Restricted oil return line

Hot and cold side oil leakage (Figure 69) can be caused by a restricted or blocked crankcase breather or turbocharger return oil line. Sometimes the leak can be bad enough to show on the outside of the turbocharger. Minor leaking will show in the exhaust by excessive black smoke.

Hot Shutdown

Repeated hot shutdowns will result in bearing failure and complete turbocharger failure due to lack of lubrication.

Restricted Air Cleaner

High exhaust temperature can result from this as well as turbocharger overspeeding due to creation of a partial vacuum on the inlet side.

Air Leaks in the intake

This can result in dust injestion.

Exhaust leaks

Exhaust leaks upstream of the turbocharger will result in reduced power output. Damaged or worn seal rings or failed gaskets, missing or loose bolts will cause this and be clearly visible on inspection.

Overfuelling

When overfuelling occurs, the turbocharger will overspeed.

High altitude Operation

The air is less dense at high altitudes, therefore less air will be provided by the turbocharger. In high altitude operations, derating (reduction of fuel setting) is required to prevent turbocharger overspeeding.

If the turbocharger is fitted with a wastegate, this system is sometimes designed to allow high altitude operation without the need for derating.

Failure to prelube

Prelubing of the turbocharger should be done after service, after oil filter change and after long shutdown periods. This will cause lack of lubrication type failures.

Leaking oil lines

Turbocharger supply and return lines should be aligned so that they fit without stress, and be correctly torqued.

Turbocharger mounting bolts

Mounting bolts and clamps need to be tight and correctly torqued.

TURBOCHARGER INSPECTION

WARNING:
Disconnect batteries before performance of any service work.

Hot engine components can cause injury from burns. Before performing maintenance on the engine, allow the engine and the components to cool.

Personal injury can result from rotating and moving parts.

Never attempt adjustments while the machine is moving or the engine is running unless otherwise specified.

The machine must be parked on a level surface and the engine stopped.

NOTICE:
Keep all parts clean from contaminants.

Contaminants may cause rapid wear and shortened component life.

NOTICE:
Care must be taken to ensure that fluids are contained during performance of inspection, maintenance, testing, adjusting and repair of the product. Be prepared to collect the fluid with suitable containers before opening any compartment or disassembling any component containing fluids.

Dispose of all fluids according to local regulations and mandates.

Before beginning an inspection of the turbocharger, be sure that the inlet air restriction is within the specifications for your engine. Be sure that the exhaust system restriction is within the specifications for your engine. Refer to Systems Operation/Testing and Adjusting, “Air Inlet and Exhaust System - Inspect”.

The condition of the turbocharger will have definite effects on engine performance. Use the following inspections and procedures to determine the condition of the turbocharger.

- Inspection of the Compressor and the Compressor Housing
- Inspection of the Turbine Wheel and the Turbine Housing
- Inspection of the Wastegate.

Inspection of the Compressor and the Compressor Housing

Remove air piping from the compressor inlet.

1. Inspect the compressor wheel for damage from a foreign object. If there is damage, determine the source of the foreign object. As required, clean the inlet system and repair the intake system. Replace the turbocharger. If there is no damage, go to Step 3.

2. Clean the compressor wheel and clean the compressor housing if you find buildup of foreign material. If there is no buildup of foreign material, go to Step 3.

3. Turn the rotating assembly by hand. While you turn the assembly, push the assembly sideways. The assembly should turn freely. The compressor wheel should not rub the compressor housing. Replace the turbocharger if the compressor wheel rubs the compressor wheel housing. If there is no rubbing or scraping, go to Step 4.

4. Inspect the compressor and the compressor wheel housing for oil leakage. An oil leak from the compressor may deposit oil in the aftercooler. Drain and clean the aftercooler if you find oil in the aftercooler.
   a. Check the oil level in the crankcase. If the oil level is too high, adjust the oil level.
   b. Inspect the air cleaner element for restriction. If restriction is found, correct the problem.
   c. Inspect the engine crankcase breather. Clean the engine crankcase breather or replace the engine crankcase breather if the engine crankcase breather is plugged.
   d. Remove the turbocharger oil drain line. Inspect the drain opening. Inspect the oil drain line. Inspect the area between the bearings of the rotating assembly shaft. Look for oil sludge. Inspect the oil drain hole for oil sludge. Inspect the oil drain line for oil sludge in the drain line. If necessary, clean the rotating assembly shaft. If necessary, clean the oil drain hole. If necessary, clean the oil drain line.

e. If Steps 4.a through 4.d did not reveal the source of the oil leakage, the turbocharger has internal damage. Replace the turbocharger.

Inspection of the Turbine Wheel and the Turbine Housing

Remove the air piping from the turbine outlet casing.

1. Inspect the turbine for damage by a foreign object. If there is damage, determine the source of the foreign object. Replace the turbocharger. If there is no damage, go to Step 2.

2. Inspect the turbine wheel for buildup of carbon and other foreign material. Inspect the turbine housing for buildup of carbon and foreign material. Clean the turbine wheel and clean the turbine housing if you find buildup of carbon or foreign material. If there is no buildup of carbon or foreign material, go to Step 3.

3. Turn the rotating assembly by hand. While you turn the assembly, push the assembly sideways. The assembly should turn freely. The turbine wheel should not rub the turbine wheel housing. Replace the turbocharger if the turbine wheel rubs the turbine wheel housing. If there is no rubbing or scraping, go to Step 4.

4. Inspect the turbine and the turbine wheel housing for oil leakage. Inspect the turbine and the turbine wheel housing for oil coking. Some oil coking may be cleaned. Heavy oil coking may require replacement of the turbocharger. If the oil is coming from the turbocharger centre housing go to Step 4.a. Otherwise go to "Inspection of the Wastegate".

   a. Remove the turbocharger oil drain line. Inspect the drain opening. Inspect the area between the bearings of the rotating assembly shaft. Look for oil sludge. Inspect the oil drain hole for oil sludge. Inspect the oil drain line for oil sludge. If necessary, clean the rotating assembly shaft. If necessary, clean the drain opening. If necessary, clean the drain line.

   b. If crankcase pressure is high, or if the oil drain is restricted, pressure in the centre housing may be greater than the pressure of the turbine housing. Oil flow may be forced in the wrong direction and the oil may not drain. Check the crankcase pressure and correct any problems.

   c. If the oil drain line is damaged, replace the oil drain line.

   d. Check the routing of the oil drain line. Eliminate any sharp restrictive bends. Make sure that the oil drain line is not too close to the engine exhaust manifold.

   e. If Steps 4.a through 4.d did not reveal the source of the oil leakage, the turbocharger has internal damage. Replace the turbocharger.

Inspection of the Wastegate

The turbocharger senses boost pressure which actuates the wastegate valve. The wastegate valve controls the amount of exhaust gas that is allowed to bypass the turbine side of the turbocharger. Regulating the amount of exhaust gas that enters the turbocharger regulates the RPM of the turbocharger.

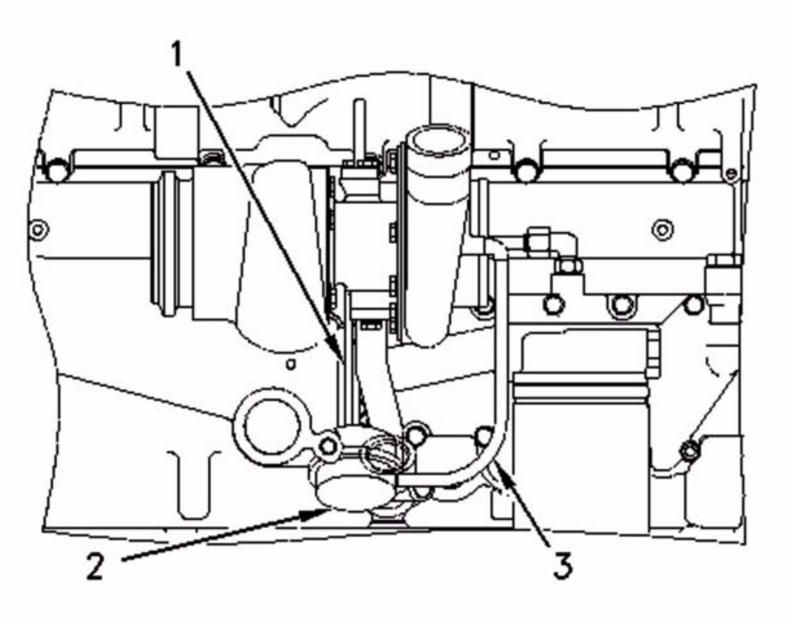

Figure 70

1. Actuating Rod
2. Canister
3. Line

Typical Example

When the engine operates in conditions of low boost (lug), a spring presses against a diaphragm in canister (2). This moves actuating rod (1) in order to close the wastegate valve. Then, the turbocharger can operate at maximum performance.

As the boost pressure increases against the diaphragm in canister (2), the wastegate valve opens. The RPM of the turbocharger becomes limited. This limitation occurs because a portion of the exhaust gases bypass the turbine wheel of the turbocharger.

The following levels of boost pressure indicate a problem with the wastegate valve:

- Too high at full load conditions
- Too low at all lug conditions.

To check the operation of the wastegate valve, verify the correct pressure for the wastegate valve. On Caterpillar engines this can be accomplished by referring to the letter designation that is stamped on the actuating lever of the wastegate valve. This letter designation indicates a corresponding amount of pressure.

Note: Refer to Table 1 for the letter designation and the corresponding amounts of pressure.

Remove the air line, and slowly apply the corresponding amount of pressure to the canister. DO NOT EXCEED 200 kPa (29 psi).

When the external supply of air that is connected to line (3) reaches the corresponding pressure for the wastegate valve, the actuating lever should move by 0.50 ± 0.25 mm (0.020 ± 0.010 inch). If the actuating lever does NOT move by this amount, replace the turbine's housing assembly of the turbocharger. This housing assembly includes the wastegate valve. If necessary, replace the complete turbocharger.

NOTE:
The housing assembly for the wastegate turbine is preset at the factory and no adjustments can be made.

Amount Of Pressure That Is Required To Check The Wastegate Valve		
Letter Designation	**kPa**	**psig**
B	(156)	(23)
C	(153)	(22)
D	(124)	(18)
E	(130)	(19)
F	(135)	(20)
G	(180)	(26)
H	(144)	(21)
J	(188)	(27)
M	(200)	(29)
V	(161)	(23)
W	(164)	(24)

Table 1

The boost pressure controls the maximum RPM of the turbocharger, because the boost pressure controls the position of the wastegate. The following factors also effect the maximum RPM of the turbocharger:

- Engine rating
- Horsepower demand on the engine
- High idle rpm
- Height above sea level for engine operation
- Inlet air restriction
- Exhaust system restriction.

Turbocharger Failure Indicator

Figure 71

First indication of turbocharger problems is usually low power or black exhaust smoke.

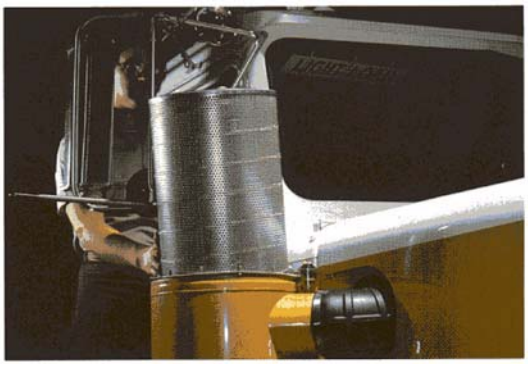

Figure 72

Too often the root cause is simply a dirty air filter which restricts inlet air supply. Be sure to check inlet air systems before stating that there is a turbocharger problem.

Lack of Lubrication

For example, lack of lubrication can be caused by low oil level, low oil pressure, wrong oil quality, high oil temperatures, etc.

Lack of lubrication produces indicators such as:

1. Temper colours and cooked oil in bearing areas
2. Adhesive wear
3. Weakened metal
4. Hot side seal ring overheating, weakening, collapse, wear and destruction.
5. Wheel contact with housings
6. Occasional wheel separation from the centre shaft.

Figure 73

Temper colours and black carburised oil are evidence of inadequate oil supply (Figure 73).

Figure 74

Continued operation without adequate lube supply allows adhesive wear of bushings and can weaken the centre shaft (Figure 74).

Figure 75

Eventually the shaft can break (Figure 75). The fracture face is usually rough and discoloured from heat. A magnet can be used to verify that centre shaft material is present on the turbine wheel, and that the friction weld has not failed.

Figure 76

Adhesive wear and presence of temper colours on the centre shaft indicate inadequate oil supply and heat removal (Figure 76).

Figure 77

One journal bearing is seized in the centre housing due to excessively high temperatures (Figure 77).

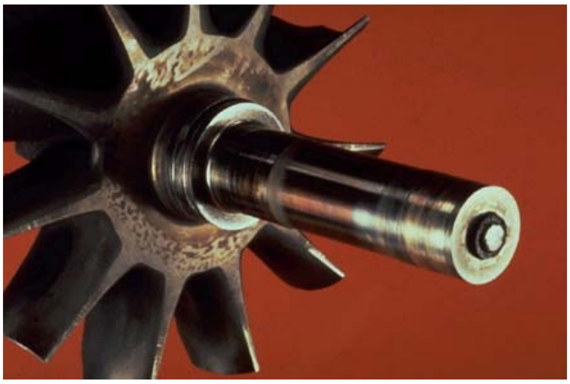

Figure 78

Fractures should be inspected and classified. The fracture shown in Figure 78 appears to be a fast, secondary fracture originating at the fillet where the diameter changes.

Figure 79

The other side of the fracture (Figure 79) shows plastic deformation and temper colours - definite signs of high temperatures and a resultant ductile fracture.

When resultant damage tells the story of lack of lubrication the remaining question that must be answered is: "**WHY** was there a lack of lubrication?". There are many root causes, such as low oil level, cold startups, wrong oil, restricted passages, contaminated oil and high temperatures.

Abrasives in Lube

Abrasive Damage

Abrasive material in the oil can damage bearings, cause excessive shaft motion and lead to total failure. Signs that abrasives have been present in the oil include:

1. Scratches, cuts or grooves in rotating parts
2. Little heat build-up
3. Rapid wear
4. Embedded debris in bearings
5. Excessive bearing wear and centre shaft motion
6. Hot and cold wheel contact with their housings
7. Seal rings leaking, collapsed, worn, missing
8. Occasional wheel separation from the centre shaft.

Careful inspection of the internal parts yields important facts.

Figure 80

The heat shield and centre bearings of the turbo shown in Figure 80 are covered with sludge and varnish, and discoloration of the journal bearings is present. The oil present appears to be contaminated with carbon and other small unfiltered debris. These signs indicate a need to get facts about oil quality, such as maintenance intervals, filters and blowby amounts.

Figure 81

The hot side bearing shown in Figure 81 has extreme wear, while the cold side bearing looks normal.

Figure 82

Closer inspection of Figure 82 shows that the seal ring came out of its groove during installation. This may be the root cause, which allowed hot exhaust and carbon to enter and cause abrasive wear.

Large foreign material can be introduced during engine or turbocharger assembly, during repairs when engine lubrication systems are open, or during maintenance operations. Because turbocharger RPM is extremely high, it only takes a short time for serious damage to occur, produce shaft motion and allow wheels to contact housings. Abrasive damage will be worse on the outer surface of journal bearings than on the inner surface due to tight clearances and centrifugal force.

Since identification of debris is often the key to finding the root cause of abrasive wear, whenever possible the recessed areas should be carefully inspected for trapped debris particles, gently remove and clean them and examine them with good lighting and magnification.

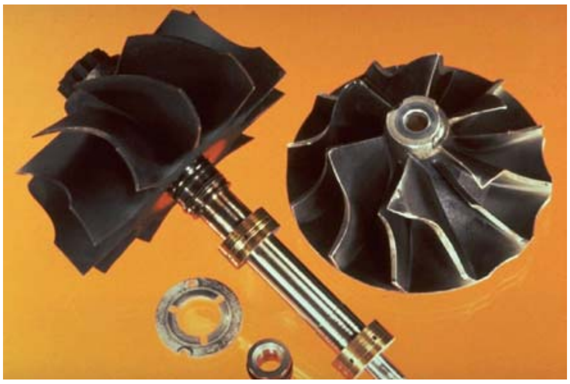

Figure 83

Large, hard debris has cut and grooved shaft bearings (Figure 83).

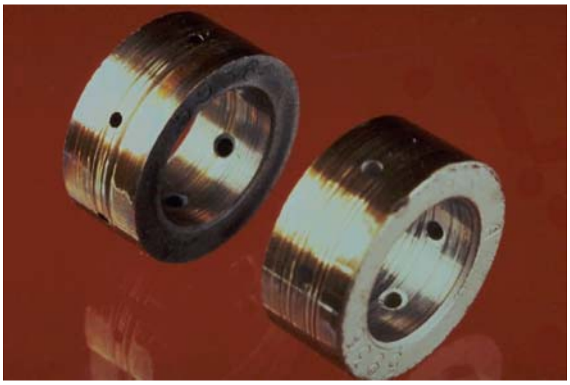

Figure 84

Abrasive damage is more severe on outside surfaces than inside (Figure 84).

Figure 85

General inspection shows that abrasive cutting is present (Figure 85), and a first preconceived idea might be that the customer has allowed debris to enter and cause the damage.

Figure 86

Only by inspecting the wear surface with magnification (Figure 86) can the abrasive particles be identified as spherical, uniform size, hard particles with temper colours.

High Exhaust Temperatures

Look for high exhaust temperature facts:

- Heat damage
- Worn bearings
- Wheel to housing contact
- Wheel to centre shaft separation.

High exhaust temperature can force heat to penetrate the centre housing of the turbocharger and damage rotating parts. Heat also causes parts, such as the turbine housing and centre housing, to oxidize and distort.

Indicators of high exhaust temperature include:

1. Extreme heat damage
   a. Cooked or carburized oil
   b. Oxidation/scaling of metal parts
   c. Temper colours
   d. Turbine seal ring collapsed.
2. Worn bearings.
3. Wheel contact with housings.
4. Occasional wheel separation from the centre shaft.

Figure 87

Visual examination of the exterior of a turbocharger subjected to extremely high temperatures usually shows extreme oxidation of all metals as well as wheel contact with housings (Figure 87).

Figure 88

Upon disassembly, internal parts should also show signs of high temperatures, such as cooked oil throughout, heavily oxidized heat shield, temper colours and bearing wear.

Foreign Object Damage

When foreign objects enter a turbocharger it is immediately and seriously damaged. Unbalance can be more destructive than the physical distortion created by foreign material.

Indicators of foreign object damage include:

1. Bent and torn wheel blades, where usually all blades are damaged
    a. at the inside diameter of compressor wheel blades
    b. at the outside diameter of turbine wheel blades.
2. Bent centre shaft.
3. Normal wear and colour of bearings (except that wear may be misaligned if the centre shaft is bent).
4. Occasional wheel separation from the shaft if foreign material was large.

Figure 89

Figure 90

When foreign objects enter the turbine wheel, the outer edges of the blades are twisted and torn (Figure 89 & Figure 90) when the high speed blade hits a stationary object (even small, light foreign material will seem heavy to a high speed blade).

Figure 91

When large foreign material enters the compressor wheel, the inner edges of the blades are twisted and torn (Figure 91).

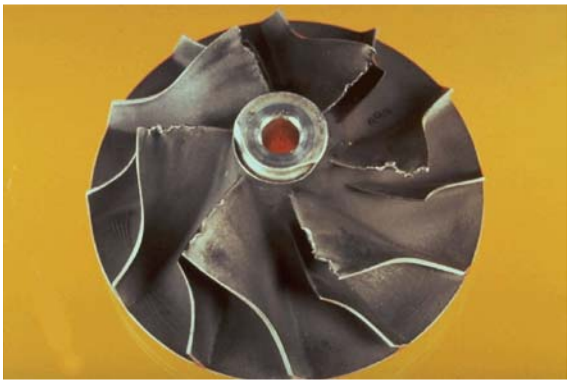

Figure 92

Smaller foreign material will do less severe damage at the same location. Dirt tracks trailing from the damage indicate that use after damage has occurred (Figure 92).

Hot Shutdown Damage

Figure 93

After full load operation, turbochargers have maximum temperature and require several minutes of no load operation, at idle, to allow lube oil to remove excess heat. When hot shut down occurs, heat is allowed to penetrate the centre housing, carburize residual oil, and at times lower strength of parts (Figure 93).

Figure 94

The hot side bearing has fine abrasive wear from the carburized oil and the surface has been scratched to show the new carburized oil layer (Figure 94).

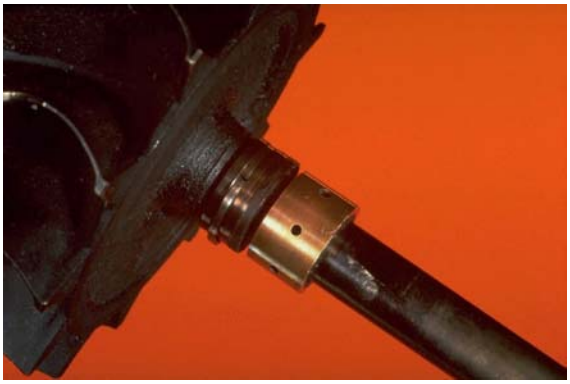

Figure 95

Figure 96

If the cooked oil causes a bearing to stick to the centre shaft, full RPM and excessive wear will occur on the outside surface (Figure 95 & Figure 96).

Figure 97

When bearings are removed from the centre shaft after hot shutdowns, it is common to find quench dots and rings (Figure 97) where residual oil has dripped onto a hot shaft through oil passages and around bearings. Repeated hot shutdowns usually produce several quench dots. More recent dots will be bright and older ones will fade with wear.

Inertial Weld Failures

Figure 98

Turbine wheels are either friction or electron beam welded to centre shafts. If a mistake is made during this process, proper melting and adhesion may not occur, as seen in Figure 98. Since the turbine wheel is non-magnetic and the shaft is magnetic, a magnet can be used to check for weld failure.

Figure 99

Weld failures are smooth and flat with little shaft metal remaining on the turbine wheel fracture face (Figure 99).

Figure 100

Exhaust energy is sufficient to keep the broken wheel spinning until it gets small enough to escape from the turbocharger (Figure 100).

Figure 101

A magnet sticks to this fracture, telling us that the shaft has broken and that the weld was ok (Figure 101).

Figure 102

Visual inspection in good lighting shows both temper colours and sheared shaft metal, also indicating that this is not a weld failure (Figure 102).

Design and Material Problems

Errors in design or materials can cause compressor wheels to fracture at high speeds. These failures are nicknamed "wheel burst" because of the massive damage done when the wheel separates at high speed. Wheel castings can have inclusions that create local weaknesses and lead to fractures. Or it is possible that those who designed the turbo wheel underestimated normal cyclic loads it would have to carry.

Wheel Burst

Figure 103

When asked: “What made this compressor wheel break?” (Figure 103), the most common answer is “Foreign material!”. All surfaces should be examined and all fractures classified before giving an opinion.

Figure 104

The largest fracture should be carefully studied. When held at arms length, it is hard to see details on the fracture face (Figure 104). The face should be looked at with good lighting and magnification.

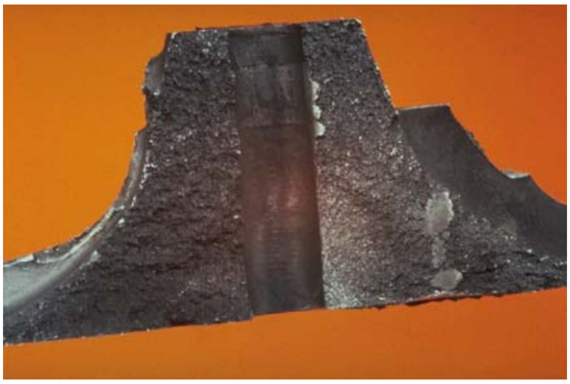

Figure 105

Now the fracture face clearly shows a semicircular area that is smoother and brighter at the lower right side of the shaft bore (Figure 105). This is a fatigue crack and resulting 'wheel burst”, caused by cyclic centrifugal force.

Casting Inclusions

Although uncommon, it is possible to have inclusions, trapped gas or other casting problems which cause discontinuity and weakness in a metal part. Since severe stresses in rotating parts are often caused by centrifugal force and high RPM, it should be expected that severe damage can be created if a casting flaw is present.

Figure 106

Casual inspection may lead one to think that this turbine wheel shown in Figure 106 has suffered resultant impact damage.

Figure 107

But when a magnet is used to check for weld failure (Figure 107), the magnet is attracted, indicating that the shaft has broken, a result of an overload.

Figure 108

As each fractured blade is inspected, one blade has a different, more interesting fracture and should be studied in good lighting with magnification (Figure 108).

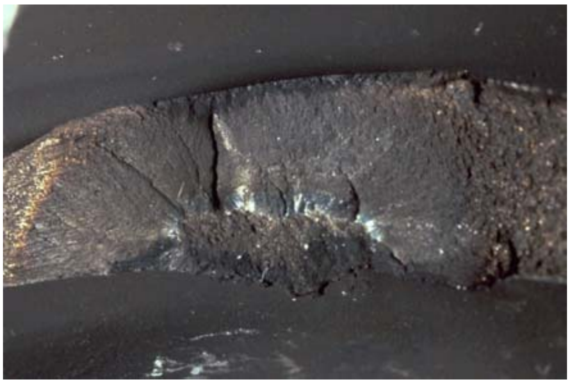

Figure 109

A casting flaw is now easily seen, which has caused fatigue fracture of the blade (Figure 109), creating the other impact damage, overloading and breaking the centre shaft.

Other Turbocharger Problems

Figure 110

When aluminium has been removed up to or under the nut seat area during nose balancing, the remaining aluminium may yield, cause off-centre shaft stress, bend the shaft, and cause wheel contact with the housing (Figure 110).

Figure 111

The lubrication passageway was not drilled in the thrust plate shown in Figure 111 and caused immediate adhesive wear.

Figure 112

Drilled passageways can be mislocated. The off-centre oil inlet passage shown in Figure 112 caused marginal lubrication of bearings.

Figure 113

At times a hot or cold wheel may have one blade missing and only minor damage present on other blades (Figure 113). A first preconceived idea is usually that foreign material has entered.

Figure 114

Closer inspection, however, shows that fatigue fracture of the blade has occurred, initiating at the centre (smoother and flatter) and ending toward the outside (rougher and woody) (Figure 114).

Workmanship

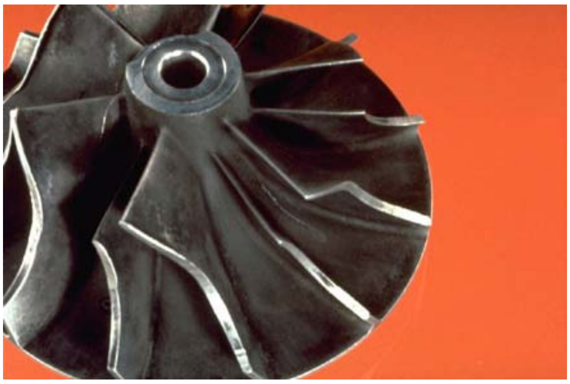

Figure 115

If compressor wheel retaining nut faces are not flat and square with the threads, they may cut into the aluminium wheel and cause clamping force to relax (Figure 115).

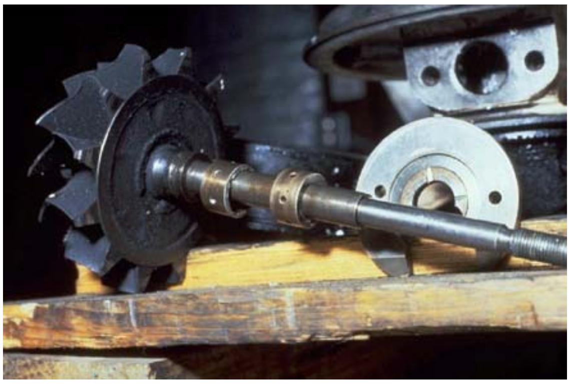

Figure 116

When housing bores are rough and bearings do not rotate freely, full RPM and excessive wear occur on the other side of the bearing (Figure 116).

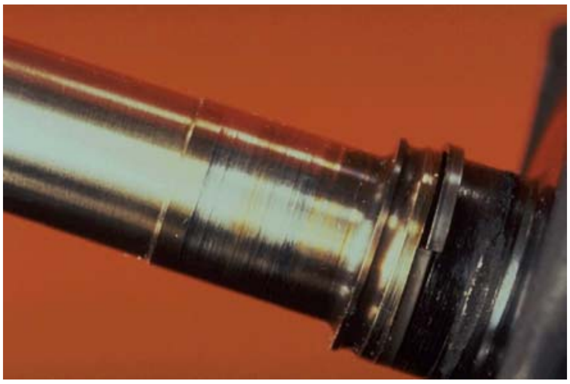

Figure 117

Rough shaft installation into the centre housing can cause impact damage to seal rings and grooves (Figure 117), creating oil leakage problems.

Figure 118

Rough handling or side loading while tightening retaining nuts can bend centre shafts (Figure 118), creating imbalance, excessive bearing wear and wheel-to-housing contact.

DISASSEMBLY OF TURBOCHARGER

Turbocharger Removal Procedure

Start by:

- Remove exhaust extension
- Remove pre-cleaner
- Remove muffler
- Remove air-cleaner.

NOTE:
Install caps and plugs on all openings in order to prevent dirt or debris from entering the system. Cleanliness is an important factor. Before the removal procedure, the exterior of the component should be thoroughly cleaned. This will help to prevent dirt from entering the internal components.

For easier assembly, mark all hose assemblies, tube assemblies, wire harnesses and cables for identification purposes.

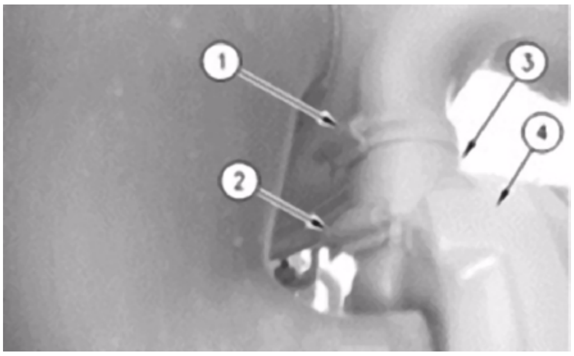

Figure 119

1. Remove clamps (1) and (2) from tube assembly (3).

2. Remove tube assembly (3) from the turbocharger (4).

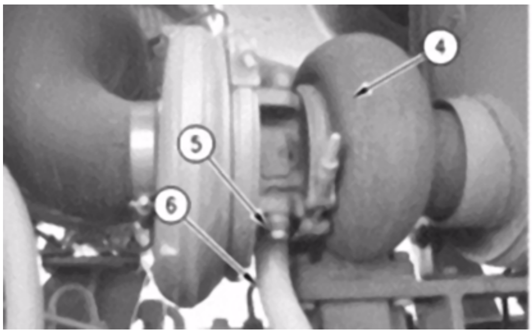

Figure 120

3. Remove two bolts (5) that secure hose assembly (6) to turbocharger (4).

4. Move hose assembly (6) away from turbocharger (4).

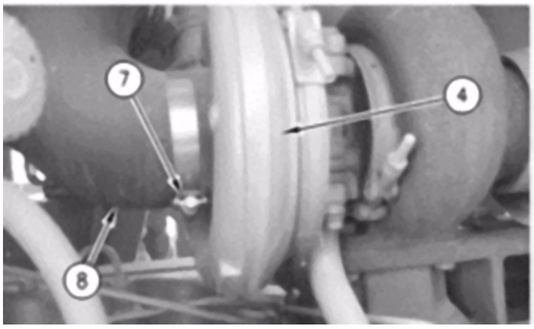

Figure 121

5. Remove clamp (7) from tube assembly (8).

6. Remove tube assembly (8) from turbocharger (4).

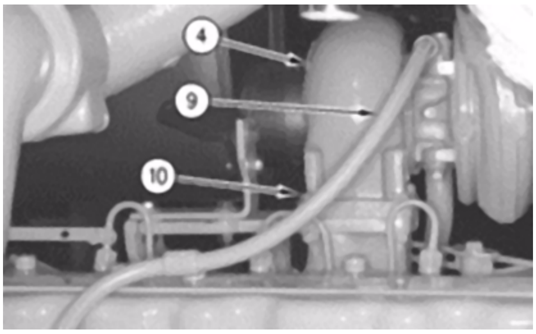

Figure 122

7. Remove hose assembly (9) from turbocharger (4).

8. Remove four bolts (10) and the locknuts that secure turbocharger (4).

9. Remove turbocharger (4) and the gasket.

Disassembly Procedure

Required Tools

- 9S6363 Turbocharger Fixture group.

Start By:

- Remove the turbocharger. Refer to Disassembly and Assembly, "Turbocharger - Remove".

NOTE:
Keep all parts clean from contaminants. Contaminants may cause rapid wear and shortened component life.

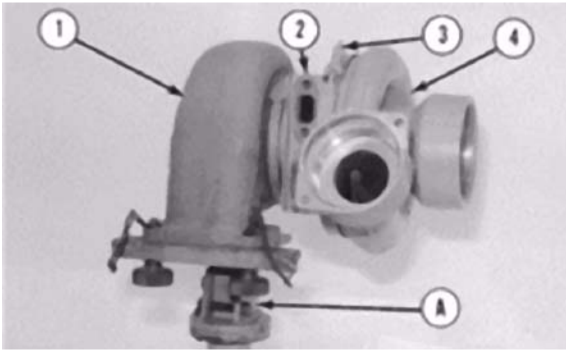

Figure 123

1. Install the turbocharger onto Tool (A).
2. Apply alignment marks to the two housings and the cartridge assembly for correct alignment during assembly.
3. Loosen clamp (3) and remove compressor housing (4) from cartridge assembly (2).
4. Loosen the remaining clamp on turbine housing (1) and remove cartridge assembly (2) from the turbine housing.

Disassembly Procedure

Required Tools

- Tool A 9S6363 Turbocharger Fixture group;
- Tool B 9S6343 Fixture assembly;
- Tool C 5S9566 T-wrench;
- Tool D 1P1861 retaining ring pliers.

Start By:

- Remove the turbocharger. Refer to Disassembly and Assembly, "Turbocharger - Remove".

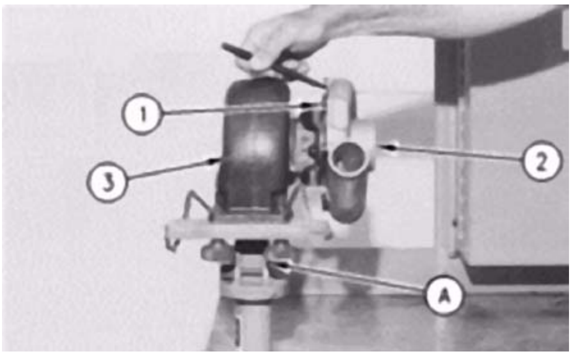

Figure 124

1. Install turbocharger (3) on Tooling (A).

NOTE:
Mark the alignment of the three turbocharger housings for installation and assembly purposes.

2. Remove four bolts (1) and the lockwashers.

3. Remove the four plates, the turbocharger gasket, the compressor clamp assembly, and compressor cover (2).

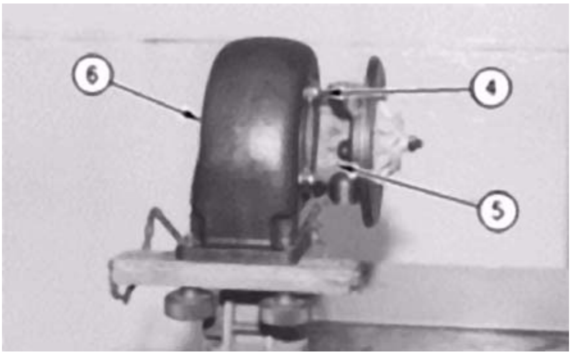

Figure 125

4. Remove two locks, two plates, and four bolts (4) that hold cartridge housing (5) to the turbine housing (6).

5. Remove cartridge housing (5).

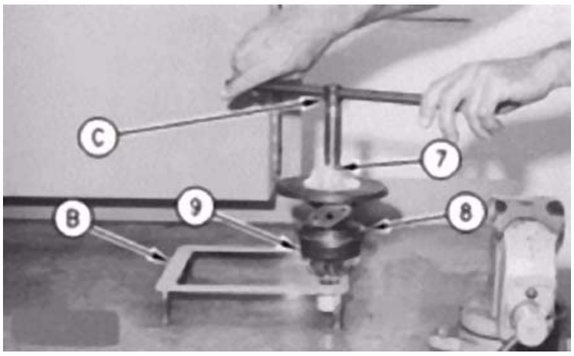

Figure 126

NOTE:
When the nut is loosened, don't put a side force on the shaft because the shaft can bend.

6. Put the cartridge assembly (8) on Tool (B), as shown.

7. Use Tool (C) and the correct size socket to remove the nut that holds compressor wheel (9) on the shaft (7).

8. Hold the cartridge assembly (8) down in Tool (B). Lift compressor wheel (9) and turn compressor wheel (9) at the same time in order to remove compressor wheel (9) from the shaft (7).

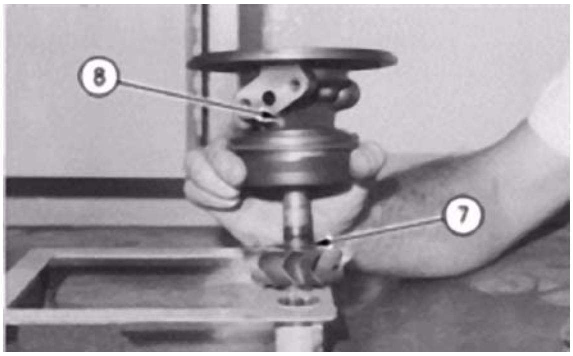

Figure 127

9. Remove cartridge assembly (8) from the shaft (7).

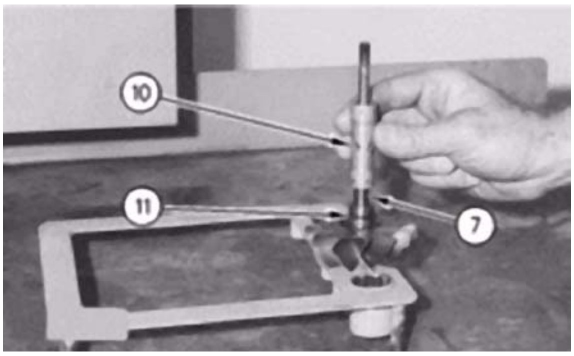

Figure 128

10. Remove bearing (10) and ring (11) from the shaft (7).