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KNOWING YOUR TURBOCHARGED ENGINE

INTRODUCTION

Before entering into a discussion concerning the turbocharged engine system, we should pause and review the basic characteristics of both the internal combustion engine and the turbocharger.

The internal combustion engine is classified as an air breathing machine. This means that the amount of power that can be obtained from a given displacement engine is determined by the amount of air that it breathes in a certain period of time and not by the amount of fuel that is used. This is because the fuel that is burned requires air with which it can mix to complete the combustion cycle. Once the air/fuel ratio reaches a certain point, the addition of more fuel will not produce more power, only black smoke. The more dense the smoke, the more the engine is being over fueled. Therefore, increasing the fuel delivery beyond the air/fuel ratio limit results only in excessive fuel consumption.

Turbochargers are installed on an engine to put more and denser air into the engine combustion chambers. Because of this increased volume and weight of compressed air more fuel can be scheduled to produce more horsepower from a given size engine. The turbocharged version of an engine will also maintain a higher level of power output than the non-turbocharged version when operated at altitudes above seal level.

WHAT IS A TURBOCHARGER?

A turbocharger is an air pump designed to operate on the normally wasted energy in engine exhaust gas. These gases drive the turbine (hot) wheel and shaft which is coupled to a compressor (cold) wheel which when rotating provides a high volume of air to the engine combustion chambers.

The turbocharger, although precision built, is basically a very simple but durable machine. It does, however, require maintenance and care as does any other piece of working machinery, but a positive head and flow of clean lubricating oil are critical.

HOW DOES A TURBOCHARGER WORK?

The heat energy and pressure in the engine exhaust gas are utilized to drive the turbine wheel. The speed of the rotating assembly and output of the compressor wheel are controlled by the design and sizing of the turbine wheel and turbine housing. The housing acts as a nozzle to direct the exhaust gas flow to the turbine wheel blades which drive the shaft wheel assembly. Since the compressor wheel is directly coupled to the same shaft, it rotates at the same speed as the turbine wheel. Clean air from the air filter is drawn into the compressor housing and wheel where it is compressed and delivered through a crossover pipe to the engine air intake manifold. Each engine and turbocharger must be properly matched. This is because the amount of air pressure rise and volume delivered to the engine form the compressor outlet is determined by wheel size, housing size, thereby performance matching the turbocharger to a specific engine.

WHAT DOES A TURBOCHARGER DO?

There are quite a number of benefits to be gained by turbo charging. Combustion of the fuel is more complete, cleaner, and takes place within the engine cylinders where its work is accomplished, because the turbocharger delivers and abundance of compressed air to the engine. The positive air pressure head (above atmospheric pressure) that is maintained in the engine intake manifold benefits the engine in several ways. During engine valve overlap (before the intake stroke starts), clean air is pushed across the combustion chamber scavenging all remaining burned gases, cooling the cylinder heads, pistons, valves and exhaust gas. The cleaner burning of the fuel plus the engine cooling which results helps to extend engine life.

Many turbochargers are used primarily for what is called the normalizing or altitude compensating of a naturally aspired engine. By this we mean that an engine and turbocharger are matched to give only a mild boots of air pressure to improve combustion and only a moderate power increase, with no increase in fuel delivery. With excess air available for combustion, the engine will produce more power both at sea level and at altitude.

It is possible to safely increase the power output of some engines by as much as 40 to 50%, with little or no change in engine components, with the correct selection and/or matching of a turbocharger. Care must be exercised to choose exactly the right turbocharger and engine fuel settings, since the turbocharger has air delivery and pressure capabilities that could easily exceed the turbocharger has air delivery and pressure capabilities that could easily exceed engine tolerances. Failure to exercise proper choice can result in engine overheating, excessive combustion chamber firing pressure and temperatures. Excessive firing pressure and temperatures could have detrimental effects on engine life by causing costly failure of engine components, such as cracked heads, scored pistons and liners, blown head gaskets, bearing, etc. Charging the engine fuel delivery schedule in the field on any turbocharger engine should only be made by following the manufacturers recommendations and procedures.

WHAT IS REQUIRED TO MAINTAIN A TURBOCHARGER?

Good maintenance practices should be observed, particularly regarding air and oil filtration, to maintain the service life and performance of a turbocharger. Years of experience has shown that the largest percentages of turbocharger failures are caused by oil lag, restriction or lack of oil flow and dirt in the oil. The second largest percentage is caused by foreign objects entering the compressor and/or turbine wheels.

1. Dust or sand entering the turbocharger compressor housing from a leaky air inlet system can seriously erode the compressor wheel blades and will result in the deterioration of turbocharger and engine performance. The wearing away of the blades, if uneven, can induce a shaft motion which will pound out and eventually fail the turbocharger shaft bearings. Ingestion of sand or dust will also cause excessive wear on engine parts, such as pistons, rings, liners, etc. Entrance of large heavy objects, bolts, nuts, rocks, tools, etc., will completely destroy the turbocharger and in many instances cause severe damage to the engine.

2. Plugged or restricted air cleaner systems, resulting from poor maintenance procedures, will reduce air pressure and volume at the compressor air inlet and cause the turbocharger to lose performance. Restricting the air inlet reduces air flow to the engine and an over fueled condition results, causing excessive engine and exhaust temperatures and black smoke. The restricted air cleaner and the idle periods, cause oil pullover at the compressor end of the turbocharger. This would be a compressor end oil seal leak without a failure of seal parts. Proper servicing of the cleaner system can prevent and correct the above problems.

3. Nearly all of the present day turbochargers operate at shaft speeds in excess of 60,000 rpm and utilize full floating bearings which have corresponding high rotational speeds. Adequate clean oil supply is required for cooling and lubrication to maintain the turbocharger bearing system.

4. Dirt or foreign material, when introduced into the turbocharger bearing system by the lube oil, creates wear primarily on the center housing bearing bore surfaces. Contaminants imbed in the bearing surfaces and act as an abrasive cutting tool and eventually wear through. When bearing and bore wear becomes excessive, the shaft hub and either or both wheels will start to rub on the housings, causing the rotating assembly to turn slower. Turbocharger and engine performance will rapidly deteriorate from this point, and such indications as engine power loss, excessive smoke, excessive noise; and the appearance of oil at either or both ends of the turbocharger could be noted. Contaminated and dirty oil is prevented when lube oil system is properly surfaces.

   Oil pressure and flow lag during engine starting can have detrimental effects on the turbocharger bearings. During normal engine starting, this should not be a problem. There are, of course, abnormal starting conditions. Oil lag conditions will most often occur during the first engine start after engine oil and filter change when the lubricating oil system is empty. Similar conditions can also exist if an engine has not been operated for a prolonged period of time because engine lube systems have a tendency to bleed down. Before allowing the engine to start, the engine should be cranked over until a steady oil pressure reading is observed, priming the lubricating system. The same starting procedure should be followed when starting an engine in cold weather as the engine oil can be congealed and take a longer period of time to flow. Turbocharger bearing damage can occur if the oil delay is in excess of 30 seconds, and much sooner if the engine is allowed to accelerated much beyond low idle rpm.

TURBOCHARGER FAILURE ANALYSIS AND CORRECTIVE PROCEDURES

The importance of determining the exact of a turbocharger failure cannot be overemphasized. The determination should be made at the time of failure and should in all cases be accomplished before a replacement turbocharger is installed.

Often, when a failed turbocharger is replaced with little or no through given to the cause of the failure, there is a recurrence of the failure, resulting in extra down time and expense. The initial and follow-on failure could also be of a type that could result in costly engine damage. Immeasurable damage is also done to the reputation of the product, the dealership and the service man. The majority of turbocharger failures are found to be due to poor operating procedures; lack of, or improper preventive maintenance; or incorrect repair practices. One important thing to remember is that the prevention of repeat failures will always mean more to the customer than a continuing and costly replacement of parts.

Although turbocharger durability and performance have greatly improved over the pas few years, operational and environmental situations still exist that can result in turbocharger failure.

MAJOR CAUSES OF TURBOCHARGER FAILURE

There are many and varied causes for turbocharger failures. They can be grouped into five major categories:

A. Lack of lubrication and/or oil lag.
B. Foreign material in the lubricating system.
C. Oil oxidation or breakdown.
D. Foreign material in either the exhaust or air induction systems.
E. Material and workmanship.

Causes of failure by type and corrective measures:

A. Lack of lubrication and/or oil lag.

1. This type of failure occurs when the oil pressure and flow is insufficient to:

a. Lubricate the journal and thrust bearings.
b. Stabilize the shaft and journal bearings.
c. Reach bearings before unit is accelerated to high speeds.

2. The turbocharger bearing's need for oil increases as the turbocharger speed and engine load increases. Insufficient oil to the turbocharger bearings for period as short as a few seconds during a heavy load cycle when shaft speed is high will cause bearing failure.

3. General precautions: When oil and/or filters are changed.

a. First engine startup after oil and filter change: crank engine, if possible, without starting until the filter and oil system is filled and steady oil pressure to obtain a steady oil pressure reading; otherwise, a bearing failure may result due to lag or lack of lubrication. Priming the oil filters with clean oil will reduce engine cranking time.

4. Engine starting procedure after installing a turbocharger:

a. Make certain that the lube oil is clean and at operating level. The oil filter should be filled with clean oil to minimize cranking time.

b. Make certain that the lube oil is clean and at operating level. The oil filter should be filled with clean oil to minimized cranking time.

c. Leave the oil drain line disconnected at the turbocharger and cranks the engine over without starting until oil flows out of the center housing drain port. A steady oil flow indicates that air pockets are out of lube oil system. A funnel can be used to return oil to drain tube.

d. Connect the oil drain line, start the engine and operate at low idle rpm for a few minutes before loading engine.

B. Foreign material in the lubricating system:

1. Operating an engine with contaminated or dirty oil and assuming that the oil filter will remove all contaminants before they reach the bearings can be costly to both the turbocharger and the engine. There are engine operating conditions when the oil completely bypasses the filter. Examples where the filter will bypassed are:

a. Cold weather when the engine oil is congealed-filter bypass can be open.

b. When oil filter is clogged-bypass can be open.

c. Filter bypass valve can stick in open or partly open position.

d. Filter element can be ruptured.

e. Filter element improperly installed.

2. Contaminated or dirty oil will wear and fail turbocharger bearings much sooner than it will fail engine bearings, because the turbocharger shaft rotates at as much higher speed than the engine. When this type of failure is found in a turbocharger, the cause of oil contamination should be located and corrected before installing a replacement turbocharger. If this is not accomplished, a second turbocharger failure will soon occur, along with the possibility of extensive engine damage. In addition, if contaminants are large enough to plug the turbocharger internal oil passages, a lack of lubrication type of failure would result.

Analysis of oil samples at oil filter change periods can help to prevent this type of failure. Oil and filter change periods should never be extending beyond the engine manufacture's recommendation interval.

C. Oil oxidation or breakdown:

Sludge accumulates in engine oil when oxidation and/or oil breakdown takes place. Sludge will affect turbocharger performance and life, and eventually engine life, when the sludge condition of lubricating oil becomes severe.

The spinning action of the turbocharger shaft throws the oil against the internal walls of the center housing where sludge particles stick and accumulate. In time, it builds up to a point that oil drainage from the turbine end journal bearing is affected. Turbine seal leakage then occurs. The deposited sludge at the turbine end may become coked (baked) and very hard because of the high temperatures in this area. This hard coke can flake off and start wearing the turbine end journal bearing and bearing bore, but turbine seal leakage usually occurs first. Shaft rotation may or may not be affected. In many cases, the journal bearing clearances are unchanged.

If turbine end oil leakage is encountered and it is suspected that sludge has built up at the turbine end of the center housing, center housing inspection can be made by looking through the oil drain opening. Heavy sludge build up will be seen on the shaft between the bearing journals and in the center housing from the oil drain opening on back to the turbine end when sludge and cooked condition exists.

NOTE: When oil leakage is noted at the turbine end of the turbocharger, always check the turbocharger oil drain tube and the engine crankcase breathers for a resident condition. Correct as necessary before working on the turbocharger.

When a sludge engine oil condition is found, it is mandatory that the engine oil and oil filters are changed, using the factory recommended lubricating oil.

Sludge accumulation results from oxidation and/or breakdown of the engine oil. Primary causes are engine overheating, excessive combustion products from piston blow by, non-compatible oils, engine coolant leaking into the oil, the wrong grade or quality of oil and the lack of proper oil change intervals.

C. Foreign material in either exhaust or air induction systems:

Foreign material which enters the exhaust or inlet air system will damage the wheel because of their extremely high speed. Small particles, such as sand, erode the leading edges of the blades. Large, hard particles tend to rip or tear the blades. Soft materials, such as shop towels or rubber items, roll the blades back, opposite the direction of the wheel rotation.

If there has been a turbocharger failure caused by foreign material damaging the wheels, a thorough cleaning of the exhaust manifold and inlet air system is essential. In many cases, compressor wheel damage can throw and embed pieces of metal into the air filter element. If this element is not replaced, metal pieces can shake out and fail a replacement turbocharger.

It is extremely important to carefully service the turbocharger air inlet system. Be sure that no foreign objects are in the piping and that all connections are secure.

D. Material or Workmanship:

This failure type is in most cases self-explanatory – faulty material, parts not assembled properly, or parts omitted.

TROUBLESHOOTING A TURBOCHARGED ENGINE SYSTEM

First it should be emphasized that a turbocharger does not basically change the operating characteristics of an engine. A turbocharger is not a power source with in itself. The turbocharger’s only function is to supply a greater volume of compressed air to the engine so that more fuel can be burned to produce more power. It can function only as dictated by the flow, pressure and temperature in the engine exhaust gas.

A turbocharger cannot correct or overcome such things as malfunctions or deficiencies in the engine fuel system, timing, plugged air cleaners, faulty liners, etc. Therefore, if a turbocharged engine system has malfunctioned and the turbocharger has been examined and determined to be operational, proceed with troubleshooting as through the engine were non-turbocharged. Simply replacing a good turbocharger with another will not correct engine deficiencies.

All too frequently, serviceable turbochargers are removed from engines before the cause of malfunction has been determined. Always inspect and assess turbocharger condition before removal from the engine.

Recommended inspection procedure:

1. Remove inlet and exhaust tubing from the turbocharger.

2. Inspect both wheels for blade damage caused by foreign material. The compressor wheel is easily inspected by looking through the compressor or housing inlet opening. A light is necessary when examining the turbine wheels blade tips, as they are positioned inside the turbine housing and you have to look between the turbine wheel blades from the exhaust outlet end of the turbine housing.
3. Examine the outer blade tip edges on both wheels, adjacent to their respective housing bores, and check for wheel rub.
4. Rotate the shaft wheel assembly by hand and feel for drag or binding conditions. Push shaft to side and rotate to feel for rub. It should turn smoothly.
5. Lift both ends of the shaft up and down at the same time and feel for excessive journal bearing clearance. If clearance is normal, very little shaft movement will be detected.
6. If the shaft assembly rotates freely and no wheel damage, binding or rub has been noted, it can be assumed that the turbocharger is serviceable.

TROUBLESHOOTING PROCEDURES

NOTE: To acquire confidence, ability and feel for accomplishing a turbocharger inspection, examine a new turbocharger as outlined. Compare inspection results between the new and used turbocharger.

Turbocharger actual shaft end play and journal bearing radial clearance can be checked as per Instructions in the applicable turbocharger service manual.

WARNING

OPERATION OF THE TURBOCHARGER WITHOUT ALL NORMALLY INSTALLED INLET DUCTS AND FILTERS CONNECTED CAN RESULT IN INJURY TO PERSONNEL AND EQUIPMENT DAMAGE FROM FOREIGN OBJECTS ENTERING THE TURBOCHARGER.

Each turbocharged engine system has its own distinctive sound or noise level when operating. If many cases, malfunctions can be detected when this noise level changes. If the noise level changes to a higher pitch it can indicated an air leak between air cleaner and engine or a gas leak in the exhaust system between turbocharger and engine. Noise level cycling from one level to another can indicate a plugged air cleaner, restriction in front of the turbocharger air inlet or heavy dirt build up in the level compressor housing and on the compressor wheel. A sudden reduction in noise level with resultant black or blue smoke and excessive oil leakage indicates a complete failure.

NOISE AND AIR LEAK CHECK

With the engine running, check the turbocharger for uneven noise and vibration. This can indicate malfunction in the shaft wheel assembly. If suspicious conditions are noted, shut down the engine immediately to protect the turbocharger and engine from further damage.

Examine the turbocharger as per recommended inspection procedures. If any damage is evident, the turbocharger will have to be removed and replaced.

If the turbocharger is assumed to be functional, proceed with a check of the air system as follows:

Engine not running:

1. Check air cleaner for a restricted condition.
2. Check all hose clamps for tightness.
3. Check intake manifold gaskets.
4. Check all hoses for cracks or deterioration.

With engine running at idle:

1. Air tube and connections between air cleaner and turbocharger can be checked by lightly spraying with starting fluid. Leaks will be indicated by an increase in engine speed because the starting fluid will be pulled through the compressor wheel and into the engine.

2. Air leaks between turbocharger and engine can be checked by feel and by an application of light weight oil or soap suds on crossover tube, connections and hoses. Look for bubbles.

Exhaust gas leakage between engine block and inlet to turbocharger will also create a noise level change and reduced turbocharger performance. Check exhausts system as follows:

1. Check manifold gaskets for leakage.
2. Check manifold retaining bolts or tightness.
3. Check manifold for cracks or porosity.
4. Check turbocharger inlet flange bolts or tightness.

Exhaust gas leakage is detected by heat discoloration in the area of the leak.

CONTINUE TROUBLESHOOTING TURBOCHARGE ENGINE SYSTEM USING THE ATTACHED CHART.

TROUBLESHOOTING CHART

TROUBLE AND SYMPTOMS	PROBABLE CAUSES BY CODE NUMBERS
Engine Lack Power	1,4,5,6,7,8,9,10,11,18,20,21,22, 25,26,27,28,29,30,37,38,39,40 41,42,43
Black Smoke	1,4,5,6,7,8,9,10,11,18,20,21,22 25,26,27,28,29,30,37,38,39,40, 41,42,43
Blue Smoke	1,2,4,6,8,9,17,19,20,21,22,32 33,34,37,45
Excessive Oil Consumption	2,8,15,17,19,20,29,30,31,33 34,37,45
Excessive Oil- Turbine End	2,7,8,17,18,20,22,29,30,32,33 34,45
Excessive Oil – Compressor End	1,2,4,5,6,8,19,20,21,29,30,33 34,45

Insufficient Lubrication	8,12,14,15,16,23,24,31,34,35 36,44,46
Oil in Exhaust Manifold	2,7,17,18,19,20,22,29,30,33,45
Damaged Compressor Wheel	3,4,6,8,12,15,16,20,21,23,24,31 34
Damage Turbine Wheel	7,8,12,13,14,15,16,18,20,22,23 24,25,28,30,31,34,35,36,44,46
Drag or Bind in Rotating Assembly	3,6,7,8,12,13,14,15,16,18,20,1,21 22,23,2431,34,35,36,44,46
Worn Bearing, Journals, Bearing Bores	6,7,8,12,13,14,15,16,23,24,31 35,36,44,46
Noisy	1,3,4,5,6,7,8,9,10,11,12,13,14 15,16,18,20,21,22,23,24,31,34 25,26,27,44,46
Sludged or Coked Center Housing	2,11,13,14,15,17,18,24,31,35,36 44,46

PROBABLE COST DESCRIPTION BY CODE NUMBERS

1. Dirty air cleaner element.
2. Plugged crankcase breathers.
3. Air cleaner element missing, leaking, not sealing correctly or connections to turbocharger are loose.
4. Collapsed or restricted air tube before turbocharger.
5. Restricted or damage crossover pipe from turbocharger to inlet manifold.
6. Foreign object between air cleaner and turbocharger.
7. Foreign object in exhaust system (from engine). Check engine.
8. Turbocharger flanges, clamps or bolts loose.
9. Inlet manifold cracked gaskets loose or missing, or connections loose.
10. Exhaust manifold cracked, burned, or gaskets loose, blown or missing.

11. Restricted exhaust system.
12. Oil lag (oil delay to turbocharger at start up)
13. Insufficient lubrication
14. Lubricating oil contaminated with dirt or other material.
15. Improper type lubricating oil used.
16. Restricted oil feed line.
17. Restricted oil drains line.
18. Turbine housing damaged or restricted.
19. Turbocharger seal leakage.
20. Worn journal bearings.
21. Excessive dirt build-up in compressor housing
22. Excessive carbon build-up behind turbine wheel.
23. Too fast acceleration immediately after initial start (oil lag)
24. Too little warm-up time.
25. Fuel pump malfunction.
26. Worn or damaged injectors.
27. Valve timing
28. Burned Valves
29. Worn piston rings
30. Burned pistons
31. Leaking oil feed line
32. Excessive engine pre-oil
33. Excessive engine idle
34. Coked or sludged center housing
35. Oil pump malfunction
36. Oil filter plugged
37. Oil-Bath type air cleaner:
    a. Air inlet screen restricted
    b. Oil pull over
    c. Dirty air cleaner
    d. Oil viscosity low
    e. Oil viscosity high
38. Actuator damaged or defective
39. Waste gate binding
40. Electronic control module or connectors(s) defective
41. Waste gate actuator solenoid or connector defective
42. EGR valve defective
43. Alternator voltage incorrect
44. Engine shut off without adequate cool-down time
45. Leaking valve guide seals
46. Low oil level