July 29, 2010

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EMD Turbocharger Change out Best Practices

One of the most complex pieces of mechanical equipment on a locomotive is the turbocharger and due to its high operating temperatures, speeds, tight tolerances, and small oil film thicknesses, it is also one of the more sensitive components. However, with proper troubleshooting, installation, and maintenance, the turbocharger will perform as intended throughout its useful life. There are three main points to keep in mind when working on EMD turbochargers: 1.) Determination of the root cause of the failure is critical before applying a replacement, 2.) Proper installation techniques ensures trouble-free start up, and 3.) Scheduled maintenance is key to turbo longevity, fuel economy, and emissions compliance.

Turbocharger Overview

Before going into these main points, a brief overview of the EMD turbocharger will be covered to help understand its unique design. The turbocharger assembly is primarily used to increase engine horsepower and provide better fuel economy through the utilization of exhaust gases. The turbocharger has a single-stage turbine with a connecting gear train. The gear-drive system takes energy from the engine's crankshaft and transmits it to the turbine wheel through a planetary gear drive system when exhaust gas energy levels are not sufficient to drive the turbine wheel. Under conditions such as engine starting, low speed/light load periods of operation, and rapid acceleration, there is insufficient exhaust heat energy to drive the turbine fast enough to supply the necessary air for combustion. During these times, the engine is actually driving the turbocharger through the gear train assisted by exhaust gas energy. Dependency on the gear drive system decreases as exhaust energy levels increase, until eventually no mechanical assist is required. It is the function of the overrunning clutch to "disengage" the gear drive. This is accomplished by allowing the rotating assembly to "overspeed" the driving gear train while the gears remain engaged. When the engine approaches full load, the heat energy in the exhaust, which reaches temperatures approaching 1000°F (538°C), is sufficient to drive the turbocharger without any help from the engine. At this point, an overrunning clutch in the drive train disengages, and the turbocharger drive is mechanically disconnected from the engine gear train. It should be noted that EMD 567/645 turbos have an internal overrunning clutch (part of the turbo) whereas the 710 has an external clutch that is part of the rear end gear train.

Another note is that there is an adapter/screen assembly (see figure 1) that goes between the exhaust manifold and the turbine inlet scroll. This screen functions as a protective device for the turbocharger by minimizing the possibility of foreign material, such as broken piston rings and small exhaust valve pieces, entering the turbine and damaging the turbine vanes. Current screen designs include a small trap box at the base of the adapter assembly to remove foreign material from the exhaust flow, thereby preventing it from continuously hitting the screen and breaking into smaller pieces. Now that the basic description of the turbo design has been covered, the key points mentioned in the first paragraph will be covered.

Troubleshooting/Inspections

The first point to cover is that determining the root cause of a turbo failure is critical before applying a replacement. It is estimated that around 85% of all turbo failures are due to external factors and not a failure originating within the turbo itself; therefore, it is obvious that before applying a replacement turbo its failure mode is determined. It is important to complete all inspections even if a failure mode has been identified since multiple conditions may exist. It is also good practice to inspect turbos that are being removed as part of routine maintenance. Troubleshooting engine performance that may be related to the turbo will not be covered in detail but some items that may point to a turbocharger problem include low turbo RPM, low airbox pressure, oil out the stack, low horsepower, turbo surging/burping, oil leaks, exhaust leaks, and opacity violations. If the turbo is identified as a potential problem from engine troubleshooting the areas that may require inspection include the turbo air inlet, exhaust inlet, exhaust outlet, and the rear end gear train.

Prior to any inspections, observe all shop safety rules including any flagging or lockout procedures and also reference applicable engine maintenance manuals for further instructions or precautions. The order of these inspections should be based on what symptoms that the engine was exhibiting or what can be learned from trouble reports or fault logs.

To conduct an air inlet inspection, remove the rubber air intake boot and flange and inspect the impeller for broken or nicked vanes due to foreign material (see figure 2) or any visible signs or rubbing. Foreign material damage to impeller can be due to debris being left in the filter housing from a previous turbocharger failure and being drawn into the new turbo. Damage can also occur if there is a misapplication of the compressor inlet boot in which the boot may travel and a clamp may enter the impeller and destroy it. If there is damage to the impeller the turbo needs to be replaced, the air filter housing cleaned out, and the air intake filters replaced. Inspect the aftercooler ducts and cores for debris as pieces of the impeller may enter the air duct and damage the aftercoolers. Also inspect for impeller rubbing which is often caused by an unbalanced condition within the turbocharger and can be detected visually or by excessive movement of the impeller. Unbalance conditions are often due to a turbine bearing failure which rarely occurs without an external contributing input. Therefore the turbocharger should be inspected for other defects prior to application of a replacement turbo such as damage to turbine blades or a lack of lubrication. If no damage is observed on the turbine blades the lube oil flow needs to be confirmed after installation of the replacement turbo prior to returning the engine to service; this will be covered in the installation section.

If the turbo clutch is suspected, turn the impeller by hand to check for a locked-up condition or a badly damaged clutch. It should turn freely in the counter-clockwise direction, but engage when turned clockwise. It is usual for a malfunctioning clutch to slip only intermittently, therefore only occasionally causing burping and smoking by its failure to engage therefore a roller clutch test should be performed. This test is outlined in the applicable engine maintenance manual troubleshooting section. If no defective conditions are found on the air inlet side of the turbo, reinstall the flange and the boot and inspect the exhaust inlet.

Inspection of the exhaust inlet (turbine inlet scroll) is conducted by removing the expansion joint and adapter/screen assembly and inspecting the leading edges of the blades and nozzle ring for damage through the nozzle between the 1:00 and 2:00 o'clock positions (see figure 3 and 4). Foreign material damage is generally in the form of small pieces of broken piston rings or exhaust valves that make it through the turbine inlet screen. It is recommended that whenever foreign material damage is observed in the turbine section that the turbo be removed prior to running it to destruction thereby increasing its repair cost. The power assemblies need to be inspected for damage such as broken piston rings, dropped valves, and scuffing. The screen must be removed and inspected for damage along with using magnetic particle inspection to check for cracks. The trap in the adapter/screen assembly (if equipped) must be cleaned out. The rest of the exhaust manifold should be inspected to ensure no other foreign material is present. The nozzle ring should also be inspected for deposits forming on the openings which indicate an engine problem such as a cooling water leak. Restriction of gas flow created by dented or plugged nozzles can cause the turbo to surge or "burp" at higher engine speeds therefore, inspect for internal water leaks.

Inspect the turbine blades to see if they are oily as this is an indication of worn power assemblies or excessive idling. Perform an air box inspection and pay particular attention to the condition of the piston, rings, and liners. If ring wear exceeds the recommended limits or if rings are broken, renew or replace power assembly. Also check the piston crown and port area for signs of oil problems in a specific cylinder. Excessively wet crowns and oil sludge throw off from the inlet ports may point out cylinders with oil control problems.

Next inspect the exhaust outlet for a warped diffuser, oil out the stack, or any other obvious failures. Exhaust diffuser vanes will appear to be "wavy" (see figure 5) when viewed from above if the turbo is subjected to an overheat/overspeed condition. Also look for a bulged turbine shroud which may also indicate an overheat/overspeed condition. The rotating assembly will be unable to turn due to elongated turbine blades from the excessive temperature and centrifugal force in which the blades contact the shroud. If the above conditions are found, the turbo will need be replaced, and the engine will have to be inspected for conditions that may create excessive heat such as broken piston rings, worn injector tips, broken exhaust valves, improperly timed injectors, incorrect valve timing, plugged aftercooler cores, and plugged engine air filters.

If there is oil out the exhaust stack (wet stack), check engine air filters for plugging. A lack of air to the turbo's labyrinth seals will cause oil migration across the seals, especially at higher speeds. If the turbine blades are found wet then the oil source is from engine, but if found dry, the turbo may have a true seal problem. Since labyrinth seals are non-wearing components, they have either plugged due to dirt or have become physically damaged from contact with the rotor as a result of a bearing failure. At this point, the turbo must be removed. Inspect the lube oil separator by removing the eductor tube looking for a damaged or missing screen, which would allow oil to be drawn out with crankcase vapors. Oil passage through the separator can occur when the flow rate through the separator exceeds design capacity. This is usually caused by combustion gases, ambient air, or pressurized air box air entering the crankcase. This condition is characterized by a reduction of crankcase vacuum, and can be detected by measurement with a manometer at the oil dipstick tube.

Removal

Once it has been determined that the turbo must be replaced, the steps from hatch removal to draining the cooling system to removing various connections to the turbo can be found in the applicable engine maintenance manual, therefore, only key points will be covered in this section. Point 1: On Tier 2 engines, the aftercoolers (charge air coolers) are to be removed as an assembly as the core is an integral part of the duct. Point 2: If turbo lube filter is extremely heavy and metallic particles are present, the main lube filter housing by-pass valve may be defective and must be verified and replaced if found defective. Point 3: When removing the turbo lube filter, don't drain it into the engine top deck as this is just putting contaminated oil back into the lube system. Point 4: When lifting the turbo, do not let the lifting chains press against the exhaust duct as this may damage to the duct. Point 5: Do not use torque wrenches for bolt removal as this a sure way to wear out, damage, or compromise its calibration; instead use a breaker bar or impact wrenches (depending on shop practices). Point 6: Use the jackscrews to drive the turbocharger away from the engine until the turbocharger pilot bore clears the No. 2 stubshaft. If the turbo does not clear the stubshaft and the turbo is lifted, it is probable that it will be broken which is very costly and time consuming to repair. A good tool for inexperienced employees, or even as an ongoing standard practice, is to use a scale on the lifting device for turbocharger removal. If the scale reads more than the turbo weighs when lifting and all the bolts have been removed, it is most likely that the turbo has not cleared the stubshaft. Point 7: It should be noted that engine timing will not be disturbed during turbocharger removal as long as the camshafts and crankshaft are not moved when gears are disengaged. If timing is suspected as a potential cause for the turbo failure or if the camshafts are moved while the idler gear is off, timing must be checked.

<u>Inspection before Application of Replacement Turbo</u>

There are inspections that need to be performed after the turbo is removed especially if the turbocharger is being replaced because of a failure. The replacement turbocharger should remain in the shipping container until actual application. Start with the exhaust manifold and inspect for foreign material, and completely remove any found. If the manifold condition is in doubt, remove and look for cracked leg baffles and cracked expansion joints which should be replaced. Inspect the screen/adapter assembly for debris and for plugging. A plugged screen must be cleaned as it will impact engine and emissions performance. It is best to Utex the screen assembly, in particular if debris is found in trap or if there is foreign material damage to the turbine wheel. Never grind or drill out holes to unplug the screen as this will impact turbo performance. A plugged screen can be an indication of an internal water leak, excessive oil blow by, excessive idling, or even from usage of ultra low sulfur diesel fuel with a high TBN oil. The engine air intake filters should be checked for foreign material and new ones applied after the filter housing completely cleaned out. Clean the air box to remove all evidence of aluminum dust and chromate or borate water stains. Inspect the cylinder assemblies for broken valves, valve blow, cracked pistons, broken piston rings, scored pistons and liners. Clean all gasket surfaces on the engine and remove any nicks or burrs. Clean the No. 2 idler turbocharger pilot stubshaft, using an oil stone and remove all indications of fretting. Inspect the seal groove for nicks and burrs, and smooth the surface after removal of any nicks or burrs. Check the gear train area and remove any metallic debris that might be found. Visually check the gear train for nicks, burrs, evidence of improper backlash, and uneven or excessive wear. Damage to the gears on the back-side of the turbo is generally an indication of an engine gear train problem rather than a turbo malfunction. Inspect for metallic debris in oil drainage screen located just below the turbomounted idler gear. If a planetary gear train component is broken, the oil drainage will carry this debris with it, and will deposit the chips against the inside of the screen. Check the spring drive gear or clutch drive assembly. On 645 engines, qualification of the spring drive gear assembly includes verification that all bolts are tight and that the lock wires are in place and not loose or broken. Verify that springs are not broken, or appear to have been damaged in anyway. If the turbocharger has experienced a catastrophic failure, replace the spring drive gear assembly. Some railroads elect to replace the spring drive gear on any turbo replacement. On 710 engines, verify that the clutch drive gear assembly rotates freely in a counter clockwise direction and listen for any clicking noises when rotating clutch gear assembly. Any clicking noise is cause for replacement of the clutch drive gear assembly. Inspect clutch gears for foreign material damage and excessive gear tooth wear.

Installation

As noted before, the turbo is one of the more sensitive pieces of equipment on the engine due to the tight tolerances and correct installation is critical to ensure trouble free start up and to reduce or even eliminate early turbo failures such as gear train or turbo bearing failures. Just like the removal process, the instructions and installation torques are fairly straightforward and well detailed in applicable engine maintenance manuals therefore only key points will be covered. Point 1: The most crucial point to turbo installation, and one that will be covered in most detail, is ensuring that the turbo housing is not distorted upon application to the engine or when the aftercoolers or exhaust silencer is applied. If distorted, the rotating assembly will not be properly aligned within the turbo housing and bearing supports causing clearance issues and will ultimately lead to a bearing failure. To avoid this situation the turbo impeller clearance between the impeller blades and impeller housing must be verified at different stages of the installation process. This clearance is called the impeller "eye" clearance. See Figure 6.

First step is to take the initial eye clearance reading when the turbocharger is in its shipping container or stand prior to application. These clearances should not be taken while the turbo is hoisted in the air with the lifting chains as this may result in improper readings. To determine the impeller eye clearance: 1.) Remove the air inlet collar if applied and mark (chalk or marker) an impeller blade at the 12 o'clock position so that the impeller can be returned to this position when the eye clearance is rechecked after turbocharger installation. 2.) Insert approximately the same feeler gage thickness at the ends of the impeller blades at the 3 and 9 o'clock positions simultaneously to determine the available horizontal clearance. Clearances should be determined with a heavy drag on the feelers. Record the clearance for these positions and remove the gages. 3.) Use the feeler gage at the 12 o'clock position to determine the upper vertical clearance. 4.) Leaving the feeler gage in the 12 o'clock position, use another feeler to determine clearance at the 6 o'clock position. Record the clearances obtained.

There are various practices in the number of eye clearance readings that are taken during the turbo application process, but the main point is to ensure that the initial readings and the final readings match after all components have been applied and torqued. Intermediate readings may be taken to minimize the chances of having to reposition the turbo or other components after the installation is complete thus reducing the overall application time. The minimal time it takes to take multiple readings is easy to justify and is also good for understanding where distortions may occur along with aiding inexperienced mechanics in proper application techniques. If at all possible, the readings should be conducted by the same mechanic as each may have their own "feel" for these readings. One railroad does six eye clearance readings during the installation process (on the stand, after turbo application, after aux gen drive application, after RB air duct, after LB air duct, after screen/adapter is applied, and after exhaust stack is applied).

Continuing on with other key points for turbo application, Point 2: It is recommended (and mandated by some railroads) that impact guns are not used for turbo installation as this causes conditions such as housing distortion, over torqued components, and flange breakage. Point 3: Make sure that all steps for aftercooler duct application are adhered to as improper gaps will result in improper eye clearance readings and/or duct flange cracking. Point 4: When applying the aftercooler ducts, start with the right bank duct because if the left duct were installed first the bolts on the right could not be tightened. Point 5: When applying the expansion joint(s), the tapered end of the interior liner should be facing toward the front of the engine. This taper will not be evident by external viewing of the expansion joint. If expansion joint is installed incorrectly the expansion joint will burn out. Point 6: Use high temperature thread lubricant on exhaust outlet and inlet flanges as this will make for easier removal at next maintenance interval. Point 7: If the turbo is equipped with a temperature probe, make sure that it is not mistakenly put into speed sensor hole as this will cause damage to the impeller blades and the turbo will have to be removed (see figure 7). Point 8: Replace the lube oil check valves in the turbo filter housing. Point 9: The turbo lube oil filter and the soakback need to be changed and filled with clean engine oil prior to application.

Once the turbo has been applied and all components attached, cooling system filled, verify that the soakback system is functioning properly. This is done by applying a 0-100 PSI gage in place of the pipe plug to the compressor bearing oil passage on the right side of the turbo (see figure 8). With soakback system running, pressure must be 10 to 35 psi, and if lower then 10 troubleshoot soakback piping. Open top deck cover and visually inspect that no oil is flowing from camshaft bearings, if there is the check valve needs to be replaced. The oil pressure at Governor should be zero. Visually inspect that a steady flow of oil is returning from the gear train to the oil pan by inspecting through the #16 crankcase cover. The oil flow should be 3 Inches wide with cold oil and about 10 inches wide with hot oil. Once verified, the following steps must be followed to verify that turbocharger is operating properly: Step 1: Move locomotive out of the shop. All safety equipment must be in place and all carbody doors open start the engine. Step 2: Let engine idle until warmed up to at least 150°. Verify reading of oil pressure gauge on turbocharger. It should read the same as oil pressure gage at the engine start station. If the replacement turbo is being installed after a bearing failure, an evaluation of the soakback oil systems should be conducted by doing an oil pressure test as outlined in the applicable engine maintenance manual. Step 3: Shut engine down and wait for soakback pump to time out (approximately 35 minutes). Then remove test pressure gauge, apply pipe plug, and then start the engine. Step 4: Verify that no leaks are present at pipe plug where gage was installed also verify that no oil leaks are present at any location around the turbocharger. Step 5: Load test and check horsepower. Step 6: Check and correct all oil leaks, water leaks, and exhaust leaks. Step 7: Let engine idle and allow engine to cool down before shutting down the engine. Step 8: Verify soakback operation. Soakback pump must operate for at least 30 to 35 minutes after the engine is shut down. If soakback pump does not operate for 30 to 35 minutes corrective action must be taken and repairs made. Then re-qualify the operation of the soakback pump.

<u>Maintenance</u>

Scheduled maintenance is important to overall engine performance and in particular health of the turbocharger. Refer to applicable OEM scheduled maintenance instructions for specific items and intervals. Replace the turbo and soakback filters at the same interval and pre-fill both with oil before applying. It is good practice to do both and keep it consistent as this will avoid doing wrong one. Dating and putting a shop ID on the filter is also a good idea so that the last change is easily identified, and if there are issues with the last change, you can feedback information to that particular shop. Verify turbo soakback and lube system are functioning properly every 6 months. Ensure that the soakback pump is allowed to operate and not shutdown to allow for other maintenance to be performed prior to completing the 30-35 minute cycle as this will result in damage to internal components. Replace engine air filters at required intervals and also clean oil separator element every year. Inspect turbo screen, as it is susceptible to plugging with carbon and water treatment residue. Should screen become plugged, performance of the turbocharger and the engine will be adversely affected. Fuel economy will also be impacted with dirty intake filters and clogged screens. It is important to follow the emissions related maintenance to ensure proper engine emissions which is outlined in specific maintenance instructions. The proper part number turbocharger must be applied per emission critical components as outlined in the applicable emission kit instructions. Applying a turbo that may be “close enough” to the original equipment is not an option as specific turbine wheel and impeller matching is critical to emissions performance and fuel economy.

Summary

Turbochargers are a critical component to engine performance, emissions, and fuel economy. Proper troubleshooting, installation, and maintenance are essential components to turbo longevity. There are no shortcuts when it comes to the turbocharger; when all steps are followed, early failures can be avoided.

Acknowledgements

We would like to thank the contributors to this paper which include Bill Hilgenberg, Mark Gronych, and Faria Yousuf from EMD along with Tom Kennedy from Union Pacific. We would also like to thank the LMOA Mechanical Committee for their review and feedback on this subject.

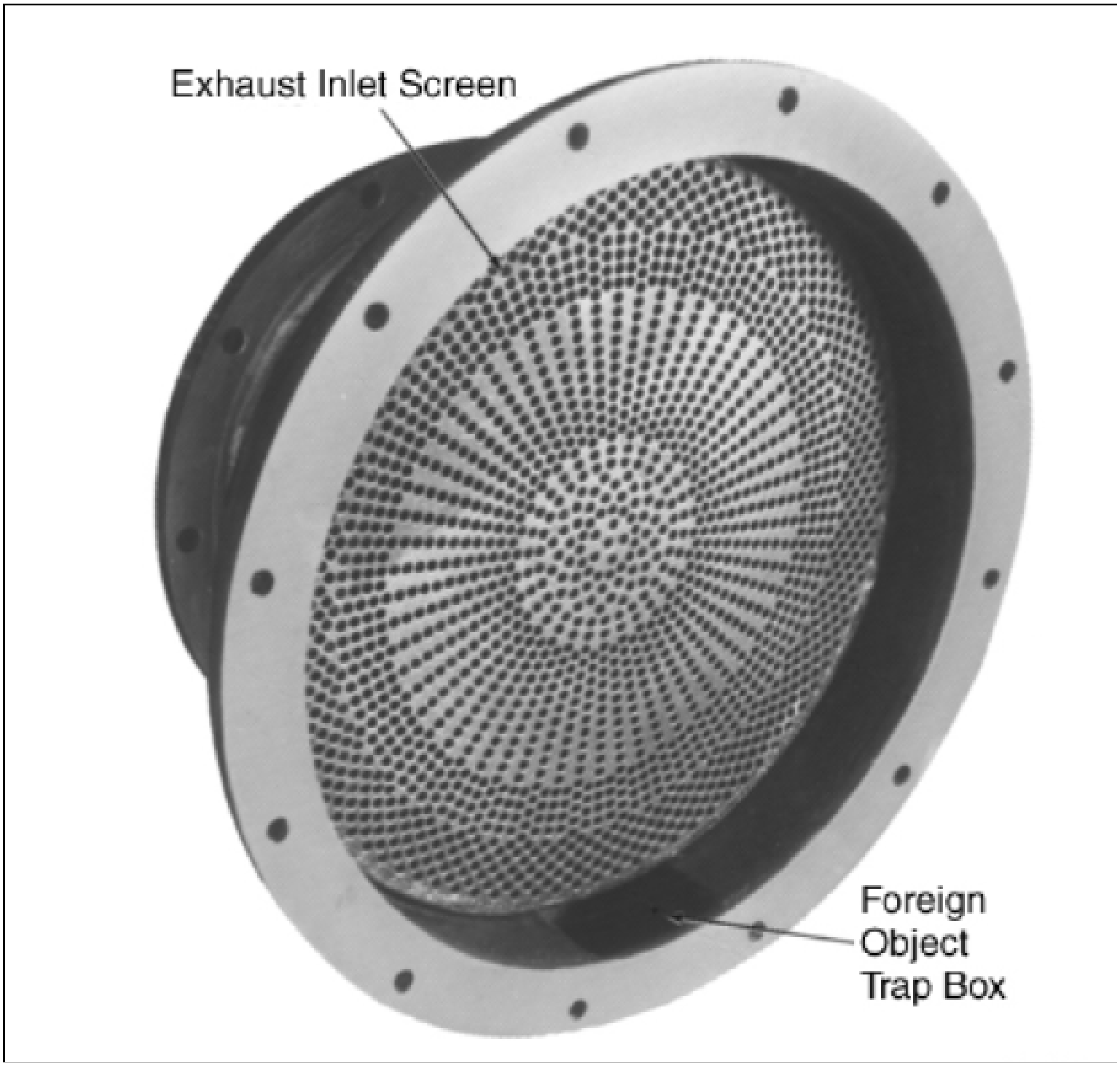

Figure 1: Turbo adapter/screen assembly


Figure 2 Impeller damaged due to foreign material ingestion

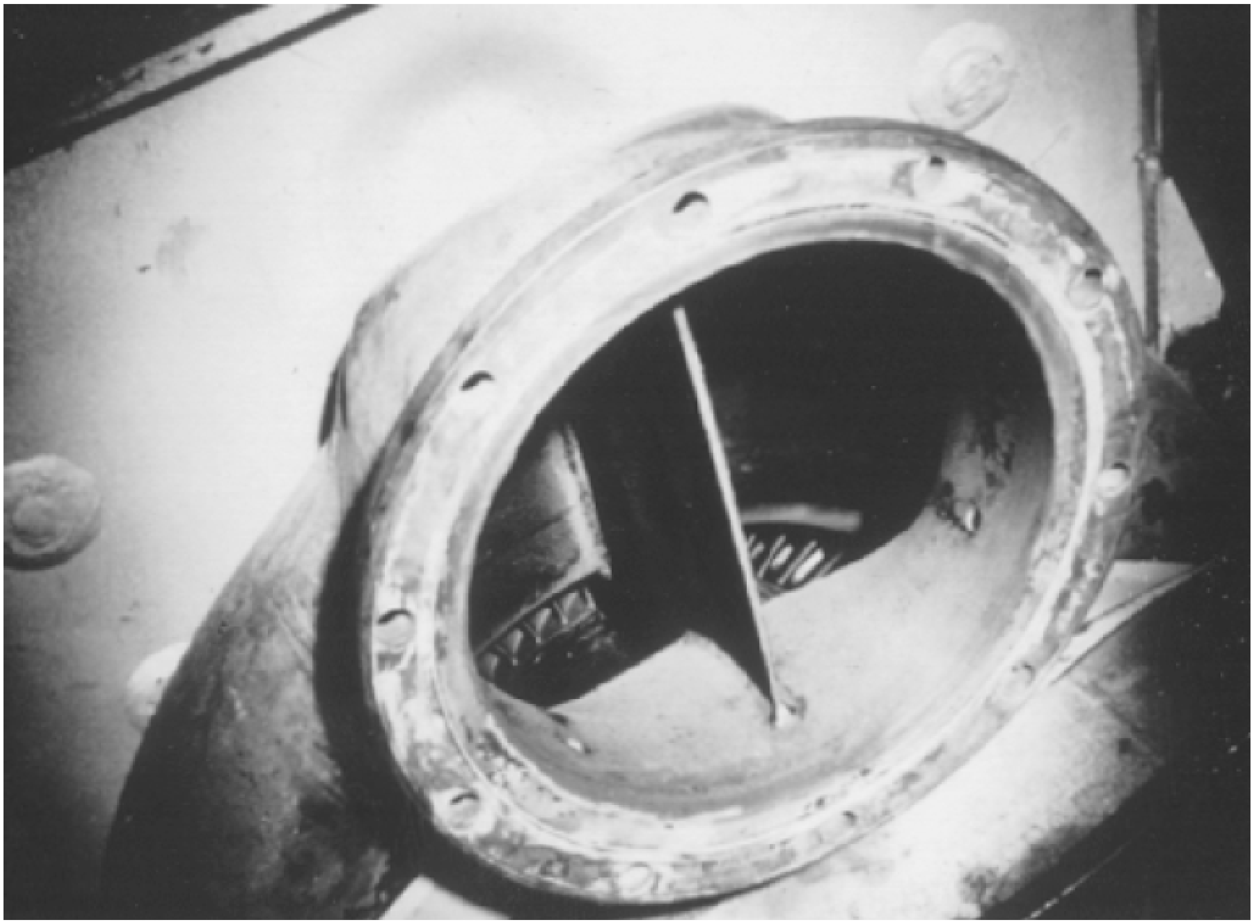
Figure 3: Turbine blade inspection through exhaust inlet scroll


Figure 4: Foreign material damage to turbine wheel


Figure 5: Warped exhaust diffuser

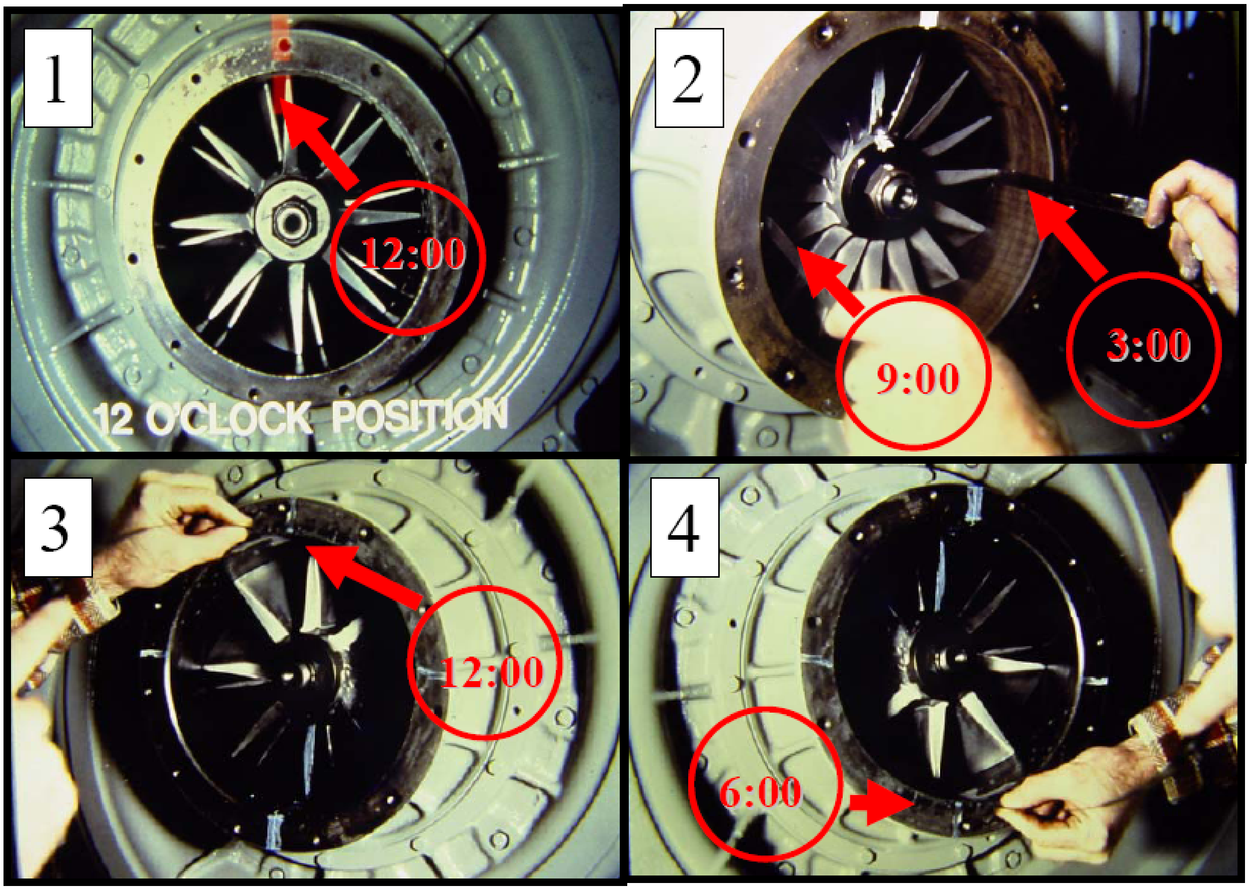

Figure 6: Impeller eye clearance measurements


Figure 7: Temperature probe improperly installed in speed pickup hole

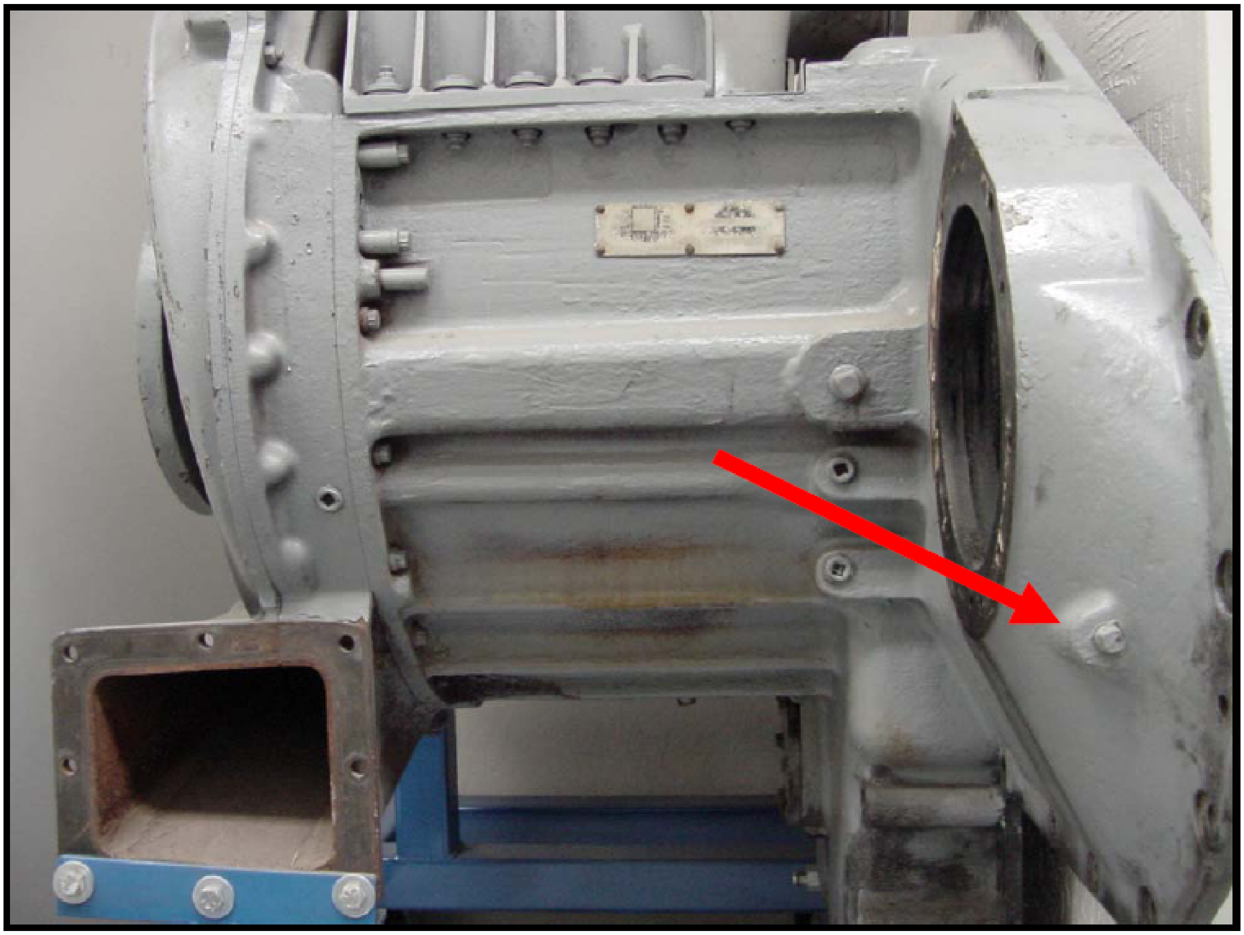

Figure 8: Where to apply pressure gage to verify oil pressure