diesel engine failure analysis

From the 1970s Detroit Diesel Training Manual
Detroit Diesel has built hundreds of thousands of engines. These engines were carefully constructed to exacting standards and have proven extremely trouble-free. Only a small percentage have experienced problems. These problems were generally caused by poor preventative maintenance, an improper application or a bad operating procedure. How WELL craftsmen analyze the engine failures determines the customer's future orders for new Detroit Diesel engines and the future service work performed by the distributor!

It's not enough to replace a failed part. It's liable to fail again. The failed part must be analyzed and the general engine condition should be considered when determining what actually caused the failure.

Only when the primary cause of failure is recognized, a repair to eliminate the cause is made, and the customer is told what he can do to prevent reoccurrence of the failure, can the problem be considered solved.
FAILURE ANALYSIS PROCEDURE

To determine the primary cause of an engine failure, here is a simple analysis procedure that consists of four steps:

1. Conduct a preliminary investigation
2. Prepare the parts for examination
3. Determine the type and cause of the failure
4. Correct the failure and the cause. Then the customer should be notified of any preventive action he can take to eliminate the cause.

PRELIMINARY INVESTIGATION

The preliminary investigation should consist of these parts:

1. Observation
2. Inquiry
3. Review of the engine history

Inquiry

After the visual examination of the engine, the operator and, if possible, the owner should be questioned. The questions asked should find out when and how the failure occurred, the oil pressure at the time of failure, whether this is a recurrent problem, and whether other engines have experienced this same problem.

Review the Engine History

To complete the preliminary investigation, the engine history should be reviewed. The history of service is shown in the Work Orders, Unit Files, and Maintenance Records that pertain to the engine. These records should show previous repairs and maintenance, any part changes to the original engine installation and service work which could aid in determining the cause of failure.

THE PRELIMINARY INVESTIGATION WILL OFTEN REVEAL A PATTERN FOR FAILURE THAT WILL HELP DETECT AND SUBSTANTIATE THE EVIDENCE FOUND WHEN THE DIAGNOSIS IS ACTUALLY MADE.

PREPARE FAILED PARTS

FOR EXAMINATION

The second step in analyzing an engine failure is to prepare the failed parts for examination. During engine disassembly, the parts should be laid out in related order on a clean surface.

Parts should not be cleaned because cleaning may destroy evidence of the primary cause of failure. This is particularly important when the cause of failure is not apparent and for parts that will be sent to the factory for analysis.

When an internal failure has occurred, save a sample of the lube oil. If the cause of failure cannot be determined visually or by mechanical means, the sample can then be analyzed.

All related parts should be tagged to key them with one another and the engine. Parts from different engines should not become interchanged.

When there is doubt as to what parts should be saved for an accurate analysis, the safe way is to save all related parts.

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DETERMINING THE TYPE AND CAUSE OF FAILURE

After the preliminary analysis and the failed parts have been prepared for examination, the type and the cause of the failure is determined.

Most causes of failures can be classified into one of four basic types:

1. Abnormal wear
2. Fatigue
3. Corrosion
4. Impact

Abnormal Wear

Abnormal wear is due to abrasion, scuffing and galling, a part deficiency or overloading. The presence of foreign matter between wear surfaces is the major cause of abnormal wear. Abrasion can be readily identified by scratch marks in the direction of part movement as shown in Fig. 1. The piston pin, shown in Fig. 2 has been worn by abrasives that entered the lubricating oil, imbedded themselves in the connecting rod and piston bushings and lapped the hardened pin surface, leaving the three high ridges shown.

The score marks in the bearing shown in Fig. 3 were caused by larger abrasive particles. This type of scoring digs furrows. The load will be concentrated on the high edges of the furrows and the bearing will eventually fail. Crankshaft bearing surface will absorb small foreign particles. But, large particles will raise high spots on the bearing surface, Fig. 4. Effective lubrication is impossible at these areas and increased friction and abrasion between wear surfaces will cause a heat build-up and the destruction of the wear surface.

Scuffing and Galling

Scuffing and galling are the more severe results of abnormal wear and are due to a lack of lubrication. A machined surface may look and feel smooth, but the surface, if magnified, would show the machined surface actually has a rough texture, see Fig. 5.

Normally, machined surfaces move past each other without harm, because they are separated by a thin film of oil, Fig. 6.
When this thin oil film is lost because of insufficient clearance or a lack of lubricating oil the two machined surfaces rub together, Fig. 7. As these two surfaces rub together, they tend to stick or grab due to their surface texture, Fig. 8. The teeth of the surfaces are torn away and heat is developed, Fig. 9. As the rubbing action continues, the heat build-up progresses until an actual welding of softer to harder metal occurs that leaves jagged gaps where the metal was pulled away.

Scuffing is the term used when slight metal transfer occurs from one surface to the other and the surfaces are not seriously damaged, Fig. 10. If scuffing continues, galling will occur.

Galling is the term used to describe a high rate of metal transfer, and surface damage is serious, Fig. 11. If galling continues, the roughness and heat generated between the two surfaces will increase until seizure finally takes place.

Scuffing and galling failures are caused by lack of lube oil or insufficient clearance and are characterized by a scuffed or a mottled appearance.

**Part Deficiency**

The third cause of abnormal wear failures is a deficiency in the part itself. The factory metalurgical laboratory found that the particular oil pump drive gear, shown in Fig. 12, failed because it was not hardened. Only through a metalurgical examination can a hardness or a material deficiency be found.

**Overloading**

Overloading is another cause of abnormal wear. Even perfectly good parts that are subjected to severe overloads will fail.
Fatigue

Fatigue failures are so-called because the parts in question are subjected to repetition of stress, Fig. 13. This simply means that a given part is loaded and unloaded many times during its normal operating cycle. Fatigue failures do not occur instantaneously, but are termed “progressive,” since they normally occur after a considerable length of service life. Under normal operating conditions, parts which are subjected to a repetition of stress may never fail, but should abnormalities occur, such as a score, nick, or small crack, then those points will act as stress raisers. Because of this, the load applied to a given part is not spread over its entirety and the areas where the stress raisers are located now become stress concentration areas. From this point, a fracture will propagate until the remaining cross-sectional area cannot support another load application and final fracture occurs. The final break has a different appearance to that of the area through which the crack first spread.

Fatigue failures are caused by repeated working of a part beyond its endurance limits until it weakens and breaks. Fatigue failures fall into two categories: bending and torsional.

A typical bending fatigue failure is characterized by two distinct areas, as shown in Fig. 14. (1) The area of fatigue failure progression, identified by an oyster shell pattern and (2) the area of the final break, identified by a more jagged surface texture.

Torsional fatigue failures are caused by a twisting action and appear similar to bending fatigue failures, but, they develop on a 45 degree angle with the shaft axis, as illustrated in Fig. 15.

The torsional fatigue failure shown in Fig. 16, started at a peened oil hole. Close examination shows the two characteristic failure areas, oyster shell pattern, as the break progressed, and the final break.

In general, a fatigue failure will start at a high stress area caused by a pit, a score mark or a poorly formed fillet. The failure spreads during repeated load cycles, and finally ruptures, leaving a jagged surface.

The three major causes of fatigue failures are: overloading due to related part failure, incorrect engine application, or poor operating procedures.

THE PRIMARY CAUSE OF A FATIGUE FAILURE MUST BE DISCOVERED TO STOP A REPEAT OF THE FAILURE.
Corrosion

Corrosion is the eating away of engine part material by either oxidation, an electro-chemical action or a mechanically-induced action.

Oxidation is the combining of oxygen and iron to form iron oxide, called rust, Fig. 17. Most iron and steel parts that are not properly protected will rust. A cooling system without a rust inhibitor caused the formation on the liner in Fig. 18.

The second type of corrosion is electro-chemical corrosion which results when two dissimilar materials are in contact with most liquids. This action is similar to that found in a battery. This type of corrosion in an engine is usually associated with the cooling system. The aluminum water manifold shown in Fig. 19, was secured to a cast iron cylinder head and both were in contact with the liquid coolant. An electro-chemical action eroded the aluminum material.

The third type of corrosion is mechanically-induced corrosion that is called “fretting corrosion”. It occurs between closely fitted parts and between bolted assemblies when a slight movement exists in them, Fig. 20. Movement causes very fine surface particles to break off. These particles react with air, forming an abrasive red oxide powder, in the case of iron and steel parts.

The continued movement between the parts produced the abrasive oxide that promotes rapid deterioration of mating surfaces as shown on the shaft in Fig. 21.

Impact

Impact type failures are breaks caused by a severe blow or blows, Fig. 22. Impact failures may be distinguished from fatigue failures by the almost complete absence of the
characteristic “oyster shell” marks, see Fig. 23. Most of
the break area is jagged, indicating that the fracture
occurred almost instantly. Impact fractures are con­
sidered secondary type failures associated with equip­
ment subjected to shock loads.

CORRECT THE FAILURE
AND THE CAUSE

When analyzing failed engine parts you will find the
four basic causes of engine failure: abnormal wear,
fatigue, corrosion, and impact, occur not only alone, but
in combination.

Discover the Primary Cause

It is easy to diagnose an engine failure when it can be
attributed solely to one of these causes. However, when
engine failure results from a combination of causes, it
is essential that the PRIMARY cause of failure be dis­
covered. Until the primary cause is discovered, an action
to prevent reoccurrence of the same failure cannot be
recommended.

Prevent Reoccurrence of
the Failure

So far we have covered the preliminary investigation,
prepared the failed parts for examination and determined
the type and the cause of failure. Step four has two parts:
(1) repairing the failure and (2) notifying the customer
of the cause of failure so that he can take measures to
prevent its reoccurrence.

If improper maintenance has been found to be the pri­
mary cause of failure, diplomatically tell the customer
how he can prevent future failures by modifying his
preventive maintenance procedure.

Should the failure be traced to an abnormal operating
practice, recommend a modification to the operating
procedure.

Keep Complete Records

When analyzing an engine failure, a complete record of
the findings should be kept to answer questions that
may arise in the future. The record on the failure should
show:

1. The engine serial number
2. What happened
3. Where it happened
4. When it happened
5. Why it happened; what you consider to be the
primary cause

Remember

The job of the Service Department is to satisfy the custo­
mer by correcting failures and preventing reoccurrences.
To satisfy the customer when he wants to increase the
engine operating life span or to stop a repeat failure, the
four basic steps described in this booklet should be
followed.

1. Perform a preliminary inspection
2. Prepare the parts for examination
3. Determine the type and the cause of failure
4. Correct the failure and the cause
A few of the terms associated with the analysis of failures are listed for the purpose of uniformity and clarity when discussing part failures.

ACCELERATE—To increase the speed of movement, such as increasing the speed of a piston or flywheel.

ACCELERATION—The rate at which the speed of an object increases.

AXIAL—A direction parallel to the center line of a cylinder or shaft.

AXIS—A center line. A line about which a body rotates or about which it is arranged.

BABBITT—A soft antifriction metal used to line bearings.

CARBON—One of the chemical elements which is the main constituent of liquid and solid fuels. Also the residual substance deposited in the combustion space and exhaust system of diesel engines when combustion of fuel oil is not complete.

CARBON RESIDUE—The carbon remaining after evaporating off the volatile portion of a fuel or lubricating oil by heating it in the absence of air under controlled test conditions. It is an indication of the amount of carbon that may be deposited in a diesel engine.

CLEARANCE—The space between two adjacent parts or a moving and a stationary part. Clearance must be provided between two surfaces to allow for lubrication and for expansion and contraction with a change of temperature.

CONCENTRIC—Having a common center.

CONTRACTION—Becoming smaller in size. In metals and fluids a result of cooling or a lowering of temperature.

CRITICAL SPEED—Speed at which the natural period of vibration of a shaft or other machine part is in phase with the power impulses.

CRUSH—The amount by which a precision bearing is compressed to ensure good contact between the back of the bearing and the bore holding it.

CRYSTALLIZE—To form or cause to form crystals or assume crystalline character. Fatigue failures are erroneously blamed on "crystallization" of the metal by persons not familiar with the nature of this type of failure. All structural metals are crystalline from the time they solidify from the molten state, so the term "crystallization" in connection with fatigue is meaningless and should be avoided.

DETONATION—A violent uncontrolled burning of a fuel in the combustion chamber.

ECCENTRIC—A circle not having the same center as another circle within it. A device mounted off-center for converting rotary motion into reciprocating motion.

"ENDURANCE" or "FATIGUE LIMIT"—The endurance or fatigue limit is the maximum stress the metal will withstand for an infinite number of cycles without failing. Let us use the illustration of a steel member supported on one end. If a given load was applied to the other end, the member would deflect downward. The top portion would be in a state of tension and the bottom portion would be in a state of compression. Now if we removed the load and pull up on this member with an equal force the tension—
failure analysis terms continued

compression areas—would reverse due to load reversal. This we can call one complete cycle of loading. If the applied load used in this example would fail the member in a given number of cycles, we have then exceeded the fatigue limit of that member. If we lessen the load where we can cycle this member an infinite number of times without failure, then we are operating within the fatigue limit of that member.

Fatigue failures are so-called because the parts in question are subjected to repetition of stress. This simply means that a given part is loaded and unloaded many times during its normal operating cycle. Fatigue failures do not occur instantaneously, but are termed "progressive" since they normally occur after a considerable length of service life. Under normal operating conditions, parts which are subjected to a repetition of stressing may never fail, but should abnormalities occur such as a score, nick, or small crack, then those points will now act as stress raisers. Because of this, the load applied to a given part is not spread over its entirety and the areas where the stress raisers are located now become stress concentration areas. From this point, a fracture will propagate until the remaining cross-sectional area cannot support another load application and a final fracture occurs. The final break has a definitely different appearance to that of the area through which the crack first spread.

ENERGY—Capacity for doing work.
FIT—The desired interference or clearance between the surfaces of two machined engine parts.
FRICITION—The resistance to relative motion between two bodies in contact.
HEAT—A form of energy.
HEAT BALANCE—A tabulation showing the percentages of the heat developed by combustion in the engine cylinder that are (1) delivered in the form of power at the crankshaft, (2) lost in friction, (3) lost to the cooling water, and (4) lost in the exhaust gases.
HEAT UNIT—The unit of heat, usually British thermal unit (Btu).
HEAT VALUE—The heat developed by the combustion of one pound of fuel or one gallon of fuel. The heat value is shown in Btu per pound or Btu per gallon. One Btu is the heat required to raise one pound of water 1 °F.
HELICAL—Flaving the shape of a helix, or screw. Helical gears have teeth shaped like a helix.
HELIX—A line cut on a cylindrical surface shaped like a screw thread.
INERTIA—The tendency of a body to maintain its existing velocity.
INTERMITTENT—Occurring at intervals.
LINEAR MOTION—Motion in a straight line.
LOAD—The useful output of an engine at a given moment.
POWER—Rate at which work is performed.
PRESSURE—The force due to the action of a gas or liquid in a closed vessel. Usually measured in pounds per square inch. Low pressures are measured in inches of a column of mercury or water. Also force applied to an area.
RADIAL—Extending from a center to the circumference, having the direction of a radius.
RECIPROCATING—Having a back-and-forth or up-and-down linear motion, such as an engine piston.

RESISTANCE—Mechanically, a force opposing the motion of a body, measured in pounds. Electrically, that which opposes the flow of an electric current, measured in ohms.

ROTARY—Turning on an axis.

ROTATIVE—Pertaining to rotation.

RPM—Abbreviation for revolutions per minute.

SLUDGE—A tarlike formation in oil resulting from the oxidation of a portion of the oil.

STABILITY—(1) Ability of a lubricating oil to withstand physical change under severe operating conditions. (2) Ability of a governor to maintain the required engine speed without fluctuations or hunting.

STRESS—The internal forces set up in a body when it is subjected to forces tending to deform it by tension, compression, shear, bending, or torsion. Anything that is loaded is subjected to a stress which is equivalent to the applied load divided by the area that is supporting it. An example of stress would be a weight of 100 lbs. applied to a member of 50 sq. in. By simple arithmetic we have a stress of 2 p.s.i.

STRESS RAISERS—Areas of a part where sharp changes in contour or surface nicks, defects or notches cause stress to become locally concentrated. An example of stress raiser can be shown by taking a wooden pencil and supporting it on both ends and applying a weight in the center. The pencil will deflect but it will support the weight, because the load tends to spread over the length of the pencil. However, if the pencil has a notch in it, and the same load is applied, the pencil would break at the notch. The reason for its breakage is due to the notch acting as a stress raiser and the load was not spread over the full length of the pencil, but became concentrated on the notched portion. That area could not support the concentrated load and breakage occurred.

STRESS CONCENTRATION AREA—An area in which the stress imposed is above the nominal value for the part in question. Using the wooden pencil, in the "Stress Raisers" example, the notched area became a stress concentration area and could no longer support the load that was imposed on the pencil.

TEMPERATURE—The intensity or degree of heat.

THERMODYNAMICS—The science of changing heat into mechanical work.

THRUST—An axial force acting on a shaft.

TOLERANCE—An allowable variation in dimensions. For example: a dimension of 0.753" with a tolerance of +0.000" and —0.003" indicates that any dimension from 0.750" to 0.753" is acceptable.

TORQUE—The effect which rotates or tends to rotate a body. Torque is the product of force multiplied by the arm, or normal distance from the center of rotation to the force. Torque is measured in lb. ft. or lb. in.

TORSION—The deformation of a body caused by a torque or twisting effort.

TORSIONAL VIBRATION—Oscillatory twisting vibration in a rotating shaft which tends to make a gear mounted on one end of the shaft whip back and forth with respect to a gear on the other end.

VELOCITY—The rate of motion or the speed of a body at any instant. Measured in feet per minute (fpm) or revolutions per minute (rpm).

WORK—The transference of energy by a process involving the motion of the point of application of a force. Work is done when a force moves a body through a certain distance.