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THE RUNAWAY DIESEL - A SIDE BY SIDE MECHANICAL ANALYSIS

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ABSTRACT

When a diesel engine is exposed to an external fuel source such as an airborne combustible hydrocarbon in the surrounding environment, it naturally ingests the mixture into the air intake system. Since diesel engines control fuel and not air, the engine can no longer maintain speed control (Fig. 1).

INTRODUCTION

On January 13, 2003 in Rosharon, Texas, two tank trucks unloaded waste liquids into an open collection pit at the BLSR Operating Ltd. disposal facility. Unknown to either driver or to BLSR personnel, the waste material was highly volatile and a flammable vapor cloud formed in the unloading area. Vapor was drawn into the air intakes of the trucks' running diesel engines causing them to overspeed, backfire, and ignite the flammable cloud (Photo 1). Two BLSR employees standing near the trucks were killed in the fire and three others suffered serious burns. The two drivers, who were employed by T&L Environmental Services Inc., were also burned after rushing back to their trucks when they heard the engines accelerate. One of the drivers died several weeks later from his injuries [1].

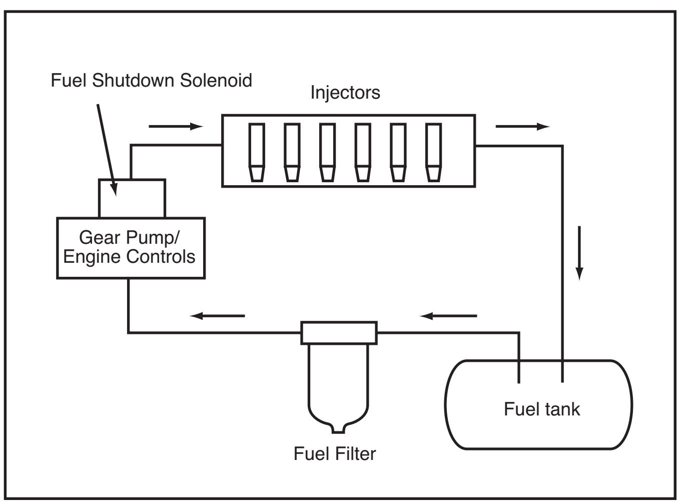

Figure 1 - Typical Diesel Engine Fuel System Schematic

DISCUSSION

In November of 1992, the phenomenon of external fuel source combustion was discussed in the authors' paper, "The Sensitivity of Motor Fuel Transportation and Delivery to Truck Selection and Specifications" [2], and again in 1996, in "The Runaway Diesel - External Fuel Ingestion" [3]. Since these publications, the authors have conducted five similar diesel engine "runaway" investigations. In each of these, there was only one engine involved. Each time the event fact pattern was consistent. Within these investigations, the mechanical signatures on the engine components were similar. The January BLSR incident allowed the unique opportunity to compare two identical engines operating side-by-side, (North, South reference) exposed to the same external fuel source where one ran away and the other did not. This side-by-side comparison of mechanical fingerprints found on the engine's components showed proof of fuel ingestion and engine overspeed followed by a "destructive backfire." These circumstances allowed the authors to develop this paper to be used specifically as a reference document for future runaway studies.

Photo 1 - Accident Scene (Two Trucks)

On February 11, April 29, and April 30, 2003, inspections of the accident site, trucks and engine teardowns were conducted. The findings within this document were derived from that work. On September 17, 2003, the Chemical Safety Board (CSB) unanimously approved two investigation reports in a public meeting in Washington, D.C. confirming the findings in this paper [1].

SIDE BY SIDE COMPARISON

Ingestion

When a diesel engine burns fuel, it leaves a distinct combustion pattern. The internal components – exhaust valves, exhaust manifold and turbocharger impeller (Photo 2) – are coated with soot and piston firing surfaces are usually coated with a dark colored mixture of oil, diesel fuel and soot which ultimately leads to a black coating (Photo 3).

Photo 2 - Turbocharger Impeller (North Engine) Soot Covered

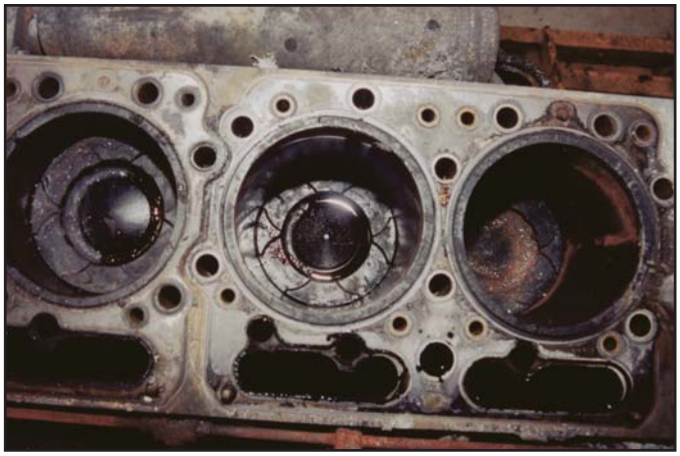

Photo 3 - Piston Firing Surfaces (North Engine) Diesel Fuel / Soot Covered

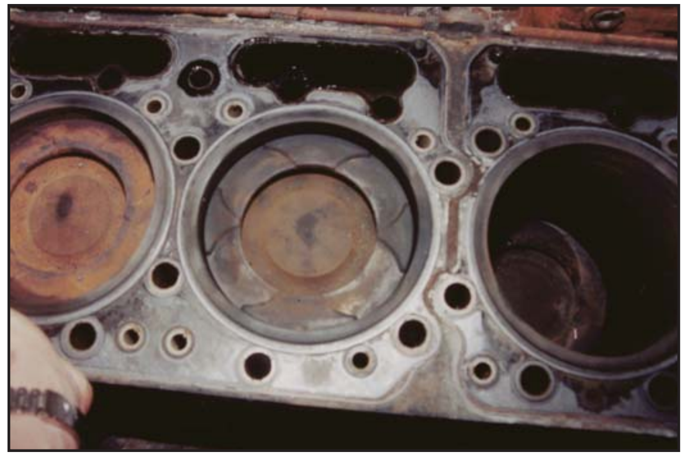

Photo 4b - Piston Firing Surfaces (South Engine) Scrubbed Clean

When a diesel engine ingests an *external fuel source*, the appearance of the internal components changes. The exhaust valves, exhaust manifold, turbocharger impeller and pistons become "cleaned" (Photo 4a, 4b) as a result of the subsequent "scrubbing" action and elevated temperatures which are noted by the blue appearance of the turbocharger bearings, etc. . . . (Photo 5).

Overspeed

Typically, a heavy-duty diesel will idle between 600-700 RPM and achieve a no-load maximum RPM of 2100-2200 with a 150 RPM "droop" resulting in an engine speed of 1950-2050 RPM under full load. Anything over full load RPM would be considered an overspeed. Engines which undergo extreme overspeed, experience what is known as valve float; exhaust and intake valves fail to close due to the excessive speed. They are actually opening and closing so rapidly that they never shut completely.

In this condition the valve train components (tappets or cam followers) lose contact with the cam lobes because the valve springs are not strong enough to overcome the momentum of the various valve train components at the overspeed RPM. The onset of valve float usually prevents higher RPM operation due to loss of compression. Extended periods of valve float will damage the valve train and subsequently put the valves in contact with piston firing surfaces (Fig. 2). This will occur at engine speeds greater than the no-load maximum. Additionally, cylinder head components, valve spring retainers and locks can become damaged (Fig. 3). Once this happens, push rods can fall down through the engine block and into the oil pan. Along the way, the push rods may become bent, showing additional evidence of overspeed. Photo 6 shows valve contact with a

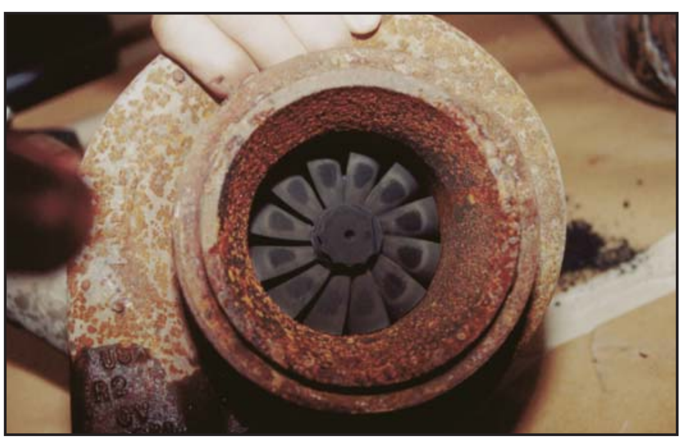

Photo 4a - Turbocharger Impeller (South Engine) Scrubbed Clean

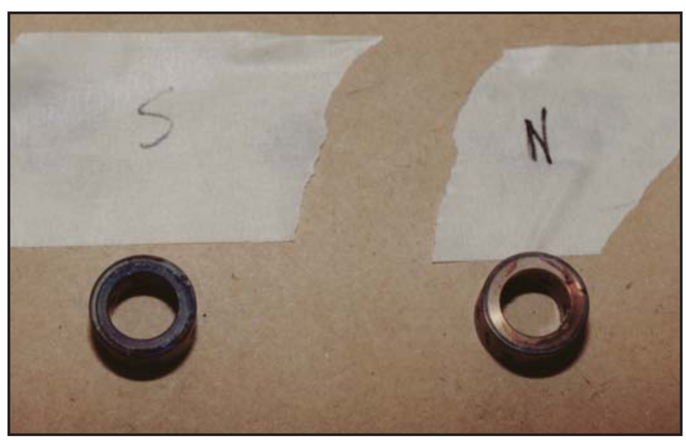

Photo 5 - Turbocharger Bearings (Left) Bluing (Right) Normal

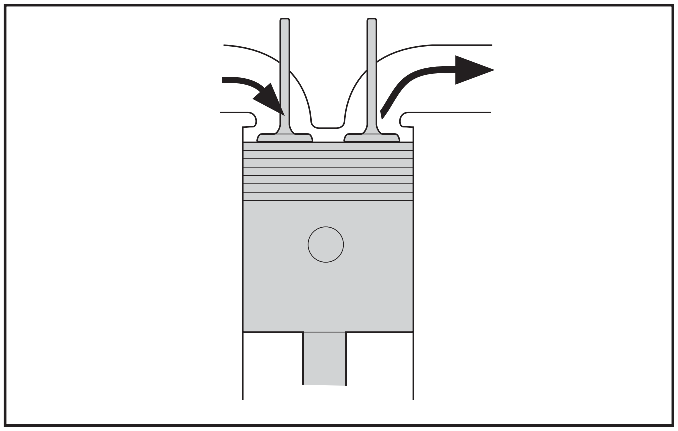

Figure 2 - Piston Valve Contact

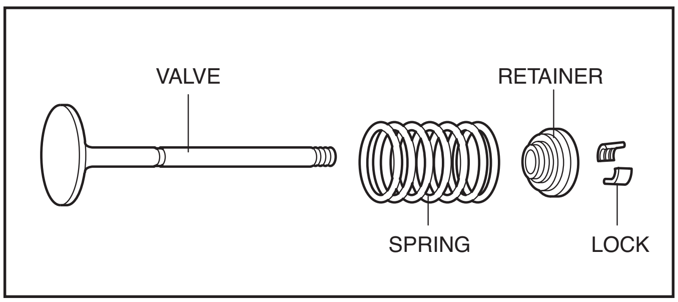

Figure 3 - Typical Valve Assembly

piston on the South engine; photo 7 shows no contact with the piston on the North engine. Photograph 8 illustrates damaged valve components for the South engine; photo 9 shows no damage on the North engine.

Whirling

Another possible mechanical signature left behind after an overspeed incident is a bent power-take-off shaft (P.T.O.). The P.T.O. is typically used to drive a pump to off-load a product from a truck or trailer. If engaged during the overspeed excursion, the P.T.O. can behave in a manner known as whirling. This is a physical phenomenon that actually bows the shaft once it achieves a certain rotational speed beyond its design speed (Fig. 4). Whirling is defined as the rotation of the plane made by the bent shaft and the line of centers of the bearings [4]. This signature can be used to further determine if an overspeed has occurred.

Ignition

If the engine has ingested enough external combustibles and runaway, the probability of fire dramatically increases. As the engine instability increases in magnitude, the likelihood of a "destructive backfire" increases. Specifically, the intake ducting and manifold fill with combustibles (Fig. 5) and due to

Photo 6 - Piston Valve Contact (South Engine)

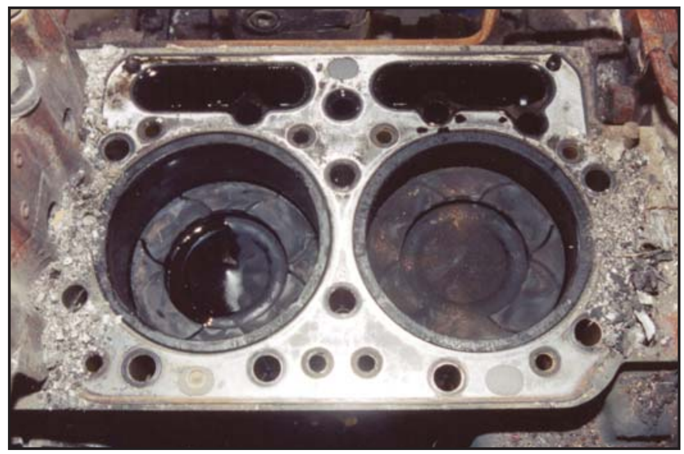

Photo 7 - No Piston / Valve Contact (North Engine)

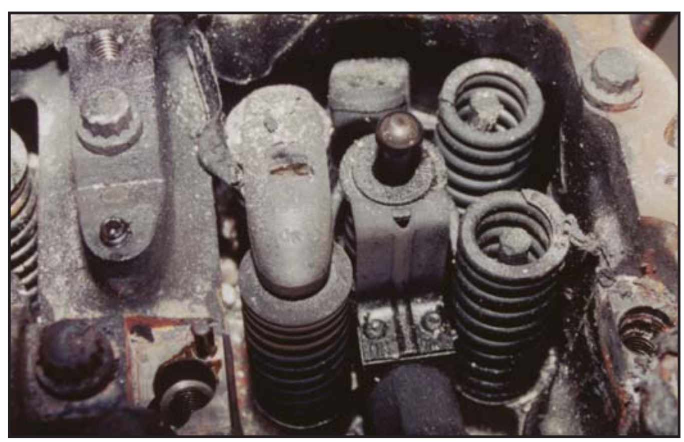

Photo 8 - Damaged Valve Components
(South Engine)

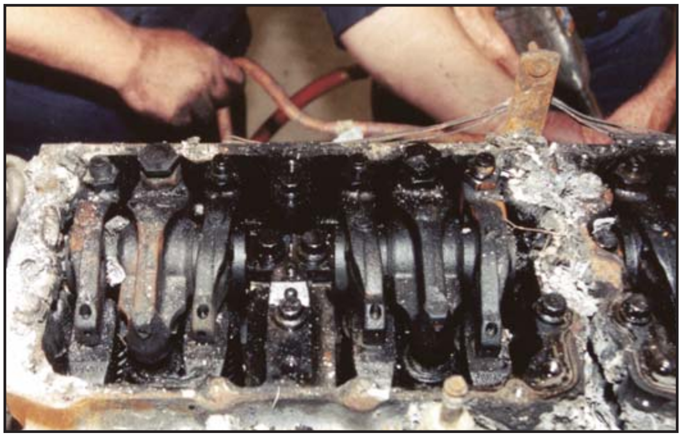

Photo 9 - Normal Valve Condition (North Engine)

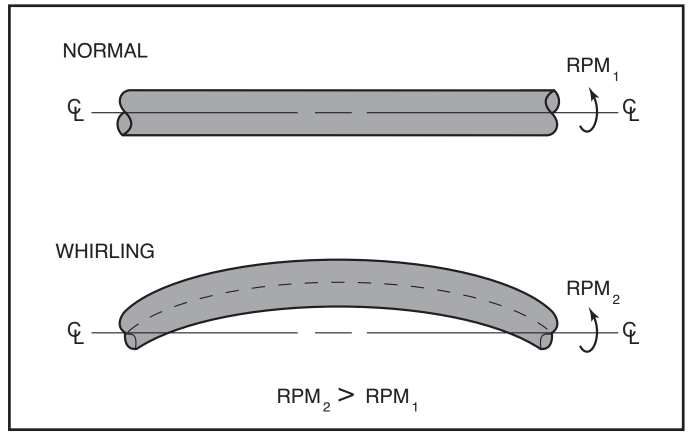

Figure 4 - P.T.O. Shaft Behavior

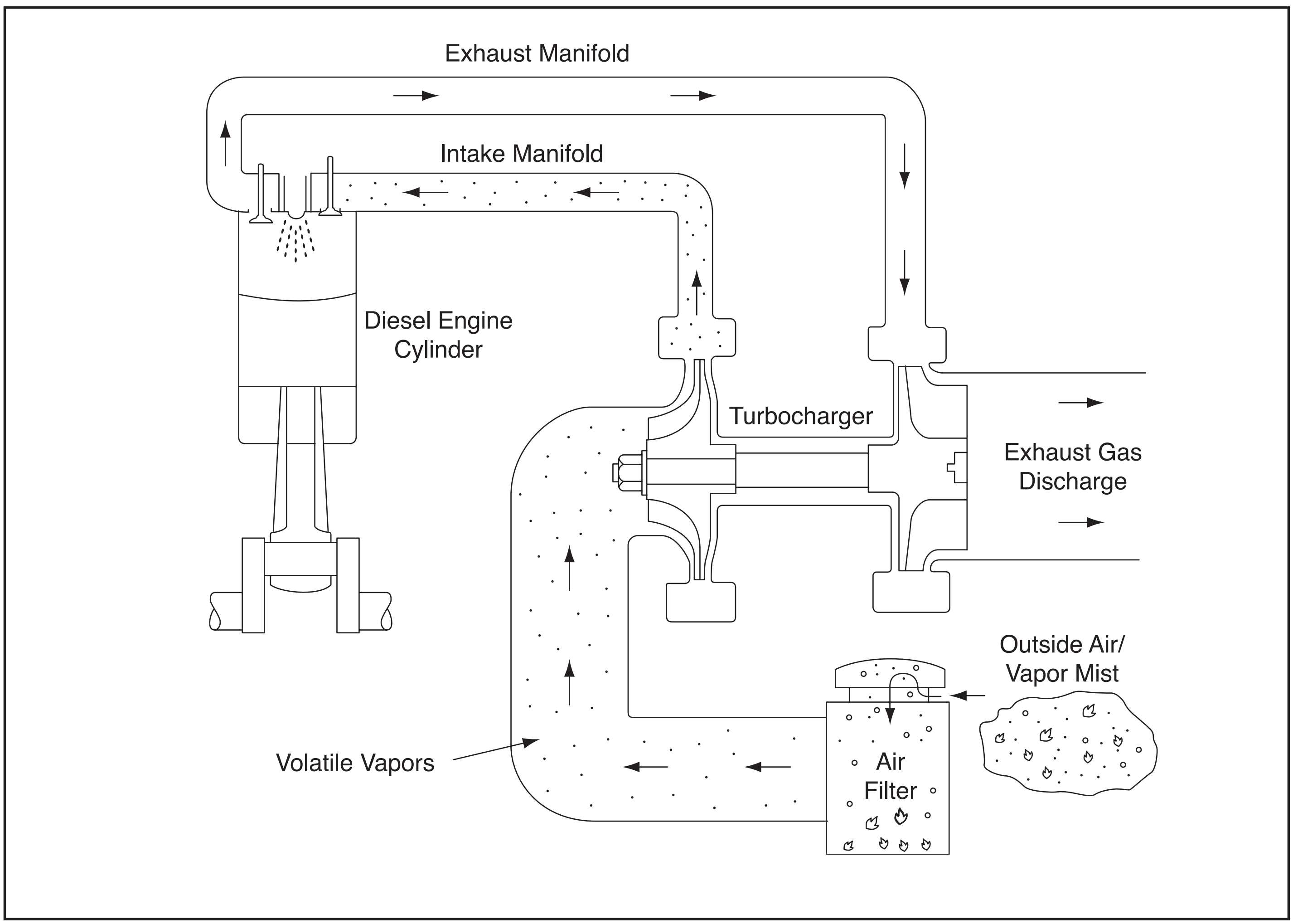

Figure 5 - Typical Air Intake System - 4 Cycle System

valve float, the combustion process is now open to the intake system, igniting the volatile mixture and creating a fire that moves backwards through the intake.

A destructive backfire is evidenced by a damaged turbocharger outlet elbow. Typically, the part is broken off of the turbocharger and "blown" clear of the main fire area (Photo 10). Damage to the 90º elbow and rubber hose (Fig. 6) is indicative of an explosion, not fire damage or heat. Photographs 11a and 11b show the South engine turbocharger with an explosion-induced broken elbow and rubber hose whereas photo 12 shows an intact, albeit melted elbow on the North engine turbocharger.

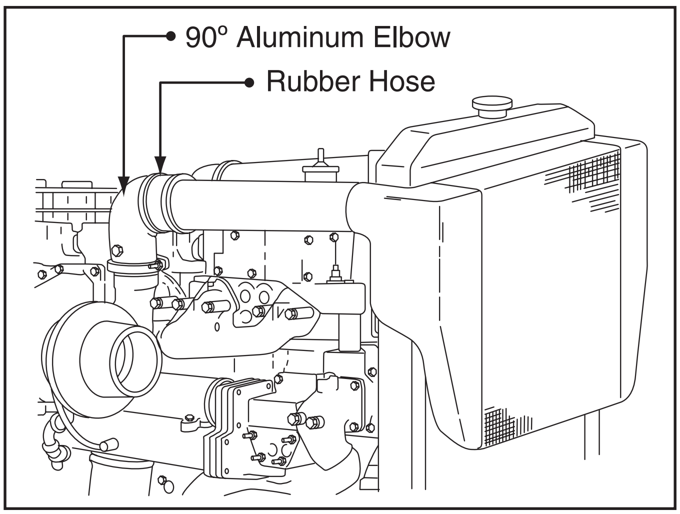

Figure 6 - Turbocharger to Aftercooler Connection

Photo 11a - Turbocharger Outlet Rubber Hose Connection (South Engine) Mechanical Failure

Photo 11b - Turbocharger Outlet Elbow (South Engine) Mechanical Failure

Photo 10 - Turbocharger Outlet Elbow (South Engine)

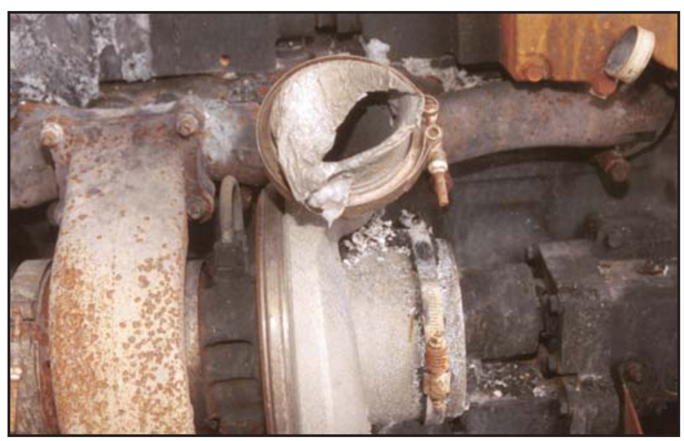

Photo 12 - Fire Damaged Turbocharger Outlet Elbow (North Engine)

The mechanical signatures observed in this investigation were obtained from two complete Cummins N14 engine tear-downs conducted on the same day, side by side.

During a diesel runaway investigation, one should look for other indications of overspeed.

- Worn/broken valve collets
- Cam gear walk-off (Fig. 7)
- Larger valve lash than specified within the engine repair manual
- Valve collet wear markings below the prescribed collet groove (Fig. 8)
- Small cracks on the underside of the valve spring retainers (Fig. 9)
- Loose vibration damper/bolt hole fretting
- Loose flywheel/broken cap screws/bolt hole fretting
- Cam lobe stress marks
- Cam follower(s)/tappets - excessive wear

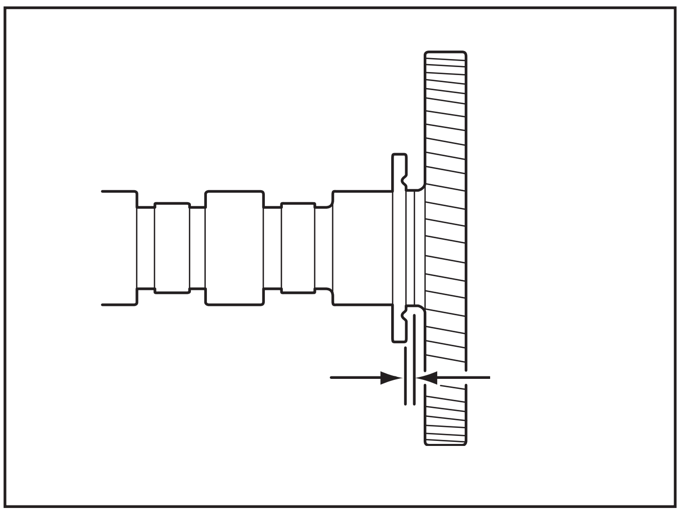

Figure 7 - Cam and Gear "Walk Off" Clearance

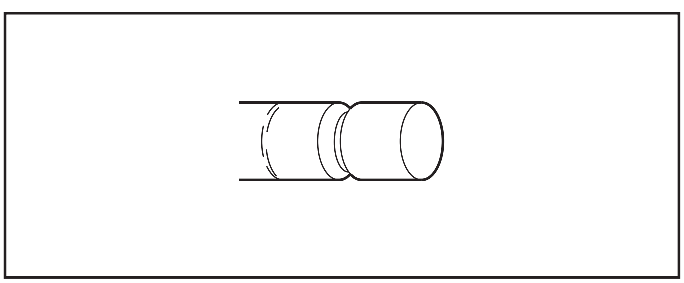

Figure 8 - Valve Stem Showing Damage

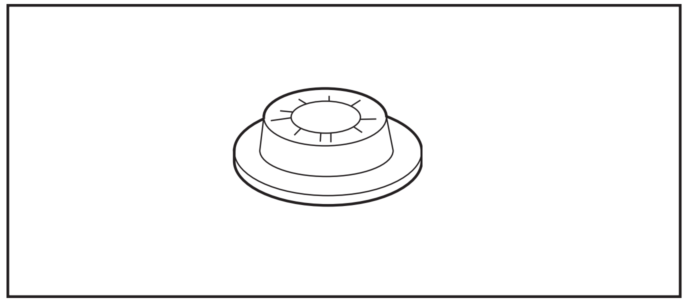

Figure 9 - Valve Spring Retainer Showing Cracks

THE SOLUTION

With all varieties of diesel engines, the common denominator is combustion air. Diesels have a multitude of fuel control schemes but utilize air the same way. Therefore controlling combustion air is the key to absolute engine control during an emergency.

The first and most direct method for eliminating a runaway is to simply shut off the engine at the loading/unloading destination. If there is a need to keep the engine running, an air intake shut-off valve can be installed. These valves come in two varieties: passive and active. The passive system is automatic and sensitive to engine RPM. If the engine exceeds a preset RPM it will shut off the engine by eliminating combustion air. Active systems are usually controlled by the driver by a pull cable or a push button. When activated, a gate swings shut and positively blocks the combustion air path between the air cleaner and the turbocharger resulting in total shut down of the engine (Photo 13).

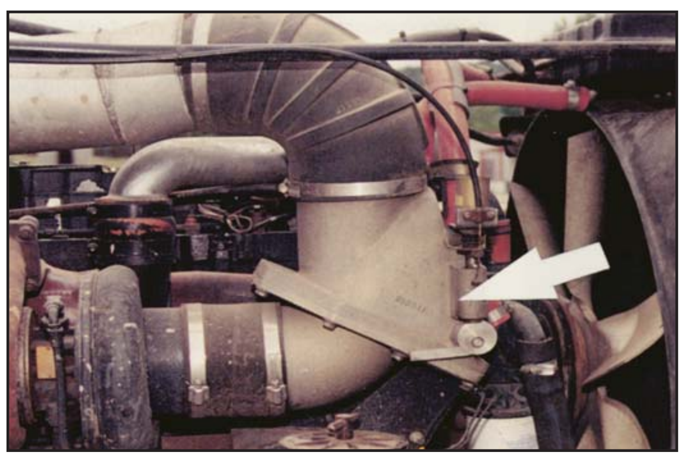

Photo 13 - Installed Air Intake Shutoff Valve

CONCLUDING REMARKS

The purpose of this paper was to put to rest any doubt about what a runaway diesel looks like after the fact. Furthermore, it is to show the mechanical fingerprints which are associated with a catastrophic backfire. In all of the other investigations by the authors only one engine was involved so the conclusive meaning of the fingerprints were difficult to prove. With this investigation, the two side by side engines showed dramatic differences in their internal condition validating the authors earlier theories about this phenomenon.

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