

Reduced Oil Consumption by Laser Surface Texturing on Cylinders

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ABSTRACT

This study mainly focuses on oil consumption behavior of laser textured cylinder bores. The results of an experimental study performed on a six cylinder, 9.0 L capacity diesel engine is presented. The engine has Compacted Graphite Iron (CGI) cylinder block, and parent bore power cylinder design. Both an instantaneous oil consumption measurement method, sulfur-tracing, and a conventional oil consumption measurement method, "drain and weigh", are used in determining the effects of different laser texture parameters at different running conditions. Oil consumption measurement results with the conventional plateau honed surface in comparison with the laser honed surface are also discussed.

INTRODUCTION

Both current exhaust emission legislations and continuously growing customer demand of less operational cost drive the diesel engine manufacturers to take measures in reducing the engine oil consumption.

The major paths of oil consumption in an internal combustion engine can be listed as power cylinder, turbocharger, valve stem seals and crankcase ventilation system. Among these paths, power cylinder has the major contribution to overall oil consumption by 40 to 80% [1].

As far as power cylinder system is concerned, four major mechanisms have been identified; evaporation, throw-off, blow-by and reverse gas flow (Figure 1) [2].

Evaporation of oil from the cylinder surface is highly affected by the surface texture of the cylinder. Smooth surface yields reduced friction, good sealing and good wear characteristics because of the increased bearing area. Oil consumption is also lower compared to a rough surface, because of reduced oil retention [3, 4]. On the

other hand, scuff resistance is decreasing with reduced oil retention. Therefore; cylinder roughness comes out as an important parameter to be optimized.

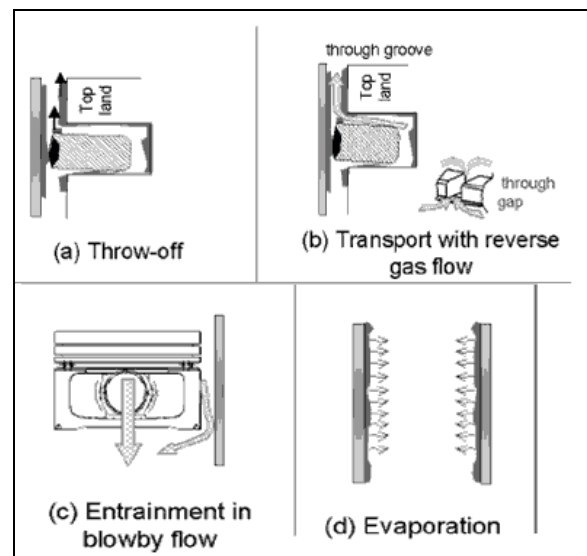


Figure 1. Oil Consumption Mechanisms [2]

Laser surface texturing is considered as a relatively new technology that can be applied to cylinder bores to improve power cylinder performance in different aspects. There are several investigations on lubrication characteristics of laser textured components available in literature [5-10]. These studies are either analytical or experimental investigations on test rigs. There are also results from fired engines published by Abeln et al. [11].

It is expected that major focus of laser textured cylinders for passenger car engine applications is reduced friction and fuel consumption. For medium and especially heavy-duty engines, major focus is expected to be reduced oil consumption since power loss due to friction is relatively smaller fraction of engine power output.

SURFACE TEXTURES AND MANUFACTURING METHODS

Plateau Honing

This method is suggested and widely used by engine manufacturers in order to establish the trade-off between reliability, life and oil consumption. The method involves creating deep scratches, and then removing the peaks by additional abrasive machining, thereby creating the "plateau". Deep scratches retain oil, provide cooling to the contact area and absorb debris, while the plateau provides the necessary bearing area. The latter process, in fact, simulates running in period of the engine, diminishing the initial wear and amount of resultant debris during engine operation. The general appearance of a plateau honed surface is shown in Figure 2a.

Laser Texturing

Laser texturing is recently introduced as an alternative cylinder surface engineering method [11]. Unlike conventional plateau honing, shallow pockets are formed with a laser over a very smoothly machined ($R_a < 0.2$) "base surface" (Figure 2b). Oil retention is provided by these small pockets while smooth base surface provides a large bearing area, which shows negligible wear and reduced friction [12, 13]. The most outstanding feature of this method is that, amount and size of pockets can be increased to certain extent where needed. That means pockets may be formed at a higher density at regions where mixed lubrication condition is dominant, such as ring reversals, while the benefits of a smooth surface can still be utilized in the rest of the stroke. Furthermore, unlike plateau honing, oil retaining features can be distributed evenly to the desired part of the stroke according to a certain pattern.

Plateau honing can be considered as a good solution for power cylinder performance; however, it is not certain that it can provide the best compromise possible. The surface parameters cannot be manufactured in every desired combination since the peaks, valleys and plateaus of the surface are not distinct features that have precise boundaries and they are not independent of each other.

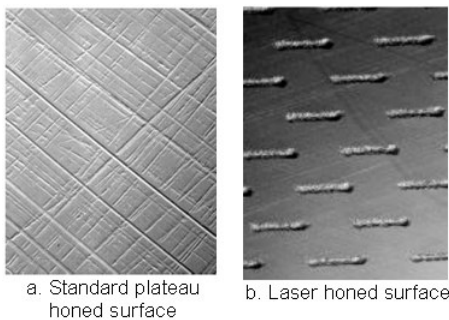


Figure 2. Appearances of Standard Plateau and Laser Textured Surfaces. Courtesy of Gehring GmbH & Co. KG.

The main objective of this study is to investigate the effect of laser surface texturing on lube oil consumption on a heavy duty diesel engine. The study was started with determination of the possible laser surface texturing patterns, in collaboration with Gehring GmbH & Co. KG. Two of these patterns were chosen and applied on Compacted Graphite Iron (CGI) cylinder blocks of Ford ECOTORQ 9.0 L engines. Both drain and weigh and Sulfur tracing methods were used during the experiments to eliminate the drawbacks of each method and to cross-check the results. In order to make a comparison between oil consumption levels of laser textured cylinders and conventional plateau honed cylinders, a similar engine with plateau honed surface was also tested.

EXPERIMENTAL METHOD

A. OIL CONSUMPTION MEASUREMENT METHODS

Drain and Weigh Method

Engine lubricating oil is discharged by following a pre-defined discharge procedure. The drain plug is incorporated with a pipe to discharge only a small portion of oil, instead of discharging the whole oil in the sump (Figure 3). This helps to work with higher consumed oil to discharged oil ratio.

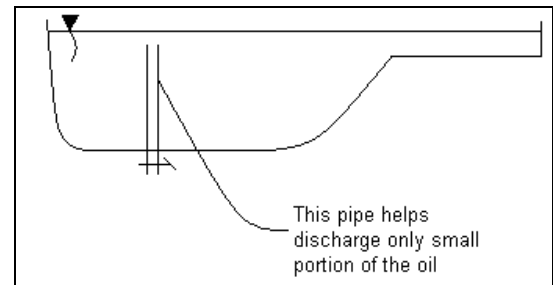


Figure 3. Schematic of the Modified Oil Sump

Five successive measurements were taken before and after test run in order to eliminate the adverse effects of potential noise factors, such as variance in oil temperature and viscosity during discharge, position of the pistons and other moving components, and errors coming from weighing operation. Average of those measurements is considered as the measurement result.

Sulfur Tracing Method

Tracing methods basically depend on the measurement of concentration of tracer material in the exhaust gas. In order to do this, oil enriched with tracer and fuel nearly or completely free of tracer should be used. Then, oil consumption can be calculated based on the conservation of mass. This method provides opportunity for monitoring average oil consumption at different operating conditions in a very short time.

Many tracing materials such as radioactive isotopes [14] or sulfur [15] have been adopted in different studies. In this study, sulfur is the tracer material.

V&F Twin MS mass spectrometer and MT 1000 TS thermal oxidizer were used for measurement of the tracer concentration in exhaust flow. The oxidizer is utilized to convert all S compounds in the exhaust into SO₂. Then SO₂ molecules are directed into the mass spectrometer, which works with IMR (Ion Molecular Reaction) principle. The spectrometer is calibrated with 2.1 mg/kg SO₂ in N₂ gas. Oil consumption is calculated as follows [3]:

$$\dot{m}_{OC} = \left[\frac{32 \cdot (\dot{m}_A + \dot{m}_F) \cdot S_{exhaust}}{M_E \cdot S_{oil}} - \frac{\dot{m}_F \cdot S_{fuel}}{S_{oil}} \right] \cdot 1000 \text{ [g/h]}$$

In order to increase confidence, measurements at each operating point were repeated four times and their average was used for evaluation.

B. ENGINE, OIL AND FUEL SPECIFICATIONS

The tests were performed on ECOTORQ 9.0L Heavy-duty diesel engines at development phase. The specification of the engine is given in the Table 1. Two engines having different laser texturing patterns, Variant 1 and Variant 2, and an engine with standard plateau honed cylinder block were used. Cylinder blocks of all engines were Compacted Graphite Iron (CGI), and have parent bore power cylinder.

Specification of the lubricating oil used for all runs is summarized in Table 2. Sulfur content of the lubricating oil is found as 10410 mg/kg.

1000 mg/kg sulfur fuel is used at drain and weigh tests while the sulfur content of fuel used at sulfur tracing tests is 0.8 mg/kg.

Table 1. Specification of Ford ECOTORQ 9.0L Heavy Duty Diesel Engine

Engine Configuration	6 Cylinder in-line
Fuel Injection System	Common Rail Direct Injection Diesel (1800 bar)
Scavenging System	Turbo-Charged, Inter cooled
Bore	115 mm
Stroke	144 mm
Swept Volume	8.974 L
Peak Firing pressure	190 bar
Rated Power	295 kW @ 2200 rpm
Peak Torque	1600 Nm @ 1600 rpm
Max. Operational Speed	2200 rpm
Max. Cont. Over Speed	3100 rpm
Valve Train	4 Valves/Cylinder

Table 2. Lube Oil Specification

SAE Grade	15W-40
Viscosity, ASTM D 445	
cSt @ 40°C	123
cSt @ 100°C	15.6
CCS, cP, ASTM D 5293	6000 @ -20°C
MRV, cP, ASTM D 4684	29,000 @ -25°C
HTHS @ 150°C, cP, ASTM D4683	4.3
Viscosity Index, ASTM D 2270	133
Sulfated Ash, wt%, ASTM D 874	1.3
Total Base #, mg KOH/g, ASTM D 2896	12
Pour Point, °C, ASTM D 97	-30
Flash Point, °C, ASTM D 92	230
Density @ 15°C kg/l, ASTM D 4052	0.879

C. SURFACE TEXTURE PARAMETERS

Characterization of cylinder surface has been a challenging task and several parameters are used to describe the surface topology. A brief description of these parameters is given below and further information can be found in the related reference [16].

- Ra : Average deviation of the roughness profile from the mean line
- Rz : Average peak to valley profile roughness
- Rpk : Reduced peak height
- Rk : Core roughness depth
- Rvk : Reduced valley depth
- Mr1 : Peak material component
- Mr2 : Valley material component

Summary of cylinder surface roughness readings of the test engines are given in Table 3. The values for the laser textured bores are tabulated in two rows, depending on whether the pockets are included or not. This is helpful to point out how smooth the surface is excluding the oil pockets.

Generally, smooth surfaces having low R_a values are avoided since it promotes ring sticking and may lead to scuffing by experience. On the other hand, base surface of laser textured bores are intentionally kept smooth in order to maintain low oil retention volume, considering the risk of scuff is eliminated by laser etched pockets.

The parameters employed to characterize the laser texture are length, depth, and vertical and horizontal distances between pockets. Since the aim of this introductory study was not to achieve a fully optimized pattern for the particular engine, only two of numerous variants determined in cooperation with Gehring GmbH & Co. KG, were selected for evaluation. The description of the variants is presented in Table 4.