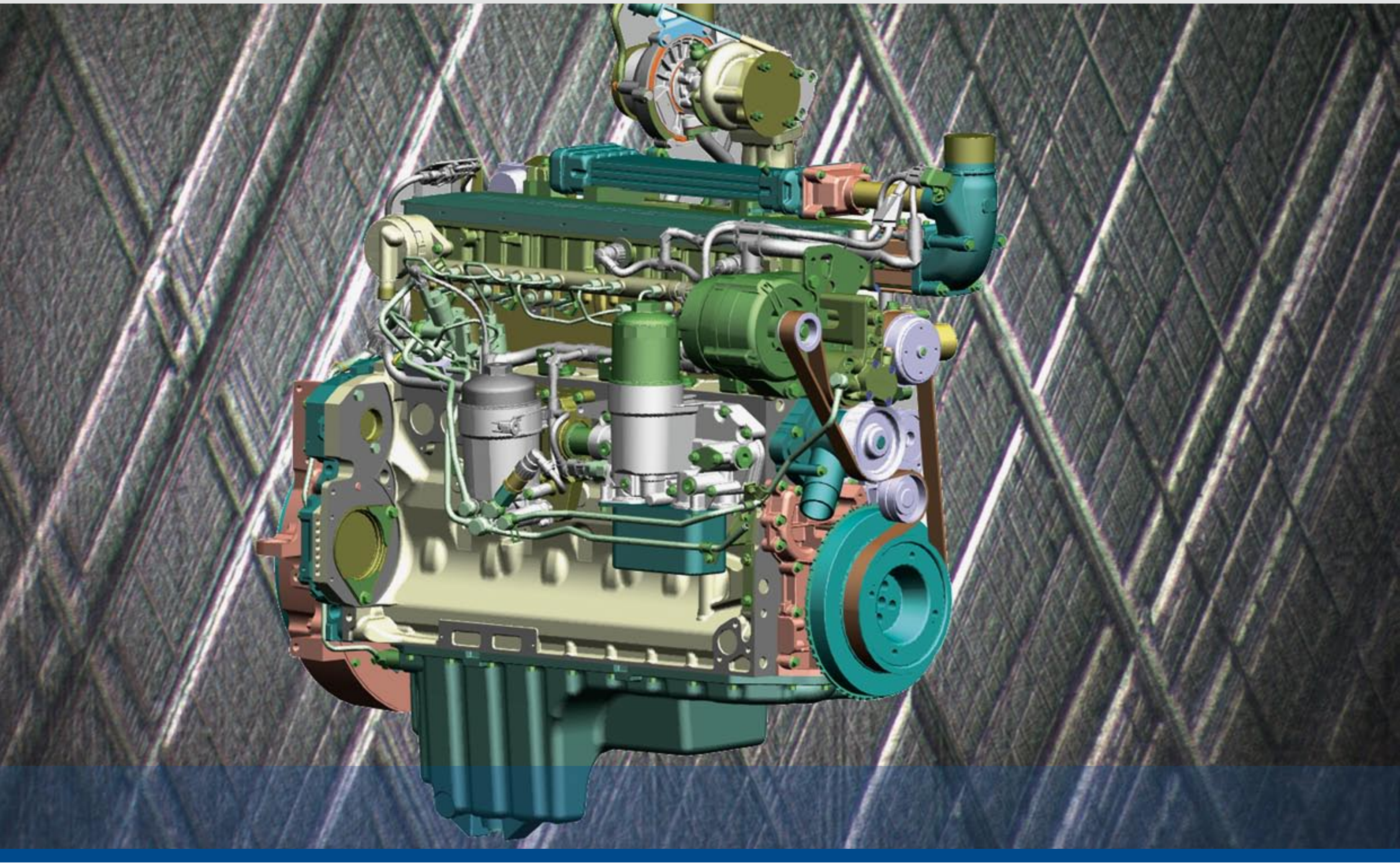

Less Wear and Oil Consumption through Helical Slide Honing of Engines by Deutz

Within the scope of continuous development for the Deutz 2012 engines (4 l and 6 l engines) and Tier 3 emissions standards, new developments are required with regard to achieving a new maximum power requirement of 178 kW at 2100 rpm and a higher EGR rate via cooled exhaust gas recirculation. Without implementing engine design changes, the new Tier III constraints are expected to lead to higher wear in the cylinder unit (cylinder bore, piston, piston rings). Together with Deutz, Nagel found a solution for the expected cylinder unit wear on the existing engine, which not only eliminates the potential future wear problem, but also contributes to the important economic considerations of oil consumption and maintenance intervals.

1 The New Engine from Deutz for Tractor Application

The TCD 2012 L04/6-4V engine, **Title Figure**, was developed within the scope of Tier 3 Standards for a tractor application using a Deutz Common Rail injection system and an e-EGR (water-cooled external EGR). **Table 1** shows the technical data of the engine with a high specific power for Tier 3 engines. The liner-less cylinder unit must be redefined in order for the engine to reliably meet the high demands of service life, oil consumption, blow-by and exhaust emissions.

2 The Cylinder Unit

2.1 Piston Rings

Federal-Mogul piston rings are used for optimizing the piston ring assembly for the TCD 2012 L06-4V engine. The running surface of the piston rings is coated with GDC on the keystone ring of the 1st groove. This is a hard chrome layer with ultrafine embedded diamond particles characterized by high wear and scuff resistance, and low cylinder surface wear [1]. The coating is a further development of the well proven CKS coating (chrome ceramic) of the basic engine. The tapered rings of the 2nd groove are made of a high resistant cast iron alloy and are uncoated. The two-part oil rings, which are also made of cast iron, have chrome-plated surfaces.

2.2 Pistons

A spray oil-cooled aluminium piston without a cooling gallery is being introduced with an enlarged compression height for reducing the bowl edge stress in the bolt axis. In order for the compression height to be increased, the connecting rod length must be shortened. This leads to an increased lateral force. The

Table 1: Technical data of the TCD 2012 L06-4V and TCD2012L04-4V

Motor data		Motor types	
		TCD2012 L06-4V	TCD2012 L04-4V
Mechanical data	**Unit**		
Number of cylinders	Qty.	6	4
Valves/cylinder	Qty.	4	4
Bore	mm	101	101
Stroke	mm	126	126
Cylinder volume	l	6,06	4,04
Performance features			
Power	kW	178	113
Rated speed	rpm	2100	2100
Mean effective pressure (rated power)	bar	16,8	16,0
Torque (Md max)	Nm	1070	657
Speed (Md max.)	rpm	1450	1500
Mean effective pressure (Md max)	bar	21,9	20,8
Fuel consumption (rated power)	g/kWh	213	217
Fuel consumption (best point)	g/kWh	202	202
Mean piston speed (rated power)	m/s	8,82	8,82
Engine output per liter	kW/l	29,4	28,0
Special characteristics			
Exhaust gas recirculation		external	external
Injection system		Deutz-Common-Rail	Deutz-Common-Rail
	bar	1400	1400

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small top land clearance should be carried over by the basic engine.

2.3 Cylinder Surface

The cylinder bore running surface is the parent block cast iron material (linerless) and has previously been plateau honed. Plateau honing was accomplished in three honing stages using ceramic honing ledges at Deutz. As a result of the considerably increased external EGR rate and power, the following problems had to be addressed, **Figure 1**:

- Cylinder bore polishing: Due to the formation of hard oil-carbons, the honing structure in the middle area of the cylinder is eroded.
- Top ring reversal bore wear: This is caused by the transition from hydrodynamic friction in the mixed friction area between the piston rings and the cylinder at TDC (top dead center) during the combustion cycle.

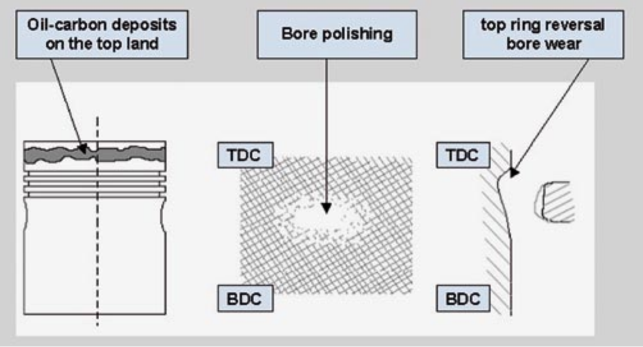


Figure 1: Wear features of the cylinder surface

3 Option for Reducing Cylinder Wear

The cylinder surface should be adapted to the increased demands with regard to wear. The options will be described in the following sections.

3.1 Surface Hardening and Coating

As there are only a few material alternatives to the GG25 crankcase material for the linerless Deutz engines, potential optimization options that do not affect changes to the base material are listed in **Table 2**.

3.2 Cooling of the Cylinder in the Reversal Zone

Through additional cooling of the cylinder in the upper reversal zone, a lack of lubrication due to oil film evaporation in the hot (upper) zone could be prevented. On the 2012 engine model, the thickness of the crankcase cover plate is reduced from 50 mm to 15 mm in the land area between the cylinders so the temperature in the reversal zone is drastically reduced.

3.3 Surface Topography

The material itself remains unchanged with the modified surface topography. The wear reduction is mainly achieved in two ways, which are interrelated:

- reduction of the run-in wear by increasing the material contact area
- reduction in friction by means of improved lubrication in the critical zones.

3.3.1 Slide Honing

As a result of significant progress in the development and application of specialized honing abrasives (mainly of diamond composition), slide honing can generate a surface very close to the „ideal plateau“, **Figure 2**.

The „ideal plateau“ is close to being realized with slide honing. Especially considering that a reduction in the Rpk and Rk values beyond what is practical in a production process is of no further advantage: Even an extremely smooth, “ideal plateau” is roughened again to a small degree after a short running time by the piston ring and the particles contained in the oil (such as oil carbons or chips).

It is important to note, that with the optimized diamond tools of the slide honing, a very small valley width can be achieved, even in combination with the required high Rvk values. These narrow grooves are significant smaller than the surface structure of other honing processes. This formation of frequent, but narrow and sufficiently deep structured valleys, reduces friction and wear in the critical area of boundary/mixed friction. Furthermore, this results in a thin oil film and therefore less oil consumption. This has been confirmed in production with more than thirty applications in use [2].

3.3.2 Helical Slide Honing

An even more consistent way of reducing wear while maintaining low oil consumption was reached by a further process development, which allows for an optimized, steep honing angle (140°) in series production. A typical (< 50°) hon-

Table 2: Surface hardening and coating for bushless engine (parent bore)

	Inductive hardening	Laser hardening	Thermal spray coating (wire/powder methods)	Strain-hardening by lapping
Advantages	Cost effective	Reduced tendency to microcrack, Less deformation	Wear-proof Friction-favorable (depending on method)	Low investment cost
Disadvantages	Danger of microcrack formation (surface breakouts) and macrocracks (great deformation) after treatment	Expensive Reduced hardening depth than with inductive hardening	Expensive process Little knowledge regarding coating adhesion on motors operated for long periods and under extreme conditions	High production cost

ing angle promotes the floating of the piston ring with increasing piston speed (at least in theory). However, the actual problem zones for increased wear and friction are the reversal zones of the piston when piston speed approaches zero; i.e. areas with limited or no existing hydrodynamics.

3.3.3 UV Laser Exposure Treatment

With this process, the entire piston running surface is treated with UV laser exposure. The laser exposure produces a material modification on the cylinder surface with improved sliding properties, **Table 3**. This change allows for less oil consumption and still has a relatively fine surface

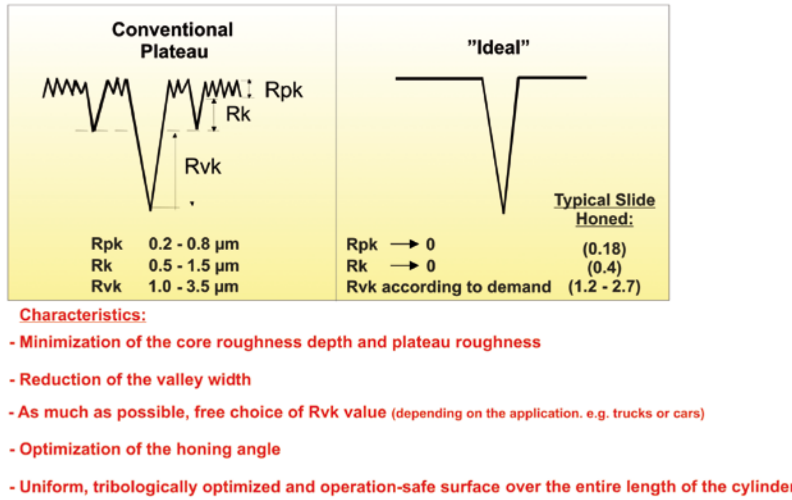
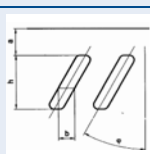
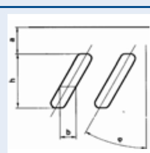
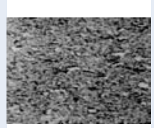
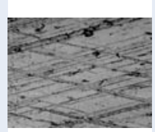
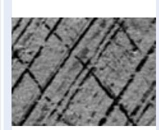
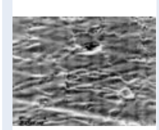


Figure 2: Comparison between conventional plateau honing and slide honing

Table 3: Comparison table of the various cylinder surface treatments

Honing types	Inductive hardening	Laser hardening	Honing lapping	Plateau honing	Slide honing	Helical slide honing	UV laser treatment
Structured area [mm]	20	20	entire length of cylinder	entire length of cylinder	entire length of cylinder	entire length of cylinder	entire length of cylinder
Work steps							
Step 1	Inductive hardening	Laser hardening					
Step 2	Coaxial honing	Coaxial honing	Pre-honing	Pre-honing	Pre-honing	Pre-honing	Pre-honing
Step 3	Honing	Honing	Lapping	Honing	Honing	Honing	Honing
Step 4	Finish-honing	Finish-honing		Finish-honing	Finish-honing	Finish-honing	Finish-honing
Step 5							UV lasering
Surface parameters							
Honing angle [°]	33	33	35	33	40 - 60	140 - 150	45
Rz [µm]	7	7	7,5	7	2,8	2,9	4,99
Rpk [µm]	0,4	0,4	0,8	0,4	0,08	0,1	0,99
Rk [µm]	1,5	1,5	2	1,5	0,33	0,5	1,42
Rvk [µm]	2	2	1,3	2	1,03	1,8	1,05
Topography							
Evaluation							
Costs	+	-	-	++	++	++	-
Proximity to current standards	+++	-	+	+++	+++	+++	+
Process reliability	+++	-	+	+++	+++	+++	+
Chances of success	+++	++	++	-	+	+++	+++

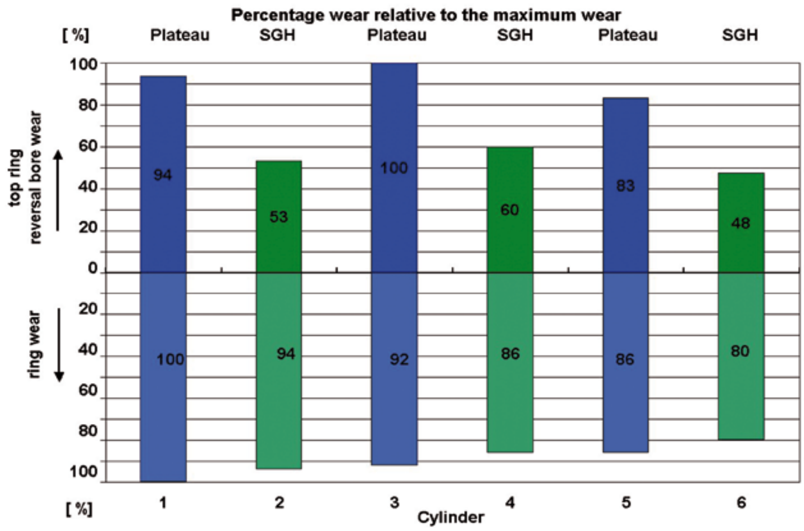


Figure 3: Cylinder and piston ring wear with plateau and helical slide honing

with low wear and friction and high operational reliability. This method has been used successfully for several years in automobile diesel engines with high specific power. However, due to economical reasons and the complex technology involved, it is not possible to carry out an engine running surface overhaul in all countries of deployment. Therefore, this process is no longer being pursued for the Deutz application.

3.3.4 Definition of the Cylinder Surface for Testing

After thorough consideration of the possible cylinder surface treatments available, Table 3, Deutz chose helical slide honing instead of conventional plateau honing as used before. Helical slide honing has many proven advantages and can be readily adapted to most production processes in use worldwide.

4 Engine Testing

4.1 Cylinder Wear: Plateau Honing Versus Helical Slide Honed Surfaces

To investigate the effect of the chosen hone process on wear of the cylinder unit surfaces, an engine block was plateau honed with the production process in cylinders 1, 3, and 5 and helical slide honed in cylinders 2, 4, and 6 at Nagel. The roughness values of the different honing processes were determined at Federal-Mogul Burscheid using a white light interferometer.

The engine was assembled with production parts and tested in a Deutz full-load continuous run for 500 h. After completion of the test, the cylinder wear was measured at Federal-Mogul. The wear of the piston rings was also determined. **Figure 3** shows the cylinder wear in the reversal zone, averaged over the circumference, as well as the associated running surface wear of the piston rings from the 1st groove.

Clearly evident is the reduced cylinder wear (40 % less) of the helical slide honed surface as compared to the plateau honed surface. Piston ring wear, due to the GDC coating, which is known to be extremely wear-resistant, there is only a slight difference between the two honing methods.

4.2 Cylinder Wear After 3000 h (Helical Slide Honed)

To confirm the previous positive results, a engine was subject to an additional 3000 h run test and the cylinder wear measured. The measured wear was much lower than permissible limits (specified by Deutz per 1000 hours of run time) and significantly less than the plateau honed version of the base engine.

To graphically depict the extent of the wear distribution of the cylinder running surface, the measured wear values are shown as isolines in the diagram in **Figure 4**. It is clearly illustrated that nowhere in the cylinder is the wear higher than 15 µm. As known from the wear evaluations of many diesel engines, this measurement is also indicative of the influence of the injection spray on cylinder wear. In the region of injection spray, the lubrication film is partially washed from the cylinder wall, increasing cylinder surface wear.

To document the optical impression and to check for the formation of bore polishing, a picture of the cylinder surface was taken by means of a scanner, **Figure 5**.

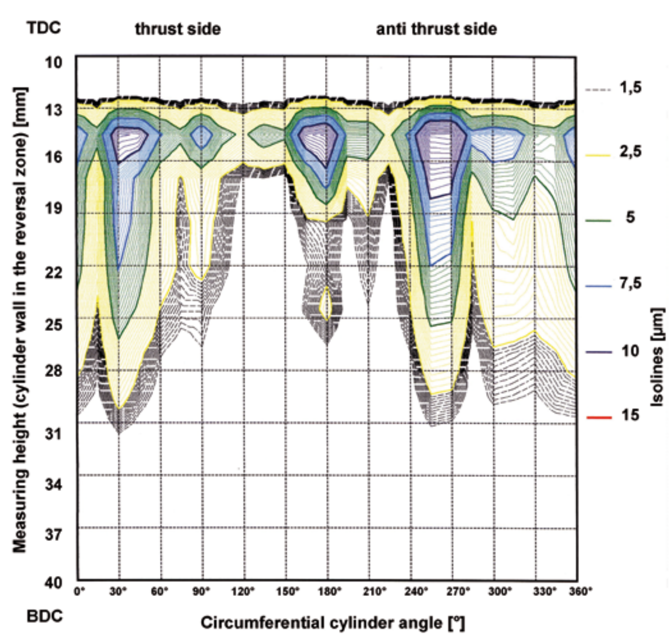


Figure 4: Isolines for the top ring reversal bore wear after 3000 h (helical slide honed)

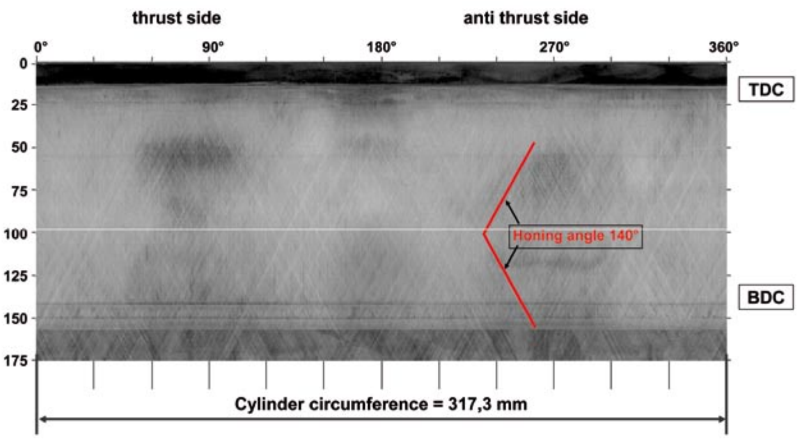


Figure 5: Cylinder scan after 3000 h of continuous running (helical slide honed)

After cylinder scanning, it can be seen that the cylinders have no bore polishing over the entire circumference and through the piston stroke, despite a narrow topland clearance. Honing valleys are still visible throughout the bore and the honing angle of 140°, typical of helical slide honing, is also clearly visible.

Lube oil consumption and blowby behaviour during the relevant engine operating conditions have been investigated using the Deutz endurance cycle test run. In the diagram, **Figure 6**, the results of the 3000 hour continuous run of a helical slide honed surface are compared with a 1500 hour of a plateau honed surface. The increased initial oil consumption measured is due to the measuring equipment and not attributed to either honing quality. Over the test run time, helical slide honing is shown to have consistently lower oil consumption than the plateau honed surface due to the reduced core roughness depths and valley widths. No significant difference in blowby behavior is noted between either honed surface.

In high and low idle running, a reduction of unburned oil in the exhaust system (slobber) could be observed for helical slide honing as compared to plateau honing. Helical slide honing, with its steeper honing angle, leads to a limitation in the oil film thickness at higher speeds, and therefore reduces oil consumption.

The piston shown in **Figure 7** exhibits very low oil-carbon build-up on the top land for the amount of run time and therefore has less of a tendency to create bore polishing. The increase in the lateral force also leads to a good wear pattern on the piston skirt with minimal wear for this long run time.

5 Discussion and Summary

The decision for helical slide honing was confirmed in the engine tests by:

- clear reduction in wear in the reversal zone by 40 % as compared to standard plateau honing (complying with the Deutz limit for 3000 hours of run time)
- no wear due to formation of bore polishing
- consistently low oil consumption over the entire engine run time
- reduction of oil slobber.

With the further engine development the requirement for the reduction of wear, oil consumption and friction will increase. Deutz will be well prepared for the Tier IV emissions levels with a helical slide honing process. For future research, UV laser exposure treatments could be potentially beneficial.

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[2] Schmid, J.: Optimiertes Honverfahren für Gusseisen-Laufflächen. VDI-Berichte Nr. 1906 (2006)

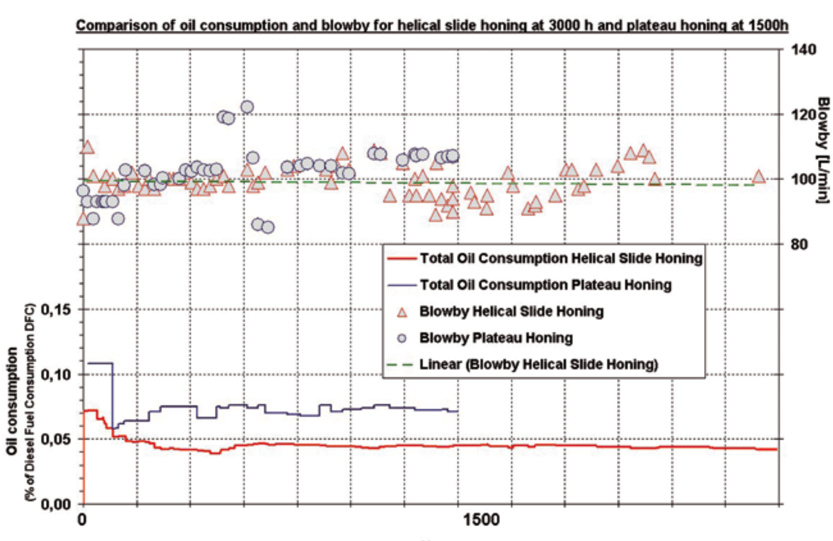

Figure 6: Oil consumption and blow-by comparison for helical slide honing and plateau honing

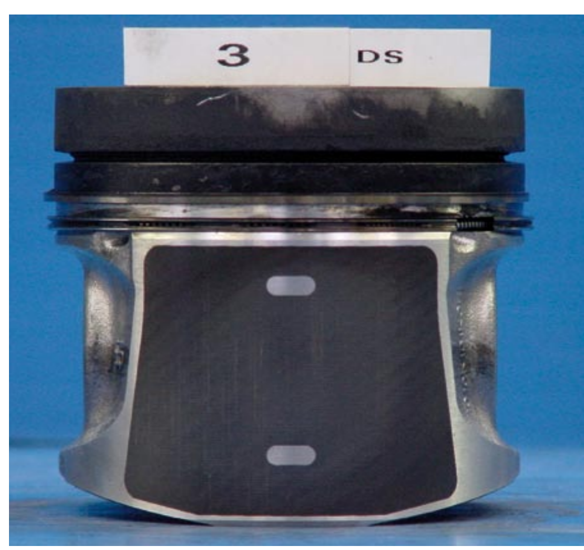

Figure 7: Piston after running for 3000 h