3D optical profilers are enabling reliable engine lightweighting

MICHAEL SCHMIDT,
MARKET DEVELOPMENT MANAGER,
ZYGO

This article discusses the significant role that 3D optical profilers can play in facilitating the manufacture of lightweighted engine components. Lightweighting is a priority for automotive OEMs in their quest to adhere to exacting engine efficiency and emission guidelines, and aluminium and lightweight alloys are fast becoming the materials of choice for engine components, because they both match the strength and eliminate the negative weight implications of conventionally used cast iron.

There have been many initiatives in recent years that are aimed at reducing vehicle emissions and increasing overall efficiency. This has required that the automotive sector focus enormous resources on optimising engine performance. Be it due to concerns over climate change or insulating economies against the vagaries of fuel costs and possible fuel shortages, the race is on to make vehicles that are considerably more efficient but afford the required levels of functionality and attractiveness to stimulate sales and profitability.

Thermal barrier coatings

Automotive OEMs are looking to reduce the weight and increase the efficiency of engines. One area of focus is lightweight and thermally efficient material solutions to replace the cast iron cylinder liners used in cast aluminium cylinders. Viable alternative solutions must be wear- and scuff-resistant as well as have a low-friction coefficient, and one such solution proving popular amongst automotive OEMs is thermal barrier coatings (TBCs).

TBCs are wear-resistant ceramic or composite materials applied to the cylinder walls by way of a spray application. The material hardens to form a much thinner surface, relative to a liner, in the cylinder. To date, the most commercially viable application of TBCs has been through the plasma spray process, since this affords superior wear resistance to cast iron.
Spray coating and metrology requirements

There are some inherent issues in the spray coating process that require the implementation of rigorous quality management procedures and measuring protocols. For instance, at the high velocity that the coating is applied to the cylinder wall, a splatter morphology occurs and this can lead to an inconsistent coating. Properties of the coating such as porosity, microhardness, thickness, adhesion and strength are essential metrics in assessing its viability and provide important tools for identifying the process parameters that need to be changed to achieve an optimum coating.

The non-deterministic porosity distribution across the surface of the cylinder after spraying requires the use of a metrology technology that is able to reliably, repeatably and accurately measure the three phases required to produce a lined cylinder, namely:

- mechanical activation,
- thermal spray application, and
- post-spray finishing.

Any metrology solution used to assess the surface characteristics of a spray-coated cylinder must be able to provide highly accurate measurements at all three phases of the process, transitioning from very rough to very smooth. This range of surface textures requires a metrology solution that employs coherence scanning interferometry (CSI) technology such as a ZYGO 3D optical profiler. CSI can capture data pertaining to a vast array of surface heights and textures.

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Mechanical activation

For the mechanical activation/pre-coating phase of the process, the cylinder walls need to be scored, but this needs to be strictly controlled as it dictates the amount of TBC that is to be applied; too thin, and the TBC might flake off, too thick, and the honing process might remove the peaks that contain the TBC. Either of these scenarios can compromise the quality and efficiency of the cylinder coating process. CSI allows ZYGO’s 3D optical profilers to cater for these step height surfaces by enabling accurate and repeatable measurement of structures down to 250 μm.
**Thermal spray application**

Following application of the TBC, automotive OEMs need to assess how the pores have developed. The variety of pore sizes, ranging from 50 µm$^2$ to over 1 mm$^2$, help to determine the lubricity retention of the newly sprayed surface. As these pre-honed coatings are typically very rough and have low reflectivity, some CSI systems have difficulty acquiring pore size data from the surface. However, the acquisition method on ZYGO’s 3D optical profilers means that this type of surface can be easily measured, thus providing consistent metrics for process engineers.

**Post-spray finishing**

Finally, it is necessary to analyse the finished surface texture of the spray-coated cylinder, checking crosshatch as well as final porosity (pore density, pore volume by area and change of pore size by cylinder depth). ZYGO’s 3D optical profilers are able to comfortably transition from providing the very rough pre-honed surface measurements required in the previous two phases to the very smooth honed surface measurements essential in this final phase. The development of the profilers’ acquisition and processing methods has enabled them to provide measurements of steep and difficult to access surfaces as well as highly polished surfaces.

**ZYGO 3D optical profilers**

**Coherence scanning interferometry**

CSI extends interferometric techniques to surfaces that are complex in terms of roughness, steps, discontinuities and structure. Additional benefits include the equivalent of autofocus at every point in the field of view and suppression of spurious interference from scattered light.

CSI enables ZYGO’s 3D optical profilers to deliver sub-nanometre height precision at all magnifications as well as analysis of a broad range of surfaces (from very rough to extremely smooth and including thin films, steep slopes and large steps) quickly and precisely. They are therefore ideally suited to applications such as that of the spray-coated cylinder.

ZYGO’s 3D optical profilers offer hundreds of reportable parameters for measuring surface structure and texture across varying surface scales, including areal surface roughness to ISO 25178 standards and 2D profile standard compliance to ISO 4287/4288.
Fax film is an extensively used alternative metrology technology. It involves affixing a thin plastic sheet to the cylinder surface and applying a solvent to soften and conform the sheet to the surface. After the sheet has been removed and sufficiently hardened, it is manually inspected under a microscope. This technology is messy and can result in very subjective results.

Other metrology technologies tend to perform sub-optimally if the surface texture is considered relatively smooth, for example, confocal and focus variation technologies require a certain level of texture on the surface to be able to resolve that surface. An important advantage of ZYGO’s 3D optical profilers is that they are non-contact, eliminating inadvertent compromising of surface integrity. In addition, CSI enables exceptionally high vertical resolution measurement agnostic of the interferometric objective.

**Mx software**

It is through ZYGO’s Mx software that the CSI data is processed and interpreted, enabling the quantification and visualisation of results. Mx drives system control and data analysis through features such as interactive 3D maps, interactive data plots that show full area data in 2D or 3D, intuitive navigation, quantitative topography data, statistical process control (SPC) and control charting and pass/fail limits.

Mx ensures that ZYGO’s 3D optical profilers are able to measure very rough and very smooth surfaces in an easy-to-assess and timely fashion. The analysis of TBCs must be undertaken in-process, thus affording high accuracy and repeatably at sufficient speed to ensure that the coating option for the cylinder lining is economically viable.

Mx uses a simple workflow-based concept, allowing the manufacturing engineers analysing the extent and uniformity of the TBCs to easily

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navigate the metrology experience from set-up through analysis and reporting. The software presents the results of its data analysis in ways that enable users to easily and quickly visualise measurements and assess results, thus facilitating fast and reliable decision making. This, in turn, has a huge impact on process development of cylinder spray coatings, leading to higher efficiencies and quality improvements.

**Summary**

The automotive industry is at the forefront of the development of technological solutions that mitigate the effects of pollution and harmful emissions. By utilising innovative materials and methods to produce modern, lightweight internal combustion engines, manufacturers can minimise fuel consumption and boost overall engine efficiency. A prime example of this progress is the development of cylinder spray coatings, namely enabling aluminium alloy engines to incorporate robust tribological materials in harsh environments such as the cylinder combustion chambers.

The nature of the coating process and the viability of the finished coating demand the use of extremely accurate and repeatable metrology tools to ensure conformance to required surface porosity specifications. The measurements needed to analyse the spray coatings can only be provided by metrology tools that are able to measure both very rough and very smooth surfaces.●

Reference


Zygo Corporation
www.zygo.com