Vehicle Powertrain Engineering and Machining Process Optimization

C.W. "Ron" Swonger

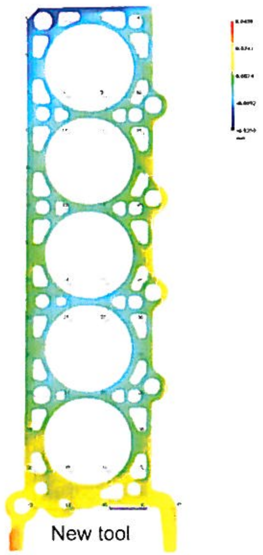
U.S. Marines assigned to the 1st Marine Logistics Group (MLG) drive a Cougar H 4x4 Mine Resistant Ambush Protected (MRAP) vehicle through desert terrain near Camp Taqaddum, Iraq, Nov. 29, 2008. Today's up-armored tactical vehicles face the need for improved engineering designs and manufacturing processes for their powertrains to maximize horsepower-to-weight ratios and fuel efficiency. Well-engineered systems components, especially in powertrains, propulsion systems and transmissions, increase reliability and sustainability and help reduce costly maintenance repairs in high-operational-tempo environments. (U.S. Marine Corps photo by SGT Jason W. Fudge.)

Today's military vehicles, as well as civilian vehicles of all types, face the need for improvement in multiple technically challenging dimensions. Improved engineering designs and manufacturing processes for these vehicles' powertrains offer the best opportunity for achieving improvements toward four critical objectives: maximizing horsepower-to-weight ratios and fuel efficiency and minimizing emissions and the potential for leakage of combustion gasses and fluids that leads to engine or transmission failure.

The keys to continuous improvement and control of powertrain engineering and manufacturing are a comprehensive knowledge of processes and an understanding of how part design relates to what a process actually produces. To be useful, this knowledge must be complete, timely and actionable. Technology research and development (R&D) has been packaged into metrology and defect detection solutions to provide such knowledge in plant-floor-ready form. Continuing R&D and factory floor validation programs are adding to this arsenal of proven engineering and manufacturing process optimization tools.

Powertrain Machining Process Critical Factors

Modern competitive powertrains must be powerful, efficient, "clean" and reliable. Strategic, mission, competitive, economical and environmental demands all call for facing these requirements simultaneously. Down in the trenches, where powertrain



In the 3-D HD holographic surface point clouds displayed here as color coded height maps, dozens of surface points are measured per square millimeter, each to an accuracy of 1 micron. The color coding shows high spots on the surface as red, low spots as blue and intermediate-height spots in a range of yellow and green shades.

The red circles on the right-hand 3-D holographic surface height map of this V10 engine block deck face show the zones in which the surface flatness has deteriorated and fallen out of specifications due to CNC cutting tool wear after 1,800 engine blocks have been processed with the same tool.

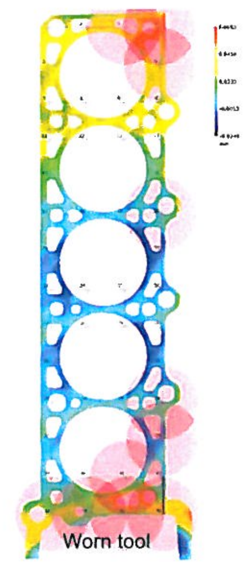


Figure 1.

critical mating parts and sealing surfaces are designed and manufactured, these multiple demands lead directly to specific requirements for:

- Mating surfaces that are flat — to within microns to reliably fit — and do not deform under high fastening forces.
- Surfaces that will not leak under increasingly high internal pressures that high-performance and high-fuel-efficiency designs require.
- Machining process operations that optimize tool changing actions, minimize tool breakage incidents and minimize production of defective parts made by worn and damaged tools.
- Detection of surface defects, including surface porosity and other machining artifacts, that lead to internal leakage or high-cost failures after powertrain parts are subjected to expensive downstream testing.
- Timely detection of process drift and machine failures causing machined features to be incorrectly located, incomplete or missing.
- Detailed comparison of parts as designed with computer-aided design (CAD) or simulation data and parts as actually built with 3-dimensional (3-D) measurement point clouds so deviations can be understood and processes or designs changed to achieve desired vehicle performance and other results, as illustrated by Figure 1.

High-Definition (HD) 3-D Technology

For more than 50 years, powertrain engineering and powertrain manufacturing were severely limited by inability of technology to supply comprehensive and timely information to enable product design, process launch and process control to fully address the factors previously listed. However, necessity breeds invention, and technologies advance as necessity requires and innovation occurs. Four critical core technologies have come together to make feasible — and deliver into engineering and manufacturing facilities — the value of rapid HD powertrain information capture and interpretation to deal with performance and reliability factors. Those core technologies are:

- High-resolution, affordable, digital photo-sensor technology, where many million samples of a manufactured surface can be captured in milliseconds without contacting the surface.
- Increasingly powerful image processing technology that benefits from *Moore's Law*, which is the prediction that transistor density on integrated circuits will double approximately every two years, leading to increased functionality and performance and decreased cost.
- Multi-wavelength laser technology, enabling the creation of instruments and gauges that measure manufactured surfaces to one micron accuracy, which is 1 percent of the diameter of a human hair, while sampling surfaces at dozens of samples per square millimeter in seconds.
- Measurement and visualization algorithms implemented in software, tying together the three technical revolutions listed above. This software technology produces visual answers that are immediately understandable and actionable by knowledgeable manufacturing processes or product engineers.

In the current era, in a sequence of ongoing industrial certification tests and experiments, it has been clearly demonstrated that powertrain engineering and manufacturing can obtain in seconds sufficient knowledge to engineer and manufacture superior powertrains. This replaces incomplete, often invalid, data that legacy devices provided only hours or shifts later after the corresponding part was produced. Working with HD metrology specialists at Coherix, Inc. and the University of Michigan Wu Manufacturing Research Center, powertrain engineering and manufacturing experts in vehicle manufacturing plants and laboratories in North America, Europe and Asia are continuously augmenting the repertoire of HD metrology knowledge production and achieving significant savings in modern powertrain design, launch and production.

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Knowledge Gems Gained

The mating surfaces of vehicle transmissions, engines, pumps and other critical assemblies must be flat to within microns to remain firmly sealed together. Under increasingly stressful high-pressure situations, shape fluctuations along the surface — "surface waviness" —must be minimized so combustion gasses, lubricants or cooling fluids do not leak, as depicted in Figure 2. The ability of gaskets to conform to an engine's shape, cylinder head and transmission part surfaces must be accurately modeled so any potential for leakage is evident before assembly occurs. Microscopic pores in machined surfaces that could produce leakage must be detected before surfaces are sealed together and expensive further powertrain manufacturing occurs. Precision part fastening into assemblies and mechanisms must not be allowed to distort parts in ways that would cause failure in field use. In combat, engine or transmission failure means much more than a dissatisfied customer.

Actionable Information as Opposed to Data

For years, supplying digital data representing precision part measurements has meant burying users in massive, incomprehensible numbers. Ironically, the massive numbers still produce final results missing 99 percent of critical surfaces. Often, data could not be understood within time spans that would allow process-correcting actions to avoid defective part production. Too often, these older manufacturing measurement methods left manufacturing engineers, product engineers and machine operators wondering about the rest of the story. To use a baseball analogy, it was like trying to discern who would win the World Series by watching only the season opener. In short, measurement systems produce too little data, too slowly and too late.

Currently, data results are derived from measuring the entire surface of a part to produce complex maps, or holograms,

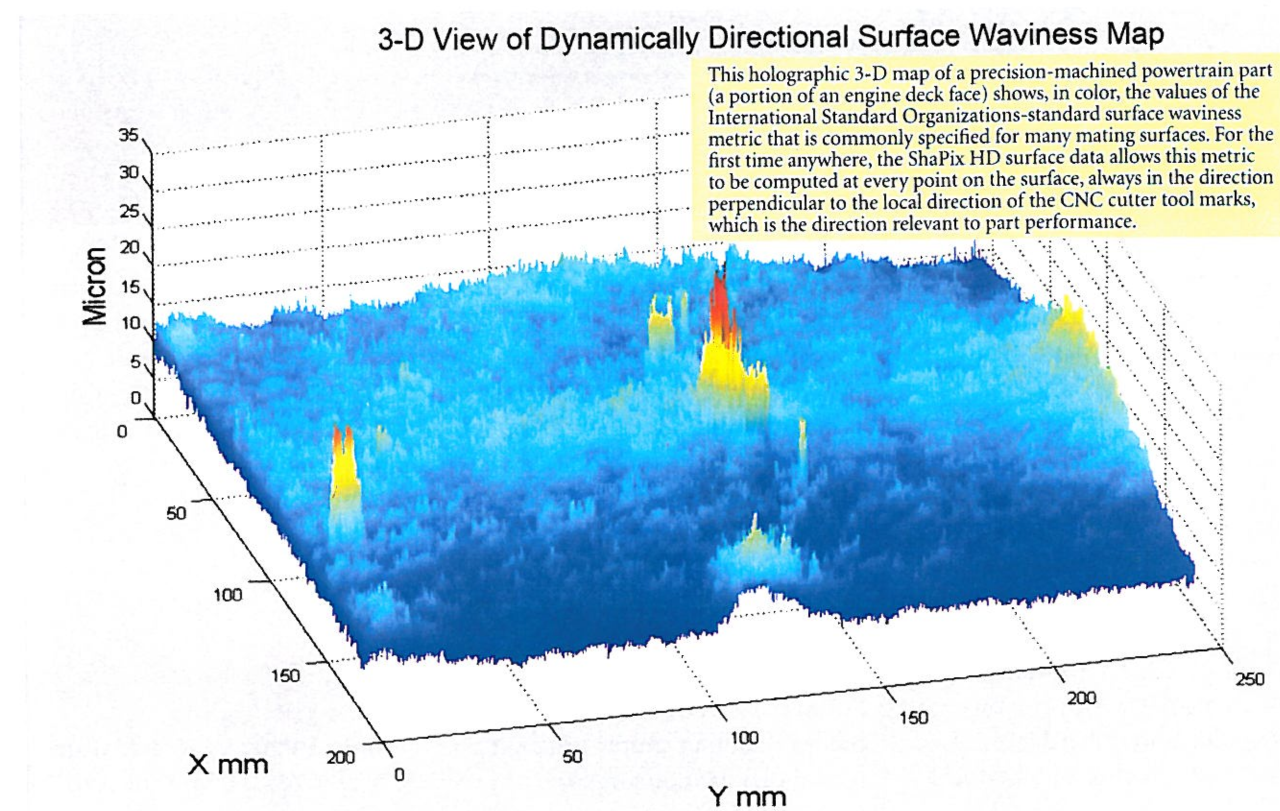

Figure 2.

A 3rd Infantry Division Soldier walks toward an M2A2 Bradley infantry fighting vehicle at the conclusion of a security patrol in search of weapons caches near a village southeast of Salman Pak, Iraq. Today's military vehicles must be highly responsive to a variety of operational environments and battlefield deployments. Powertrain engineers and manufacturers must have a comprehensive understanding of how part and component design relates to the end user's exacting specifications. (U.S. Army photo by SGT Timothy Kingston.)

of part surfaces. Looking at color-coded, HD, 3-D maps of machined surfaces identifying microns of surface differences is a revelation. Figure 3 provides a 3-D, HD, holographic, micron-level measurement of the multisurface flatness, paralleslism and separation of four precision-machined surfaces on a vehicle powertrain torque converter case. Today's knowledgeable manufacturing floor personnel can understand immediately what must be adjusted on which machine without needing any new training whatsoever.

The Real World of Powertrain Manufacturing

Micron-level, full-surface measurement of powertrain parts is far from the simple world of measuring small components in an optical laboratory. Single powertrain surfaces may have an area of several square feet. The relationship among multiple surfaces on a single large part may be vital to its performance. Surfaces may be separated by inches such that simple optical techniques cannot compare them. The measurements must be performed close to where the parts are made and must be made quickly. Then a significant fraction, or perhaps all, of the parts can be measured and confirmed before defective parts may be produced. The ShaPix holographic interferometer system family is routinely used in that operational plant floor environment to provide actionable process information where microns matter.

The Engineering and Manufacturing Value Equation

The value of HD, 3-D, micron-level surface metrology begins when each precision part is being designed and prototyped.

It continues as process launches occur and pilot production is accomplished with minimum downtime and as few production cycles of unacceptable parts as possible, while all of the CNC machines are dialed in. The value keeps flowing in as process operations continue, productivity needs to be optimized and scrap and downtime need to be pushed toward zero. The typical time to recover the new measurement and defect detection system's cost is a few weeks or months, and the value continues to be delivered indefinitely. Meanwhile, R&D from multiple Michigan universities, with guidance from multiple collaborating civilian vehicle manufacturers, are adding to the repertoire and identifying additional applications for HD, 3-D technology. To complete the continuous deployment process, Coherix, Inc. performs the role of packaging these ongoing technology enhancements into fielded industrialized systems delivered to powertrain plants from Michigan to Georgia and beyond.

Proving the Point

As with any game-changing technology, healthy skepticism is to be expected and must be overcome before widespread acceptance occurs. Ann Arbor, MI, the birthplace of HD holographic measurement technology and

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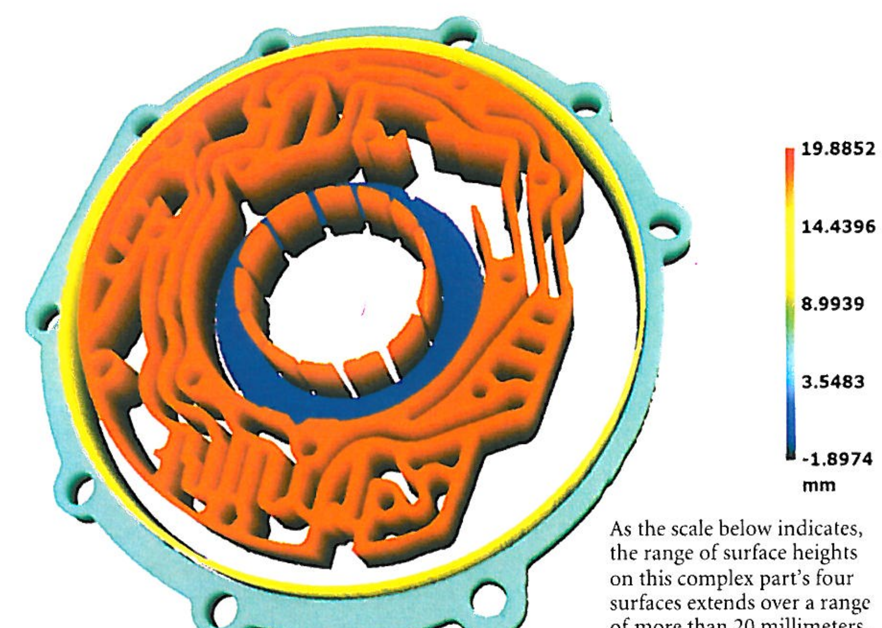
where holography was originally demonstrated and applied for government use, was the ideal venue for proving the technology's benefits and value. Nearby powertrain plants of all domestic vehicle manufacturers have applied ShaPix Surface Detective systems to hundreds of different powertrain components across many vehicle lines. The technology has been subjected to industrial concept-ready and implementation-ready certification processes for more than four years for off-line and in-line production cycle times and in real-world powertrain plant environmental conditions. ShaPix systems have been delivered to multiple manufacturers and multiple sites per manufacturer, in multiple countries. The value delivered and the record of providing continuous manufacturing and engineering benefits is well established. Tier 1 suppliers, machine tool makers and system integrators have also learned that that they can supply parts or machines to end-user vehicle manufacturers more competitively by ensuring that the results consistently meet their micron-level specifications.

The National Bottom Line

In the current era, cost competitiveness and quality delivery are key prerequisites to the survival of U.S. manufacturers in many processes across all industries. Michigan-based research, development and application teams from multiple organizations are collaborating to make precision machining processes and their operating companies globally competitive. These revolutionary powertrain engineering and manufacturing solutions are available to employ for any organization seeking to outperform the ground systems, air systems and marine systems communities' rising demands, just as they have delivered results in the civilian sector.



As the scale below indicates, the range of surface heights on this complex part's four surfaces extends over a range of more than 20 millimeters. They are measured to 1 micron accuracy.

Figure 3.

C.W. "Ron" Swonger is Vice President, Advanced Technology for Coherix, Inc. He has technically contributed to, and led, development and delivery of advanced solutions for military targeting, machine vision, industrial metrology and other image-based applications for more than four decades. He served for six years on the U.S. Army Science Board. He holds a B.S.E.E. degree from Tufts University and an M.S.E.E. degree from the Massachusetts Institute of Technology.