Evaluating Engine Health From the Inside

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Nearly indestructible 40 kHz SenX sensors connect to a PicoScope oscilloscope on one end, and either the oil dipstick tube or exhaust pipe on the other to simultaneously test and evaluate the lower and upper engine, respectively....

It was one of the most unusual demonstrations of a new technology I'd ever seen. Doug Strock, President of Predictive Fleet Technologies (PFT), suggested we meet somewhere halfway between his office and mine. That put us in the largest parking lot near the freeway exit that merges into the Flint, MI, business district. It just happened to belong to the local Hooters.

In the cold, gray winter drizzle, Strock pulls a small Pelican hard case out of his fourth-generation Chrysler minivan, and begins setting up the system. This requires hooking a thin cable and connector to each of the SenX piezoelectric sensors, and then to the corresponding inputs on the PicoScope automotive oscilloscope. As Strock clamps the blue silicon hose attached to the business end of one sensor to the exhaust pipe (to measure the upper engine), and pushes the clear tube of the other into the 3.8-liter V6's dipstick tube (to measure the lower engine and crankcase), the drizzle turns to a cold, hard sleet. Quickly bringing the Engine Angel software up on his laptop, he selects the engine to be tested from a drop down menu, confirms there are two waveforms moving across the screen, and raises the engine speed to 1,500 rpm. When a steady signal appears, Strock presses the space bar to capture the trace, saves the file, and sends it out for an assessment. In less than two minutes, the Engine Polygraph evaluation is on the desktop. And, as if on cue, the rain/sleet combination abates.

How it works.

"My background is physics and mathematics, with 40+ years in mathematical modeling of physical, logistics and business process," says Jim Mentele, the man behind the Engine Angel and Engine Polygraph software. "I started looking at the [PicoScope's] FirstLook waveforms with the intent of 'deciphering' the story it was telling." Certain there would be variations, Mentele wanted the ability to classify all input signatures by manufacturer and model, so he and his team developed a table of internal combustion engines complete with firing sequences and "other [relevant] details".

....Scored on a 1-10 scale, the results assess the mechanical health of the engine, and provide an analysis of where any problems are located. Testing takes about two minutes in the field. Built on a neural network platform, the

Mentele and his crew kept the test rpm near 1,500 rpm to make it easy to visualize the differences as, at this rpm, all the cylinders behave about the same in a good engine. The curve that captures the pressure variations is then extracted and represented graphically as a colored line. "Then we subtract that pressure curve from the original to get the residual 'higher frequency' curve for further analysis," says Mentele.

This is done concurrently for both the upper and lower engine, with the exhaust sensor curve showing the gas from the cylinder most clearly. That is analyzed to calculate the rpm where the cycle is seen to be repeating, and from this the software solves for the cylinder boundaries based on inflection points in the pressure curve. "At a convenient point," says Mentele, "we start the analysis by cylinder, with most of the action taking

Engine Angel/Engine Polygraph software that drives this output in the future will expand to reliably detect nearly a dozen specific engine defects.

place from combustion (or the lack thereof) in the crankcase during the power stroke via blow-by. In a four-stroke engine," he continues, "we shift the curve by 1/4 of the four-stroke cycle time so that, when we display the data, the exhausting cylinder's graph is aligned with the same cylinder's crankcase curve when it was in the power stroke." This is just the start of the process.

According to Mentele: "We then extract and quantify several sets of higher frequency variations to find physical variations of smaller sizes." These can take the form of cam lobe pits not more than one millimeter in size, for example. A set of frequencies is bracketed to look for high amounts in that range in the residual signal. "At a higher frequency, 'turbulence' can be detected in the airflow of the exhaust, and teapot whistling can be measured from valves leaking due to carbon deposits on the valve seals." These measures are scored as "Volumetric Efficiency" and "Valve Seating" from the exhaust, and — in the next version of Engine Polygraph — "Rumbling and Scraping" from the crankcase. (Scores range from 1-10, with the lower the number the better.) Mentele concludes his mini dissertation by observing: "The analysis is complicated by the fact that, at any instant, the sensor is collecting all simultaneous pressures from all of the cylinders in the receptive region. So we allocate the curve to a cylinder assigned to each portion of the stroke (720°/number of cylinders), so the high frequency from a cylinder in the power stroke will occur while another cylinder is exhausting." In addition, work is proceeding on development of cylinder-by-cylinder analysis that will reliably detect about a dozen specific engine defects, ranging from wearing and fractures to carbon accumulation.

On the assembly line, and in the lab.

Engine Angel and Engine Polygraph are integral to Predictive Fleet Technology's goal of creating a fleet management system that integrates engine health and maintenance information; predictive failure analysis; and weather, road, traffic and various other data to improve trip efficiency and reduce cost. (And, yes, they see it as part of the autonomous mobility fleets with which the industry is so enamored.) However, it was the ability to diagnose the persistent lack of power in one fleet's engines that suggested a new use for the test and analysis software.

End-of-line testing with this technology could be completed in less than a minute with dedicated hookups and engine-specific software. Though it would require development of a database and scoring models, the information gained could discover problems prior to shipment, and also be used to compare this information with dealer-generated engine signatures gathered during routine service. This offers myriad opportunities for OEMs, from predictive failure analysis to process improvements to creation of performance and efficiency enhancements, and more.

"No amount of investigation by the fleet owner's mechanics could explain why the engines performed so poorly on the road," says Doug Strock, "especially since no OBD code was generated." The lower engine test returned solid ratings of four, while the upper engine was consistently near the limit at nine. "The scores showed us where the problem was," says Strock, "and we discovered that his 14-liter diesel engines had come from the factory with heads for the smaller 12-liter engine." In addition to getting the affected engines repaired under warranty, this event showed the system's potential effectiveness in a production setting.

"Currently, our test takes about two minutes to run, but with specialized adapters and a consistent throughput, this could be cut in half on the assembly line," Strock claims. Because it "interrogates" the upper and lower engine, a number of defects could be uncovered quickly, with subpar engines sent back to the repair line along with an analysis of where the problem lies. Getting to this point, however, will take some effort, though how much is open to interpretation.

"Whether tens or thousands of engines will have to be tested in order to create a database," says Mentele, "depends on the number of variations expected as favorable versus those that are considered defective, and what you are looking for." Direct injection, port injection and hybrid (direct and port) injection can affect blow-by, and — if the engine doesn't have a PCV valve — the crankcase will look quite different. "This doesn't invalidate cylinder-to-cylinder analysis," says Mentele, "but it does prevent you from directly comparing different engine designs." In addition, variable valve timing has its own effects on signature shape, and this would require changes to the scoring model based on expert input in order to create meaningful training sets. However, as Strock is quick to point out, "This is a learning platform, a neural network platform. So, the more data we get, the better the Engine Angel database and the Engine Polygraph analysis get. In an OEM setting, it should be possible to dial it in very quickly, and — because this testing is repeatable and scalable — it can be expanded to do real-time evaluations during the research, design and development phases."

Currently, Predictive Fleet Technologies and Kettering University are using Engine Angel and Engine Polygraph to evaluate the differences in conventional and synthetic oils. PFT also has analyzed specific gasoline and oil additives for their ability to remove carbon deposits ("You could 'see' the carbon being removed," says Strock.), and consulted with racing engine developers. He and Mentele, the only two people working full time on the technology, have a number of developers under contract, and have invested more than $1 million in its development. Yet they are still in search of that first contract that will break things wide open. As he puts the sensors and cabling away Strock muses, "You can imagine how difficult it is to create an 'elevator pitch' for this as it depends on the audience and its needs, and the capability and potential may not, at first, be apparent to them." Unfortunately, until they discover a way to break through that barrier, this technology's days may continue to be cold and gray.

Sidebar:

The men behind the technology.

During his career at Dow Corning, Jim Mentele formed and managed the IT development center, helped form and manage the Numerically Intensive Technical Computing Group, formed and managed the Translation Capability Center, was the company's SAP Application Architect, and is currently Scientist Emeritus. He's also a Senior Research Fellow at Central Michigan University's Institute for Health and Business Insights, and is a consultant at Global Language Translations & Consulting and several other small businesses. Also, he sits on the board of SenX Technologies. In comparison, Doug Strock is no slouch. A graduate of the U.S. Military Academy with a BS in Aerospace Engineering, Strock was a Project Leader at Dow Corning, is an Information Systems Technician in the Army National Guard, President of both Angel Enterprise Systems and the Association of Language Companies, and Vice President of Global Language Translations & Consulting. Together he and Mentele co-founded Midland, Michigan-based Predictive Fleet Technologies, where Strock is President and Mentele Applications Architect.