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LETTERS

Prognostics and health management

While reading the article titled "Predicting and preventing machine failures" (*The Industrial Physicist*, December 1998, pp. 20-23) I was struck by the omission of the systems people for calibration support. How are they involved in developing prognostics and health management (PHM) systems to assure that the information used by their system is accurate?

The reference in the article to self-calibrating MEMS sensors is a misuse of the terminology. It implies the ability of a sensor to calibrate itself without outside reference. Calibration should be considered a process that (1) compares the response of the sensor to a known stimulus (calibration standard); (2) traces the measurement accuracy of the standard to standards at the National Institute of Standards and Technology (NIST) or to recognized intrinsic standards; and (3) establishes a calibration interval. The calibration interval is set to assure that the measurements made during the interval will be accurate. The U.S. Navy's Metrology and Calibration Program has proposed designing the capability for automated calibration into the MEMS sensor package—transducer and electronics. Alternate recommendations of redundancy (or "built in test") may extend the calibration interval or provide a functional check of the MEMS sensor, but neither can replace calibration.

As MEMS are incorporated into more systems, I would ask the system engineers to consider how they can assure the measurement accuracy of these sensors throughout the major system's lifetime.

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[*Author replies:* Sensor calibration is an integral part of our condition-based maintenance (CBM) concept and implementation. Prior to installation, and certainly as part of manufacture, there is a requirement that calibration of all CBM sensors be traceable to NIST. In addition to this initial calibration, the intelligent sensor/processor that monitors the health (we call this an intelligent component health monitor (ICHM) unit) has the capability to check calibration by monitoring transducer input impedance, pattern matching of sensor output signatures, and in the most demanding applications, "built-in" reciprocity calibration with a second, co-located transducer.

Reciprocity calibration is a NIST-traceable measurement in which the responses of two transducers are compared for an external excitation (e.g., environmental or machinery vibrations), and then one transducer is reversed as a transmitter and the transmit-to-receive response is measured by the other. By knowing the mechanical transfer function between the two transducers, the receiving sensitivity of the nonreversed transducer can be recovered. We call this "self-calibration" because the absolute reciprocity measurement does not actually require a "built-in" reference transducer that is NIST-traceable.

To understand the significance of the



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ICHM calibration and health indication, you have to consider the user's point of view. At the first sign of poor sensor performance, the ICHM processor informs the user of low sensor confidence and provides evidence of such (changed sensor input impedance, changed calibration, etc). In the proposed modular, open-architecture diagnostic system, the user will simply change out the ICHM unit and sensor(s) for a new, calibrated one. The ICHM unit has done its job by recognizing a problem with a component's operation and automatically notifying the user before questionable data gets into the CBM decision process. Troubleshooting the ICHM unit to find out whether the fault is with the sensor, the cable, or analog electronics is done back at the factory or in a metrology laboratory, where it can be recalibrated with NIST traceability. The important technological step here is the intelligent sensor (the ICHM unit) automatically taking itself out of the CBM problem when it detects that its data is questionable.

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and Bill Nickerson
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I read with great interest your article in the December issue of *The Industrial Physicist* ("Predicting and preventing machine failures," pp. 20-23). In your experience, has thermal imaging been used for airplane maintenance? I know that a thermal camera can see the heat or shorts in wiring. Has it been used to check stress in other parts, such as landing gear, or moisture in the honeycomb of the wing structure?

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[*Author replies:* I have not been directly involved with them, but there have been programs that use thermography to detect structural cracks and stress concentrations in aircraft. The Machinery Failure Prevention Technology (MFPT) wing of ASME has an annual conference that publishes proceed-

ings. ASNE (naval), AIAA (aerospace), and SAE (automotive) also have diagnostics and nondestructive inspection subcommittees for their areas of interest. The subject of the article, the Joint Strike Fighter, is focused on the lower manpower requirements of PHM, so the program office will favor any on-line method rather than a more manpower-intensive diagnostic procedure (as thermography tends to be).

Carl Byington]

Managers

Having spent the first 30 years of my career in industry, I feel obliged to comment on the letter by Marc Levenson in the February issue. He attributes his apparently negative experience in industry to his managers ("trained narrowly and inappropriately") and to his colleagues ("even less able to put the facts of a complex problem together"). Unfortunately, the author never confronts his own limitations but is willing to attribute all his problems to those of fellow employees. This suggests just the kind of intellectual arrogance that some academic physicists unfortunately still preach. When this is coupled to narrow, unconstrained, individualistic thesis research projects, the students who emerge are frustrated by the reality outside the university. They may even feel embarrassed that they are working in industry. The failure of their industrial colleagues to acknowledge their brilliance, the constraints on their research direction by their manager, and the inexplicable success enjoyed by many engineering colleagues defy all their painfully earned beliefs. This would make anyone unhappy.

The good news is that more and more physics faculty are joining multidisciplinary, collaborative research projects with engineering faculty, creating an environment of mutual respect. Often, these programs are directed to a particular technological area with research partially funded by industry, so students emerge knowledgeable about the challenges facing that industry and familiar with the industry's research leaders. This provides an easy entree to a challenging industrial R&D job.

I would be less than honest if I did not

admit that while in industry I often expressed frustration, anger, and disillusionment. Welcome to the real world! I often feel the same emotions at the university. When faced with these situations, it's easy to strike out at "management," based on the simple principles espoused by the rectal theory of the universe: "they" are ignorant and evil! My best advice to younger scientists is to recognize that this theory is generally inadequate. Most decision makers want to make the best decisions. They may make them on the basis of less than accurate information and/or with consideration for external constraints (budget, head count, competitive programs, etc.), but probably not because they are stupid. Trying to understand the decision-making process is much harder for most of us than condemning it, but ultimately it is more fruitful.

Despite Marc Levenson's concerns, many physicists can and do enjoy rewarding research careers in industry.

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Technology, and MINT Chair,
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The pits

In your Figure 1 of "Stimulating high-risk, high-payoff research" (February 1999, p. 9), I think that, if you're implying that there is a move from 1 bit of information per pit to 3 bits, then the pits will allow the coding of numbers from 0 to 7 (for a total of 8), rather than from (as stated), 0 to 8.

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[Thomas R. Burke, chairman of Calimetrics, Inc. (Alameda, California), tells us that the picture shows a disc stamper (mold) for pits of eight different depths, and a land, or zero level (nine levels total). The nine levels are used with Calimetrics' proprietary encoding scheme to deliver 3.17 bits per pit ($9 = 2^{3.17}$)—Ed.]