Thermocouples' cold-junction blues no longer play

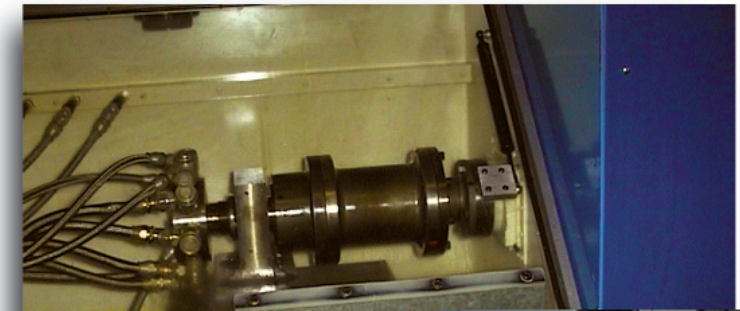
By Robert Brewer

New technology improves production and testing of heavy-duty transmissions.

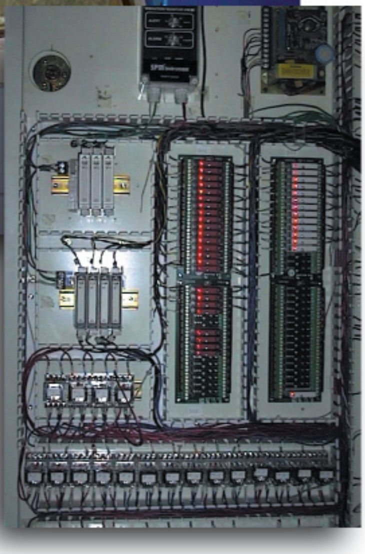
Instrumentation engineers at General Motors' Allison Transmission Division are challenged daily to improve products' and materials' production and testing for maximum quality and reliability at lowest cost.

Often these engineers are expected to develop improvements in systems called the best in the industry only a year or two earlier.

Allison Transmissions has temperature measurement requirements in a reliability test lab environment. There and elsewhere, temperature is the most measured process-industry variable, and thermocouples are the most used temperature sensors.



Component test bench



Instrument panel with thermocouple conditioners

To meet these requirements, Allison selected a particular thermocouple technology to meet present and anticipated requirements.

Why new technology sought

Allison designs, manufactures, and sells automatic transmissions for trucks, buses, and tanks, as well as new light-truck transmissions for commercial-duty pickups and motor homes.

At its test labs, Allison is replacing existing signal conditioning with products to improve measurement accuracy and reduce typical test-cycle time. For reliability testing, equipment must be accurate, repeatable, and dependable.

Currently, the company is modifying and upgrading some test stands and expects to continue to upgrade other test areas. Rather than select signal conditioners piecemeal, Allison reviewed everything commercially available to standardize on equipment that not only worked well but also could be used in various applications throughout various test and reliability labs.

Measurements can be challenging

Temperature is measured by the millivolt signal generated by the temperature difference between the junctions of two dissimilar metals. One junction is typically encased in a sensor probe at the point of measurement, while the other junction is connected to the measurement or control instrument.

That instrument, in the field or the control room, is affected by changes in ambient temperature; the actual millivolt-signal fluctuates accordingly. To offset this error, the temperature at the instrument terminals is measured and a compensating signal, the cold-junction compensation, is inserted. The overall measurement accuracy depends on the accuracy of cold-junction temperature (CJT) compensation.

Measuring exact CJT at the instrument has always been challenging. The most significant reason is the sensor is never exactly located at the thermocouple connection terminals where dissimilar thermocouple wires are connected to the instrument. Even though the terminals and cold-junction sensor may be fairly close together, perhaps a half-inch, there is still a temperature difference between them.

Measurement accuracy also is affected by temperature changes from outside ambient temperature variations as well as instrument warm-up after being switched on.

The cumulative effect of these variations may be 5-10 degrees, which is potentially significant.

Waiting, warm-up prolonged calibration

To minimize cold-junction error, technicians typically perform instrument calibration a few minutes after the measuring instrument is powered up, allowing the cold junction to stabilize. However, measurement accuracy is still affected by outside temperature transients; for example, when adjacent instruments such as programmable controllers, recorders, and power controllers are switched on or off.

To overcome these errors, instrument engineers typically wait several more minutes before calibrating thermocouple measurements. Any changes or disturbances will cause further delays.

Allison Transmission requires traceable calibrations at least annually, involving several thousand instruments being handled by only a few technicians. Thus, calibration of thermocouple signal conditioners can be quite time-consuming if each instrument requires several minutes to warm up or stabilize.

What Allison needed

The company looked for thermocouple signal conditioners that provide good accuracy with minimal warm-up time after the system is turned on as well as good repeat accuracy for extended periods.

When ambient temperature changes, thermocouple measuring instruments typically drift by a few degrees. Allison wanted to minimize this variation. While initially measuring a few temperature points, Allison also wanted a modular system that would allow additional points to be added easily, without affecting the previous installation.

Another feature Allison required was wide-ranging calibration in a single product, to handle

The technology shortens thermocouple signal-conditioner warm-up, hence calibration.

Cold-junction temperature measurement challenge overcome

By Millard Schewe

The cold-junction temperature (CJT) measurement technique minimizes warm-up and ambient-temperature fluctuations.

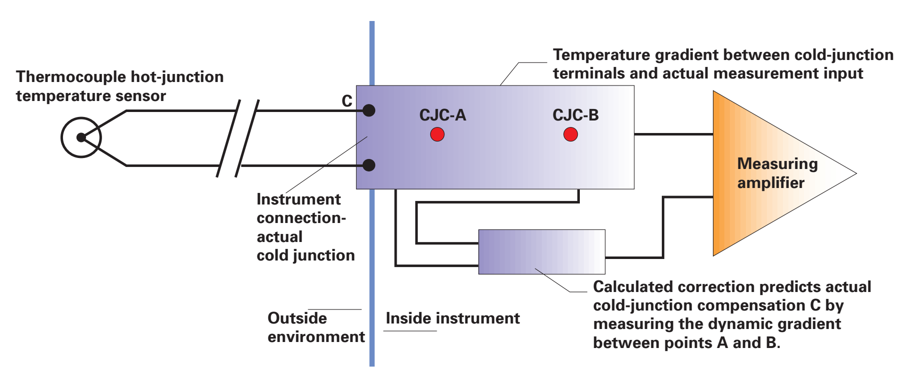
To accomplish this, two junction temperature sensors are mounted linearly down a focal plane of the printed circuit board, aimed at the terminals. By knowing or characterizing the focal plane's thermal conductivity and measuring differential temperature between sensors, accurate CJT measurements are made.

The exact temperature of the terminals is predicted by extrapolation of the CJT (third point) from the other two measurements. While calculations may be different for a different physical geometry, in any fixed-geometry instrument the calculation remains the same.

A temperature-plunge test was performed to monitor the unit's behavior with a constant input applied, while the unit was physically subjected to a sharp change in ambient temperature. An older unit was also tested. Both were placed in an environmental chamber and heated to 65°C for over an hour while connected to the thermocouple simulator through identical lengths of wire. Each output was monitored by an identical meter.

At temperature equilibrium, the units' outputs were measured, meters were nulled to display only deviation from initial readings, heaters were shut off, and the chamber door was fully opened. Readings then were logged every 15 seconds.

Performance differences were apparent. The older unit showed a broad peak in the 3- to 5-minute range of up to 1.76% error; the error remained over 1% for nearly 15 minutes. The new unit showed a maximum error of 0.5% in the first 2 minutes; error shrunk to 0.03% within 5 minutes.



How instant-accuracy technology works

Source: Action Instruments

Behind the byline

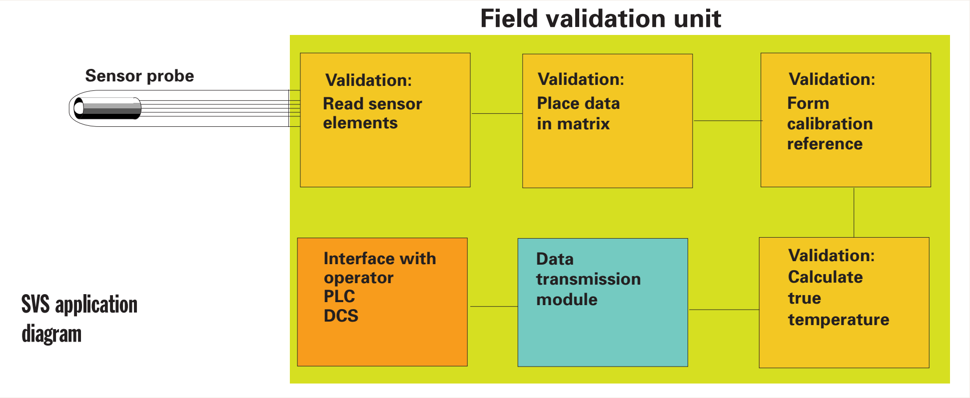
Millard Schewe is product manager with Action Instruments, San Diego, Calif., and can be reached at millards@actionio.com.

New smart temperature device melts the mold

By Kenna Amos

In *InTech's* January 1999 Industry Outlook (pages 38-45), GRTW, Inc., president Gerald White predicted: "Self-diagnosing field devices will evolve into intelligent, high-performance, autonomous devices . . . that will validate data within their [control] loops and manage communications to others [in process control centers elsewhere]."

It appears that AccuTru International's SVS *in situ* temperature measurement system—self-validating, self-diagnosing, and self-correcting—does this now.



SVS application diagram

Source: AccuTru International Corp.

Process use demonstrated

At DuPont's Victoria, Texas, facility, operators needed responsive, accurate, and repeatable temperature sensors that could survive a harsh, high-temperature environment.

"Our incentive for installing the new sensor technology was improved yield and longer catalyst life in a high-value application," said senior engineer Gary Carrier. "Self-validation was another key driver, because knowing if your measurement has been compromised or degraded has tremendous value in our process." Early results of DuPont's new system are very impressive, he said, "and we are planning to install additional probes to complete our yield improvement program."

One self-validating temperature-sensing system has been installed at Allied Signal's Torrance, Calif., facility. "The new temperature-measurement system solved a major process problem and paid for itself in less than a month," said Allied Signal senior engineering specialist Matt Pohlman.

Harsh-environment application examined

The new technology appears to have potential environmental cleanup applications in harsh and demanding conditions like the treatment and storage of high-activity nuclear waste (HAW).

The U.S. Department of Energy's Idaho National Engineering and Environmental Laboratory (INEEL), managed by Lockheed Martin Idaho Technologies, is working on that issue. There, various methods such as glass vitrification are examined.

To produce a consistent HAW glass that meets stringent repository criteria, INEEL staff must be able to accurately monitor and verify glass-melt temperature. Staff tried thermocouples and radiation pyrometers, the most common glass-industry temperature sensors, but found them not sufficiently accurate or reliable for the specific application.

That led to INEEL's "evaluating an integrated sensor and control technology to improve temperature sensing and reliability for high-level waste vitrification," said Dr. Marty Sorensen, manager of INEEL's Applied Materials and Technology group.

"We tested an SVS self-validating temperature sensor, which uses advanced contact probe technology, in a laboratory-scale, Joule-heated, refractory-lined glass melter," Sorenson stated. "This innovative temperature probe monitors melt temperature at any given chamber location and reports to a data acquisition system, providing us with real-time, molten-glass temperatures."

Test results indicate the self-validating sensor probe is more accurate and reliable than classic platinum-rhodium thermocouple-and-sheath assemblies used previously, said Sorensen. "INEEL is planning on using this new technology in our HAW pilot plant."

AccuTru is now working with INEEL to incorporate fuzzy-logic control into the technology.

Technology validates, manages itself

For the past four years, the new technology was researched, developed, and tested in the lab and field. The system is based on electrical properties, potential and impedance, of various combinations of different materials in changing thermal-stress environments.

The field electronic package, designed and developed by Scientific-MicroSystems (Tomball, Texas) is a microprocessor-based module that manages individually calibrated responses, characterization curves, and algorithms for self-calibration, self-diagnostics, self-correction, and validation status of the probe output. Capable of predictive maintenance, the field electronic module provides multiple output protocols.

Said AccuTru president Bernard Conner: "The applications for our technology are processes where very tight, accurate, and repeatable temperature data is essential. The data displayed, over the life of the sensor, is traceable to the NIST standard used to calibrate the instrument."

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several thermocouple types and ranges, so there would be no need to stock several different instruments for the variety of thermocouples.

Ideally the instrument would be either PC programmable or, if there was no PC access, manually activated by flipping a few dip switches to select thermocouple type and range. Finally, instrument calibration needed to be user friendly, requiring a minimal amount of time for calibration.

Allison Transmission's first thermocouple signal-conditioner system split oil ring seals.

Insoluble temperature-sensing problem yields innovation

By John Houldsworth

Because temperature is the most widely measured process variable and thermocouple measurement technology is so mature, we wouldn't expect improvements or new technology—but that happened.

Out of a seemingly insoluble problem came a new cold-junction temperature (CJT) sensing technology that virtually eliminated warm-up drift and sensitivity to ambient temperature changes.

It began in the R&D labs of a company where I used to work. My colleagues had nearly completed developing a range of DIN panel-mount temperature indicators. Qualification testing revealed something totally unexpected, though: large repeatability errors (more than 10 times greater than expected values) traced to CJT sensing.

The designer understood CJT sensing was temperature measurement's Achilles heel. He thought he'd followed accepted guidelines. His goal: make the CJT sensor's internal temperature the same as that of the actual cold junction (the screw clamp of a printed circuit board [pcb] edge connector). So what was going wrong?

Being asked to investigate, I started by trying to build a quantitative model of the thermal situation to see if the model would predict poor performance. I knew variable heat dissipation from relays, displays, etc., could cause these errors. This happened only if thermal resistance between sensor and screw clamp was high *and* sufficient heat flowed along this path.

I calculated thermal resistances of obvious components from physical-constants tables and found the error should be a factor of 10 smaller, not what we were seeing. Obviously something was still missing.

I wondered about the connector's point contact. Calculations of its thermal resistance from geometry or direct measurements proved impractical. However, I knew a metal sample's thermal resistance could be estimated within 5% of its more easily measured electrical resistance.

My measurement of the connector gave an equivalent thermal resistance for pcb pad to screw clamp of 10 times higher than in the initial model. Now, I had an accurate thermal model that predicted actual performance.

With this model, we questioned the limits of performance: How good is it possible to make this design? The disappointing answer was: Not good enough!

Why not? It's because of the relative magnitudes of the connector's high thermal resistance and the very low resistance to heat flow through and along the glass-epoxy pcb from possible heat sources. Even with constant heat sources, this large temperature offset would build up during the warm-up time of 20 minutes or so that is typical of many products.

At this point, it seemed to me physically impossible to get the CJT sensor to achieve the desired performance.

Surprisingly, realizing this made it easier for us to consider this alternative: Accept the temperature difference, and rather than try to eliminate it physically, eliminate it mathematically by measuring and correcting for heat flow. That solution made error vanish under *all* conditions.

The new scheme was simple: Have two sensors, close to the connector, make a weighted difference of their outputs to give a single value that behaves as if it came from a "phantom" sensor positioned at the ideal point or location on the screw clamp.

Our lab trials quickly confirmed dramatic improvement with this new scheme. The company subsequently patented the technology, which has been incorporated into new product designs in that and other sister companies.

When I first looked at this problem, I never imagined where my work would lead. In hindsight, it appears that, in this problem and others, we are continually faced with great opportunities brilliantly disguised as insoluble problems.

Behind the byline

John Houldsworth is vice president for technology for Duality Semiconductor, Inc., Fairfax, Va., a fabless semiconductor company providing signal-processing solutions. He can be reached at duality@erols.com.

Thermocouples monitor oil sump and test part temperatures and the temperature of the test-spindle drive-bearing block. Typically, Allison vents the test area to eliminate exhaust gases; the venting may cause a considerable shift in ambient temperature.

Allison's calibration lab staff reported thermocouple signal conditioners take from several minutes to a half-hour to stabilize. In some applications, a drift of a few degrees doesn't matter, but when several hundred instruments are being calibrated, prolonged warm-up time makes the job considerably more difficult.

New technology handled issues

Calibration staff were interested in technology that would make this less of an issue. Action Instruments provided a thermocouple conditioner, with the new instant-accuracy technology, that did that.

The technology provided another significant benefit. Allison's safety program provides for a shutdown of the complete test system when critical temperatures go out of range. Since Allison's test labs are typically a single-shift operation, even a shutdown of a few minutes after the end of the main shift could delay the test program until the next day.

If shutdown occurs, not because of a malfunction, but due to temperature error or drift, this can become a significant problem. This makes repeat accuracy and stability of temperature measurement extremely important. This new technology helps: When a shutdown occurs, it is a real shutdown, not just measurement error. IT

Behind the byline

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