new; however, the diagnostic methodology itself, which utilizes a combination of existing devices for a particular application, is a novel concept.

The present methodology employs two key optical devices: a pulsed laser (nanosecond pulses) and a frame-transfer CCD sensor. Frame-transfer CCD sensors have been historically used to capture fast (microsecond timescale) transient events, such as Bose-Einstein condensate phenomena, over a short period of time (milliseconds). By their operation, the sensor area is exposed for a certain time and the charge is then transferred to the frame transfer area (or masking area) row-by-row, and is read out via a gain register or serial register. This is called "frame-transfer" readout or "kinetics" readout. The use of frame-transfer readout provides a very effective way of isolating true Raman signals from laser-generated optical interferences in any combustion environment, in principle, without having to employ multiple CCD detectors or polarizer on the detection side.

Since laser-induced background emissions are unpolarized, unlike Raman scattering, which is polarized, they can be selectively isolated (and subtracted). While the theory of this polarization technique has been proposed previously, the implementation of this technique for time-resolved Raman diagnostics has not been matured. A principal reason is that an enabling technology that can increase the SNR was needed. When a flame receives two orthogonally polarized, but otherwise identical, laser pulses, Raman scattering can be observable only for the vertically polarized excitation pulse. The (unpolarized) laser-generated background emissions are observed regardless of the polarization state of the excitation pulses. If the two orthogonally-polarized laser pulses are separated in time so that they just fall onto a pair of consecutive sub-frames on the CCD sensor, subtracting the one (laser-generated background emission only) from the other (Raman signal plus background emission) results in a true Raman spectrum.

This work was done by Quang-Viet Nguyen, David G. Fischer, and Jun Kojima of Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18483-1.

Thermal Properties of Microstrain Gauges Used for Protection of Lithium-Ion Cells of Different Designs

Commercial uses include lithium-ion batteries used in a human-rated environment, such as in automobile applications.

Lyndon B. Johnson Space Center, Houston, Texas

The purpose of this innovation is to use microstrain gauges to monitor minute changes in temperature along with material properties of the metal cans and pouches used in the construction of lithium-ion cells. The sensitivity of the microstrain gauges to extremely small changes in temperatures internal to the cells makes them a valuable asset in controlling the hazards in lithium-ion cells. The test program on lithium-ion cells included various cell configurations, including the pouch type configurations.

The thermal properties of microstrain gauges have been found to contribute significantly as safety monitors in lithium-ion cells that are designed even with hard metal cases. Although the metal cans do not undergo changes in material property, even under worst-case unsafe conditions, the small changes in thermal properties observed during charge and discharge of the cell provide an observable change in resistance of the strain gauge. Under abusive or unsafe conditions, the change in the resistance is large. This large change is observed as a significant change in slope, and this can be used to prevent cells from going into a thermal runaway condition. For flexible metal cans or pouch-type lithium-ion cells, combinations of changes in material properties along with thermal changes can be used as an indication for the initiation of an unsafe condition.

Lithium-ion cells have a very high energy density, no memory effect, and almost 100-percent efficiency of charge and discharge. However, due to the presence of a flammable electrolyte, along with the very high energy density and the capability of releasing oxygen from the cathode, these cells can go into a hazardous condition of venting, fire, and thermal runaway. Commercial lithium-ion cells have current and voltage monitoring devices that are used to control the charge and discharge of the batteries. Some lithium-ion cells have internal protective devices, but when used in multi-cell configurations, these protective devices either do not protect or are themselves a hazard to the cell due to their limitations. These devices do not help in cases where the cells develop high impedance that suddenly causes them to go into a thermal runaway condition. Temperature monitoring typically helps with tracking the performance of a battery. But normal thermistors or thermal sensors do not provide the accuracy needed for this and cannot track a change in internal cell temperatures until it is too late to stop a thermal runaway.

The microstrain gauges under study have shown remarkable changes in resistance with changes in temperature that show a very close tracking to the current used to charge and discharge the lithium-ion cells. As the cells are charged, there is a very slight increase in temperature at the end of charge, and the same during the discharge process. Although normal thermistors do not show a big change in temperature, the strain gauges have been able to track with great accuracy the thermal changes in the cells during these processes. Although strain gauges have been used to track pressures internal to cells in battery chemistries that use pressure vessels such as the Ni-hydrogen cells, they have not been used to track resistance changes due to temperatures. Existing thermal sensors do not have the sensitivity to be able to track small changes in internal temperatures of the cells, so monitoring systems cannot detect changes fast enough to be able to provide any protection. With lithium-ion cells, when the thermal sensors record an alarming temperature reading, it indicates that the cell's internal temperatures have reached a point where no external controls can stop the thermal runaway. With the thermally sensitive new strain gauges, the changes in slope are so sensitive that this change can be used to stop the charge or remove the load on the lithium-ion cells before the event can spiral into an uncontrollable one.

Four different configurations of lithium-ion cells of were tested. Two cylindrical cells with metal containers (two different diameters), a prismatic metal container cell type, and a pouch cell type (aluminized plastic pouch) were used for the study. Several tests were performed on all our designs. The tests included normal charge and discharge cycling at two different charge and discharge rates at room temperature and at low temperature. The tests also included off-nominal conditions of overcharge, overdischarge, external short, heat-to-vent, and crush (simulated internal short). Overcharge tests and external short tests provide the most valuable data as these conditions produce the worst-case reactions in lithium-ion cells.

This work was done by Judith Jeevarajan of Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-24764-1

In-Service Monitoring of Steam Pipe Systems at High Temperatures

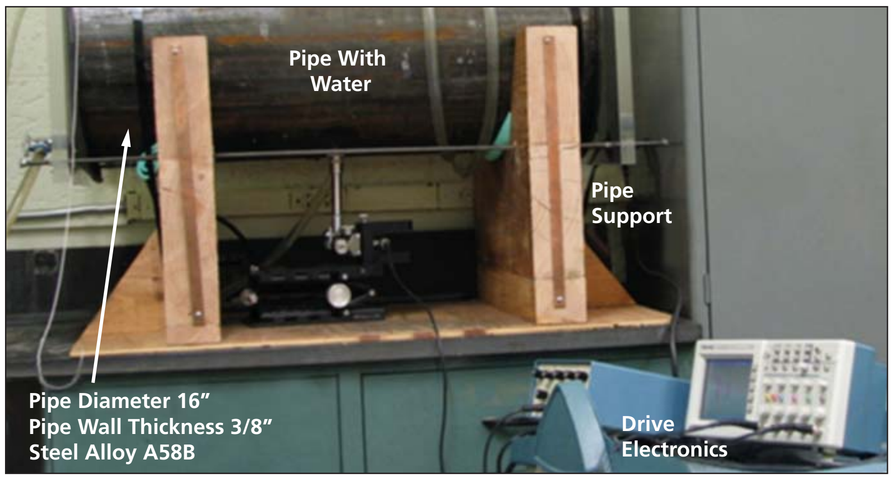
This system can be used by utility companies for steam pipe systems incorporating multiple manholes.

NASA's Jet Propulsion Laboratory, Pasadena, California

An effective, in-service health monitoring system is needed to track water condensation in real time through the walls of steam pipes. The system is required to measure the height of the condensed water from outside the pipe, while operating at temperatures that are as high as 250 °C. The system needs to account for the effects of water flow and cavitation. In addition, it is desired that the system does not require perforating the pipes and thereby reducing the structural integrity.

Generally, steam pipes are used as part of the district heating system carrying steam from central power stations under the streets to heat, cool, or supply power to high-rise buildings and businesses. This system uses ultrasonic waves in pulse-echo and acquires reflected signal data. Via autocorrelation, it determines the water height while eliminating the effect of noise and multiple reflections from the wall of the pipe.

The system performs nondestructive monitoring through the walls of steam pipes, and automatically measures the height of condensed water while operating at the high-temperature conditions of 250 °C. For this purpose, the ultrasonic pulse-echo method is used where the time-of-flight of the wave reflections inside the water are measured, and it is multiplied by the wave velocity to determine the height. The pulse-echo test consists of emitting ultrasonic wave pulses from a piezoelectric transducer and receiving the reflections from the top and bottom of the condensed water. A single transducer is used as a transmitter as well as the receiver of the ultrasonic waves. To obtain high resolution, a broadband transducer is used and the frequency can be in the range of 2.25 to 10 MHz, providing sharp pulses in the time domain allowing for higher resolution in identifying the individual reflections.



The testbed simulating the **Steam Pipe** and the *in situ* ultrasonic test setup.

The pulse-echo transducer is connected to both the transmitter (function generator), which sends electric signals to generate the elastic wave, and the receiver, which amplifies the attenuated reflected waves that are converted to electric signals. To avoid damage to the receiver, the large signal from the generator is blocked by an electronic switching mechanism from reaching the receiving circuitry. To assure the operation of the transducer at the required temperature range, the piezoelectric transmitter/receiver is selected with a Curie temperature that is much higher. In addition, the system can be improved by introducing a heat sink between the transducer and the steam pipe, reducing the temperature requirements on the transducer.

This work was done by Yoseph Bar-Cohen, Shyh-Shiuh Lih, Mircea Badescu, Xiaoqi Bao, Stewart Sherrit, James S. Scott, Julian O. Blosiu, and Scott E. Widholm of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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