

# The Use of Temperature Sensors for Liquid Hydrogen Testing at NASA Glenn Research Center

Wesley L Johnson<sup>1</sup>, Mark J Kubiak<sup>1,2</sup>, Dustin J Dombrowski<sup>1,2</sup>, Keith P Johnson<sup>1</sup>, Erin M Tesny<sup>1</sup>, and Eric R Carlberg<sup>1</sup> <sup>1</sup>Glenn Research Center, Cleveland OH 44135 <sup>2</sup>HX5 Sierra, Cleveland OH 44135

### NASA's Experience With LH<sub>2</sub>

- NASA has been a major user of Liquid Hydrogen for the past 80 years.
- While many outside of the space sector only see the large storage / distribution system at KSC, there is a wide variety of activities going on that are even better suited for engaging with the liquid hydrogen push than at KSC.
- How can this be leveraged to help US Industry move forward in it's interest in hydrogen aviation?



Liquid-hydrogen fuel system for one engine of a B-57 flew successfully in 1957. Image from NASA SP-4404, "Liquid Hydrogen as a Propulsion Fuel, 1945-1959"





Liquid Hydrogen Technology Development

and Testing







Transportation Systems Vehicles



Low Temperature Materials Development and Characterization

## Thermocouples



- NASA has extensive experience using thermocouples in cryogenic systems:
  - Best used for systems above 70 80 K.
  - Can perform end to end system calibration for temperatures below 70 K.
  - Best if used with some length of wire along sensor as close to isothermal as possible.
  - Generally, Type E is most common used has best sensitivity of thermocouple types at temperatures below ~ 100 K.
  - Published uncertainty ~ +/- 1.6 K + electronics. In practice, we frequently get better than that.
- Typically potted on using Stycast 2850 FT or attached via taping.
- Commonly available NIST standard curves make T/Cs cheap and easy to use.
  - Can buy 500 ft spool and spot welder to make yourself as opposed to buying pre-made thermocouples.

# **RTD, Silicon Diodes, and Cernox**<sup>®</sup>



- NASA has extensive experience using silicon diodes from Scientific Instruments and Lakeshore as well as Cernox<sup>®</sup> sensors from Lakeshore.
  - Used as both temperature sensors and wet/dry sensors in cryogenic fluids.
  - Mounted externally to fluid tubes and internally with several different configurations
- Multiple different wiring schemes
  - 2 wire
  - 3 wire
  - 4 wire
- Require current excitation and measure:
  - Voltage for silicon diodes.
  - Resistance for Cernox<sup>®</sup>

# Silicon Diodes and Cernox<sup>®</sup> as Wet/Dry Sensors



- NASA GRC discovered the ability to use diodes as a wet/dry sensor.
  - Dempsey and Fabik, "Using Silicon Diodes for Detecting the Liquid-Vapor Interface in Hydrogen", NASA TM-105541.
  - Metzger and Zimmerli (NASA GRC) determined that Cernox<sup>®</sup> had a 6 15 x larger response than the silicon diodes (lower values for CX-1080 with LN2).
  - Normally chip sensors are used for this implementation.
- Normally, a diode (or Cernox<sup>®</sup>) receives an excitation current or voltage:
  - Silicon Diodes: 10  $\mu$ A
  - Cernox<sup>®</sup>: <10 mV
- By increasing the voltage or current across the sensor, it causes the sensor to self-heat more.
  - In a liquid that self heating is easily removed through convection, the measured response does not change.
  - In a vapor the self heating causes the diode to respond as if the fluid is warmer and the voltage response changes.
  - Based on the response to self heating, logic can be applied to the DAQ to determine if the sensor is wet or dry.
  - This also requires thermal isolation from the temperature rake or any other thermal mass.
- On SHIIVER, cylinder ("can") style SI diodes were used and this did not work for a few reasons.
  - The "can" had more thermal mass than the normally used chip configurations and took longer to "overheat"
  - The sensors were more closely coupled to the perforated board (tied down with wire) to prevent damage during installation and filling of the tank.

#### Overpowering data with LH<sub>2</sub>



#### **Delta-V vs power dissipation**



Credit Metzger and Zimmerli, NASA GRC

#### **External Tank Attachments**



- GRC uses Stycast 2850 FT for epoxying sensors in place.
  - The Stycast is thermally conductive, but not electrically conductive.
- Often use "band-aids" to hold sensor in place while epoxy is drying.





#### **Temperature Sensors in Tank**



- GRC often uses temperature sensors in the tank, exposed to liquid hydrogen.
  - Mounted on epoxy perforated board that allows sensor to "hang out" into the liquid that surrounds it.
  - Image below shows Si diode (SD style) mounted on perf-board.
  - Wires run through board and then out through 20 K certified connector (CeramTec, Douglas, or equivalent).
  - Teflon coated 26 AWG wires
  - 63/37 solder with resin core
- Sensors used to measure stratification within the liquid of a tank and not the metal they are mounted on.



#### Images of SHIIVER Diode Rake





### **Silicon Diodes in Flow**



- There are multiple different ways to get a temperature sensor into an internal flow:
  - Probes available from multiple sources (or made in house).
  - GRC SMiRF internal diode transition.
  - GRC SHIIVER internal diode mounting.
- These mounting techniques would work with Cernox<sup>®</sup> or RTDs as well as Silicon Diodes.

#### **SMiRF** internal transition



- Developed by GRC for various testing activities there.
  - Uses two wire Ceramtec feedthrough and VCR gland to attach in a VCR tee.
  - Sensor may not be fully immersed in flow due to length of Ceramtec feedthrough.





## **SHIIVER Internal Transition**



- Developed in conjunction with GRC instrumentation shop to support SHIVER testing.
- Similar to probes, but doesn't weld tip closed.
  - Epoxy used to isolate diodes from tube wall.
    - Tried just sealing tube off at top and bottom with potting compound. Had some leaks over time, eventually filled whole tube.
  - Uses tubing to support diodes against internal flow forces
- Use SI can type diodes
  - Single sensor in 1/8<sup>th</sup> inch tube
  - Dual sensors in 1/4 inch tube
  - Goes into piping via swage fitting





Temperature sensors (2x) in SHIIVER vent line.

SHIIVER TP: NASA TP 20205008233

# **Different Wire Measurement Options**

- A standard diode/RTD/Cernox<sup>®</sup> requires excitation.
- The excitation wires can be used to measure response in a two wire system:
  - Depending on the wire length (i.e. resistance), this can lead to large offsets in readings.
  - Different types of wire (copper or phosphor bronze) can be used to adjust offsets.
- This is usually corrected for by measuring response with two separate wires, hence the four wire system.
- GRC does have experience wiring up to six diodes in series for excitation.
  - This is the three wire configuration
  - This also minimizes the number of current sources required if current sources are used separately from monitoring response.
  - If one diode is lost, then all diodes on that string are lost (not appropriate for measurement redundancy).
  - There may also be some accuracy losses with this method.













- An array of different temperature sensors can be used effectively in liquid hydrogen systems.
- Can measure hardware or fluid temperatures within a system.
- Experience developed at NASA GRC over the past 80+ years of liquid hydrogen system testing has been shared to help the general audience with their measurement needs.
  - This presentation is a cumulation of the developments and lessons learned and not solely of the authors or presenters.

#### Thank you for your Attention!