FY12 Center Innovation Fund Project

Project Title: An Intelligent Strain Gauge with Debond Detection and Temperature Compensation

Principal Investigator: Scott Jensen, Engineering & Test Directorate, Scott.L.Jensen@nasa.gov, 228-688-2102

The harsh rocket propulsion test environment will expose any inadequacies associated with preexisting instrumentation technologies, and the criticality for collecting reliable test data justifies investigating any encountered data anomalies. Novel concepts for improved systems are often conceived during the high scrutiny investigations by individuals with an in-depth knowledge from maintaining critical test operations. The Intelligent Strain Gauge concept was conceived while performing these kinds of activities. However, the novel concepts are often unexplored even if it has the potential for advancing the current state of the art. Maturing these kinds of concepts is often considered to be a tangential development or a research project which are both normally abandoned within the propulsion-oriented environment. It is also difficult to justify these kinds of projects as a facility enhancement because facility developments are only accepted for mature and proven technologies. Fortunately, the CIF program has provided an avenue for bringing the Intelligent Strain Gauge to fruition.

Two types of fully functional smart strain gauges capable of performing reliable and sensitive debond detection have been successfully produced. Ordinary gauges are designed to provide test article data and they lack the ability to supply information concerning the gauge itself. A gauge is considered to be a smart gauge when it provides supplementary data relating other relevant attributes for performing diagnostic function or producing enhanced data. The developed strain gauges provide supplementary signals by measuring strain and temperature through embedded Karma and nickel chromium (NiCr) alloy elements. Intelligently interpreting the supplementary data into valuable information can be performed manually, however, integrating this functionality into an automatic system is considered to be an intelligent gauge. This was achieved while maintaining a very low mass. The low mass enables debond detection and temperature compensation to be performed when the gauge is utilized on small test articles. It was also found that the element's mass must be relatively small to avoid overbearing the desired thermal dissipation characteristics.

Detecting the degradation of a gauge's bond was reliably achieved by correlating thermal dissipation with the bond's integrity. This was accomplished by precisely coupling a NiCr element with a Karma element for accurately interjecting and quantifying thermal energy. A finite amount of thermal energy is consistently placed in the gauge by electrically powering the NiCr element. The energy will only be temporarily stored before it begins to dissipate into the surrounding structure through the gauge bond. The ability to transmit the energy into the structure becomes greatly inhibited by any discontinuity in the bond's substrate. Therefore, the way the thermal dissipation occurs will reveal even the slightest change in the integrity of the bond.

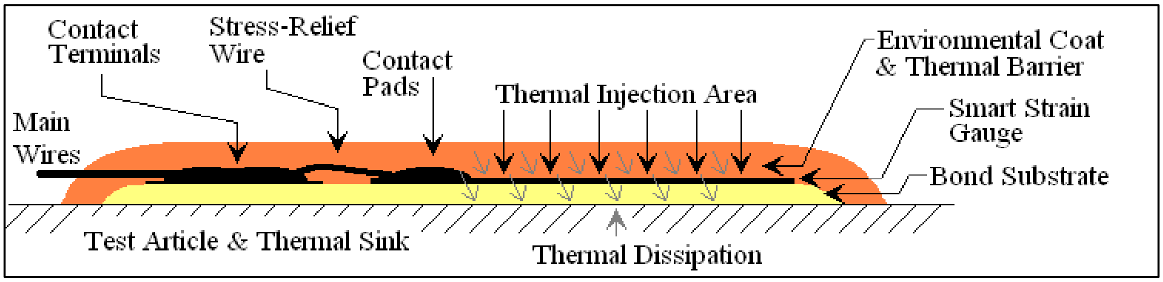

Illustration 1: Type 1 Smart Strain Gauge Profile

The NiCr element is integrated within a Karma foil strain gauge pattern in the first type of smart strain gauges (see illustration 1 & 2). The thermally injected energy conducts into the surface through one main bond while the environmentally protective coating helps to direct conduction toward the bond. This design also maintains the gauge bondability for utilization within extreme conditions by keeping the two elements within a single flat package. This allows the bond to be evenly applied in a thin layer for surviving exposure to cryogenic temperatures. Exposure at these temperatures will produce large internal stresses within the bond substrate, and the bond will experience cracking if it is thick or uneven. This gauge type also avoids thermally introducing stress into the strain sensing element by independently encircling the element. This also provides better detection around the border of the internal strain element.

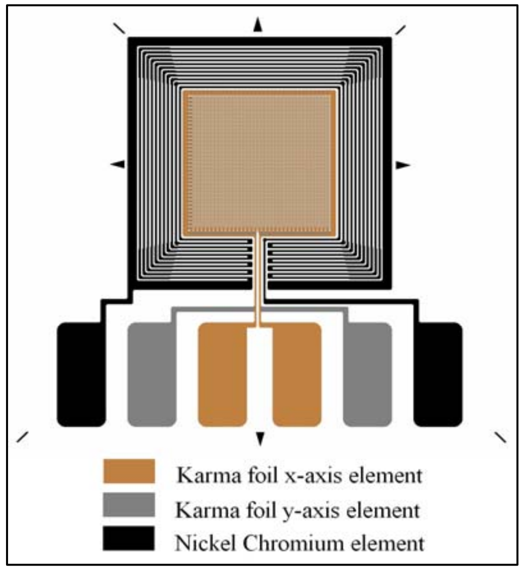

Illustration 2: Type 1 Smart Strain Gauge Pattern

The NiCr element is integrated within the environmental coating in the second enhanced type of smart strain gauges (see illustration 3). This more economical design is better at isolating any thermally induced stresses as well as maintaining a highly reliable bond. The NiCr element is bonded directly over the strain sensing element, which helps with detecting degradation near the center of the gauge. This configuration introduces a second bond layer through which the interjected test energy must propagate. However, the additional layer produces no discernable decrease in debond detection, and it provides better resilience against bond creepage within high heat environments. This type also functions independently from the strain gauge which makes it suitable for use within a wide variety of applications. It can be applied to most kinds of preexisting strain gauges, and any other thinly bonded components. It can even be employed for monitoring laminated materials for detecting delamination.

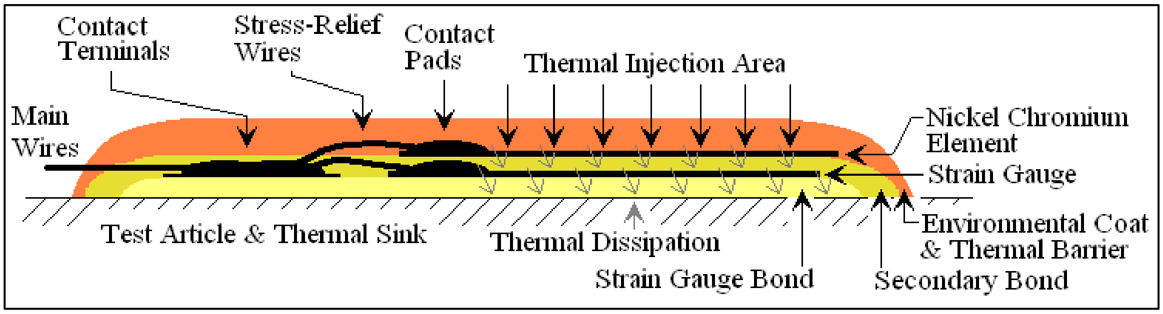

Illustration 3: Type 2 Smart Strain Gauge Profile

Another main portion of the overall process entails interpreting the thermal dissipation profile. Data from a thermal test sequence can be independently reviewed for determining the integrity of the bond under test (See the bonded versus debonded data illustration 4). However, this project developed the system further for making it suitable for deployment. This was accomplished by developing intelligent signal processing circuitry for automatically performing and interpreting a test sequence. Developing the intelligent system began with generating an operational algorithm. The algorithm was then encoded into the intelligent signal processing circuitry's microprocessor. This step successfully converted the specialized smart gauges into a fully functioning intelligent sensor system.

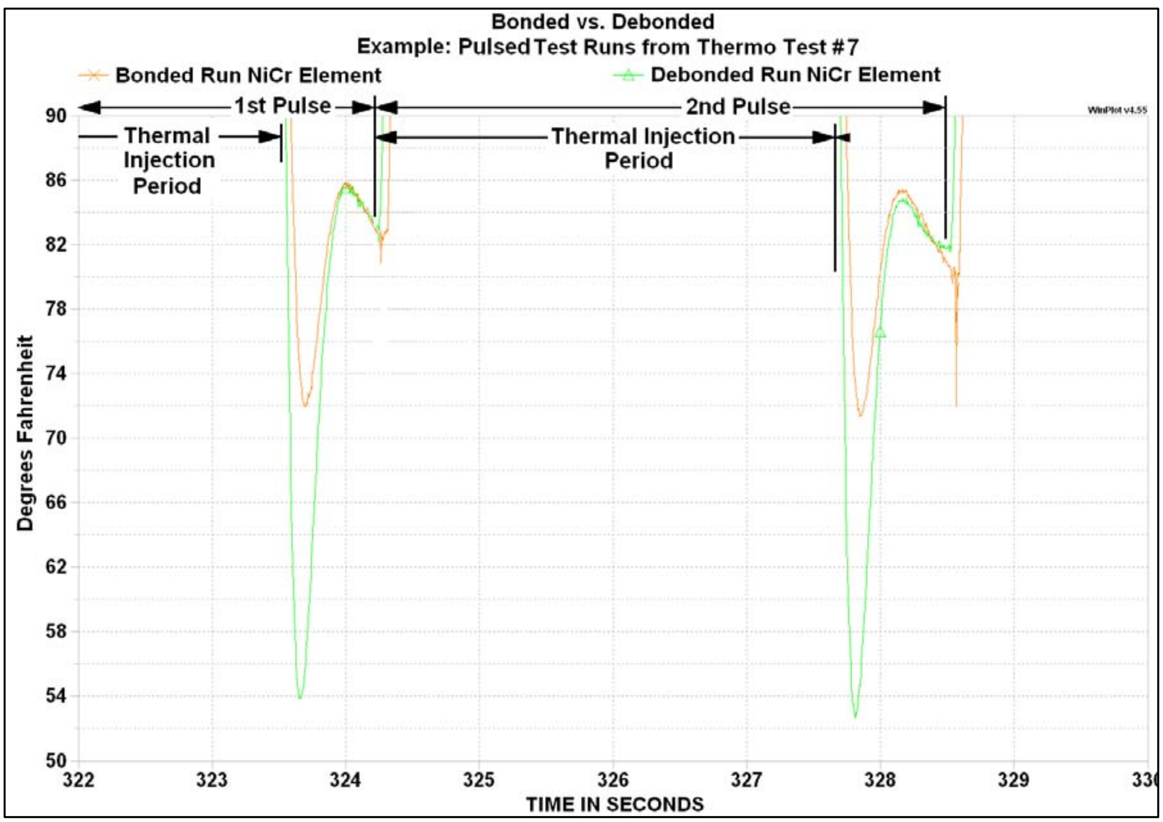

Illustration 4: Example of a good bonded gauge transition into a bad debonded gauge within a pulsed test

The intelligent system operates in the calibration, gauge test sequence, and data streaming modes. The system will always revert into the data streaming mode when the other operational modes are inactive. This mode allows unaffected data to be streamed out from the strain gauge, or it can be configured to perform real-time temperature compensation prior to transmitting the data. The gauge temperature can also be streamed out as a supplementary data channel for post-processing functions. At any time the calibration mode can be triggered, and doing so will collect an initial base line characterization. This is typically performed once for the life of the gauge. It is preferable to execute the calibration at the temperature range where the subsequent test will be performed, but advanced systems should be capable of collecting multiple base lines for testing within different temperature ranges. Then periodically a test sequence can be triggered for which the stored base line is compared with a new set of thermal dissipation characteristics. The test mode execution is primarily intended for data verification preceding or following an event. However, it can be performed while collecting strain data, but doing so can artificially introduce a slight bump in strain levels due to introducing thermal energy during the test sequence. Enabling the real-time temperature compensation function will typically remove any effects from the test. The finalized results from executing a test sequence are condensed into a discrete indication, and the last known indication state is held as a good or bad condition.

The intelligent system is an economically viable method for feasibly employing strain instrumentation throughout NASA and industry. It is highly applicable and more sensible to implement with the same level of effort as existing strain instrumentation systems, and it can be directly integrated into pre-existing Stennis Space Center Ground Propulsion Test Facilities. Additionally, utilizing the system's advanced functionality can help prevent the use of erroneous data in strain analyses. Therefore, the work should be made known through technical society publications. The submission for publication and presentation is currently planned for the 49th American Institute of Aeronautics and Astronautics (AIAA) Joint Propulsion Conference and the 2013 Institute of Electrical and Electronics Engineers (IEEE) Sensors Applications Symposium. The achievements of this project also warrant the submission of a New Technology Report (NTR).