Contribution ID: **343** Type: **Regular Oral (15m)**

Advancements in cryogenic cable harness technology: Enabling connectivity for extreme-temperature environments in space and earthbound missions

Thursday 25 July 2024 09:15 (15 minutes)

Cryogenic space missions with extremely low temperature experiments such as Herschel, Ariel and Athena present unique challenges on cable assemblies in order to connect electrical devices in a temperature range down to a few millikelvin with those at room temperature. Similar demands are encountered in earthbound telescopes such as ALMA, ELT, and VLT, where large temperature variations challenge harness development.

The critical challenge with low-temperature cable assemblies is to reconcile physically contradictory requirements for the conductor material. While low thermal conductivity minimizes heat flux, sufficient electrical conductivity is essential for power and signal transmission between hot and cold electronics. Achieving optimal thermal and electrical properties for each system involves using selected conductor materials with low thermal conductivity and sufficient electrical conductivity, along with minimizing wire diameter and maximizing transmission paths. Heat sinks strategically placed in the system to facilitate optimal heat flow, conducting heat out of the wiring harness at designated positions.

Extremely thin wire diameters, even as small as 0.1 mm, necessitate advanced production technologies, including soldering, crimping and high-precision work under microscopic conditions. The physical properties, combined with vibrations, temperature cycles, and vacuum conditions, demand the highest quality standards in production and testing for both space missions and earthbound cryogenic systems.
Our study analyzes material properties to select suitable conductor materials, including Brass, phosphor bronze, manganin, niobium-titanium, and steel. Steel wire offers the lowest thermal conductivity with acceptable electrical conductivity suitable for signal transmission. We have developed processes to reliably solder and crimp very thin wire diameters of steel, building upon Herschel's technology.
PTFE and polyimides serve as insulation materials for cryogenic cables, providing high electrical insulation strength and low thermal conductivity. Both loomed and classic cryogenic harnesses with EMI shielding have been developed for various applications.
The production of cryogenic cable assemblies with these wire and insulation materials involves the development of new manufacturing processes for reliable connector termination using new soldering and crimping techniques, capable of withstanding cryogenic and vacuum conditions.
Consideration is also given to the termination of the stainless-steel shield connection, along with the development and optimization of heat dissipation elements for cryogenic harnesses.

The validation of developed manufacturing methods and processes occurs during the qualification phase. Non-destructive electrical verification is conducted by measuring cable resistance, while destructive testing methods, including pull-out tests and micrograph analysis, ensure mechanical resilience.
Thermal cycle simulation during qualification ensures that the connections and materials withstand a sufficient number of cold/hot cycles throughout the entire service life of the cable assembly. Comprehensive qualification, including electrical tests, micrograph, and pull-off tests, confirms the absence of degradation.
This conference presentation will showcase sample harnesses featuring solder and crimp connections and heat sinks, accompanied by corresponding mechanical and electrical tests with and without completed temperature cycles.

The completion of cryogenic technology development related to cryogenic cable assemblies paves the way for the success of future scientific missions, pushing the boundaries of what is technically feasible in extreme-temperature environments.

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Session Classification: Thu-Or14

Track Classification: Tracks ICEC 29 Geneva 2024: ICEC 05: Cryogenic applications: aerospace