Ceramic Materials Improve Spacecraft Insulators

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Scientists and engineers conducting research for the Air Force Research Laboratory's Materials and Manufacturing Directorate have identified ceramic materials that could increase the life of ceramic Hall thruster insulators for spacecraft, including satellites and microsatellites.

Part of the Integrated High Payoff Rocket Propulsion Technology program, the efforts of the directorate focus on identifying engineered ceramic materials with improved erosion resistance over the current boron nitride composition used in Hall thrusters.

In addition, the directorate expects to lower the cost and increase the efficiency of the components' manufacturing process by adapting advanced, rapid prototyping techniques, which are expected to shorten the materials evaluation cycle and allow flexibility in component configuration.

During the 1970s, engineers in Russia developed a type of electric thruster called the Hall thruster. Hall thrusters are low thrust propulsion devices used for making adjustments to keep satellites in the correct orbit and for attitude changes to allow for proper alignment of telescopes and antennas.

Unlike chemical rocket thrusters, which rely on the combustion of propellants and the expansion of hot combustion gases through a nozzle to produce thrust, electric thrusters use a gaseous Xenon propellant.

The Xenon propellant is injected into a chamber where it is ionized through collisions with electrons emitted from a cathode. The charged Xenon ions are then expelled at high velocity from the chamber by an electromagnetic field.

Because Xenon ions are expelled at a much higher velocity than the reactant gases of a chemical rocket engine, a Hall thruster can accomplish more maneuvering with same amount of propellant mass.

Chemical rocket thrusters typically exhaust their propellant supply in a matter of hours, while Hall thrusters can operate for hundreds of hours.

So, the Air Force and the National Aeronautics and Space Administration (NASA) became interested in the potential payoffs of Hall thrusters, which they expect to include reduced propellant mass, increased satellite payloads, increased maneuverability and increased satellite life.

Unfortunately, the lifetime of Hall thrusters is currently limited by erosion of the ceramic insulators that make up the walls of the discharge chamber.

The high velocity Xenon ions that are expelled from the thruster collide with and erode the chamber walls, eventually degrading thruster performance.

Current Hall thruster insulators composed of a boron nitride-silica mixture (BN-SiO2) have good mechanical and thermal properties, but only marginal erosion resistance.

With the Integrated High Payoff Rocket Propulsion Technology program funding and input from the directorate's Ceramics Branch, partners from Lockheed Martin Astronautic Systems conducted a series of screening tests, using BN-SiO2 as the baseline, to identify whether other ceramic materials would demonstrate erosion resistance.

Small ceramic samples were mounted in a fixture and exposed to a Xenon ion beam produced by an ion milling machine.

Engineers measured the mass of the samples before and after each test to determine the relative erosion rates of the sample materials.

Results of the testing showed significantly improved erosion resistance, three and five times better than BN-SiO2, in two alternative ceramic materials.

To manufacture prototype insulators from the erosion resistant ceramics the directorate partnered with Javelin 3D, a small business located in Salt Lake City, Utah.

Javelin 3D will use a rapid prototyping technique called the Laminated Object Manufacturing method to fabricate the prototype insulators.

This method is one of a variety of techniques that have been developed to produce parts directly from computer-aided drawings.

A major goal of this research effort is to apply the technique to thruster manufacturing, which will allow flexibility in design and prototyping, without incurring large set-up tooling costs.

The process involves casting ceramic powders along with organic binders into thin, eight-inch by 10-inch sheets. A single sheet is fed onto a platform where a mounted laser cuts the correct profile for the insulator.

The platform is lowered, another sheet is fed onto the previous one, and the laser cuts the correct profile for that cross section of the insulator.

The component is built layer by layer, repeating this process. The layered component is then heated in a furnace at low temperatures to remove the organic binder.

Finally, it is heated to high temperatures to sinter the ceramic particles together, bonding the layers to form a strong structural component.

Although two ceramics with improved erosion resistance were identified, engineers conducting the initial screening tests observed erosion patterns on test specimens that suggested that Xenon ions were attacking small impurities and imperfections.

The impurities may be caused by the remaining presence of the organic material used to bind ceramic particles together.

Researchers will further examine the phenomenon and ways to optimize the processing to further improve the erosion resistance of the ceramics.

In order for the insulators to maintain the proper electromagnetic fields around the Xenon ions, the ceramics must maintain their high electrical resistivity at the high operating temperatures of the Hall thruster.

The Materials and Manufacturing Directorate is conducting additional in-house electrical testing on the ceramic samples to verify this.

During the next two years, researchers involved in this program will select the ceramic material with the best performance, finalize the chamber design and construct prototype chambers for testing in an actual thruster.

Follow-on thruster life testing will take place at the Air Force Research Laboratory's Propulsion Directorate, Edwards Air Force Base, Calif.

When successful performance of the thruster has been demonstrated, the directorate plans to transfer the technology directly to domestic Hall thruster manufacturers.

Advances in propulsion achieved during this effort will advance the goals of the Integrated High Payoff Rocket Propulsion Technology program. This program is a Department of Defense, NASA, and industry coordinated effort that provides maximum connectivity among various propulsion activities.

The goal of the program is to develop revolutionary and innovative technologies by the year 2010 that will enable a doubling of rocket propulsion capabilities over 1993 state-of-the-art technology.

The program will improve the nation's capability to move into full-scale development of rocket propulsion systems with improved performance, affordability, operability, reliability, and maintainability.

Researchers expect that the first Air Force application for Hall thrusters will be on microsatellites as part of the Technology Satellite of the 21st Century (TechSat 21) program.

The TechSat 21 program, which explores the concept of using a cluster of microsatellites to accomplish surveillance, passive radiometry, terrain mapping, navigation, and communications missions, is a joint effort between several of Air Force Research Laboratory's technology directorates.