Space Mirror Alignment System

NASA's Jet Propulsion Laboratory, Pasadena, California

An optical alignment mirror mechanism (AMM) has been developed with angular positioning accuracy of ±0.2 arcsec. This requires the mirror's linear positioning actuators to have positioning resolutions of ±112 nm to enable the mirror to meet the angular tip/tilt accuracy requirement. Demonstrated capabilities are ±0.1 arc-sec angular mirror positioning accuracy, which translates into linear positioning resolutions at the actuator of ±50 nm.

The mechanism consists of a structure with sets of cross-directional flexures that enable the mirror's tip and tilt motion, a mirror with its kinematic mount, and two linear actuators. An actuator comprises a brushless DC motor, a linear ball screw, and a piezoelectric brake that holds the mirror's position while the unit is unpowered. An interferometric linear position sensor senses the actuator's position. The AMMs were developed for an Astrometric Beam Combiner (ABC) optical bench, which is part of an interferometer development. Custom electronics were also developed to accommodate the presence of multiple AMMs within the ABC and provide a compact, all-in-one solution to power and control the AMMs.

This work was done by Bruno M. Jau, Colin McKinney, Robert F. Smythe, and Dean L. Palmer of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47928

Thermionic Power Cell To Harness Heat Energies for Geothermal Applications

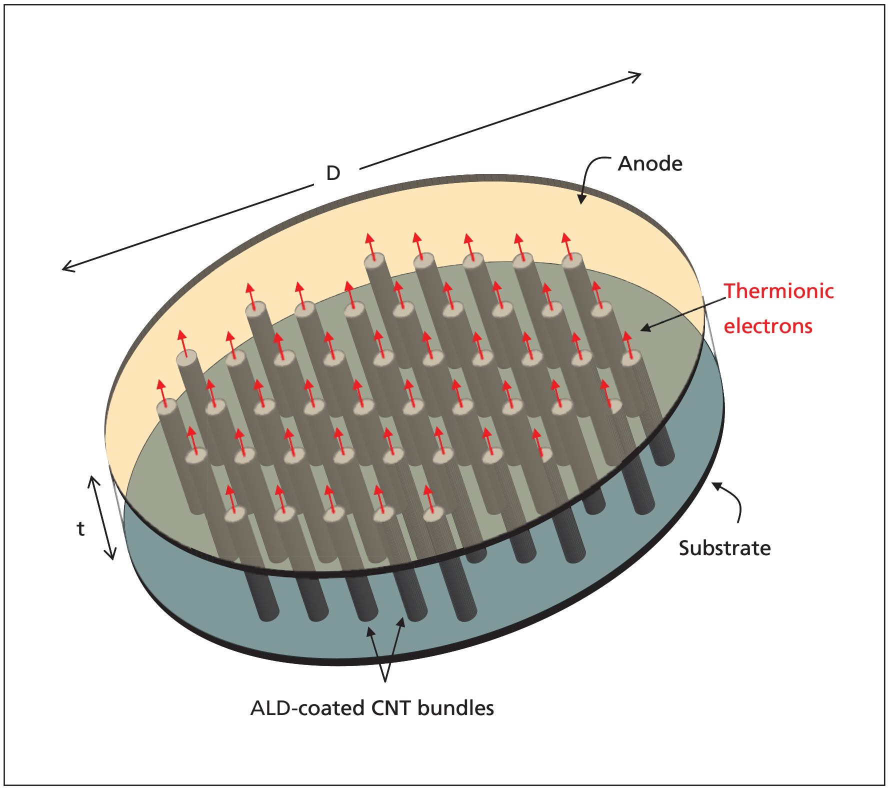
Possible uses include geothermal exploration, automotive, and renewable energy applications.

NASA's Jet Propulsion Laboratory, Pasadena, California

A unit thermionic power cell (TPC) concept has been developed that converts natural heat found in high-temperature environments (460 to 700 °C) into electrical power for *in situ* instruments and electronics. Thermionic emission of electrons occurs when an emitter filament is heated to "white hot" temperatures (>1,000 °C) allowing electrons to overcome the potential barrier and emit into the vacuum. These electrons are then collected by an anode, and transported to the external circuit for energy storage.

The thermionic emission current density (A/m^2) = $AT^2e^{(-\phi/kT)}$; where A= a constant, T = temperature (K), ϕ = work function (eV), and k = Boltzmann constant. The efficiency of emission increases with decreasing work function of the emitter material and increasing temperature. For example, the emission efficiency is much higher for cesium (ϕ = 2.4 eV) compared to pure carbon nanotube (CNT) (4.9 eV) and tungsten (4.5 eV). Additionally, the total current produced can be increased by enhancing the emitter surface area.

In this proposed approach, the higher emission efficiency of low-work function metal is combined with the enormous surface area achievable using CNT bundles to produce mA to A range current at lower temperatures of 460 to 700 °C range. This is achievable by conformally coating CNT (see figure) bundle arrays (or simply arrays of CNTs) with alkali metals such as potassium (ϕ = 2.3 eV) or cesium using an atomic layer deposition process. Projected emission area of such an alkali metal-coated CNT bundle array (2-µm diameter, spaced 2 µm apart) over a 4-in. (≈10-cm) diameter wafer is ≈3.0 × 10^4 cm^2. This leads to an estimated current production of ≈500 µA (> 200 Wh/kg) at 460 °C to ≈1.3 A at 700 °C, which is comparable to standard high-temperature batteries (for example, for $Na\text{-}NiCl_2$ high-temperature batteries produce ≈90–130 Wh/kg), and sufficient to power communication, computational and control electronics, as well as sensors



Schematic representation of the **Thermionic Power Cell** (TPC) with alkali-metal coated CNT bundles to enhance thermionic emission.

and miniature motors. Large areas of TPC or multiple TPC plates can be employed to produce much higher electrical energy to power heavier systems.

This highly miniaturized, high-temperature, long-life power source can be supplementary to primary high-temperature battery. The concept applies familiar thermionic emission principle for power generation by harnessing the local heat in the application environments. The approach of power production and design flexibility naturally provides an attractive option to harness *in situ* heat to produce power enough to operate electronics and miniature instrumentation. TPC can be designed to support geothermal explorations by harnessing heat energy of the local environment.

This work was done by Harish Manohara, Mohammad Mojarradi, and Harold F. Greer of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-46967

Graph Theory Roots of Spatial Operators for Kinematics and Dynamics

These concepts can be applied to modeling, simulation, and control of robots and other mechanisms.

NASA's Jet Propulsion Laboratory, Pasadena, California

Spatial operators have been used to analyze the dynamics of robotic multibody systems and to develop novel computational dynamics algorithms. Mass matrix factorization, inversion, diagonalization, and linearization are among several new insights obtained using such operators. While initially developed for serial rigid body manipulators, the spatial operators — and the related mathematical analysis — have been shown to extend very broadly including to tree and closed topology systems, to systems with flexible joints, links, etc. This work uses concepts from graph theory to explore the mathematical foundations of spatial operators. The goal is to study and characterize the properties of the spatial operators at an abstract level so that they can be applied to a broader range of dynamics problems.

The rich mathematical properties of the kinematics and dynamics of robotic multibody systems has been an area of strong research interest for several decades. These properties are important to understand the inherent physical behavior of systems, for stability and control analysis, for the development of computational algorithms, and for model development of faithful models.

Recurring patterns in spatial operators leads one to ask the more abstract question about the properties and characteristics of spatial operators that make them so broadly applicable. The idea is to step back from the specific application systems, and understand more deeply the generic requirements and properties of spatial operators, so that the insights and techniques are readily available across different kinematics and dynamics problems.

In this work, techniques from graph theory were used to explore the abstract basis for the spatial operators. The close relationship between the mathematical properties of adjacency matrices for graphs and those of spatial operators and their kernels were established. The connections hold across very basic requirements on the system topology, the nature of the component bodies, the indexing schemes, etc. The relationship of the underlying structure is intimately connected with efficient, recursive computational algorithms. The results provide the foundational groundwork for a much broader look at the key problems in kinematics and dynamics.

The properties of general graphs and trees of nodes and edge were examined, as well as the properties of adjacency matrices that are used to describe graph connectivity. The nilpotency property of such matrices for directed trees was reviewed, and the adjacency matrices were generalized to the notion of block weighted adjacency matrices that support block matrix elements. This leads us to the development of the notion of Spatial Kernel Operator SKO kernels. These kernels provide the basis for the development of SKO resolvent operators.

This work was done by Abhinandan Jain of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47313

Spacesuit Soft Upper Torso Sizing Systems

This system has application in medical devices for immobilizing injured limbs or applying controlled pressure to areas of the body of a burn victim.

Lyndon B. Johnson Space Center, Houston, Texas

The passive sizing system consists of a series of low-profile pulleys attached to the front and back of the shoulder bearings on a spacesuit soft upper torso (SUT), textile cord or stainless steel cable, and a modified commercial ratchet mechanism. The cord/cable is routed through the pulleys and attached to the ratchet mechanism mounted on the front of the spacesuit within reach of the suited subject. Upon actuating the ratchet mechanism, the shoulder bearing breadth is changed, providing variable upper torso sizing.

The active system consists of a series of pressurizable nastic cells embedded into the fabric layers of a spacesuit SUT. These cells are integrated to the front and back of the SUT and are connected to an air source with a variable regulator. When inflated, the nastic cells provide a change in the overall shoulder bearing breadth of the spacesuit and thus, torso sizing.

The research focused on the development of a high-performance sizing and actuation system. This technology has application as a suit-sizing mechanism to