Non-Destructive Testing for Corrosion Detection and High-Temperature Applications

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Chevron Fellows Visit at JPL
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Focus areas at the Advanced Technologies Group

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The mechanisms that were developed at the NDEAA Lab are driven by elastic waves, mechanical vibrations and/or electromagnetic materials. Examples of these mechanisms include the ultrasonic cleaner (USCC) that uses low frequency and is developed for planetary sampling, deep drilling, high-temperature drilling, proton, e-beam and in situ analysis making it a Lab-on-a-Chip. Also, the developed ultrasonic and surface acoustic wave motors and piezoelectric pumps that are driven by traveling flexural waves. This lab made major contributions to the field of electromagnetic power for use as actuators (artificial muscles) and, in various focus, is reviewing artificial tissues. Other technologies that are being explored include ultrasonic, high power ultrasound for medical treatment, ferroelectric source that generates various radiations and charged particles, wireless high power transmission, biomimetic technologies and peripheral sitting using elastic waves. In addition to planetary applications, the developed devices and mechanisms have potential terrestrial applications for medical, commercial, construction and others. These efforts involve cooperation with scientists and engineers at various universities, research institutes, medical centers and industry in the USA and internationally. Further, the Nov. 2001 issue of NASA Tech Briefs covered Dr. Bar-Cohen and NDEAA in a "What’s New in NASA" article.

Applications of electromechanical materials in space mechanisms is one of the links:
Applications to NDE

• Elastic waves as means of material characterization and monitoring changes
• Health monitoring via piezoelectric and eddy-current sensors
• Operation at extreme environments
Innovation at NDEAA

Electroactive Polymers (EAP)

For MSR: Sample containerization using brazing and inductive heating

3D Barth Motor

2 DoF SAW motor

Ultrasonic Motors (USM)

NDE - Measuring the elastic properties of composites using LLW

Acoustic levitation

Wireless power feed-thru

Sensor array for shear and pressure measurements

MACS

Monitoring condensation in steam pipes

Ferrosource

NDEA - Monitoring condensation in steam pipes

Laboratory Flume Design

Piezopump

Piezopump rotary-hammering drill
In-situ sampling and electroactive mechanisms

http://ndeaa.jpl.nasa.gov

Concept

Actuators (USM, EAP, Piezopump)

Other technologies (drilling, wireless power transmission, sensor arrays, etc.)

Robotics (MACS, MEMICA, Biomimetics)

Mission

Components

Systems
HT piezoelectric materials (sensors and actuators)

Sensors that operate in harsh environments including extreme heat (300F-1,000F), cold, and corrosive gases (e.g. H2S, CO2, Sulfur Species).

- Such piezoelectric materials as BSPT can be used to as high as 500°C and we already demonstrate a ultrasonic/sonic drill with such actuator.
- One can use LiNbO₃ or maximize the response by using BSPT with optimal dopants content of
  - $\text{Bi}_4\text{Ti}_3\text{O}_{12}$, $(1-x)\text{BiScO}_3\cdot x\text{PbTiO}_3$ (BSPT), Mg modified BSPT, Bismuth Titanate, AlN
  - Effective electrodes
High Temperature Piezoelectric Actuated Sampler for Operation on Venus

**Objective**
- Develop a sampler breadboard that can be operated at temperatures as high as 500°C
  - Develop new piezoelectric ceramic actuator with high electromechanical conversion efficiency at 500°C.
  - Produce ultrasonic/sonic driller and corer (USDC)-based sampler for cores and powdered cuttings

**Accomplishment:**
1. Developed novel design that makes the drill a rotary-hammer - the rotation is generated by the vibration of the piezoelectric actuator.
2. Isothermal tests of LiNbO₃ piezoelectric discs at 500°C for 1000 hours yielded no change in properties
3. Novel horn and free-mass designs increased the coupling and maintain pre-stress and thermal stability and also induced rotation.
4. Bismuth Titanate with various doping of tungsten showed thickness coupling coefficient that is about 15 to 20% at 500°C.
5. Successfully drilled at 460°C thru a 25 mm thick brick sample in 21 minutes accumulated time. This is a significant accomplishment for this very challenging task and it required a lot of innovation to reach this success [submitted several related New Technology Reports]. The use of brick sample was chosen since more uniform properties were observed as opposed to natural rocks.
Advanced health monitoring of steam pipe systems

Under a contract from Consolidated Edison Company (Con-Edison) an ultrasonic system is being developed for monitoring the water condensation height in steam pipes thru the pipe wall at 250°C.

**Phase I**
- A testbed was developed to simulate the pipe and its high temperature.
- An ultrasonic pulse/echo technique was developed where auto-correlation data processing was used
- A transducer was demonstrated to survive the condition of ≤250°C

**Phase II**
- A prototype system is being developed
Test setup hardware, and drive electronics

- Water height
- Pipe with water
- 16” OD x 36” long
- Wall thickness 3/8”
- Steel alloy A58B
- Drive electronics
- Pipe support
- Transmitter / Receiver
- Reflections from the water surface
- 1 - 5 MHz transducer
- Manipulator and support
The arrow pointing to the scope has the tip in the wrong location.

Badescu, Mircea (355N), 11/21/2011
Use of various ultrasonic wave modes and Eddy-Currents

- Sensors and smart materials that can detect or measure chemical reactions and/or certain kinds of corrosion by-products.
- Detection and characterization of corrosion damage.

Ultrasonic surface or plate waves can be used to detect corrosion or other types of damage and discontinuities.
At certain incidence angle surface wave is generated and for when resonance occurs where the plate thickness is related to the wavelength plate waves are induced with symmetric or asymmetric mode.
Quartz Crystal Microbalance (QCM)

Sensitivity

\[ m_0 = \rho At \]
\[ = (2650 \text{ kg/m}^3)(5 \times 10^{-5} \text{ m}^2)(3 \times 10^{-4} \text{ m}) \]
\[ = 0.04 \text{ g} \]

\[ f = 6 \times 10^6 \text{ Hz} \]
\[ \Delta f = 0.2 \text{ Hz} \]
\[ \Delta m = m_o \Delta f / f_o = <1.3 \text{ ng} \]
Mass Loading

\[ Z_L = i \rho_1 A_i v_i \tan \left( \frac{\omega L}{v_i} \right) = i \rho_1 A_i v_i \left( \frac{\omega L}{v_i} \right) = im \omega \]

Elastic Loading

Load Impedance cannot be simplified and resonance in the layers are seen in spectra

\[ Z_L = i \rho_1 A_i v_i \tan \left( \frac{\omega L}{v_i} \right) \]
SAW Resonator

Why resonators?
- Scalable
- Robust
- Low Power
- Can be designed for extreme environments (e.g., High Temperature)
- Frequency can be measured very accurately
- Resonance frequency to first order independent of parasitic impedances

Sensitivity
\[ \Delta m = kA \Delta f / f^2 \]
\[ \approx 0.1 \text{ ng} \]