Piezofiber Composites

Flexible Elemente für Sensorik, Aktorik und Ultraschall

Übersicht

- Wer wir sind, wo wir sind & was wir tun
- Einstieg Piezo-Effekt & Piezo-Composites
- Piezo-Composites für Ultraschallanwendungen
- Flexible Piezofaser-Elemente für Sensoren und Aktoren
- Wort zum Schluss

Smart Material Group - History

Smart Material Corporation with its affiliated company Smart Material GmbH is developing and manufacturing piezo-composite materials. Piezo-composites are part of the group of new materials or smart materials.

Founded in 2000 **Smart Material** has become a major supplier of piezo-composite materials, which are assembled into components and complete systems by its customers.

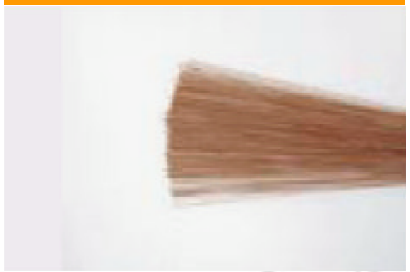
Our mission: To provide advanced piezo composites for commercial applications in high quantity, high quality and low cost.

Intelligente Werkstoffe formen unsere Zukunft.
Anpassungsfähig. Schnell. Zuverlässig.

Smart Material Group – Locations

Smart Material Group - Products

Piezo-Fibers



- 100 – 800 µm Diameter
- PZT NAVY types II, III, IV und VI
- tubes with diameters of 400-1000 µm

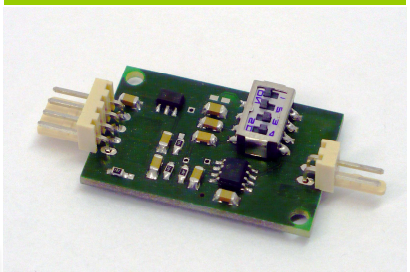
1-3 Piezo Composites

- arrange & Fill
- frequency range 25 kHz – 6 MHz
- fiber fill factor 25% - 65 %
- discs up to 3“ or rectangular plates
- random or regular fiber distribution
- array-designs

Macro Fiber Composites

- 12 different Standard-Types
- types using the d_{33} or d_{31} Effect
- customized Layouts within 5 weeks
- fabrication licensed by NASA

Electronics / Systems



- High voltage amplifiers
- Charge preamplifiers
- Ultrasound transmitter & receiver equipment
- Energy Harvesting development kits

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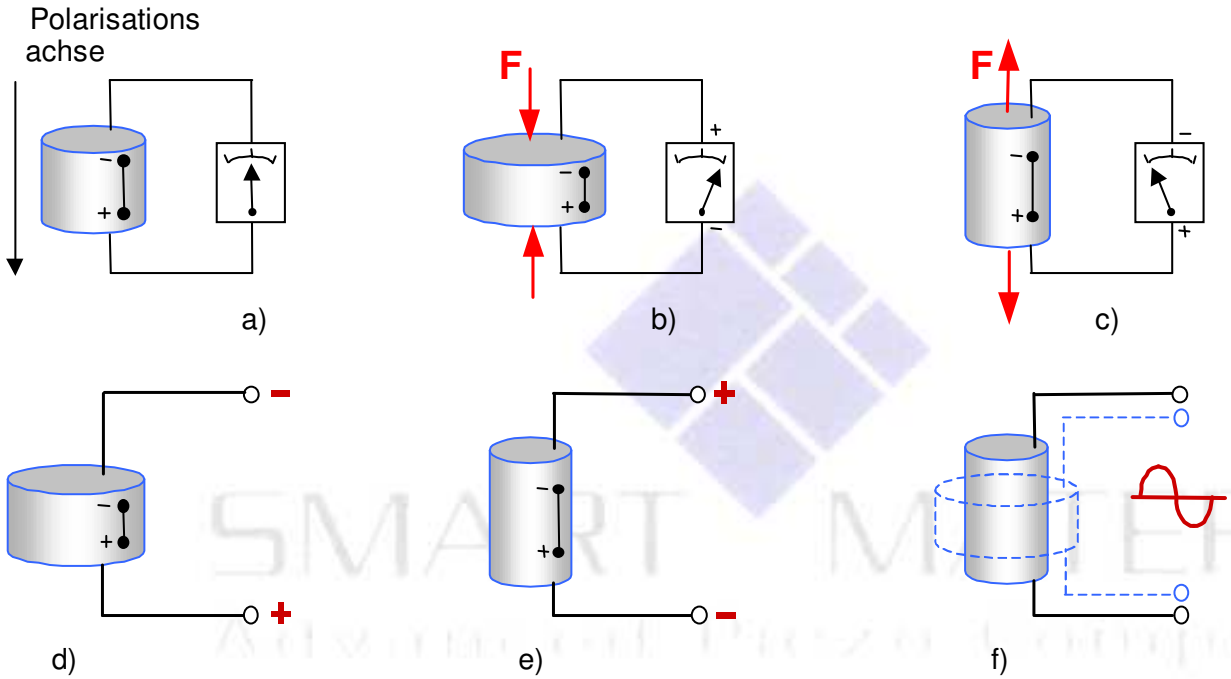
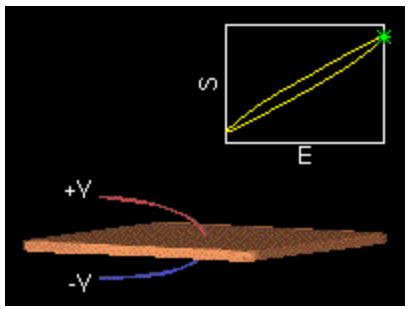
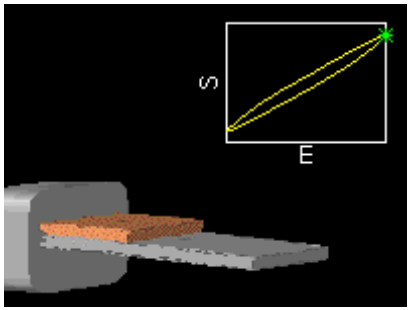
Direct and inverse Piezo-Effect

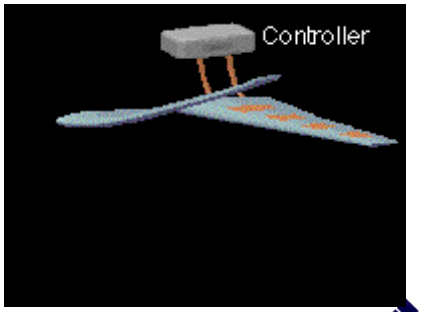


direct Piezo-Effect

inverese Piezo-Effect

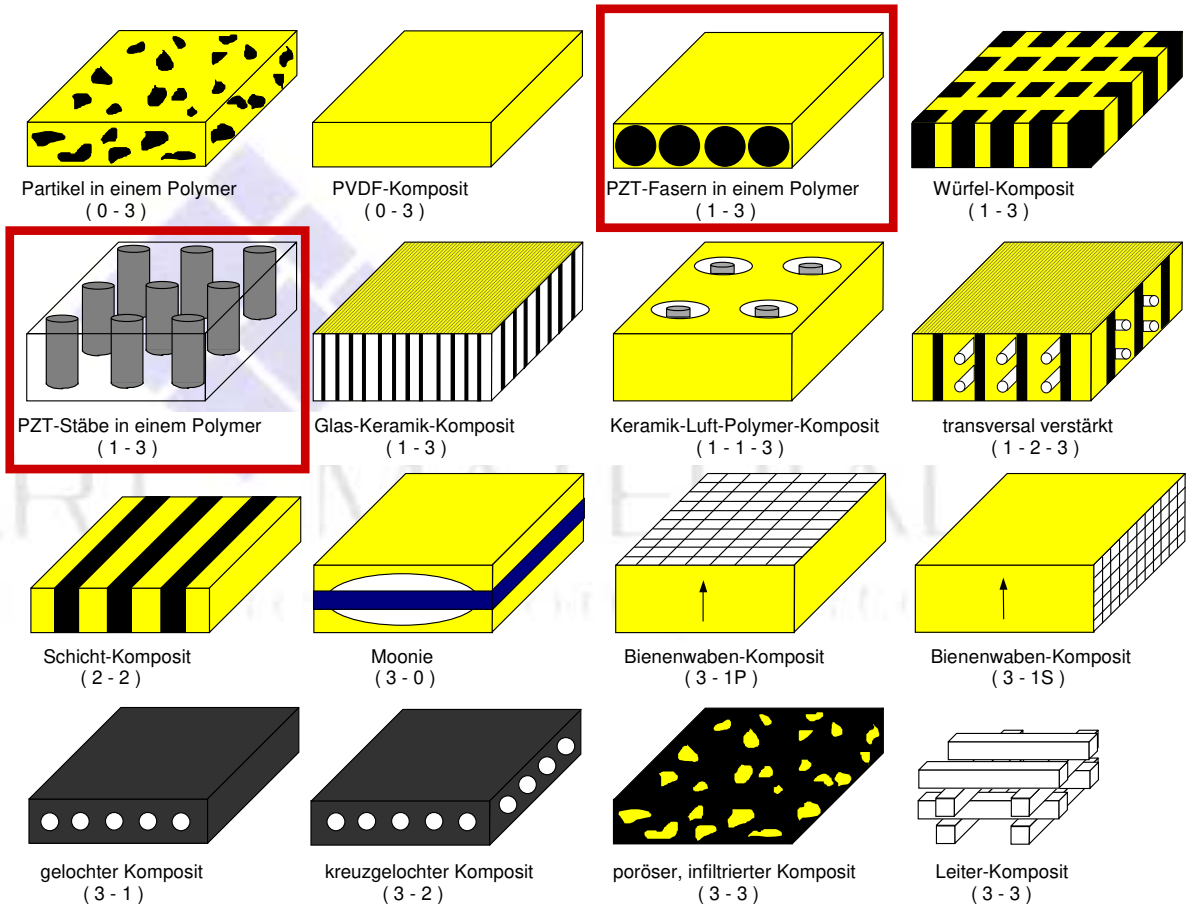






First Piezo-Composites in the ´70s

- **First piezo composite was a rubber piezo-ceramic composite built in ’70s**
- **Classification of different types of piezo composites first introduced by R.E. Newnham et al. (PennState)**



Übersicht

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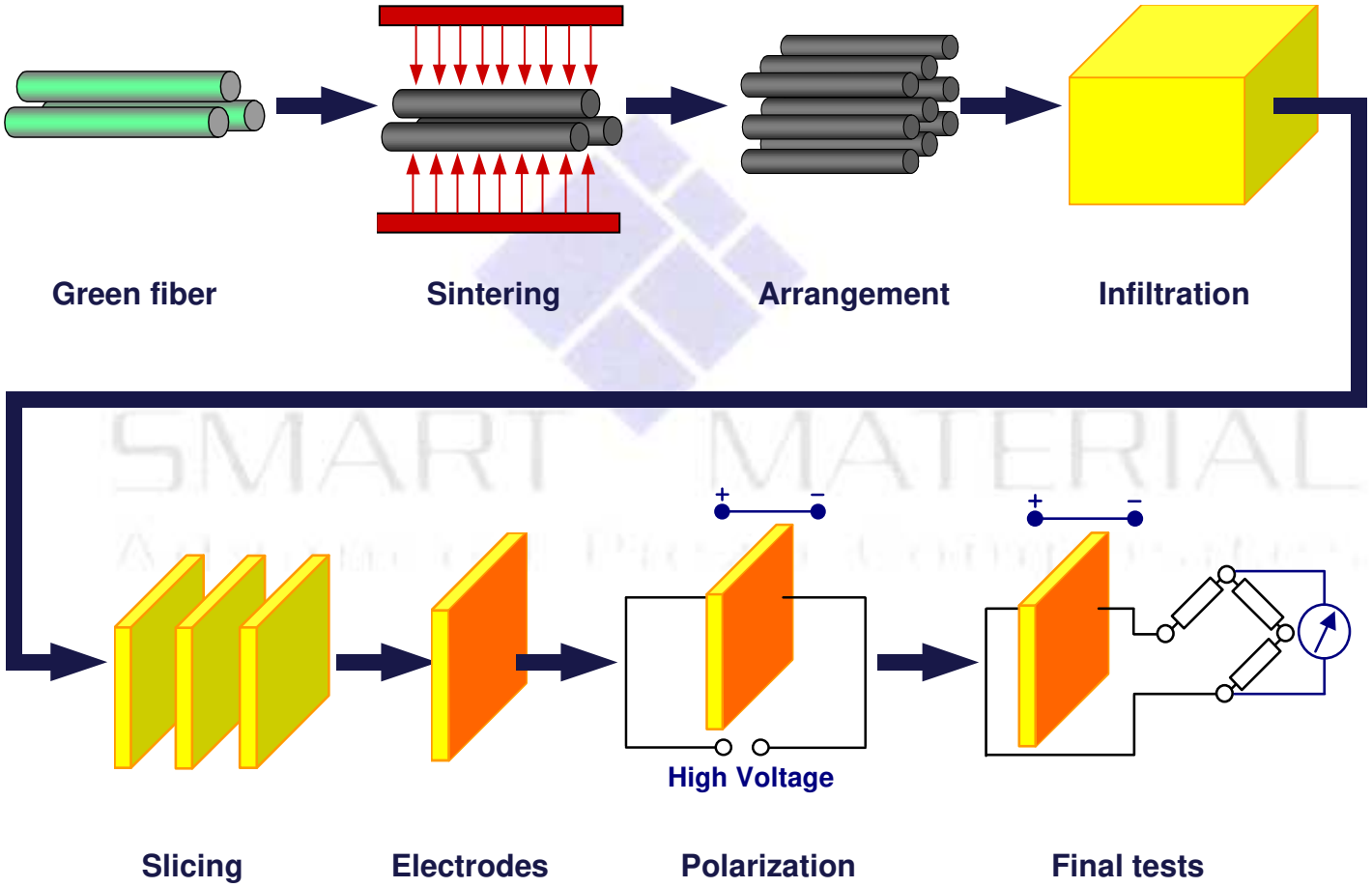
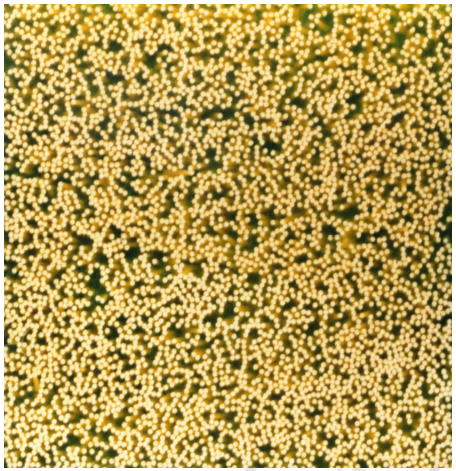
Advantages of 1-3 composites

1. **Better efficacy** (higher coupling coefficient) due to fibers as uniaxial resonators without lateral clamping
2. **Lower acoustic impedance** leads to a better matching to the most load mediums
3. **Adjustable damping** by choosing different interstitial materials for a broadband behavior
4. **Excellent sensitivity** for receiver applications due to low fill composites with a “softer“ behavior

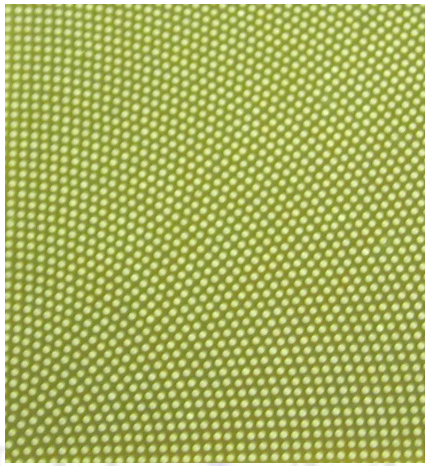
1-3 Composites by Arrange-&-Fill Technology



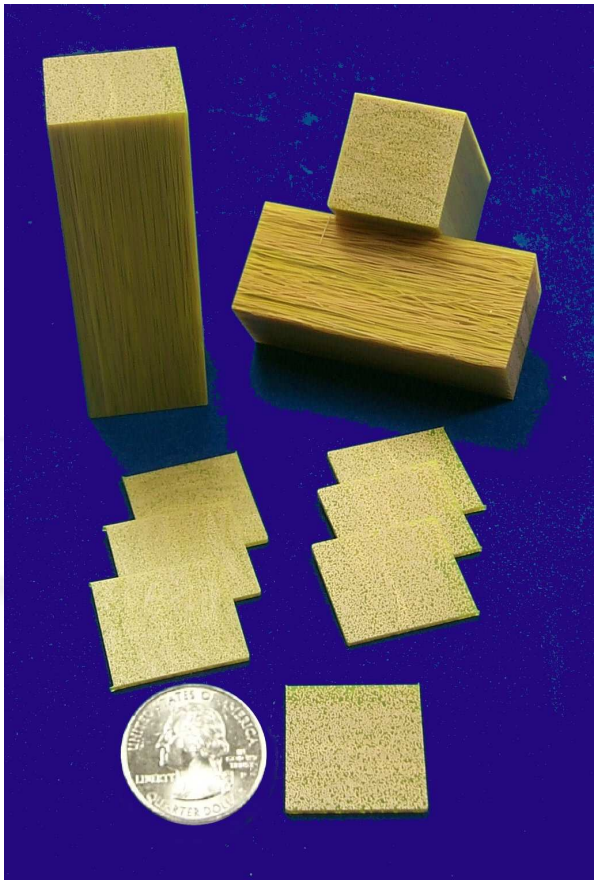
1-3 Composites by Arrange-&-Fill Technology



random fill

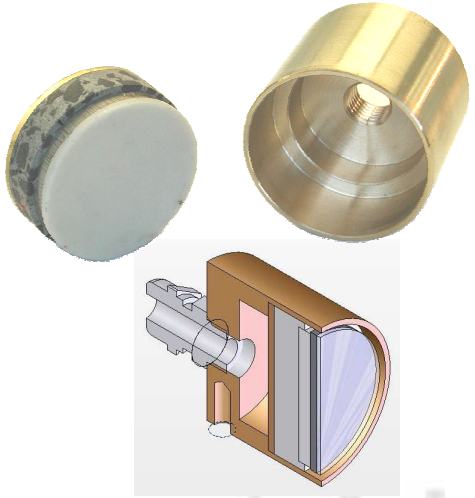


regular fill



3D machining

1-3 Composites for novel transducers

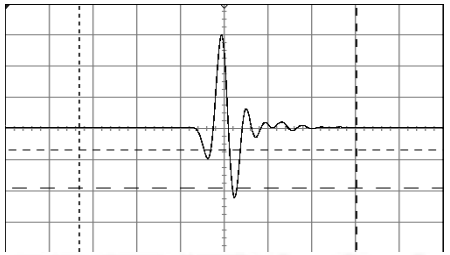


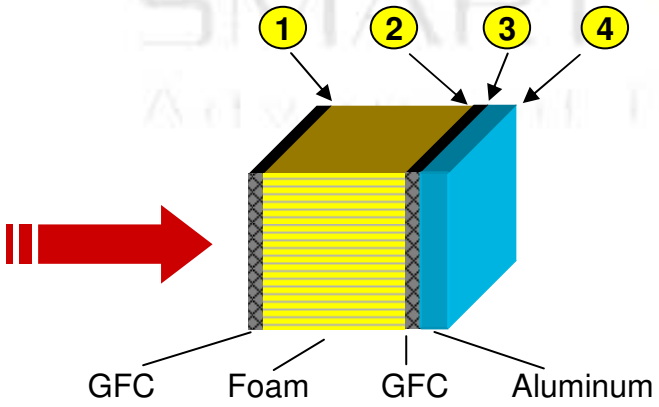
NDT probe for metallic parts

high acoustic impedance

NDT probe for composite materials

low acoustic impedance





Composite sandwich inspection

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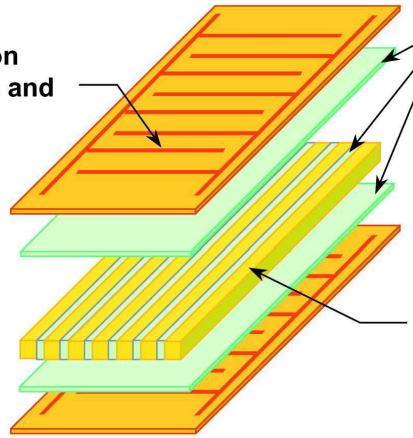
Developments started in 1989

- First developments driven by aerospace and defense applications in the USA, funded by the DoD
- Targeted applications: vibration control and morphing (structural control)
- Goal was to overcome some of the shortcomings of PZT wafers and mono/bi-morphs
  - Improve **reliability** in high strain application
  - **Encapsulation** against environmental factors
  - Increasing strain (utilize also d_{33} **effect**)
  - Increase **flexibility** without sacrificing lifetime
  - Easy application and **integration** (in)to existing structures
  - Electrical **insulation** of contacts to allow for embedding in composite structures

MFC – Principles of operation

Interdigitated electrode pattern on polyimide film (top and bottom)

Permits in-plane poling and actuation of piezoceramic (d_{33} versus d_{31} advantage)

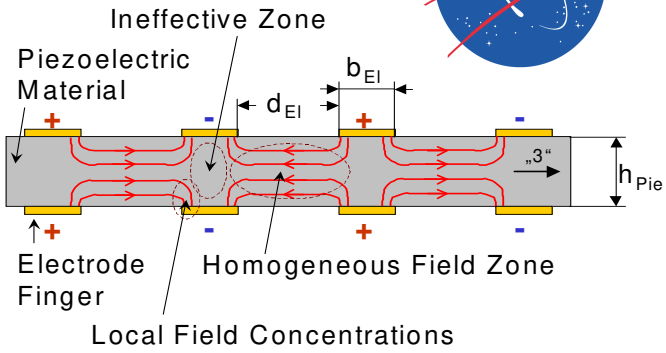


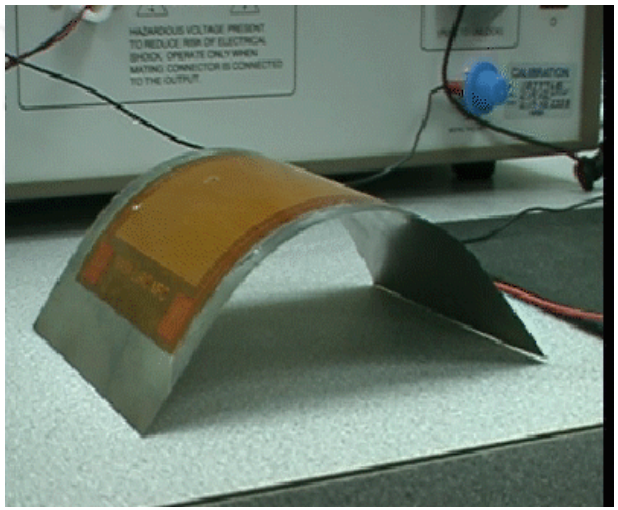
Structural epoxy

Inhibits crack propagation in ceramic. Bonds actuator components together.

Sheet of aligned rectangular piezoceramic fibers

Improved damage tolerance and flexibility relative to monolithic ceramic.

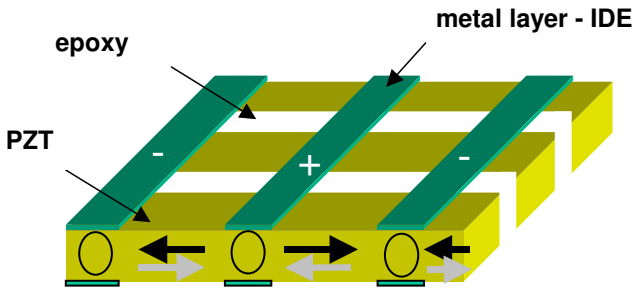


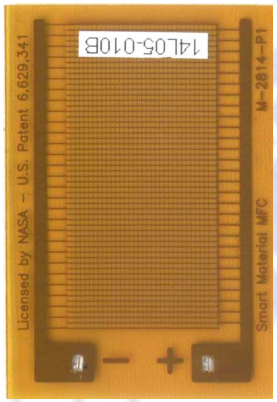


advantages:
- flexibility
- conform to composite design
- usage of d_{33} in-plane
- anisotropic Sensor/Actuator

Available MFC Types

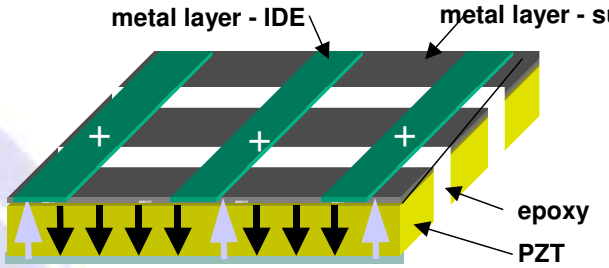
P1-Type MFC (d33)

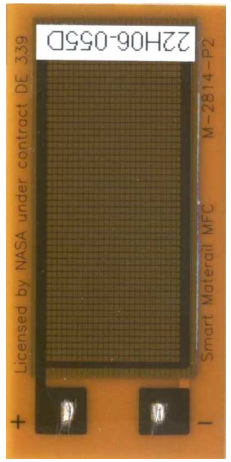




Elongator

P2-Type MFC (d31)



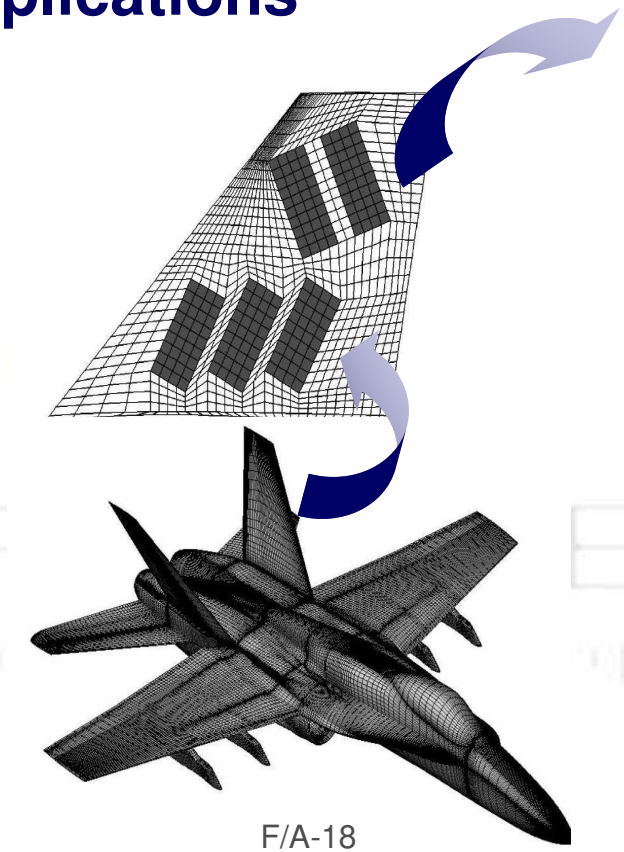


Contractor

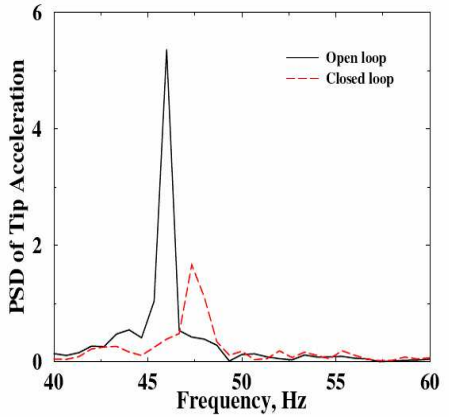
Device	Operation voltage		Capacity	Sensor characteristic		Actuator characteristic	Generator characteristic
	V_{op}^{+} [V]	V_{op}^{-} [V]	C_{bol} [nF / cm²]	d_{33}^{eff} [pC / N]	d_{31}^{eff} [pC / N]	Strain / Volt. [µstrain / V]	Charge/Strain [pC / ppm]
3-3 MFC	**1500**	**-500**	**0,42**	**460**	**-**	**0,7..0,9** [0 … 1500V]	**1670** [> 100V]
3-1 MFC	**360**	**-60**	**4,5**	**-**	**-370**	**- 2** [0 … 360 V]	**3250** [< 100 V]

Space & Aircraft Applications

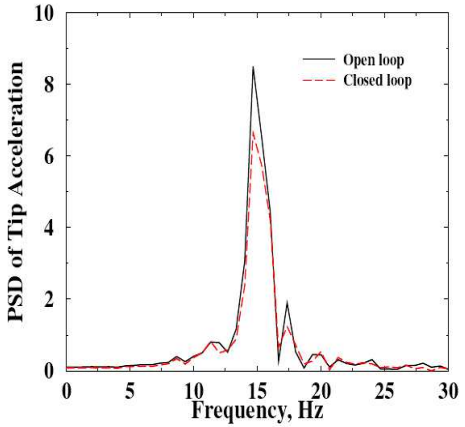
Twin-tail buffet loads alleviation (NASA, AFRL, Boeing)



F/A-18

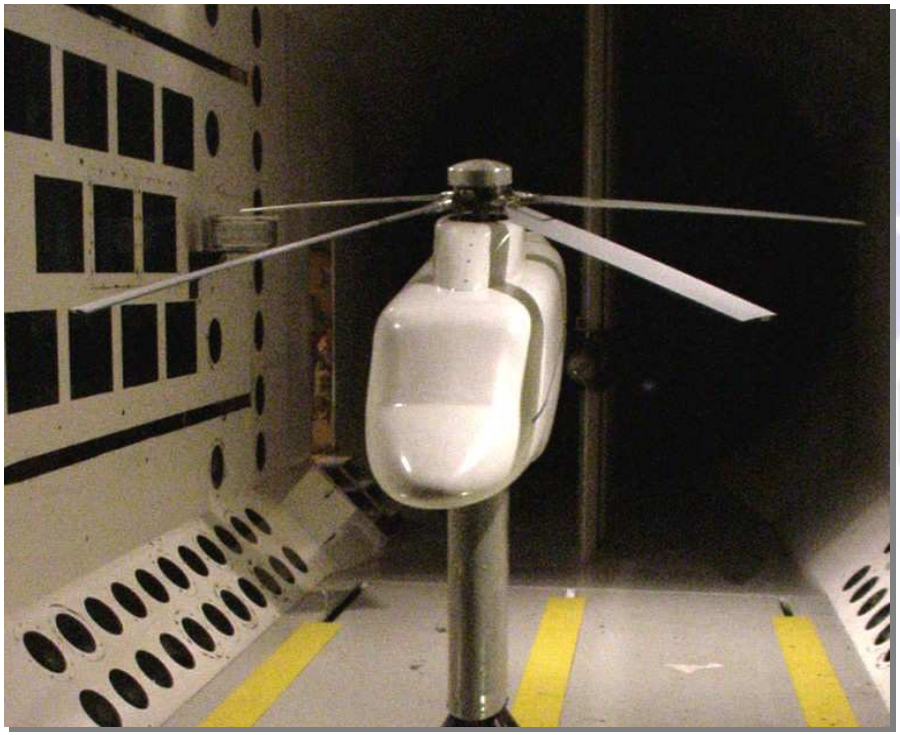


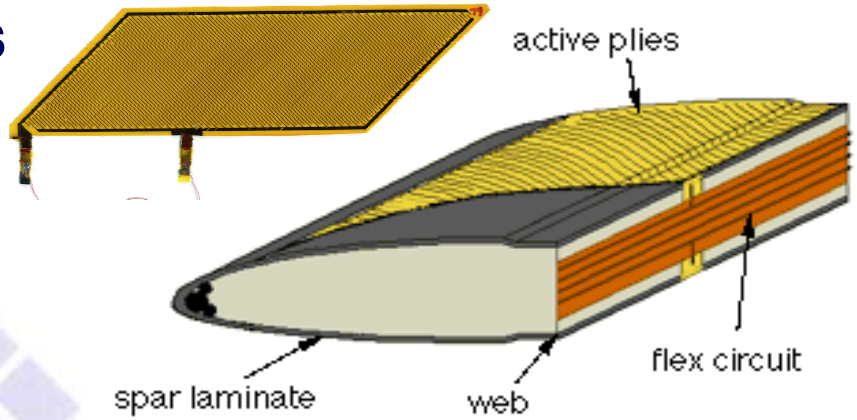
(b) PSD of tip acceleration at torsion mode

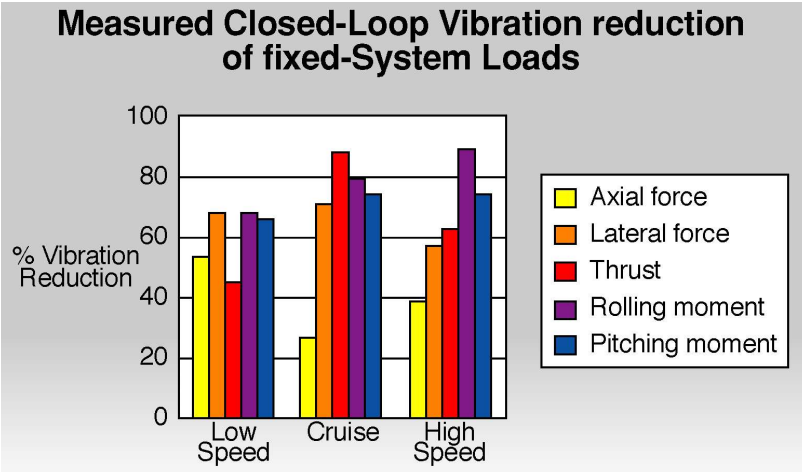


(a) PSD of tip acceleration at bending mode

Space & Aircraft Applications

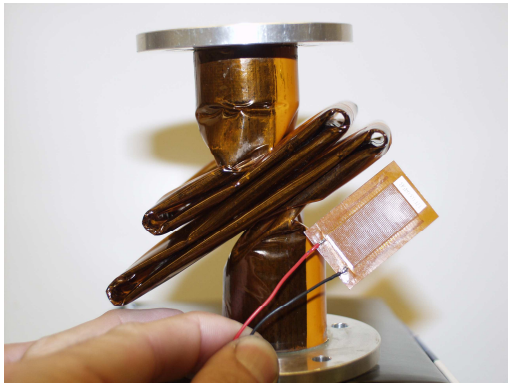


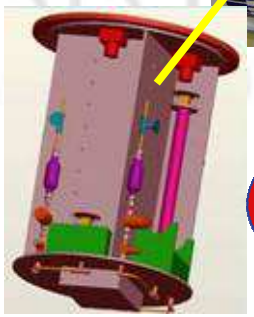


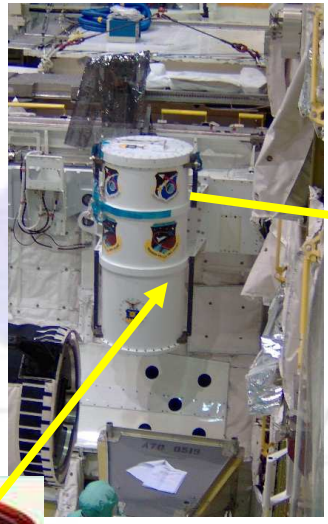


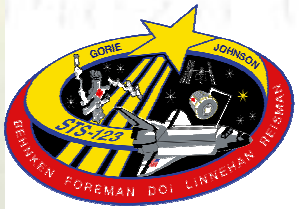
Active Twist Rotor (NASA, ARL, University of Michigan, Sikorsky)

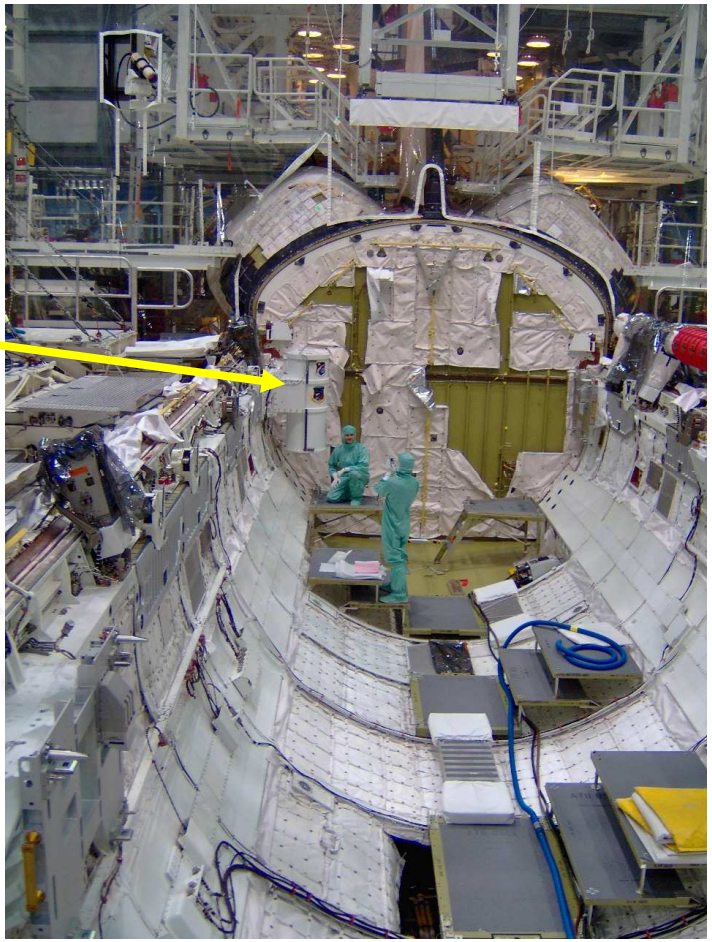
Space & Aircraft Applications











On-orbit rigidizeable structures dynamics Shuttle flight experiment (NASA, AFIT)

Fully solid state flight control for small UAVs

Photos courtesy SDI & Virginia Tech

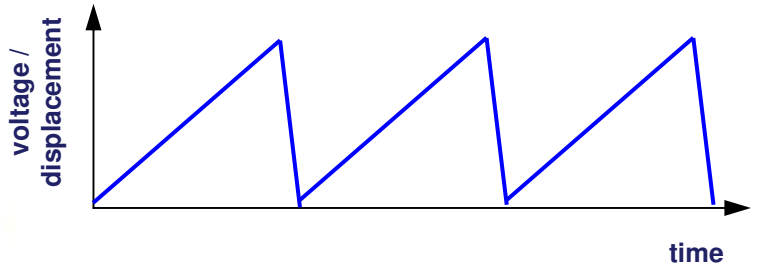
- **UAVs up to 2m wing span, elevators and aerilons controlled with MFCs.**
- **Allows to fold the wings around fuselage for compact transportation/deployment and adding robustness in flight operations.**
- **Developed by System Dynamics under US Army contract.**
- **New generation of power supplies developed with AMPower, USA. Low cost, battery operated device for -500 to 1500V output for the MFC.**

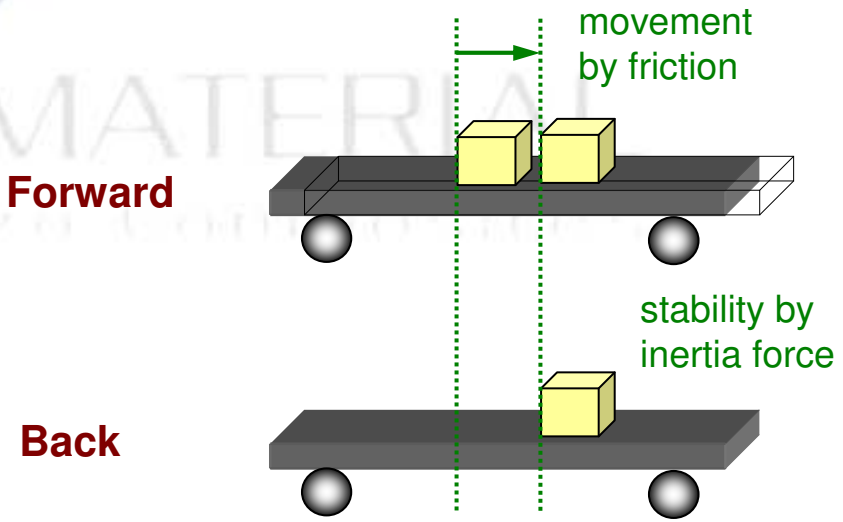
AMD-2012-CE battery operated power supply with analogue or PWM control input

Double Rainbow (or Moonie) MFC-Design

Application in a linear conveyor

Principle of work

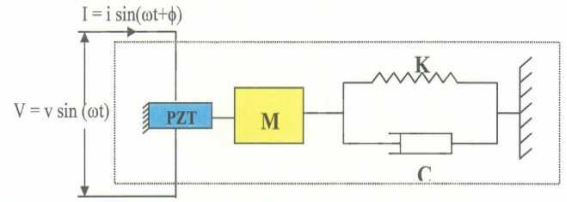


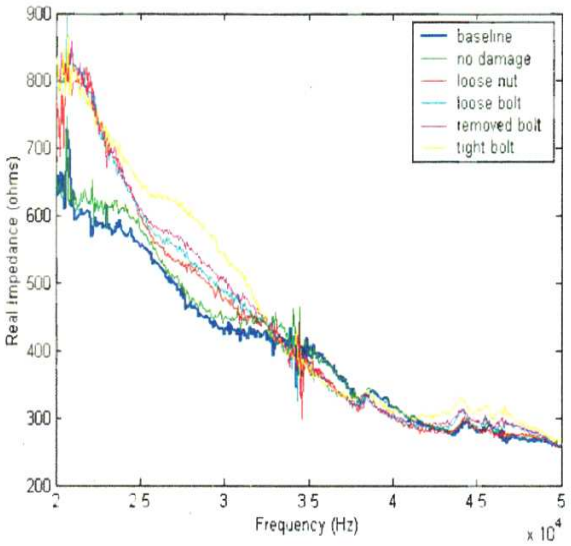


Advantages:

- Full speed control without resonance restrictions
- No resonance tuning necessary
- Low noise conveying

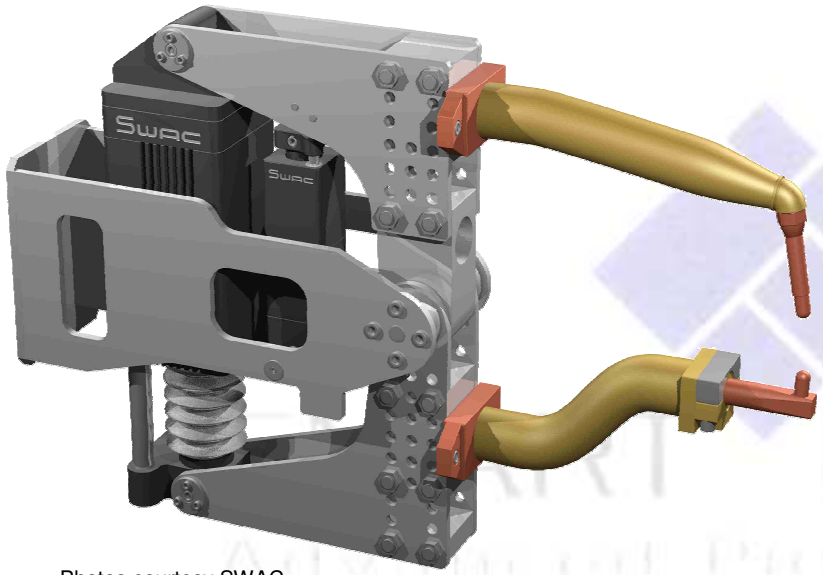
Space & Aircraft Applications





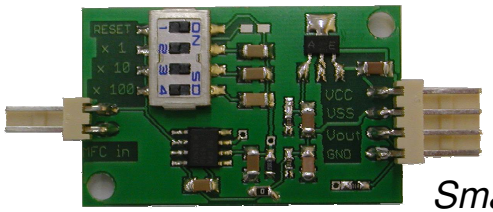
KSC launch tower white room impedance-based health monitoring (Virginia Tech, LANL),
KSC crawler bearing health monitoring (Virginia Tech, LANL),

Online spot welding quality control



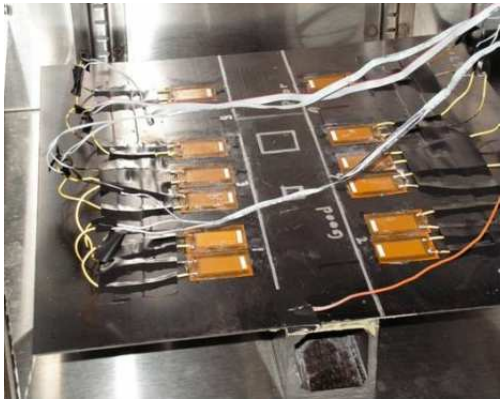
Photos courtesy SWAC

- **The MFC continuously senses the strain inside the arms of the spot welder**
- **Feedback loop with electric motor is controlling the pressure in real time**
- **Allow for welding with higher yield and new materials**
- **Improves yield of car body production and allow for welding of harder steels**



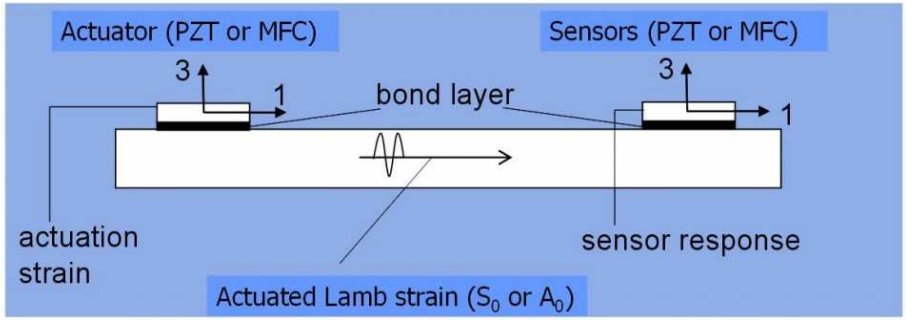
SmartCharge™
low frequency piezo sensor electronic

Transducers for long range ultrasound inspection



UC San Diego

WINTUR

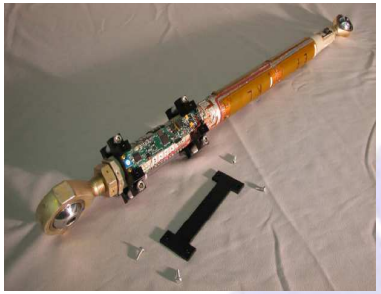


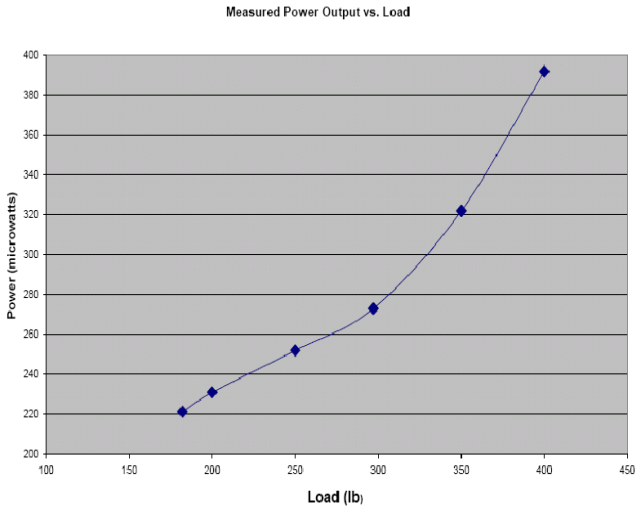
In plate-like structures (where material thickness is comparable to the ultrasound wavelength) it is possible to propagate guided waves (Lamb waves) parallel to the plate surfaces.

Lamb waves can propagate for considerable distances in plates thus making it possible to detect flaws over a sizable area with a single transducer (or pair of transducers).

Self powered SHM sensor for helicopter blades

Bell M412





RF antenna

Circuit board module, microprocessor, and electrochemical battery

Piezoresistive strain gauge

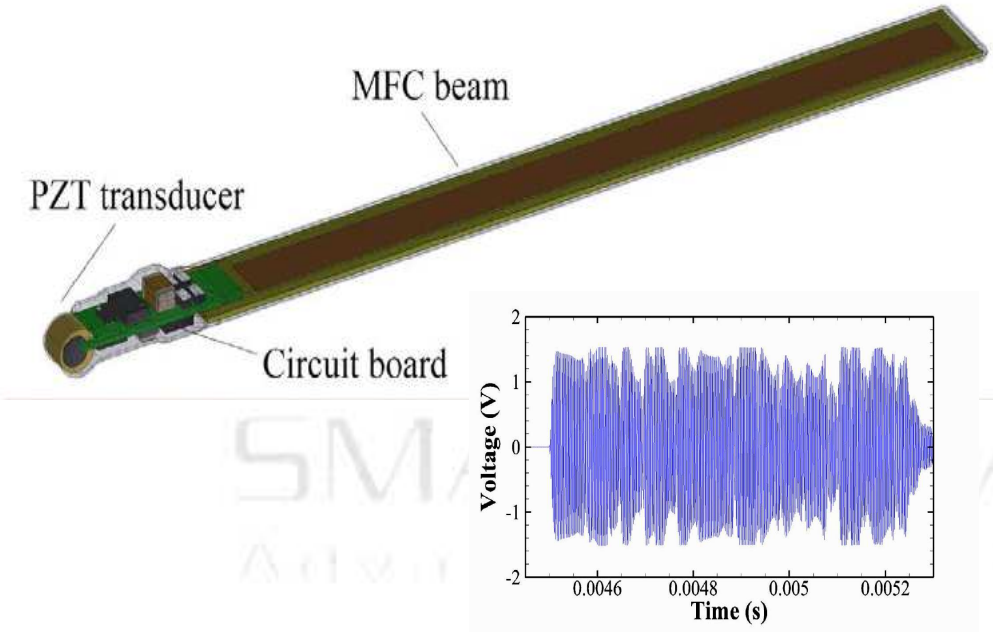
Electrical insulation, EMI shielding, & protective covering (shown transparent for illustration purposes)

Piezoelectric energy harvesting elements

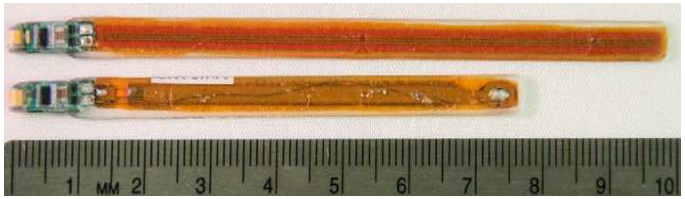
Energy Harvesting on helicopter pitch links (potos & data courtesy mircostrain inc., St. Arms)

Sikorsky H-60 Blackhawk

Self powered tag for long life fish tracking

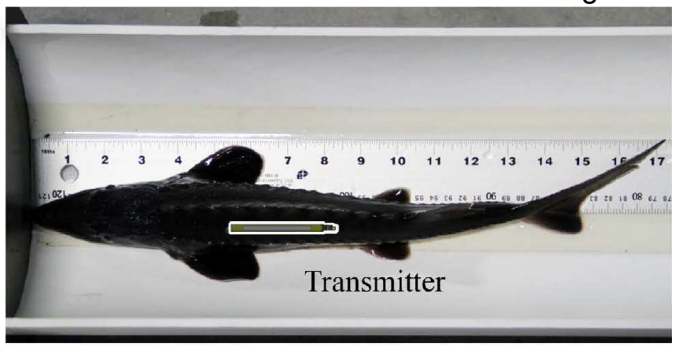


MFC harvesters



rainbow trougt

white sturgeon



- **100m detection range**
- **energy harvested from swimming motion**
- **31bit tag code incl. redundancy check**
- **successfully tested in vivo for 2 weeks**

(potos & data courtesy Huidong Li / ScientificReports)

Wort zum Schluss

Piezofaser-Verbunde kombinieren die interaktiven Möglichkeiten der piezoelektrischen Materialien mit dem ingenieurtechnisch-gestalterischen Freiraum von Verbundwerkstoffen.

Sie ermöglichen so anwendungszugeschnittene Bauelemente, hierzu ist aber ein deutlich erhöhter Entwicklungsaufwand einzuplanen.

Thank you for your attention

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