LOW PROFILE PIEZOCOMPOSITE TRANSDUCERS FOR SMART STRUCTURE APPLICATIONS

A. Schönecker*, T. Rödig, U. Keitel, Fraunhofer-IKTS, Dresden, Germany;
T. Daue, Smart Material, Corp., Osprey, Fl; W. Esler, Smart Material GmbH, Wolfsburg
P. Wierach, German Aerospace Center, Institute of Structural Mechanics, Braunschweig, Germany

Abstract:

The concept of smart structures is based on intelligent materials giving the means to react on external stimulation by changing local mechanical properties. The market needs a high degree of integration of all components: sensors, actuators and electronics. At present, three different low profile piezocomposite actuator types are commercially available. The designs are arising from the R&D work at MIT in the years 1991/92 funded by the US Department of Defence. Recently the German Aerospace Center, DLR, Braunschweig has developed a flexible and reliable PZT wafer based design. Smart Material GmbH is manufacturing the Macro Fiber Composites, licensed by NASA in a full-scale production. The paper is giving an update on availability and developments of low profile piezoelectric sensors and actuators.

Keywords: light weight design, smart structure, piezocomposite, actuator, PZT, MFC

Introduction

There is an increasing need for vibration and shape control in advanced load carrying structures. Light weight design, increased precision, higher safety, reduced noise and last not least more comfort are the most sought after goals. Conventional technical solutions are based on the use of higher amount of mass, which is in conflict with the demands of the market. An alternative approach is given by the concept of smart structures, which is based on intelligent constitutive materials giving the means to react on external stimulation by changing local mechanical properties of the structure [1, 2, 3].
The approach is based on the integration of sensors and actuators, which are connected to an electronic circuit. This can be a simple passive network, but also a complex micro-controller driven circuit. The market needs a high degree of integration of all components. Beside of integrated sensors and actuators, electronic circuits are also expected to become an integrated part of the structure.
Suitable composite material systems that combine load carrying, sensory and active properties are a vital prerequisite for the development of adaptive structures. Due to the overall performance, piezoceramics are considered the most promising basis for active materials. The use of thin monolithic piezoceramic wafers and fibers as actuating and sensing material for structural control has been discussed in many publications. However the production of these devices is still very demanding since the extreme brittleness of the piezoceramic material requires sophisticated manufacturing techniques to avoid damages. An appropriate solution for this problem is to pre-encapsulate the brittle piezoceramic wafers or fibers before processing. With this step the piezoceramic is provided with a mechanical stabilization, electrical insulation and electrical contacts. At present, three different low profile actuator types are commercially available [4], wafer based -, fiber based (so called Active Fiber Composites AFC [5]) – and macro fiber based actuators (so called MFC [6]). These designs are arising from the R&D work at MIT in the years 1991 / 92 funded by the US department of Defence. Progress has been attained due to ongoing R&D activities. Recently the German Aerospace Center, DLR, Braunschweig has developed a flexible and reliable PZT wafer based design [7, 8]. Progress is also seen in the commercialization of fiber composites. For example, Smart Material Corp. is manufacturing the Macro Fiber Composites (MFC), licensed by NASA in a full-scale production. A new design using the 3-1 coupling allows for the reduction of drive voltage down to 360 V. The paper is giving an update on availability and developments of low profile piezocomposite actuators and compares the performance data of different designs.

Commercial low profile actuators and pilot products

PZT Wafer Based Design
The US-company ACX has developed encapsulated patches (Quickpack®). Here the encapsulation is done by wafer coating (polyimide) with copper stripes to contact the electrodes. Main supplier is now the US company MIDE Technology Corp.,

Medford, having licensed Quickpack® technology. 14 different actuators are offered, the ceramic wafer thickness is ranging between 125 µm ... 250 µm. The patch size covers 40mm x 25mm to 110mm x 40mm. Stacks are available to raise the generative force. A similar approach has been done by NASA with the development of the so called "flex-patch" .

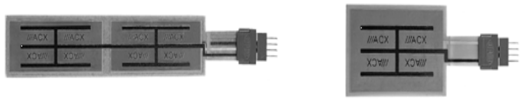

Fig. 1: PZT – Wafer derived low profile actuators, developed by ACX, now supplied by MIDE.

The development of a new technology for the manufacturing of adaptive structures on the basis of piezoceramic materials was an important goal of the German industrial project "Adaptronik". A new modular concept for pre-encapsulated actuators has been developed by German Aerospace Center DLR Braunschweig [7, 8]. During manufacturing the piezoceramic material is provided with a mechanical stabilization, an electrical insulation, electrodes and reliable electric contacts. The multifunctional elements are characterized by an increased damage tolerance, good long term properties and an easy handling. Due to the modular concept, the multifunctional elements can be designed to meet a great variety of different requirements. This involves for example driving voltages, size and shape of the elements and the piezoceramic material itself. See Figs. 2 and 3.

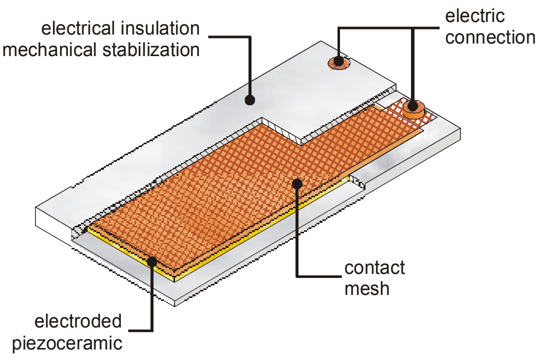

Fig. 2: *Design of PZT wafer deduced low profile actuator, as developed by German Aerospace Center (DLR), Braunschweig.* The device uses transversal (3-1) coupling. Indication: 3-1 DLR FM

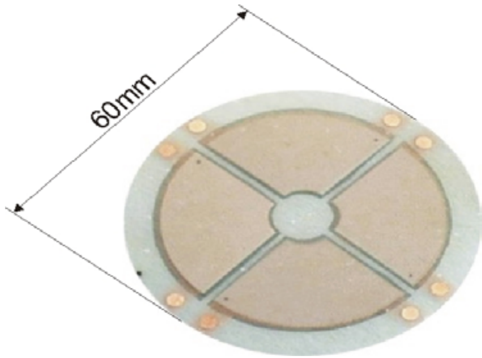

Fig. 3: *Example of circular shaped PZT wafer module based on the DLR technology. The PZT wafer was cut by Laser beam.*

PZT Fiber Based Design

The so-called MFCs (macro fiber composites) consist of rectangular uniaxially aligned piezofibers sandwiched between layers of adhesive and electroded polyimide films, see fig. 4. Smart Material has commercialised the MFC – technology now offering a variety of different design forms [www.smart-material.com].

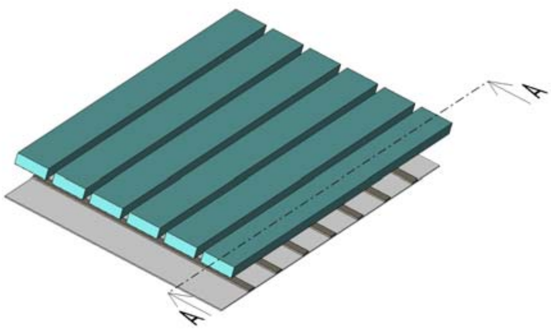

Fig. 4: *MFC, design, as developed by NASA and produced by Smart Material. Diced PZT wafer are packaged with IDE on Kapton film (only the bottom film is shown. The IDE is directly pressed onto the PZT surface and fixed with an adhesive agent. The drive mode depends on the electrode design, see text and Figs. 4 and 5.*

Using non-metallized PZT the electric field couples between neighboured finger electrodes of different polarity in the fiber direction (3-3 MFC), see Fig. 5.

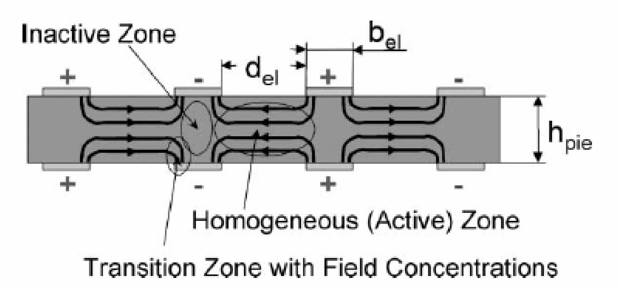

Fig. 5: *3-3 MFC cross section (A-A cut) showing the electric field distribution (black arrows). The device is an elongator.*

Recently, a contracting MF has been developed with the advantage of reduced driving voltage of 360V. This device uses PZT fibers with top and bottom electrodes obtained by dicing metallized PZT-wafers. All finger electrodes of each side connected together. Thus, the applied electric field drops across the fiber thickness, see Fig. 6.

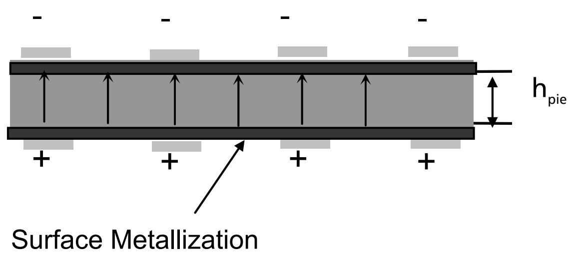

Fig.6: *Cross section through 3-1 MFC (A-A cut) showing the electric field distribution (black arrows) This MFC design allows for low driving voltages. The finger electrodes of each side are directly pressed onto the electrodes on the PZT surface, thus coupling the electric field across the fiber thickness.*

The MFC assembly enables in-plane actuation and sensing in a sealed, durable, ready-to-use package.

Performance of low profile transducers

The here described piezocomposite transducers are innovative devices. Geometrical data and used constituent materials are still subjet to modification.. Nevertheless, basic engineering data are known, partly by publications of developing groups, partly from own measurements. Table 1 to 3 give essential engineering data.

Table 1: DC poling voltages and maximum operation

Device	V_{pol}^{+} [V]	V_{op}^{+} [V]	V_{op}^{-} [V]
3-3 MFC.	1500	1500	-500
1-3 MFC.	360	360	-60
1-3 DLR FM	400	400	-60

Table 2: Specific capacity C_{pol} (after poling, 1 kHz, at room temperature) and effective piezoelectric constant $d_{33/13}^{eff}$

Device	C_{pol} [nF/cm²]	d_{33}^{eff} [pC/N]	d_{13}^{eff} [pC/N]
3-3 MFC.	0,42	460	-
1-3 MFC.	4,5	-	-370
1-3 DLR FM	8,9	-	-220

Table 3: Linear elastic properties, measured at constant electric field

Device	E_{1x} [Gpa]	E_{1y} [GPa]	ν
3-3 MFC.	30	16	0,31
1-3 MFC.	30	16	0,31
1-3 DLR FM	19	-	0,25

Both, 3-1 DLR FM and 3-1 MFC are contractors, whereas the 3-3 MFC is an elongating device. Fig. 7 and Fig. 8 are showing the strain response as function of applied voltage for the 3-1 MFC and the 3-3 MFC, respectively.

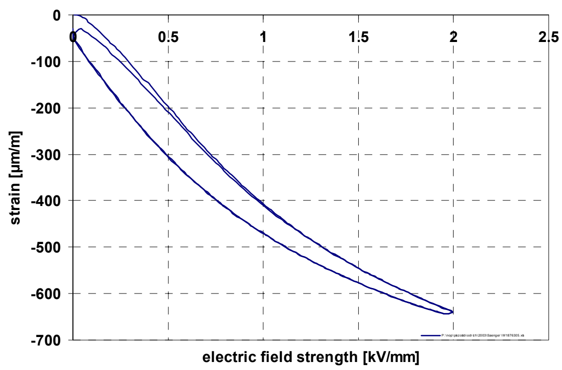

Fig.7: *Free strain as function of applied electric field for the 3-1 MFC*

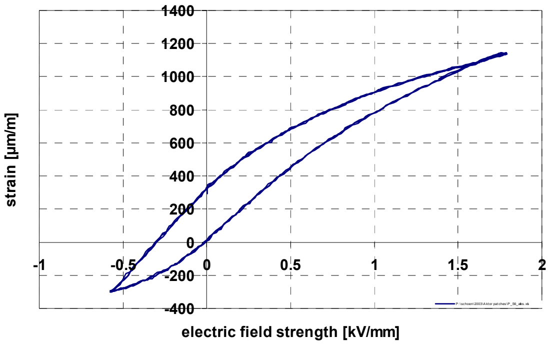

Fig.8: Free strain as function of applied electric field for the 3-3 MFC

R&D on low profile piezocomposite actuators

The goal of R&D is to develop new elements with improved performance that can easily be adapted to different applications. With respect to the great variety of industrial demands standardized solutions still not exist. Ongoing R&D concerns different levels, like

- constitutive phases (piezoceramic, epoxy, insulating and conductive materials)
- scale, shape and connectivity defining the piezocomposite
- device design, especially mesoscopic electrical and mechanical field distribution, interfaces and geometry
- coupling to the load carrying structure (size scaling, placement) and the electronic circuitry (voltage, current, time processing) .

Knowledge on all these levels is necessary to improve device performance and the efficiency for structural control. Progress has recently be attained in the availability of piezoceramic elements (rectangular and circular fibers, tubes, different materials), the device design (geometry and materials for max authority, efficiency, lowest drive voltage). The correlation between structure and the design and placement of the actuators has also been analyzed showing a strong interaction. In other words, patches and structure must be designed in close combination.

Applications

Low profile actuators are innovative actuators that offer high performance and flexibility in cost-competitive applications. When embedded or attached to flexible structures, the MFC actuator provides distributed solid state deflection and vibrational control. NASA has tested a variety of applications in aircraft's like active buffets and internal noise reduction. Commercial applications are still under development and are seen in vibrational reduction, shape control, micro positioning and structural health monitoring.

Conclusion

Adaptronics is going to be used in first applications. Because basic performance parameters are considerably improved, like for example energy economy, precision and comfort, a widespread use is expected in the next future.
The availability of low profile piezocomposite actuators and sensors has been raised in 2002/ 2003. The offer of commercial products will exceed the demands of consuming industry in 2004. Thus, prize reduction is expected. Concerning applications, we expect a shift from defence and sport items to industrial applications and consumer goods.

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