Tremor Suppression Using Smart Textile Fibre Systems

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Abstract: This research deals with a non-invasive system that can be used to harvest waste mechanical energy and utilise this energy to suppress tremors. Hand tremors can emanate from medical conditions such as Parkinson disease and Arthritis. These tremors can be distinguished from other vibrations due to the associated frequency spectra. Mechanical signals are picked up by piezoelectric sensors before the generated voltage is filtered, converted and stored, or used directly to suppress the tremor. Two system level methods used for the suppression of tremor are discussed. As the device is proposed for glove structures, material flexibility is of key significance thus not hindering the bearer's motor functions. Conventional piezoelectric ceramic materials are recognised for their high piezoelectric coefficients in comparison to flexible piezoelectric polymer films. However, ceramic materials are rigid, heavy and offer limited opportunities for forming and shaping. Ceramic based piezoelectric materials in fine fibre form across a range of diameters (10-250μm) were used in this research. When integrated into composite structures the resulting materials retained all the qualities of bulk piezoelectric ceramics (electrical, mechanical, chemical) and mitigated the disadvantages of weight and brittleness. Various piezoelectric fibre composites and piezoelectric polymer film structures were compared, and the potential for their exploitation in glove based power harvesting and tremor suppression structures assessed.

Keywords: piezoelectricity, energy harvesting, vibration suppression, piezoelectric fiber composites, wearable, synchronized switched harvesting on inductor, active vibration control

1. Introduction – Piezoelectricity and Materials

Jacques and Pierre Curie discovered the phenomenon of piezoelectricity in 1880, a category of smart materials that exhibit unique and interrelated properties. Application of stress to a piezoelectric crystal generates an equivalent electric charge; conversely applying a voltage induces a shape change.

The concept of utilising piezoelectric materials for energy generation has been studied greatly over past decades. Hausler [1] proposed an implantable physiological power supply using PVDF films. Umeda et al. [2] looked at using impact energy from a steel ball dropped onto a plate with a piezoelectric material attached. Elvin et al. [3] theoretically and experimentally investigated the use of self powered PVDF strain sensors.

Two common piezoelectric materials are polymers (polyvinylidene fluoride, PVDF) and ceramics (lead zirconate titanate, PZT). The polymer materials are soft and flexible; however have lower dielectric and piezoelectric properties than ceramics. Conventional piezoelectric ceramic materials are rigid, heavy and tend to be in block form. Ceramic materials can therefore add mass and stiffness to bonded structures, especially when working with flexible/lightweight materials. This property and their fragile nature limit possibilities for wearable devices. Comparisons between several piezoelectric materials are presented in Table 1.

Table 1 Comparison of piezoelectric materials

Materials	Density (g/cm^3)	Piezoelectric constant d_{33} (pC/N)	d_{31} (pC/N)	g_{33} x10^{-3} (m^2/C)	g_{31} x10^{-3} (m^2/C)	Dielectric constant ε
Z_nO	5.61	12	7	156	91	8.66
A1N	3.3	4.5, 6.4	6.45	110	158	4.6
PZT	7.8	289-500	150-250	25	11	380-1500
Quartz	2.64	2.3 (d11)	20	60	525	4.3
$L_iN_bO_3$	4.64	100		132		85 (29)
PVDF	1.79	-33	-28	-339	-240	9-13
PVDF/TrFE	1.88	-33.5	-80	-340	-695	9-13

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Ceramic fibres can be produced in the diameter range of 10-250μm with a low cost method [4]. When formed into composite structures they posses all the qualities of conventional ceramics (electrical, mechanical, chemical) and mitigate problems such as weight and brittleness.

The piezoelectric fibre composites (PFCs) consist of unidirectional aligned piezoelectric fibres embedded in an epoxy matrix and sandwiched between two copper clad polymeric laminates (Figure 1). The PFCs [5] have higher efficiency than traditional bulk piezoelectric ceramic materials, due to there large length to area ratio [6]. Typically, when in fibrous form crystalline materials have much higher strengths, and the polymer shell of the PFC allow the fibres to withstand impacts and harsh environments far better than monolithic piezoelectric ceramic materials. The technique of applying interdigitated electrodes takes advantage of the higher d_{33} piezoelectric constant where full electrode coverage of top and bottom of the sample makes use of the lower d_{31} response, highlighted in Table 1. A test method and data has been reported for interdigitated electrode configurations of several line widths and spacing ratios [7]. Concluding that output strain per volt progressively increases as electrode spacing decreases (however narrowest spacing ratios are prone to voltage breakdown), with single crystal fibres again increasing the free strain actuation [8].

2. Power Harvesting

One ambient vibration source is human movement; Starner [9] explored the possibility of acquiring energy exhausted from everyday activities, such as: breathing, blood pressure and walking. Calculating that approximately 60-70W of power is lost during walking and by using a piezoelectric material in a shoe with a conversion efficiency of 12.5%; 8.4W of power could be harvested.

Intelligent clothing with flexible piezoelectric materials integrated into fabrics, may be capable of collecting a portion of the mechanical energy associated with everyday activities, e.g. piezoelectric materials embedded in shoes [10-12].

An overview of a patented device used in the suppression of tremors [13] is presented. The device contains a means of detecting the tremors and means of counteracting the detected tremors. Both sensing and actuating mechanisms employ the piezoelectric effect. Piezoelectric materials are incorporated into glove structures. In addition to sensing and suppressing vibrations, these materials can harvest a portion of the mechanical energy associated with everyday hand movement.

Advances in low power electronics have provided means for powering devices solely from piezoelectric harvested energy, especially with the advent of PFCs. Numerous applications of wireless sensor networks and self-powered systems have emerged, however energy harvesting is not a new concept: hand cranked radios, shake powered flashlights, wind farms and solar energy have found commercialisation in multiple occasions. Through the use of standard electronic techniques the acquired power can be converted, stored and regulated. It is possible to scale the extracted power output using multimode excitation and multiform materials.

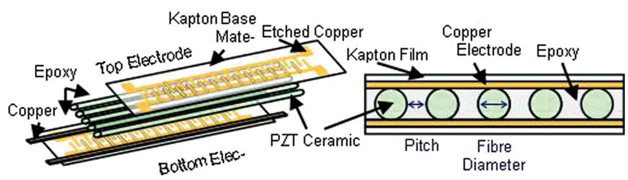

Figure 1 Piezoelectric fibre composite.

In the proposed device the PFCs act as micro power generators, whenever flexed or stretched through normal hand motion a voltage is generated proportional to the stress induced in the material. The voltage produced may be fed through the conducting polymer fibre to a rectification circuit and then used to charge a capacitor, battery or related storage medium, additionally the generated voltage may be used on-line, as per needs.

3. Vibration Suppression

Piezoelectric vibration suppression can be characterised as one of the following: 1) shunting the energy developed on passive electrical elements, 2)