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A painting type of flexible piezoelectric device for ocean energy harvesting

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ABSTRACT

Energy harvesting using piezoelectric materials can be realised by periodic external force. Piezoelectric material directly converts strain energy into electric power to capture a wasted ambient kinetic energy. This recovered energy can be used for operating wireless sensors, such as those found in environmental monitoring, mechanical sensing and structural diagnostic. In our previous work, a flexible piezoelectric device, FPED, was proposed and developed as an energy harvester for generating electric power from flow-induced vibration in ocean and wind environments. In this study a FPED with a painted piezoelectric layer, highly durable in order to withstand extreme bending and weathering caused by waves and currents, is proposed and developed by spray coating for use as an ocean energy harvester. A numerical method is developed to predict electro-fluid–structure interactions and to evaluate electrical performance and mechanical behaviours of the painted FPED. Additionally, validation of the numerical model is provided through several experimental tests. This study also investigates the relationship between the stiffness of the painted FPED and the vibrated frequency, as well as determining their influence on the electrical performance. Finally, the outcomes from a field test, conducted in real ocean space, is presented to provide information on electrical performance, mechanical behaviours and durability of painted FPEDs. The paper shows that a painted FPED is a useful and robust energy harvester for generating electric power from harsh environments.

1. Introduction

Numerous ocean energy technologies have been proposed and developed over the last two decades [1], with several already constructed and installed for real sea operation. A recent trend in the development of wave/tidal current energy devices is the focus on high efficiency and designing for larger scales capable of production levels to meet future energy requirement demands. Large scale devices for ocean energy extraction can have detrimental effects on the ocean environment and this has resulted in unease between engineers and (i) the fishing industry and (ii) environmental preservation groups. Regarding the practical use of current devices, there are several known issues such as high construction and maintenance costs, the use of complex mechanical systems, negative impact on marine biology, challenging site and power line installation, etc. Additionally, some ocean devices could disturb fishing areas and the inhabitant environment of marine mammals. These challenging issues must be considered when designing novel harvesting devices for the ocean environment.

In contrast, small-sized energy harvesters have several attractive features such as compactness, portability, structural simplicity, and lower noise levels. Although the electric power levels are relatively low, small-scale energy harvesters allow for the realization of distributed power sources to fulfil energy supply requirements instead of having a single large power station source. Energy harvesting on the small scale is a topic of global appeal and it is receiving growing interest in terms of both research and practical application possibilities. In essence, small scale energy harvesters can convert wasted ambient energy into useful electrical energy, often at the location it is required. In particular, energy harvesters using piezoelectric materials [2] can be utilized in conditions where

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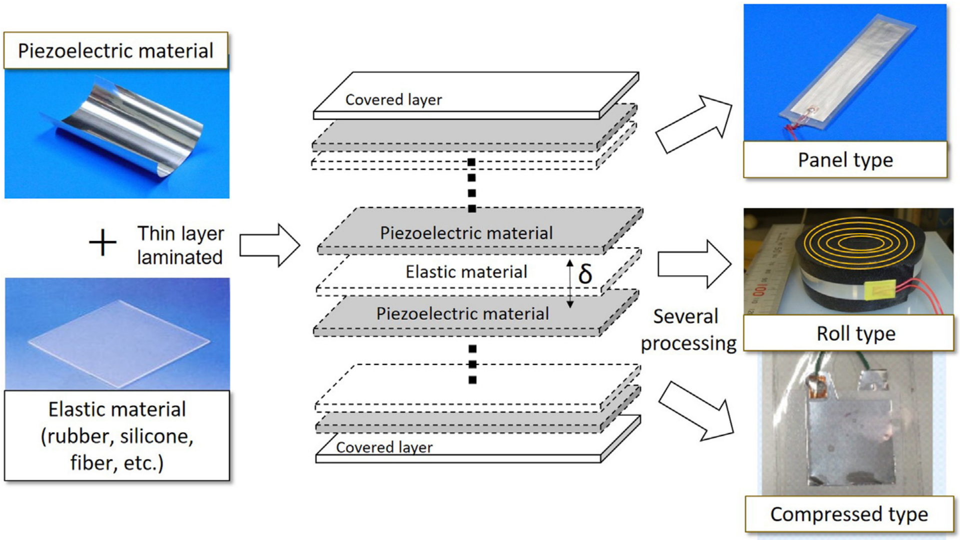

Fig. 1. Overview of flexible piezoelectric device, FPED [11–14].

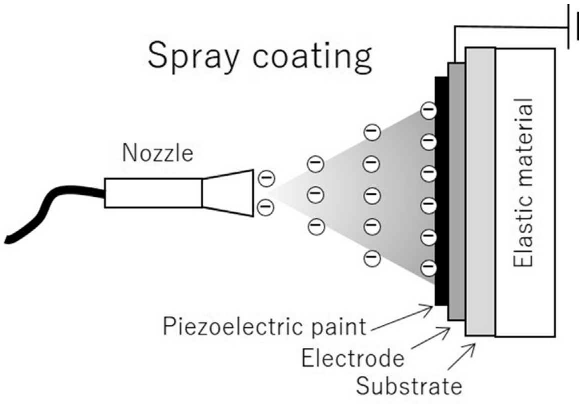

Fig. 2. A painting type of FPED coated by spray nozzle.

a periodic external force is present. In general, piezoelectric materials directly convert strain energy into electric energy to capture wasted ambient kinetic energy. This recovered energy can be used to power wireless sensors such as those found in environmental monitoring, mechanical sensing and structural diagnostic. Some energy harvesters with piezoelectric materials have been applied to wind energy harvesting [3,4], ocean energy harvesting [5–8], and vortex induced vibrations and self-excited vibrations [9]. A brief survey of piezoelectric devices for ocean energy harvesting can be found in [10]. In our previous work a flexible piezoelectric device, FPED, has been proposed and developed as a small scale energy harvester to generate electric power from ambient kinetic energy from water [11,12], wind [13] and mechanical vibration [14]. In terms of wave and current, the generated electric power can be used to activate and operate wireless sensors for ocean environment monitoring and disaster prevention. The power generated by FPEDs could contribute to an environment-friendly ecosystem from use in artificial ocean infrastructures by leading fishes to feeding areas and safety. In the field, FPEDs were already mounted near the water surface, on a floating structure, in order to obtain electric power from wave motion and current.

In this study, a FPED with a painted piezoelectric layer is proposed and developed by spray coating for use as an ocean energy harvester. Its advantages include flexibility, whereby paint can be applied anywhere, process ability, i.e. the ease at which paint can be applied, and high durability to cope with excessive bending and weathering caused by wave and current. The sections of this paper are broken down as follows. Section 2 provides details on the manufacturing procedure for painted FPEDs. This is followed, in Section 3, by the presentation of a numerical model which considers electro-fluid–structure interactions and evaluates electrical performance and mechanical behaviour of painted FPEDs. Sections 4 and 5 provide information on the undertaken experimental work which was conducted to (i) validate the numerical model, and (ii) investigate the relationship between the stiffness of the painted FPED and electric performance in various wave and current conditions. Section 5 also provides insights, from field tests in real ocean environments, on practical electrical performance and mechanical behaviours of painted FPEDs.

2. Overview of flexible piezoelectric device, FPED

In our previous works [11–14], a Flexible Piezoelectric Device, FPED, see Fig. 1, has been proposed and developed as an energy harvester to generate electric power from flow-induced vibration, that is, ambient kinetic energy in ocean, current and wind environments. The FPED is comprised of laminated thin layers of piezoelectric material, e.g. polyvinylidene fluoride (PVDF), and elastic material such as silicon, rubber or textile. FPEDs are highly flexible and adaptable for harvesting energy from various external forces and can also be customized and optimized to tailor to the forcing magnitude and electrical demand. A pair of piezoelectric layers are located at a certain distance δ away from the centreline of the FPED in a typical bimorph configuration (Fig. 1).

Our previous works revealed that the electric power increased with (i) laminated number of piezoelectric layers, N, and (ii) layer location from the neutral axis, δ. Using these two parameters, FPEDs can be carefully designed and optimized to resonate at the dominant excitation frequency. Moreover, the electric power can be further increased when using highly elastic material for the FPED substrate. However, one drawback with current laminated FPEDs is the interface, bonding layer, between the piezoelectric material and elastic material. This layer is subjected to shear stress due to bending, and it was occasionally observed that delamination occurred and the output voltage naturally decreased and eventually disappeared. Considering this critically issue, especially in real world scenarios where forcing magnitudes are likely to cause delamination, an alternate new design for a highly flexible piezoelectric energy harvester should be proposed.