A Bellows Type of Flexible Piezo-electric Energy Harvester for Structural Health Monitoring of Pipelines

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ABSTRACT

To overcome difficulties that Structural Health Monitoring Devices (SHMDs) are sometimes isolated without power supply, this study proposed a real-time SHMD for pipelines using a bellows-type of flexible piezoelectric device (FPED) as a vibration energy harvester to obtain a piezo-voltage frequency response (PFR). The vibration experiments were conducted to find out the characteristics of the frequency distribution of the pipeline. A finite element model was also developed to investigate the disturbance in PFR with cracks and suitable occasions of the energy harvester. The reliability of a bellows-type of FPED was verified by the comparison between the numerical results with the experiment ones. The device shows good performance on monitoring of pipelines and reliability as an energy harvester.

KEY WORDS: Structural Health Monitoring; Piezoelectric paint; Flexible sensor; Energy harvester; U-shaped bellows; Pipeline.

INTRODUCTION

Structural Health Monitoring (SHM) of pipelines in the Ocean Engineering field is a well-established research area. The specific objective of SHM is to detect degradation caused by strategy landslides, earthquakes, corrosion and fatigue. Huge economic investment and human resources could be consumed if the systems will require access to AC power supply or if batteries have to be periodically replaced. For these reasons, the technologies of SHM meet requirements of harvesting ambient energy sources and surveilling quality of products in real-time.

To make clear characteristics of structures such as strain, displacement, curvature, mode shapes, mode shape curvature, modal strain energy and natural frequencies, frequency response function (FRFs) and strain frequency response function (SFRFs) are useful for monitoring identification of structural damage. Especially, strain must be more sensitive than displacement to structural local changes in the previous research (Yam et al., 1996). However, strain monitoring on pipelines in ocean engineering field might be difficult and impossible anytime and anywhere.

On the other hand, utilization of materials coupling two forms of energy is one of the most promising ways of developing real-time Structural Health Monitoring Devices (SHMD). The materials in previous research (Sun et al., 1995; Giurgiutiu et al., 1997; Park et al., 1999; Lopes et al., 2000; Park et al., 2000b) have drawn main attention on Piezo-ceramics (PZT) coupling electric and mechanical energy, magnetorheological (MR) fluid or heat coupling magnetic and mechanical energy, and shape memory alloy (SMA) coupling heat and mechanical energy. The device with those could be placed in a closed room and isolated without power supply. Especially, nondestructive evaluation technique utilizing the piezoelectric material, shows great promise for SHMD. At the same time, Real-time SHMD systems should be a strongly positive-correlation between output voltage and strain of piezoelectric material.

In the previous studies (Ying et al., 2013), Piezoelectric transducers (PZTs) permanently installed on steel straight pipes were used to investigate feasibility of continuous monitoring techniques, and then they demonstrated that multiple pattern recognition techniques with multiple potentially effective features are useful to find out identification of the structure. However, there is no unique best feature for every set of the data from every PZT points. To this end, the highly flexible piezoelectric devices (FPEDs) have been developed by Mutsuda et al. (2017b), and then FPEDs can be attached on a curved surface and exhibit high-level adaptability of deformation.

In this study, a real-time SHMD for pipelines using a bellows-type of FPED is proposed and developed as a vibration energy harvester to obtain a piezo-voltage frequency response (PFR). Bellows has a flexible part where vibration energy can be absorbed and can protect the whole system (Vishnu Rajan, 2016). In this way, the FPED attached on a U-shaped bellows part jointed between straight pipelines, is proposed and developed in this study. There are two primary aims of this device as below:

1. To assess characteristics of flexible device as an energy harvester.
2. To investigate performance on structural health monitoring of pipelines without power supply.