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A flow sensing method of power spectrum based on piezoelectric effect and vortex-induced vibrations

Jie Hu[1], Hanmin Peng[1,3], Tingyu Liu[2], Xinke Yao[1], Huiyang Wu[1], Penghui Lu[1]

[1]State Key Lab of Mechanics and Control of Mechanical Structures, Nanjing University of Aeronautics & Astronautics, Nanjing 210016, China

[2]Jiangsu Engineering Laboratory of High-end Manufacturing Equipment and Technology, Nanjing University of Science and Technology, Nanjing 210094, China

[3]Corresponding author

Abstract. This study introduces a piezoelectric sensor based on vortex-induced vibrations. Such sensor module is endowed with a piezoelectric cantilever and cylinder, which can be used to measure the wind flow from the characteristic signals of vortex. In contrast to the conventional sensors using peak-to-peak, zero-to-peak or root-mean-square voltages as the characteristics of the vortex, the proposed sensor takes advantage of the power spectrum in the vortex frequency as the sensing intensity of the characteristic vortex, contributing to successfully sensing weak flow signals. Then, we propose a fluid-solid-electric coupling finite element method to investigate the relationship between the power spectrum and the geometrical parameters (including size and position). The calculated and experimental results show that increasing the cylinder's diameter can linearly enhance the optimal sensing region and the power spectrum, but the region does not change with altering the amplitude of wind velocity. In our experiment, the sensor can effectively test the wind velocity of 1.5 m/s, which is difficult to be measured by traditional sensors. Therefore, this fluid-solid-electric coupling calculation method can be used to design the structure of flow sensor.

Keywords: piezoelectric sensor, vortex-induced vibrations, fluid-solid-electric coupling calculation, power spectrum, LabVIEW

1. Introduction

The vortex-induced vibration (VIV) is a forced flow induced vibration (FIV) induced by periodic vortex shedding under flow field in non-streamlined structures. Such vibration may be introduced through excitation of the transverse vibration of the structure by a periodic aerodynamic force on the structure's surface. This periodic aerodynamic force is vertical to the flow direction of the flow field [1,2]. Since the flow velocity is related to the shedding frequency of the vortex, such phenomenon has been widely used for the realization of a variety of vibration sensors in various applications, including the wind energy harvesting, flux measurement and weather monitoring [3,4,5]. Most conventional FIV sensors are based on the mechanical rotation of the structure, and thus, suffer from complexity as they require machining accuracy and mechanical stability [6,7]. However, the piezoelectric-based VIV sensors require no rotating components, and therefore, can be realized with a simple and miniaturized structure, and are integrable with Micro Electro-Mechanical System (MEMS) processing technology [8,9,10,11].

Recently, there are mainly two piezoelectric materials employed in the VIV sensor: lead zirconate titanate piezoelectric ceramics (PZT) and polyvinylidene difluoride (PVDF). PVDF film is usually used in vortex induced vibration because of its electrical characteristics, and it is suitable for alternating load