The Application of Fluttering Thin-flat Plates for Wind Harvesting using Electromagnetic Converter

I P. G. Sopan Rahtika[a], I Made Suarta[b] and I Komang Rusmariadi
Department of Mechanical Engineering, Bali State Polytechic, Badung, Bali, Indonesia

Keywords: Flutter, Wind Harvesting, Thin-flat Plates, Electromagnetic Converter.

Abstract: In this study, a new energy conversion device was designed to convert the energy harvested by fluttering thin–flat plates into electrical energy. This design uses an electrognetic converter in the form of a magnetically induced ferromagnetic thin-flat plate to induce electromotive force in a solenoid. The purpose of this study was to determine the effect of the size of the thin-flat plates on the electromotive force generated by the wind harvester. Several wind harvesters with various sizes of thin-flat plates were placed in a subsonic wind tunnel for testing. The test included measuring the energy produced by the wind havester in the form of the generated electrical voltage.

1 INTRODUCTION

Renewable energy is a type of energy obtained from unlimited or inexhaustible natural resources, such as wind and sunlight. Renewable energy is an alternative to traditional energy that relies on fossil fuels, and tends to be less harmful to the environment.

As the world's population increases, so does the demand for energy to power our homes, businesses and communities. Innovation and expansion of renewable energy sources is key to maintaining sustainable energy levels and protecting the planet from climate change.

Fossil fuels are not renewable energy sources because of their limited nature. Plus, they release carbon dioxide into our atmosphere which contributes to climate change and global warming.

Wind is a renewable energy source. This type of energy is a clean energy source, meaning it does not pollute the air like other forms of energy. Wind energy does not produce carbon dioxide, or release harmful products that can cause environmental damage or have a negative impact on human health such as smog, acid rain or other heat-trapping gases.

Wind farms capture wind energy using turbines and convert it into electricity. Commercial grade wind power generation systems can power communities.

The use of wind turbines requires wind farms that are sufficiently strong and must meet a certain minimum speed to operate, so they can only be applied to certain locations that meet the requirements for wind speed stability. An alternative technology that can be used to utilize wind energy is to use a fluttering flat plate. This technology is still at the basic research stage. This technology is better known as a wind harvester because it can be an alternative solution for the use of wind energy in urban areas where the wind flow is not so strong.

In this study, a new energy conversion design is designed to convert the energy harvested by fluttering thin–flat plates into electrical energy. This design of several wind harvesters with various sizes of thin-flat plates will be placed in the subsonic wind tunnel for testing. The test includes measuring the energy produced by the wind havester in the form of the generated electrical voltage. The purpose of this study was to determine the effect of the size of the thin-flat plates on the electromotive force produced by a wind harvester using an electromagnetic converter.

[a] https://orcid.org/0000-0001-5290-6910
[b] https://orcid.org/0000-0002-6915-0475

Rahtika, I., Suarta, I. and Rusmariadi, I.
The Application of Fluttering Thin-flat Plates for Wind Harvesting using Electromagnetic Converter.
DOI: 10.5220/0010948100003260
In *Proceedings of the 4th International Conference on Applied Science and Technology on Engineering Science (iCAST-ES 2021)*, pages 499-502
ISBN: 978-989-758-615-6; ISSN: 2975-8246

2 THEORY

The main literature that forms the basis of this research theory is knowledge about aeroelasticity, especially about the flutter phenomenon.

Quite a lot of literature on flutter has been published. In the history of flutter, the results of the first theoretical study were carried out by Lord Rayleigh (Rayleigh, 1878) who discussed the instability of plates with infinite dimensions in axial flow. A more practical scientific understanding of the flutter phenomenon can be traced from the NACA Technical Report No. 496 on General Theory of Aerodynamic Instability and the Mechanism of Flutter (Theodorsen, 1934). In that report, Theodorsen explained theoretically how flutter could occur in an airplane wing by explaining the interaction between elasticity of structure, inertial forces, and aerodynamic forces. The dynamics of the airplane wing is modeled in mathematical form and the solution of the model can explain the occurrence of flutter. This research was continued as an experimental investigation and reported in NACA Technical Report No. 685 (Theodorsen, 1940). The effect of adding Aeleron and Tab on flutter was further reported in NACA Technical Report No. 736 (Theodorsen, 1941).

Flutter phenomena are also encountered in the engineering world outside of aircraft. The collapse of the Tacoma Narrows Bridge in the US state of Washington in 1940 was finally concluded as a design failure due to neglect of aerodynamic effects. The bridge flutters when wind gusts with a speed of 48 km/hour come (Fox & McDonald, 1994).

The development of the printing industry requires machines with higher speeds to motivate Watanabe et al. (Watanabe, 2002a) investigated the flutter problem on paper. There are two methods used, namely potential flow and numerical Navier-Stokes to describe the flutter mode shape as a function of mass ratio. Time domain analysis was performed using the Navier-Stokes method. Experimentally Watanabe et al. (Watanabe, 2002b) observes the minimum speed limit so that the paper stops fluttering.

Fluid Structure Interaction (FSI) on a flag or long ribbon has similarities to thin flat-plates. Research on flags and long ribbons has been carried out by Connell & Yue (2007), Lemaitre et al. (2005), Michelin et al. (2008), Manela & Howe (2009), and Virot et al. (2013).

With the advent of computer technology, many flutter analysis uses the finite element method. LAPAN researchers conducted a Flutter Analysis to optimize the Fin design of the satellite launch rocket (Andria, 2010). Manikandan & Rao performed the finite element method to optimize the mounting system of the aerofoil flutter test (Manikandan & Rao, 2011).

The bimodal flutter phenomenon was discovered by Drazumeric et al. (2014) on a rigid airfoil that is hung flexibly with a flexible plate mounted on the trailing edge of the airfoil. The flutter behavior was predicted using the eigenfunction expansion approach and the bimodal flutter behavior was also demonstrated experimentally.

Flutter in biological systems in humans was investigated by Balint & Lucey (2005), Huang (1995), and Howell et al. [2009]. They found that the snoring phenomenon was similar to the flutter of the cantilevered flexible plate in axial flow. The use of flutter for wind energy harvesting has been explored by Doaré & Michelin (2011) and Dunmon et al. (2011). Other research on energy harvesting using a slender structure behind the bluff body was also conducted by Allen and Smits (2001) and Kuhl & DesJardin (2012).

Previous works by authors include the study on the flutter similitude of the free leading edge plates in axial flow (Rahtika, 2017a), their numerical and experimental investigation (Rahtika, 2017b), and the effect of the angles of attack to the plate flutter speeds. Another priliminary study on the application of hidro flutter to field of renewable energy has also been done by the authors (Rahtika, 2019).

Based on all these previous research, a new type wind harvester was designed in ths research. The final design of the wind harvester is shown on Figure 1.

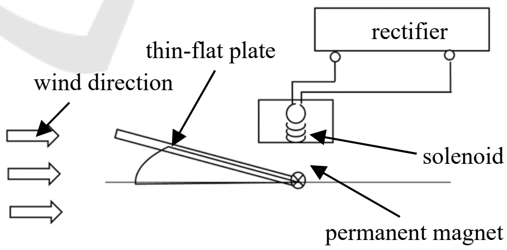

Figure 1: The wind harvester design.

The basic working principle of the design is to convert mechanical energy of fluttering magnetically induced ferromagnetic plate into electrical energy using solenoid. A ferromagnetic thin-flat plate will experience a Limit Cycle Oscillation (LCO) when it is placed in flowing air if the fow reach a certain range of speed before the plate will experience unstability. The plate absorbs energy from the flowing air and saves it in the form of mechanical energy. Since the plate is magnetically induced by a permanent magnetic, its vibration will generate a fluctuating magnetic field which induced an electromotive force in the solenoid. Then, the generated current out of the solenoid is rectified using a Wheatstone bridge circuit.

3 RESULT

During the experiment, the thin-flat plate was placed in a wind tunnel test chamber which had laminar airflow. The thin-flat plate was clamped at one end and left free at the other (cantilevered). The angle of incidence was defined as the angle between the thin-flat plate and the airflow. The angle of incidence is defined as zero (0) if the free end is facing the wind. The flutter speed is defined as the wind speed at the time of plate instability.

A coil of conductor and permanent magnet was placed on one side of the thin-flat plate which does not move. Permanent magnets induced thin-flat plates to become magnets. Thin-flat plate vibrated due to flutter, and then induced coiling of the conductor to produce electromotive force. The resulting electromotive force will be recorded.

In step-by-step manner, the testing procedure carried out in this study was as follows:

1. Thin-flat plate was placed in the wind tunnel test chamber
2. The airflow waas increased slowly until the thin-flat plate flutters.
3. The voltage generated by the coil is recorded.
4. Perform steps 1 to. 3 for the other plate dimensions.

The experimental observation results from the above test was analyzed qualitatively by paying attention to the DC voltage generated out of Wheatstone bridge restifier from three dimensions of the thin-flat plate.

The DC volteges are the RMS values of the voltages out of the solenoid. Table 1 shows the voltages generated by the wind harvester with three different plates' thicknesses.

Table 1: RMS voltages of the wind harvester.

Plate thickness (mm)	Voltage RMS (Volts)
0.010	2.24
0.015	4.69
0.025	6.36

The voltage generated increased with the increacing plate thickness because the thicker plate has higher flutter speed and also has higher vibration frequency during LCO which eventually would generated higher voltage.

4 CONCLUSIONS

A wind harvester design using fluttering ferromagnetic thin-flat plate has been constructed and experimentally tested. Measurements have been made to measure voltage produced with different sizes of the wind harvester in a subsonic wind tunnel.

ACKNOWLEDGEMENTS

We would like to thank Bali State Polytechnics for the funding that made this study could be completed.

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