Aeroelastic Flutter Energy Harvesting

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Abstract – *Energy harvesting is the process by which light, thermal, solar and kinetic energy of wind can be converted to a usable form of energy with the ultimate objective of developing self-powered sensors , actuators and other electronic devices. In this paper, we are discussing the method of energy harvesting from the aeroelastic flutter. Flutter is a well-known dynamic excitation phenomenon in wind energy. Flutter is basically a self-sustained oscillatory instability. Flutter phenomenon has been used to convert wind energy into mechanical vibrations which is then transformed into electrical power. The aeroelastic flutter is the phenomenon of aerodynamics. Aeroelastic flutter involves aerodynamic forces acting on a structure to result in self-exciting high energy oscillations. Flutter has the potential to occur in any object subject to force. Flutter is basically a dangerous phenomenon encountered in flexible structures subjected to aerodynamic forces. These vibrations can cause structural failure. But these vibrations can be used to generate the electrical energy as in case of wind belt. Wind energy harvesters based on the fluttering phenomenon is an emerging area that offers an efficient alternative approach to traditional wind turbines. The study of this wind to vibration converter explores and evaluates the effects of belt tension, length and coil position on maximum vibration acceleration.*

Key Words: Aeroelasticity, Flutter, Harvesting, Vibrations, Wind.

1.INTRODUCTION

Wind energy has long been used to generate power mostly using wind turbines. But in the last few years studies have been focused on small energy harvesting devices using ambient vibrations and piezoelectric energy. The different types of energy harvesting techniques are used to capture the energy from natural resources. Among all natural resources wind energy can be considered as one of the most promising source because of its attractive features. The aeroelastic flutter makes use of the wind energy. It captures the kinetic energy of wind. Instead of using conventional, geared, rotating airfoils ,the aeroelastic flutter energy harvester can be proven as the best alternative approach. Aeroelastic flutter is a self-feeding vibration of an elastic structure in an air flow. It occurs from the flutter limit wind speed, when there is a positive feedback between the structure natural vibration and the aerodynamic forces exerted by the air flow. The amplitude of vibration will increase, only limited by the mechanical and aerodynamic damping, which can eventually result in large amplitude oscillations and structural failure. Fluttering can be destructive and therefore civil structures exposed to aerodynamic forces such as wings, bridges or chimneys have to be designed and carefully tested in order to avoid fluttering effects. However it has recently been demonstrated that flutter is not always a destructive phenomenon. Energy harvesters have been realized, that take advantage of the self-feeding vibration of a membrane subjected to a wind flow. A piezoelectric or an electromagnetic device attached to this membrane is then used to convert the vibrations into electrical energy. Such a system offers a cheap, small and simple alternative to classic rotary wind turbines. The company Humdinger Wind energy has first developed and commercialized an energy harvester based on wind fluttering. The harvested power ranges from several milli-watts for the smallest device to 7:2 kWh for a 1 meter- length wind belt under a wind speed of 6 m/s, as specified by the supplier.

1.1. Wind as a Source of Energy Harvesting

Wind power has been recognized as a viable source of 'free' energy from hundreds of years. Wind energy has long been used to generate power mostly using wind turbines by exploiting the blades' lift and drag forces to rotate an electromagnetic generator. This conventional approach for generating power is, however, difficult to apply to small scale energy harvesters, because small size generators are difficult to make and have low efficiency. Wind induced vibrations have been used as an alternate input source for small scale energy harvesters. Wind induced vibrations have been used to mechanically strain piezoelectric transducers to generate power (Allen 2001, Sun 2011) and to generate inductance power in electromagnetic transducers (Jung 2011). Aeroelastic instability phenomenon, which is referred to as flutter, has also been suggested as an input source for energy harvesters because of its potential capacity for generating electrical power. Flutter induced vibration of T-shape cantilever beam and plate have been used to mechanically strain piezoelectric patches to generate power (Kwon 2010, Bryant 2011). A leaf-like structure has also been proposed to convert cross-flow flutter into electricity using Poly Vinylidene Fluoride (Li 2011). Wind possesses many advantages as a renewable energy source. Particularly, generating energy by wind does not depend on a dominant-frequency; as a result, the natural frequency of the vibrating structural part does not need to match a certain frequency, which results in great flexibility in the configuration of energy harvesters. Wind, however, posseses many challenges that must be addressed in order for wind to be used as a reliable input source for energy harvesters. These challenges include intermittency which hinders continuous energy production and inconsistent quality of wind flows that reduces the efficiency of energy harvesters. The intermittency problem can be overcome if the generated power is sufficiently large for storage in batteries.

1.2. Limitations of Wind Turbines

Wind turbines have been the primary focus of wind harvesting technologies. They are extremely unreliable under some atmospheric conditions. The energy generation from wind turbine becomes more costly due to large structure. The variation in wind speed affects the output of wind turbine considerably. Whereas the output of aeroelastic flutters energy harvester is more as compare to the wind turbine at same wind speed. The aeroelastic flutter energy harvester does not include any type of gears or bearings. Hence making the construction more simpler so many limitation of the wind turbine can be overcome by the use of aeroelastic flutter energy harvester.

2. AEROELASTIC FLUTTER

Flutter is a dangerous phenomenon encountered in flexible structures subjected to aerodynamic forces. This includes aircraft, buildings, telegraph wires, stop signs and bridges. Flutter occurs as a result of interactions between aerodynamics, stiffness, and inertial forces on a structure. In an aircraft, as the speed of the wind increases, there may be a point at which the structural damping is insufficient to damp out the motions which are increasing due to aerodynamic energy being added to the structure. This vibration can cause structural failure and therefore considering flutter characteristics is an essential part of designing an aircraft. Aeroelasticity phenomena involve the study of the interaction between aerodynamic forces and elastic forces (static aeroelasticity), aerodynamic forces, inertia forces and elastic forces (dynamic aeroelasticity), and aerodynamic forces, inertia forces, elastic forces and control laws (aero-servoelasticity). Modern aircraft structures may be very flexible and this flexibility of the airframe makes aeroelastic study an important aspect of aircraft design and verification procedures.

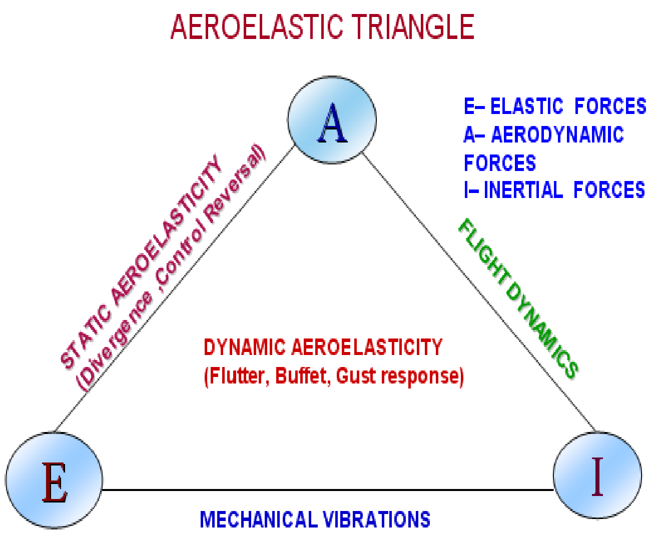

Fig -1: Aeroelasticity triangle

Wing torsional divergence and flutter are the two major aeroelastic phenomena considered in aircraft design. Divergence is a static instability which occurs when the static aerodynamic effects counteract the torsional stiffness of the structure. Flutter is a dynamic aeroelastic instability characterized by sustained oscillation of structure arising from interaction between the elastic, inertial and aerodynamic forces acting on the body. the general approach to harvesting energy from these "aeroelastic" vibrations is to attach the beam to a secondary vibrating structure, such as a wing section, the new design eliminates the need for the secondary vibrating structure because the beam is designed so that it produces self-induced and self-sustaining vibrations. As a result, the new system can be made very small, which increases its efficiency and makes it more practical for applications, such as self-powered sensors. The different types of forces acting on the aero elastic bodies are shown in Fig.1.

2.1 Methods Of Energy Harvesting

The different methods are used for energy harvesting. These methods are used for harvesting energy from the aeroelastic flutter vibrations which is an aeroelastic phenomenon.The different methods and materials used for energy harvesting are

i) Piezoelectric Transduction
ii) Electromagnetic Induction
iii) Electrostatic Transduction
iv) Electroactive Polymers

3. PROPOSED STRUCTURE

The omni-directional wind energy harvester is made of three subsystems

i) A wind-to-vibration converter, which is here a direct conversion system taking advantage of the fluttering effect on a thin ribbon.

ii) An electromagnetic transducer to convert the vibratory mechanical energy into electricity. Rather than a piezoelectric transducer, an electromagnetic one is chosen. This one is more suitable in the case of large amplitude oscillations like the ones induced by fluttering. A fixed magnetic circuit coupled with permanent magnets induces a static electromagnetic field while the copper coil, lighter than the magnetic circuit is chosen to be mobile, attached to the ribbon. When there is a relative displacement between the coil and the magnetic field, a voltage is generated across the coil ends according to Faraday's law of induction.

iii) An extraction circuit is used to rectify and regulate the generated voltages.

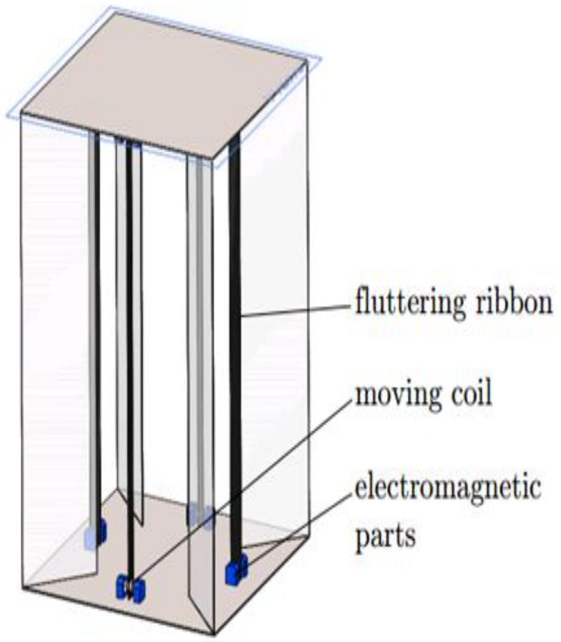

Fig -2: Proposed Structure

Only the first subsystem will be studied here, that is to say the fluttering wind belt used to convert the wind energy into vibrations. The electromagnetic transducer and extraction circuit will be studied and optimized in further works. Given the unstable wind direction, an efficient windbelt based generator should either be able to rotate around itself accordingly with the wind direction, or to present the ability to flutter in all directions. For simplicity reasons, the second solution is chosen here. The proposed generator is made of 4 vertical tensioned ribbons. Two of them are aligned towards the west, the last two are aligned in the perpendicular direction towards the north. Aerodynamic walls are placed between each two ribbons, making a 45 angle with them. As, according to, the flutter effect is only slightly altered when the wind is blowing towards the ribbon with an attack angle smaller than around 45, this structure will allow the fluttering of one or several of the ribbon anytime when wind is blowing, whatever its direction.

4. CONCLUSION

The advanced method of energy harvesting is studied. The arrangement of coils and magnets are analyzed for the desirable output. An electromagnetic transducer has then to be added to convert the mechanical energy from the vibrations into electricity. Its dimensions will be optimized to get the maximum power given the input ribbon acceleration. Finally a nonlinear energy extraction circuit will be added to rectify and regulate the coil voltage.

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