ENERGY GENERATION USING STRUCTURAL VIBRATIONS AND ITS ANALYSIS

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Abstract—Vortex induced vibration is a well-known fluid flow phenomenon studied in multiple engineering disciplines and typically sought to be minimized. However, a potential exists to harness this phenomenon for electrical energy generation from low and high velocity air. In this project, a mathematical model was created to predict the dynamic response and mechanical power of vertically mounted tapered cylinder subjected to a range of flow velocities. Next, a mechanism is designed to convert this motion into electricity using dynamo over a range of flow velocities. An analysis was conducted on the setup to study the flow behavior around it. Cylinder displacement, velocity, and acceleration, as well as flow velocity, were measured and recorded. From these data, oscillation frequency, mean amplitude, and fluid force vs. time were calculated, as well as an estimate of available mechanical power in the cylinder oscillations. These calculations were then with other derived properties to develop an electrical power using dynamo for range 5x10e3< Re <1.5x10e4. Additionally, efficiency calculations indicated that the tapered cylinder with mean diameter 0.13m produced the maximum result of 10W/m3.

Keywords—Vortex Induced Vibration, Dynamic Response, Tapered Cylinder, Oscillation Frequency, Mean Amplitude, Fluid Force, Dynamo

1. INTRODUCTION

The global demand for scalable renewable energy sources is large and ever growing. Many kinetic wind energy technologies exist currently, but are unable to truly meet this demand due to self-limitations. The Earth’s air constitutes a huge portion of the planet and their motion represents a vast, but as yet untapped energy resource. Most energy is currently harnessed by traditional wind turbines. Newer and less ecologically intrusive technology is needed to support growing energy demand. One promising new technology that meets these criteria utilizes vortex induced vibrations in air to extract energy.

Structures subjected to fluid flow are usually designed to minimize fatigue caused by vortex induced vibrations. Only recently has the idea been proposed to enhance the vibrations in order to maximize energy extraction from the fluid. Flow over this cylinder creates an alternating vortex pattern which exerts alternating lift forces on the cylinder, pushing it to and fro. This motion is then converted into electricity via a power take-off mechanism. This technology is superior to traditional wind turbines in several ways, traditional wind turbines have more initial cost, foundation cost, noise, moving parts and are not safe for birds. A vortex induced vibration based generator could potentially function in moving air over a wide range of frequencies. The vortex induced vibration (VIV) concept is capable of producing energy from air flow without altering the local environment, posing any danger to nearby residents. Energy generation from VIV has significant potential for coastal areas as well as hilly areas. Scalability and versatility are two of the greatest strengths of this technology. Modules can range in size from single cylinder arrays to mega-watt producing power plants.

This study examined the potential for vortex induced vibrations as a source of energy by accomplishing the following goals:

- The development of a mathematical model to predict the dynamic response of a cylinder in water flow
- The design of a small-scale setup and methodology to experimentally test cylinder behavior under varying conditions
- The use of the experimental results to determine potential mechanical power and efficiency, and the validity of the model
- The use of observations and data to propose a larger scale testing setup with power take-off ability

2. LITERATURE REVIEW

Vortex shedding is a widely occurring phenomenon applicable to nearly any bluff (no streamlined) body submerged in a fluid flow. Since any real fluid flow is viscous, there will be a significant boundary layer on the bodies’ surface for all but the lowest Reynolds number flows. At some point along the bodies’ surface, separation of the boundary layer will occur, depending on the exact surface geometry. This separated layer, which bounds the wake and free stream, will tend to cause fluid rotation, since its outer side, in contact with the free stream, moves faster than its inner side, in contact with the wake. It is this rotation which then results in the formation of individual vortices, which are then shed from the rear of the body and travel down the wake. Typically, a pattern of periodic, alternating vortex shedding will occur in the flow behind the body, which is referred to as a vortex street depending
upon the characteristics of the flow, mainly the Reynolds number flow.

3. DEFINITIONS

3.1 VORTEX SHEDDING

Like many fluid flow phenomenon, vortex shedding has been observed to be directly dependent on the Reynolds number of the flow, which is defined in Eq.

\[ \text{Re} = \frac{UD}{\mu} \]

Nature of shedding pattern is strongly influenced by Reynolds number.

3.2 STROUHAL NUMBER

An additional non-dimensional parameter has been established to relate the frequency of vortex shedding \( f_s \) to the flow conditions. This is given by the Strouhal number \( S \), and is defined in Equation

\[ \text{St} = \frac{(f_sD)}{U} \]

Again, \( U \) is the free stream velocity, and \( D \) is the cylinder diameter. For a wide range of Reynolds number, the Strouhal number varies very little and can be taken as 0.2 based on passed research.

3.3 LOCK IN

As introduced earlier, lock in is a particular aspect of vortex induced vibrations which can result in relatively large amplitudes of forced vibration. An analytical theory of lock in based on first principles does not presently exist, and much of the research encountered only gives descriptive or semi empirical evidence. As a result, the present analysis only focuses on the key findings which are relevant to achieving large amplitude vibrations, for the purpose of energy generation. Lock in is similar to linear resonance in that the vibration amplitudes increase as the natural frequency of the cylinder is approached by the vortex shedding frequency. shedding frequencies within a range of about +/- 30% of the natural frequency can lock on and shift to match the natural frequency.

4. MODELLING

In order to establish estimates of the potential dynamic performance of a VIV based energy harnessing device, a relatively simple mathematical model was constructed to describe the fluid-oscillator interaction. This section seeks to explain this process and also demonstrate the results for one particular cylinder size.

<table>
<thead>
<tr>
<th>Property</th>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean diameter</td>
<td>( D )</td>
<td>0.075m</td>
</tr>
<tr>
<td>Cylinder length</td>
<td>( L )</td>
<td>1.4m</td>
</tr>
<tr>
<td>Cylinder material density</td>
<td>( \rho_{cyl} )</td>
<td>7800 kg/m³</td>
</tr>
<tr>
<td>Air density</td>
<td>( \rho_{fluid} )</td>
<td>1.2 kg/m³</td>
</tr>
<tr>
<td>Air dynamic viscosity</td>
<td>( M )</td>
<td>( 1.983 \times 10^{-5} ) Pa s</td>
</tr>
<tr>
<td>Flow speed</td>
<td>( U )</td>
<td>6–8 m/s</td>
</tr>
</tbody>
</table>

Since a basic concept of how the testing would later be carried out had already been established, many physical parameters of the setup were known or at least bounded within a specific range. The initial model calculations were based on the use of a 0.13m in mean diameter tapered cylinder section, and the geometrical and fluid properties show in Table 1.

5. EXPERIMENTAL SETUP

![Assembly of the prototype](image)

6. CONCLUSION

Through mathematical modeling and small-scale experiments, the potential for vortex induced vibrations as an energy source. Based on the background research, a mathematical model was created in order to predict the relationship between experimental parameters and cylinder response, to establish feasibility of small scale vortex induced vibrations testing and to create estimates for experimental results. Measured oscillation frequencies were generally in-between the measured natural frequency and the theoretically calculated shedding frequency. From above analysis we achieved the frequency of the structure close to 30% of natural frequency which makes the structure vibrate at a very high amplitude which in turn convert those vibrations into electricity.

In this project we converted wind energy into electricity. This project can be easily implemented and utilized for large as well as small scale industries.

REFERENCES