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Additive Manufacture Applications to Harvest Energy Using Vortex-Induced Vibration Method

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ABSTRACT

The experiment was able to produce an application of additive manufacturing to harvest energy. The way to harvest energy uses the Vortex-Induced Vibration (VIV) method. The manufacturing process uses the Additive Manufacturing Fused Deposition Modeling (AM FDM) method. In this experiment, the length of the VIV apparatus was varied. From research it was found that, the longer the apparatus, the smaller the voltage produced. At the same time, the resulting vortex shedding frequency is also getting smaller. In the research, natural frequency measurements were also carried out in the hope that the advantage of AM FDM is that it can produce VIV apparatus with different elastic moduli which is expected to be able to make natural frequencies from the VIV apparatus that are close to the vortex shedding frequency. This frequency equalization process is expected to have resonance from the VIV apparatus which will be able to have a greater frequency.

INTRODUCTION

3D printing, or additive manufacturing, is an innovative technology that converts digital designs into three-dimensional physical objects (Jadhav & Jadhav, 2022). In the 3D objects with varying complexity and geometry (Mecheter & Tarlochan, 2023) according to design needs (Thakar et al., 2022), shortening printing process, forming materials, such as plastic or metal, are arranged layer by layer to form the final object. This technology allows users to create various production times and increase design flexibility. Apart from being used in prototyping, 3D printing is also being applied in end-use production in various sectors (Jiang et al., 2023), opening massive potential in revolutionizing how we make and use products in this modern era. One of the 3D printing methods that is widely used is FDM (Siemiński, 2021).

The ever-growing innovation in 3D printing, primarily through the FDM method, has opened the door to various new products and solutions that are changing multiple industries. For example, FDM technology has been utilized in the health sector to create precise models of body organs (Jiang et al., 2023), allowing medical experts to plan operations more effectively. Additionally, the automotive industry has leveraged FDM to create part prototypes quickly and speed up product development (Salifu, Desai, Ogunbiyi, & Mwale, 2022). The field of architecture and design is also experiencing a significant transformation with FDM's ability to print building models and interior designs with a high level of detail. In addition to these applications, FDM has also inspired innovation in various sectors, including producing special tools, tools, and even consumer products. The design freedom enabled by FDM spurs designers and engineers to think creatively and deliver new solutions that were previously difficult to achieve. With its high degree of flexibility and ease of use, FDM continues to be a catalyst in unlocking unlimited potential for innovations and products that define the future of manufacturing and design.

3D printing has exciting potential in optimizing and changing how we utilize and produce energy (Egorov, Gulzar, Zhang, Breen, & O'Dwyer, 2020). One promising application is the development of more efficient energy harvesting devices using 3D printing methods. For example, 3D printing can create complex, geometric structures tailored to

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specific needs, such as miniature wind turbines, solar panels, or other renewable energy machine components. 3D printing can also speed up the production process of small components, such as batteries or energy sensors (Egorov et al., 2020), needed in energy harvest technology. Thus, 3D printing not only facilitates innovation at the design level but also increases production efficiency, bringing revolutionary potential to how we harness and produce energy in the future. With the continued development of 3D printing technology, the hope of creating more sustainable and efficient energy solutions is increasingly wide open.

However, there are few innovations in harvesting energy with 3D printing using the Fused Deposition Modeling (FDM) method. Although FDM is often used in printing prototypes or consumer products, its potential in the context of energy harvesting is still only being explored. Perhaps the challenge is ensuring sufficient structural strength and material efficiency to produce an energy-harvesting device that can function optimally. Further research and development are needed to integrate FDM with conductive or photovoltaic materials supporting energy generation (Egorov et al., 2020). Apart from that, it is also necessary to consider how to design the internal structure of the energy harvesting device to suit the technical demands.

Integrating FDM to harvest energy can provide innovative solutions using the Vortex-Induced Vibration (VIV) method (Duranay, Demirhan, Dobrucali, & Kinaci, 2023). In the context of renewable energy, VIV becomes increasingly attractive because it can convert the kinetic energy of fluid flow into electrical energy (Cao, Ding, Guo, Yao, & Technology, 2021). Complex and scalable structures with FDM can be designed to exploit the VIV effect with high precision. The FDM process enables the creation of optimal geometric shapes to capture fluid flow effectively, increasing the energy yield potential of the VIV method (Adhikari, Rastogi, Bhattacharya, & Structures, 2020). For example, turbines or other structures specifically designed to stimulate vibrations and produce energy can be printed using FDM with materials that meet the required durability and conductivity requirements.

Although this concept is still in the exploration stage, combining FDM with VIV opens new opportunities to optimize energy harvest technology. It is hoped that continued research and ongoing design development will prove the effectiveness and reliability of this concept. Thus, integrating FDM with the VIV method can open the door to a new generation of energy-harvesting devices that are more efficient and widely accessible.

EXPERIMENTAL SETUP

The research was carried out as in the schematic diagram in Fig 1. As we can see in the picture, we are trying to flow water at a constant speed. The research was carried out using water flow in a pipe flowing from a reservoir tank. River water is channeled into the tank until it spills utilizing a pump. As a result of the more significant water pressure below, the water will flow out through the pipe and return to the river.

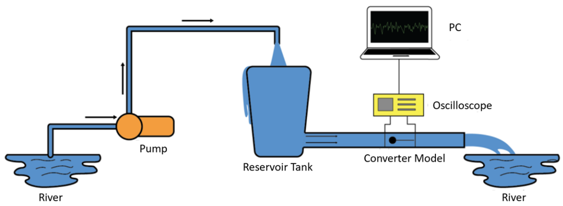

Fig. 1 Schematic Diagram of the experiment

The application of the schematic diagram to the actual experiment looks like fig 2 below. Water flow testing uses a reservoir tank with a capacity of 43 liters attached to a series of pipes 1.092 mm long. It is known that the distance between the water surface and the center of the outlet hole in the tank is 390 mm. The flow rate of water leaving the pipe was determined experimentally by determining the time required to fill a 19-liter tank. The pump will continue to raise water into the tank to maintain the water level. The speed of water flow in the pipe will be constant if the water level remains constant. The converter model is installed in the middle of the pipe to receive water flow. The oscilloscope will read the AC voltage resulting from the piezoelectric vibrating on the converter model, then a voltage graph is displayed on the laptop.

Fig. 2 Actual experiment

The VIV apparatus model created in this

experiment refers to the model studied by Adhikari, et Al. 2020 as seen in Figure 3. In this research, Adhikari examined how Piezoelectric vortex induced vibration energy harvesting in a random flow field.

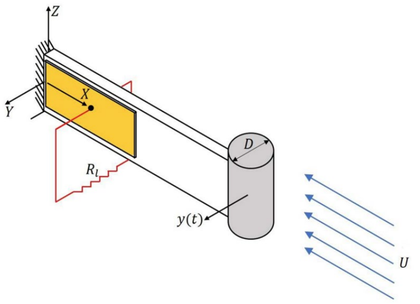

Fig. 3 VIV apparatus diagram schematic

By referring to the model made by Adhikari (Adhikari et al., 2020), the VIV apparatus made in this experiment looks like in Figure 4. Please remember, the position of the VIV apparatus is in a pipe that is flowing with water at a constant speed. In the schematic diagram in Figure 1, the position of the pipe is as a converter model which is fed by water coming from the reservoir tank.

Fig 4. VIV Apparatus Inside Converter Pipe

This is where additive manufacturing becomes crucial, serving as a medium for constructing VIV apparatus. The specific additive manufacturing method employed in this context is FDM. The fabrication process is illustrated in Figure 5 below.

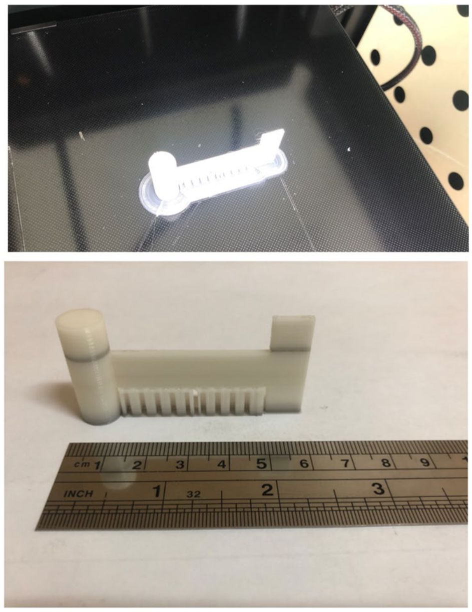

Fig. 5 Manufacturing VIV Apparatus using FDM Printing

RESULT AND DISCUSSION

The vortex shedding frequency (Cravero, Marogna, & Marsano, 2021) value in this study can be determined from the vibration graph read by the Oscilloscope when the converter model oscillates due to water flow. The vibration graph of the converter model forms a non-periodic signal, so Fast Fourier Transform (FFT) (Chen, Cao, Wang, Li, & Control, 2021) calculations are needed to determine the frequency. Data obtained from Oscilloscope readings were 1024 samples taken at a time interval of 4.187 seconds.

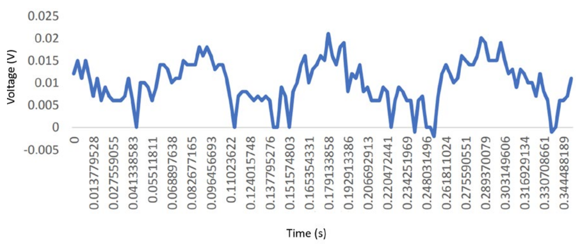

Fig. 6 Voltage acquired from the Oscilloscope.

In this study, the length of the VIV apparatus was varied. The VIV apparatus studied in this study used lengths of 30 mm, 40 mm, and 50 mm. A graph of the voltage test results at different VIV apparatus lengths can be seen in Figure 7 below. The voltage generated from the VIV apparatus is 30, 21, and 18 mV. The largest voltage is produced from the VIV apparatus with a length of 30mm.

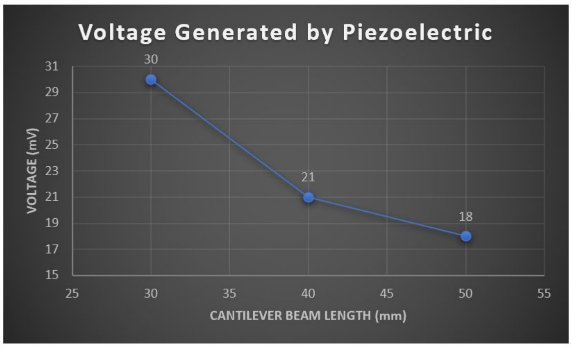

Fig. 7 Voltage generated from various beam lengths.

To get the frequency from the Voltage graph above, it is necessary to use the Fast Fourier Transform (FFT) method. FFT is processed using Microsoft Excel software to calculate the frequency of vibrations. This method converts the time domain to the frequency domain. The results of the FFT can be seen in Fig 8 below.

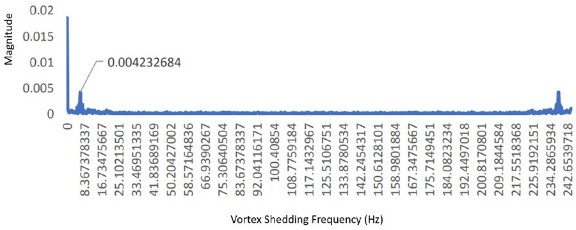

Fig. 8 Fast Fourier Transform of Voltage graph.

Still related to variations in the length of the VIV apparatus (Conway, Jeffers, Agarwal, & Punch, 2020), the graph of the FFT results for each voltage obtained is summarized into one graph in Fig 9 below. The Vortex Shedding frequencies produced by the VIV apparatus are 14.34, 12.9, and 6.45 Hz (Du et al., 2020). The largest Vortex Shedding frequency is produced from the VIV apparatus with a length of 30mm.

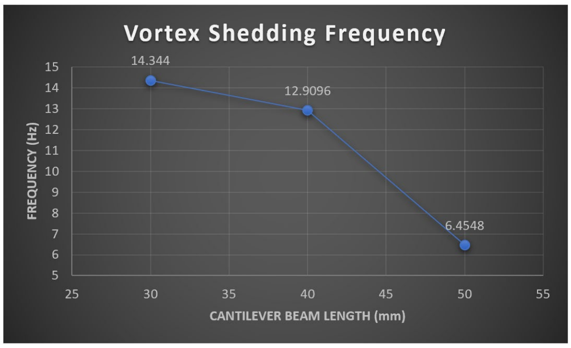

Fig. 9 Vortex Shedding Frequency from various beam length.

The length of the cantilever rod and the mass of the bluff body in the converter model will influence the free vibration frequency or also known as the natural frequency. Free vibration response data was collected in air conditions, but in this study the converter model was in water conditions. The natural frequency value in water conditions will decrease by 20% from the natural frequency in air (Green & Sader, 2002). This is because the properties of water have more excellent dampening properties compared to air. Graph of the influence of cantilever length and bluff body mass on natural frequencies in the water can be seen in Fig 10.

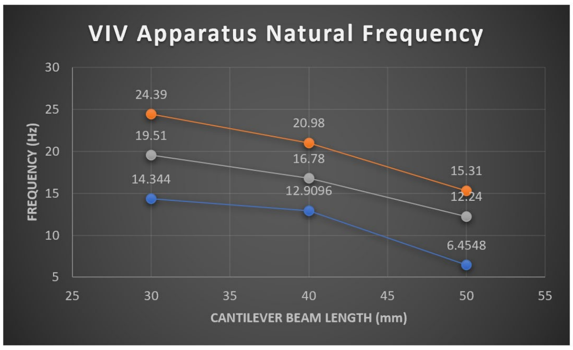

Fig. 10 VIV Apparatus Natural Frequency.

CONCLUSIONS

Conclusions that can be drawn from the experiment are that the voltage generated from the VIV apparatus is 30, 21, and 18 mV. The most significant voltage is produced from the VIV apparatus with a length of 30mm. The Vortex Shedding frequencies produced by the VIV apparatus are 14.34, 12.9, and 6.45 Hz. The most significant Vortex Shedding frequency is made from the VIV apparatus with a length of 30mm. Natural Frequency Values in the air from the VIV apparatus are 24.39, 20.98, and 15.31 Hz. Natural Frequency Values in water from the VIV apparatus are 19.51, 16.78, and 12.24 Hz.

The relationship between the vortex shedding frequency and the natural frequency of the VIV apparatus is that the closer the vortex shedding frequency value is to the VIV apparatus value, the greater the potential for the VIV apparatus to resonate. The research results concluded that the shorter the cantilever beam, the closer the vortex shedding frequency value to the natural frequency of the VIV apparatus.

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