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Enhancing Oscillation Amplitude Response Generated by Vortex Induced Vibrations Through Experimental Identification of Optimum Parameters

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Abstract**—**Vortex Induced Vibrations (VIV) is a phenomenon that occurs as a result of a flow passing by a bluff body. The aim of this paper is to identify factors for maximizing oscillation amplitude generated by VIV in order to enhance the energy harnessed through this method. The experimental study in this paper will examine the effect of oscillating cylinder diameter, surface roughness, the location of surface roughness with respect to the centreline of the oscillating cylinder and the velocity on the oscillation amplitude of the used module.

Keywords**—**Energy, renewable, electrostatic, vibration, vortex.

I. Introduction

ENERGY plays an important role in humanity's needs where it is the heart of the world's economy and without it many of modern life functions such as communication, transportation, medical care and other functionalities will not be operational. Oil and Gas have been the main source of global energy for around a century. As Oil and Gas are scarce in some of the world's countries and abundant in others, a dependency equation between countries has been naturally created. Improving efficiency and finding new solutions of renewable and alternative energy sources is the desired solution by many countries to reduce this dependency.

VIV is a phenomenon that was originally studied to ensure offshore platforms stability. This phenomenon occurs when a fluid flow passes over a bluff body (a body that creates separated flow over a significant portion of its shape) and it causes a boundary layer to form. This boundary layer later deforms due to the geometry of the body. This deformation causes a rotation in the fluid as the outer layers of the fluid, which are not in contact with the body, have a higher velocity than the deformed layer. The rotation of the fluid creates vortices that cause fluctuations in pressure resulting in vibration of the bluff body.

As VIV causes vibration, a number of studies have been conducted to utilize this vibration in generating energy [1], [2], [9]. The current models utilized in electrical generation using VIV, generally, use the same concept where water flow is separated behind a cylinder and the cylinder vibrates due to the periodically generated vortexes known as Karman vortex street. The cylinder in some of these models is fixed on a cantilever beam which oscillates up and down as a result of the cylinder vibration. During this oscillation, electricity is generated through electrostatic induction and triboelectric effect by the contact and separation of materials such as Teflon and Nylon as shown in Fig. 1.

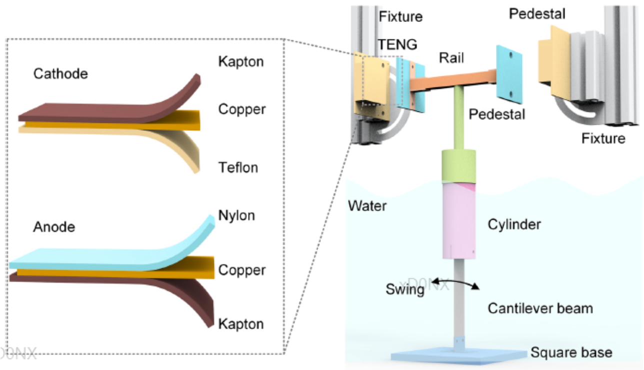

Fig. 1 VIV Utilizing Triboelectric and Electrostatic Induction [1]

This system can capitalize on slow water current movements to generate electricity which is not common in hydroelectrical applications which will use high flow velocities. Additionally, the system does not produce pollution that impacts marine environment.

II. Variable Impacting Oscillation Amplitude by VIV

A. Reynold's Number

The vortex shedding is affected by Reynold's number:

$$Rd = \frac{UD}{v} \tag{1}$$

where U is the flow velocity, D is the hydraulic diameter and v is the kinematic viscosity. Vortex shedding is observed to start at Reynold numbers greater than 40 (Fig. 2), where the flow is laminar and vortex shedding stops during the transition from laminar to turbulent at Reynold number values greater than three and a half million. Ranges of Reynold's number where no vortex shedding occurs are not desired as there will be no generated energy from VIV.

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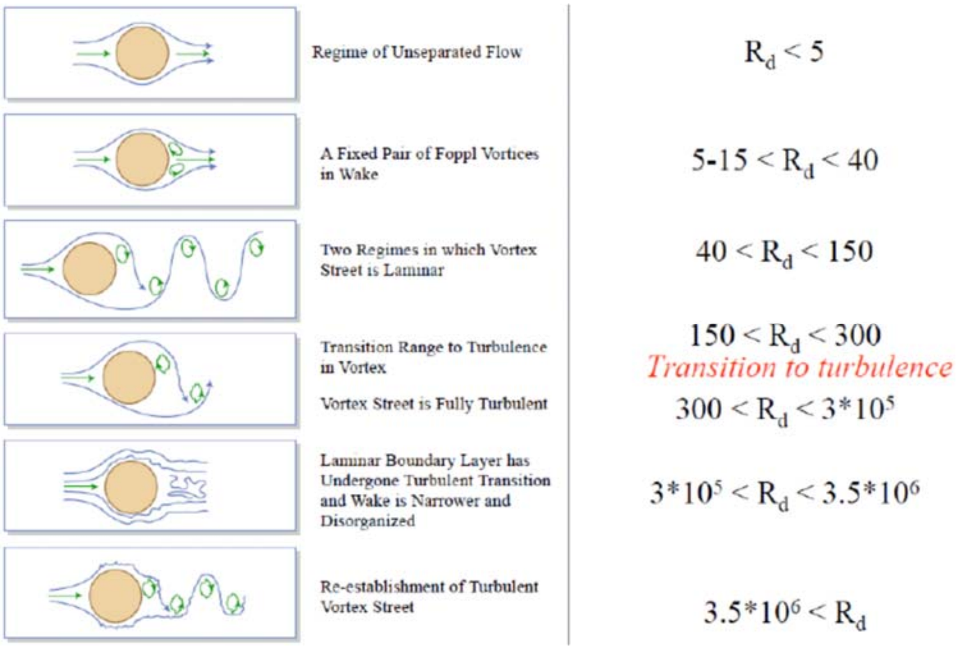

Fig. 2 Vortex Shedding Regimes [2]

B. Surface Roughness

There is a relationship between the critical Reynolds number and the surface roughness of the body. The surface roughness of the body influences the Reynold's number of a flow by:

1- Affecting the transition zone between laminar and boundary layers.
2- Manipulating the flow separation point on the circular cylinder surface.

The impact of increasing the surface roughness will be further investigated in this paper through a practical experiment.

There are additional factors impacting the oscillation amplitude by VIV which are covered in detail in the following studies:

- Ratio between natural frequency and oscillation frequency [3], [4].
- Ratio between the length of the oscillating cylinder to its diameter [5]-[7].
- Mass and damping ratios [8]
- Wake Modes of vortex shedding [9].

III. Practical Experiment Methodology

The aim of this experiment is to study the impact of water flow velocity, surface roughness, effective stiffness and cylinder diameter on the oscillation amplitude with the goal of determining the optimum conditions of these variables to maximize the oscillation amplitude which increases the power harnessed through VIV.

A. List of Used Materials

1- Open channel flow tank.
2- Submersible Pump.
3- Flow rate sensor.
4- Set of compression and extension springs.
5- Set of cylinders with different lengths and diameters.
6- Roughness papers strips.
7- Experimental module.

B. Description of Experiment

The open channel will be used to contain the water flow, which is measured by a flow rate sensor, and host the experimental cylinder oscillation model (Fig. 3) where the experiment conditions will be changed to measure the impact on oscillation amplitude. The configuration of the experiment is shown in Fig. 4. A valve is used to control the velocity of flow that passes through the cylinder oscillation model where the amplitude of oscillation will be measured to test the impact of changing experimental variables.

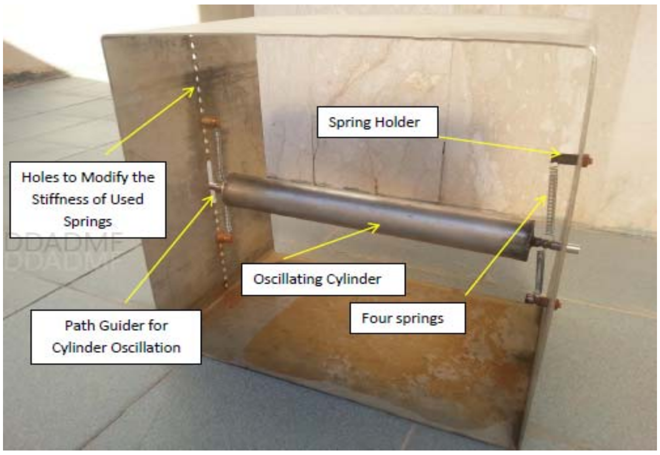

Fig. 3 Cylinder Oscillation Model

The experiments will be divided into three sections where each section will record the impact of changing one variable on the oscillation response. The problem definition and the solution approach will be stated at the beginning of each section.

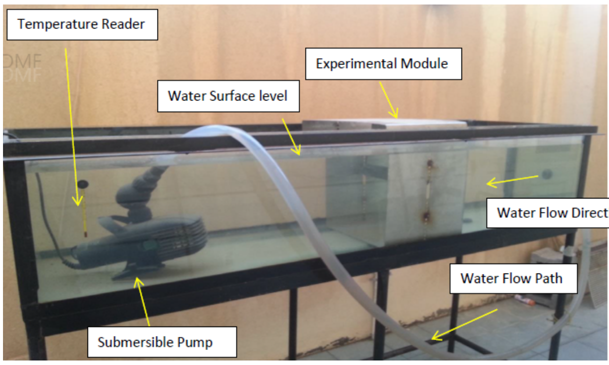

Fig. 4 Experiment Configuration

IV. Effect of Aspect Ratio on Oscillation Amplitude Over a Velocity Profile

A. Problem Definition

We examine the effect of cylinder diameter on oscillation amplitude response generated by VIV over a velocity profile. The cylinder is perpendicular to the flow direction and parallel to the free water surface.

B. Solution Approach

In each of the following experiments, a unique cylinder in terms of diameter will be exposed a velocity profile and compared with other cylinders with different diameters in order to understand the impact of cylinder diameter on the oscillation amplitude.

Six steel 304 cylinders with different diameter sizes will be utilized (Fig. 5) where the cylinders are end-plated and attached to the test module by four springs. The gap between the channel walls and the module is 20 mm.

Fig. 5 Cylinder with Different Outer Diameters (from Right to Left 13 mm, 25 mm, 38 mm, 51 mm, 64 mm, and 76 mm with a length of 400 mm)

C. Results and Observations

Table I contains the data of the first set of conducted experiments. Each set of these data contains the recorded temperature and utilized diameter size as a heading.

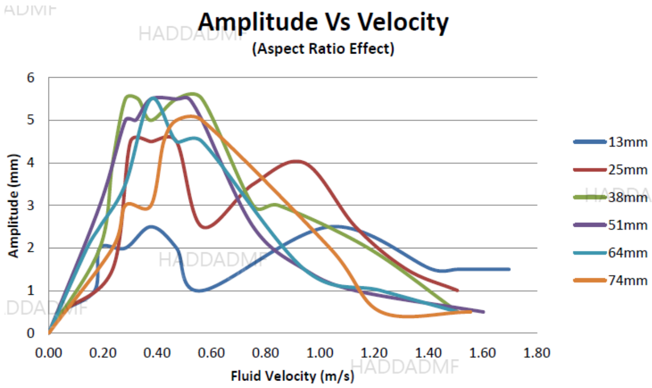

Fig. 6 Aspect Ratio Effect on Amplitude Versus Velocity

For all cylinders there is a general trend (Fig. 6 and Table I) of reaching the maximum amplitude in a velocity range between 0.28 m/s and 0.57 m/s. The highest amplitude reached is 5.5 mm and it was achieved with the diameters 38 mm, 51 mm and 64 mm. The highest achieved amplitude was not achieved by the smaller diameter cylinders, despite being the lightest, or by the largest diameter cylinder. This indicates that there is a certain optimum range for the aspect ratio of length over diameter where the optimum amplitude for oscillation can be obtained. Fig. 7 shows the impact of modifying the aspect ratio where the optimum aspect ratio to achieve the highest amplitude is at an aspect ratio range of 7.8 to 10.5.

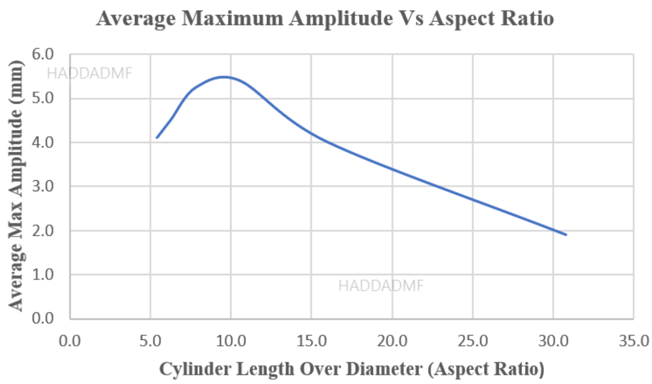

Fig. 7 Impact of Aspect Ratio on Oscillation Amplitude Response

V. Effect of Roughness Strips on Oscillation Amplitude

A. Problem Definition

We examine the effect of applying roughness strips at different angles on the oscillation amplitude of a cylinder which is triggered by VIV. The aim will be to record the response for different angle configurations of applied roughness strips in order to find optimum one that achieves the highest oscillation amplitude. The cylinder is perpendicular to the flow direction and parallel to the free water surface.

TABLE I
EFFECT OF ASPECT RATIO ON SYSTEM'S RESPONSE OVER A VELOCITY PROFILE

Temp = 32 °C, Diameter D = 13 mm				Temp = 26 °C, Diameter D = 25 mm				Temp = 33 °C, Diameter D = 38 mm			
#	Velocity (m/s)	Reynold Number	Amplitude	#	Velocity (m/s)	Reynold Number	Amplitude (mm)	#	Velocity (m/s)	Reynold Number	Amplitude (mm)
1	0.00	0	0	1	0	0	0	1	0	0	0
2	0.05	798	0.5	2	0.05	1351	0.5	2	0.19	9522	2
3	0.17	2873	1.0	3	0.24	6753	1.5	3	0.24	11902	4
4	0.19	3192	2.0	4	0.3	8644	4.5	4	0.28	14282	5.5
5	0.28	4788	2.0	5	0.38	10805	4.5	5	0.33	1663	5.5
6	0.38	6384	2.5	6	0.47	13506	4.5	6	0.38	19043	5
7	0.47	7980	2.0	7	0.57	16207	2.5	7	0.47	23804	5.5
8	0.57	9576	1.0	8	0.75	21609	3.5	8	0.57	28565	5.5
9	1.04	17556	2.5	9	0.94	27011	4	9	0.75	38086	3
10	1.41	23940	1.5	10	1.13	32414	2.5	10	0.85	42847	3
11	1.51	25536	1.5	11	1.32	37816	1.5	11	1.18	59510	2
12	1.7	28728	1.5	12	1.51	43218	1	12	1.51	76173	0.5
Temp = 30 °C, Diameter D = 51 mm				Temp = 32 °C, Diameter D = 64 mm				Temp = 28 °C, Diameter D = 74 mm			
#	Velocity (m/s)	Reynold Number	Amplitude (mm)	#	Velocity (m/s)	Reynold Number	Amplitude (mm)	#	Velocity (m/s)	Reynold Number	Amplitude (mm)
1	0	0	0	1	0	0	0	1	0	0	0
2	0.19	12015	3	2	0.14	11786	2	2	0.24	20883	2
3	0.28	18022	5	3	0.19	15714	2.5	3	0.28	25060	3
4	0.32	20425	5	4	0.28	23571	3.5	4	0.38	33413	3
5	0.38	24029	5.5	5	0.38	31429	5.5	5	0.42	37589	4.5
6	0.47	30036	5.5	6	0.47	39286	4.5	6	0.47	41766	5
7	0.52	33040	5.5	7	0.57	47143	4.5	7	0.57	50119	5
8	0.57	36044	5	8	0.94	78572	1.5	8	1.04	91885	2
9	0.75	48058	2.5	9	1.23	102143	1	9	1.23	108591	0.5
10	0.94	60073	1.5	10	1.51	125714	0.5	10	1.56	137827	0.5
11	1.13	72087	1								
12	1.6	102123	0.5								

TABLE II
DATA OF ASPECT RATIO IMPACT ON OSCILLATION AMPLITUDE

Diameter (mm)	Aspect Ratio	Average Maximum Amplitude (mm)
74	5.4	4.1
64	6.3	4.5
51	7.8	5.3
38	10.5	5.4
25	16.0	4.0
13	30.8	1.9

B. Solution Approach

A unified diameter size (51 mm), level of roughness scale (P100) and effective spring stiffness (44.6 N/M) will be used for this set of experiments where roughness papers will be applied to the cylinder on the side facing the water flow in order to examine the effect on the amplitude response. The parameters that will be changed are shown in Fig. 8 namely, $\theta_a, \theta_b, \alpha_a$ *and* α_b, where the first two parameters are the roughness strips angles clock wise and anti-clock wise, and similarly, the latter two parameters are the angles from the cylinder centreline to the start of roughness strips clock wise and anti-clock wise.

C. Results and Observations

Table III shows the obtained results in this set of experiments.

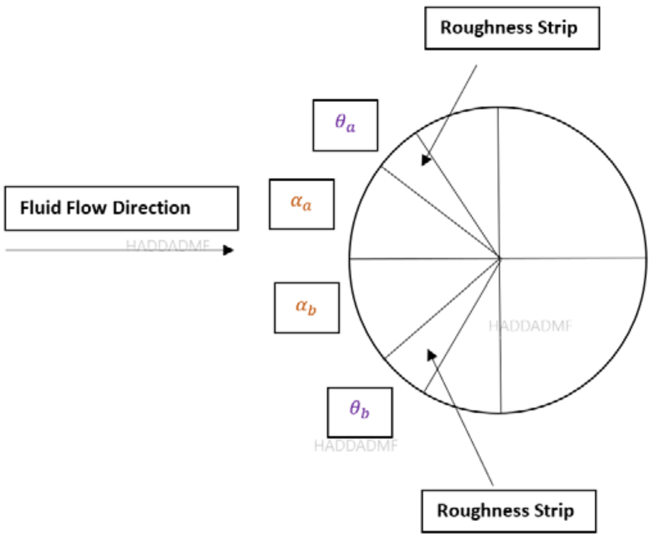

Fig. 8 Roughness Strips Arrangement on the Oscillating Cylinder

Referring to the data obtained in Table III, which are graphically represented in Fig. 9, the maximum achieved amplitude was obtained in the same velocity range 0.28 m/s to 0.57 m/s similar to the first set of experiments. The maximum achieved oscillation amplitude while modifying the roughness strips application angle was achieved with $\theta_a = \theta_b = 22.5^{\circ}, \alpha_a = \alpha_b = 67.5^{\circ}$ at an amplitude of 8 mm.

TABLE III
EFFECT OF ROUGHNESS STRIP LOCATION ON SYSTEM'S RESPONSE

Temp = 29℃ $\theta_a = \theta_b = 90^{\circ}, \alpha_a = \alpha_b = 0^{\circ}$				Temp = 28℃ $\theta_a = \theta_b = 78.75^{\circ}, \alpha_a = \alpha_b = 11.25^{\circ}$				Temp = 21℃ $\theta_a = \theta_b = 67.5^{\circ}, \alpha_a = \alpha_b = 22.5^{\circ}$			
#	Velocity (m/s)	Reynold Number	Amplitude	#	Velocity (m/s)	Reynold Number	Amplitude (mm)	#	Velocity (m/s)	Reynold Number	Amplitude (mm)
1	0.00	0	0.0	1	0	0	0	1	0.00	0	0.0
2	0.14	8822	4.5	2	0.09	5757	2	2	0.09	4911	1.0
3	0.20	12351	6.0	3	0.14	8635	2.5	3	0.19	9821	2.5
4	0.28	17645	6.5	4	0.19	11514	3.5	4	0.24	12277	4.0
5	0.32	19997	6.5	5	0.24	14392	3.5	5	0.28	14732	4.5
6	0.38	23526	7.5	6	0.26	16119	4	6	0.33	17187	6.5
7	0.47	29408	3.5	7	0.28	17271	6.5	7	0.36	18661	6.0
8	0.57	35289	0.8	8	0.33	20149	6.5	8	0.41	21116	5.0
9	0.85	52934	0.5	9	0.38	23028	7	9	0.52	27009	4.5
10	1.04	64697	0.4	10	0.47	28785	4	10	0.57	29464	3.5
11	1.25	78225	0.3	11	0.9	54691	0.5	11	0.85	44196	0.5
12	1.41	88224	0.2	12	1.17	71386	0.5	12	1.23	63839	0.5
				13	1.41	86354	0.5	13	1.68	87410	0.5

Temp = 18℃ $\theta_a = \theta_b = 56.25^{\circ}, \alpha_a = \alpha_b = 33.75^{\circ}$				Temp = 18℃ $\theta_a = \theta_b = 45^{\circ}, \alpha_a = \alpha_b = 45^{\circ}$				Temp = 21℃ $\theta_a = \theta_b = 33.75^{\circ}, \alpha_a = \alpha_b = 56.25^{\circ}$			
#	Velocity (m/s)	Reynold Number	Amplitude (mm)	#	Velocity (m/s)	Reynold Number	Amplitude (mm)	#	Velocity (m/s)	Reynold Number	Amplitude (mm)
1	0	0	0	1	0	0	0	1	0	0	0
2	0.14	6844	3	2	0.13	6388	2.5	2	0.19	9821	2.5
3	0.19	9125	4.5	3	0.19	9125	3.5	3	0.23	11786	2.5
4	0.24	11407	6	4	0.24	11407	5	4	0.28	14732	3.5
5	0.28	13688	6	5	0.28	13688	5.5	5	0.33	17187	6.5
6	0.33	15970	5	6	0.33	15970	6.5	6	0.38	19643	5
7	0.38	18251	4.5	7	0.38	18251	2	7	0.42	22098	5
8	0.42	20532	3.5	8	0.42	20532	6	8	0.47	24553	4.5
9	0.47	22814	3	9	0.47	22814	6.5	9	0.85	44196	0.5
10	0.9	43346	0.5	10	0.75	36502	0.5	10	1.12	58437	0.5
11	1.23	59315	0.5	11	0.94	45627	0.5	11	1.27	66294	0.5
12	1.41	68441	0.5	12	1.18	57034	0.5	12	1.60	83482	0.5
				13	1.46	70722	0.5				

Temp = 22℃ $\theta_a = \theta_b = 22.5^{\circ}, \alpha_a = \alpha_b = 67.5^{\circ}$				Temp = 22℃ $\theta_a = \theta_b = 11.25^{\circ}, \alpha_a = \alpha_b = 78.75^{\circ}$			
#	Velocity (m/s)	Reynold Number	Amplitude (mm)	#	Velocity (m/s)	Reynold Number	Amplitude (mm)
1	0	0	0	1	0	0	0
2	0.19	10057	3	2	0.19	10057	1
3	0.24	12572	4.5	3	0.24	12572	3
4	0.28	15086	8	4	0.28	15086	3
5	0.38	20114	6.5	5	0.33	17600	3
6	0.42	22629	4.5	6	0.38	20114	4.5
7	0.47	25143	4.5	7	0.42	22629	1.5
8	0.57	30172	4.5	8	0.47	25143	0.5
9	0.87	46263	0.5	9	0.51	27154	0.5
10	1.13	60343	0.5	10	0.94	50286	0.5
11	1.46	77943	0.5	11	1.23	65372	0.5
				12	1.6	85486	0.5

Table IV shows the impact of changing the application angle of roughness strips on the average maximum oscillation amplitude region. These data show that the maximum region average oscillation amplitude occurred when the strips were applied at 90° for θ_a& θ_b meaning that the side facing the water flow was fully covered with roughness strips.

Fig. 10 shows roughness strips impact on the oscillation in comparison to oscillation without roughness strips. This comparison shows that the average oscillation amplitude with roughness strips in the peak oscillation velocity region (0.28 m/s to 0.57 m/s) has increased. However, the oscillation amplitude response profile for the cylinder without roughness strips is generally higher. Table V shows the data of average maximum oscillation amplitude for both cases.

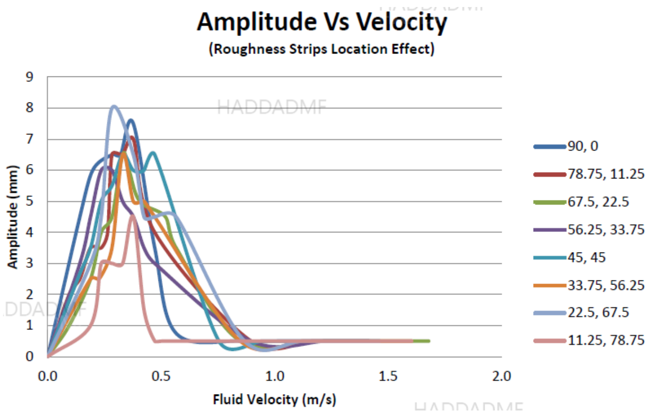

Fig. 9 Impact of Changing Roughness Strips Application Angle on Amplitude Response Over a Velocity Profile

TABLE IV
IMPACT OF ROUGHNESS STRIPS APPLICATION ANGLE ON AVERAGE MAXIMUM AMPLITUDE

θ_a& θ_b/ α_a & α_b	Average Maximum Amplitude Region (mm)
90,0	6.0
78.75,11.25	5.0
67.5,22.5	4.7
56.25,33.75	4.6
45,45	5.6
33.75, 56.25	4.2
22.5,67.5	5.2
11.25,78.75	2.4

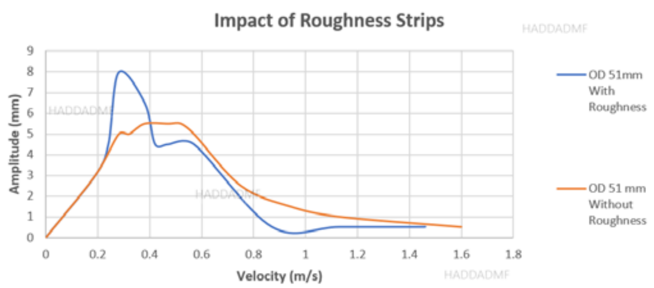

Fig. 10 Impact of Roughness Strips on Oscillation in Comparison to Oscillation Response without Roughness Strips

TABLE V
DATA OF AVERAGE MAXIMUM OSCILLATION AMPLITUDE FOR OD 51 MM WITH AND WITHOUT ROUGHNESS

Velocity (m/s)	Amplitude with Roughness (mm)	Amplitude without Roughness (mm)
0.19	3	3
0.28	8	5
0.38	6.5	5.5
0.47	4.5	5.5
0.57	4.5	5
Average	5.875	5.25

VI. EFFECT OF CHANGING SIZE OF ROUGHNESS STRIPS ON OSCILLATION AMPLITUDE

A. Problem Definition

We examine the effect of changing the roughness strips sizes on the oscillation amplitude of the cylinder which is generated by VIV. The cylinder is perpendicular to the flow direction and parallel to the free water surface.

B. Solution Approach

In this set of experiments, the following conditions will be fixed: roughness strips will be applied at the location which generated the highest oscillation amplitude which is 90° for θ_a& θ_b, the outer diameter of the cylinder is 51 mm, the effective stiffness of the springs is 44.6 N/m. In accordance with ISO scale, the size of roughness strips is represented by the capital letter P which is followed by numerical numbers “PXXX”. As the numbers that follow the letter P increase, the grit size decreases.

C. Results and Observations

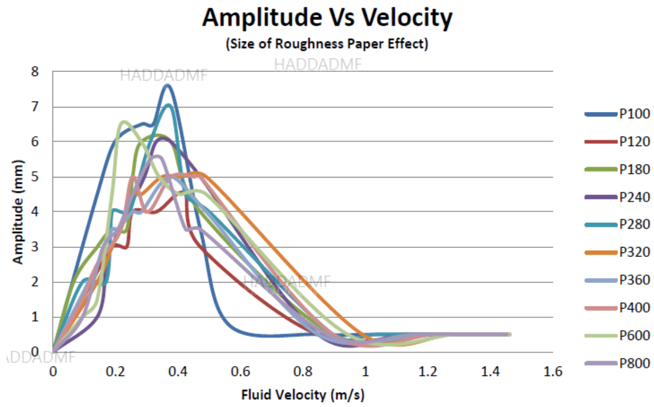

Fig. 11 Effect of Paper Size Roughness on the Cylinder Amplitude Response over a Velocity Profile

Table VII, which is obtained from Table VI and Fig. 11, shows the impact of changing roughness strips grit size on the average maximum oscillation amplitude region. In this table, it can be seen that most of the obtained values are within the same range except P100. This indicates that grit maximum influence on oscillation is when it is P100 and as grit size decreases to P120 and less, the impact on oscillation amplitude is minimal. However, more experiments should be conducted with higher grit size to compare the influence on amplitude with of P100.

VII. CONCLUSION

The main goal of this paper was to determine the conditions that generated the maximum oscillation amplitude response from VIV with the aim of sharing these conditions with future researchers in order to utilize them in enhancing the energy harnessed from low velocity water flows.

The experiments conducted showed that the optimum velocity profile to generate the maximum oscillation amplitude from VIV is between 0.28-0.57 m/s. While the amplitude response gradually increased until it reached its maximum in the optimum velocity range, further increase to velocity caused the amplitude response to drop significantly. The optimum aspect ratio of cylinder length over its diameter to achieve the highest amplitude is range of 7.8 to 10.5.

TABLE VI
EFFECT OF CHANGING SIZE OF ROUGHNESS STRIPS

Temp = 29°C , P100				Temp = 26°C , P120				Temp = 24°C , P180			
#	Velocity (m/s)	Reynold Number	Amplitude (mm)	#	Velocity (m/s)	Reynold Number	Amplitude (mm)	#	Velocity (m/s)	Reynold Number	Amplitude (mm)
1	0	0	0	1	0	0	0	1	0	0	0
2	0.14	8822	4.5	2	0.09	5510	1.5	2	0.07	3687	2
3	0.2	12351	6	3	0.19	11021	3	3	0.14	7901	3
4	0.28	17645	6.5	4	0.24	13776	3	4	0.19	10535	3.5
5	0.32	19997	6.5	5	0.25	14878	4	5	0.24	13169	3.5
6	0.38	23526	7.5	6	0.33	19286	4	6	0.25	14222	5
7	0.47	29408	3.5	7	0.4	23143	4.5	7	0.28	15802	6
8	0.57	35289	0.8	8	0.42	24796	4.5	8	0.38	21070	6
9	0.85	52934	0.5	9	0.47	27552	3	9	0.47	26337	4
10	1.04	64697	0.4	10	0.85	49593	0.5	10	0.9	50041	0.5
11	1.25	78225	0.3	11	1.21	70532	0.5	11	1.23	68477	0.5
12	1.41	88224	0.2	12	1.45	84859	0.5	12	1.41	79012	0.5
Temp = 22°C , P240				Temp = 22°C , P280				Temp = 18°C , P320			
#	Velocity (m/s)	Reynold Number	Amplitude (mm)	#	Velocity (m/s)	Reynold Number	Amplitude (mm)	#	Velocity (m/s)	Reynold Number	Amplitude (mm)
1	0	0	0	1	0	0	0	1	0	0	0
2	0.14	7543	1	2	0.09	5029	2	2	0.14	6844	2
3	0.17	9051	2.5	3	0.17	9051	2	3	0.19	9125	3
4	0.19	10057	3	4	0.19	10057	4	4	0.22	10494	3.5
5	0.24	12572	4	5	0.22	11566	4	5	0.25	12319	4.5
6	0.29	15589	5	6	0.25	13074	4	6	0.28	13688	4.5
7	0.33	17600	6	7	0.31	16594	6	7	0.35	16882	5
8	0.38	20114	6	8	0.38	20114	7	8	0.41	19620	5
9	0.47	25143	5	9	0.42	22629	4.5	9	0.49	23726	5
10	0.85	45257	0.5	10	0.5	26652	4	10	0.99	47909	0.5
11	1.13	60343	0.5	11	0.9	47772	0.5	11	1.27	61597	0.5
12	1.41	75429	0.5	12	1.04	55315	0.5	12	1.45	70266	0.5
				13	1.46	77943	0.5				
Temp = 23°C , P360				Temp = 23°C , P400				Temp = 19°C , P600			
#	Velocity (m/s)	Reynold Number	Amplitude (mm)	#	Velocity (m/s)	Reynold Number	Amplitude (mm)	#	Velocity (m/s)	Reynold Number	Amplitude (mm)
1	0	0	0	1	0	0	0	1	0	0	0
2	0.14	7721	2.5	2	0.09	5148	1.5	2	0.09	4678	1
3	0.19	10295	3.5	3	0.14	7721	2.5	3	0.14	7016	1.5
4	0.21	11325	3.5	4	0.22	11839	3.5	4	0.19	9355	4.5
5	0.25	13899	4	5	0.25	13899	5	5	0.22	10759	6.5
6	0.28	15443	4	6	0.3	16472	4	6	0.28	14033	6
7	0.38	20590	5	7	0.38	20590	5	7	0.34	16839	5
8	0.49	26767	4	8	0.45	24708	5	8	0.41	20114	4.5
9	1.41	77214	0.5	9	0.47	25738	5	9	0.49	24324	4.5
10	1.19	64860	0.5	10	0.9	48902	0.5	10	0.94	46776	0.5
11	0.85	46328	0.5	11	1.23	66919	0.5	11	1.29	64084	0.5
				12	1.46	79788	0.5	12	1.46	72503	0.5

Temp = 19°C , P800			
#	Velocity (m/s)	Reynold Number	Amplitude (mm)
1	0	0	0
2	0.09	4678	1
3	0.16	7952	3
4	0.21	10291	3.5
5	0.25	12630	4.5
6	0.31	15436	5.5
7	0.35	17307	5.5
8	0.42	21049	3.5
9	0.47	23388	3.5
10	0.88	43502	0.5
11	1.17	58003	0.5
12	1.45	72036	0.5

When paper roughness strips were applied, the maximum average oscillation was achieved when the cylinder side facing the waterflow was fully covered with roughness strips of grit size P100. Decreasing the grit size or the area covered with roughness strips from the cylinder side facing the water flow will cause oscillation response to decrease.

Further experiments of roughness with larger grit size are recommended to be conducted in order to compare them with the results obtained with grit size P100.

TABLE VII
EFFECT OF CHANGING SURFACE ROUGHNESS OF AVERAGE MAXIMUM REGION AMPLITUDE

Roughness Paper Size	Average Maximum Region Amplitude
P100	6.0
P120	4.0
P180	4.7
P240	4.8
P280	4.8
P320	4.4
P360	4.0
P400	4.6
P600	5.2
P800	4.3

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