Jurnal Teknologi

Full paper

# Acoustic Doppler Velocimeter Data Analysis of Turbulent Flow of Vortex Generator Cylinder

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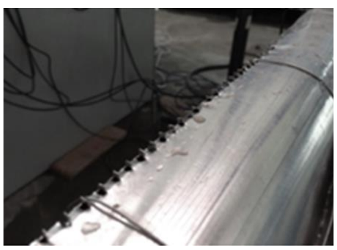
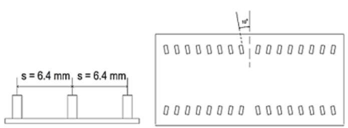
**Article history**

Received : 13 February 2015
Received in revised form :
8 April 2015
Accepted :1 May 2015

**Graphical abstract**






**Abstract**

The demand to suppress vortex-induced vibration (VIV) in the offshore industry is increasing nowadays. VIV is one of the biggest impacts that caused fatigue damage to the marine risers and pipelines. In exploring the mechanisms of VIV reduction by vortex generators (VGs), the experimental measurements in a water flume were performed. The experiments compared the wake of a stationary bare cylinder with a VGs cylinder at a uniform flow with Reynolds number 8,400. The velocity measurement was sampled at a frequency of 200 Hz and was measured by an Acoustic Doppler Velocimeter (ADV) instrument. From the ADV data, it was found that the signal correlations of turbulent flow and the percentage of acceptable data after the filtering process using WinADV of VG cylinder flow was higher than those of bare cylinder, and quite similar with the no-cylinder wake.

*Keywords*: Turbulent flow; vortex generator; Acoustic Doppler Velocimeter (ADV); WinADV

**Abstrak**

Permintaan untuk menindas getaran vorteks atau dikenali sebagai *vortex-induced vibration* (VIV) dalam industri luar pesisir semakin meningkat pada masa kini. VIV adalah salah satu impak yang paling besar yang menyebabkan kerosakan lesu kepada penaik dan saluran paip marin. Dalam meneroka mekanisme pengurangan VIV oleh penjana vorteks atau *vortex generators* (VGs), pengukuran secara eksperimen di dalam flum air telah dijalankan. Eksperimen membandingkan keracak di belakang silinder biasa (tidak bersalut) dengan silinder VG pada aliran seragam dengan nombor Reynolds 8,400. Pengukuran halaju telah di sampel pada frekuensi 200 Hz dan diukur dengan menggunakan alat *Acoustic Doppler Velocimeter* (ADV). Melalui data yang diperoleh menggunakan ADV, korelasi isyarat aliran gelora dan peratusan data boleh diterima selepas proses penapisan menggunakan WinADV bagi silinder VG lebih tinggi berbanding silinder biasa, dan agak sama dengan keracak tanpa silinder.

*Kata kunci:* Aliran gelora; penjana vortex; Acoustic Doppler Velocimeter (ADV); WinADV



## ■1.0 INTRODUCTION

The manipulation of offshore oil and gas resources are towards the deep sea of thousands meters water depth. Time-dependent drag and lift forces formed when vortices are shed from a cylinder or pipe. The lift force oscillates at vortex shedding frequency while the drag forces oscillate at twice the vortex shedding frequency[1]. The interaction of currents and waves with cylinder can produce vortex-induced vibration (VIV), as the cylinder represents the risers and pipelines in an offshore drilling platform. Thus, the flow of current and wave through pipelines can increase fatigue failure because of the cylinder-water interaction vibration. The vibration caused by the 'lock-in' phenomenon which the frequency of vortex shedding is closely similar with the natural frequency of the pipelines[2].

VIV is one of most important factors need to be considered in the structure design of risers and pipelines. This is because VIV not only give dynamic load to the structure but will also influence the structural stability[3]. The combination of the lateral vibration and drag force caused by the flow resulted the structure in a high stress state, thus increasing the fatigue damage to the structural pipelines and risers. Deep elongated flexible riser system in the event of damage, repair is difficult, costly and also cause serious pollution to the marine environment.

Control of vortex shedding and VIV of a bluff body have been the topics of research and patent for about a hundred years due to its significance in engineering applications[4]. According to Zhou *et al.*[3], suppression of VIV can be divided by using active methods (using external energy), passive methods (without external energy to control the flow), or a combination of the above two methods. However, due to the large scales of the offshore structures, the control method needs to be simple and reliable with low cost. Therefore, VIV control methods has preferred the passive control devices over the active control methods.

Passive methods involved modifying either on the flow around the structure or the structure itself, while active methods use the input of an external source of energy to control the vibration. Active methods in the offshore industry are generally impractical as it needs an external source of energy which is not viable for large structures. Passive methods can help to reduce VIV by disrupting the vortex formation and affecting the periodicity of the vortex shedding using various suppression devices. Structural modification can change the natural frequencies of the structures or change structural formation to avoid the lock-in state.

According to Kumar *et al*.[5] passive control of VIV is divided into seven types which is by increasing damping, avoiding resonance, Stream-Lining the Structural Geometry, and introducing add-on devices. Another three types are through body surface modifications, boundary layer control, and by using control or interfering body.

The increasing damping value more than 64 has caused the peak amplitude at resonance to come down at 1% of the cross stream dimension of the body. Higher damping can achieve the objective of suppression of VIV by introducing scrapping material of materials having high internal damping such as visco-elastic materials between structural members or by using external dampers[5].

Extreme vibration that causes structural failure normally occurs in resonance conditions where the natural frequency of the structural is closely with external forcing frequency which is frequency of vortex shedding. Thus, avoiding resonance can be achieved by reducing the excitation level and to ensure structural safety through stiffening the structure[5].

Using the Stream-Lining Structural Geometry method has been proved to be able to mitigate VIV by 80% with drag coefficient about 0.1 to 0.3. The most effective of the streamlining is during the fixed direction of flow relative to the structure and the structural has sufficient stiffness to avoid flutter[5].

One of the add-on device methods being used widely in offshore industry is helical strakes to control VIV. Usually the helical strakes are being attached to cylindrical structure such as marine risers and pipelines. Even though the helical strakes are effective and economical devices, the disadvantages are that the drag coefficient gets higher and causes large inline forces to the structure. Besides, the increasing turbulence intensity and reduced velocity have caused less effectiveness to suppress VIV[5].

Owen *et al*.[6] ran the experiment about body surface modification which provides hemispherical bumps and found that maximum drag reduction is up to 45% and suppresses VIV for cylindrical structure. They also found that reduction of drag can be achieved if the separation lines on bluff body are forced to be sinuous.

Vortex Generator (VG) is developed to energize the boundary layer over the body. Using VG on the surface of body can result into the reduction of VIV and drag. VG is one of the add-on devices that an aerodynamic design consists of one of a small vane that creates vortex. It is one of the most effective passive techniques to retard flow separation smoothly. VG provides momentum enhancement near the wall by mixing high energy fluid found in the free stream with low energy fluid in the boundary layer[7]. More likely, this device is often used in the aircraft design. Vortex generators function as a device that can delay flow separation and aerodynamic stalling. Experiment conducted by Joubert and Hoffman[8] found that the optimum VG is angled at 50°, resulted a maximum of 71% drag reduction at a Reynolds number equal to 170,000.

The objective of this paper is to compare the signal correlation of a stationary bare cylinder with a stationary VGs cylinder velocity wake at a Reynolds number of 8,400 in a water flume. The velocity of the flow was measured by an Acoustic Doppler Velocimeter (ADV).

## 2.0 ACOUSTIC DOPPLER VELOCITY METERS (ADV)

Various methods have been considered for measuring velocity of water in experiment. One of them is Acoustic Doppler velocity meters (ADV)[6] as shown in Figure 1 which has been used world widely especially in the experiment to determine the velocity of water in three dimensions. The basis measurement technology is coherent Doppler processing, which is characterized by accurate data with no appreciable zero offset. Pulse coherent instruments utilize a pair of acoustic pulses with a known time lag to determine a Doppler induced phase shift. This measured phase shift is converted to velocity by scaling with the speed of sound in water.

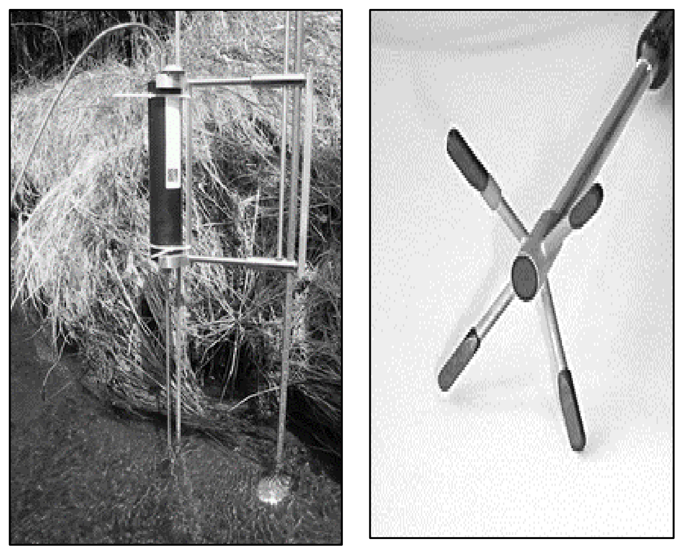


**Figure 1** Acoustic Doppler Velocimeter[10]

The primary data collected by ADV is a time series of velocity vector component. The sample data collection rate can be recorded until 200 Hz by using Vectrino Plus software as shown in Figure 2. ADV is unlike other measurement methods because it has unique operative data processing requirements due to their method of operation and some inherent limitation of acoustic Doppler measurement technique. The accuracy of ADV measurements of flow velocity can be increased by lowering of the signal-to-noise ratio (SNR) and by increasing the correlation percentage. Through filtering the data collection using this two parameters, the quality of the measurement[11] can be obtained. Figure 3 shows the filtering option of the data collection.

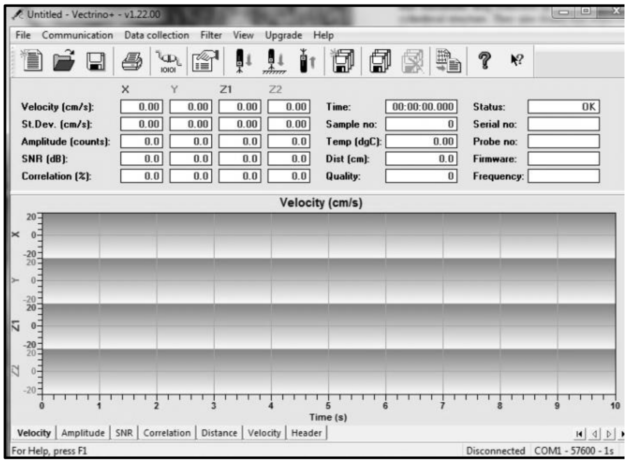


**Figure 2** Vectrino Plus Interface

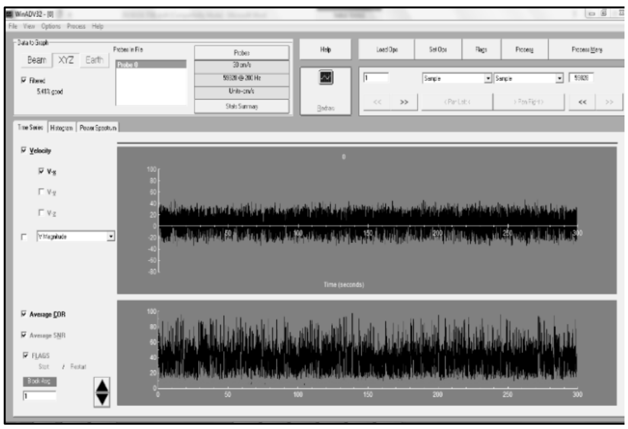


**Figure 3** WinADV program

The mounting of ADV must be 5 cm from sampling the volume to the centre of transducer. All acoustic transducers must be submerged during data collection process, otherwise errors of data can be occurred. The best quality measurements of data can be obtained when the main flow direction is perpendicular to the transmit axis. The most important procedure is to make sure that the mouthing structure is stable and tough because small vibration can cause big error to occur in data collection[12] results.

After using the measuring ADV device and collecting data, they need to be analysed using WinADV program as shown in Figure 3. WinADV is a software written in visual basic and being used in this experiment. The main function of this software is to display the velocity time series provided by Vectrino Plus software. Through WinADV software, single data files can be reviewed, filtered and processed[8]. The file type that can be read by WinADV is *.adv* where it can be created by Vectrino Plus software. Then, the filtering option can be selected by user, as shown in Figure 4. Figure 5 shows the percentage of data after the filtration process is completed. Percentage of acceptable data is only 5.41% for the minimum correlation and minimum SNR are 50% and 5 dB, respectively

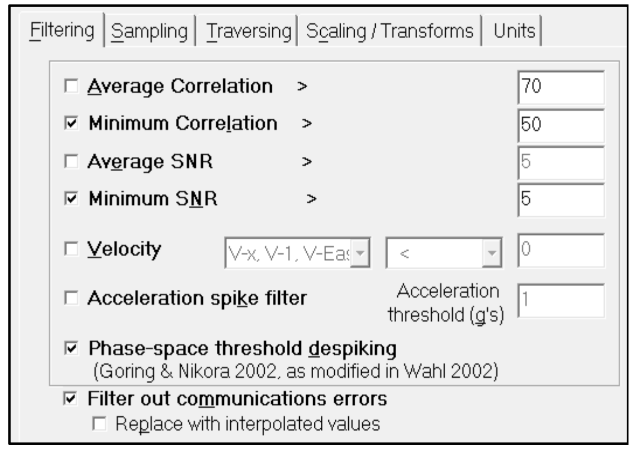



**Figure 4** Filtering option

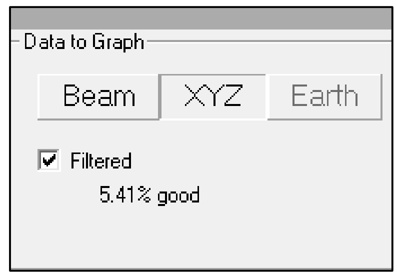



**Figure 5** Percentage data depend on filtration option

## ■3.0 EXPERIMENTAL DETAILS

In these experiments, a circular cylinder is attached with and without vortex generators in a steady water current. The test section of the water flume is 0.9 m (depth) × 0.6 m (width) × 19 m (length). For all experiments, the flow is a uniform and gravitational sources system, where the average free-stream velocity $U_\infty$ was about 11 cm/s, resulting in a Reynolds number of 8,400. The circular cylinders used in the experiments were made from stainless steel with a diameter *d* of 76.2 mm and length of 500 mm.

VG used in these experiments were manufactured from stainless steel plates with a 0.2 mm thickness. The dimensions of the VG were determined based on Unal and Atlar[5] where the width was 3.2 mm, height was 1.6 mm, and the spacing between every VG was kept constant at 6.4 mm. The height/width ratio ($h/b$) and spacing/height ($s/h$) ratio of the VG were 0.5 and 4.0, respectively. The detail dimensions of VG can be seen in Figure 6(a-d). The VG were positioned with an angle ±10º to the central symmetry axis, which parallels to the flow direction, as seen in Figure 6(b). The VG were fitted symmetrically on two rows in vertical orientation, and the angular position ($\alpha$) of the rows from the first stagnation line was systematically varied (see Figure 6b). The angle between VG and the separation line were fixed at 70º after considering the best dimensions.

The test cylinder was horizontally fixed in the middle of the tunnel width. The centre of the cylinders was located at 7.54 m downstream of the entrance of the water flume. A schematic view of the set-up and the general coordinate system used in the experiment are shown in Figure 7. The flow velocity was measured by the Acoustic Doppler Velocimeter (ADV) from Nortek[9]. The sampling rate used in this experiment is 200 Hz. The

ADV were positioned at 10*d*, 20*d and* 40*d* downstream from the cylinder horizontally with *x* is the flow direction.

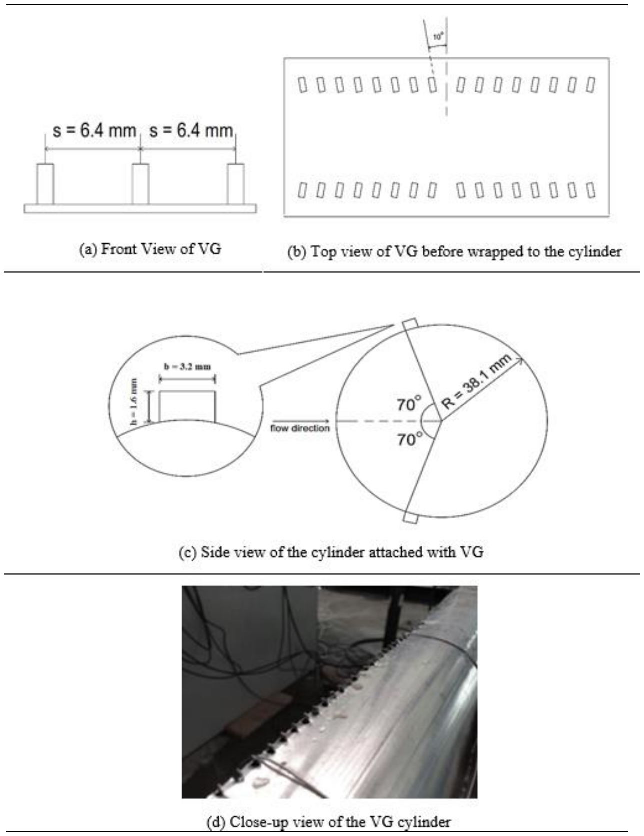



**Figure 6** Two-dimensional schematic view of vortex generators

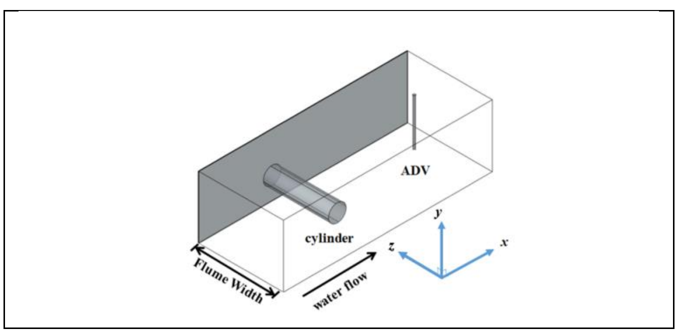



**Figure 7** Schematic view of ADV set-up and the general coordinate system

## ■4.0 ANALYSIS AND DISCUSSION

### 4.1 Wake Flows at $x/d = 10$ for Bare and VG Cylinders

Velocity data from the ADV need to be filtered by the WinADV software before any further analysis can be carried out. Low correlation data is caused by the combined effects of disturbances to the data such as turbulence velocity fluctuations, Doppler noise, signal aliasing and installation vibration[13].

In a steady flow, the phase-space thresholding despiking techniques is used to eliminate spikes that are aliasing errors[13]. The data was filtered to have a minimum SNR equal to 5 dB based on Wahl[11], with the minimum correlations are 30%, 50% and 70%, also with and without the phase-space thresholding despiking technique. The percentages of acceptable data for three cases (freestream, bare cylinder and VG cylinder) based on with and without phase-space thresholding techniques are shown in Figures 8 and 9, respectively.

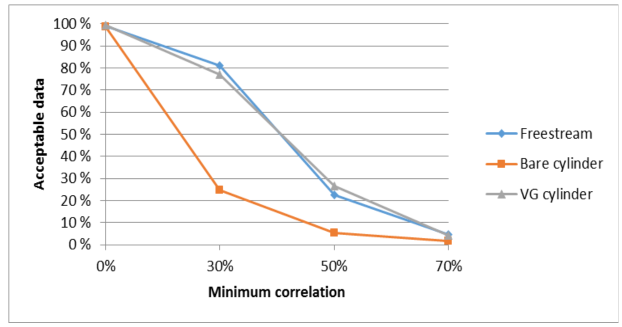



**Figure 8** Acceptable data after data filtration without phase-space thresholding despiking technique at $x/d = 10$ for different cases

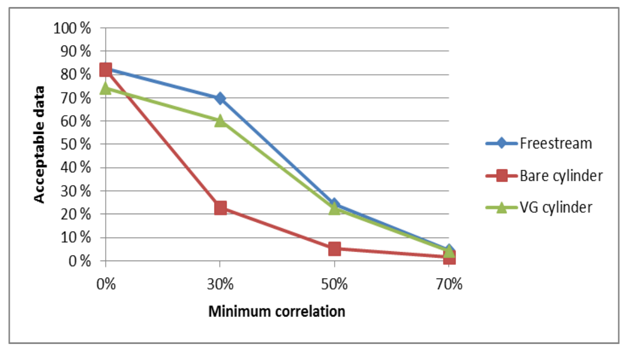



**Figure 9** Acceptable data after data filtration with phase-space thresholding despiking technique for at $x/d = 10$ different cases

Both results shown in Figures 8 and 9, are the percentages of the acceptable data with the minimum SNR is equal to 5 dB. It is evident that with the phase-space thresholding despiking technique, the percentages of the acceptable data are decreasing as the spikes data were eliminated. The low correlation data for all cases are caused by irregular velocities of flow caused by the gravity flow. The percentage of the acceptable data for bare cylinder is very low compared to the other two cases. This shows that the bare cylinder data has more noise where the flow of the bare cylinder has higher turbulence and vortex. Therefore, the velocity fluctuations became stronger and the correlations between signals became lower.

Vortex generators cylinder was found successfully suppressing the vortex of the flow as the VG cylinder data correlations seem to have quite similar values with those of the freestream (without cylinder). Acceptable data of VG cylinder is 37.3% higher than those of bare cylinders when the data was filtered at 30% minimum correlation with the phase-space thresholding despiking technique. Then, the differences in percentages of the acceptable data between VG and bare cylinders are 17.2% and 2.5% when the data were filtered at 50% and 70% minimum correlations, respectively. This shows that at higher minimum correlations, the original turbulence data was also diminished in the filtration process. There is no large difference in data for all three cases at 70% minimum correlation as all noise including turbulence characteristics became the 'bad' data. This extreme filtration of low correlation signal problem also has been reviewed in Martin *et al*.[14].

### 4.2 Wake Flows at Different Wake Locations for Bare and VG Cylinders

Figures 10 and 11 present the percentage of the acceptable data after data filtration of bare and VG cylinder wake, respectively, at different locations: $x/d = 10$, 20 and 40. The data set to be filtered at several criteria. The signal-to-noise ratio (SNR) was set to be at least 5 dB, the minimum correlations were set to be at 30%, 50% and 70%, and with the phase-space thresholding despiking technique. Both results are compared with the freestream flow (without any cylinders) at $x/d = 10$.

The result in Figure 10 shows that acceptable data for bare cylinder wake are increasing with the increase of wake location, which is from $x/d = 10$ to 20 and 40. The percentage of acceptable data for 30% minimum correlation of the wake of bare cylinder at $x/d = 10$ is the lowest compared to the wakes of $x/d = 20$ and 40. While for the 70% minimum correlation, the percentages of acceptable data are almost the same between different wake locations.

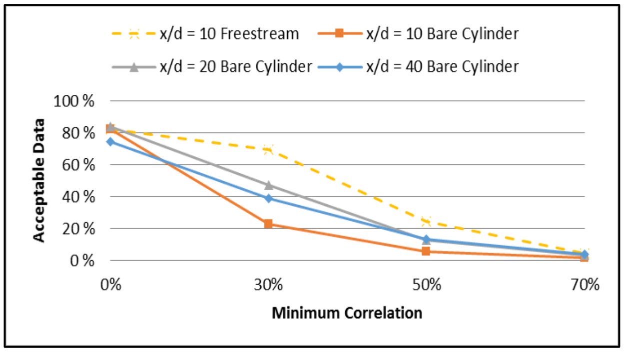



**Figure 10** Acceptable data after data filtration of bare cylinder wake at different locations

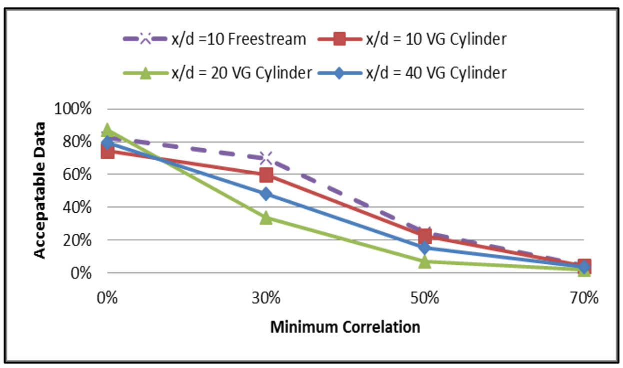



**Figure 11** Acceptable data after data filtration of VG cylinder wake at different locations

Contradicting result for VG cylinder is shown in the Figure 11, where the percentage of acceptable data after filtration is decreasing with the increase of wake location that is from $x/d = 10$ to 20 and 40. This is not applicable to the data for the minimum correlation equal to 0%. As an example, at minimum correlation 30%, the acceptable data for VG cylinder wake is 69.8% ($x/d = 10$) decreasing to 33.7% and 48.4% ($x/d = 20$ and 40, respectively). It shows that the VG cylinder may only suppress turbulence effectively at $x/d = 10$ and not at farther locations. At a minimum correlation of 70%, the acceptable data of VG cylinder wake are not really affected by the wake locations.

## 5.0 CONCLUSIONS

The correlation values of the vortex generator cylinder flow data are near to those of flow without any cylinder. In all three cases, the correlation values of the bare cylinder flow data were the lowest. Therefore, it can be concluded that the flow of VG cylinders has lower turbulence than that of bare cylinder. The effectiveness of the suppression of turbulence wake by VG cylinder is higher at $x/d = 10$ compared to the other farther locations. The minimum correlation of the flow during filtration process also should be reviewed as it may not necessarily demonstrate good data, it also may have eliminated the original turbulence data and characteristics if high minimum correlations are chosen.

### Acknowledgments

This research is supported by Ministry of Education Malaysia research grant ERGS/1/2012/TK03/UKM/02/5 and university grant DPP-2014-073. Their financial supports are gratefully acknowledged.

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