WITT: HARVESTING ENERGY FROM SUBSEA, VORTEX-INDUCED VIBRATION

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ABSTRACT

The WITT (Whatever Input to Torsion Transfer) energy harvesting device converts chaotic motion in six degrees of freedom to a single unidirectional output, this can be coupled to a generator to provide electrical power. The WITT energy device of this size order has an operational sweet spot of approximately 2Hz with up to 100mm amplitude displacements, although it is tunable within the WITT device by varying the pendulum length and mass. To operate in this nature subsea Vortex Induced Vibration (VIV) was chosen to drive the system. This is achieved by connecting the WITT energy transmission to cylindrical cross section pipe sections, creating a modular system that can be varied for sites with different conditions or power requirements. Numerical predictions were performed for a wide range of design variations over a broad range of operating conditions using different VIV calculation techniques. This informed the likely dimensions for different sites and power requirements, so that an off the shelf solution could be quickly provided to a client, providing a sealed modular subsea energy solution. Tank testing was performed to compare to the numerical predictions and determine the effect of the WITT energy device on the system dynamics, demonstrating the concept is feasible. A range of possible applications are provided, from powering subsea monitoring equipment through to reduction of riser fatigue by reducing VIV.

INTRODUCTION

The WITT (Whatever Input to Torsion Transfer) energy device converts chaotic motion in six degrees of freedom to a single unidirectional output, which can be coupled to a generator to provide electrical power. The WITT system is described as follows:

"Contained within a sealed unit, a WITT uses two pendulums connected to a flywheel to generate electricity. Movement causes the pendulums to swing, they are attached to a shaft that then turns a flywheel in one direction. The flywheel is connected to a generator, which produces electricity. The unit harvests chaotic motion, fast, slow or erratic, turning it into useable power. The company claims that no other device captures energy from all six degrees of motion. Where most energy harvesting devices are point absorbers, taking up-and-down or side-to-side motion and turning it into useable power, the WITT takes all motion." (WITT, 2018)

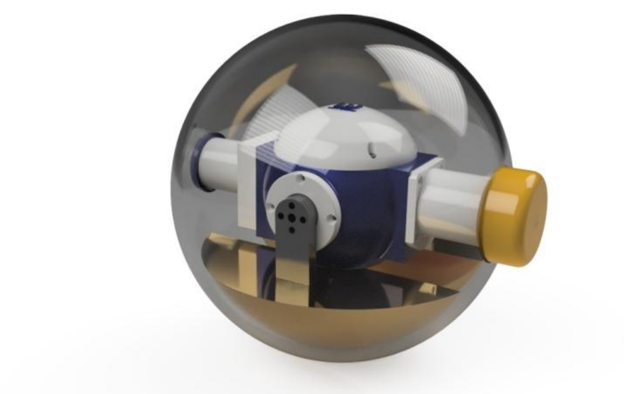

Figure 1 - Small WITT in Sealed Housing

While the WITT device has multiple uses both on land and sea, and also harvesting human animal motion, this subsea application is focused on small scale power generation for subsea electronics, particularly where the replacement of battery packs is an expensive offshore activity requiring ROVs (Remotely Operated Vehicles) and their supporting ships and crew.

The WITT system of this size approximately 250mm in diameter, capable of generating 5W, requires movement to generate power. The ideal operating point is an amplitude of up to 100mm with a frequency of 2Hz. Larger systems will require lower frequency, but amplitude would be larger. The power output and target frequency is tunable within the WITT device by changing the internal pendulum mass distribution. To achieve these target operating conditions for the WITT generator, Vortex Induced Vibration (VIV) was chosen to drive the system. The design philosophy was to develop something simple and scalable, that could be deployed cost effectively. A patent has been filed and is now pending., WITT conducted trials at Solent University flow tank over a 3 day period; to view the video please click on the following link:- https://vimeo.com/user78912806/review/314797385/2fc3ba2275 and type in the following password: witt_310119

WITT VORTEX INDUCED VIBRATION OPERATING CONCEPT

The operating concept of the subsea WITT is motion from vortex induced vibration, this is achieved by connecting the WITT energy device to cylindrical cross section pipe sections, the periodic vortex shedding generates lift and drives the WITT generator. The aim is to create a modular system that can be varied for sites with different conditions or power requirements with ease of installation and minimum maintenance at the forefront.

High Density Polyethylene (HDPE) has been initially selected for the cylindrical pipe sections due to its low cost, fatigue performance and corrosion resistance. HDPE is readily available and can be easily joined using electro-fusion techniques offshore too. For different sites/sizes other materials could be used such as composites or steel with the necessary level of scrutiny applied to fatigue life and corrosion protection. The circular cross section pipe is also useful as a conduit for power/communication cables, enabling an entirely self-contained system.

A wide range of design options were studied to determine the parametric basis of the system as multiple parameters can be adjusted to affect the performance. Also, the natural frequencies and mode shapes of the system require consideration to ensure the WITT energy converters are placed at the antinodes where displacement is at a maximum.

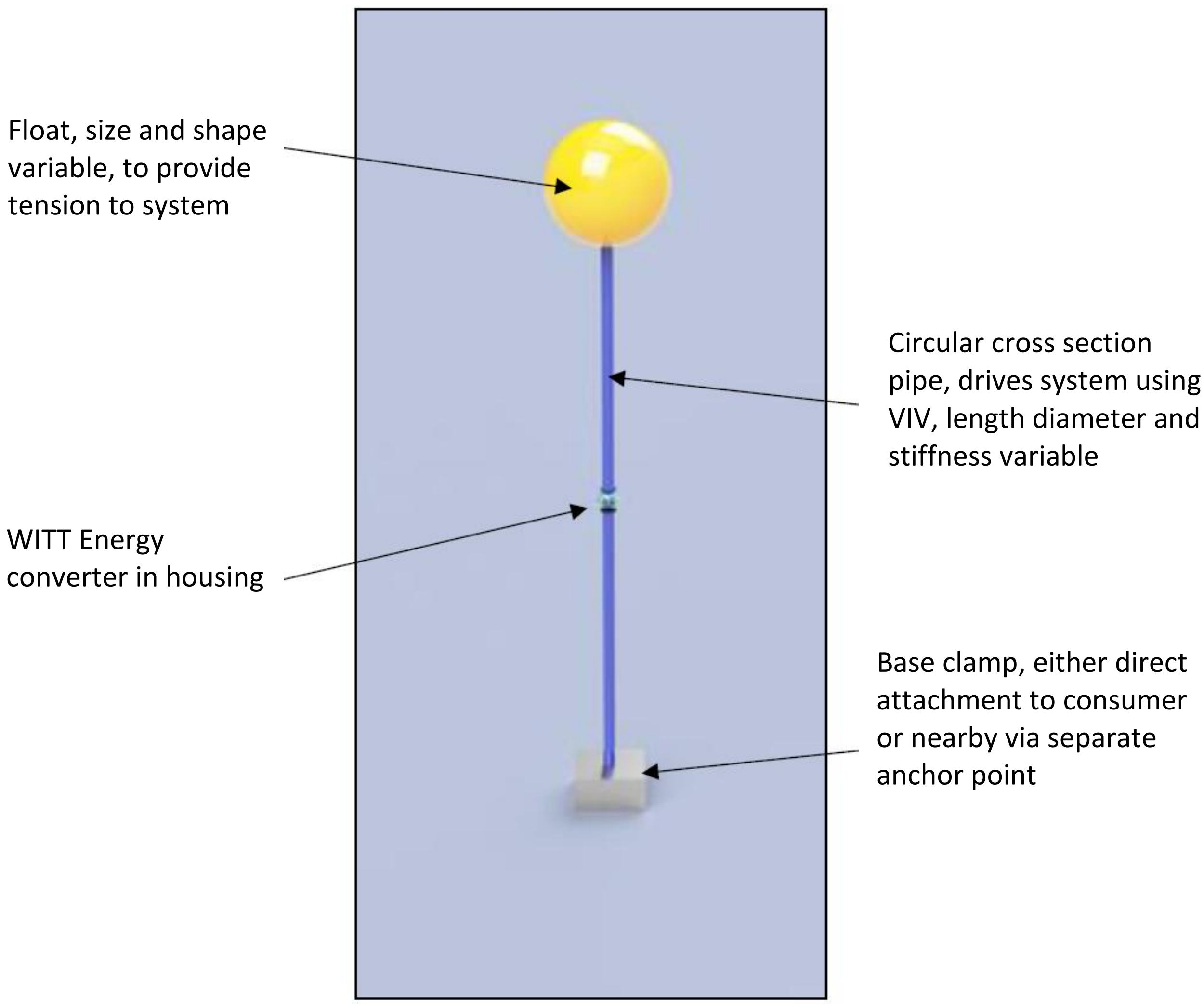

Figure 2 – General Arrangement for Subsea Use

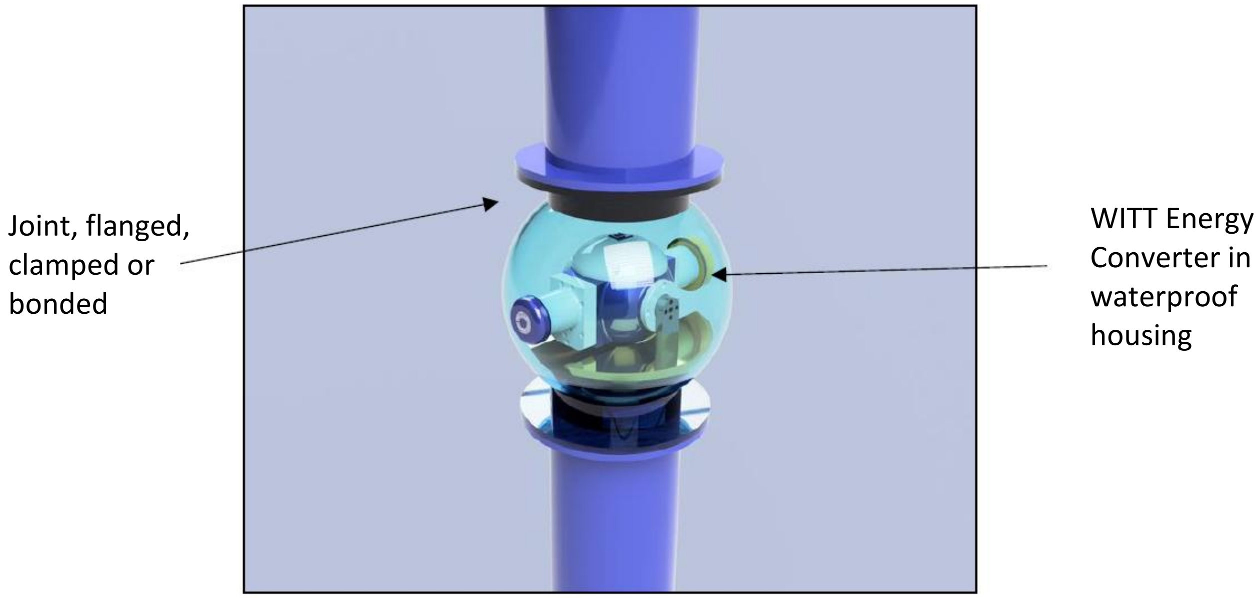

Figure 3 – Possible Subsea Design Embodiment

POSSIBLE APPLICATIONS

The WITT device has many applications harvesting Natural Occurring Motion Energy (NOME) that is all around us. This subsea version driven by VIV has two primary applications as follows, although there may be many more:

1) Subsea power: Where the primary aim is to power subsea electronics in remote locations where battery replacement is a costly exercise. The low maintenance strategy and lack of external moving parts lend it to uninterrupted operation. Low ocean current speeds can be exploited by increasing the length of the system. Alternatively, areas with high current speeds can also be used by reducing the length of the system. Tuning is then achieved for a given power requirement by adjusting the pipe diameter and stiffness. Also, a top float can be used to adjust the line tension. The application could

be used to power ROV/AUV (Autonomous Underwater Vehicles) charging stations, or wherever a remote subsea power requirement exists, such as remote sensing in aquaculture and scientific data. The WITT energy converter would charge local energy storage for demand when required. Some of this energy may also be used for impressed current corrosion protection systems.

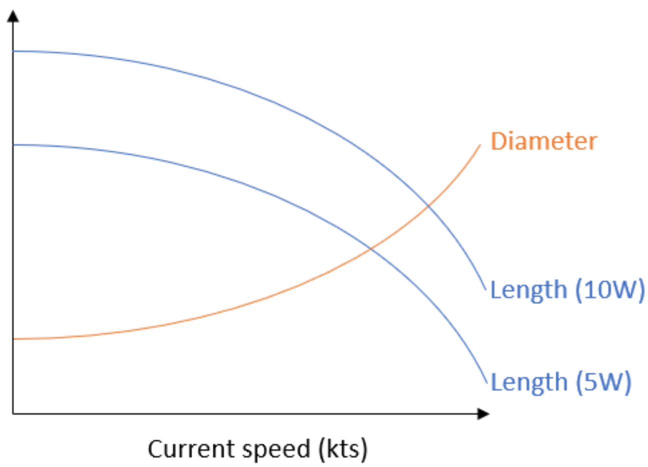

Figure 4 – WITT VIV Operational Current Speed and Diameter Relationship

2) Riser/umbilical VIV reduction measures: Here the WITT generator load can be varied to maximize the opposing force, effectively damping the VIV magnitude. This could be a pre-set load, or an active tuning performed remotely or onboard using an array of WITT devices along the length of the riser. A concept is shown in Figure 5.

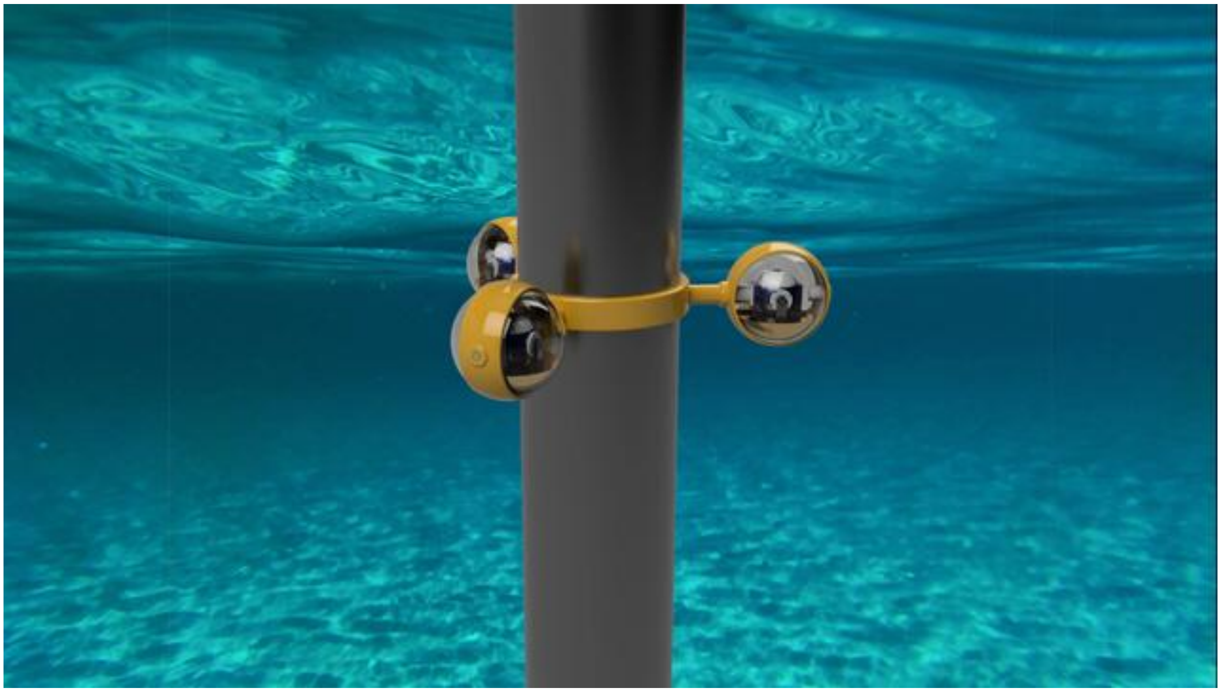

Figure 5 – WITT Suggestion for Riser Damping Configuration

The designs are focused on achieving VIV lock in, such that the natural frequency for a given mode shape is close to 2Hz thus achieving VIV lock in around the WITT optimal operating frequency to maximize performance.

An initial estimation of the pipe diameter for a given current speed can be made using the calculated Strouhal number of 0.2, to achieve VIV lock in. The natural frequency of the system using the transverse mode driving the WITT is then adjusted targeting 2Hz by varying the stiffness via the pipe wall thickness. Also, while the system can be tuned by varying the tension which is driven by the float, this parameter was fixed to reduce the number of variables at this feasibility stage.

NUMERICAL SIMULATIONS

Numerical predictions were performed for a wide range of design variations over a broad range of operating conditions using different VIV calculation techniques. This informed the likely dimensions for different sites and power requirements, so that an off the shelf solution could be quickly provided to a client for an affordable modular subsea energy solution.

The simulations were performed using OrcaFlex 10.3a in three phases: 1) initially just using the HDPE pipe of varying properties to observe the response and sensitivity to VIV prediction methods; 2) refining the model with a numerical approximation of the WITT with a fixed gearbox (no movement) in an arrangement that aligned with planned tank testing; and 3) a tank arrangement as tested.

The pipe only simulations covering the following parameters:

- Diameter (20mm, 100mm, 150mm, 200mm, 300mm, 400mm, 500mm)
- Contents (Air, Sea water)
- Length (2.5m, 5m, 7.5m, 10m, 15m, 20m)
- Current Speed (range from 0.1m/s to 5m/s)

The VIV was predicted using the Milan Wake Oscillator method. In summary, without any optimization, current speeds down to 0.2m/s can meet the WITT input motions (100mm amplitude at 2Hz). The required driving frequency is determined from the WITT drivetrain pendulum resonant frequency, for example a pendulum length of 65mm will have a natural frequency of approximately 2Hz (see Figure 6).

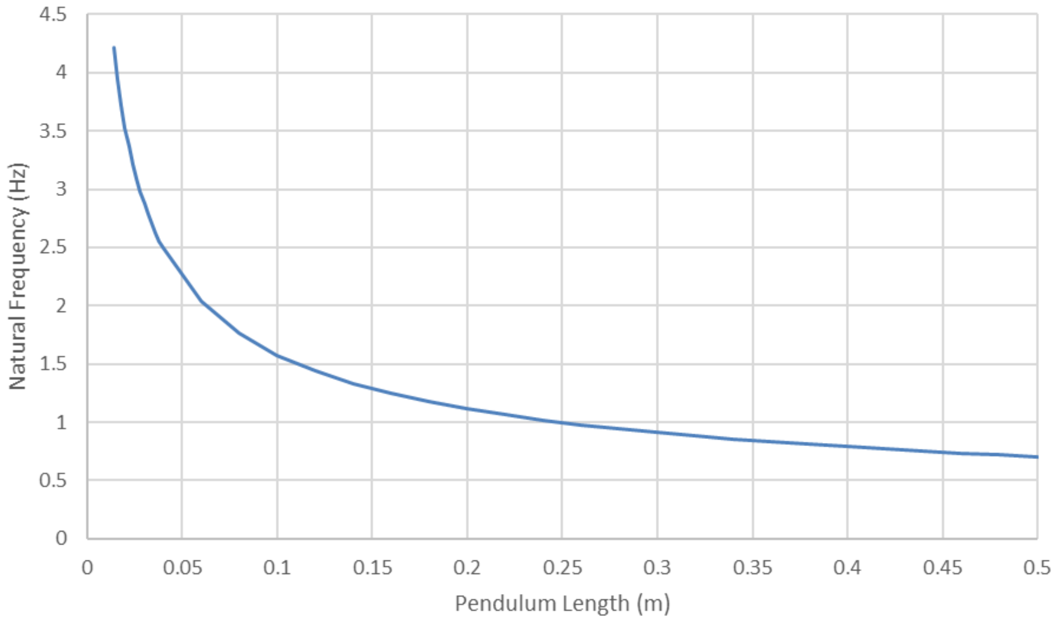

Figure 6 – Pendulum Natural Frequency Relationship

Varying the mass on the pendulum is proportional to the power available, for example a mass of 1kg can generate a peak power of 5W (see Figure 7). Typical power outputs around 2-3W are expected.

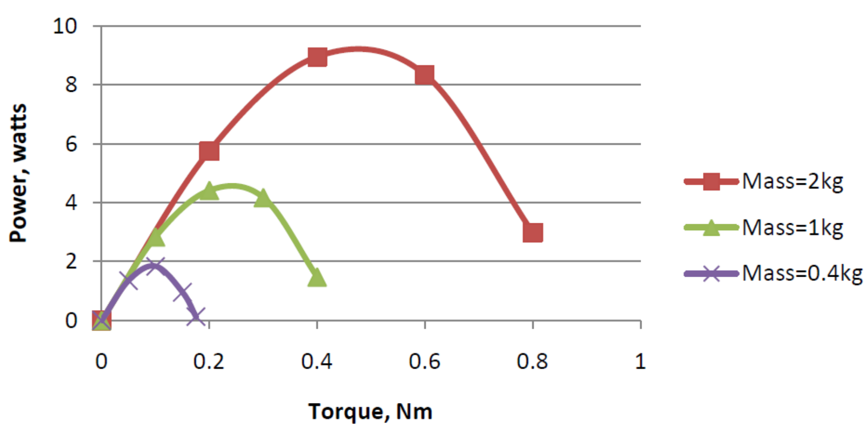

Figure 7 – WITT Power capacity for 65mm pendulum arm

The distribution of predicted pipe diameters for a range of current speed such that the VIV frequency is 2Hz is Figure 8. This provides initial design guidance for pipe diameter selection.

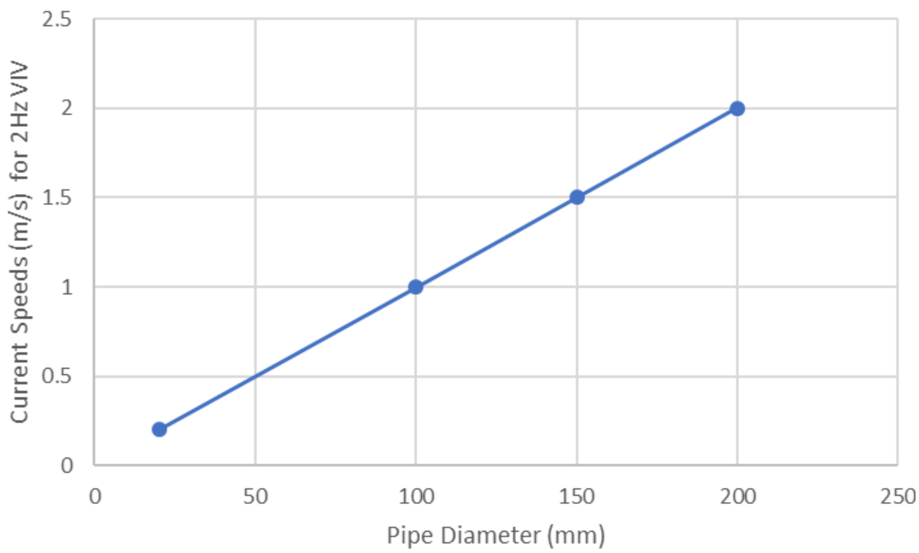

Figure 8 - Current Speed and Pipe Diameter Prediction for 2Hz VIV

These initial predictions informed the next stage of development, this was focused on providing power at low current speeds. To maintain the WITT motion at low current speeds, diameters ranging from 50mm to 200mm were assessed in more detail over a range of current speeds from 0.2m/s to 2 m/s. These included an approximation of the WITT in a housing in a likely tow tank arrangement. The effect of the housing were predicted, showing a limiting diameter of approximately 200-250mm for this unit due to reducing VIV amplitude (see Figure 9).

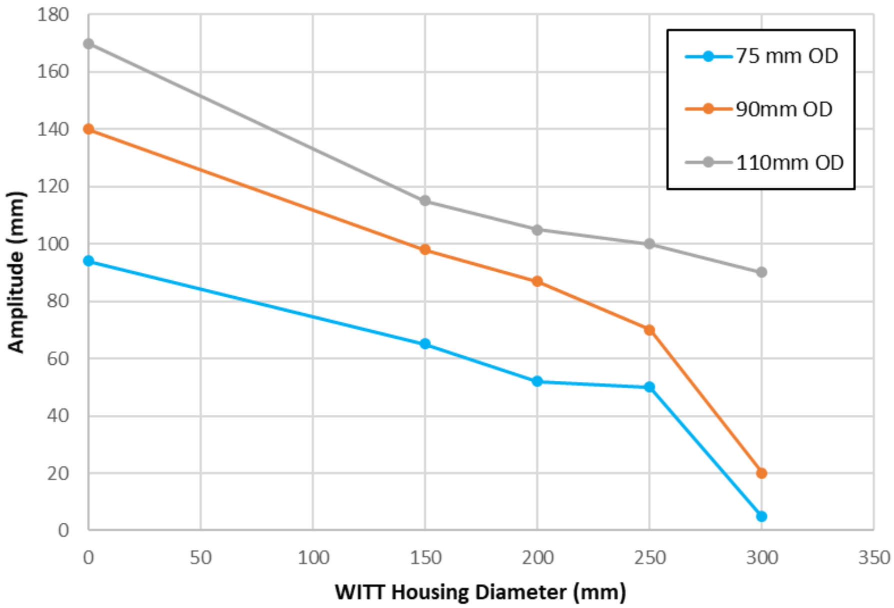

Figure 9 – WITT VIV Amplitude for 3 pipe diameters (75mm 90mm 110mm) using the Milan Wake Oscillator [MWO] to assess the sensitivity of WITT housing diameter

The feedback from testing would inform VIV prediction techniques for the next stages of development, therefore four VIV methodologies were utilized to enable comparison with the tank tests:

- Milan Wake Oscillator [MWO]
- Iwan and Blevins Wake Oscillator [IBWO]
- Vortex Tracker 1 (developed by Sarpkaya and Shoaff) [VT1]
- Vortex Tracker 2 (as per Vortex Tracker 1 but with coalescing vortices) [VT2]

The predicted WITT VIV amplitudes and frequencies were calculated for a range of pipe speeds and diameters. The results are presented for the three most favorable diameters for minimum current speed applications that would work with the 5W WITT drivetrain VIV requirements and that coincide with ocean currents.

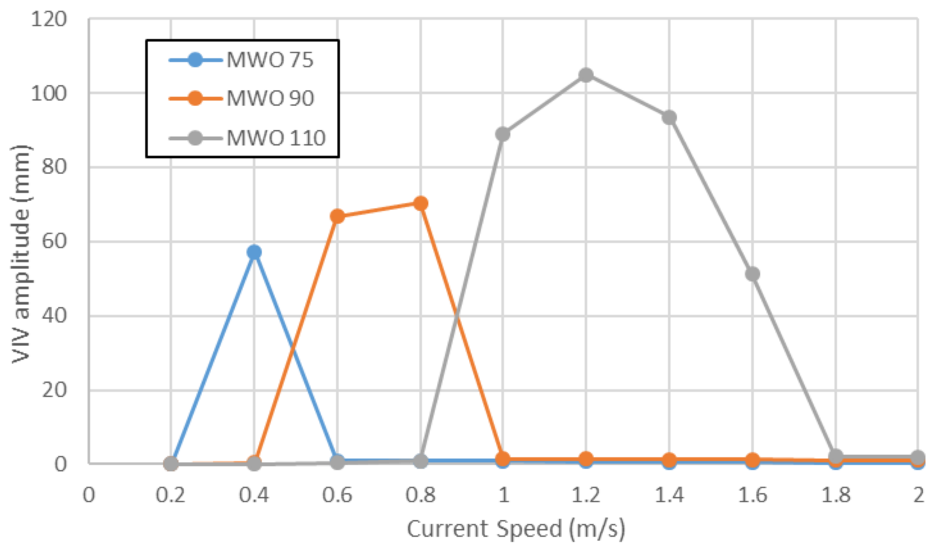

Figure 10 – WITT VIV Amplitude for 3 pipe diameters (75mm 90mm 110mm) using the Milan Wake Oscillator [MWO]

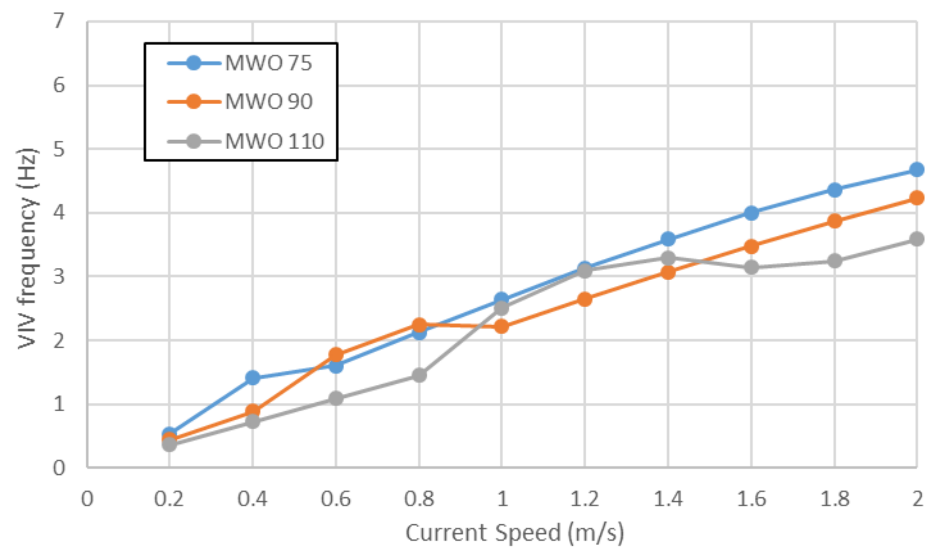

Figure 11 – WITT VIV Frequency for 3 pipe diameters (75mm 90mm 110mm) using the Milan Wake Oscillator [MWO]

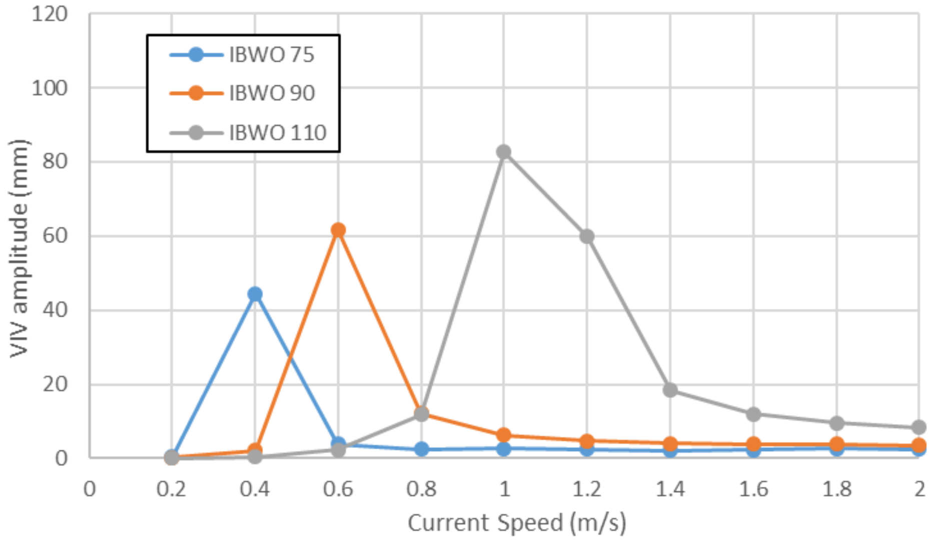

Figure 12 – WITT VIV Amplitude for 3 pipe diameters (75mm 90mm 110mm) using Iwan & Blevins Wake Oscillator [IBWO]

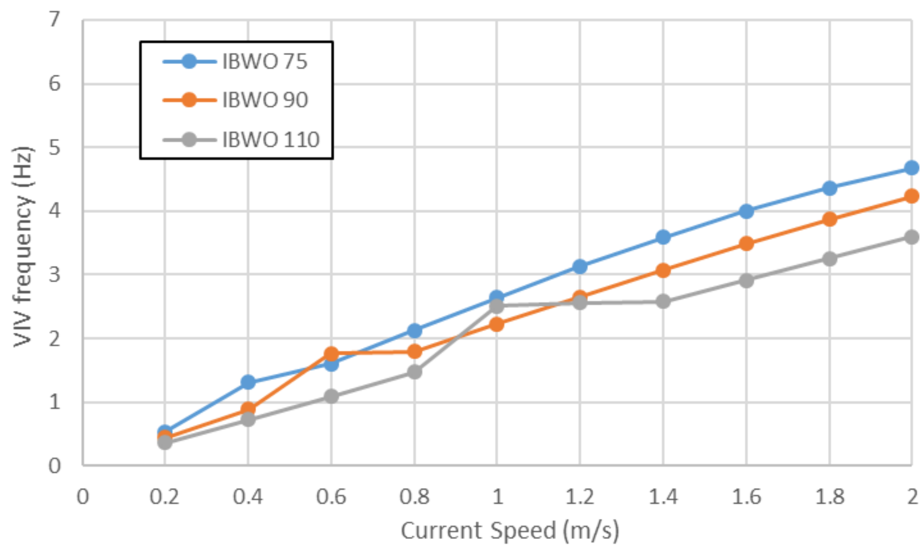

Figure 13 – WITT VIV Frequency for 3 pipe diameters (75mm 90mm 110mm) using Iwan & Blevins Wake Oscillator [IBWO]

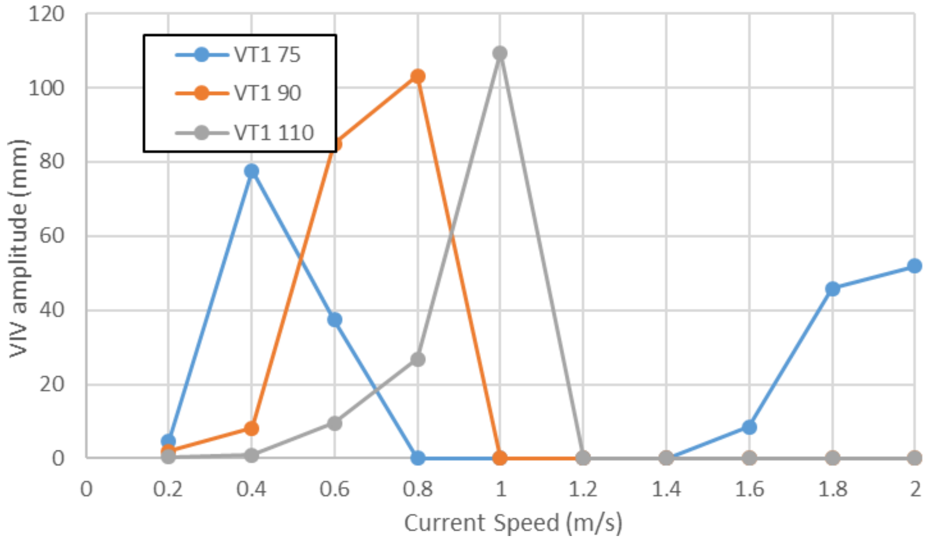

Figure 14 – WITT VIV Amplitude for 3 pipe diameters (75mm 90mm 110mm) using Vortex Tracking 1 [VT1]

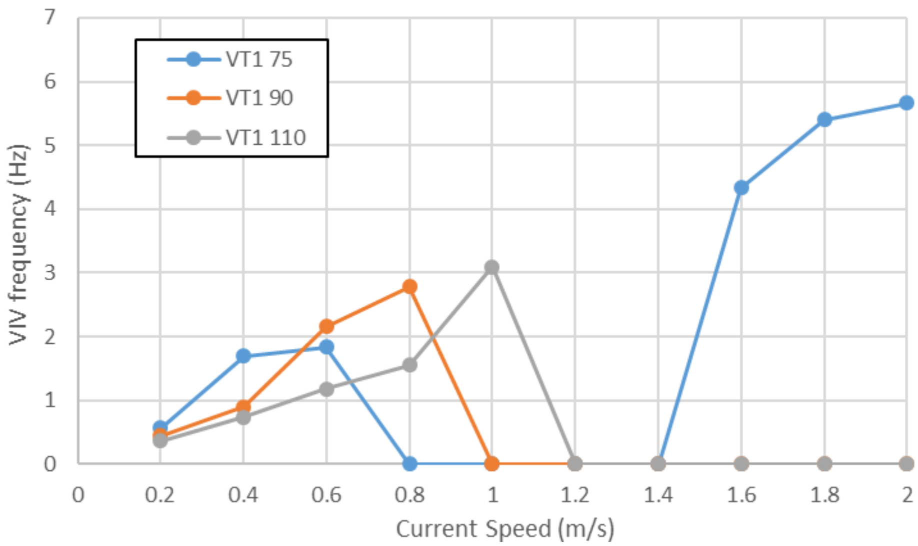

Figure 15 – WITT VIV Frequency for 3 pipe diameters (75mm 90mm 110mm) using Vortex Tracking 1 [VT1]

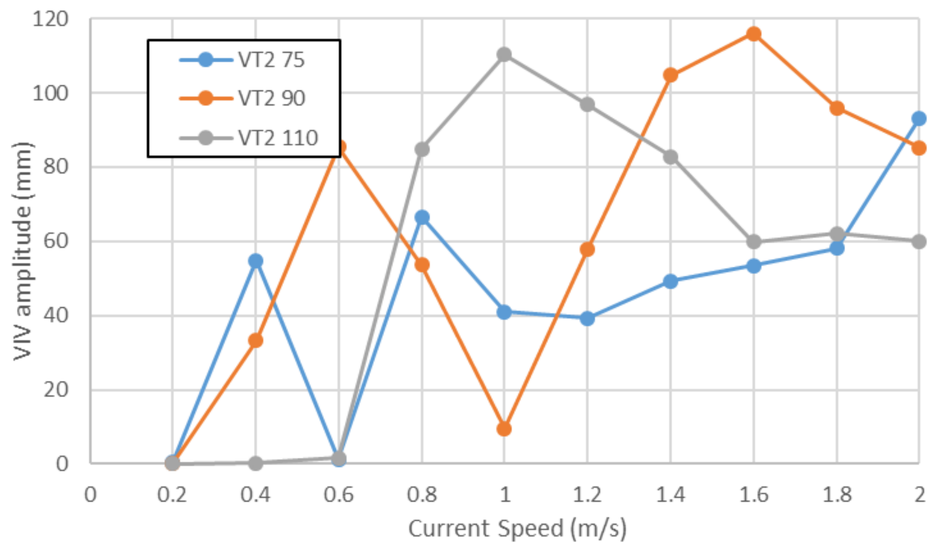

Figure 16 – WITT VIV Amplitude for 3 pipe diameters (75mm 90mm 110mm) using Vortex Tracking 2 [VT2]

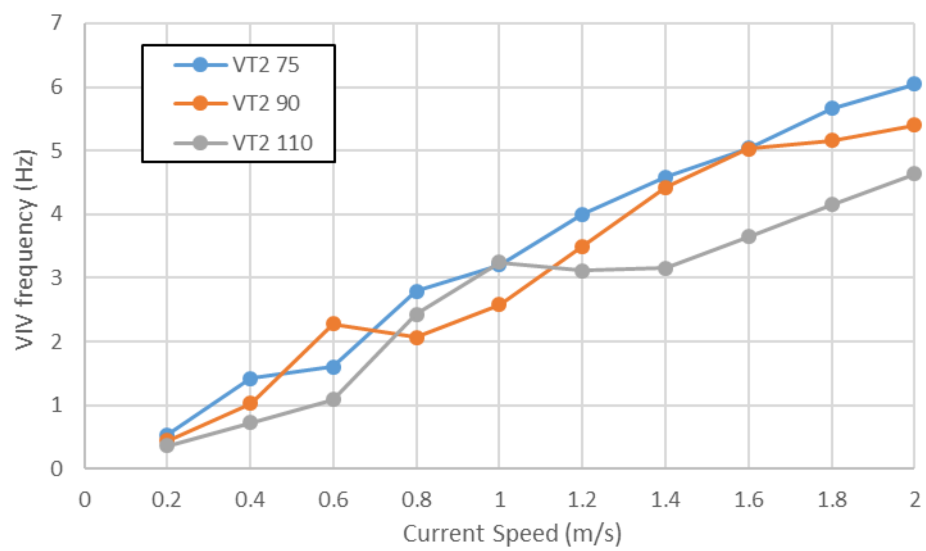

Figure 17 – WITT VIV Frequency for 3 pipe diameters (75mm 90mm 110mm) using Vortex Tracking 2 [VT2]

An image of the vortex tracking methods in OrcaFlex is show in Figure 18 below, one can note the deflection of the device and Von-Karmon vortex street.

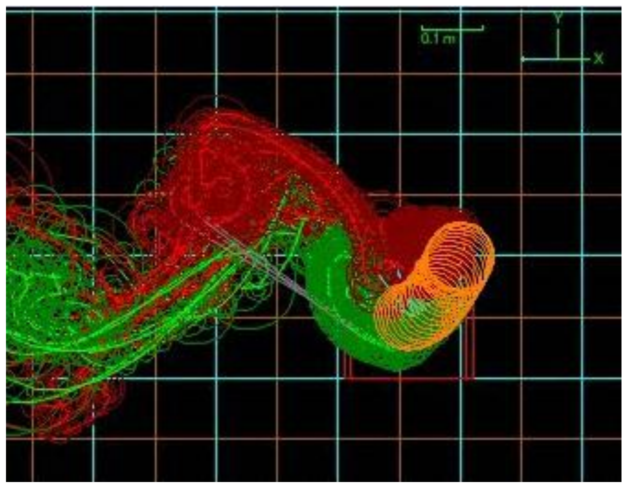

Figure 18 – WITT VIV Calculated in OrcaFlex using Vortex Tracking

All of these simulations do not include a moving/free WITT drivetrain in the system, tank testing is performed to provide insight into the effects of the dynamic WITT on the whole system dynamics.

The tank testing predictions enable the following tank test matrix to be determined that focus on the required operating WITT VIV amplitude and frequencies (see Figure 18 and Figure 19). Averaged values were used to ensure the whole area with different speed and diameter combinations were performed in the tank.

		Diameter (mm)		
		75	90	110
Current Speed (m/s)	0.2	0.001	0.001	0.000
	0.4	0.059	0.011	0.000
	0.6	0.011	0.075	0.004
	0.8	0.023	0.060	0.031
	1	0.015	0.006	0.098
	1.2	0.014	0.021	0.087
	1.4	0.017	0.037	0.065
	1.6	0.016	0.040	0.041
	1.8	0.027	0.034	0.025
	2	0.037	0.030	0.023

Figure 19 – WITT VIV Amplitude for 3 pipe diameters (75mm 90mm 110mm) Average values presented for the 4 VIV techniques

		Diameter (mm)		
		75	90	110
Current Speed (m/s)	0.2	0.540	0.445	0.365
	0.4	1.458	0.926	0.729
	0.6	1.659	1.991	1.115
	0.8	2.345	2.222	1.726
	1	2.829	2.340	2.839
	1.2	3.421	2.931	2.921
	1.4	3.921	3.521	3.008
	1.6	4.346	3.996	3.235
	1.8	4.952	4.297	3.549
	2	5.263	4.619	3.939

Figure 20 – WITT VIV Frequency for 3 pipe diameters (75mm 90mm 110mm) Average values presented for the 4 VIV techniques

A tank test target speed of approximately 0.2 to 1.6m/s was chosen. This provided a diameter range of 75mm to 110mm using off the shelf HDPE (High Density Polyethylene) pipe with an SDR (Standard Diameter Ratio) of 17.6.

TANK TESTING

The purpose of the testing was to cover several aspects; observe VIV occurrence, determine the effect of the WITT energy device on the overall system dynamics, measure WITT displacements and frequencies over a range of operating conditions.

Uncertainty over the influence of the WITT energy converter moving mass may affect the system dynamics. This is a complex area to simulate, so a small-scale tank test was employed to validate the work to date and inform the influence of the WITT energy device on the system.

The length, diameter and stiffness can be optimized for a given site/power requirements (number of WITT on a string), after the tank testing preliminary calculations are performed to enable general system specification for a range of sites and power requirements.

A traditional towing tank was chosen as one can finely adjust the speed of the water passing the device by adjusting the carriage speed. The testing was performed in the towing tank at Solent University, UK. This is a fixed basin of water with a moving carriage, with the following main dimensions:

- Length = 60m
- Width = 3.7m
- Water Depth = 1.8m
- Max Carriage speed = 4.0m/s

A full scale 5W WITT drivetrain was available so a full-scale test program, looking at the first section of the system comprising clamp, pipe and WITT in an inverted configuration, was carried out.

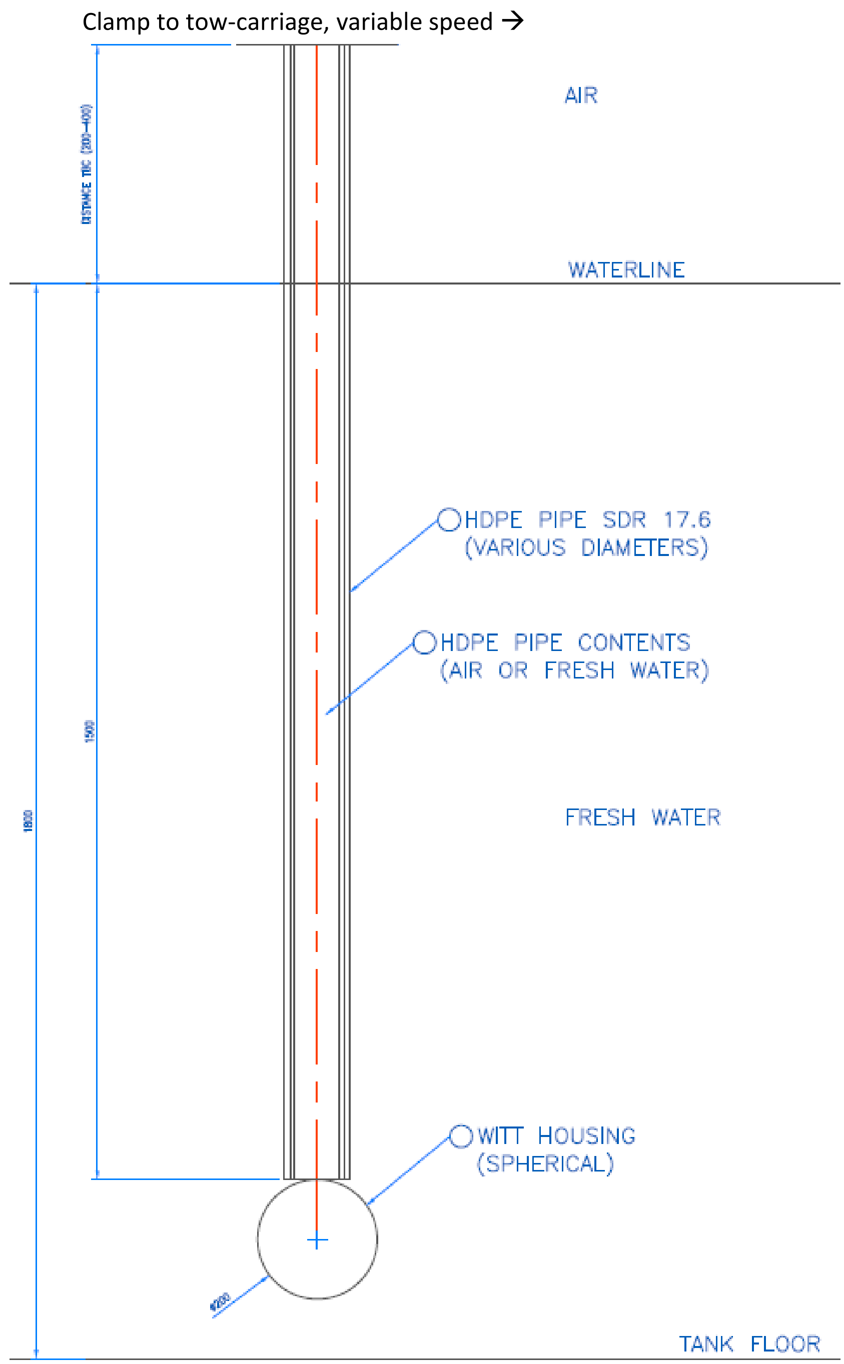

Figure 21 – Inverted WITT Test Arrangement for Solent Tow Tank

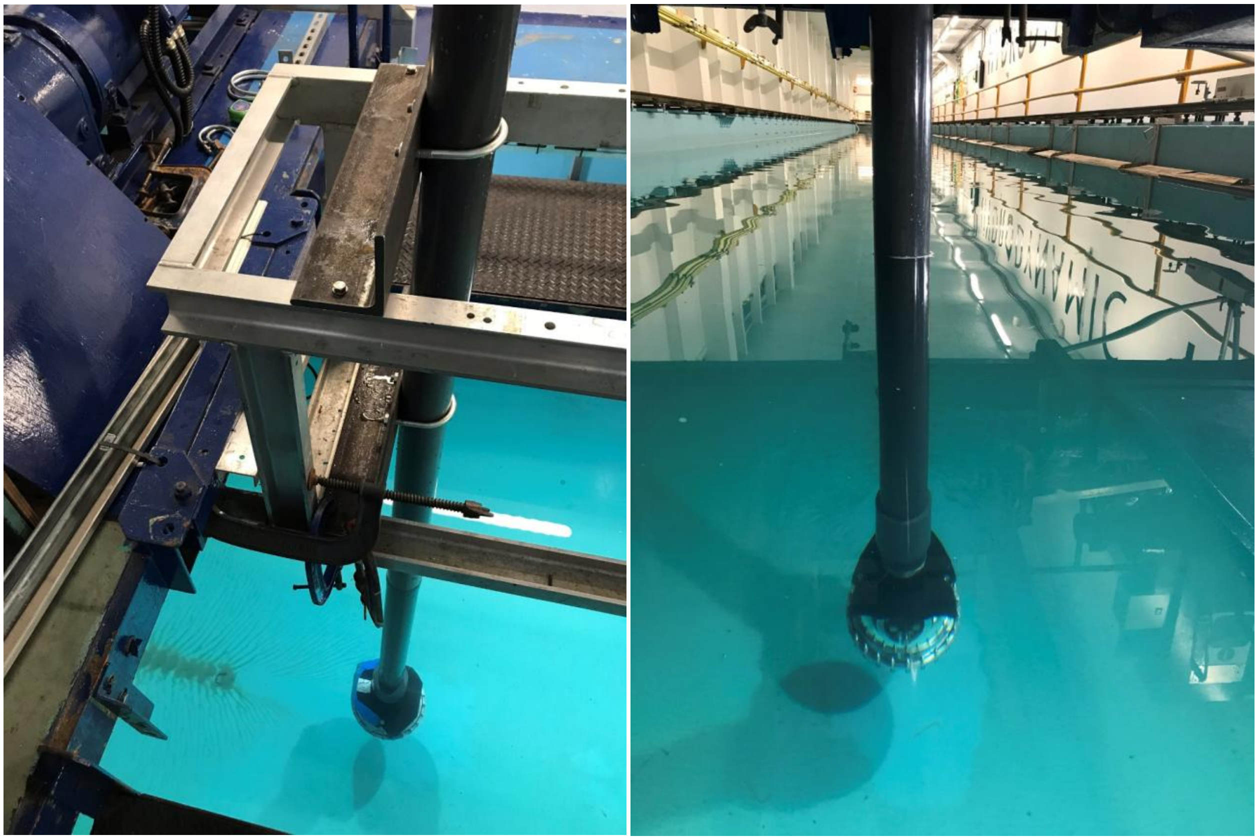

Figure 22 – Inverted WITT Test Images from Solent Tow Tank

A 3-axis accelerometer and gyro were fitted to the WITT to determine the displacement amplitude and VIV frequencies. This unit is battery powered and attached to the WITT housing. The summary VIV amplitude results from the tank testing are shown in Figure 23, it can be noted that the VIV occurs over a more broad spectrum of current speeds than initially simulated in OrcaFlex. This indicates that the VT2 method for VIV predictions, which also captured the dual peak response for the 90mm diameter pipe, is most suited to performance prediction, however all methods capture the general trend.

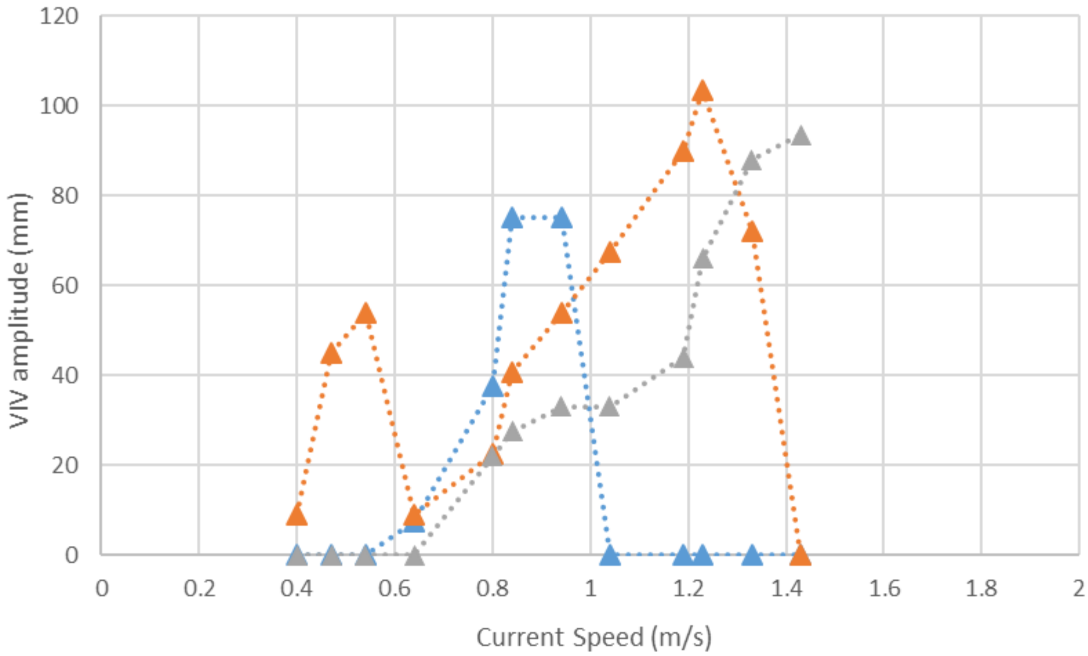

Figure 23 – WITT VIV Amplitude for 3 pipe diameters (75mm 90mm 110mm) from Tank Testing

The extent of VIV present in the physical tests are very encouraging, the feedback of the WITT drivetrain and relatively short pipe section still results in an easily driven system. The VIV prediction techniques would benefit from further investigation to improve their fidelity.

CONCLUSIONS

The simulations, validated by tank testing prove that the subsea WITT energy harvester, using vortex induced vibration is a feasible technology. The technology has the following advantages:

- Current direction independent
- Modular
- Scalable

- Tuneable
- Sealed generator
- No external moving parts
- No shock loads

The scalability and modularity of the subsea WITT allows for cost-effective tailoring for a site’s individual met ocean characteristics and power requirements. A wide range of applications are possible, from powering subsea monitoring equipment through to reduction of riser fatigue by reducing VIV.

The difference in performance of the system free flooded or filled with air was negligible, therefore a seawater filled (free flooding) design is favored, as it would be more cost effective to achieve.

Further investigations to determine the effect of the VIV subsea WITT are to be performed to better inform the end user and advance the product, in a range of applications:

i. Dynamic generator load (for maximum power or VIV damping),

ii. Surface roughness of the subsea system,

iii. Wave particle velocity,

iv. Alternative pipe structure, composites for example,

v. Float shape and size,

vi. WITT device fatigue and maintenance requirements.

Note these are not mutually exclusive, adjusting the size of the float changes the tension in the pipe which changes the system stiffness and hence natural frequency. These areas are focused on the hydrodynamics, but also equally important are the generator control, assembly and deployment techniques so that a robust capital cost and deployment cost can be determined, therefore providing clients with the information required to enable them to make an informed procurement decision.

Turbulence, both large scale (eddies in current, waves) and small scale (surface roughness due to fouling) are worth investigating, as is driving the WITT with waves in more shallow water applications.

The wave element may increase possible sites, small wave (low period, thus higher frequency) would be most suitable, also during the tank testing during the acceleration phase as the device travelled up to speed some large VIV motions were observed, this accelerating and decelerating cycle may also have a contribution to the possible motion but it requires further investigation.