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DEVELOPMENT OF A ROTATING ARM SYSTEM TO STUDY VIV PHENOMENA IN AN OFFSHORE BASIN

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Abstract. *The methodology used to develop a rotating arm system to study Vortex-Induced Vibration in slender structures is presented. This system was designed to meet the needs of performing tests in a offshore basin, where the space to tow a model in a straight line is restricted. The solution was to tow the model in circular paths, which also provided the possibility of performing tests with variable speed current profile. Some testing has proven the equipment ability to perform VIV experiments and, as a result, some plots showing the model behavior are presented. Furthermore, the auxiliary equipment used to monitor and control the system parameters are described.*

Keywords: *rotating arm, vortex-induced vibration, ocean basin, model test, flexible riser*

1. INTRODUCTION

Risers are long tubular suspended structures which are responsible for conveying hydrocarbons from the ocean floor to the oil platforms and vice-versa. These structures operate under various types of static and dynamic forces, especially those caused by the current, its own weight, the platform motion and the soil interaction.

In particular, this study addresses a very common phenomenon, to which such structures are subjected: the vortex-induced vibration (VIV). Depending on the speed of ocean currents focusing on these pipes, alternating vortex are released in the flow. Such vortex shedding generates a cyclical differential pressure in the direction perpendicular to the velocity direction, responsible for the actuation of oscillatory forces, longitudinal and transverse to the flow.

Quite simply, when the frequency of these emissions occur near to the frequency of some pipe vibration modes, there is a resonance phenomenon which generates cyclic loading on the riser. If these loads occur for extended periods of time it is possible that these pipes present fatigue failure.

For its high cost and important role in the exploration of oil and gas, as well as environmental issues, it is imperative that these pipes have high durability and high level of security. Thus, for the design of these structures, the determination of all the efforts involved during their time of use, including efforts due to VIV, is required.

Many of the studies conducted on VIV are related to experiments with one or two degrees of freedom with rigid cylinders mounted on elastic foundations (Sarpkaya, 2004). However, the intention here is to study structures closer to the final problem such as flexible cylinders and catenary, like those presented by Pesce and Fujarra (2000).

A technique widely used to study structures like that is to tow a riser model in a towing tank or to perform a test in a circulating water channel as presented in Franzini *et al.* (2009). However these techniques only allow the flow simulation with constant-velocity profile. For the representation of ocean current in marine riser it is important to consider speed variation along the depth, this causes vibration in different frequencies and modal shapes and it has a critical effect in the structure fatigue life.

Furthermore, it is interesting to perform this study in an offshore basin, once the dimensions of a tank of this type enable the study with very slender structures. In this regard, a solution is to use a rotating arm in order to tow the model through circular paths. If the model is installed along the arm length it is possible to obtain a linear variation of the velocity profile, as depicted in Fig. 1.

With this purpose, a rotating arm was designed to support the researches at the University of Sao Paulo, in the ocean basin located at Numerical Offshore Tank facilities. In the next section, the study methodology is presented as well as the main characteristics of the rotating arm.

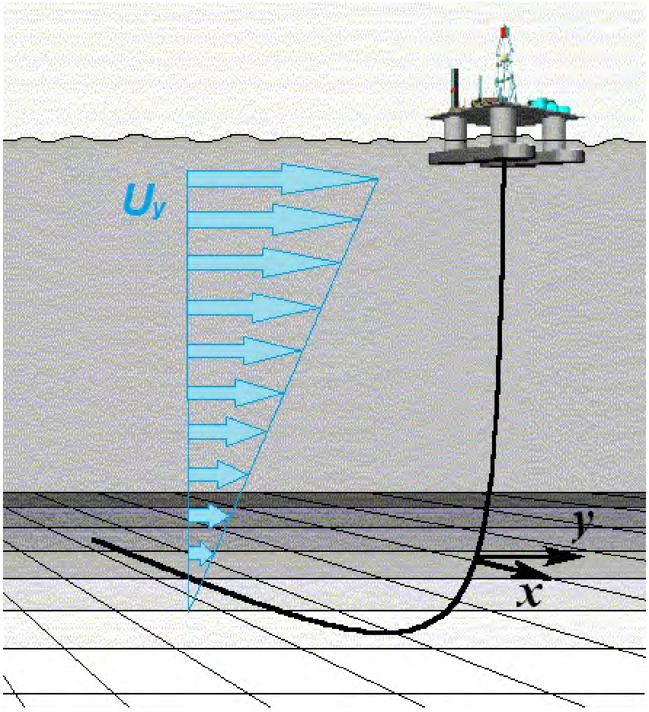

Figure 1. Schematic arrangement that illustrates the interesting problem: VIV acting on a riser.

2. Methodology

2.1 The Hydrodynamic Calibrator

The Hydrodynamic Calibrator (CH-TPN) is an offshore basin located at Numerical Offshore Tank laboratory (TPN, in portuguese). The CH-TPN is 14 meters long, 14 meters wide and 4 meters deep, allowing experiments with a very slender model. At CH-TPN center - and taking advantage of the support provided by the bridge (the blue structure illustrated in Fig. 2) - there is rotating arm equipment responsible for towing the model (flexible line) as described below.

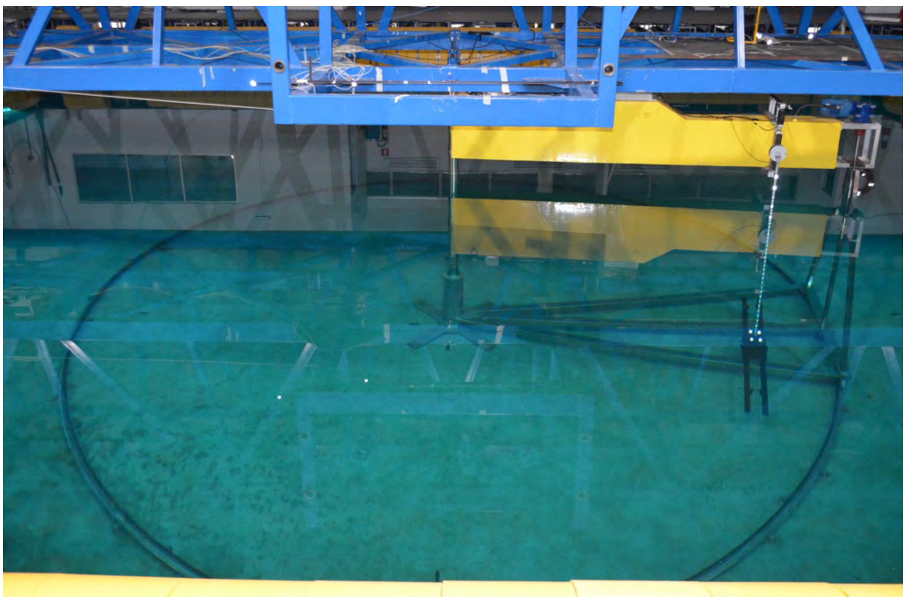

Figure 2. Rotating arm installed at Numerical Offshore Tank Hydrodynamic Calibrator.

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2.2 The Rotating Arm

The rotating arm consists in a stainless steel structure composed by a truss arm inside a fiber glass box, a vertical spindle, and two trapezoidal supports mounted in a circular trail centered in the tank. Figure 3 provides a schematic arrangement with some details of the equipment installed on the CH-TPN.

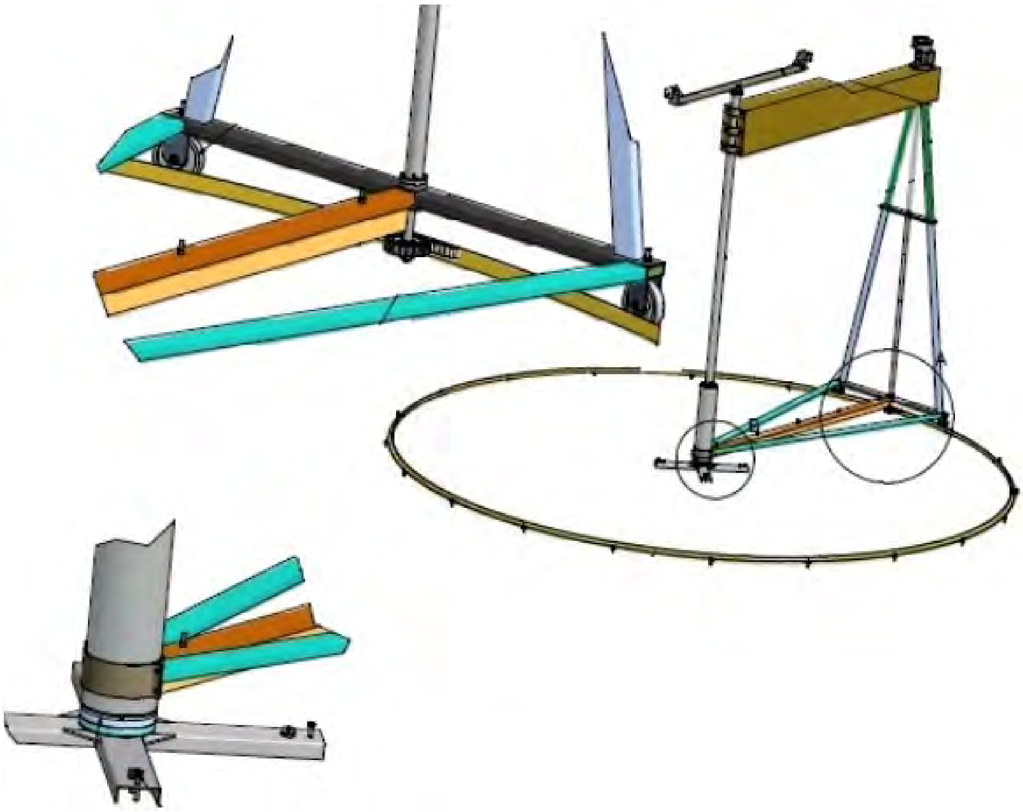

Figure 3. Schematic arrangement with details of the arm installed on the CH-TPN.

With this particular assembling, this equipment allows the obtaining of:

- *Constant current profiles*, for cases in which the line is vertically arranged in radial positions on the arm; or even,

- *Variable current profiles* (increasing or decreasing in intensity, depending on where the ends are attached), for the cases in which the line is installed in a radial plane passing through the arm's rotation center.

Beforehand, it is known that accurate experiments in an infrastructure of this type must rely on only one complete turn of the rotating arm, preventing the model passing through the generated diffuse wake. However, it is also known that models designed for testing are very slender and flexible, characterized by very low natural modes which, on the other hand, require very low arm rotation speed for excitation of the VIV phenomena. Thus, we can conclude that a single turn, or even a fraction of revolution should be sufficient for an excellent characterization of the investigated dynamic behavior.

Figure 4 shows the main dimensions of the major components of the rotating arm. It is important to highlight the 3923x4025mm span where it is possible to install rigid and flexible models, arranged vertically, horizontally or in catenary. Arrangements as lazy-waves and riser-towers, for example, can also be tested, of course, observing the hydrodynamic and structural similarity, but without the strict commitment to the geometric similarity in large water depths.

Figure 5 presents again a view of the rotating arm, in this case, however, highlighting the installation of a flexible line model vertically arranged in a fixed radial position.

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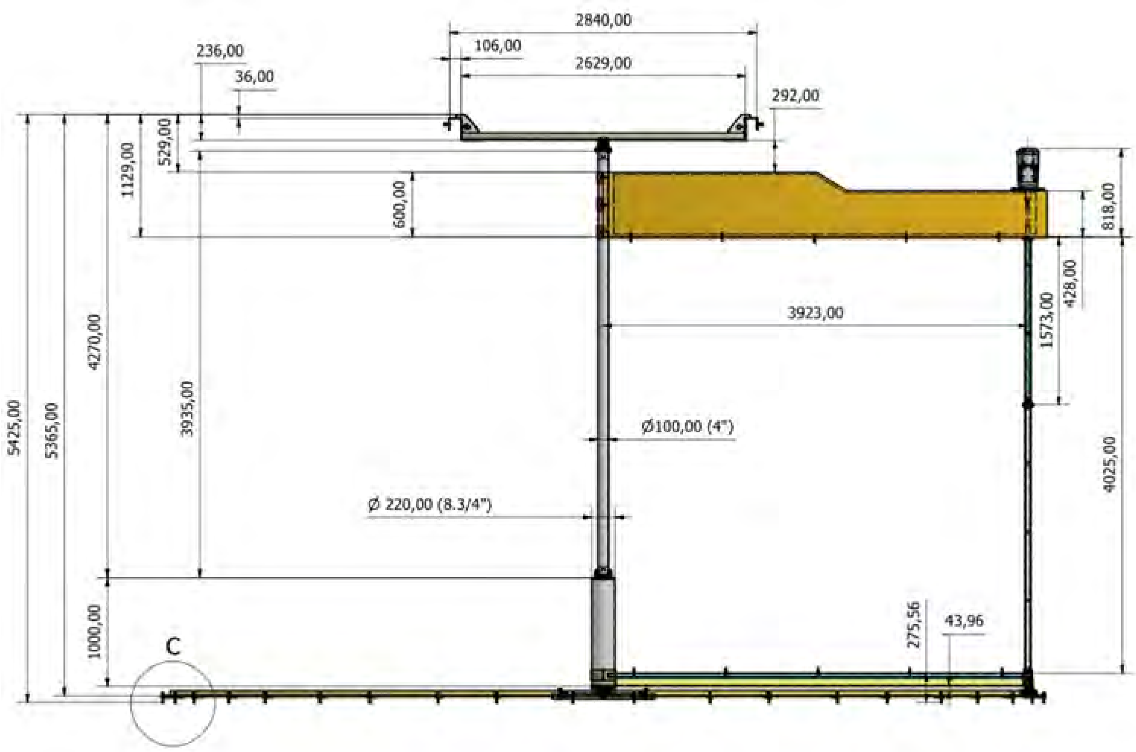


Figure 4. Rotating Arm Main Dimensions

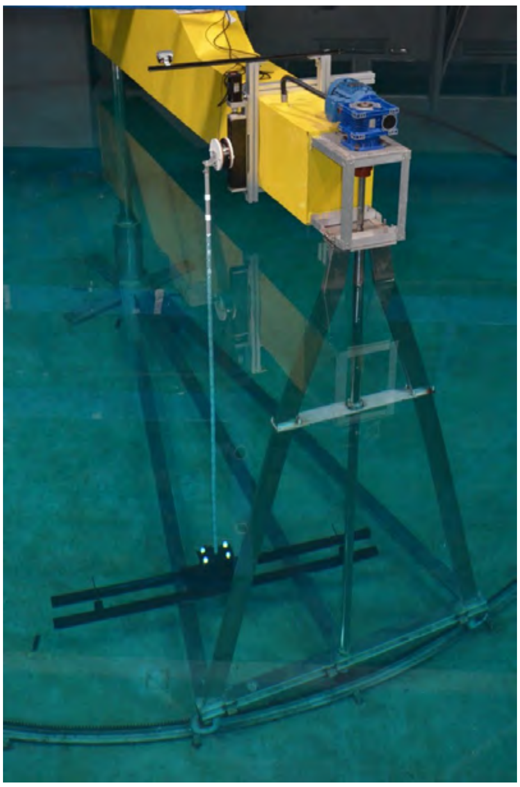


Figure 5. Approximate view of the rotating-arm equipped with a flexible line vertically arranged.

ISSN 2176-5480

2.3 Monitoring the motions of the submerged systems.

In this study the capacity of monitoring the submerged system motions along the model is crucial. It is known that any equipment installed within the model (usual practice in most experimental activities developed so far) usually affects considerably the investigated behavior. To avoid such problems a system of submerged tracking cameras is used. Figure 6 presents, in detail, the setup of two cameras.

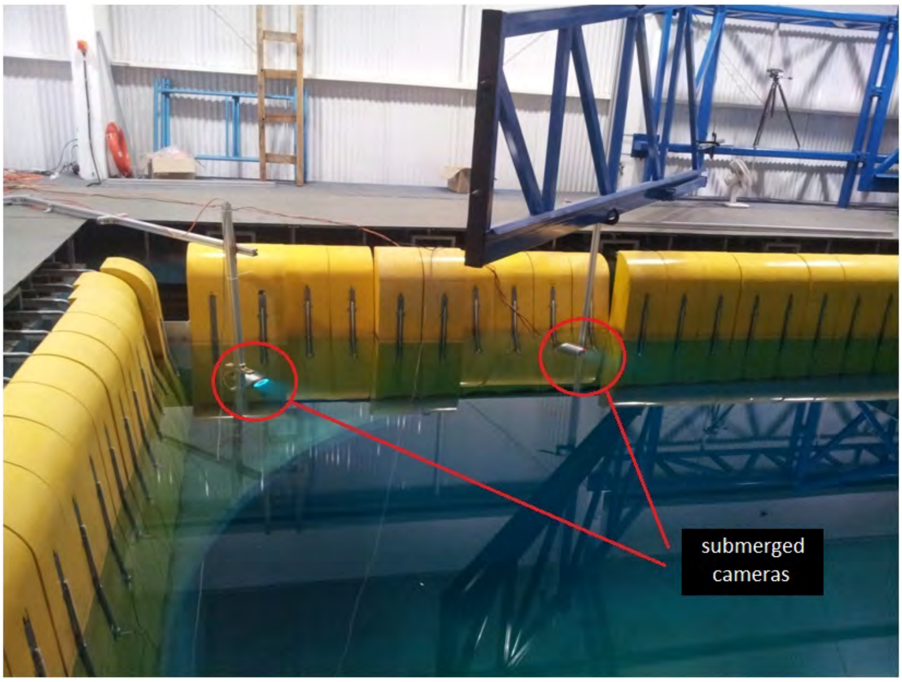


Figure 6. Two submerged cameras used to monitor the model tested in rotating arm.

For monitoring the system motions it is necessary to stick reflective targets along the flexible model. These targets are identified by the camera system, having its motions tracked (in the three coordinates) by an image processing routine provided by a dedicated software.

Figure 7 presents how the reflective targets are arranged along the line model.

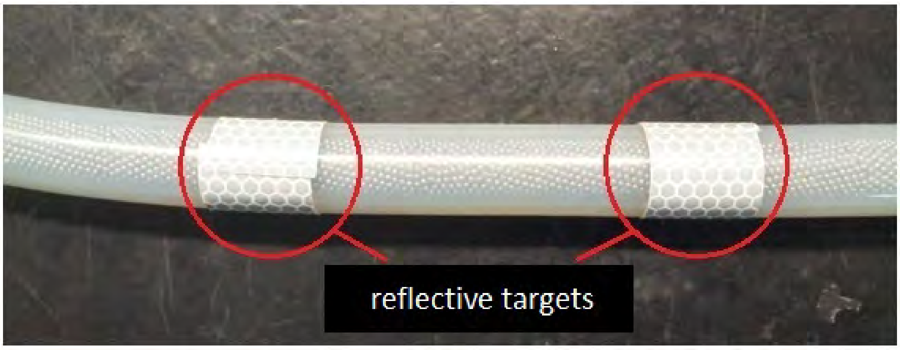


Figure 7. Reflective targets

Figure 8 presents an example of the target capture in several different cameras. Each target does not need necessarily be identified by all the cameras simultaneously, according to the usual process of identifying/monitoring, only two are enough.

Figure 9 presents the static monitoring result, referenced in a fixed coordinate system and defined in the calibration process. In this figure it is possible to observe four targets near to bottom. These targets are set still in the rotating arm to capture a rigid body motion. The motion of these targets is used to change the coordinate system from a fixed system (global) to a system that follows the rotation.

ISSN 2176-5480

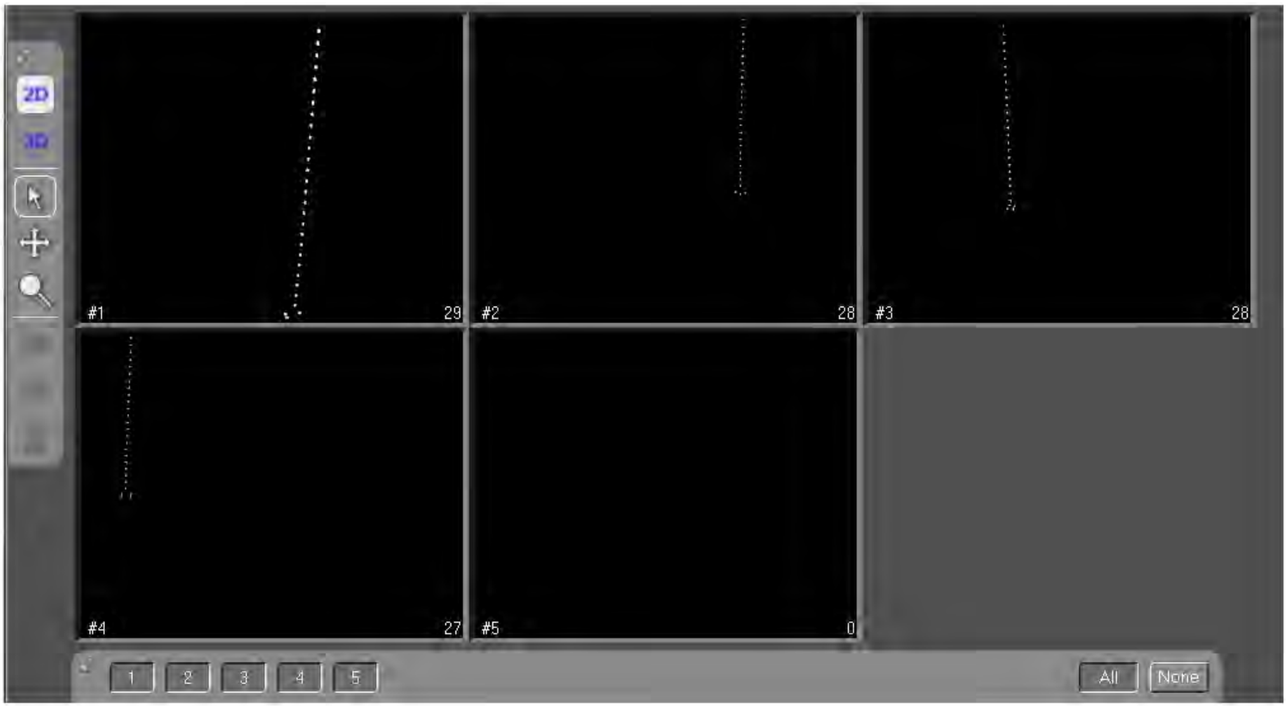


Figure 8. Capture System

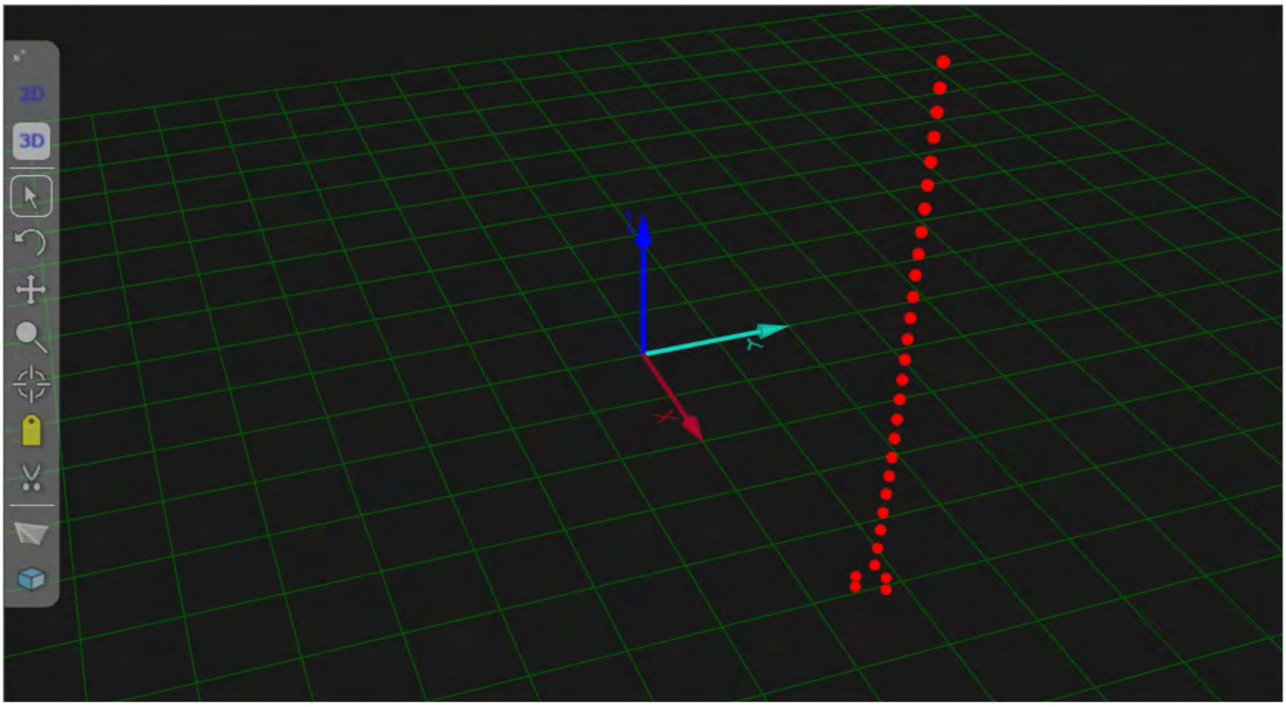


Figure 9. Virtual model tracking referenced on a system axis.

ISSN 2176-5480

2.4 Control and other monitoring systems

Besides the monitoring of the motions along the flexible model, other equipment can also be installed for a more clever operation and test monitoring, including control over certain test parameters. Among these we can highlight the arm rotation speed, the top of the model vertical position and tension monitoring.

The electronic components that enable the desired control and monitoring are installed on a workbench disposed on the arm, thus rotating with the whole test. See detail in Fig. 10.

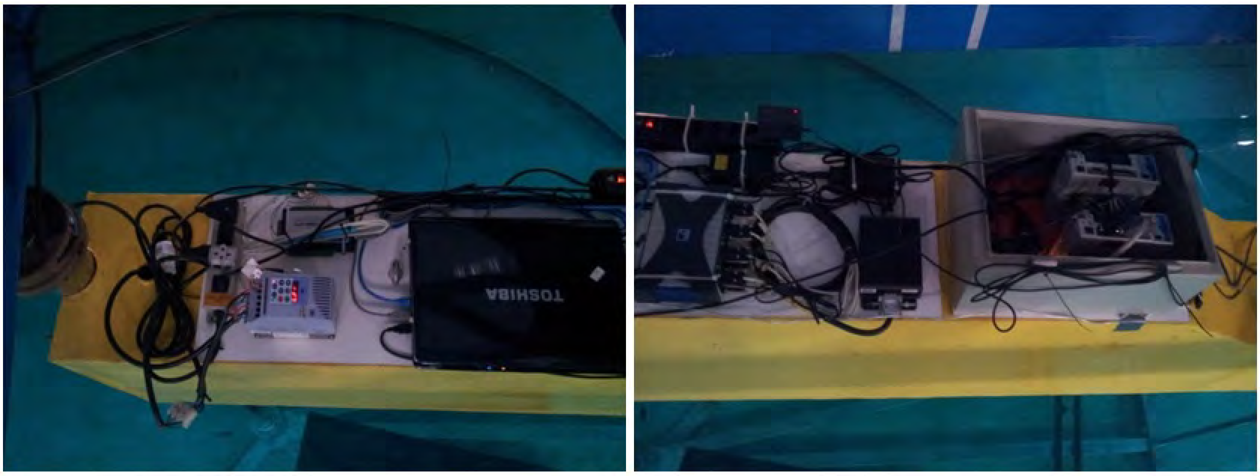


Figure 10. Onboard Electronics

Figure 11 shows a possible test arrangement, in which the top of the model vertical position control was done using a unidirectional actuator and the tension monitoring was done using a six degree of freedom load cell installed in the fixing point between the model and the actuator.

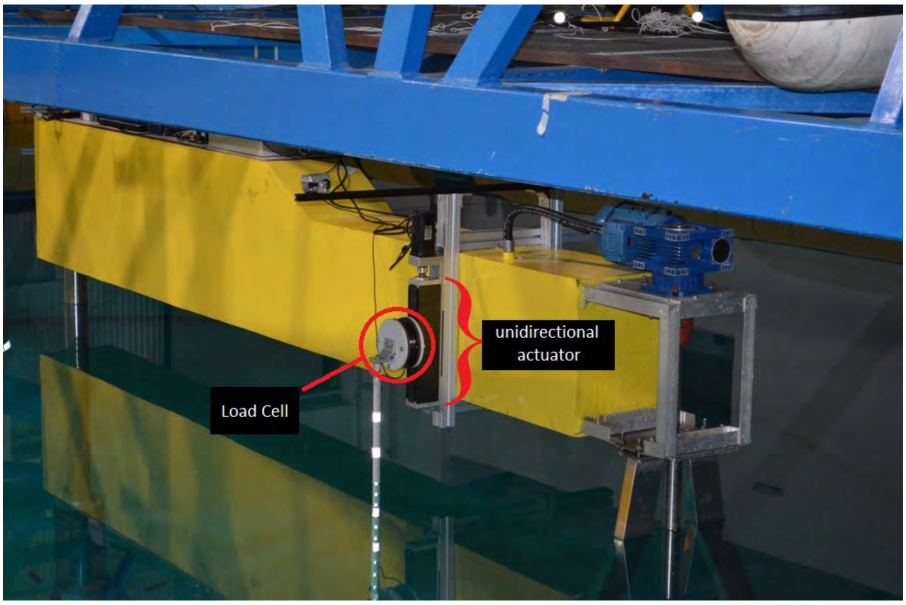


Figure 11. Possible arrangement

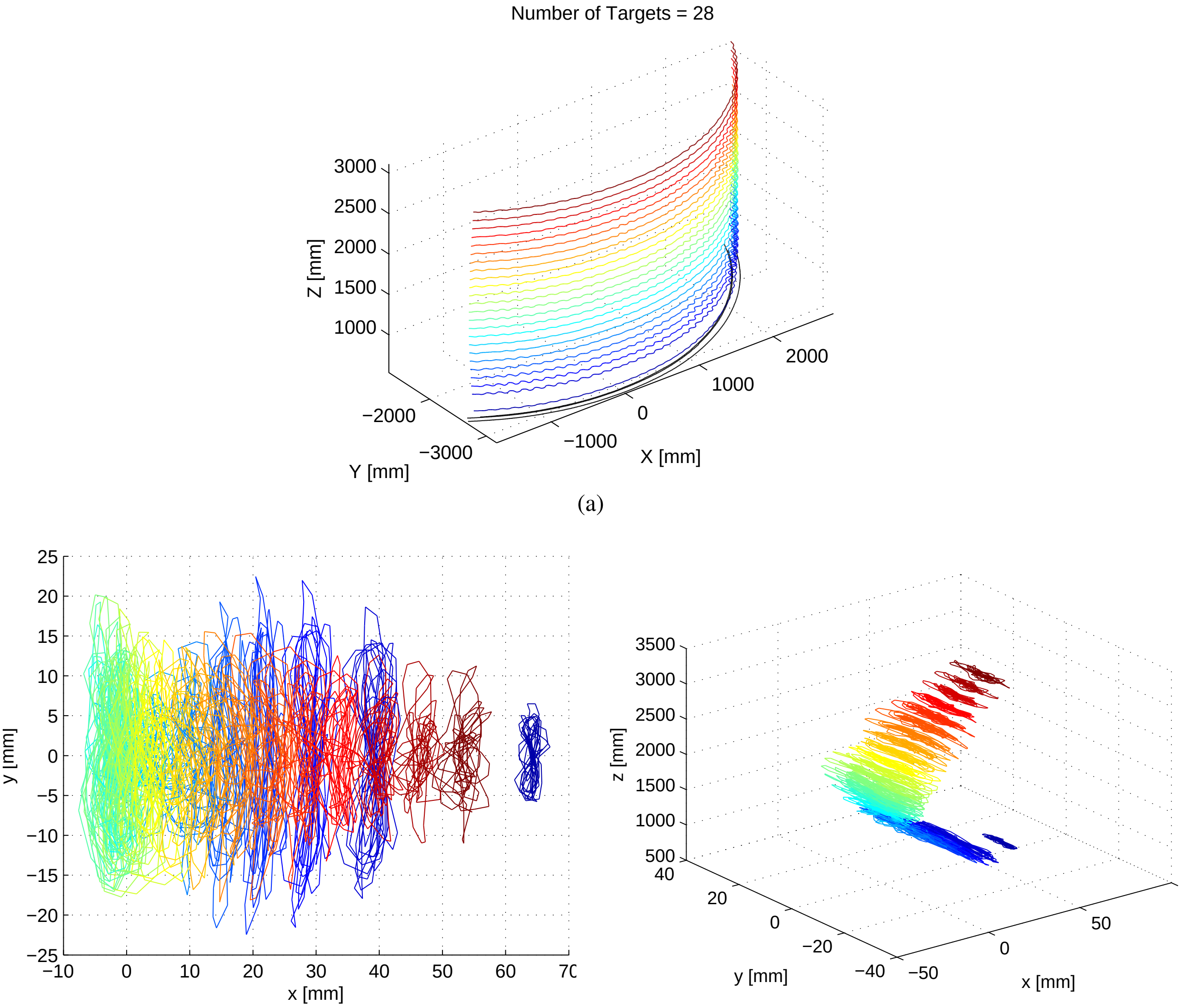
ISSN 2176-5480

3. RESULTS

Since the focus of this work is obtaining a viable system to study VIV phenomenon in an offshore basin, the main result is the own installation and the execution of experiments with this system. Since this was presented above, this section presents examples of results obtained from some realized tests.

The model used here has the same characteristics that Rateiro *et al.* (2012) used. It is a silicon tube filled with steel micro-spheres installed in a vertical arrangement (as presented before in Fig. 5). The intention is to simulate the VIV dynamics of an 8" steel riser.

Figure 12a shows the temporal evolution of twenty eight trajectories obtained in a fixed referential system. After a change of coordinates operation, the targets are show in a referential system that moves together with the rotating arm (a non-inertial reference system). Fig. 12b and 12c presents these trajectories after this change, first projected on the horizontal plane and after in a three dimensional plot.



(a)

(b) (c)

Figure 12. Trajectories obtained through the submerged motion capturing system.

In these two last figures it is possible to observe the vibration pattern of the various analyzed model points. In some of these trajectories the "eight" pattern is noticed, i.e. the in-line frequency is twice the cross frequency. This is a well known vibration pattern of VIV phenomenon (Blevins, 1977) and it is confirmed in Fig. 13, which shows the Power Density Spectrum (PSD) for the series obtained as explained above.

ISSN 2176-5480

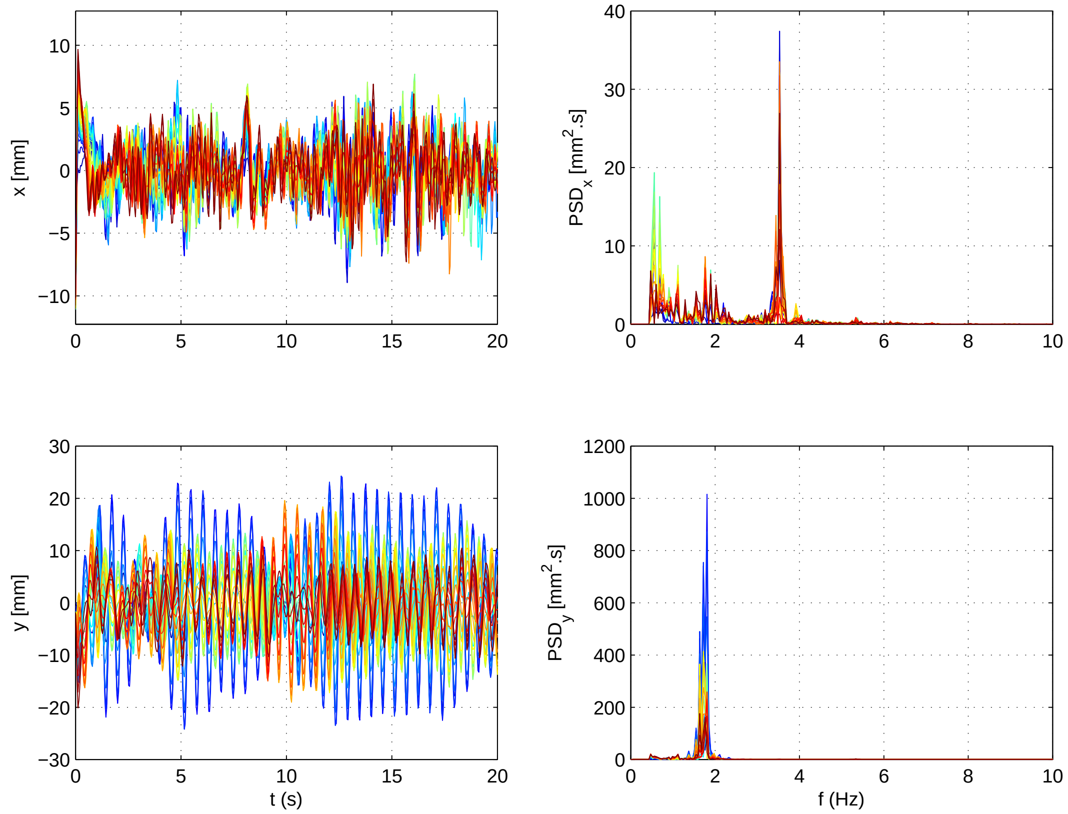


Figure 13. In-line and cross Power Density Spectrum of all obtained target trajectories.

4. CONCLUSIONS

The presented method showed that is possible to perform tests to study the VIV phenomena in an offshore basin using a rotating-arm system. The main advantage of this system is the possibility to obtain variable current profile. The viability of using optical measurements in a rotating arm in order to study the VIV phenomenon was presented. Furthermore, the use of submerged optical system is interesting to avoid interference of the measurement system on the experiment result. The measurement is captured in an inertial coordinate system and it is changed to obtain the model in-line and cross motion in a non-inertial system that moves together with the arm. The results shown as an example, presented some of the behaviors expected in the VIV study, as the presence of vibration forming an "eight" pattern, which was confirmed by the frequencies obtained in the PSD analysis.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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