24th ABCM International Congress of Mechanical Engineering
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017-0361
Measurement of the forces on two cylinders side-by-side in bistable flow

Gustavo da Cunha Dias
Andrei La Rosa
Universidade Federal do Rio Grande do Sul
gustavodias@furg.br
andreilarosa@hotmail.com

Dolir Climaco Varela
Universidade Federal do Rio Grande do Sul
dolirvarela@gmail.com

Alexandre Balbinot
Universidade Federal do Rio Grande do Sul
alexandre.balbinot@ufrgs.br

Sérgio Viçosa Möller
Universidade Federal do Rio Grande do Sul
svmoller@ufrgs.br

Abstract. *The bistability is a physical phenomenon that occurs when a pair of parallel cylinders spaced in a certain distance are under the action of the flow. There are generated vortexes downstream the cylinders that change the modes creating an additional dynamic charge. This work aims to develop a force measurement system using strain gauges. The methodology was based in the numerical and experimental analysis of the developed load cell. Infinite cylinders with p/d ratio of 1,26 were used on the test benches and submitted to the air flow. The steps of conditioning and acquisition of signal were made and the results of mechanical deformation showed convergence between numerical and experimental values. However, twelve cases were analyzed with different Reynolds numbers and for 23000 was encountered a force of 2,61cN with torque of 84,95Nmm.*

Keywords: *cell load, bistability, experimental, force.*

1. INTRODUCTION

Flow characterization is an important area of Fluid Mechanics to allow the understanding of its interaction with various structures. In this particular case in which cylinders are under flow, the growth of the axial velocity generates instabilities due to transverse velocity fluctuations. According to White, (2011) when a body, independent of form, is submitted to a flow, it will suffer the action of forces and moments. The force that acts in the body in the same direction of the flow is denominated drag and the moment under its axis is called rolling moment. The Reynolds number is a dimensionless that determines the type of the flow. For values above a critical value of the Reynolds number the flow can be considered turbulent. According to Möller and Silvestrini (2004) the turbulent flow is characterized by presenting pressure fluctuation and overlapped velocity main flow, arising thus, vortexes of several scales. A phenomenon derived of turbulent flow occurs when the pair of cylinders is positioned side by side, displaced in a certain distance and submitted to a transversal flow (Alam et. al., 2003), that results in the denominated bistability. An important parameter for bistability to occur is the relation p/d, where p is the distance between centers and d is the diameter of the cylinders. Several authors like Olinto et. al. (2006) and De Paula et. al. (2013) used the ratio of 1.26 to confirm the occurence of bistability. However, in this situation there is a formation of two wakes downstream the cylinders. These wakes have different widths with respective frequency of vortex detachment, which alternate the position resulting in bistability, such as shown in figure 1:

In this paper, a force measurement system for application in the fluid-structure interaction of two cylinders inbistable flow using strain gauges is presented.

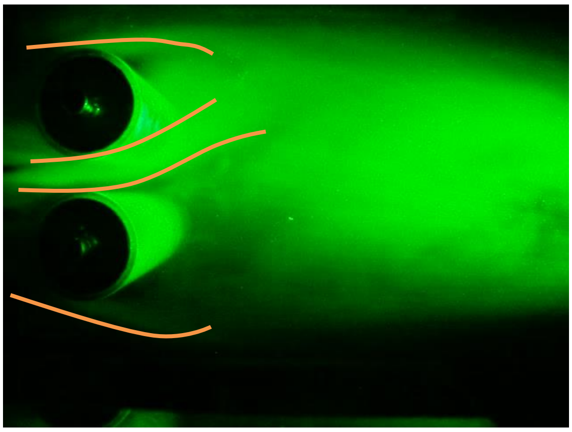


Figure 1. Visualization of wakes downstream the cylinders

.

2. EXPERIMENTAL PROCEDURE

The methodology has covered the development of the cylinders positioning device, choice of load cell, design of the signal conditioner and the data acquisition. The cylinders positioning device was built in nylon with axis where two bearings were fixed according showed the Figure 2.

Figure 2. Apparatus to positioning of the cylinders

This way the cylinders could rotate when the air flow went through. The load cell was based in the numeric simulation where the deformation of two models was analyzed. Figure 3 shows the relative deformation of the chosen load cell.

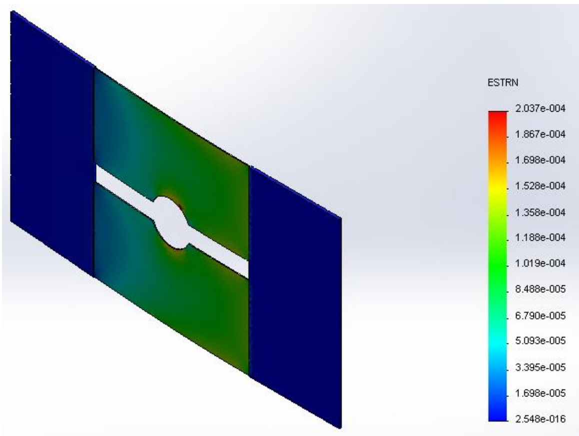


Figure 3. Relative deformation of the load cell

After that, a razor blade was used as a spring element in which four strain gages were crossed by to assemble the full bridge configuration. The calibration was realized with the standard mass of 1g of resolution in 0-10g of range. The relative deformation was measured with a Bridge Analogic Input model NI 9237 by Texas Instruments. Then, the eletric resistance variation was measured in the output of the bridge with a multimeter model DMM 4050 by Tectronics, keeping the same input of resolution and range. Finally, the eletric voltage was measured in the output of the bridge.

The values obtained in the procedures previously cited were used to determine the conditioning of the signal. First, the necessary gain was specified and after that, two steps of the amplification and a stage of filter were determined.

An instrumentation amplifier (INA) was used to amplify the output voltage range of the bridge. in addition, an 8-order low pass filter (anti-aliasing) with a cutoff frequency of 280 Hz was designed. In order to ensure signal integrity was used the frequency 1 kHz sampling with Acquisition Data NI model 9237 by Texas Instruments, thus respecting the Nyquist theorem, since the most important frequency of bistability of the phenomenon are lower than 100Hz. Figure 4 shows a block diagram representing the developed conditioning system.

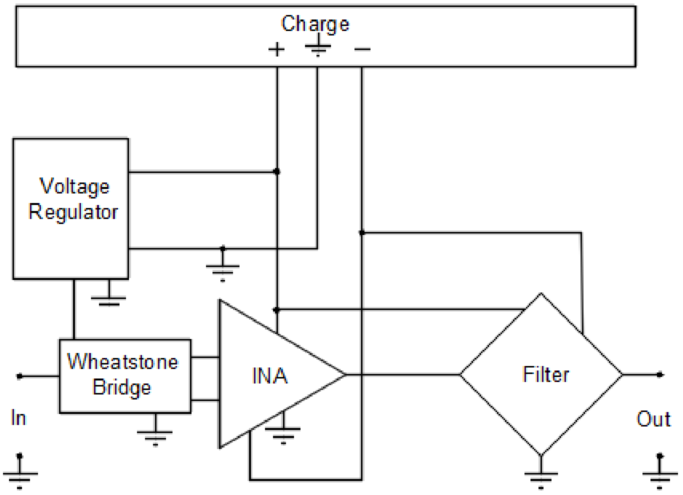


Figure 4. Blocks diagram of the conditioning system

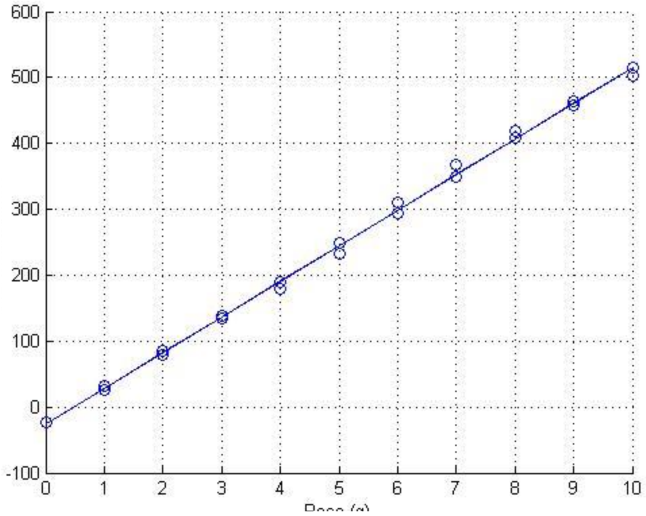
Finally the instrumentation system was assembled at a wind tunnel allowing the force measurement of the cylinders submitted to the air flow as shown in Figure 5.

Figure 5. Instrumentation system assembled at a wind tunnel

3. RESULTS

With the results of this work, the measurement system for all steps was determined. Figure 6 shows the calibration curve of the load cell.

Deformation [µd]



Mass [g]

Figure 6. Calibration curve of the load cell

The transfer function is shown for equation 1 with a linearity error of 3,01%.

$$def = -25{,}13 + 54{,}01 \cdot m \quad (2)$$

Where:
def: relative mechanical deformation [µd]
m: mass [g]

The sensibility of the load cell is $54{,}01\, {}^{\mu d}/_{g}$ with a measurement uncertainty of $\pm 0{,}04 \mu d$. The calibration measuring system with all steps that was developed in this work is showed in the Figure 7, where it is possible identified the range of the variables involved in the process.

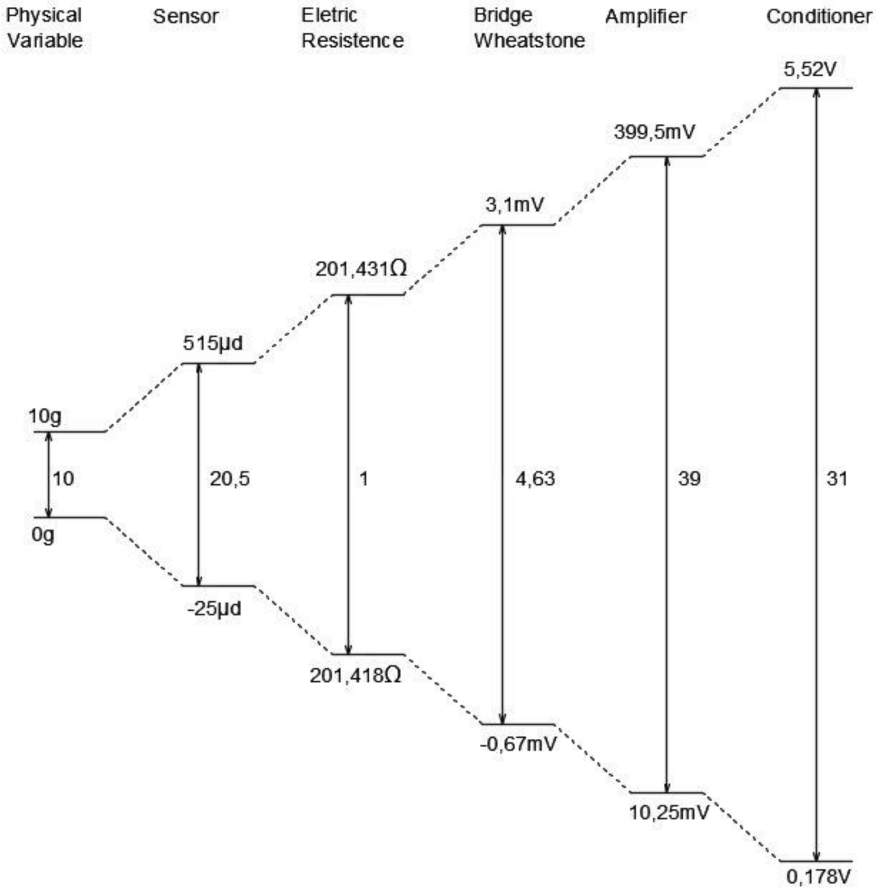


Figure 7. Calibration measuring system

For each stage was determined the experimental curve, transfer function and sensibility. The final result of calibration process is showed in the Figure 8, where the input and output variable were related.

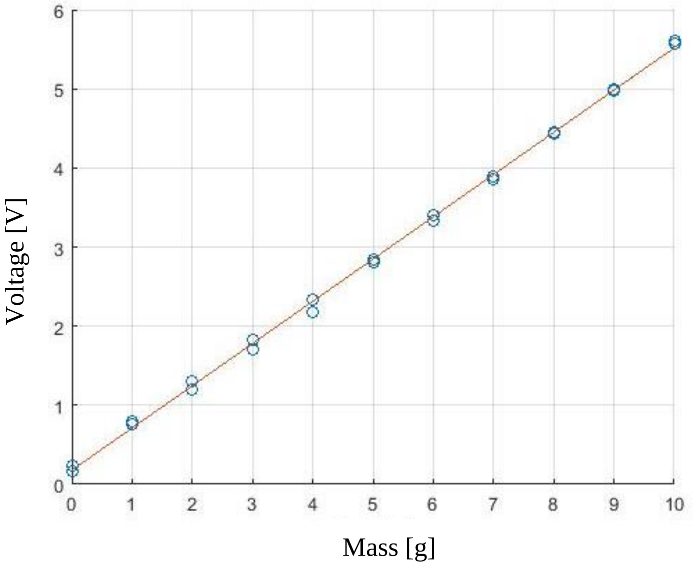


Figure 8. Calibration curve in the output of the conditioning system

The linearity error is 2,61% and the transfer function is determined by equation 2. The sensibility is $0{,}534 V/_g$ with a measurement uncertainty of ±115,62µV.

$$V = 0{,}178 + 0{,}534 \cdot m \tag{2}$$

Where:
V: Electric voltage in the conditioning system output [V]

Consequently, the next step was to measure the mechanical deformations with the wind tunnel turned on. In order to do that, the inverter frequency that controls the fan of the wind tunnel was adjusted. Figure 9 shows these results.

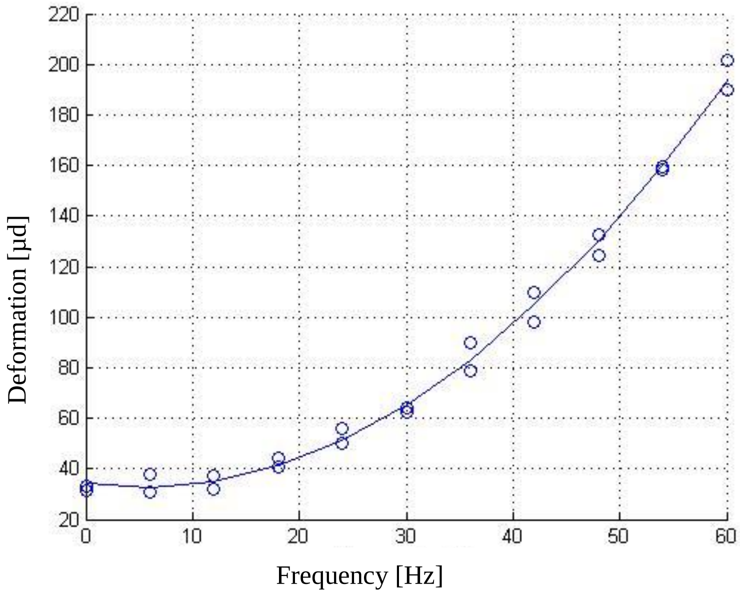


Figure 9. Mechanical deformation of load cell connected to the cylinders

The transfer function is shown for equation 3 with compliance error of 4, 16%; uncertainty type A of ±0,13µd.

$$Def = 34{,}37 - 0{,}5898 \cdot f + 0{,}054 \cdot f^2 \tag{3}$$

Where:
f: frequency adjusted in the inverter

After this test, an acquisition data device was connected to the conditioning system output and the curve was obtained as shown in figure 10:

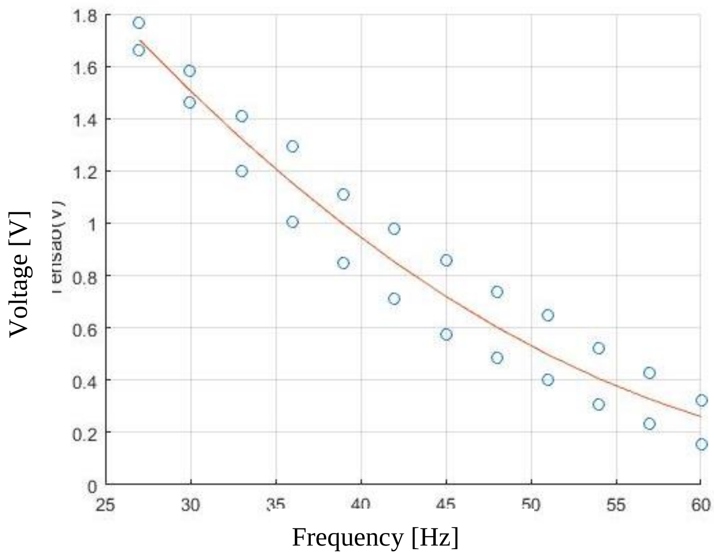


Figure 10. Electric voltage in the conditioning system output

The transfer function is shown in equation 4 with compliance error of 8,99% and uncertainty type A of ±1,8mV.

$$V = 4{,}052 - 0{,}1066f + 7{,}23 \cdot 10^{-4} f^2 \tag{4}$$

However, there is a need to analyze the force for each air flow velocity. For this purpose, equation 4 was replaced for equation 2 resulting in equation 5.

$$F = (75{,}1 + 35{,}58f - 1{,}354f^2) \cdot 10^{-3} \cdot g \tag{5}$$

Where:
F: force of cylinders [N]
g: gravitational acceleration [m/s²]

After to analyze all process of signal transformations were determined the measurement system of the device. In conclusion, the measurements of the atmospheric pressure, temperature, and the differential pressure in the Pitot tube were made. Besides, the forces according to the flow characteristics were determined. Table 1 shows these results.

Table1 – Velocity, electric voltage, Reynolds number and force measurements

f	V [V]	Pd [pa]	Ve[m/s]	Re	F [cN]
27	1.72	26.516	6.69	10679.56	-0.048
30	1.66	32.625	7.42	11846.16	-0.075
33	1.58	39.406	8.16	13019.22	-0.221
36	1.5	46.766	8.89	14182.92	-0.391
39	1.41	54.594	9.60	15324.06	-0.585
42	1.33	63.031	10.32	16465.7	-0.803
45	1.2	72.078	11.04	17607.76	-1.045
48	1.1	81.516	11.76	18725.04	-1.311
51	0.95	91.203	12.41	19806.47	-1.601
54	0.75	103.453	13.22	21094.74	-1.915
57	0.57	113.703	13.86	22115.08	-2.252
60	0.4	123.000	14.42	23001.43	-2.614

*Ambient temperature 26°c e atmospheric pressure 751mmHg

4. CONCLUSION

In spite of the initial obscurity of the dimensional values involved in the phenomenon, the methodology used was satisfactory, considering the convergence of the numerical values of the relative mechanical deformation with the experimental results obtained. The developed load cell allowed force measurements from 27Hz of drive frequency which is equivalent to CNTP at 6.7m/s. Thus, it can be concluded that the force quantities involved in the bistability of the tubes proposed in this study is inferior to the initial assumptions. The conformance errors of the transfer functions along the levels of the experimental measurement chain were less than 10%, which validates the resulting equations. However, the development met the proposal of measurement of the forces originated by the vortex detachments and will allow the development of other studies for comparison and optimization of the system as well as the simultaneous measurement of the speeds with hot wire anemometry.

5. REFERENCES

Alam, M.M.; Moriya, M.; Sakamoto, H. **Aerodynamic characteristics of two side-by-side circular cylinders and application of wavelet analysis on the switching phenomenon**, Journal of Fluids and Structures, v.18, n. 3-4, p. 325-346, 2003.

Balbinot, A.; Brusamarello, V.J. **Instrumentação e Fundamentos de Medidas**, Volume 1, 2ª Edição, 2010, 385p.

De Paula, A.V. ; Möller, S.V**. Finite mixture model applied in the analysis of a turbulent bistable flow on two parallel circular cylinders**. Nuclear Engineering and Design, p. 203-213, 2013.

Holman, J. P., **Experimental Methods for Engineers**, 8th Edition, Ed. McGraw Hill, 2001, 739p.

Moffat, R.J. **Describing the uncertainties in experimental results**, Experimental Thermal and Fluid Science, v.1, p. 3-17, 1988.

Möller, S.V.; Silvestrini, J.H. **Turbulência: Fundamentos in**: Möller, S.V.; Silvestrini, J.H. Editores, v.4, p. 1-32, Rio de Janeiro, ABCM, 2004.

Olinto, C. R.; Indrusiak, M. L. S; Möller, S. V. **Experimental study of the bistable flow in tube arrays**. Journal of the Brazilian Society of Mechanical Sciences and Engineering (Impresso), São Paulo, v. 28, p. 233-241, 2006.

Olinto, C.; Indrusiak, M.L.S.; Endres, L. A.; Möller, S.V. **Experimental study of the characteristics of the flow in the first rows of tube banks**, Nuclear Engineering and Design, v.239, p. 2022-2034, 2009.

Xu, S.J.; Zhou, Y.; So, R.M.C. **Reynolds number effects on the flow structure behind two side-by-side cylinders**. Physics of Fluids, v.15, n. 5, p. 1214-1219, 2003.

6. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.