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SHEDDING PROCESS OF FINITE CYLINDERS WITH HIGH BLOCKAGE RATIO

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Abstract. *An important parameter which can affect the flow, influencing others parameters like Reynolds Numbers, it is called blockage ratio. Increasing blockage ratio causes an increase in velocity around the cylinder outside the boundary layer, influencing the pressure and velocity distribution. In case of finite cylinder, to obtain a high blockage ratio it is necessary to test cylinders with larger diameters. The use of larger diameters leads to an approximation with the near wall region directly affecting the flow. This paper presents an experimental study about the shedding process of a finite cylinder with high blockage ratio (between 8.8 and 25.2%) and its effects, where finite cylinders of different diameters are tested. The vortex shedding frequency is obtained through auto spectral density function with the use of hot-wires anemometry. To observe the blockage ratio effects, measurements were performed at different flow velocities to maintain the Reynolds number of 20000 constant. Analysis of the results of time series obtained from the experiment was performed by means of Fourier and Wavelet techniques. Results confirm the high blockage ratio has influence in the shedding process of finite cylinders.*

Keywords: *turbulent flow; hot-wire anemometry; blockage ratio; finite cylinder.*

1. INTRODUCTION

The study with finite circular cylinder has recently attracted greater attention due several structures in the world use cylinders in its composition and many tall buildings can be simplified as a finite cylinder with a free end (Park and Lee, 2000). The finite cylinder has different characteristics from the infinite cylinder and the free end of a finite cylinder is a significant factor. The flow around the finite cylinder is more complicated compared to the case of the infinite cylinder and the main cause for the flow three dimensionality is the presence of longitudinal vortices and small aspect ratio of cylinder height *H* to diameter *D* (Park and Lee, 2003).

One of the parameters used in flow analysis in circular cylinders is the dimensionless frequency associated with vortex shedding, the Strouhal number (*St*) is defined by:

$$St = \frac{f_s . D}{U} \tag{1}$$

where *fs* is the vortex shedding frequency, *D* is the diameter and *U* the freestream velocity. The Strouhal number of a circular cylinder is a function of Reynolds number (Blevins, 1990). The Strouhal number is considered constant for each body exposed to the flow in a certain range and the vortex shedding frequency is obtained from the turbulence spectrum using the Fourier transform. However, the blocking ratio which is the ratio between the body area and the test section area can influence on the Strouhal number.

For finite cylinders of small aspect ratio, the flow around the free end may suppress the Kármán vortex shedding process, and arch vortices may form in the near-wake and for cylinders of larger aspect ratios, the dimensionless vortex shedding frequency, or Strouhal number, may either vary continuously or in a standard along the height of the cylinder (Sumner, 2004). West and Apelt (1982) found that for blockage ratios less than 6%, the Strouhal number is independent of the blockage ratio and the aspect ratio of the cylinder.

In this paper, wind tunnel experiments were conducted to measure the vortex shedding frequency along the height of the finite cylinders. Eight circular cylinders of aspect ratios *AR* =3 and 4 for 32 mm diameter, *AR* =2 and 3 for 40 mm, *AR* =1 and 2 for 50 and 60 mm were tested at a Reynolds number of 20000 constant. Since the minimum blockage ratio for finite cylinder should be 6%, different aspect ratios were necessary to get high blockage ratio.

2. METHODOLOGY

Velocity measurements were made with DANTEC StreamLine hot wire anemometer in an aerodynamic channel to investigate the flow along the height of the finite circular cylinder and the shedding process. The test apparatus, shown on Fig. 1, with 147 mm height, width of 194 mm an total area of 28518 mm². Air, at room temperature, is the working fluid, driven by a centrifugal fan of 0,75 kW, passed by a diffuser and a set of honeycombs and screens, which reduce the turbulence intensity in the channel to about 1%. A frequency inverter controls the fan speed, where the flow velocity in the aerodynamic channel can be varied from 0 to 15 m/s. To measure the velocity reference a Pitot tube fixed before to the test section is used.

The cylinders have a diameter of 32 mm, 40 mm, 50 mm, 60 mm and are rigidly mounted in vertical position inside the channel. The cylinder blockage ratio (cylinder area versus aerodynamic channel area) is between 8.8 and 25.2% depending the diameter and the incidence angle of the flow on the cylinder is 90°. The experiment was performed with a Reynolds number Re = 2 x 10^4.

For the measurement of velocity and velocity fluctuations, a single hot wire probe was placed at the wake region in a location 1D downstream of the cylinder.

Data acquisition was performed with a 16-bit A/D-board (NATIONAL INSTRUMENTS 9215-A) with USB interface through software DANTEC StreamWare 3.4 , with a sampling frequency of 1000 Hz and a low pass filter at 300 Hz.

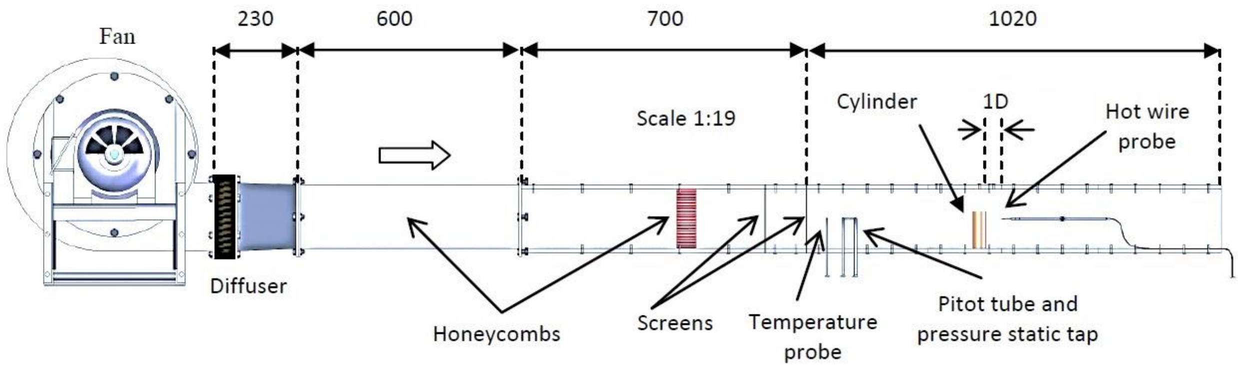

Figure 1. Schematic view of the aerodynamic channel (measures in mm).

3. MATHEMATICAL TOOLS

The aim of this study is to analyze the vortex shedding process and the effects of high blockage ratio about the Strouhal number. The cylinders and its proportions are presented in Table 1.

Table 1. Cylinder characteristics.

Diameter (mm)	Heigh (mm)	Blockage Ratio
32	96	10.8%
	128	14.4%
40	80	11.2%
	120	16.8%
50	50	8.8%
	100	17.5%
60	60	12.6%
	120	25.2%

Analysis of the results of time series obtained from the experiment was performed by means of Fourier and Wavelet techniques. Computations of the Fourier transform and wavelet transform were performed using the Matlab R2012a software. Continuous wavelet transforms are used in this study. The mathematical analysis was made with using the toolboxes for the signals, statistical, spectral and wavelet analysis.

3.1 Fourier and Wavelets Transforms

In this paper, the analysis was made by Fourier transform and the Fourier spectrum, with the aim of obtaining a frequency domain analysis. The spectral (or frequency domain) analysis can be done through the power spectral density function (PSD). While the Fourier transform uses trigonometric functions as basis, the bases of wavelet transforms are functions named wavelets, with finite energy and zero average that generates a set of wavelet basis.

In the wavelet spectrum, the energy is related to each time and scale (or frequency), Daubechies (1992). This characteristic allows the representation of the distribution of the energy of the signal over time and frequency domains, called spectrogram.

The velocity signals were analyzed using wavelet transforms to obtain the energy distribution of the turbulent flow over time-frequency domain. The continuous wavelet spectrum (CWS) was obtained through continuous wavelet transform.

4. RESULTS AND DISCUSSION

Table 2 shows the values obtained for the velocity, vortex shedding frequency and Strouhal number associated with the tubes studied and their respective blockage ratio.

Table 2. Velocity data, vortex shedding frequency and Strouhal number.

Diameter (mm)	Velocity Data (m/s)	Vortex Shedding Frequency (Hz)	Strouhal Number
32	9.42	50.78	0.172
	9.42	54.69	0.186
40	7.50	35.16	0.188
	7.50	35.16	0.188
50	6.03	23.44	0.194
	6.03	23.44	0.194
60	4.97	19.53	0.236
	4.97	19.53	0.236

These data show the trend of increasing the Strouhal number with the blockage ratio. This increase is associated with blockage in cylinder of smaller diameter and aspect ratio. The blockage ratio has influenced mainly regarding the width of the blockage, because shedding process is less the closer the wall. According Silveira (2011) the Strouhal number for infinite cylinders 32, 40, 50 and 60 mm is respectively 0.22 0.23 0.24 and 0.25, confirming the increase of the Strouhal number with increasing blockage ratio. However, for finite cylinders with a diameter above 40 mm and even Reynolds number, the trend is to stabilize the Strouhal number at intermediate aspect ratios. This happens because in the free end, the flow can interact with the regular Kármán vortex shedding, and this interaction may suppress the shedding process in cylinders with small aspect ratio or even change the vortex shedding frequency, also visualized by park and lee.

In the figures, Fourier and Wavelet analysis are presented for all configurations studied. Through the Power Spectral Density (PSD), it is possible to determine the vortex shedding frequency and through the Continuous Wavelet Spectrum (CWS), it is possible to observe the concentration of energy around the fundamental frequency, without a constant value along time.

The measurements were performed at the mid height of the cylinders, where may occur influences the free end depending on the aspect ratio, more visible in Fig. 2 compared to Fig. 6, where it is possible see that small aspect ratios can change the vortex shedding frequency or even reduce the shedding process, as Fig. 3, 4 and 5 compared to Fig. 7, 8 and 9, until suppress the shedding process.

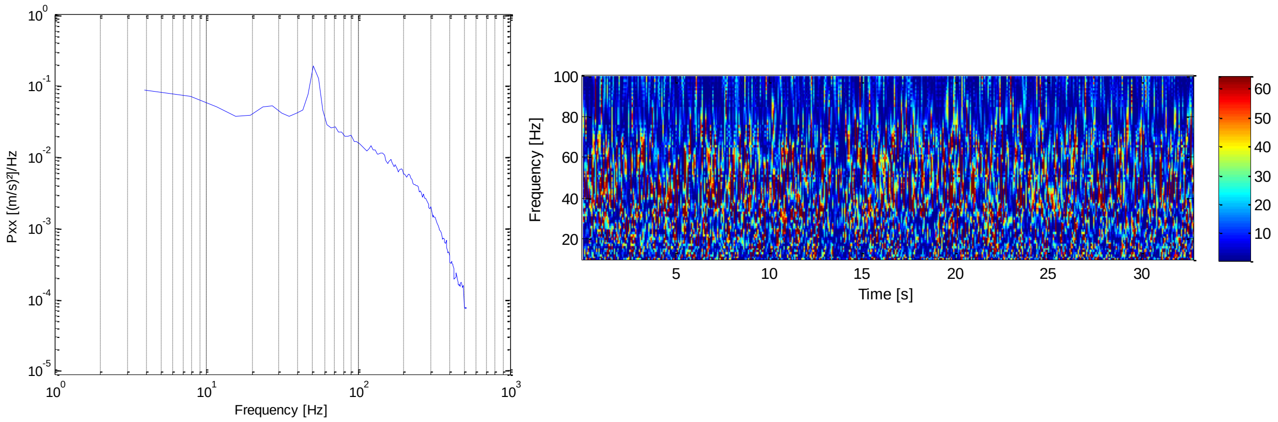

Figure 2. PSD and CWS of the hot wire signal in cylinder 32 mm *AR* =3 with shedding frequency at 50.78 Hz.

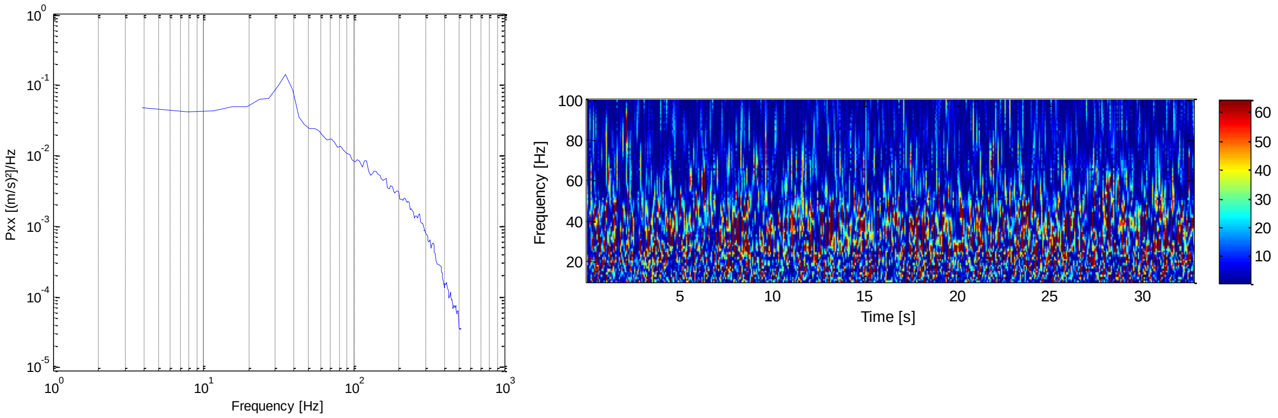

Figure 3. PSD and CWS of the hot wire signal in cylinder 40 mm *AR* =2 with shedding frequency at 35.16 Hz.

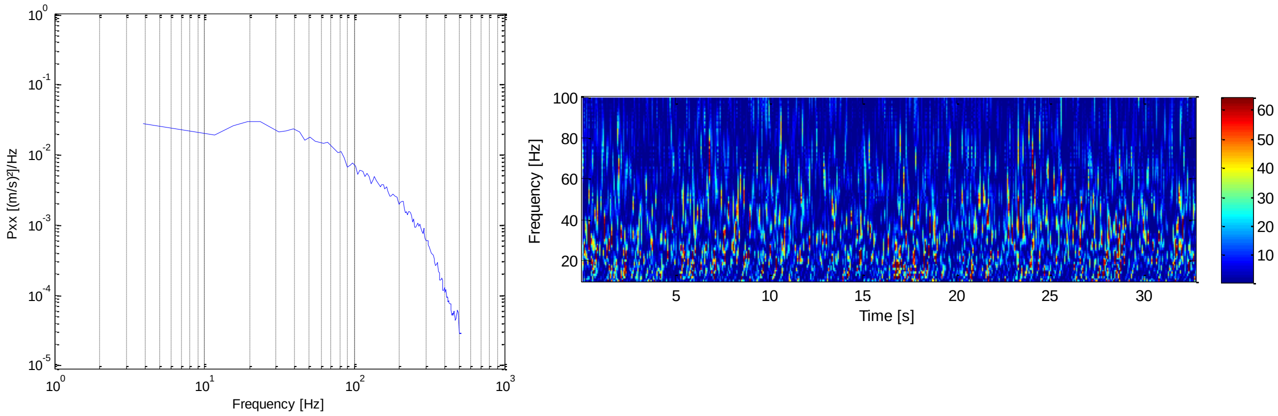

Figure 4. PSD and CWS of the hot wire signal in cylinder 50 mm *AR* =1 with shedding frequency at 23.44 Hz.

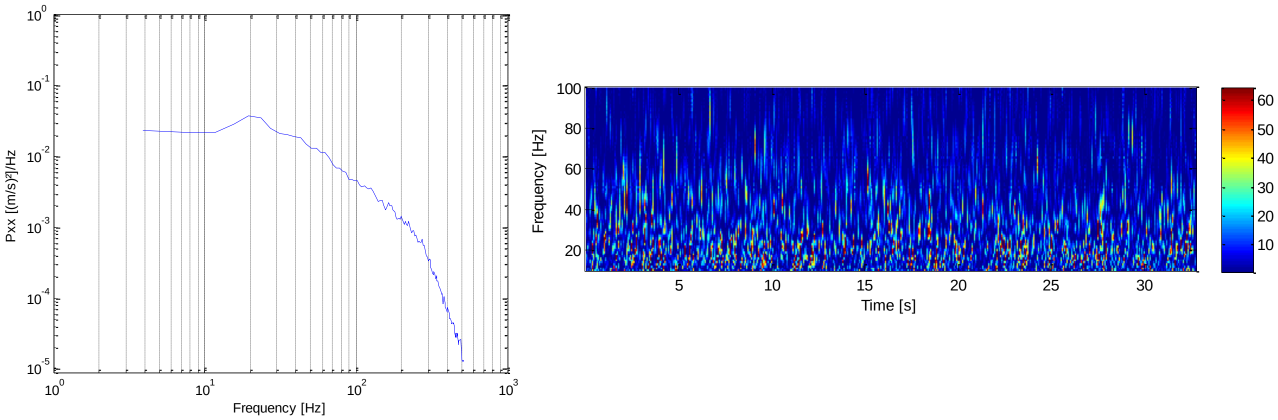

Figure 5. PSD and CWS of the hot wire signal in cylinder 60 mm *AR* =1 with shedding frequency at 19.53 Hz.

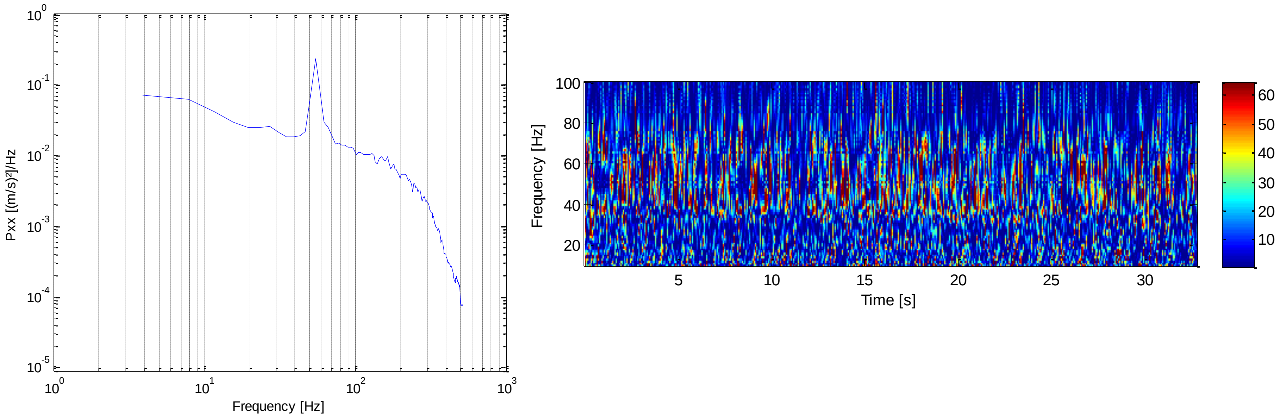

Figure 6. PSD and CWS of the hot wire signal in cylinder 32 mm *AR* =4 with shedding frequency at 54.69 Hz.

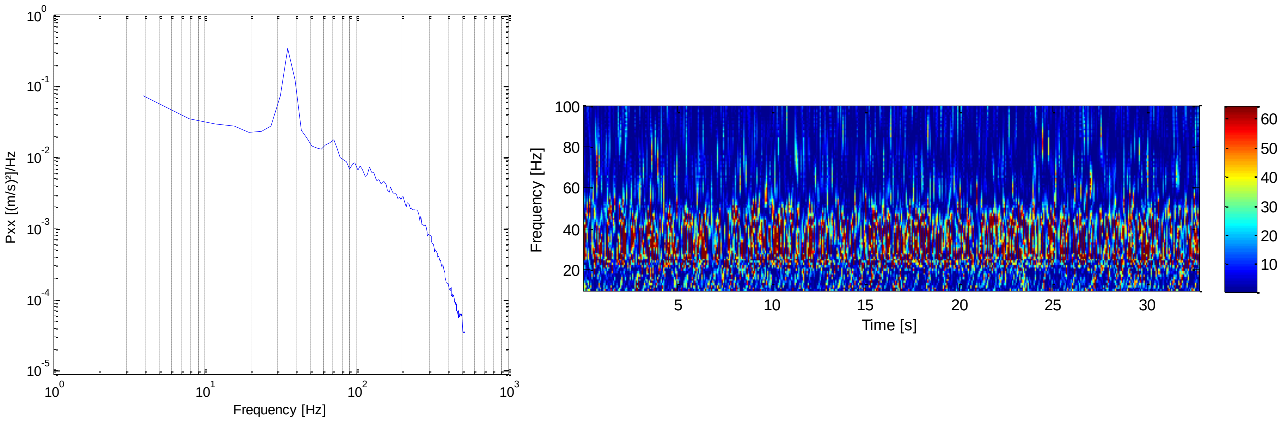

Figure 7. PSD and CWS of the hot wire signal in cylinder 40 mm *AR* =3 with shedding frequency at 35.16 Hz.

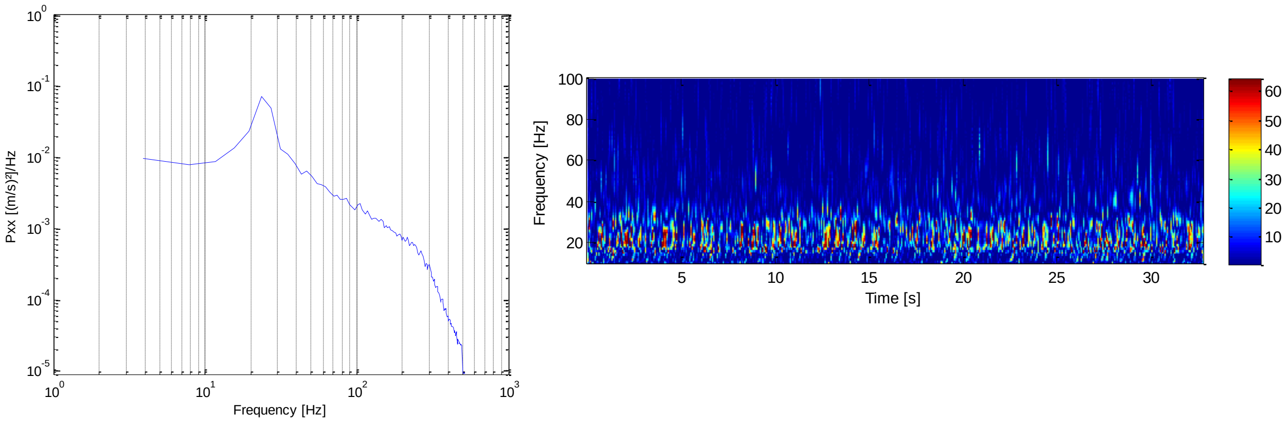

Figure 8. PSD and CWS of the hot wire signal in cylinder 50 mm *AR* =2 with shedding frequency at 23.44 Hz.

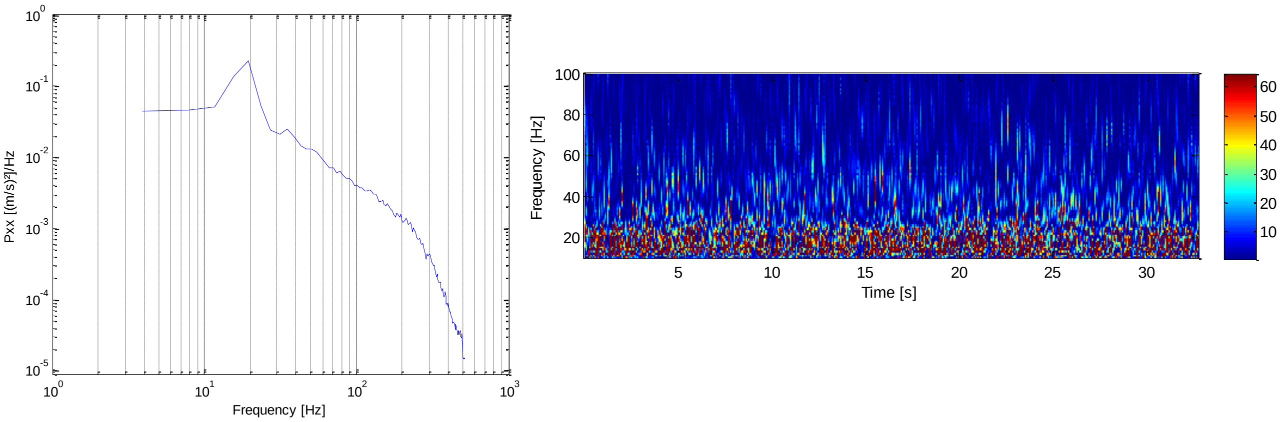

Figure 9. PSD and CWS of the hot wire signal in cylinder 60 mm *AR* =2 with shedding frequency at 19.53 Hz.

Figures 2, 3, 4 and 5 show that when the blockage ratio is lower, the power spectral density is also lower. In Figures 6, 7, 8 and 9 the opposite occurs because the blockiage ratio is higher and the power spectral density is higher. Another notable difference is related how the blockage is done. If the cylinder has larger diameter and low blockage ratio, Fig. 5, there is less energy in the shedding process because the cylinder height is lower. When the cylinder has a smaller diameter and high blockage ratio, Fig. 6, there is high energy and it is distributed naturally in the cylinder height.

When a cylinder has been analyzed at the base, center and free end the behavior in the shedding process is according with literature because near the free end, the flow may suppress the shedding process in cylinders with small aspect ratio, Fig.10. According Luo et al. (1996) the peaks and the Strouhal number magnitude indicate that the flow pattern varies along the heights of the cylinders.

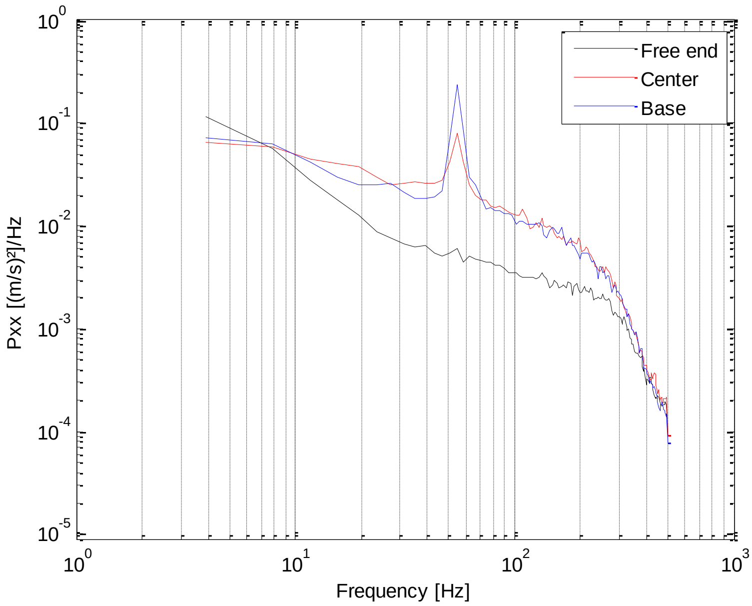

Figure 10. PSD of the hot wire signal in cylinder 32 mm *AR* =4 at the base, center and free end.

When a cylinder has been analyzed at the base and moving the hot wire to the wall “n” diameters, the shedding frequency is the same for each cylinder. The peaks indicate that the flow pattern varies according the hot wire is moving, because the energy decreases moving away from the cylinder. Figure 11 and 12 show the behavior to cylinders 32 and 40 mm respectively.

Figures 13 and 14 show that it occurs mainly because the finite cylinders with high blocking ratio has a behavior similar to infinite cylinders.

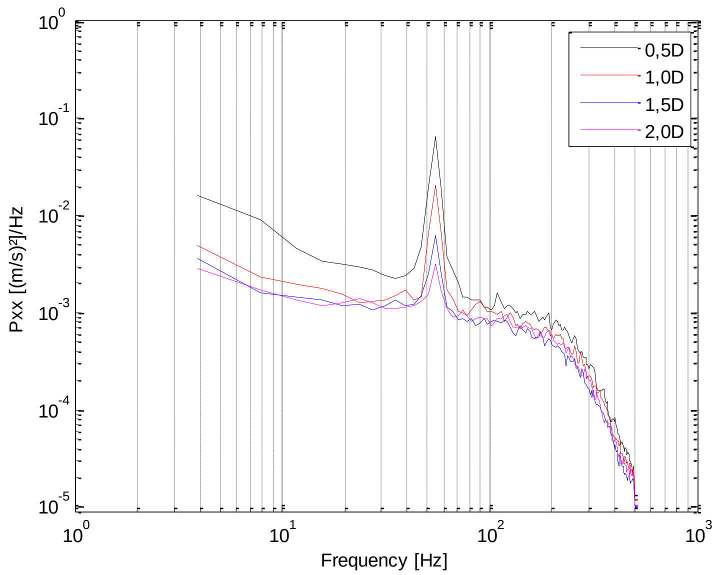

Figure 11. PSD of the hot wire signal in cylinder 32 mm *AR* =4 at the base distant n diameter from the cylinder.

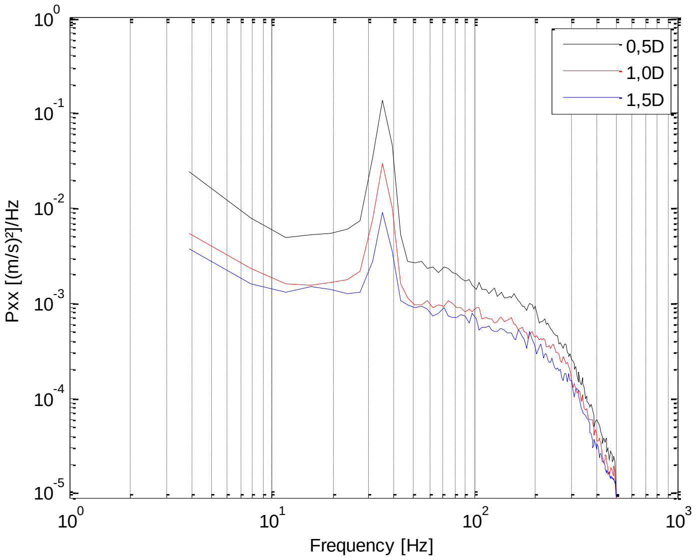

Figure 12. PSD of the hot wire signal in cylinder 40 mm *AR* =3 at the base distant n diameter from the cylinder.

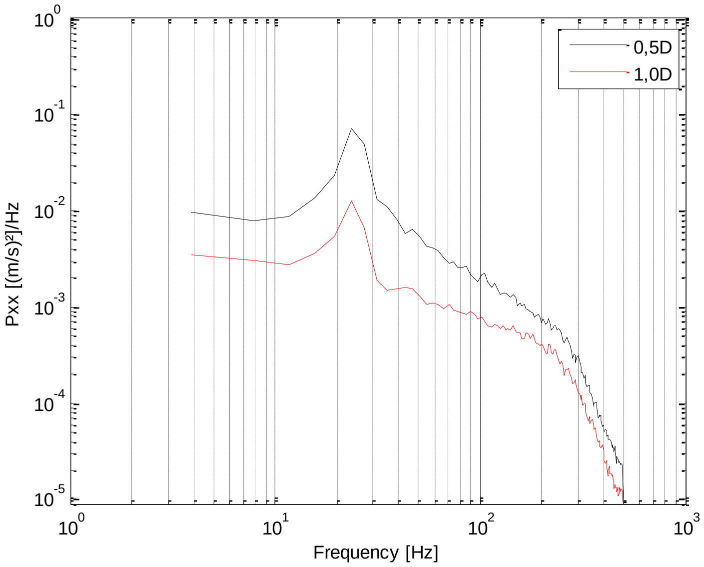

Figure 13. PSD of the hot wire signal in cylinder 50 mm *AR* =2 at the base distant n diameter from the cylinder.

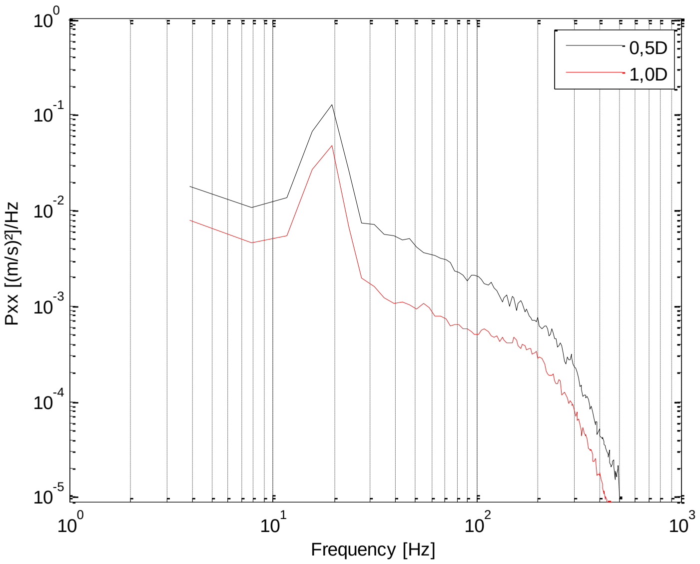

Figure 14. PSD of the hot wire signal in cylinder 60 mm *AR* =2 at the base distant n diameter from the cylinder.

5. CONCLUDING REMARKS

The general conclusions from the power spectrum density of the velocity fluctuations showed that strong peaks are observed around the center of the cylinders and weak peaks or no peaks are found near the free ends of the cylinders. The use of quantitative flow visualization techniques can clarify this phenomenon. The vortex shedding frequency generally does not change along the heights of the cylinders, at least for cylinders with larger diameters. This phenomenon also does not occur for smaller diameters with high blockage ratio.

The analysis about blockage ratio, indicate that blockage ratio in relation to height has influence at finite cylinder because occurs change at vortex shedding frequency compared to infinite cylinder. In the blockage ratio in relation to diameter occurs weak peaks or in some cases, no peak due to proximity to the free end.

Compared to the results of infinite circular cylinders, the Strouhal number values measured from the finite cylinder are close to those of the infinite cylinder when used larger cylinders, but the values of Strouhal number for the smaller cylinder are lower for the finite cylinder case.

Regarding vortex shedding process on finite cylinder, it was observed that the closer to the free end, the shape of the power spectrum becomes irregular and the peaks change to be lower and broader, indicating that the regular shedding process was influenced by the irregular vortex from the free end. The irregular flow from the free end is main reason for the reduction vortex shedding frequency and consequently smaller Strouhal number at finite cylinder.

6. ACKNOWLEDGEMENTS

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