



Wall Pressure Field in a Tube Bank after a Baffle Plate

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ABSTRACT

This paper presents the experimental study of pressure and velocity fluctuations of the cross flow in a simulated tube bank, with square arrangement and a pitch to diameter ratio of 1.26. Measurements were performed with a double wire probe and a pressure transducer. Behavior of fluctuating quantities is described by means of dimensionless autospectral density functions and their interdependence is discussed.

INTRODUCTION

Banks of tubes or rods are found in the nuclear and process industries, being the most common geometry used in heat exchangers. Attempts to increase heat exchange ratios in heat transfer equipments do not consider, as a priority of project criteria, structural effects caused by the turbulent fluid flow, unless failures occur (Païdoussis, 1982). By attempting to improve the heat transfer process, dynamic loads are increased and may produce vibration of the structures, leading, generally, to fatigue cracks and fretting-wear damage of the components, which are one of the failure sources affecting nuclear power plant performance (Pettigrew et al., 1997). While static loads seem to appear mainly due to the strong pressure drop which occurs in the narrow gaps between the tubes, in small aspect ratio tube banks, dynamic loads, arising from the fluctuating pressure field, have a random behavior, without any characteristic frequency (Endres et al., 1995). Pressure fluctuations result from velocity fluctuations at several points of the flow field (Willmarth, 1975).

In shell-and-tube heat exchangers, the cross flow through the banks is obtained by means of baffles, responsible for changing the direction of the flow and for increasing the heat exchange time between fluid and the heated surfaces. Baffles have also the purpose of increasing turbulence levels and, thus, heat exchange ratios. On the other side, boundary layer separation after the baffles may occur, as demonstrated in the old, but still very interesting results of flow visualization in models of heat exchangers and steam generators by Wiemer, 1937, in his Thesis. This can be an additional and important source of disturbances in the flow, which can travel through the bank, influencing the tube bank and the baffles.

The purpose of this paper is to investigate the wall pressure distribution and the behavior of pressure and velocity fluctuations, and their interdependence, in a simulated tube bank, where the turbulent flow is deflected by a baffle plate before reaching the bank.

TEST SECTION AND MEASUREMENT TECHNIQUE

The test section is the same described in Endres et al. (1995) and Endres and Möller (1997), being a 1370 mm long rectangular channel, with 146 mm height and a width of 193 mm. Air is the working fluid, driven by a centrifugal blower, passed by a settling chamber and a set of honeycombs and screens, before reaching the tube bank with about 2 % turbulence intensity. The tube bank is a two-row P/D=1.26, 146 mm long, set of tubes in square arrangement, rigidly mounted in a plexiglass plate perpendicular to the main flow direction. Tube axes are, therefore, parallel to the channel. A second baffle is placed on the opposite channel wall, in the other extremity of the tubes. The flow rate, and thus the Reynolds number, was controlled with help of a gate valve. Before the tube bank a Pitot tube was placed, at a fixed position to measure the reference velocity for the experiments. The Reynolds number, calculated with the tube diameter (32.1 mm) and the entrance velocity, under the first baffle is $Re = 1.5 \cdot 10^4$. This velocity was determined with help of the reference velocity, described above.

Velocity and velocity fluctuations were measured by means of a DANTEC *StreamLine* constant temperature hot wire anemometer. Pressure fluctuations were measured by an ENDEVCO piezo-resistive pressure transducer, mounted inside one of the tubes in the bank, and connected to pressure taps by plastic tubes (Endres, Möller, 1994), as shown in Fig. 2. Previous analysis of the behavior of the test section, by means of METRA accelerometers, and of the measurement technique, allowed to identify peaks in spectra due to resonances not related to the phenomena investigated. The tube instrumented with the pressure transducer in the bank could be rotated, so that measurements of pressure fluctuations at the tube wall were performed at several angular positions. Pressure and pressure fluctuations were measured also at the first baffle plate and at the channel walls. A double hot wire probe placed between two tubes in each row, near the location of the pressure tap, was used for the measurement of two components (parallel and normal to tube axis) of the velocity vector and velocity fluctuations. Data acquisition of pressure and velocity fluctuations was performed simultaneously by a Keithley DAS-58 A/D-converter board controlled by a personal computer, which was also used for the evaluation of the results.

For the determination of autospectral density functions, the sampling frequency was of 5 kHz, while the signals of the instruments were high pass filtered at 1 Hz and low pass filtered at 2 kHz. Previous studies of pure cross flow through tube banks showed, for this test sections, to be the frequency range of importance (Endres and Möller, 1997).

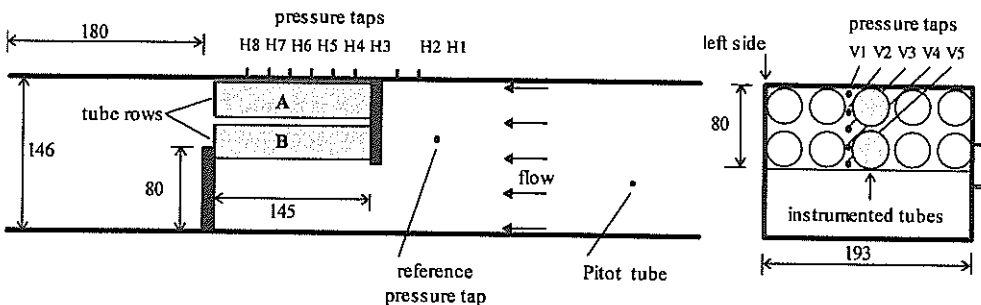


Fig. 1: Test section (schematic).

Analysis of uncertainties in the results have a contribution of 1.4 % from the measurement equipments (including hot wire, pressure transducer and A/D converter). In the measurements of pressure fluctuations, tubings are responsible for 5 % of the uncertainties, leading to a total value for the spectra of pressure fluctuations, up to 1000 Hz, of 6.4 %.

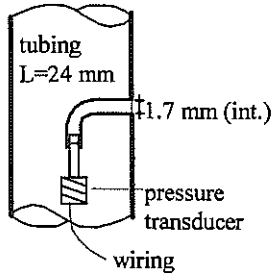


Fig. 2: Instrumented tube (schematic).

RESULTS

Experimental results are presented in form of dimensionless mean and RMS-values, as well as auto spectral density functions. Figures 3 and 4 show dimensionless values of the mean wall pressure and RMS-values of pressure fluctuations, respectively, in form of Euler numbers, obtained by means of fluid density, ρ , and the average entrance velocity, U . Results are presented as functions of the angular position of the tube: 0° corresponds to the position facing the main flow. In general, results of wall pressure and wall pressure fluctuations have higher values than in pure cross flow (Endres and Möller, 1997).

Since the bank studied has only two rows, the influence of the channel wall in the results of the tube closer to it, noted as tube "A", can be noticed by decreasing values of the mean wall pressure and of the RMS-values of the pressure fluctuation from 90° to 180° . From 0° mean wall pressure decreases to a minimum at 45° , while pressure fluctuations show a maximum at this position.

Tube "B" has a strong influence of the channel flow directly impinging on the bank, characterized for almost constant RMS values of the wall pressure fluctuations. Diffusion effect of the test section outlet after the second baffle is responsible for the positive azimuthal mean pressure gradient in tube "B", from 0° to 90° .

Figures 5 and 6 show spectra of pressure fluctuations in tubes A and B, respectively. Spectra measured in tube A do not differ significantly from spectra in pure cross flow through this geometry of tube bank (Endres and Möller, 1997), although showing some influence of the upper channel wall, which dump the values of the spectral functions. In contrast, very important peaks appear in the spectra measured at tube B. There, frequencies corresponding to values of the Strouhal number Str of about 0.2, not associated with natural resonance frequencies of the channel, are expected to be present in the spectra of velocity fluctuations inside the bank.

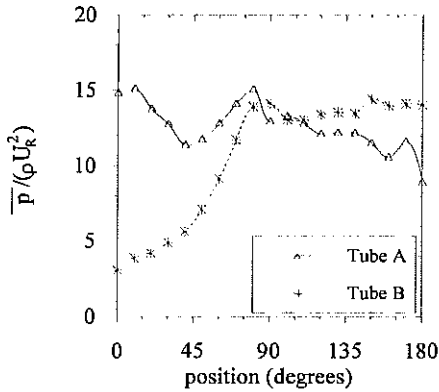


Fig. 3: Mean wall pressure distribution on two tubes of the bank (dimensionless).

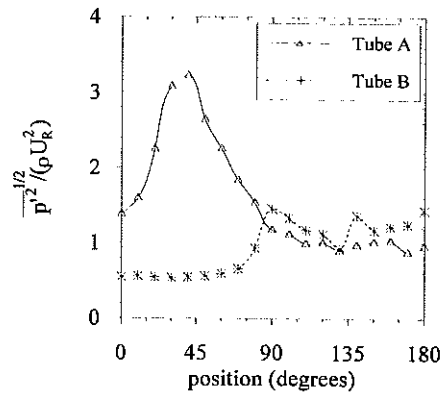


Fig. 4: RMS values of the wall pressure fluctuations on two tubes of the bank (dimensionless).

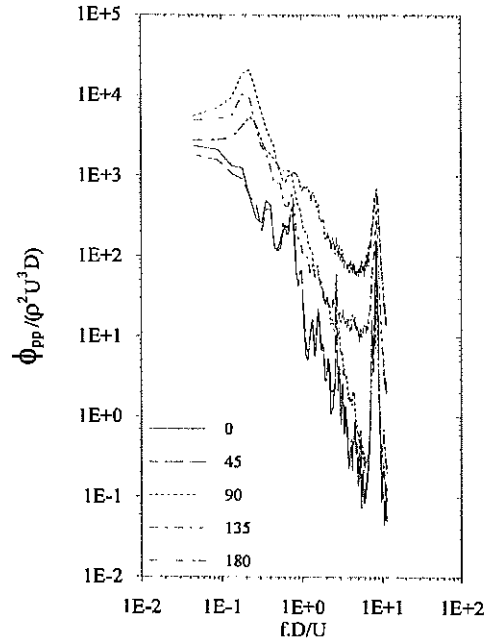
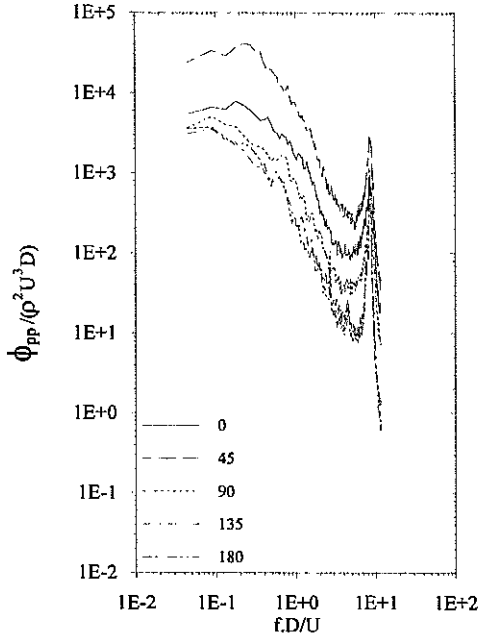
These frequencies are present, as shown in Figs. 6 and 7 for positions in the center of the tube length and at $\frac{3}{4}$ of the tube length. However, other important peaks appearing in RMS-values of pressure fluctuation at tube B walls, for values of the Strouhal numbers of about 0.8 and 1.8, for positions of 0° and 45° , do not appear in velocity spectra. They are neither associated with resonance frequencies of the test section, nor to values given by Fitzhugh's map, presented by Blevins, 1990.

Measurements of the autospectral densities of velocity fluctuations at the same locations of the results of Figs. 6 and 7, but without the tube bank, were then performed. They had the purpose of determining whether these effects came solely from the baffles. The results, shown in Figs. 8 and 9, do not present that peaks, leading to the conclusion that they are produced mainly by the inclined flow over the tube bank. It is also remarkable that they present very lower values than those measured inside the bank.

CONCLUDING REMARKS

This paper presents the experimental study of the velocity and wall pressure fluctuations in the turbulent flow through a simulated tube bank with square arrangement after passing a baffle plate. Experimental results of velocity fluctuations and wall pressure fluctuations were obtained by means of hot wires and a pressure transducer.

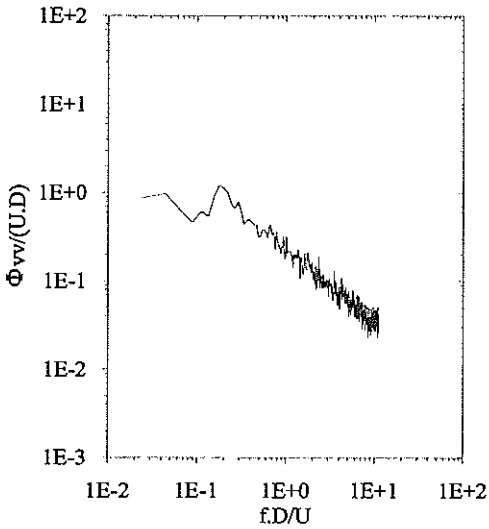
In general, results of wall pressure and wall pressure fluctuations have higher values than in pure cross flow (Endres and Möller, 1997). The characteristic value of the Strouhal number found was about 0.2. Important additional peak frequencies, appearing in tube wall pressure fluctuation spectra, cannot be associated neither to effects of pure cross flow through the bank nor to effects produced solely by the baffles. The results presented in this paper are, therefore, not conclusive. The correct interpretation of the phenomena studied here may be obtained by the study of pressure fluctuations of the turbulent flow through inclined tube banks, which is being initiated, as well as by the complete mapping of the fluctuating wall pressure and velocity fields.



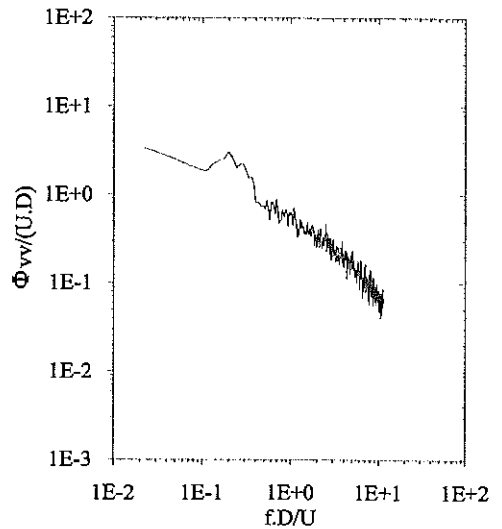
(a)

(b)

Fig. 5: Autospectral densities of wall pressure fluctuations in several positions of the tubes in the bank. (a) Tube A; (b) Tube B.

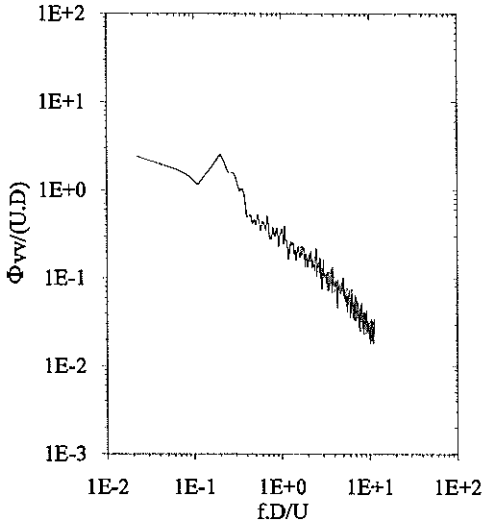


(a)

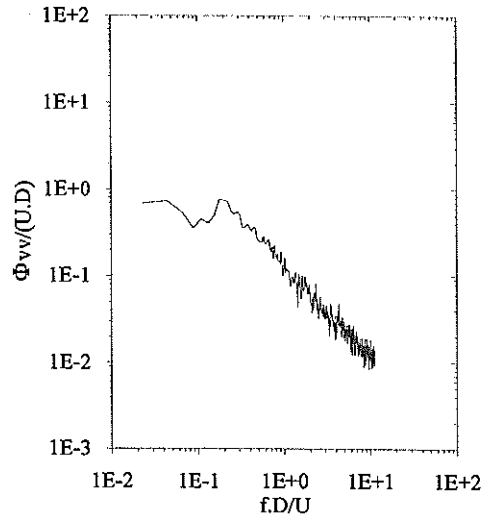


(b)

Fig. 6: Autospectral densities of velocity fluctuations in the narrow gap beside tube A in a position at half length of the tube. (a) Axial; (b) Transversal.

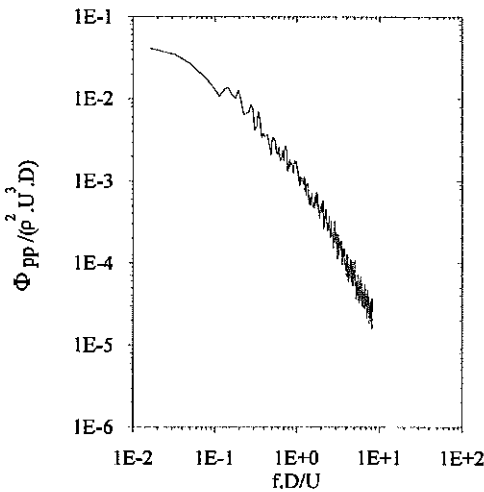


(a)

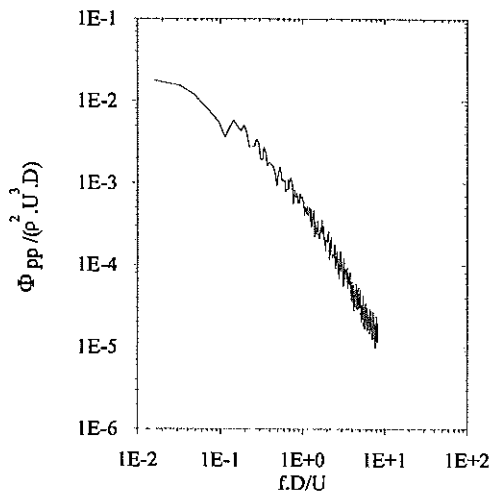


(b)

Fig. 7: Autospectral densities of velocity fluctuations in the narrow gap beside tube A in a position at 3/4 length of the tube. (a) Axial; (b) Transversal.



(a)



(b)

Fig. 8: Autospectral densities of velocity fluctuations at the corresponding position of Fig. 6 without tube bank. (a) Axial; (b) Transversal.

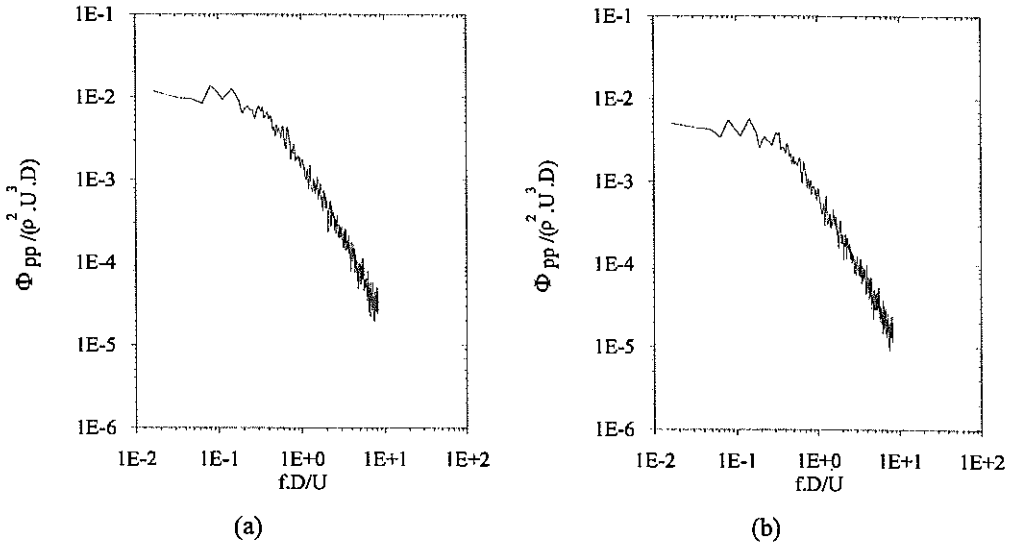


Fig. 9: Autospectral densities of velocity fluctuations at the corresponding position of Fig. 7 without tube bank. (a) Axial; (b) Transversal.

ACKNOWLEDGEMENTS

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