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Effect of Pitch Ratio of Tube Banks on Passive Acoustic Properties

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ABSTRACT

Tube banks are common design elements in heat exchangers. The most common tube bank patterns are in-line tube banks which consists of tubes spaced parallel and equally. Tube banks are characterized by their longitudinal and transverse pitch ratios (pitch to diameter). The tube bank with a pitch ratio of less than 1.25 is considered a compact tube bank and a pitch ratio equal to or greater than 2 is considered as widely spaced. In this paper, the attention is focused on the effects of pitch ratio in tube banks on its passive acoustics properties which are experimentally investigated. The flow duct experimentation is performed with flow to analyse the passive acoustic properties of tube banks. The experiment is conducted for three In-line tube banks with pitch ratios 1.2 ,1.4 and 2. The Experimental results consist of scattering matrix coefficients and power balance. The results are compared to see the pitch ratio effect. Transmission and reflection coefficients were found to increase with frequency for higher flow speeds and shows more waviness for compact tube bank. The power balance is calculated to see the amplification and attenuation effects of the tube bank. It is observed that compact tube banks give amplification for higher frequencies and wide spaced tube bank give moderate attenuation for all frequencies.

Keywords: Tube Banks, In-line arrangement, Pitch Ratio, Passive Acoustic properties.

1. INTRODUCTION

Boilers and condensers contain tube banks, The tube banks have a wide range of applications in combustion industries. Plain tube banks are vital design elements in heat exchangers and automotive radiators. Tube banks are subcomponents in shell and tube heat exchangers, where flow resembles crossflow and longitudinal flow at different places of the tube bank [1]. A tube bank is often used, to denote crossflow along with the bank and tube bundle to longitudinal flow across the tubes. Plain tubes are a recent addition to automotive air conditioning, evaporators, and condensers [2]. The tube bank configuration is an important issue of design along with the control of thermoacoustic instabilities. In an acoustic instability context, tube banks can act as both acoustic absorbers and generators based on the tube bank pattern.

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The tube bank patterns are characterized by the transverse and longitudinal pitch-to-diameter ratio which is also called the pitch ratio. Pitch ratios are the most common parameter to vary the tube bank pattern. Based on the pitch ratio the tube bank is considered either compact or widely spaced. For widely spaced tube banks, flow across the tubes is smooth and for compact tube banks, there is a lot of turbulence along the tubes. This instability by flow with combined sound excitation creates a feedback loop and creates aeroacoustics instabilities. Pitch ratio was and is an important parameter in the design of tube bank structures.

Literature on the heat transfer and pressure drop of plain and finned tubes in heat exchangers with experimental measurements was reviewed [3]. A relationship was established between the heat transfer and the pressure drop. Regardless of the influence of the tube diameter, the severity of the turbulence within the bundle depends on the velocity of the air and the tube spacing. Thus, these parameters have a strong effect on the pressure drop in the banks of tubes. When the transverse pitch of the tube was changed, the existence of a clear influence on the pressure drop at the side-air was observed, while there was a lack of significant change in the heat transfer performance [4]. Fujii et al. [5] developed a numerical 2D laminar flow and heat transfer simulation over tube banks. The study was carried out for an in-line square configuration of the tube banks with five rows with the pitch diameter ratio fixed at 1.5. Chen and Lai [6] studied the effect of pitch-to-diameter ratio and Reynolds number (Re) number, pressure drop, total drag, and friction drag. The ranges of the pitch-to-diameter ratio and Re number were 1.7–2.0 and 4–40, respectively. Beale and Spalding [7] numerically evaluated the heat transfer and fluid flow in a tube bundle.

From the above literature, it is shown that there has been a lot of work performed in the field of fluid or airflow and heat transfers with the dependence of pitch ratio of tube bank. There is a research gap in dealing with acoustic instabilities and acoustic passive and active properties. In this paper, research is focused on the pitch ratio of tube bank effects on the passive acoustic properties like transmission and reflection coefficients.

2. MODELLING

2.1. Experimental Setup

The experimental setup used in this work consists of a rectangular duct with samples at the centre as shown in the schematic diagram Figure 1. Acoustical excitation is created by loudspeakers on the upstream and downstream side. The upstream end is connected to anechoic chamber to create pressurized flow. Downstream end is connected to a muffler to reduce the end reflections. The acoustic pressure fluctuations up and the downstream of the sample were recorded using eight flush mounted microphones, four on either side of the sample. The microphones were all calibrated, relative to each other. This was done using a calibrator, where all the microphones were subjected to the same sound field.

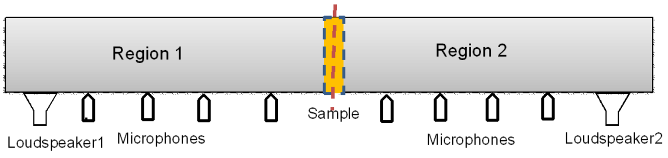

Figure 1: Schematic representation of experimental setup.

The microphone signals passed through signal conditioners to the data acquisition system. The DAQ also acted as signal generator for the loudspeakers; these were driven with a variable amplification, which was adjusted to the sound field in the duct. The flow velocity in the upstream end was measured using a pitot tube and a pressure transducer [8].

2.2. Sample

In this paper, sketches of the sample used for the experimental study are shown in Figure 2.

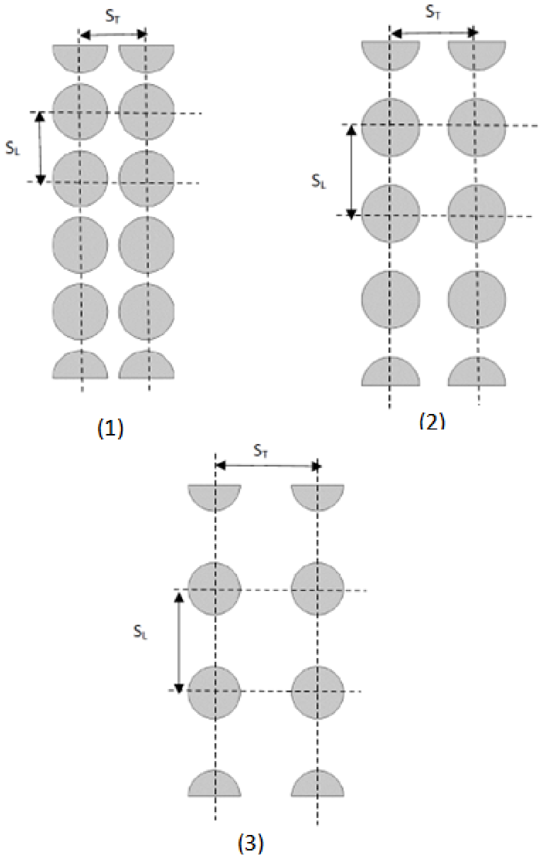

Figure 2: In-line tube samples with pitch ratios (1) P/D = 1.2 (2) P/D = 1.4 and (3) P/D = 2 .

In-line arrangement: The tubes are all parallel and equally spaced.Which consist of two rows of tubes of diameter 20mm with pitch ratios 1.2, 1.4 and 2. As noted above,a pitch ratio with less than 1.25 is considered a compact tube bank setup and 2 is widely spaced arrangement.

3. EXPERIMENTAL PROCEDURE

Experiments were conducted for the tube bank sample for measuring scattering matrix conducted using a stepped sine excitation for frequencies from 100 Hz to 2000 Hz for different flow speeds.

3.1. Scattering Matrix

A two-port multi-microphone measurement technique [9] was used to obtain the pressure data. The acoustic pressure field within the duct can be written as a superposition of forward and backward travelling waves as expressed in Equation 1.

$$p\left(x\right) \;=\; p^{+}e^{ik_{+}x} + p^{-}e^{-ik_{-}x}, \tag{1}$$

where *p(x)* is the measured complex pressure value at *x* and *p*± are the unknown pressure amplitudes. These unknown quantities are evaluated by measuring the pressure data at least two positions. In our experiments, the measured data is obtained from four microphones, placed on either side of the sample. Using Equation 1, the upstream and downstream pressure amplitudes can be evaluated. The scattering matrix, given by

$$\begin{bmatrix} P_1^+ \\ P_2^- \end{bmatrix} = \begin{bmatrix} T_{1-2}^+ & R_2^- \\ R_1^+ & T_{2-1}^- \end{bmatrix} \begin{bmatrix} P_2^+ \\ P_1^- \end{bmatrix} \tag{2}$$

Here, R has the physical meaning of reflection coefficient of waves propagating towards that region, and T is the transmission coefficient of waves from Upstream to downstream or vice-versa. 1 and 2 represents upstream and downstream regions.

3.2. Power Balance

From the determined scattering matrices amplification, attenuation and non-linear effects can be studied by applying a power balance calculation [10]. The ratio between the sum of the powers from all branches to incoming acoustic power can be calculated as shown in Equation 3 and 4

$$\frac{w_{out}^1}{w_{in}^1} = \frac{|R_1|^2\,(1+M)^2}{(1+M)^2} + \frac{|T_{1-2}|^2\,(1+M)^2\,A}{(1+M)^2\;A} \tag{3}$$

$$\frac{w_{out}^2}{w_{in}^2} = \frac{|R_2|^2\,(1+M)^2}{(1+M)^2} + \frac{|T_{2-1}|^2\,(1+M)^2\,A}{(1+M)^2\;A} \tag{4}$$

Here, *W* refers to the acoustic power, and *A* refers to the duct cross section area. The ratios will be larger than unity for amplification and smaller than unity for attenuation of the incident power.

4. RESULTS

4.1. Scattering Matrix

Three samples with different pitch ratios has been tested for different velocities. Figure 3 and 4 displays the magnitude of transmission and reflection coefficients as a function of frequency for two flow velocity cases: 6m/s (which is lowest flow speed in the testing) and 30m/s.

From Figure3 and 4 it can be seen that transmission coefficient for the widely spaced tube bank arrangement i.e, pitch ratio of 2, increases with frequency up to 600 Hz and then decreases showing the behaviour of flow through constrictions at higher frequency level. The other two moderately packed and compact tube banks (Pitch ratios of 1.4 and 1.2) give a transmission coefficient that is increase with the frequency for the both the flow speeds 6 m/s and 30 m/s. In Figure 4 we observe that compact packed tube bank structure is showing more waviness compared to other two samples specially after 1200 HZ due to unsteady flow caused by less open area producing vortices around the sample and causing whistling.

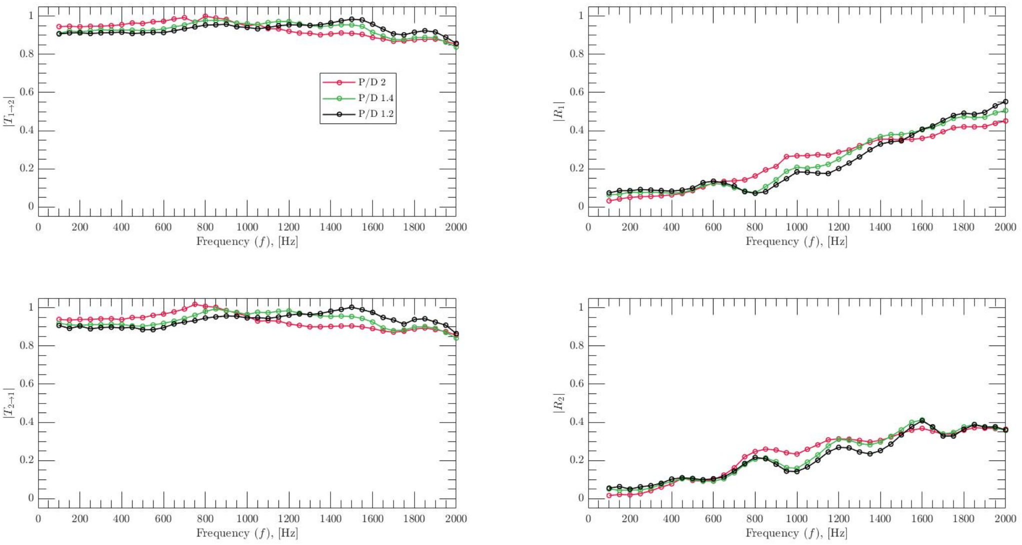

Figure 3: Transmission and Reflection coefficients for three samples with 6 m/s flow speed .

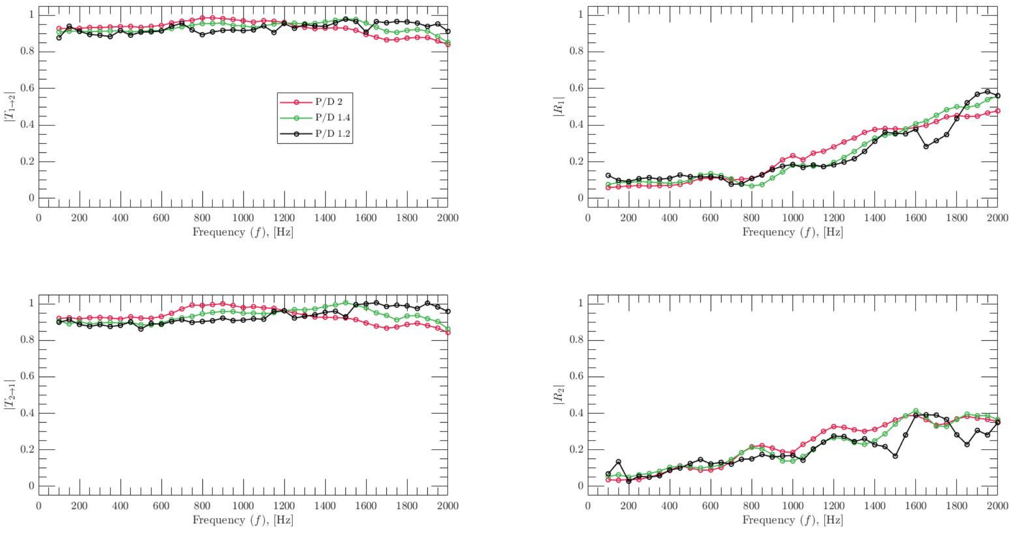

Figure 4: Transmission and Reflection coefficients for three samples with 30 m/s flow speed for different pitch ratios.

4.2. Power Balance

In order to test if samples are acting as amplifiers or attenuators of sound the power balance was calculated from the determined scattering matrices and which is showed in Figure 5 for all the three samples with flow speed of 30m/s.

From Figure5 it can be seen that all three samples with excitation from the upstream side give some attenuation up to frequency 1400 Hz. For excitation from the downstream side, two regions of power amplification is seen. For the widely spaced tube bank, amplification occur at 800-1000 Hz and for other two samples amplification occur from 1400 Hz. The amplification which is found regardless of which region the sound power originated from. This effect is probably turbulence,and

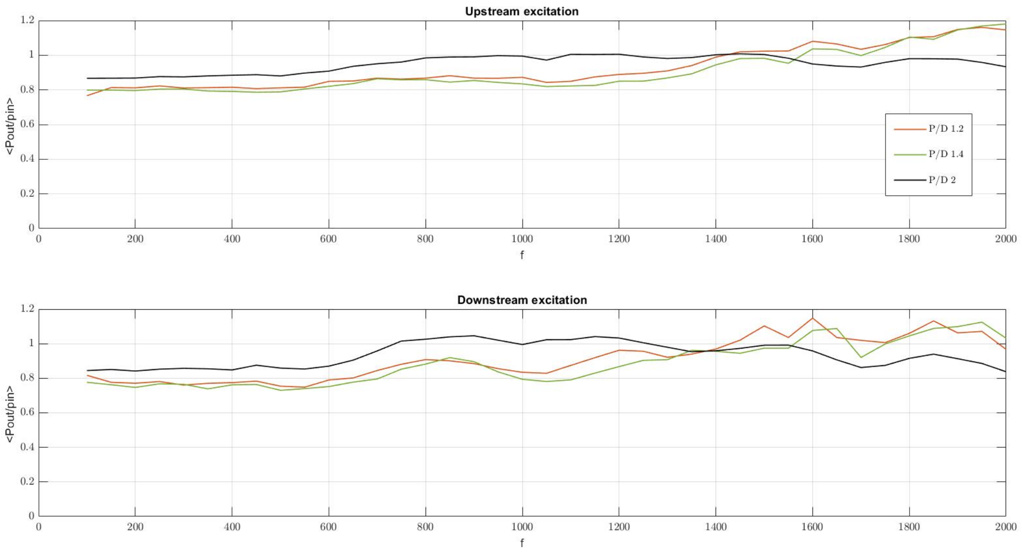

Figure 5: Power balance for waves incident from the upstream and downstream duct part, respectively.

it is thus not certain that the scattering matrix is an appropriate model to use for the power balance calculations [10].

5. CONCLUSIONS

In this present paper, the passive acoustic properties of three different tube bank arrangements based on their pitch ratios varying from 1.2 to 2 has been examined experimentally. From the experimental data, the passive acoustic properties were determined by transmission and reflection coefficients. The Scattering matrix is determined by the two-port multi-microphone technique. The Power balance has been calculated from the scattering matrix to observe the amplification and attenuation properties of the samples in presence of cross flow.

In this paper the Scattering matrix is shown for 6 m/s for all the three samples (P/D : 1.2, 1.4 and 2) were discussed. For the widely spaced sample transmission coefficient decreases after certain frequency range, Whereas for other two samples transmission and reflection coefficients are increasing with the frequency. For the flow speed 30 m/s, we see the waviness for the compactly packed sample. From the Power balance calculation, it is observed that the widely spaced space is acting as an attenuator and other two samples are acting as amplifiers.

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REFERENCES

[1] Steven Beale. *Tube banks,crossflow over.* International encyclopedia of heat and mass transfer, 1997.

[2] Rahman. MM Tahseen. TA and Ishak. M. Effect of tube spacing, fin density and reynolds number on overall heat transfer rate for in-line configuration. *International Journal of Automotive and Mechanical Engineering*, 12:3065–3075, 2015.

[3] Rahman. MM Tahseen. TA and Ishak. M. An experimental study of air flow and heat transfer over in–line flat tube bank. *International Journal of Automotive and Mechanical Engineering*, 9:1487–500, 2014.

[4] Nir. A. Heat transfer and friction factor correlations for crossflow over staggered finned tube banks. *Heat Transfer Engineering*, 12:43–58, 1991.

[5] Fujii. T Fujii. M and Nagata. T. A numerical analysis of laminar flow and heat transfer of air in an in-line tube bank. *Numerical Heat Transfer*, 7:89–102, 1984.

[6] Chen. H-T and Lai. J-R. Study of heat-transfer characteristics on the fin of two-row plate finned-tube heat exchangers. *Journal of Heat and Mass Transfer*, 55:4088–4095, 2012.

[7] Beale. S and Spalding. D. Numerical study of fluid flow and heat transfer in tube banks with stream-wise periodic boundary conditions. *Transactions of the CSME*, 22:397–416, 1998.

[8] Luck Peerlings. *Methods and techniques for precise and accurate in-duct aero-acoustic measurements: Application to the area expansion*. KTH, School of Engineering Sciences (SCI), Aeronautical and Vehicle Engineering, MWL Flow acoustics., 2015.

[9] M. Åbom. Measurement of the scattering-matrix of acoustical two-ports. *Mechanical Systems and Signal Processing*, 5:89–104, 1991.

[10] M. Karlsson and M. Åbom. Aeroacoustics of t-junctions – an experimental investigation. *Journal of Sound and Vibration*, 329:1793–1808, 2010.