NUMERICAL ANALYSIS OF FLOW INDUCED VIBRATION OF DIFFERENT SHAPES OF THE TUBE SUBJECTED TO CROSS FLOW

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Abstract -Heat exchangers play an important role in various industries including its application in chemical industry, pharmaceutical industry, food industry etc for the transfer of heat through liquids for carious purposes. The design and analysis of heat exchanger including its size and shapes of tubes etc plays an important role in the performance of the heat exchanger. The efficiency of heat exchanger is increased by the optimum selection of the factors mentioned above.This paper gives an insight about various shapes taken into consideration while the experimentation such as circular, rectangular and Pentagonal. The flow analysis is performed at the input velocity of 2m/s and the pressure and velocity variation is validated between the referred research paper work and experiments carried by author. The optimum design between circle, square and pentagon is found out by dynamic and harmonic analysis.

In the current paper various experiments and analysis were carried out to investigate the optimum shape of the tube to reduce flow induced vibration, to determine the pressure and velocity contour, to investigate the deformation of the tube, and the turbulence and resonance frequency.

Keywords:-Flow Induction Vibration, Cross Flow, Heat Exchanger, Natural Frequency, Turbulent Frequency, Resonance Frequency

INTRODUCTION

Shell and tube heat exchangers are the most common types in chemical industry, oil-refining process, power plant, and food industry and so on. According to the statistical data, more than 35–40% of the heat exchangers worldwide are STHX. The main reason is that they can be easily designed and constructed with a low cost. The heat transfer rate in STHX with segmental baffles can be very high. However, some other problems such as large pressure drop, flow induced vibration, fouling can be encountered [1]. In the last few decades, heat exchanger tube failures have become an increasing problem for several branches of the process industry. A heat exchanger tube rupture due to fluid-induced vibrations or other causes very often leads to a plant shut down with heavy losses in production income as a consequence. In the last two decades fluid-induced vibrations in heat exchangers has been the subject of an extensive research. Different models have been developed. Many experiments have been performed. The occurrence of tube vibration induced by fluid flow is a common phenomenon in many engineering applications such as in heat exchangers, fluidized beds and nuclear steam generator. The focus on suppressing flow-induced vibration attracts many researchers because of the tube fatigue failure resulted from the flow-induced vibration. However, flow-induced vibration can be an alternative technique to enhance heat transfer with proper design. Thus, it captures more and more attention to enhance heat transfer using flow-induced vibration [2].

Tube failures due to excessive vibration must be avoided in heat exchangers and nuclear steam generators, preferably at the design stage. Thus, a comprehensive flow-induced vibration analysis is required before fabrication of shell-and tube heat exchangers. It must be shown that tube vibration levels are below allowable levels and that unacceptable resonances and fluid elastic instabilities are avoided.

Flow-induced vibration is a global term to indicate that the vibrations are caused by the interaction of a structural component with a fluid flow surrounding it. A common classification is based on the excitation mechanism: extraneously, instability, and movement-induced vibrations. The extraneously induced vibrations consist of all flow-induced vibrations in which the fluid flow carries an external pressure excitation. An example of this type of instability is vibration caused by turbulence in the flow.

The vibration behavior of heat exchangers is governed by vibration excitation mechanisms and by damping mechanisms. Generally, in heat exchangers there are several significant damping mechanisms: (i) friction damping between tube and tube-support, (ii) squeeze-film damping at the support, and (iii) viscous damping between tube and shell-side fluid.

Several vibration excitation mechanisms are normally considered in heat exchanger tube bundles in cross flow, namely: (i) fluid elastic instability, (ii) periodic wake shedding, (iii) Turbulence-induced excitation and (iv) acoustic resonance. In the fluid elastic instability, the fluid flow becomes unstable due to the geometry of the structure involved. This happens, for example, in vortex-induced vibrations. As a fluid flow crosses a bluff body, the wake behind it can, under the right conditions, become unstable, with vortices being shed. Fluid elastic instability is the most important vibration excitation mechanism for tube bundles in cross flow. It is equally important for liquid, gas and two-phase cross flow. Fluid elastic instabilities result from coupling between fluid-induced dynamic forces and the motion of structures. Instability occurs when the flow velocity is sufficiently high so that the energy absorbed from the fluid forces exceeds the energy dissipated by damping. Fluid elastic instability usually leads to excessive vibration amplitudes. The minimum velocity at which instability occurs is called the critical velocity for fluid elastic instability.

Periodic wake shedding resonance may be of concern in liquid cross flow where the flow is relatively uniform. It is not normally a problem at the entrance region of steam generators because the flow is non-uniform and quite turbulent. Turbulence inhibits periodic wake shedding. Periodic wake shedding is generally not a problem in two-phase flow except at very low void fractions. Periodic wake shedding often occurs immediately downstream of structures subjected to cross flow. Periodic wake shedding generates periodic fluid forces. If the shedding frequency coincides with a natural frequency of the structure, resonance may occur. This may be a problem if the vibration response is large enough to control the mechanism of wake shedding. Then the periodic forces become spatially correlated to the mode shape and large vibration amplitudes may result.

Vibration excitation may be induced by turbulence. Turbulence can be generated locally by the fluid as it flows around the component of interest. This is called near-field excitation. Alternatively, far-field excitation can be generated by upstream components such as inlet nozzles, elbows and other piping elements. Turbulence-induced excitation generates

random pressure fluctuations around the surface of components forcing them to vibrate. Turbulence-induced excitation is the principal vibration excitation mechanism in axial flow. Turbulence-induced excitation is also important in cross flow. While fluid elastic instability and periodic wake shedding may cause failure in a very short time, turbulence excitation may induce enough vibration response to cause long-term fretting-wear damage. Turbulence-induced excitation should be considered in both liquid and two-phase cross flow Turbulence excitation can be very important near fluid elastic instability when the apparent damping becomes very small.

Acoustic resonance is possible in tube bundles subjected to gas cross flow. It occurs when the periodic wake shedding frequency coincides with the natural frequency of the acoustic cavity formed by the structures surrounding the tube bundle. The acoustic cavity resonance correlates shedding and causes intense acoustic noise, which can lead to severe structural damage. Acoustic pressure pulsations originating from the pumps or acoustic noise generated by piping elements such as valves can promote acoustic resonance in a receptive section of the piping system. If the acoustic resonance frequency is close to that of the structure, large vibration amplitudes and damage may occur.

PROBLEM DEFINITION

Flow induced vibration (FIV) has been a long-standing issue because of the structural failures. The heat exchange tubes are the key factor in flow induced vibrations. When fluid flows across tubes, a typical cross flow was formed and each tube will suffer from strong cross forces with oscillating vortices shed downstream, which greatly enriches the frequencies of the cross forces. These cross forces with abundant frequencies can make the tubes vibrate, triggering the problems of friction, wear, fatigue and so on. The prediction of the oscillating vortex behaviours and structural responses contributes to be one of the most important issues in the tube fluid dynamics, structural design and fatigue life design.

METHODOLOGY

In the following research geometry is created using ANSYS modeler workbench including all the geometric parameters. A schematic of a flexible single tube in a rigid array subjected to cross flow is shown in Fig.1. Both ends of tube is in fixed support. The motion of surrounded tube can be ignored, which is mainly dues to the small interaction of tube on the water flow, and the assumption can largely enhance the calculation efficiency. The inner diameter of the single tube Di is 11 mm, and the outer diameter Do is 12 mm, the Young modulus E of the central tube is set as 2.0×1011 Pa. The rigid array is set in the center of a fluid domain of size 800mm×340mm×120 mm, which is large enough to resolve the water flow field.

A velocity inlet boundary condition is set at the left side of the computational domain, and a pressure outlet boundary condition is set at the right side of the computational domain. The top and bottom sides of the computational domain is defined as symmetry boundary conditions, and the tube outer surface is defined as an interface boundary condition.

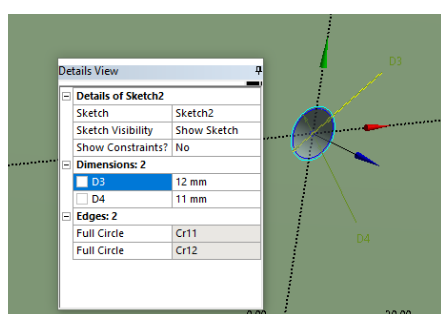

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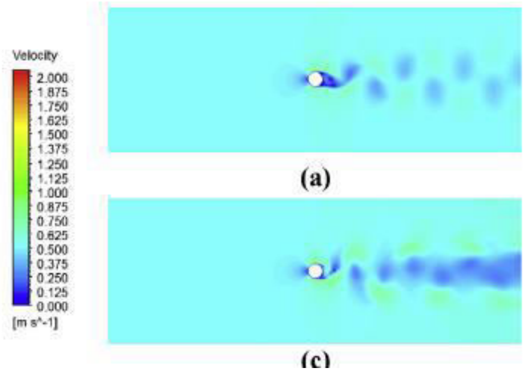
Fig. geometry of tube

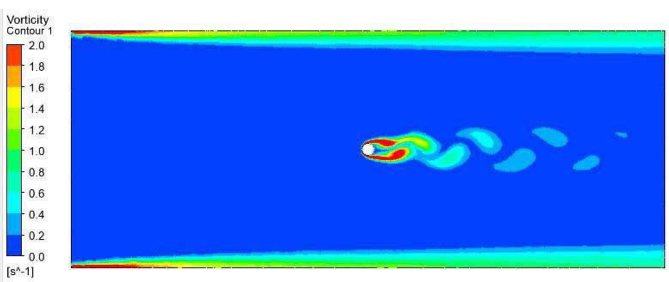
RESULTS & VALIDATIONS

(A)Velocity Validation

Figure shows the velocity contour which is given in the research paper.



Velocity contour for single tube from the simulation result

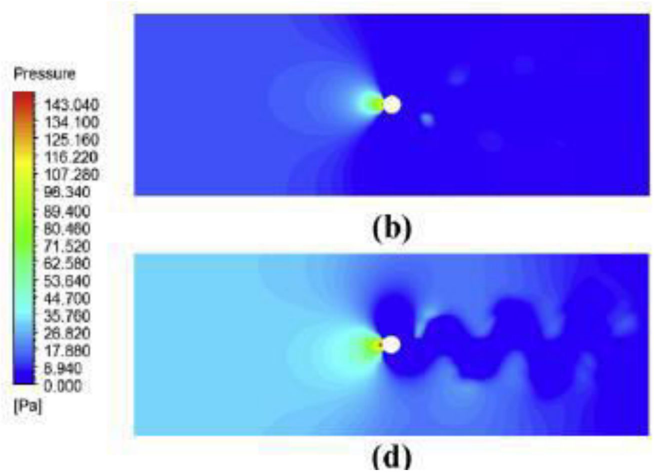


From both figure we can observe behavior of fluid at velocity 2 m/s.

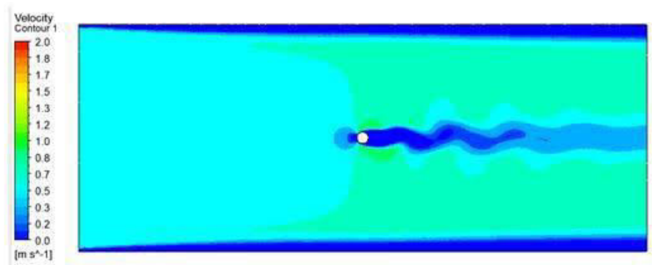
The simulation results and author results of velocity contour shows that the simulation result are in agreement with author result.

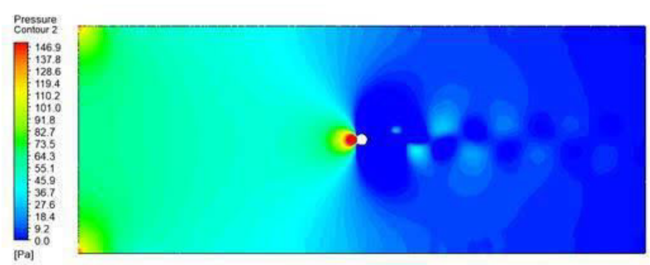
(B) Pressure Validation

In reference paper



In this study investigation





Max pressure we get inside is 146.9 Pa and in research paper it is 143.040 Pa. from both reading we see that the error between these are 2.70% which is considerable

VALIDATION RESULTS

a) Flow Analysis was performed considering velocity of 2m/s at inlet.
b) Observed good correlation with research paper for velocity and pressure prediction.

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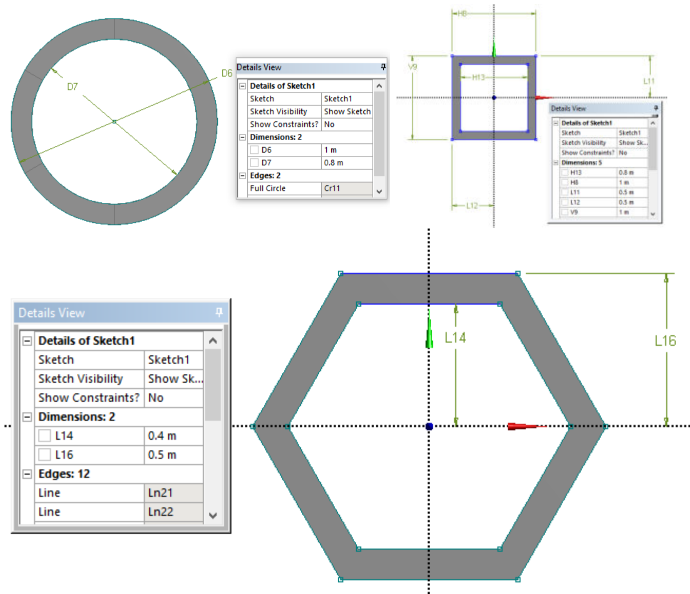
GEOMETRIC MODELLING DETAILS



Meshing: Final model from design modeler then imported in ANSYS WORKBENCH. Circle wall edge uses inflations layers for having proper flow and vary fine meshed used to capture the accuracy of solution. Body size of 0.3m used for fluid domain and 0.02m element size used at circle edges.

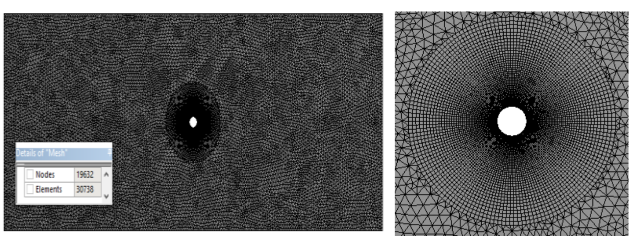


Fig: Mesh Derails (Circle Shape)

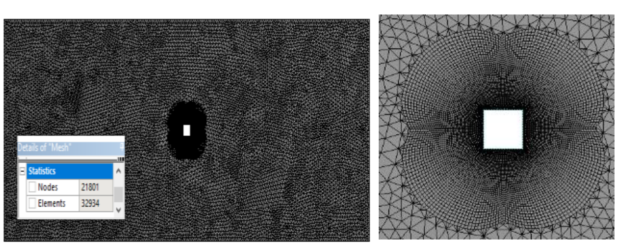


Fig: Mesh Derails (Square Shape)

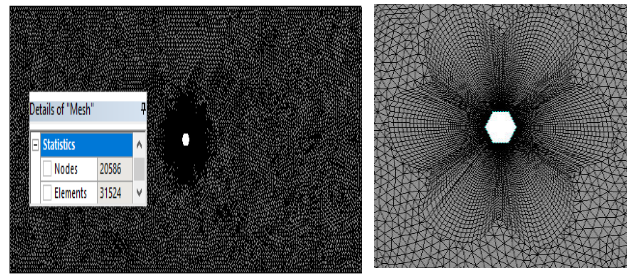
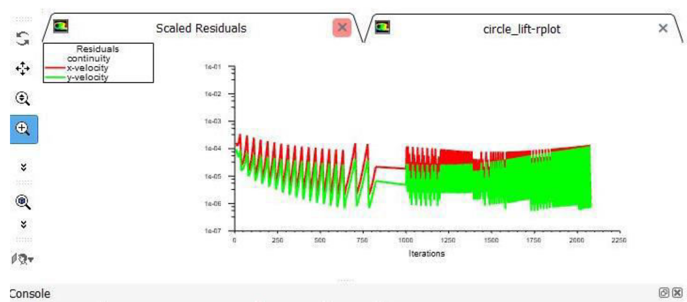


Fig: Mesh Derails (Pentagon Shape)

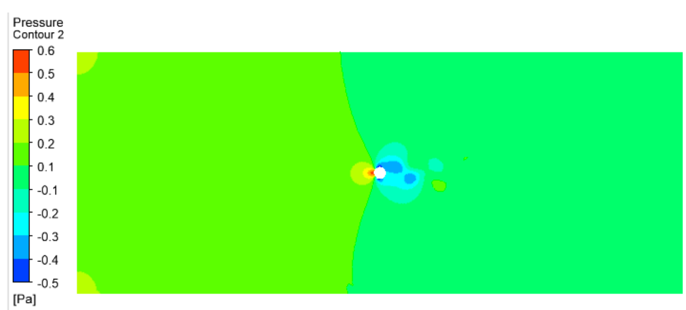
RESULTS CONVERGENCE

After 2000 iteration the results observed to be stabilize and hence current iterations is good enough for this analysis.



CFD Results:

Pressure plot: Max pressure of 0.6 ~ 1pa is observed as shown in below figures. This pressure will be used to calculate forces (e.g. drag, lift, or torque) on objects by integrating the pressure over the surface of the object.



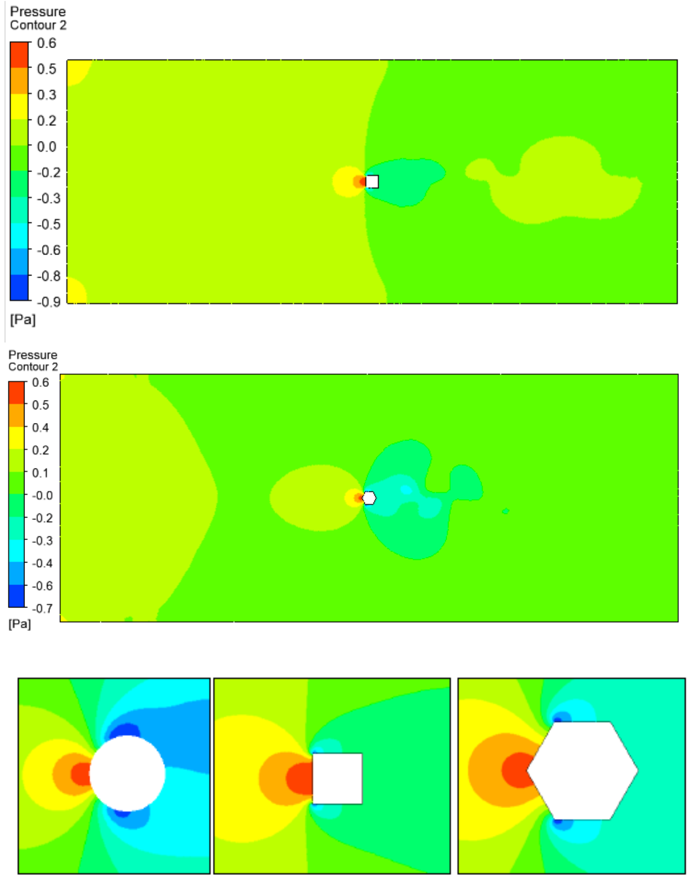


Fig: Pressure contour for circular square and pentagon

Circle shape shows lower pressure at outer surface compared to square and pentagon shape.

THE VELOCITY PLOT AT INLET

The velocity plot at inlet:Pressure and fluid velocities are always calculated in conjunction. Fluid velocities can be visualized to show flow structures.

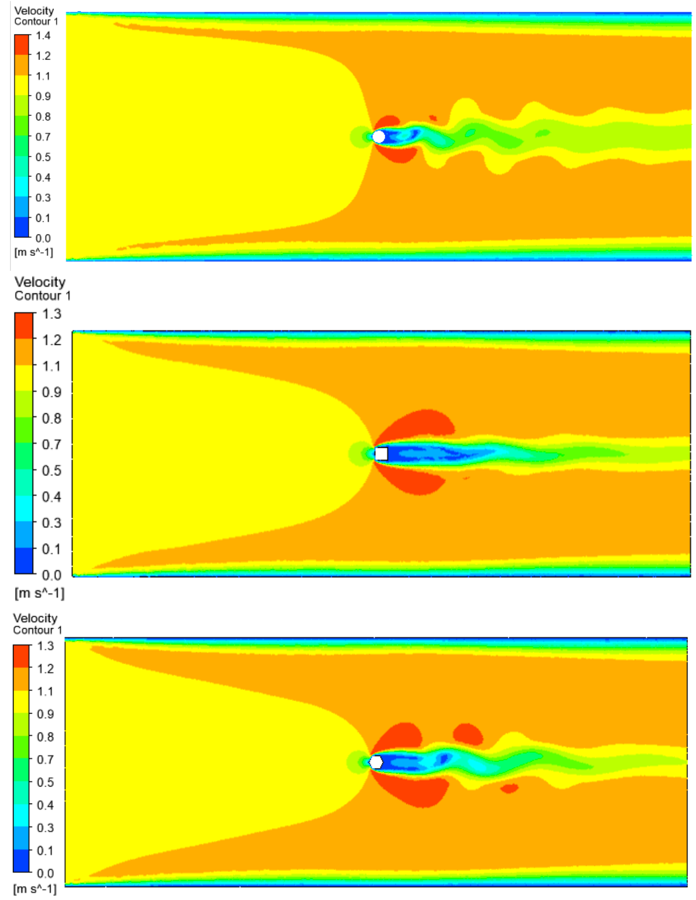
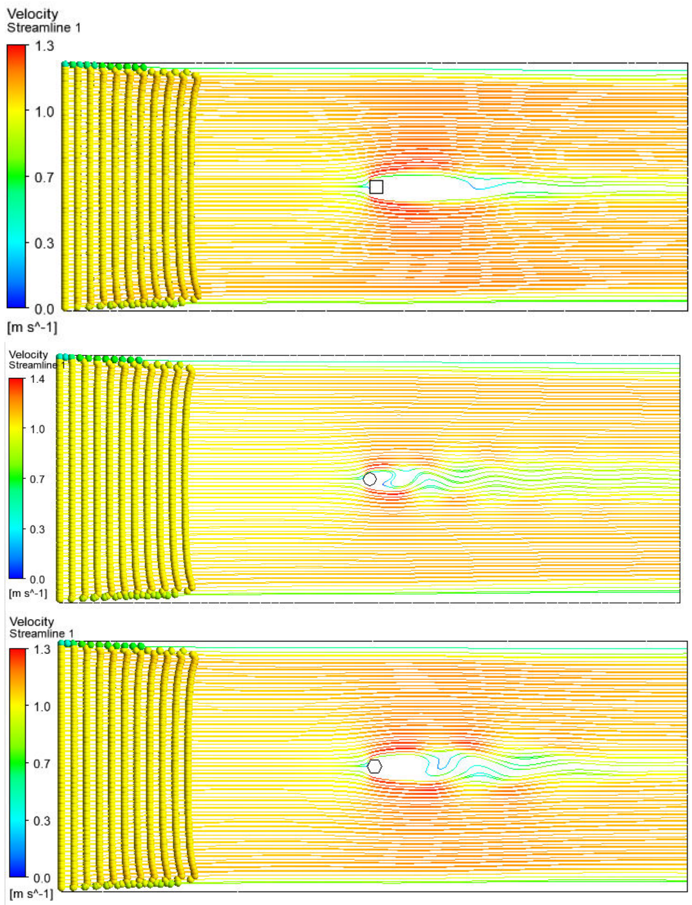


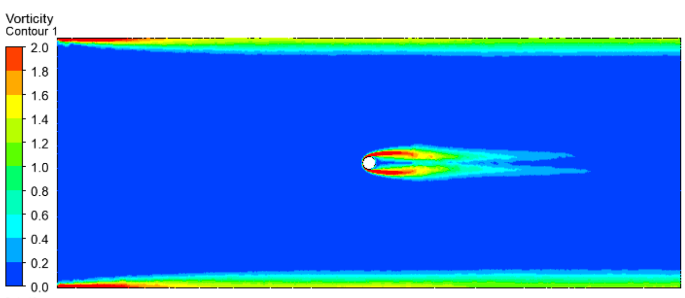
Fig: Velocity Plot

Velocity Streamline (path) Plot:A pathline is the trajectory followed by an individual particle. The pathline depends on the location where the particle was injected in the flow field and, in unsteady flows, also on the time when it was injected. In unsteady flows pathlines may be difficult to follow and not easy to create experimentally.



VELOCITY PLOT

From the flow field we can derive other variables such as shear and vorticity. Shear stresses may relate to erosion of solid surfaces. Deformation of fluid elements is important in mixing processes. Vorticity describes the rotation of fluid elements. Motion of each fluid element can be described as the sum of a translation, rotation, and deformation. The animation shows a translation and a rotation. Vorticity is a measure of the degree of local rotation in the fluid. This is a vector. Unit is 1/s.



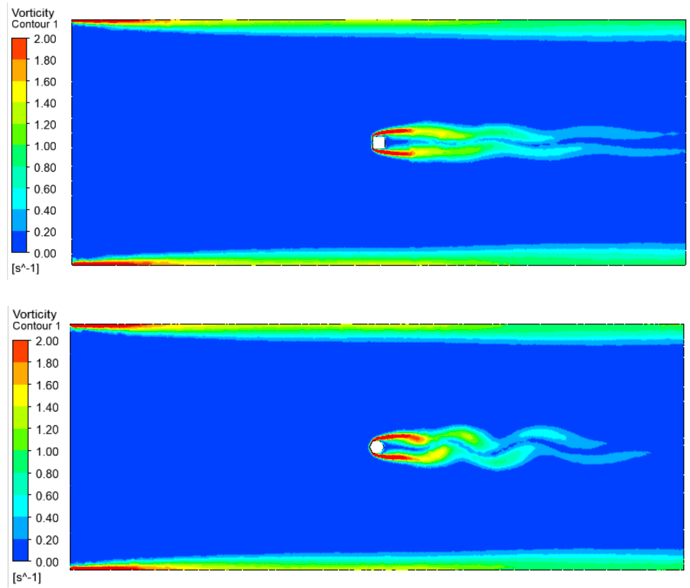


Fig:-velocity contours for circular square and pentagon

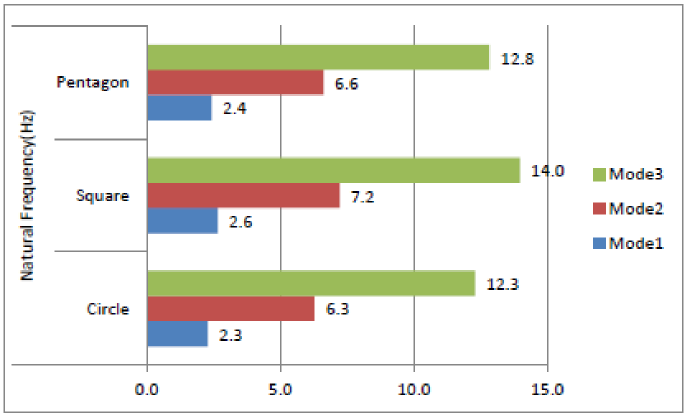
DYNAMIC ANALYSIS

MODAL AND DYNAMIC ANALYSIS

The goal of modal analysis in structural mechanics is to determine the natural mode shapes and frequencies of an object or structure during free vibration. It is common to use the finite element method (FEM) to perform this analysis because, like other calculations using the FEM, the object being analyzed can have arbitrary shape and the results of the calculations are acceptable.It is also possible to test a physical object to determine its natural frequencies and mode shapes. This is called an Experimental Modal Analysis. The results of the physical test can be used to calibrate a finite element model to determine if the underlying assumptions made were correct (for example, correct material properties and boundary conditions were used). For the most basic problem involving a linear elastic material which obeys Hooke's Law the matrix equations take the form of a dynamic three-dimensional spring mass system.

Harmonic analysis is used to predict the steady state dynamic response of a structure subjected to sinusoidally varying loads. The structure is excited harmonically at the fixed degrees of freedom. The excitation is defined by a direction vector of displacement, velocity or acceleration.

EXPERIMENTAL RESULTS

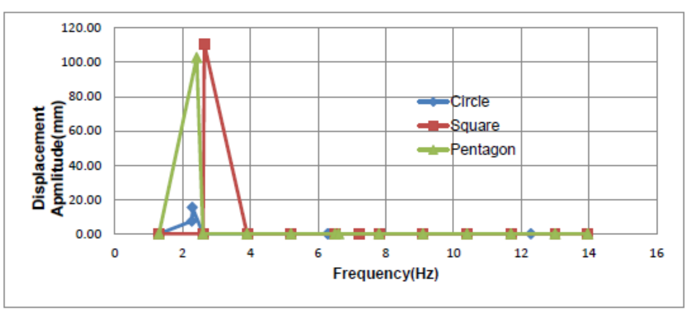


	Natural Frequency(Hz)		
Mode No	Circle	Square	Pentagon
Mode1	2.3	2.6	2.4
Mode2	6.3	7.2	6.6
Mode3	12.3	14.0	12.8

Circle shape section modulus is lowest among all other designs and hence circle design have observed lowest frequency of 2.3Hz where as square has observed 2.6Hz.

Mode shapes all three natural frequency of circle, square ad pentagon designs are shown below.

HARMONIC ANALYSIS RESULTS SUMMARY



Based on frequency vs displacement amplitude graph it is observed that 1st natural frequency is getting excited with pressure loading and circle design is observed to have lowest vibration amplitude. Hence stress for 1st mode need to check with material limit.

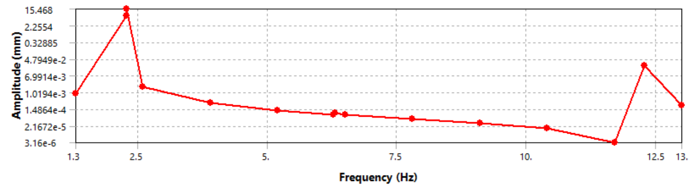


Fig: Circle

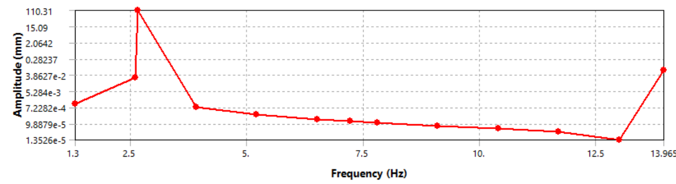


Fig: Square

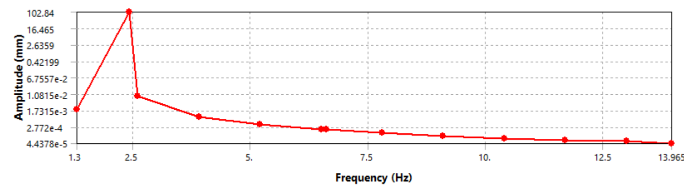
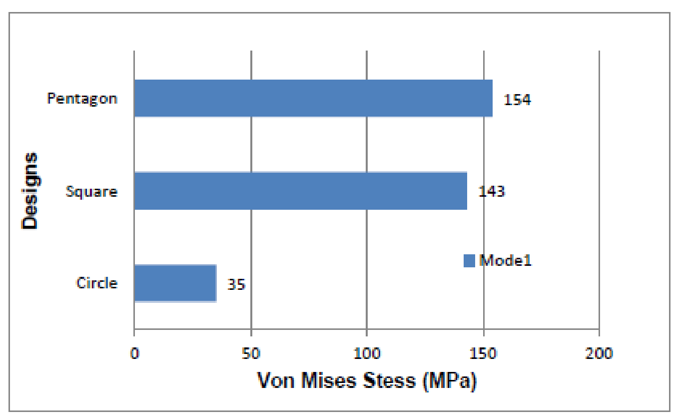


Fig: Pentagon.

COMPARISON OF VON MISES STRESS (MPA) FOR THE THREE GEOMETRIES

Von Mises Stress (MPa)			
Designs	Circle	Square	Pentagon
Mode1	35	143	154



Stress of circle designs is observed 35MPa which is lowest among all designs and also less than material endurance Limit of 230MPa. Also other designs stress is observed to be less than material endurance limit. Stress plot for 1st mode are shown below.

CONCLUSION

a) Flow induced vibration with input velocity of 2m/s is studied for tree different shape of geometry which are circle, square and pentagon.
b) Pressure distribution from CFD analysis shows max pressure of ~1pa also the distribution of pressure over circle area is slightly lower than other designs. This pressure is used as excitation force in harmonic analysis to assess its impact on vibration.
c) Pressure and fluid velocities are always calculated inconjunction. Fluid velocities can be visualized to show flow structures. A path line is the trajectory followed by an individual particle. The path line depends on the location where the particle was injected in the flow field and, in unsteady flows, also on the time when it was injected. In unsteady flows path lines may be difficult to follow and not easy to create experimentally.
d) From the flow field we can derive other variables such as shear and vorticity. Shear stresses may relate to erosion of solid surfaces. Deformation of fluid elements is important in mixing processes. Vorticity describes the rotation of fluid elements. Motion of each fluid element can be described as the sum of a translation, rotation, and deformation. The animation shows a translation and a rotation. Vorticity is a measure of the degree of local rotation in the fluid. This is a vector. Unit is 1/s.
e) Circle shape section modulus is lowest among all other designs and hence circle design have observed lowest frequency of 2.3Hz where as square has observed 2.6Hz.
f) Stress of circle designs is observed 35MPa which is lowest among all designs and also less than material endurance Limit of 230MPa.
g) Based on all observations, circle shape design is observed to be best and recommended for manufacturing. Induced flow has observed some impact on vibration spatially 1st natural frequency of design but stresses are observed to less than endurance limit and hence no risk involved.

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