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Experimental Study and Analysis of Flow Induced Vibration in a pipeline

R.Veerapandi [a] G. Karthikeyan[b] Dr. G. R.Jinu[c] R. Kannaiah [d]
[a] Final Year M.E(CAD),Regional Centre of Anna University,Tirunelveli-629004
[b] Asst .Professor, Regional Centre of Anna University,Tirunelveli Region,Tirunelveli-627007.
[c] Asst .Professor, University College of Engineering,Nagercoil-629004.
[d] Scientist/Engineer, ISRO Propulsion Complex,Mahendragiri-627133

Abstract- This paper deals with the mathematical model and Computational analysis of flow induced vibration of Rocket Engine Test Facility. In this set up, the main components of piping elements which causes vibration is angle type valve. Experimental study and analysis of flow induced vibration is to be carried out by study the effect of turbulence of gas flow in the piping system during the course of sub cooling of flight static fire test or flow trial. Mathematical Model of pinned-pinned pipe carrying fluid has been developed. Governing Equation of motion for pipe conveying fluid of real system has been derived. The critical fluid velocity has been calculated by analytical approach.

The vibration structure of pipeline is modeled by using CATIA software as per specifications and the effect of turbulence of gas flow in the piping element is analysed by using Fluent and ANSYS software. The main piping element which causing Flow Induced Vibration is angle type valve. Analytically and computationally the dynamic behavior of fluid flow through this valve is studied. Modal Analysis has been carried out and found the natural frequency of six mode shape. Experimental studies/flow trials are to be carried out to validate the analytical and computational results.

Keywords: Flow Induced Vibration, Mathematical model, Frequency, ANSYS, Fluent, Computational analysis

1. INTRODUCTION

The failure of components or parts occurred by the reversal cyclic stress which is well below the yield stress of the material. This type of failure is called a fatigue. The vibration of structure or components is subjected to cyclic stress and that will lead to Fatigue failure. The vibration caused by a fluid flowing in or around a body is known as Flow Induced Vibration (FIV). FIV best describe the interaction that occurs between the fluid's dynamic forces and a structure's inertial, damping and elastic forces.

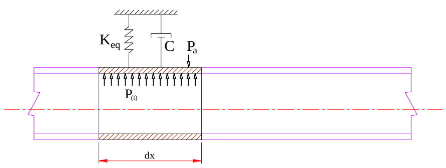
Various researchers have considerably contributed by doing lot of researches to study the characteristics behavior of pipe conveying fluid flow. D.S. Weaver and B.Myklatun [1] to [4] studied analytically the stability behavior of thin and clamped end pipe with high velocity internal fluid flow. Considering straight stub pipe with pinned end taken bending moment in to account for governing equation of motion of pipe. Bong Soo Kim, Young Ki Kim and Jung woon Choi[7] made the analytical study of flow induced vibration in consideration with cooling effect. The developed the equation of motion by the relationship between pipe structure and fluid pressure and modified the equation motion to account the ‘coriolis force’. Mao Qing, Zhang Jinghui, LuoYushan, Wang Haijin and DuanQuan[10] done a experimental study for studying orifice induced wall pressure fluctuations and vibration in a pipeline. one of the main flow induced vibration sources in the pipe flow circuit is a singularity that disturbs the flow, such as a pump, valve and orifice etc. PSD is used to define the fluctuating pressure. The characteristics of pressure fluctuations before and after the orifice plate and natural frequency of the pipe are used to build the mathematical model.

Inference from the literature survey, the natural frequency of the system is affected by velocity of fluid flow and density of fluid flow and stiffness, modulus of elasticity of pipe material and length of the pipe.

Many researchers are done analysis in one dimensional fluid flow but very few researchers are attempted 3-Dimensional fluid flow analysis and very few researchers are done analysis in Fluid Structure Interaction. But any real physical system, the fluid flow is 3-Dimensional and noticed that there is a research gap in this advance development field hence I have been studying in this paper.

2. ANALYTICAL AND COMPUTATIONAL METHOD

2.1 Mathematical Model



MATHEMATICAL MODEL OF THE SYSTEM

From the Newton second law of linear motion

$F = m * a$

From the free body diagram

$M_{eq}\ddot{x} + \frac{\mu A}{t}\dot{x} + kx \quad = F(t)$

$M_{eq}\ddot{x} + c\dot{x} + kx \qquad = P(t) * A_p$

Let us assume the pressure function is harmonic, then

The equation of motion

$= P_0 \sin\omega t \ * \ A p$

$\ddot{x} + \frac{c}{M_{eq}}\dot{x} + \frac{k}{M_{eq}}x \qquad = \frac{P_0 * A p}{M_{eq}}\sin\omega t$

$\ddot{x} + \frac{c}{M_{eq}}\dot{x} + \omega^2 x \qquad = \frac{P_0 * A p}{M_{eq}}\sin\omega t \ ; \omega = \sqrt{k/M}$

For free vibration

$\ddot{x} + \frac{c}{M_{eq}}\dot{x} + \omega^2 x = 0$

$\omega = \sqrt{k/M}$

Deflection of cantilever beam with point load at the free end

$\delta = wl^3/3EI$

$k = w/\delta = 3EI/l^3$

= 5177.94 KN/m

Mass = density x volume

Mass per unit length = 41.4229

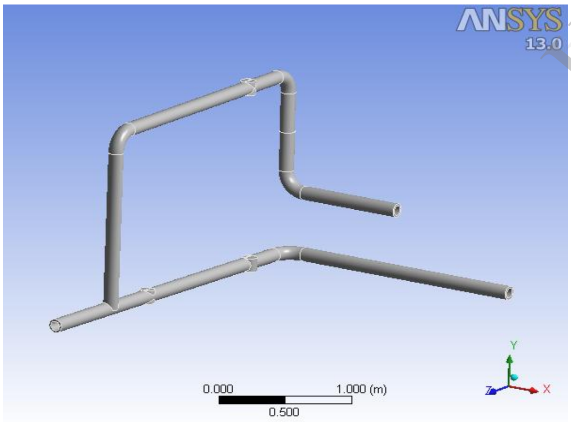
Total mass = 41.4229 x 8 (length of oscillating pipe = 8m)

= 324.85 Kg

$\omega_n = \sqrt{K/m}$

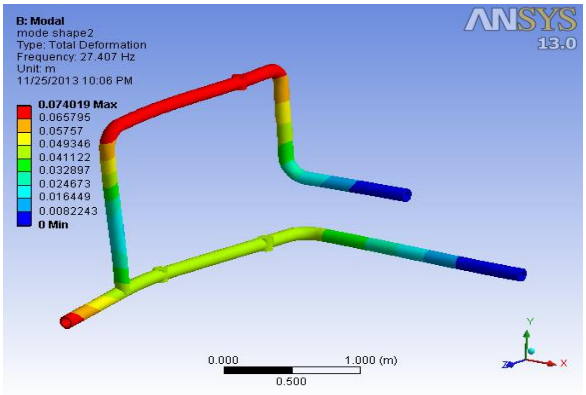
= 27.912 Hz

2.2 Computational Method



Model of Pipe Flow Configuration

The Computational Model of pipe flow configuration is developed by CATIA Software. There is a valve pressure boundary at all the end of the pipe and assuming that the valves are as a fixed support because of Lumped mass and 3 clamps are taken as pin point supports. The Structural Model Analysis has done in ANSYS Workbench 14.5 Software. Solver used is ANSYS Mechanical APDL. Six mode shape and corresponding natural frequencies are found and validate the Mode Shape 2 with the analytical results.



Deformation of Mode shape 2

Table

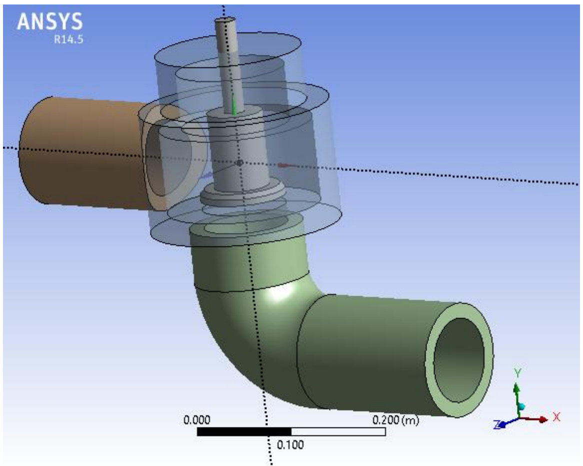
Mode Shape	Frequency [Hz]
1.	16.108
2.	27.407
3.	32.234
4.	69.891
5.	78.026
6.	92.993

Result : The maximum deformation occurs at the top pipe configuration is 0.074019 mm and the corresponding natural frequency is 27.407 Hz

Analytical result of Natural Frequency at Mode Shape 2 is 27.912.

Accuracy: 1.8 %, hence the computational results are validated.

3. COMPUTATIONAL FLUID DYNAMICS ANALYSIS



Angle Type Valve

The Model of the Valve (Structural Domain) developed by ANSYS Workbench 14.5 Software. Mesh developed by ANSYS mesh tool and mesh type is Tetrahedral (10 Nodes) and mesh size is $1x10^{-3}$ m

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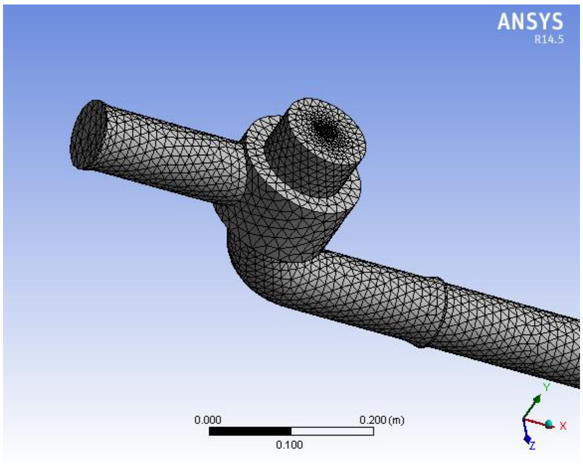


Fluid Domain

The Model of the Fluid flow through valve with pipe stub.(Fluid Domain) developed by ANSYS Workbench 14.5 Software. Mesh developed by ANSYS mesh tool and mesh type is Tetrahedral (10 nodes) and mesh size is $1x10^{-3}$ m and the mesh element in the fluid domain is around 1Lakh

CFD Analysis

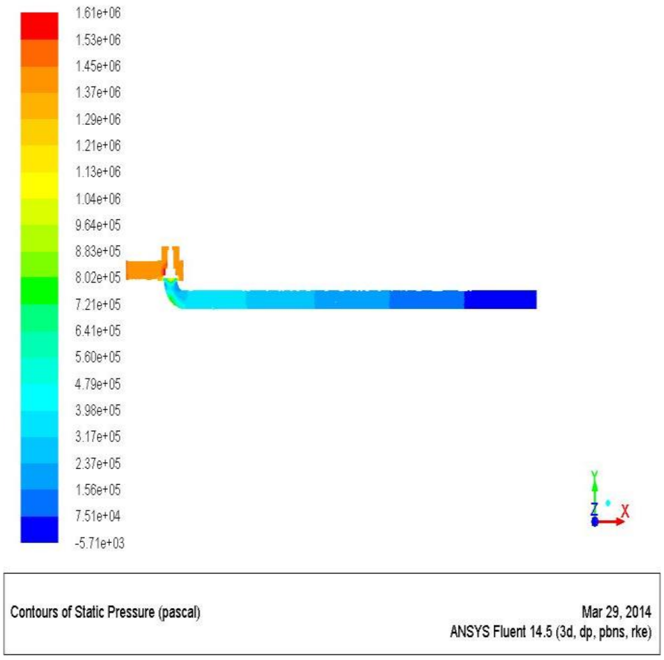
Software used – ANSYS Workbench & Fluent

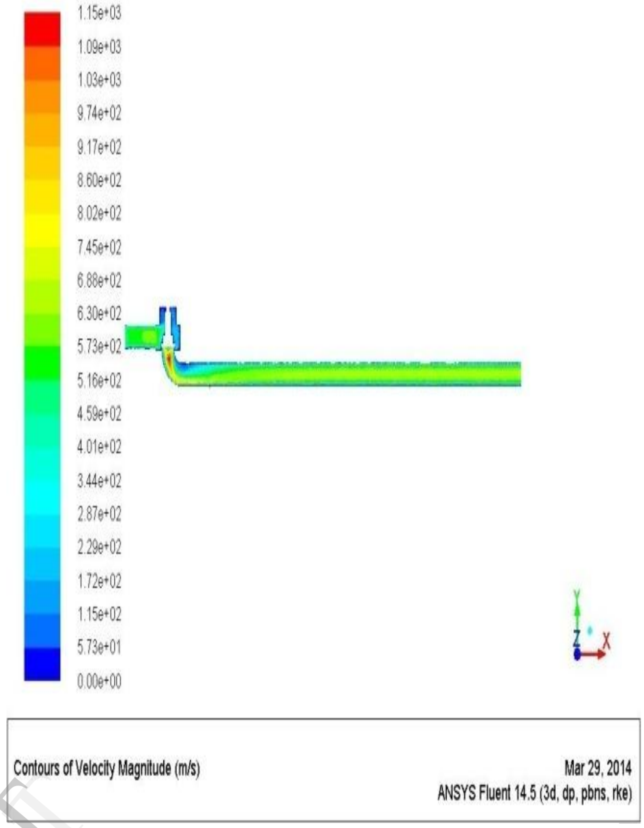
Solver – ANSYS Mechanical APDL

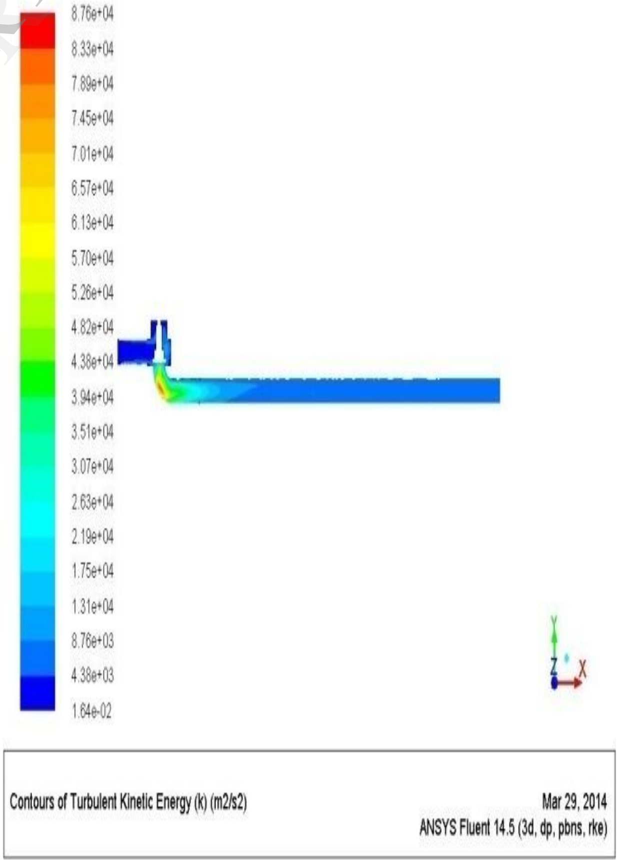
Turbulence Model – Standard K-ε Model

Assumption

Flow is Steady, Irrotational, Uniform, Viscous, Turbulent and 3 Dimensional Symmetry.







4. CONCLUSION AND FUTURE WORK

This paper deals with the Analytical study and Computational analysis of flow induced vibration in pipeline. Modal Analysis in the pipe flow configuration is studied. The dynamic fluid behaviors in the valve annular region are studied and obtained results in CFD and Fluid Flow analysis to be extended full pipe configuration. Flow Induced Vibration of Coupled analysis to be done by ANSYS CFX. Experimental Study and Analytical Study to be extended to solve the real physical problem are planned.

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