FEA Based Frequency Optimization Of Duct With Variable Cross Section Through Structural Modifications For Avoiding Resonance

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ABSTRACT

Ducts are used to carry fluid in various applications in HVAC systems, thermal power plants, cement and other process industries. Such ducts are generally subjected to failure due to cyclic stresses either caused by high temperature fluctuations, mechanical vibrations or due acoustic vibrations caused due to the fluid flowing through the ducts. In this paper we study the failure of one such duct in which acoustic vibrations cause resonance leading to weld failure and cracks.

A lot of work has been earlier done to improve the frequency of ducts using CFD analysis for finding the nature of the flow, effect of the varying C/S of the duct on the flow and duct vibration. Through the earlier works, the methods like active noise control, and development of mathematical model for finding analytical solutions to the duct acoustic failure have been demonstrated.

In this paper different methods to improve natural frequency of variable cross sectioned ducts(was duct) are discussed briefly while the main onus of the paper is on use of structural modifications for frequency improvement. Frequency of fluid flowing in duct under study was(earlier it was 'is') measured onsite and was found to be 14Hz.So all modes of vibration needed to be greater than 14 Hz for avoiding resonance and reducing vibrations by great extent. The paper focuses on the structural modification approach in order to improve the frequency and thus presents the various structural modifications and the optimized solution along with the impact of various modifications on the frequency. The duct is modelled in pro-e while the modal analysis is performed in ansys.

Keywords –Ansys, Duct frequency optimization, FEA, Modal analysis, Structural modifications.

1. INTRODUCTION

Ducts are normally used in industry for carrying various fluids. The fluids may range from water, to petroleum from chemicals to air. Their applications range from HVAC industries to thermal power plants, cement industries to process industries. These ducts are subject to failure due to thermal stress, cyclic stresses generated as a result of the mechanical vibrations or due to acoustic vibrations generated as a result of the fluid flowing through the ducts.

A lot of work has been done to suggest various methods for avoiding the failure of ducts due to acoustic vibrations. The work done by a lot of authors is mainly restricted to the area of active noise control, cancellation of noise or similar methods to reduce the turbulence in the fluid flow in order to avoid resonance.I-Chien Lee, Kun-Yu Chen , Jing Wang Yu [1] studied the vibration of flue-gas system duct downstream the induced draft fans. Through their research they introduced the modified turning vanes and splitters which helped to reduce the turbulence and avoid vibration.

Sing Vivek Asnani, Rajendra and Stephen Yurkovich[2] have proposed method to nullify vibrations using adaptive noise equalize (ANE) sound waves. This method generates sound waves equal in magnitude and opposite in direction to the disturbance wave. So all disturbances are nullified and hence the vibration is reduced.

The following paper deals with the use of structural modifications in order to increase the frequency instead of dealing with the velocity of the fluids or nullifying the sound to reduce the vibrations.

Challenges in duct design

Challenge while increasing the frequency of duct is:

Frequency, $f = (1/2\pi)*\sqrt{(k/m)}$

Since frequency is a function of both mass and stiffness, the effect of increase of mass in order to increase frequency was done but the increase in mass did not improve the frequency significantly hence the approach the increasing the stiffness of the duct through structural modifications was adopted to improve the frequency.

The duct in consideration is one with variable C/S of the types used in cement plants. The duct was observed to undergo failure due to due to acoustic resonance caused due to the pumping modes observed as a result of the fluid passing through the duct.

This paper aims at using the structural modifications as the basis of frequency improvement. Further it goes on to checking the effect of change of number of support structures on the frequency of vibration. The paper thus describes a methodology using modal analysis in ansys for improvement of frequency of the duct above 14 Hz to avoid resonance.

2. METHODOLOGY AND ANALYSIS

The duct is one with variable cross section as shown in FIGURE 1 :

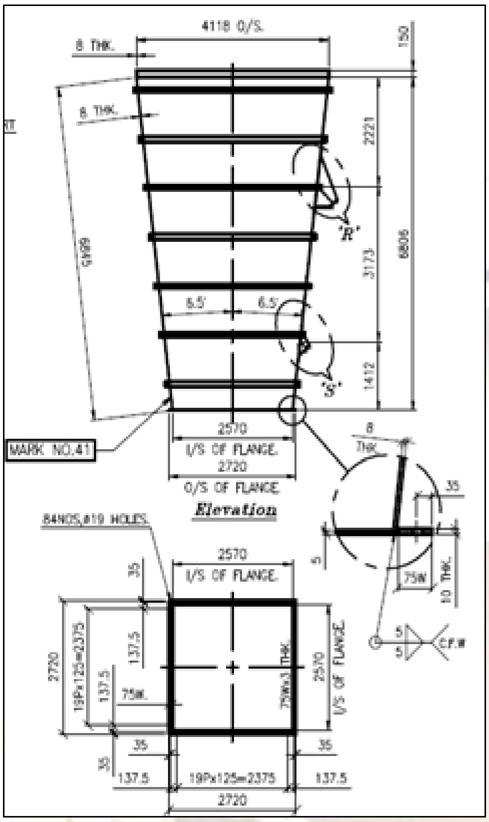

Fig 1 : Duct layout.

2.1 FEA approach

1) Modelling of duct with its support is done in Pro-E
2) Element used for meshing are 10 node tetrahedron
3) 10 node tetrahedron element is used for leg support meshing.
4) Sizing for tetrahedron element for duct is 0.05 m.
5) All the support are fixed from bottom.
6) Finding out all modes of vibration in Hz for baseline model
7) Finding out all modes of vibration with structural modifications i.e. addition of the triangular supports.
8) Repeating step 10 till the frequency of the duct is not greater than 14 Hz which is the frequency of the fluid flowing through the duct.
9) Performing convergence analysis for the selected optimized solution in order to demonstrate stable solution.

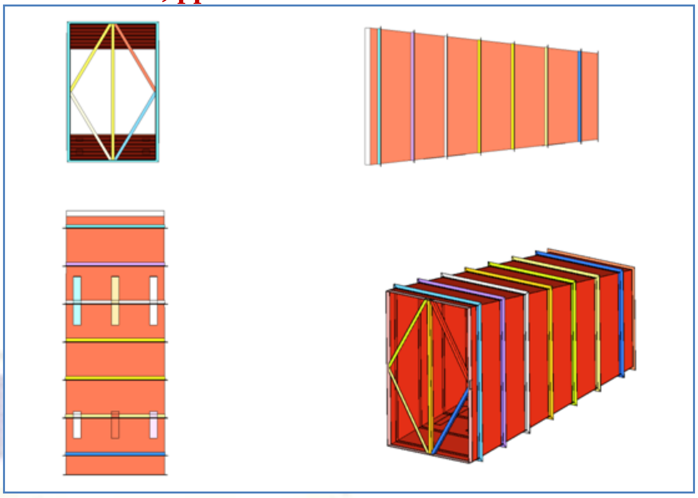

Fig 2 : Pro-E model

2.2 Meshing of the model

Meshing is the method of dividing the model into the number of element to obtain the good accuracy in the analysis. As the number of element increases the accuracy of analysis increases. In this paper meshing size is taken as 0.05 m for duct and the support structure.

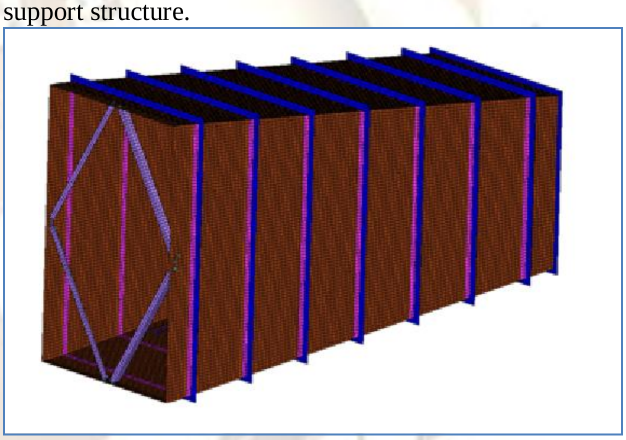

Fig 3 : Meshing of the model

3.
4. ANALYSIS OF BASE MODEL AND THE STRUCTURAL MODIFICATIONS

Analysis of the base model reveals that the 1st modal frequency is around 4Hz.Hence the duct fails. The structural modifications are suggested to improve the frequency above 14 Hz. The iterations done are with 1, 2, 3 sets of triangular support structures.

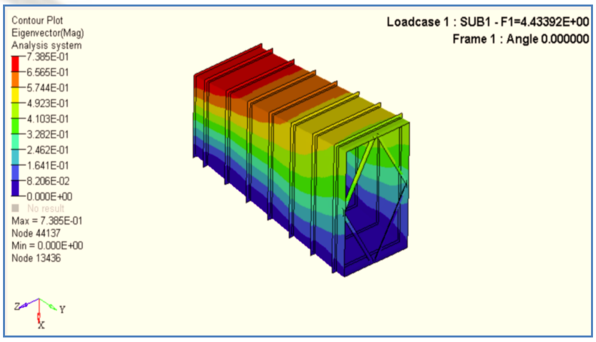

Fig 4: Original Model

3.1 Iteration I with 1 set of triangular support structures

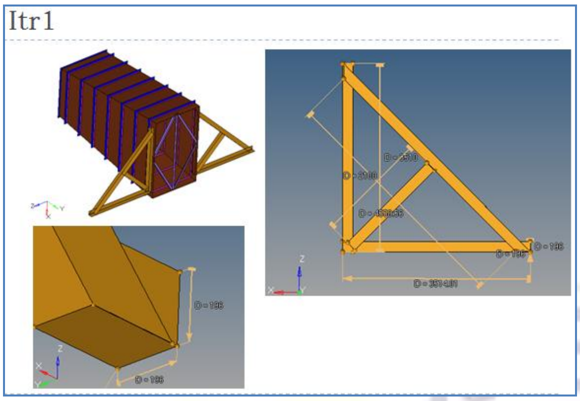

Fig 5 : CAD geometry with 1 set of triangular structures.

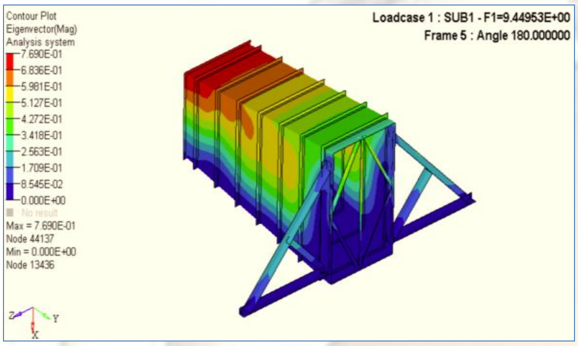

Fig 6 : Analysis of iteration I

The frequency obtained by 1st iteration is 9.45 Hz which is less than 14 Hz hence the structural modifications are added.

3.2 Iteration II with 2 sets of triangular support structures

In the second iteration, the number of structural supports is increased to two at two locations near the duct stiffeners.

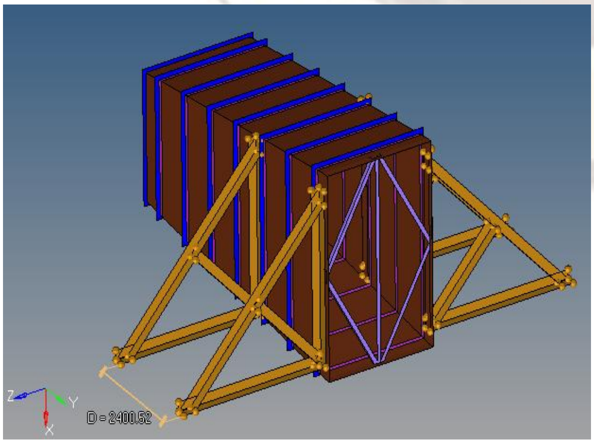

Fig 7 : CAD geometry with 1 set of triangular structures.

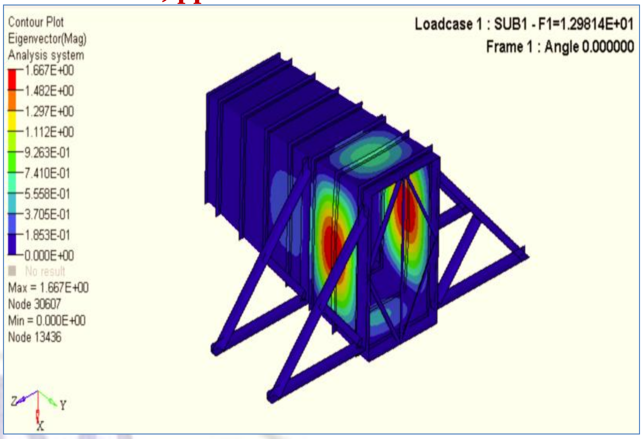

Fig 7 : Analysis of iteration II

The frequency obtained by 2nd iteration is 12.98 Hz which is less than 14 Hz hence the structural modifications are added.

3.3 Iteration III with 3 sets of triangular support structures

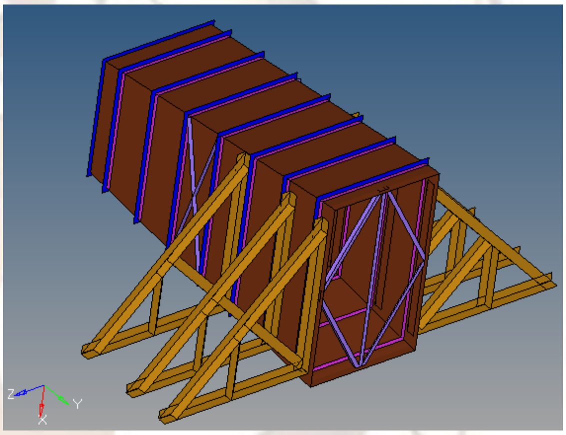

Fig 8 : Iteration III design with 3 support structures.

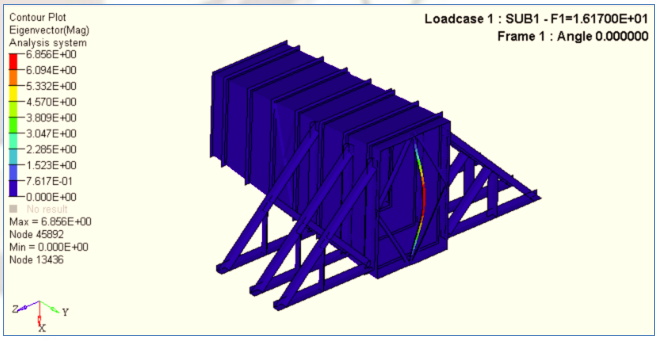

Fig 9 : Analysis of iteration III

The frequency obtained by II iteration is 16.1 Hz which is less than 14 Hz hence the structural modifications are added.

3.4 Convergence:

The convergence of the meshing was studied for iteration 5 to validate the consistency of the FEA results. The element size was varied by generating a coarse mesh initially and then refining the mesh for increasing accuracy.

As the number of nodes varied, the frequency varied and over the finer mesh sizes, the frequency remained almost constant with not much change with respect to the increase in the number of modes.

The following table gives the frequency values V/S the number of nodes also the plots give the frequency at every iteration. The graph of nodes v/S displacement is also plotted.

Table 1: Table of Nodes V/S frequency, Maximum Displacement

Mesh Size(mm)	No. of Elements	Frequency (Hz)	Max displacement (mm)
25	206767	14.3172	0.1773
50	51540	14.538	0.177
100	14486	14.65	0.17656
150	5846	14.6584	0.17336
200	4158	14.9148	0.16661

The following graph shows the convergence of the frequency V/S the number of elements.

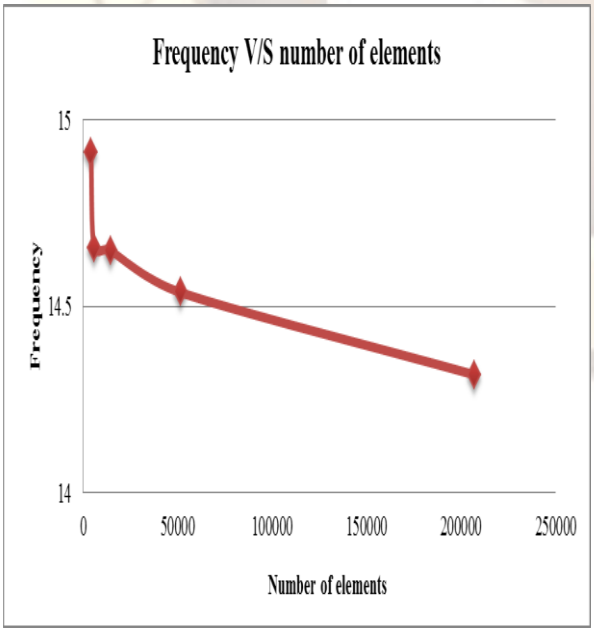

Fig 10: Convergence of Frequency

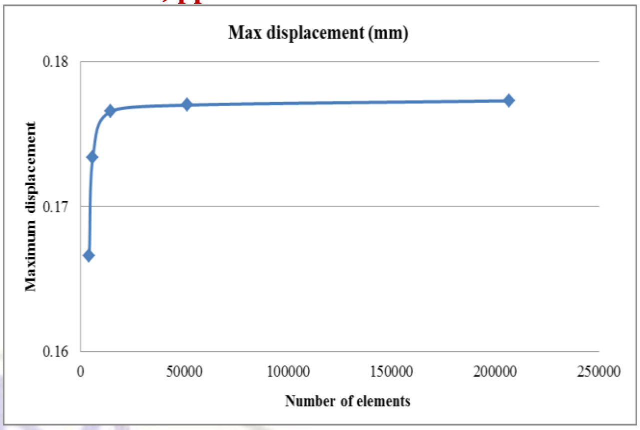

Fig 11 : Convergence of Displacement

4. RESULTS AND DISCUSSIONS

Analysis methodology stated above in section 3 helped to conclude that with the increase in the number of the support structures the frequency of vibration improved. Analysis is done and values of lowest modes are compared in graph shown below for the various iterations V/S the modal frequencies. Also the graph of frequency V/S the number of modes for increasing number of supports is also plotted to see the effect of increase of the supports on the frequency. It shows that as the number of supports and their stiffness increases, the frequency also improves.

Table 2 : Frequency V/S Mode for different number if support structure.

	Frequency (Hz)			
Mod	**1 Set of support structures**	**2 Sets of support structures**	**3 Sets of support structures**	**4 Sets of support structures**
1	9.45E+00	1.30E+01	1.45E+01	1.53E+01
2	1.23E+01	1.38E+01	1.50E+01	1.55E+01
3	1.37E+01	1.46E+01	1.62E+01	1.62E+01
4	1.38E+01	1.48E+01	1.72E+01	1.71E+01
5	1.57E+01	1.62E+01	1.81E+01	1.88E+01
6	1.61E+01	1.73E+01	1.87E+01	1.92E+01

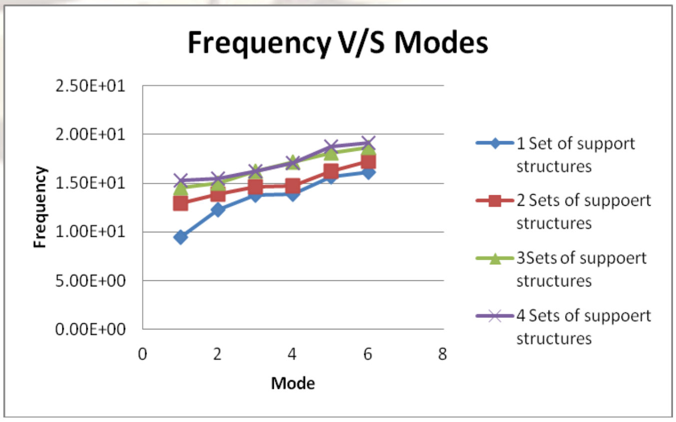

Fig 12 : Frequency Vs/S modes for diff support sets

The above graph shows the increase in the frequency of vibration of the duct with the change in the number of the of structural supports added to the duct structure for improving the frequency.

As we try to increase number of supports over 4, nature of graph flattens which means that the increase in the number of supports after a certain number does not improve the frequency drastically, rather the frequency increases slightly. Also the local modes get improved by addition of cross stiffeners. We can conclude that the increase in the support structures coupled with the change in locations of the structures is a method for optimization of the duct frequency.

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REFERENCES

[1] I-Chien Lee, Kun-Yu Chen , Jing Wang Yu, 'Vibration reduction of flue gas duct system on the site of Tai-Chung No9 power plant'.18th conference of electric power supply company.

[2] SingVivake Asnani, Rajendra h, Stephen Yurkovich, 'Active Control of Amplitude or Frequency Modulated Sounds in a Duct.'

[3] G. E. Driesen ,Tsu-te wu, Dilip A. Amin ,'Structural integrity justification of a rectangular duct under large external pressure.'ASME conference San Diego,1998.

[4] Kenneth A. Ramsey,' Experimental Modal Analysis, Structural Modifications and FEM Analysis on a Desktop Computer',1st international modal analysis conference USA , 1982

[5] Sai Jagan Mohan, Rudra Pratap , 'A natural classification of vibration modes of polygonal ducts based on group theoretic analysis.',Journal of sound and vibration,2003.

[6] Ansys 12. Ansys manual.