Effect of Angular movement of Lifting Arm on Natural Frequency of Container Lifting Mechanism using Finite Element Modal Analysis

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***Abstract* - Hydraulic machines are commonly placed in the industry of now a day. Study of vibrations in hydraulic cylinder is very much important in container lifting devices, which cause seal failure, reduction of fatigue life of cylinder, reduction on control, energy loss, increase in oil temperature results in low viscosity. To study the effect of vibration, root cause for vibration and identifying the natural frequency of hydraulic cylinder and also dynamic behavior of loading condition are required. Vibrations in hydraulic cylinder are multi degree of freedom problem. So, analysis of mode shapes of vibration is required. In this paper, modal analysis of container lifting mechanism was carried out in ANSYS workbench. Maximum deformation due to vibration has been studied and effect of angular movement of arm on natural frequency of lifting container is obtained through finite element analysis. As angle of arm increase, the natural frequency of mechanism is slightly increased.**

***Index Terms* - Finite element analysis, Modal analysis, lifting container, hydraulic cylinder**

I. INTRODUCTION

Hydraulic cylinders are one of the most common components of the hydraulic systems used in many engineering applications like; automatic manufacturing and montage lines, heavy construction equipments, control systems, sensitive measurement and test systems. The applications can vary from very robust excavators to very precise manufacturing robots but in outline the hydraulic actuators are quite similar in mechanical sense. Hydraulic cylinders are actuation devices that used for producing linear motion in the hydraulic systems and they convert the hydraulic energy of the pressurized fluids into the mechanical energy needed to control the movement of machine linkages and attachments. [1]

A. Ylinen et. al. [2] have been studied the multibody simulations of a hydraulic cylinder model. Friction plays an important role in dynamical analyses by introducing damping to the system. The very basic friction model is the Coulomb friction where the friction force is dependent only on the contact force. However, in systems as the hydraulic cylinder, the friction force is known to be a function of the sliding velocity thus a dynamical friction model is required to capture the velocity dependent properties. Furthermore the stick–slip phenomenon where the sliding is not continuous is an important factor to take into account. In stick–slip phenomenon the friction alternates between the static friction and sliding friction. Through the stick–slip effect the extension of the cylinder is not continuous and it can induce high stress peaks to the system. The dynamical friction model however is not suitable for initial state computation because of the velocity dependency of the model. Moreover, the dynamical friction model introduces a new variable to the system. Therefore it will be derived a friction model for the initial state computations based on the parameters of the dynamical friction model.

In recent times, many investigations have been motivated by the engineering applications of vibration, such as the design of machines, foundations, structures, engines, turbines, and control systems. Multibody dynamics analysis was originally developed as a tool for modeling rigid multibody systems with simple tree-like topologies, but has considerably evolved to the point where it can handle linearly and nonlinearly elastic multibody systems with arbitrary topologies. [3-4] Pavankumar Shah et al. [5] carried out dynamic Analysis of Hydraulic Cylinder of JCB JS 130. The vibration of cylinder using simply supported beam concept under a moving point load was analyzed by using finite element analysis. Modal analysis was done on the basis of different mode. Total deformation under static loading condition has been studied and the critical region of the cylinder was found by using finite element analysis. [6, 7]

II. FINITE ELEMENT ANALYSIS PROCEDURE

Finite element analysis of container lifting mechanism has been carried out using ANSYS Workbench. Deformation due to vibration and mode shapes are calculated using modal analysis. From finite element analysis results, first ten natural frequencies are considered to study effect of angular movement of lifting arm with respect to natural frequency.

Geometric Modeling

Schematic diagram of container lifting mechanism is shown in figure 1. 3 dimensional model of container lifting mechanism has been made in creo 2.0. Figure 2 shows the 3D assembly model of container lifting mechanism.

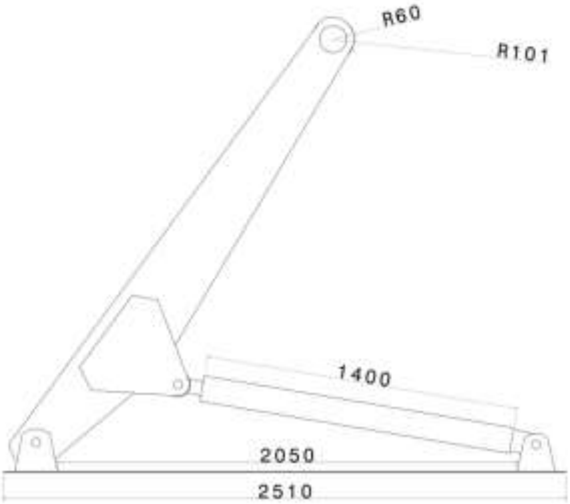


Fig 1 Schematic diagram of container lifting mechanism

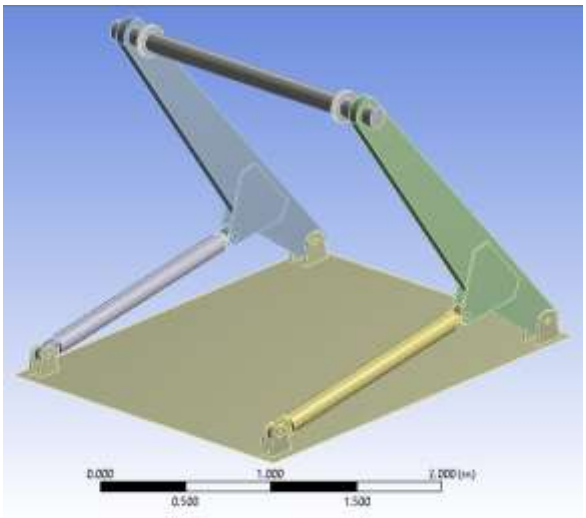


Fig 2 3-D model of container lifting device

Assumption

- Container mass is attached or lifted during operating condition. In finite element analysis, effect of container mass on natural frequency is negligible. So, container mass is not consider in finite element analysis.
- Materials for all components of lifting device are considered as homogeneous. But, in actual condition its properties gets change near welded and machined parts.
- Hydraulic oil is not considered in modal analysis
- Only first ten natural frequencies obtained from modal analysis are considered to study mode shapes.
- The angle of arm in lifting device with respect to horizontal is considered as 20° equal divisions in 20° to 140° span.

Boundary Condition

Container lifting mechanism is mounted on trailer. So, base plate of mechanism is taken as fixed as actual condition. The connection between piston and cylinder in hydraulic cylinder is taken as slider. Bonded type connections are used to define pinned joint between linkages of lifting mechanism for particular position of mechanism.

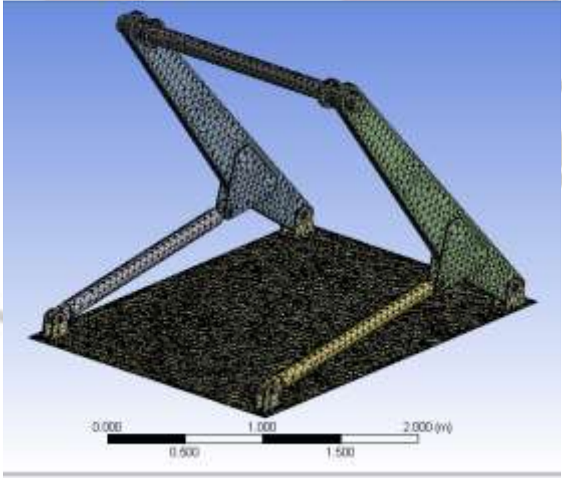


Fig 3 Meshing of CAD Model

Meshing

For meshing of different parts of lifting mechanism, type 10 noded tetrahedral structural solid element (SOLID187) is used. This element have 3 degree of freedom at each node; i. e. translation in x, y and z directions. Total number of 46857 nodes and 22797 elements are generated in meshing. Minimum edge length of element is 0.5 mm. Tetrahedral mesh created in ANSYS of CAD model is shown in figure 3.

Material Modeling

In container lifting device, different materials are taken as per application. Base plate and linkages are structural members. So, it is made of structural steel. Piston and cylinder are made of SAE 1045 and ST 52 material respectively. Cross rod is made of S355 material. Following mechanical properties are considered for different materials as shown in table 1.

Table 1 Properties of material for container lifting device components

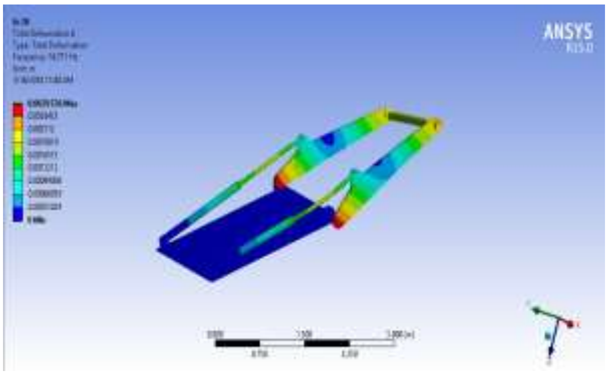
	Base plate and linkages	Piston	Cylinder	Cross rod
Material	Structural steel	SAE 1045	ST 52	S355
Density (kg/m^3)	7850	7872 kg/m^3	7800	7800

Young’s Modulus (Pa)	$2x10^{11}$	$2x10^{11}$	$2x10^{11}$	$2.1x10^{11}$
Poisson’s ratio	0.3	0.29	0.3	0.3
Bulk Modulus (Pa)	$1.667x10^{11}$	$1.587x10^{11}$	$1.667x10^{11}$	$1.75x10^{11}$
Shear modulus (Pa)	$7.692x10^{10}$	$7.752x10^{10}$	$7.692x10^{10}$	$8.077x10^{10}$

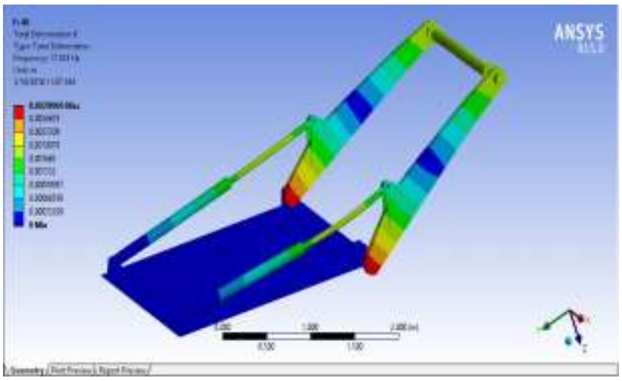
III. RESULTS AND DISCUSSION

Post-Processing

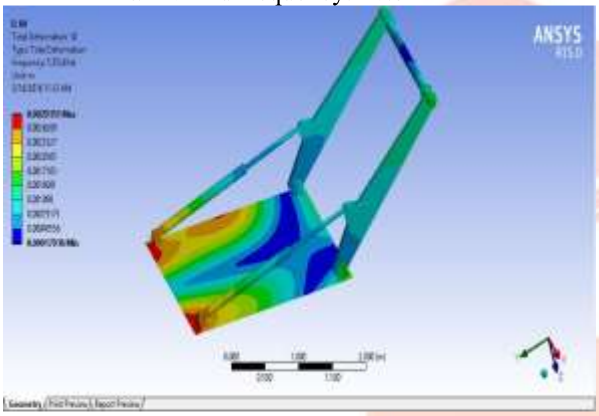
In post processing, results of deformation due to natural frequency of vibration and mode shapes are calculated. Various results obtained at different angle of lifting arm are discussed below. (Figure 4)



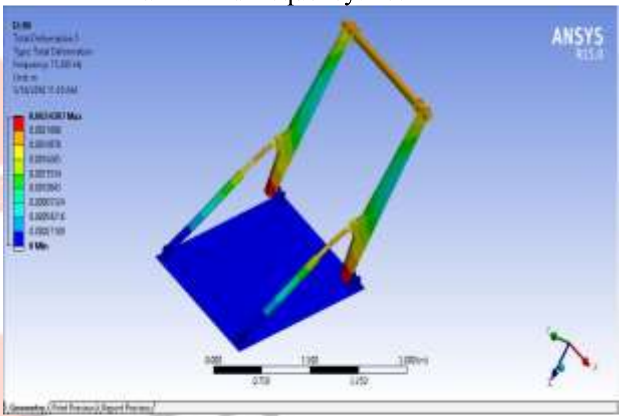
α=20°and frequency: 16.711 Hz



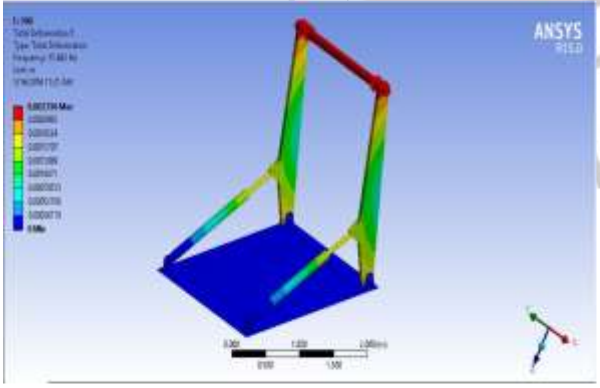
α=40°and frequency: 17.414 Hz



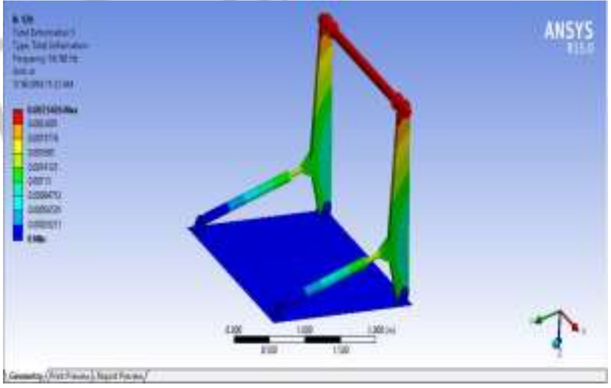
at α=60°and frequency: 5.5528 Hz



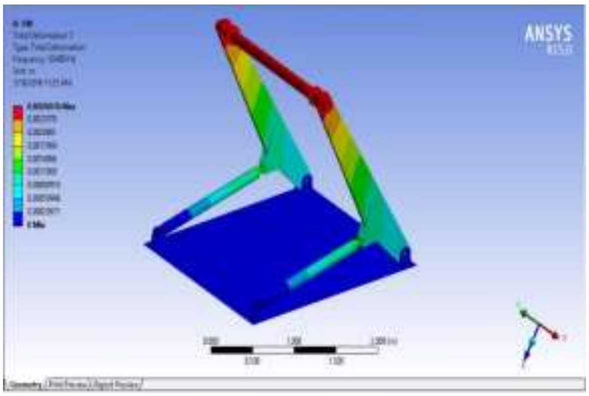
α=80°and frequency: 15.283 Hz



α=100°and frequency: 15.643 Hz



α=120°and frequency: 16.163 Hz



α=140°and frequency: 18.408 Hz

Fig 4 Natural frequencies at different angular position of lifting arm

From the results of finite element analysis, First ten natural frequencies are obtained at different angular position of lifting arm listed in table 2. Figure 5 shoes the graphical representation for first ten natural frequencies is obtained at different angular position of lifting arm.

Table 2 Natural frequencies obtained while angular displacement of rotating arm step by step

No of Modes	**Rotation given to Arm (in Degrees)**						
	20°	**40°**	**60°**	**80°**	**100°**	**120°**	**140°**
1	2.3034	2.4597	2.8618	3.2639	4.1333	5.3417	7.2271
2	3.9499	4.1245	4.5259	4.9274	5.5204	6.3619	7.729
3	7.2311	7.14	7.4443	7.7486	8.4521	9.4421	10.979
4	11.876	12.05	12.1435	12.237	12.284	12.304	12.335
5	11.964	13.243	14.263	15.283	15.643	16.163	18.408
6	16.711	17.414	18.6675	19.921	20.926	21.475	21.736
7	20.188	20.961	22.046	23.131	24.442	25.757	28.382
8	39.791	40.098	41.383	42.668	49.088	60.157	72.761
9	43.082	44.409	45.8035	47.198	53.233	63.863	74.951
10	49.017	54.201	60.929	67.657	69.609	71.131	77.742

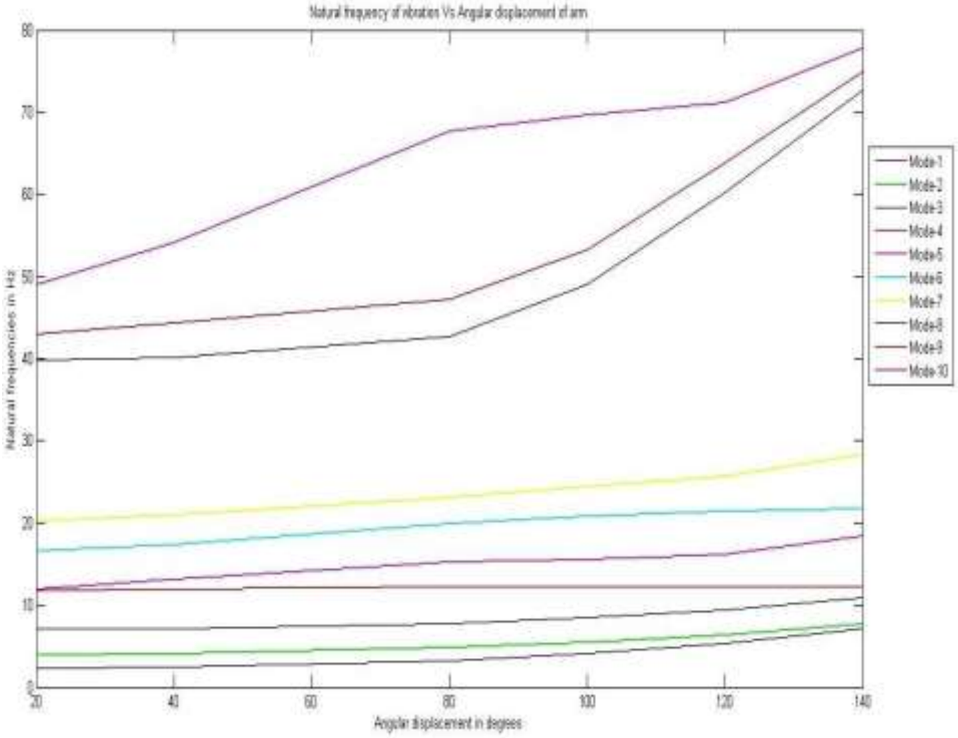


Fig 5 Graphical representation of natural frequencies at different angular positions

IV. CONCLUSION

From finite element analysis of container lifting device, deformation due to natural frequency of vibration is evaluated and mode shapes of vibration are calculated. Deformation is obtained at first natural frequency as 2.1 mm at 140° position of lifting arm. As angular position of arm increase from 20° to 140°, the natural frequency of lifting mechanism is uniformly increases. Also the slope of the curves between 120° to 140° is higher more to other angular position of lifting arm. The difference between natural frequencies of 7th and 8th mode shapes are comparatively high, which shows that lifting mechanism must be operated in between 28.382 to 39.791 Hz.

V. REFERENCES

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