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Dynamic Analysis of Hydraulic Cylinder of JCB JS 130 -Tracked Excavator

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***Abstract* - Many machines and machine mechanisms run under dynamic working conditions. The vibrations produced under dynamic conditions affect many important design parameters such as strength, production costs, productivity. In this dissertation work, the vibration analysis of a hydraulic cylinder subjected to dynamic loads is studied. Computer aided engineering (CAE) procedures are used to analyze the dynamic response of the cylinder walls. The finite element methods used in the analysis are applied by a computer aided design and analysis software ANSYS. First of all, the vibration under the moving load problem is studied. The vibration of simply supported beam under a moving point load is analyzed by using ANSYS. In addition to studies in the literature, it is considered that the static and dynamic analysis of the hydraulic cylinder by applying of operating pressure and hydrostatic pressure respectively justifying behavior of both pressure in cylinder. Also identifying which boundary condition will suitable for sustaining and minimum failure occur by evaluate simulation result of ANSYS such like total deformation, deformation in X-direction, Y-direction and Z-direction. Also identifying modal analysis of hydraulic cylinder in both conditions.**

***Index Terms* - ANSYS, CAE, dynamic analysis, modal analysis, and static analysis**

I. Introduction

Hydraulic and pneumatic system equipments are the important components of engineering applications. Especially hydraulic and pneumatic cylinders are used in many engineering applications like; automatic manufacturing and montage lines, heavy construction equipments, control systems, sensitive measurement and test systems.

One of the most important factors considering at the design step of these equipments is working conditions of cylinder. Cylinders have different working frequencies according to their usage fields. While the huge sized cylinders used in systems that requires higher force and moment inputs, works generally in lower frequencies, the small sized cylinders used in sensitive application fields like test and measurement systems can have higher working frequencies.

At the lower working frequency situations, pressure effect on the cylinder is considered as static load, and the hydraulic system equipments are designed according to this criterion. Besides this, at the design procedure of cylinders with higher working frequencies, the dynamic effect with respect to instantaneous change of pressure must be taken into consideration as well as the static analysis.

When the dynamic loading on cylinder is investigated, it is seen that, cylinder surface area subjected to the hydraulic pressure increases with respect to time while the piston travels from one end of the cylinder to the other and it reaches to the highest value at the end of the stroke. Despite the forward movement of the piston, the loaded surfaces are unloaded until the piston comes over that region and these surfaces are reloaded with the passing of the piston. Loading in the cylinders with the present conditions can be defined as a moving load with some differences.

II. Specification of the Hydraulic Cylinder

Fig. 1 JCB JS 130 (Tracked Excavator)

As shown Figure 1 JCB JS 130 (Tracked Excavator) which having maximum operating weight 13900kg and net engine power is 63kW (85hp). By detail study of specification of this Tracked Excavator and identified detail of hydraulic cylinder.

HYDRAULIC SYSTEM
A variable flow load sensing system with flowon demand, variable power output and servo operated, multi-function open centre control.

PUMPS
Main pumps: 2 variable displacement axial piston type.
Maximum flow: 2 x 121 L/min (2 x 26.6 UK GPM).
Servo pump: Gear type.
Maximum flow: 20 L/min (4.4 UK GPM).

CONTROL VALVE
A combined four and five spool control valve with auxiliary service spool as standard. When required twin pump flow is combined to boom, dipper and bucket services for greater speed and efficiency.

RELIEF VALVE SETTINGS
BOOM/ARM/BUCKET 318 bar (4610lbf/sq.in)
With power boost 343 bar (4975lbf/sq.in)
Swing circuit 279 bar (4045lbf/sq.in)
Travel circuit 343 bar (4975lbf/sq.in)
Pilot control 40 bar (569lbf/sq.in)
A separate Cushion Control valve in the servo system provides cushioning of the boom and dipper spools selection and quick warm-up of the servo system.

HYDRAULIC CYLINDERS
Double acting type, with bolt-up end caps and hardened steel bearing bushes. End cushioning is fitted as standard on boom, dipper and bucket rams.
Dimensions:
BOOM
Bore 100mm (3.9in)
Rod 75mm (3.0in)
Stroke 1081mm (42.5in)

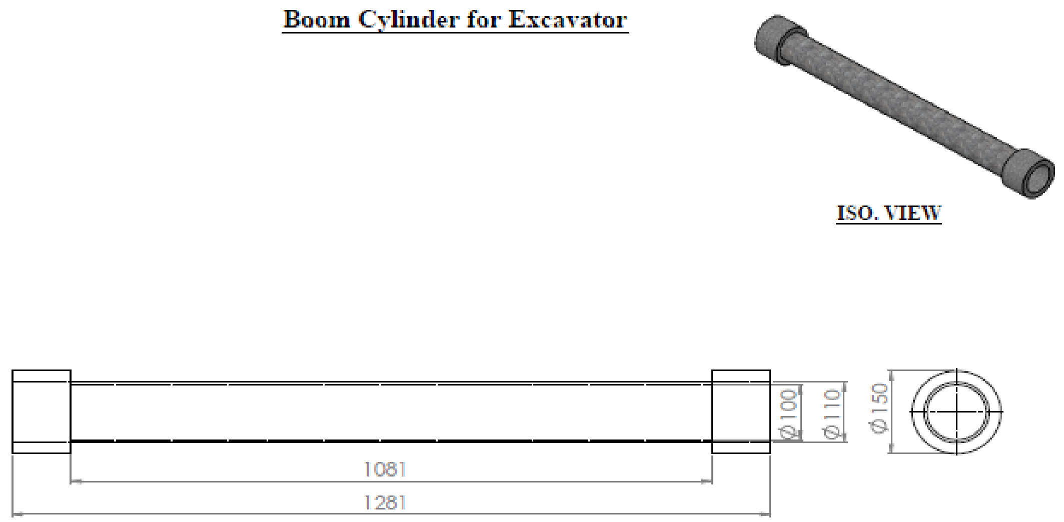

Fig.2 Detail drawing of Boom Cylinder for Tracked Excavator

DIPPER
Bore 115mm (4.5in)
Rod 80mm (3.1in)
Stroke 1205mm (47.4in)
BUCKET
Bore 95mm (3.7in)
Rod 70mm (2.8in)
Stroke 924mm (36.4in)
FILTRATION
The hydraulic components are protected by the highest standard of filtration to ensure long hydraulic fluid and component life.
In tank: 150 micron, suction strainer.
Main return line: 10 micron, fibre form element.
Nephron Bypass line: 1.5 micron, paperelement.

Pilot line: 10 micron, paper element.
Hydraulic hammer return: 10 micron, reinforced microform element.

COOLING

Worldwide cooling is provided via a full return line air blast cooler with anti-block wavy cooling fins and separate easy clean fine mesh grill.

III. Analysis of the Hydraulic Cylinder as Cantilever Beam Boundary Condition

Basic Steps of FEA Analysis

1. **Pre-processing:** defining the problem.
   The major steps in pre-processing are
   a. Define key points/lines/areas/volumes,
   b. Define element type and material/geometric properties,
   c. Mesh lines/areas/ volumes as required. The amount of detail required will depend on the dimensionality of the analysis, i.e., 1D, 2D, axisymmetric, and 3D.
2. **Solution:** assigning loads, constraints, and solving
   Here, it is necessary to specify the loads (point or pressure), constraints (translational and rotational), and finally solve the resulting set of equations.
3. **Post processing:** further processing and viewing of the results
   In this stage one may wish to see
   a. Lists of nodal displacements,
   b. Element forces and moments,
   c. Deflection plots, and
   d. Stress contour diagrams or temperature maps.

Step-1 Pre-processing

1. Preparing cylinder model in Ansys Workbench
2. Check the Geometry for Meshing.
3. Apply Material for Each Component.
4. Create fine mesh.
   No. of Nodes: - 17494
   No. of Elements: - 2660
5. Define Boundary condition

Apply Fixed Constraint, Right hand end is fixed at X, Y and Z rotate at X, Y and Z, Left hand is free.

Results of Analysis Total Deformation

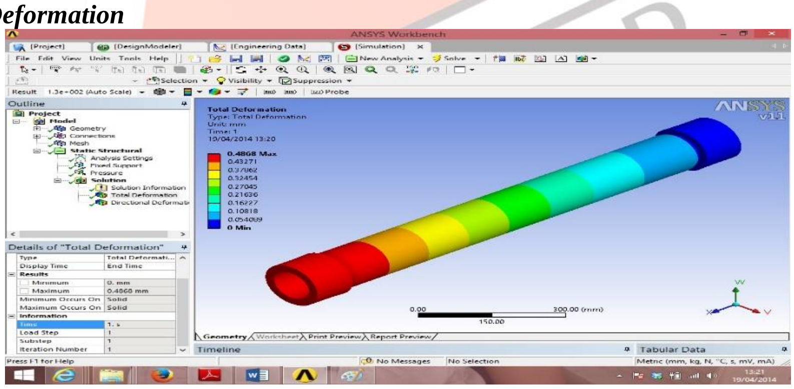

Fig. 3 Total deformation of Cylinder

Directional Deformation X- Direction

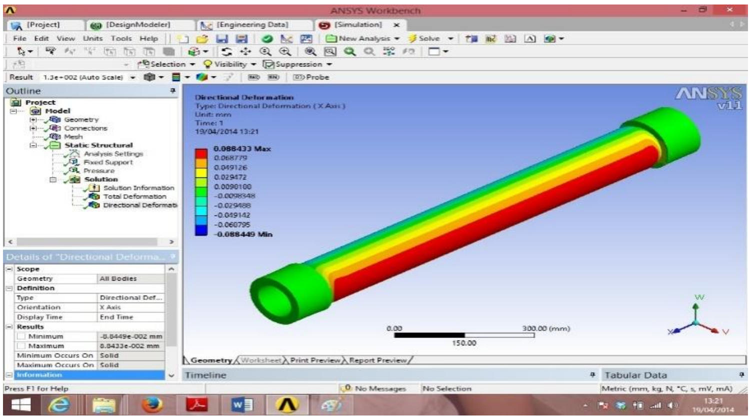

Fig. 4 Directional deformation in X

Y- Direction

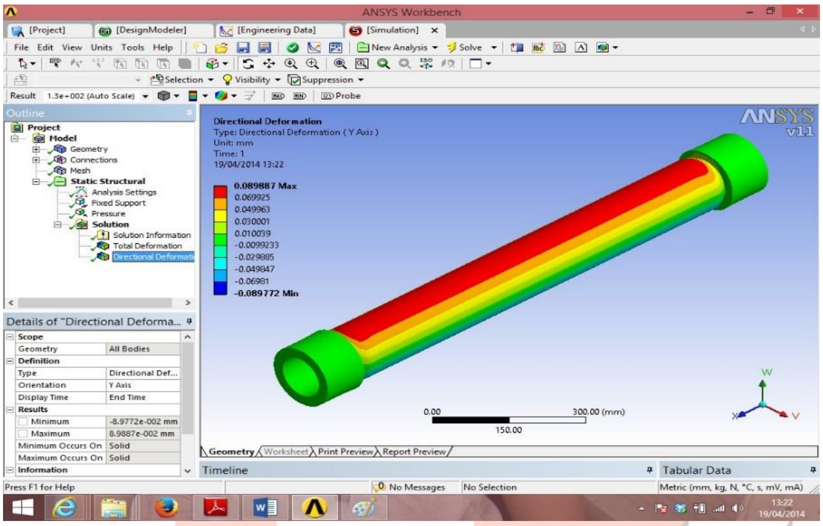

Fig. 5 Directional deformation in Y

Z- Direction

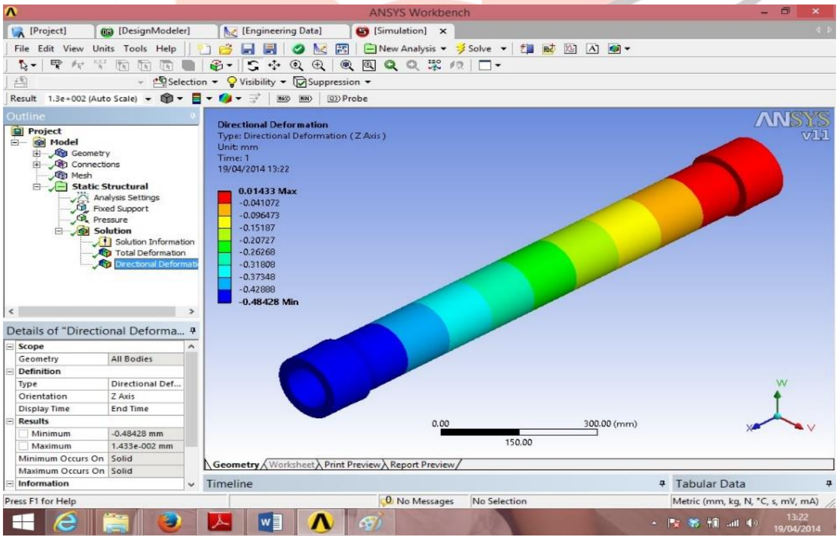

Fig. 6 Directional deformation in Z

STEPS OF DYNAMIC ANALYSIS
MODEL ANALYSIS
RESULTS OF ANALYSIS
Mode - 1

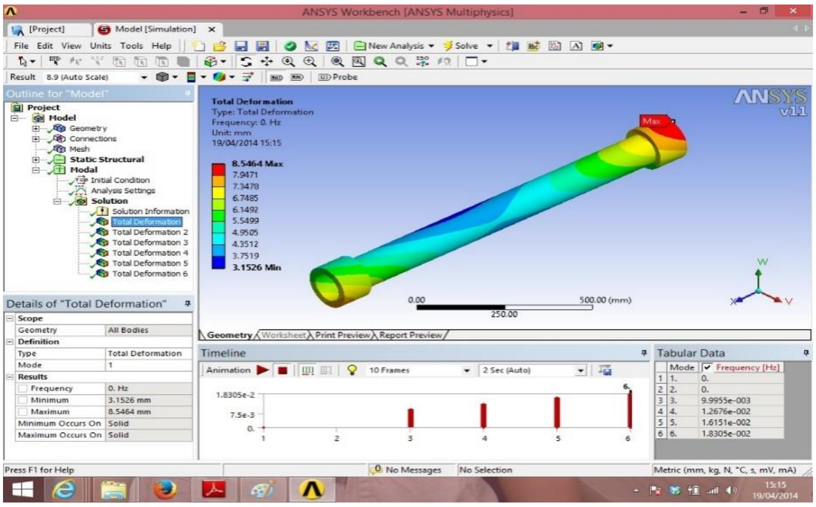

Fig. 7 Total deformation of mode 1

Mode-2

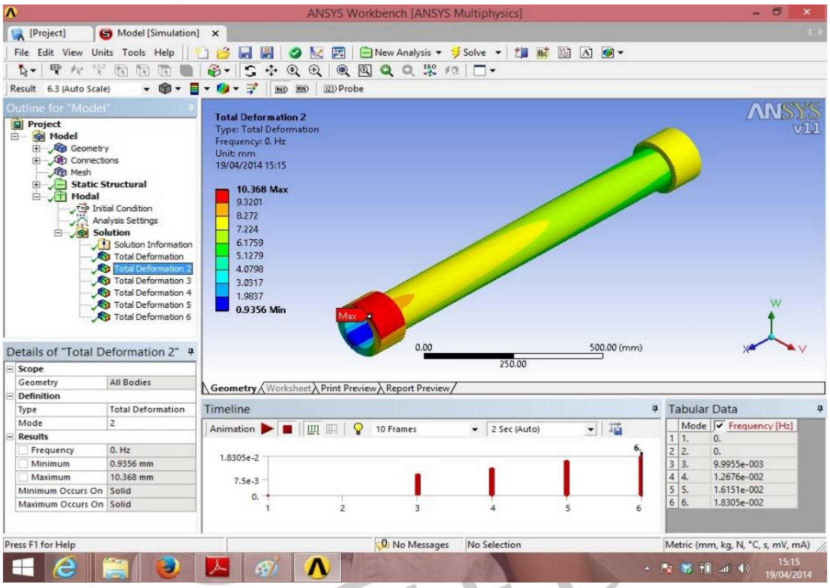

Fig. 8 Total deformation of mode 2

Mode-3

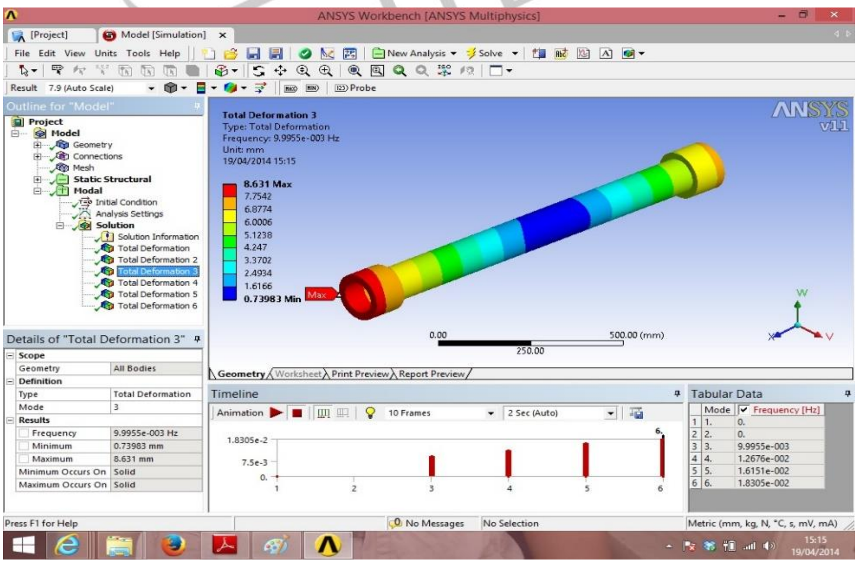

Fig. 9 Total deformation of mode 3

Mode-4

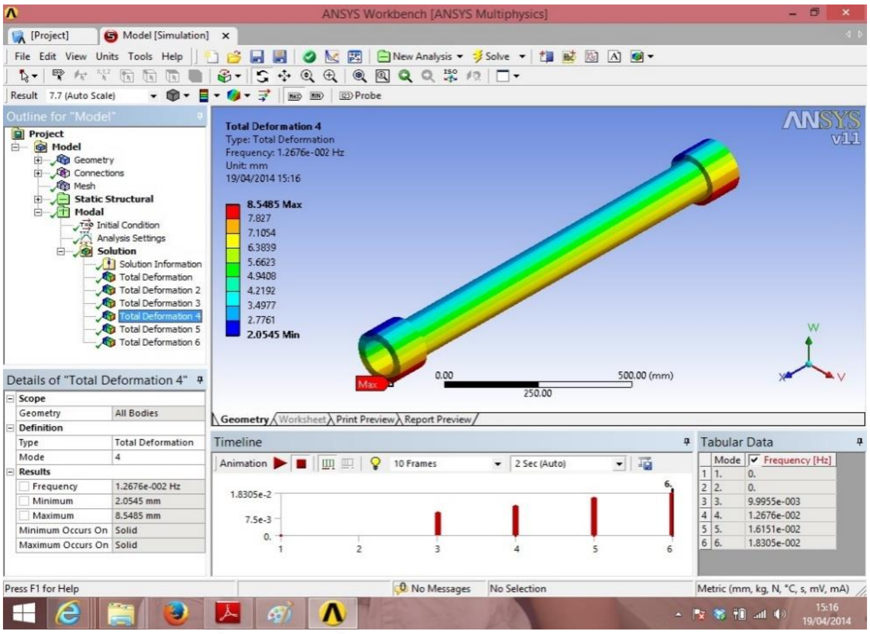

Fig. 10 Total deformation of mode 4

Mode-5

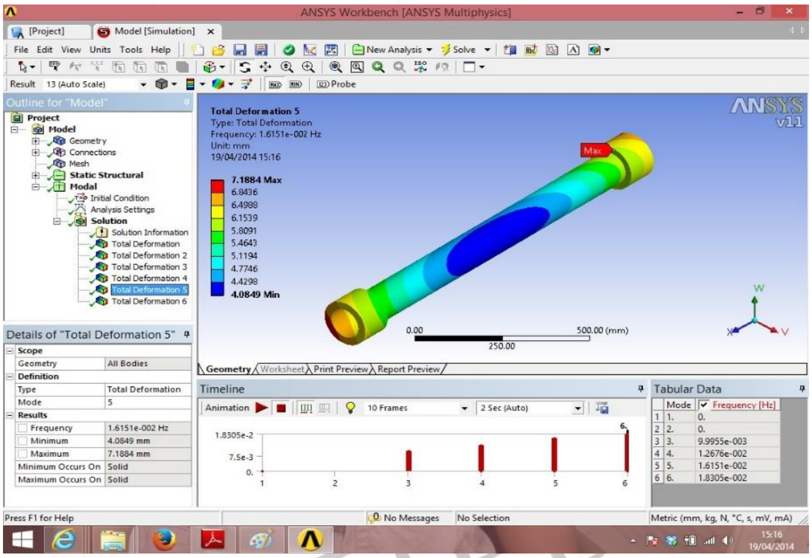

Fig. 11 Total deformation of mode 5

Mode-6

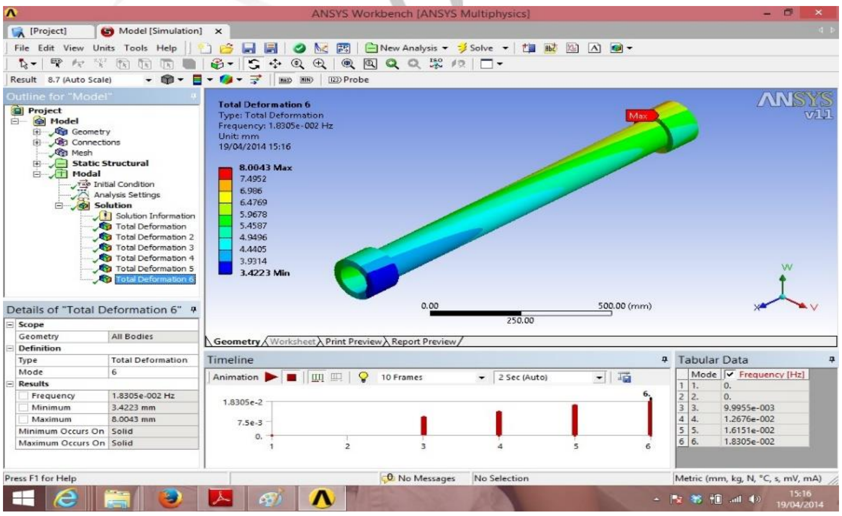

Fig.12 Total deformation of mode 6

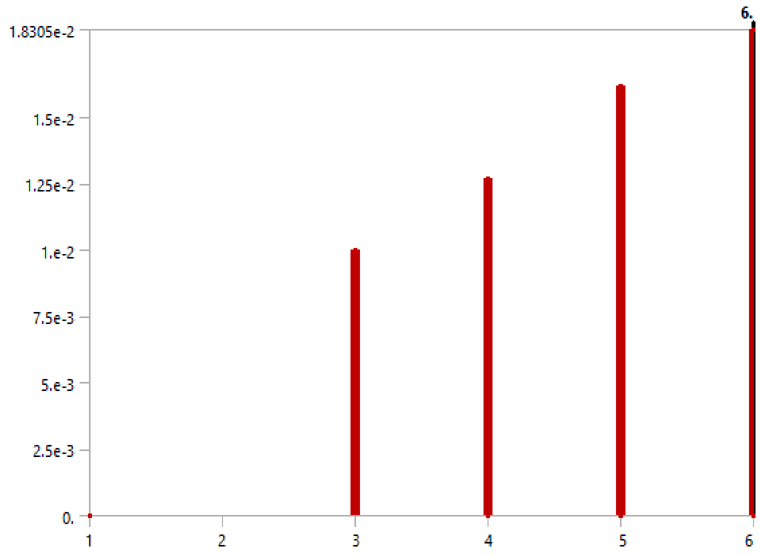

Fig. 13 Modal-Mode-Solution

Table 1 Natural frequencies of the Cylinder

Mode	Frequencies (Hz)
1	0
2	0
3	9.9955e-003
4	1.2676e-002
5	1.6151e-002
6	1.8305e-002

IV. ANALYSIS OF THE HYDRAULIC CYLINDER AS SIMPLY SUPPORTED BEAM BOUNDARY CONDITION

Basic Steps of FEA Analysis

1. **Pre-processing:** defining the problem
   The major steps in pre-processing are
   a. Define key points/lines/areas/volumes,
   b. Define element type and material/geometric properties,
   c. Mesh lines/areas/ volumes as required. The amount of detail required will depend on the dimensionality of the analysis, i.e., 1D, 2D, axisymmetric, and 3D.
2. **Solution:** assigning loads, constraints, and solving
   Here, it is necessary to specify the loads (point or pressure), constraints (translational and rotational), and finally solve the resulting set of equations.
3. **Post processing:** further processing and viewing of the results
   In this stage one may wish to see
   a. Lists of nodal displacements,
   b. Element forces and moments,
   c. Deflection plots, and
   d. Stress contour diagrams or temperature maps.

Step-1 Pre-processing

1. Preparing cylinder model in Ansys Workbench
2. Check the Geometry for Meshing.
3. Apply Material for Each Component.
4. Create fine mesh.
   No. of Nodes: - 17494
   No. of Elements: - 2260
5. Define Boundary condition
   Apply Fixed Support Constraint on both end of cylinder.

RESULTS OF ANALYSIS TOTAL DEFORMATION

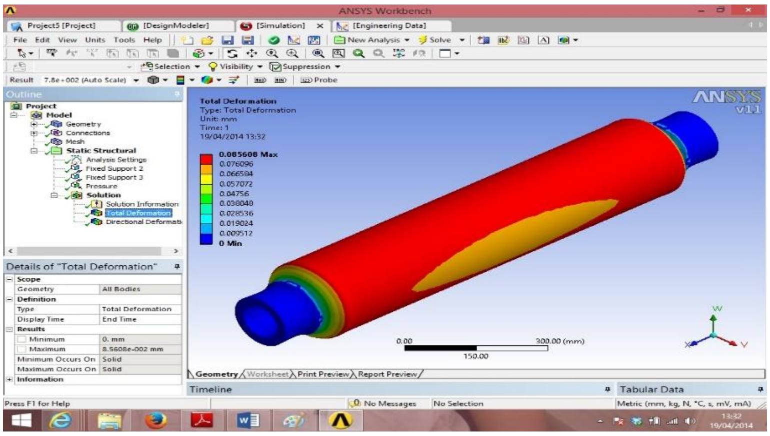

Fig. 14 Total deformation of Cylinder

Directional Deformation

X- Direction

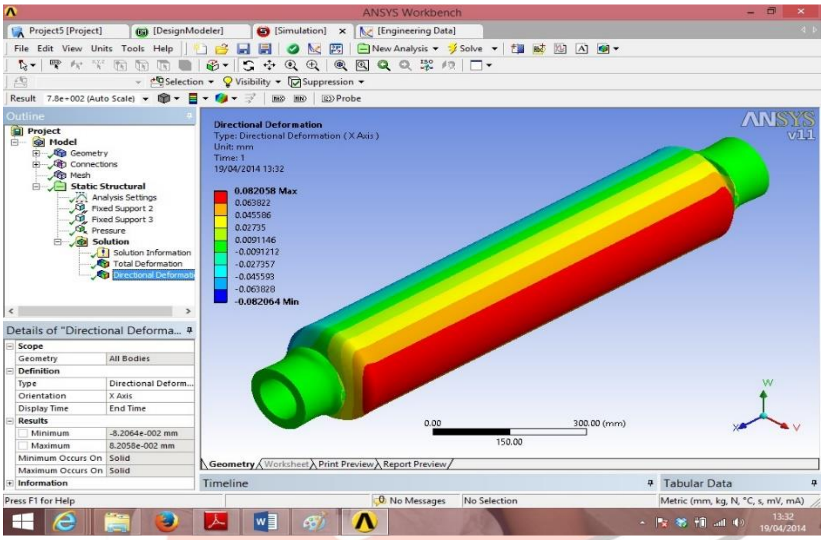

Fig. 15 Directional deformation in X

Y- Direction

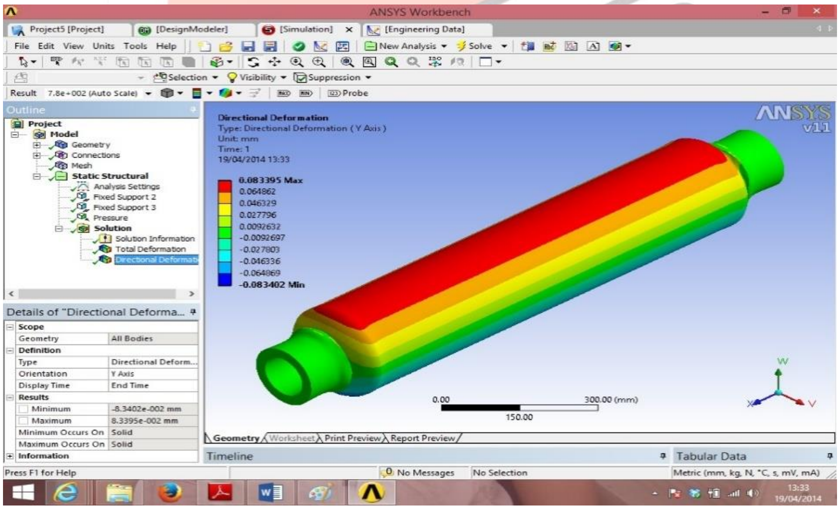

Fig. 16 Directional deformation in Y

Z- Direction

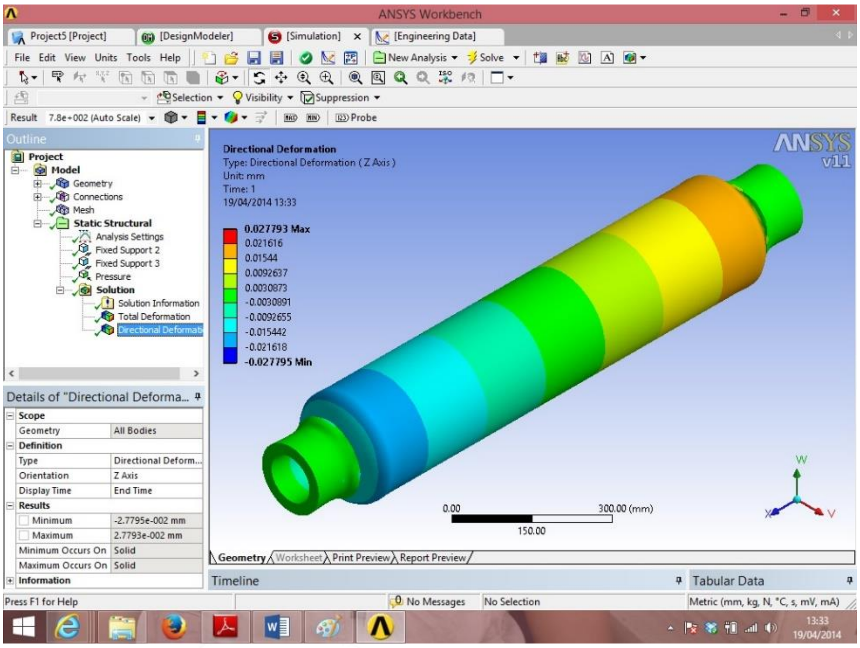

Fig. 17 Directional deformation in Z

STEPS OF DYNAMIC ANALYSIS
MODEL ANALYSIS
RESULTS OF ANALYSIS
Mode - 1

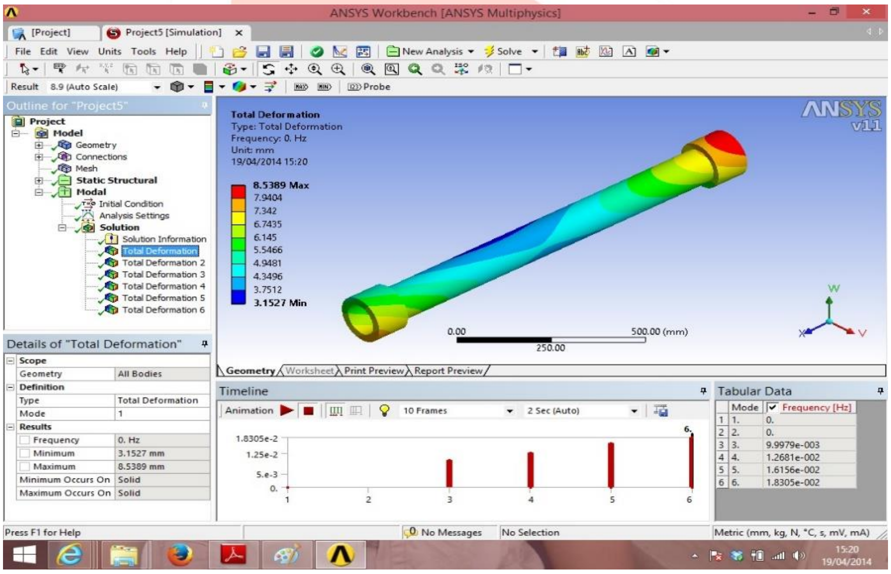

Fig. 18 Total deformation of mode 1

Mode-2

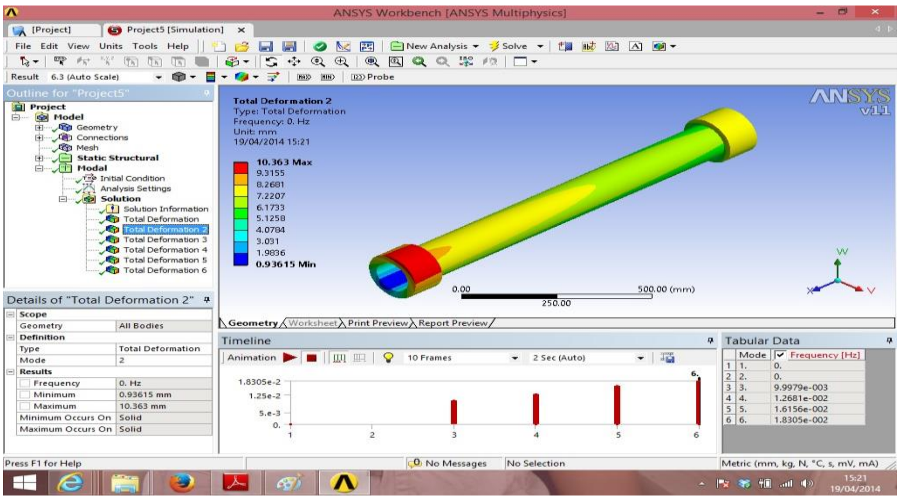

Fig.19 Total deformation of mode 2

Mode-3

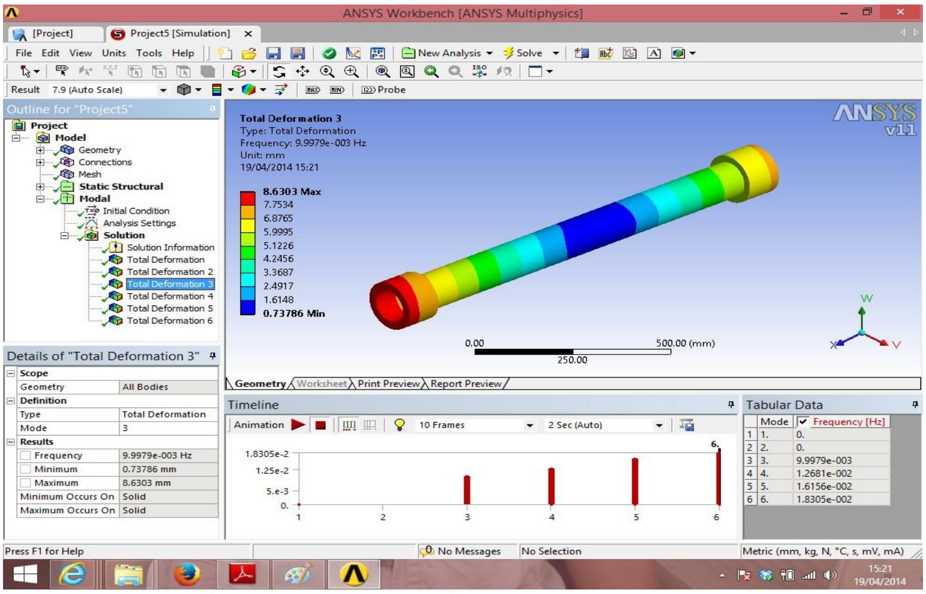

Fig. 20 Total deformation of mode 3

Mode-4

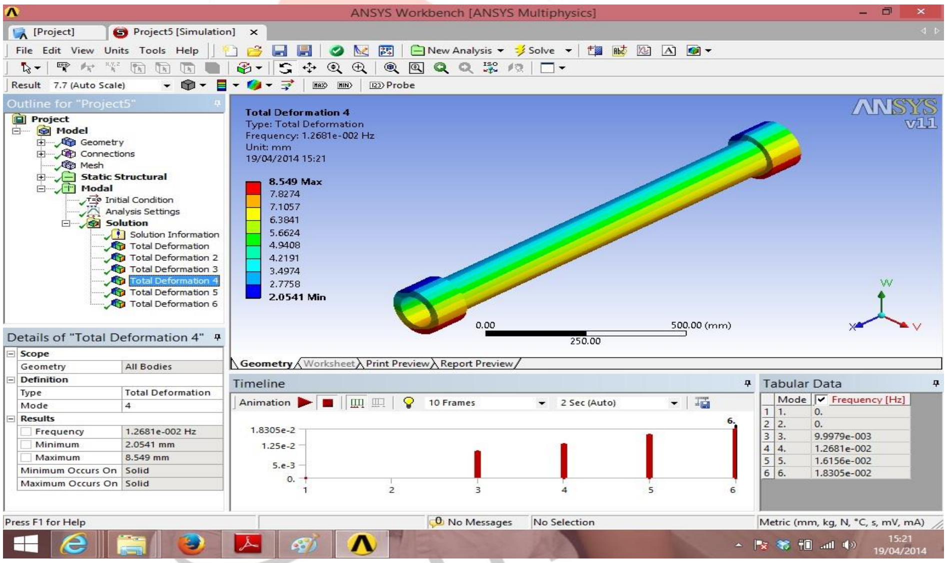

Fig. 21 Total deformation of mode 4

Mode-5

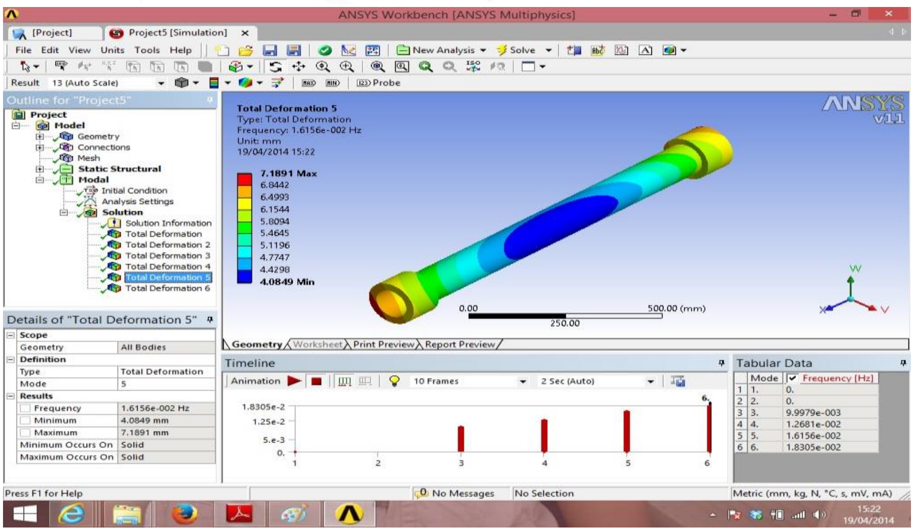

Fig. 22 Total deformation of mode 5

Mode-6

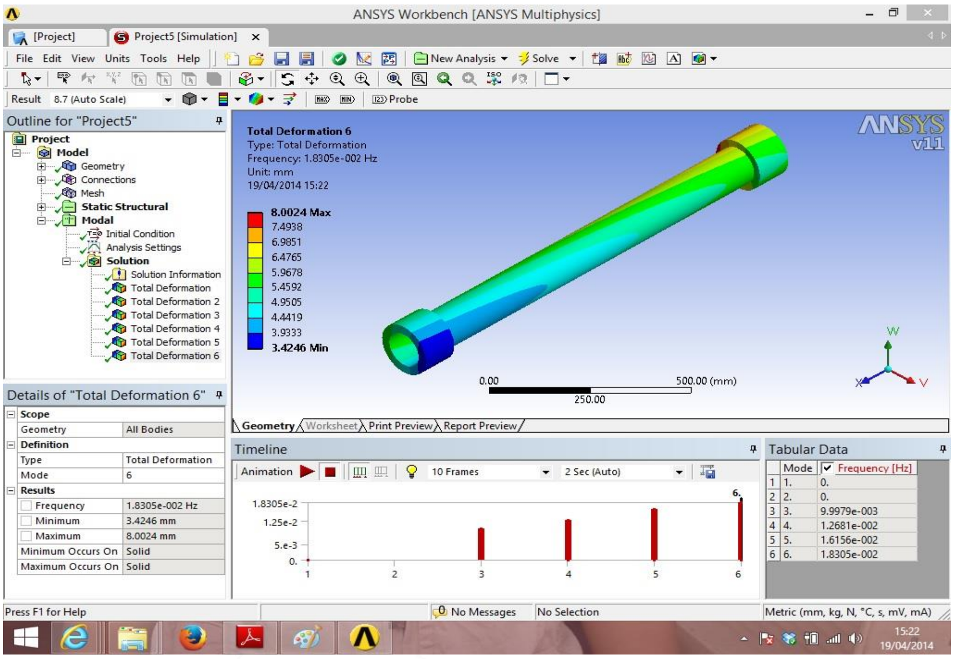

Fig. 23 Total deformation of mode 6

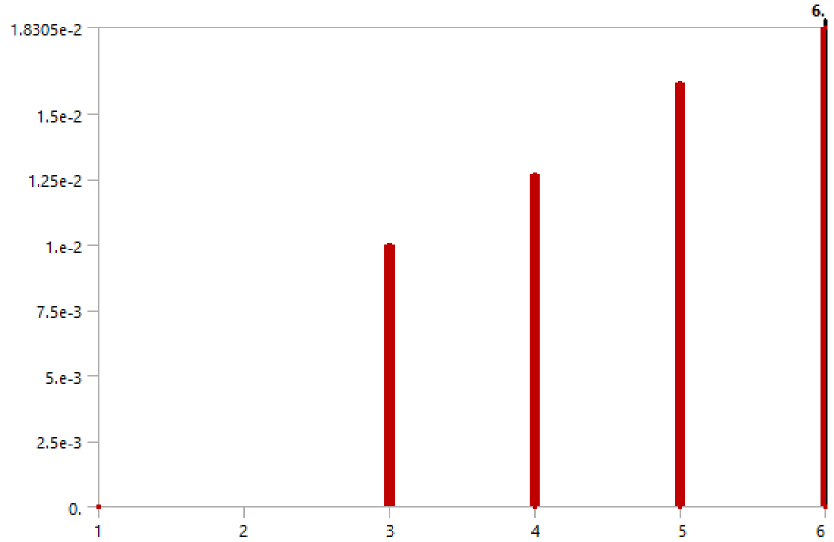

Fig. 24 Modal-Mode-Solution

Table 2 Natural frequencies of the Cylinder

Mode	Frequencies (Hz)
1	0
2	0
3	9.9979e-003
4	1.2681e-002
5	1.6156e-002
6	1.8305e-002

V. CONCLUSION

Vibration analysis of the hydraulic system components for the different speed, size and the loading conditions can be performed by using the commercial finite element packages if the dynamic loading of the structure is properly defined. By simplifying problem and study of FEA for justifying both term static and dynamic pressure applying to cylinder wall and see result for dimensional optimization of cylinder.

From theresults obtained in the analysis, thefollowingcan beconcluded:

- The commercial finite element packages can be used to analyse the static and modal analysis of the engineering structures subjected to moving loads with the proper definition of the dynamic loading. A simply supported beam

subjected to singular moving load is analysed with the finite element package ANSYS. Good agreement is found between the results obtained by ANSYS.
For Beam - Boundary Condition is both end fixed.

	Equivalent Stress in MPa		Shear Stress in MPa		Total Deformation in mm	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Simply Supported Beam	74.862	0.033	12.363	-12.364	21.469	0.0004

- Static analysis of hydraulic cylinder as cantilever beam boundary condition to get following result by ANSYS. These is first boundary condition to check behavior of operating pressure in cylinder.

	Total Deformation in mm		Deformation (X-direction) in mm		Deformation (Y-direction) in mm		Deformation (Z-direction) in mm	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Hydraulic Cylinder	0.486	0	0.088	-0.088	0.089	-0.089	0.014	-0.484

- Modal analysis of hydraulic cylinder as cantilever beam boundary condition to get following result by ANSYS. These is first boundary condition to check behaviour of operating pressure in cylinder.

Hydraulic Cylinder (Boundary Condition-1)			
Mode	Natural Frequency in Hz	Total Deformation in mm	
		Maximum	Minimum
1	0	8.5464	3.1526
2	0	10.368	0.9356
3	9.9955e-003	0.7398	8.631
4	1.2676e-002	8.5482	2.0545
5	1.6151e-002	7.1884	4.0849
6	1.8305e-002	8.0043	3.4223

- Static analysis of hydraulic cylinder as simply supported beam boundary condition to get following result by ANSYS. These is second boundary condition to check behaviour of operating pressure in cylinder.

	Total Deformation in mm		Deformation (X-direction) in mm		Deformation (Y-direction) in mm		Deformation (Z-direction) in mm	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Hydraulic Cylinder	0.085	0	0.082	-0.082	0.083	-0.083	0.027	-0.027

- Modal analysis of hydraulic cylinder as simply supported beam boundary condition to get following result by ANSYS. These is second boundary condition to check behaviour of operating pressure in cylinder.

Hydraulic Cylinder (Boundary Condition-2)			
Mode	Natural Frequency in Hz	Total Deformation in mm	
		Maximum	Minimum
1	0	8.5389	3.1527
2	0	10.363	0.93615
3	9.9979e-003	0.7398	8.631
4	1.2681e-002	8.6303	0.73786
5	1.6156e-002	8.549	2.0541
6	1.8305e-002	7.1891	4.0849

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