International Journal of Engineering Research ISSN:2319-6890)(online),2347-5013(print)
Volume No.3 Issue No: Special 1, pp: 140-143 22nd March 2014

Static and modal analysis of laminated composite Hydraulic Cylinder

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Abstract:

Hydraulic and pneumatic system equipments are the important components of engineering applications. 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. They are used for producing linear motion in the hydraulic systems and they convert hydraulic energy to mechanical energy. Many machines and machine mechanisms run under static and dynamic working conditions. The vibrations produced under static and dynamic conditions affect many important design parameters such as strength, production costs, productivity. In this paper, the dynamic and static analysis of a composite hydraulic cylinder subjected to pressure by varying fibre orientation and different boundary conditions is determined. The finite element methods used in the analysis are applied by using analysis software ANSYS.

Keywords—Static and modal analysis, hydraulic cylinder, finite element method, ANSYS

I. Introduction:

Hydraulic and pneumatic system equipments are the important components of engineering applications. 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.

In this study, hydraulic and pneumatic system components are modelled with the computer aided Static and modal analysis performed by using finite element methods. First of all, a finite element model of a double-acting hydraulic cylinder is created by ANSYS software. Then by performing a static analysis, the static displacements under the working pressure of cylinder are obtained with respect to boundary conditions. Nodal force functions formed by pressure changes on nodes under the working conditions are developed with a written ANSYS software code. In the next step, natural frequencies of the cylinder and mode shapes are obtained. Finally, dynamic loading of the cylinder is formed by considering the force functions and dynamic analysis which is realized according to this loading condition.

There are some studies in the literature that interest with the dynamic response of cylinders.Tzeng & Hopkins (1996) study the dynamic response of composite cylinders subjected to a moving internal pressure. Tzeng (1998) also analyzes the resonance of stress waves in the cylinder at the instant and location of the pressure front passage, when the velocity of the moving load approaches to the critical velocity. A basic study upon the moving load problem and reference data is given by Olsson (1991). Olsson studies the dynamics of the beam subjected to a constant force moving at a constant speed and presents analytical and finite element solutions. T

Thambiratnam & Zhuge (1996) study the dynamics of beams on an elastic foundation and subjected to moving loads by using the finite element method. They investigated the effect of the foundation stiffness, traveling speed and the span length of the beam on the dynamic magnification factor which is defined as the ratio of the maximum displacement in the time history of the mid-span to the static mid-span displacement. Wang (1997) analyzes the multi-span Timoshenko beams subjected to a concentrated moving force by using the mode superposition method and made a comparison between the Bernoulli-Euler beam and Timoshenko beam. Wu & Shih (2000) study the dynamic responses of railway and carriage under the high-speed moving loads and consider the action of the multi-roller carriage.

Static Analysis:

For the hydraulic cylinder, the static loading condition is defined with applying the pressure to the inner surface of the cylinder. The pressure loading to the inner surface is considered by the arrival of the piston to the end of the stroke and the filling the cylinder with the fluid. Static analyses are made with APDL codes and static displacement values of the nodes are obtained for both of the boundary conditions.

These analyses are made in the static analysis module under ANSYS solution task. The stiffness matrix of the system is obtained with the static analysis by using the finite element method. Displacement values for every node are calculated by using the equation below under specific loading. The overall equilibrium equations for linear structural static analysis are:

$[K]\{u\}=\{F\}$

Where;

[K] = Total stiffness matrix

{u} = Nodal displacement vector

{F} = Total applied load vector

Modal Analysis:

Natural frequencies of the system and mode shapes have to be calculated for the full solution method and mode superposition method which will be used in dynamic analysis step. Response of the system for the external forcing is determined by forcing frequency shapes. According to these methods, initially the model analysis is done for the present boundary conditions of the cylinder and 5 natural frequencies and vibration shapes are obtained for both.

II Modeling of the Hydraulic Cylinder:

ANSYS software is used for creating the model and performing the analysis of this study. APDL stands for ANSYS Parametric Design Language, a scripting language that one can use to automate the common tasks or even building the model in term of parameters. In this thesis, a double-acting hydraulic cylinder is used in the analysis. The model shown in Figure 4.1 is created as finite elements. In this finite element model, Solid45 element with eight nodes and three degrees of freedom in each node and layered 191 is chosen from ANSYS element library. All the dimensions of the cylinder are parametric and the dimensions used in the analysis are shown in Figure shown below

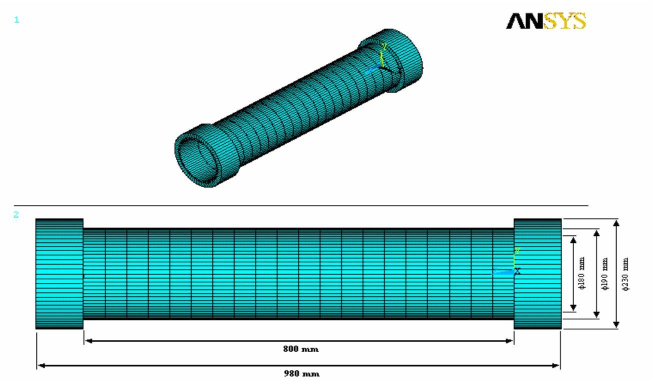

Figure 4.1 The finite element model and the cylinder dimensions

In the analysis, two different boundary conditions are considered for the hydraulic cylinder. It is assumed that, the cylinder is directly installed to the other components or to the body in two different mounting types and the static and dynamic analyses is made for these two mounting types. The degree of freedom boundary conditions is shown in Figure2.2 and 2.3 working pressure of cylinder is taken as 250 bars.

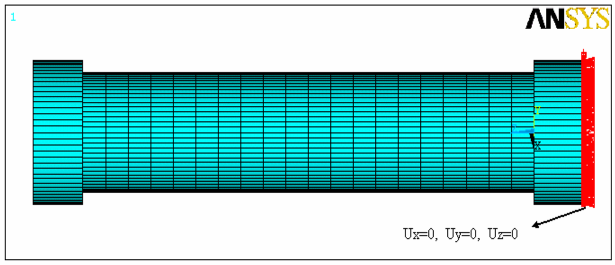

Figure 4.2 Boundary condition a) Bc-type 1

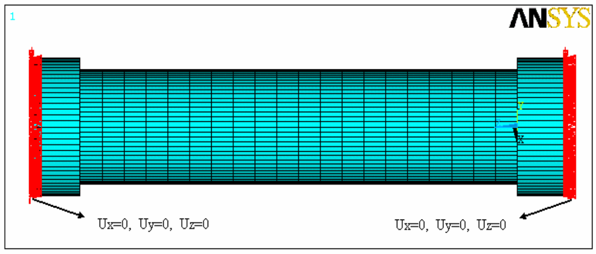

Figure **4.3** Boundary condition a) Bc-type 2

Hydraulic cylinder, modeled as finite element, is made of steel. The properties of steel is given as

Modulus of Elasticity, E	203 GPa
Poisson Ratio, n	0.3
Density,	7869 Kg / m3

Hydraulic cylinder, modeled as finite element, is made of Carbon Material properties. The properties of steel are given as.

Modulus of Elasticity, E	Poisson Ratio, n	Shear Modulus,	Density
E1=142000	0.27	7200	1.5(10)6
E2=10300	0.27	7200	
E3=10300	0.27	7200	

III. Results and discussions

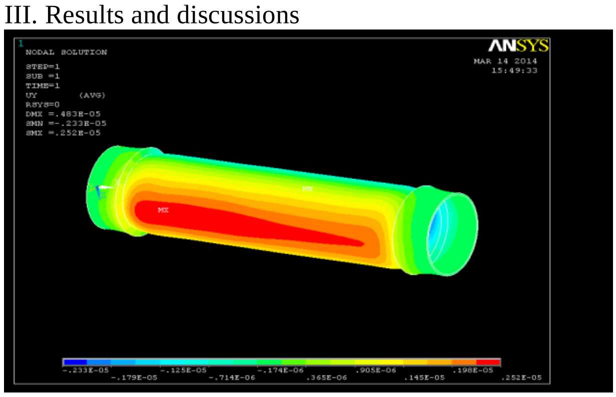

Figure 4.4 Static displacement distributions (u_y) of cylinder, Bc-type1

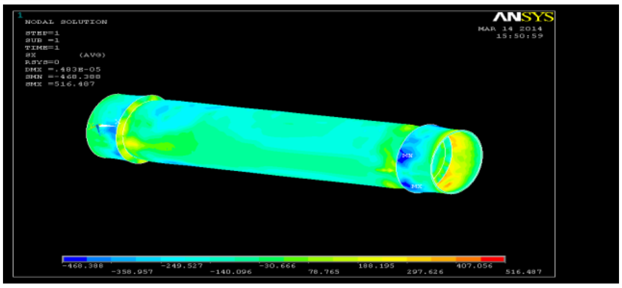
Figure 4.5 Static stress distributions (σ_x) of cylinder, Bc-type1

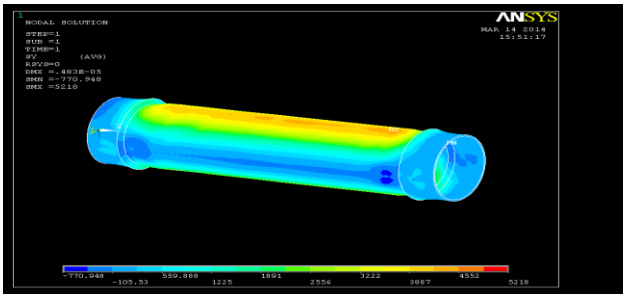
Figure 4.5 Static stress distributions (σ_y) of cylinder, Bc-type1

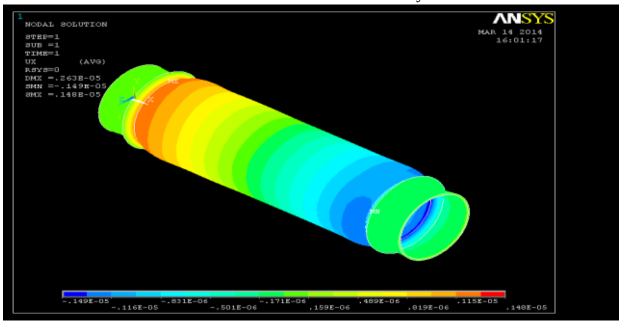
Figure 4.6 Static displacement distributions (u_x) of cylinder, Bc-type2

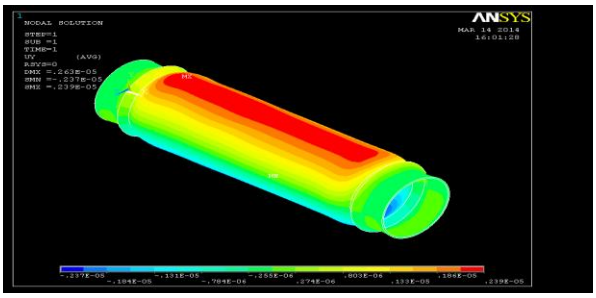
Figure 4.7 Static displacement distributions (u_y) of cylinder, Bc-type2

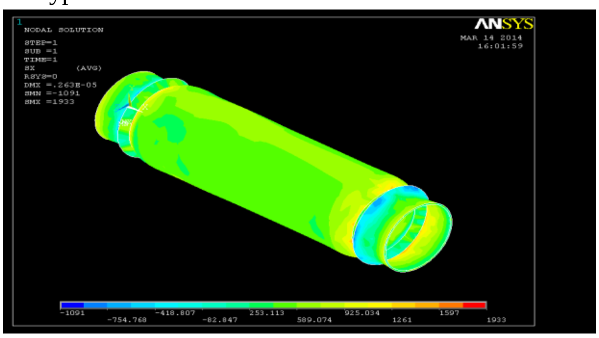
Figure 4.8 Static stress distributions (σ_x) of cylinder, Bc-type2

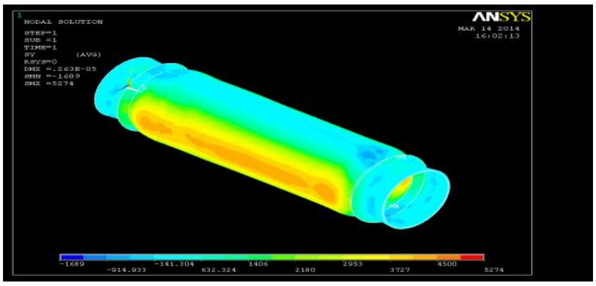
Figure 4.9 Static stress distributions (σ_y) of cylinder, Bc-type2

Table 4.1Comparision of deflection of cylinder for different materials and boundary conditions

Deflections	Steel		Carbon/Epoxy(0/90/90/0)	
	Bc-type1	Bc-type2	Bc-type1	Bc-type2
ux (m)	1.52E-04	1.40E-04	2.50E-05	1.48E-06
uy (m)	1.52E-04	1.40E-04	4.83E-05	0.293-5

Table 4.3 Natural Frequencies of Cylinder, Bc-1type of carbon/Epoxy

SET	TIME/FREQ
1	66.115
2	67.078
3	163.41
4	253.68
5	256.19

Table 4.3 Natural Frequencies of Cylinder, Bc-type2 of carbon/Epoxy

SET	TIME/FREQ
1	243.81
2	245.13
3	274.02
4	275.06
5	370.76

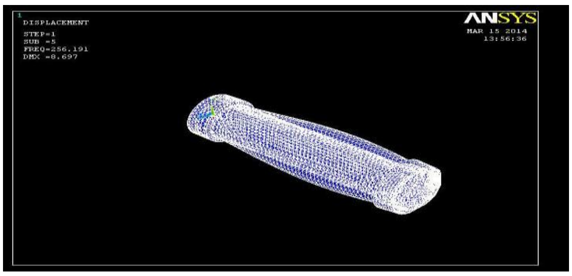
Figure 4.10 Mode Shape Bc-1type Mode5 (26.19Hz) For Carbon/Epoxy

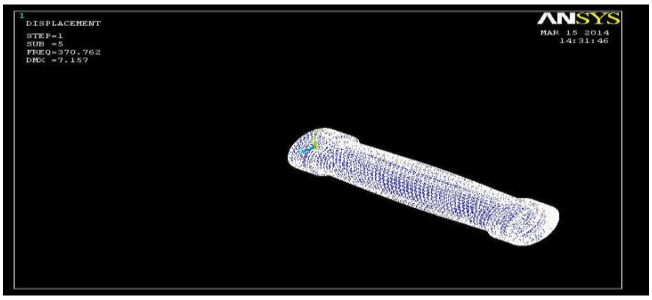

Figure 4.11 Mode Shape Example, Bc-2type Mode5 (370.76Hz) for Carbon/Epoxy

IV. CONCLUSIONS:

The dynamic and static analysis of a composite hydraulic cylinder subjected to pressure by varying fibre orientation and different boundary conditions is determined.can be performed by using the commercial finite element packages. For 0/90/90/0 fiber orientation having less deflection for carbon/Epoxy made of laminated composite compared with hydraulic cylinder made of steel. The results may be important to the designer in the field of laminated composite construction.

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