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Investigation Of Stresses In Crane Hook By FEM

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Abstract

Crane hooks are important components from safety point of view since they are subjected to large amount of stresses. Hence to study the stress pattern in crane hooks; analytical, numerical and experimental methods are used. For analysis purpose virtual model of crane hook is prepared by picking data from design data book. Curved beam formula is used for determination of stresses in crane hook analytically. For numerical analysis CAD model of crane hook is prepared using Pro-E and this model is imported in ANSYS where stress analysis is done by FEM. Finite Element Analyses have been performed on various models of crane hooks having trapezoidal, modified trapezoidal, circular and rectangular cross sections. Also for rectangular hook stress analysis is done by using method of photoelasticity. From the output of these analyses it is observed that results obtained are in close agreement with each other and maximum stress concentration occurs at inner most surfaces.

Keywords: Crane hook, Curved Beam Theory, FEA, Photoelasticity

1. Introduction

A crane is a machine, equipped with a hoist, wire ropes or chains and sheaves used to lift and move heavy material. Cranes are mostly employed in transport, construction and manufacturing industry. Overhead crane, mobile crane, tower crane, telescopic crane, gantry crane, deck crane, jib crane, loader crane are some of the commonly used cranes. A crane hook is a device used for grabbing and lifting up the loads by means of a crane. It is basically a hoisting fixture designed to engage a ring or link of a lifting chain or the pin of a shackle or cable socket [1]. Crane hooks with trapezoidal, circular, rectangular and triangular cross section are commonly used. So, it must be designed and manufactured to deliver maximum performance without failure. Thus the aim of this research is to study stress distribution pattern within a crane hook of various cross sections using analytical, numerical and experimental methods.

2. Introduction to Problem, Scope and Methodology

The crane hooks are vital components and are most of the time subjected to failure due to accumulation of large amount of stresses, which are ultimately leading to failure. Cranes are subjected to continuous loading and unloading. This causes fatigue of the crane hook. If the crack is developed in the crane hook, it can cause fracture of the hook and lead to serious accident. Bending stress, tensile stress, weakening of the hook due to wear, plastic deformation due to overloading, excessive thermal stresses are some of the other reasons of failure.

In this project work stress analyses of crane hooks with trapezoidal, modified trapezoidal and circular cross section have been carried out considering hook for the safe working load = 5.0 Tonne-force, bed diameter = 72 mm, depth=68mm. Properties of material used for crane hook are given in Table 1.1.

Table1. Properties of material SAE 1040

Property	Symbol	Value
Modulus of Elasticity	E	203x103 MPa
Poisson's ratio	μ	0.292

For the purpose of analysis, hook is treated as fixed at shank end and the load is applied exactly at the centre in downward direction. Maximum value of stress in crane hooks has been determined using curved beam formula. The CAD models for trapezoidal hook with variation in length of parallel sides, for modified trapezoidal with variation in inner and outer radius and with diameter variation for circular cross sections are prepared in Pro-E. FEA have been carried out by importing each model in ANSYS. Finally CAD model of crane hook having rectangular cross section with bed diameter = 38 mm, depth = 32 mm and thickness = 5 mm is prepared and stress analysis is done using FEM by varying load on hook from 324 N to 647.5 N. A prototype model of crane hook with rectangular cross section similar to the CAD model is prepared using photoelastic material (egg. Epoxy) and stresses are analyzed using photoelasticity experiment. Results obtained by analytical method and FEM are compared with the results obtained by photoelasticity.

3. Analytical Estimation of Stresses

If the ratio of the radius of curvature to depth of beam is less than 5, beam bending theory becomes inadequate for the calculation of stresses. Formula based on mechanics of materials methods which consider the effect of curvature may be used for the determination of stresses in the curve beams like crane hooks [11]. This curve beam formula (1) is given as below.

$$\sigma = \frac{P}{A} + \frac{M \times (A - r.A_m)}{A.r.(R.A_m - A)} \quad \text{.................. (1)}$$

Where,
σ = Stress
P= Applied force
A= Area of cross section of curve beam
M= Applied Bending moment
R= Radius of centroidal axis
r= radius of curvature at the point of interest

$$A_m = \int \frac{dA}{r}$$

Explicit expressions for A, R and A_m for several curved beam cross sectional areas are available [11]. By using curve beam formula and explicit expressions, value for maximum stress for different cross section has been calculated. Maximum stress occurs at inner side of critical section A-A as shown in fig.1 which resembles as inside fibre.

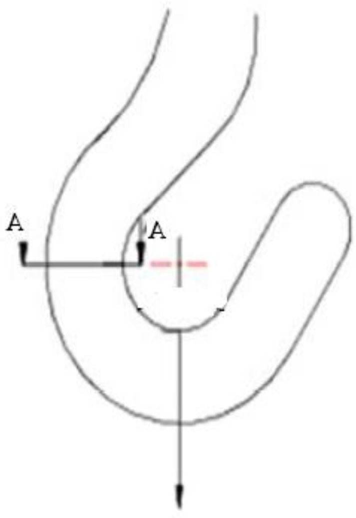

Figure1 Critical section of crane hook

4. Preparation of CAD Model of Hook

For generation of CAD model of crane hook various geometrical features and dimensions are selected from IS: 3815-1969[12]. Some features are approximated for simplification. Pro-E Wildfire 5.0 software is used for creating solid model of hook. Swept Bend advance feature in Pro-E is used. Complete Solid CAD model is prepared which is shown in fig. 3 and it is saved in .igs format. Similarly for all required cross section solid CAD model is generated.

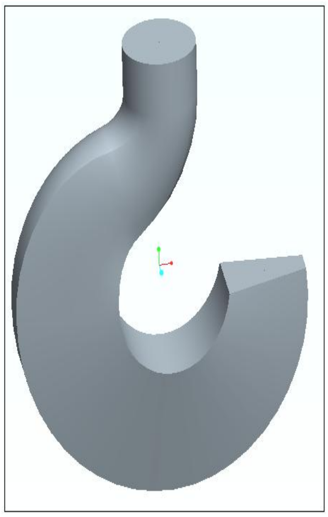

Figure2. Solid CAD model of crane hook

5. Stress Analysis Using FEM

The solid CAD model in .igs format is imported to ANSYS for FEA. A structural 10 node Tetrahedral Solid 187 element is selected for creating FE model of the crane hook. Material properties as shown in table 1 are assigned. And model is meshed using free meshing and smart size option. Slider for smart size is set to 4.The FE model created is shown in fig.3.

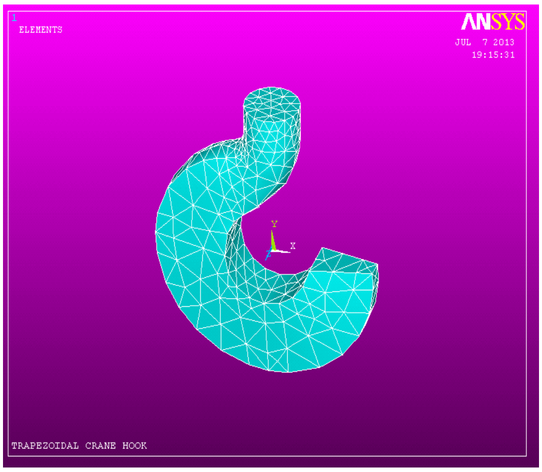

Figure3 Finite element model of crane hook

For imposing boundary condition all degrees of freedom are restricted at the top of shank end. And the force of 100 kN is applied on bunch of nodes at lower centre of hook in downward direction.

Then model is submitted to the ANSYS solver where it is solved. This is called as solution phase. Then results are presented by general post processor in graphical as well as table format. The pattern of first principal stress distribution in trapezoidal crane hook is shown in figure 4.

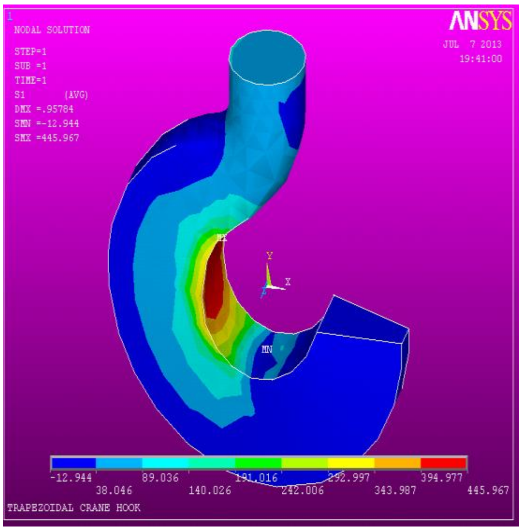

Figure4. First principal stress distribution contour in trapezoidal crane hook.

Similarly first principal stress contour plot for modified trapezoidal, circular and rectangular hook is presented in figure 5 to 7.

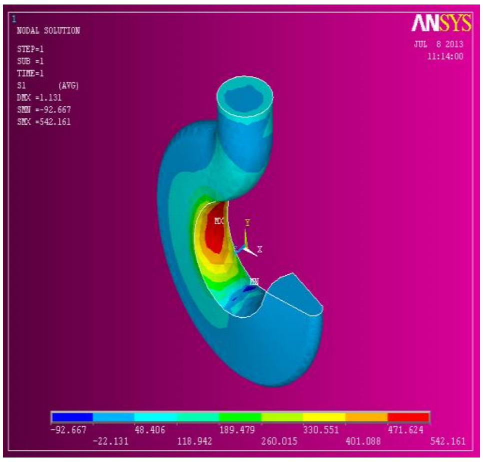

Figure5. First principal stress distribution contour in modified trapezoidal crane hook

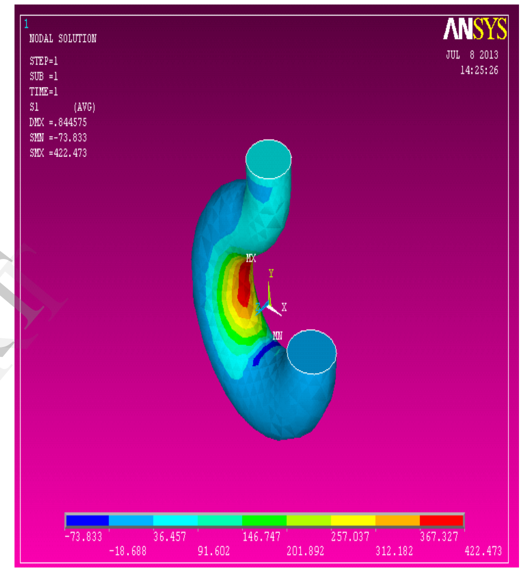

Figure6. First principal stress distribution contour in circular crane hook

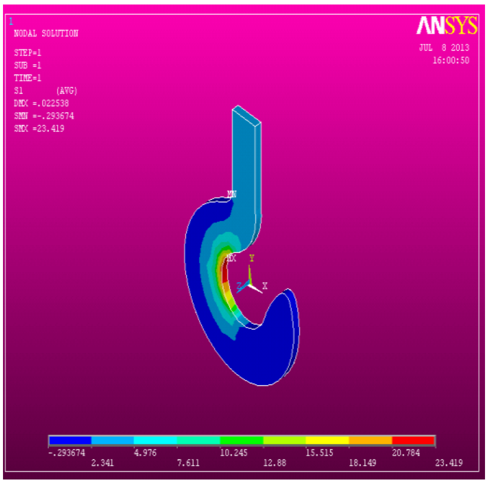

Figure7. First principal stress distribution contour in circular crane hook

6. Experimental Stress Analysis of Crane Hook Using Photoelasticity

For the verification of the results obtained from FEM, the experimentation is conducted using photoelasticity. Photoelastic model of rectangular section crane hook is prepared from 5 mm thick sheet casted from epoxy resin (mixture of Araldite CY 230 and hardener HY951). Also circular shaped disc (calibration disc) of 65 mm diameter is prepared from the same sheet. Calibration of disc is done to find material fringe value, $F_{\sigma.}$ This disc is taken and subjected to compressive load in the circular Polariscope setup as shown in fig.8.

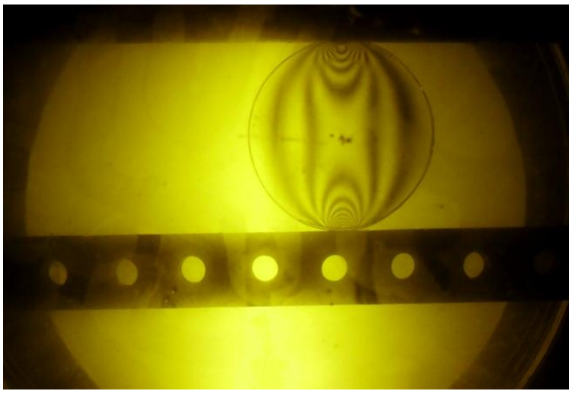

Figure8. Isochromatic fringe pattern developed in circular disc under compression

Values of fringe order are noted down for different loads as shown in table 2. Using formula F_σ= 8P/πDN, material fringe value is determined and average is taken as 10.19 N/mm. where P=Load in N, N= Fringe order and D= diameter of disc=65 mm.

Table 2. Determination of material fringe value

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SN	Load (N)	Fringe order			Fringe Value(F_σ)	
		Lower	Higher	Avg.	F_σ	Avg. (F_σ)
1	162	0.64	0.65	0.64	9.83	10.19 N/mm
2	194	0.75	0.74	0.74	10.21	
3	226	0.87	0.86	0.86	10.26	
4	258	1.01	1.0	1.00	10.09	
5	291	1.13	1.09	1.11	10.28	
6	323	1.21	1.21	1.21	10.48	

Isochromatic fringe pattern developed in photoelastic model of crane hook is shown in fig.9. Readings are taken for various loading conditions as depicted in table 3. And stresses are determined using formula, σ = NFσ/h.

Figure9. Ischromatic fringe pattern developed in photoelastic model of crane hook

Table 3. Readings for Determination of Stresses using photoelasticity

SN	Load (kgf)	Fringe Order , N			σ = NFσ/h (MPa)
		Lower	Higher	Avg.	
1	33	10.5+0.78 = 11.28	11.5-0.22 = 11.28	11.28	22.98
2	49.5	16.5+0.66 = 17.16	17.5-0.33 =	17.165	34.98
3	66	22.5+0.42 = 22.92	23.5-0.63 =	22.895	46.66

7. Result, Discussions and Conclusions

The results of stress analysis evaluated from analytical and FEM for trapezoidal and circular crane hooks are presented in table 4.

Table4. Comparison between Analytical and FEA results for different cross sections

Sr. No.	Cross Section	Max. Analytical Stress (MPa)	Max. FE Stress (MPa)	% Error
1	Trapezoidal	418.80	445.16	5.92
2	Circular	387.01	422.47	8.39

The induced stresses obtained from analytical calculation are compared with results obtained from FEA software. The results are in close harmony with each other with a small percentage of error as depicted in table4.

The value of maximum stress obtained through analytical calculations, FEM and photoelasticity experiment of crane hook having rectangular cross section for different loads is shown in table 5.

Table3.Comparisson between analytical, FEA and photoelasticity results for rectangular crane hook.

Sr. No.	Load (N)	Max. FE Stress (MPa)	Max. Experimental Stress (MPa)	Max. Analytical Stress (MPa)	% Error
1	324.0	23.42	22.98	21.31	9.00
2	485.5	35.23	34.98	31.97	9.25
3	647.5	47.40	46.66	42.92	9.45

The induced stresses in rectangular crane hook obtained from analytical calculation, FEM and photoelasticity are compared with each other. The results are in close agreement with each other with a small percentage of error as depicted in table 3. This comparison has also been shown in fig. 10.

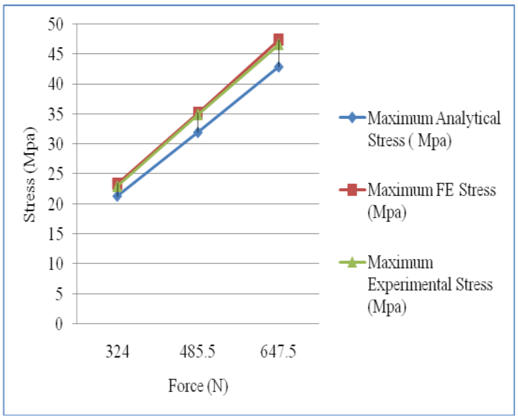

Figure10. Comparison of maximum stresses evaluated by analytical, FEM and photoelasticity

Stresses induced in crane hook from inner most fibre to outer most fibre at critical section A-A have been calculated using curved beam formula and result is represented graphically by figure 11.

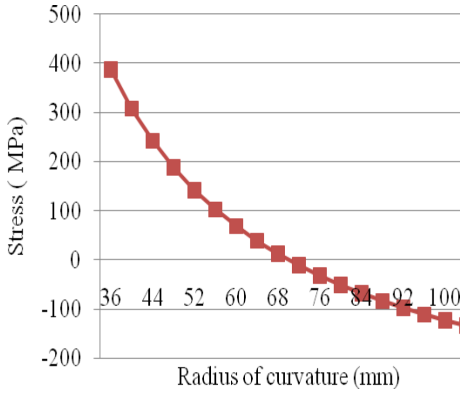

Figure11. Variation of stress with the depth of cross section at critical section

Maximum stress on the inner most surfaces is 387 N/mm^2 which is tensile in nature and on the outer most surface of the hook it is -134 N/mm^2 which is compressive in nature as shown in fig. 11.

The results confirm that FEA procedure is well established and can be used for complex accurate models also.

8. Justification for Variation in Results

The possible reasons of error might be due to:

- Assumptions made during analytical calculations.
- The CAD model imported may lose some features.
- Due to tetrahedral shape of element
- Loading is considered as point loading in analytical calculation while it is taken as bunch of nodes in ANSYS.
- During photoelasticity experiment, it is difficult to find the magnitude of stress exactly on the plane of fringe closest to inner surface.

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