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Design, Analysis and Optimization of Electric Overhead Travelling Crane Hook

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Abstract— Electric Overhead Travelling Crane popularly known as EOT crane, which is widely used in the industries for lifting and moving the loads. EOT crane consists of hoist mechanism, electric motors, end carriage, upper and lower block, bearing, drum, wire rope, pulley, hook, girder etc. Hook is used for lifting the load and it is one of the most stressed component of EOT crane, so it has been selected as an area of interest. Design of hook depends upon load lifting capacity, which may be ranging from 10 kN to as per requirement. Most commonly used capacity is 50 kN. So, in this work, we are considering 50 kN as the working load lifting capacity. In this study, Modeling, Design, Analysis and Optimization of EOT Crane hook is carried out. Pro-Engineer software has been used for modeling and ANSYS software has been used for obtaining analysis results. From the stress diagram, dimensions are optimized as per stress pattern and saving in the material has been carried out without disturbing the stability and safety, as per IS code and sound engineering practice.

Keywords- Analysis, ANSYS, Crane hook, Design, EOT, Modeling, Optimization, Pro-Engineer

I. INTRODUCTION

A crane is hoisting device used for lifting or lowering load by means of a drum or lift wheel around which rope or chain wraps. EOT crane is a mechanical lifting device used for lifting or lowering the material and also used for moving the loads horizontally or vertically. It is useful when lifting or moving the loads is beyond the capacity of human. Crane is specially design structure equipped with mechanical means for a load by raising or lowering by electrical or manual operation. Cranes are commonly employed in the transport industry for loading and unloading of freight, in construction industry for the movement of materials; and in the manufacturing industry for the assembling of heavy equipment [3,4,5].

Appropriate solution of shape and materials of hooks enables the increase of loading capacity of hoisting machines [1]. In order to optimize the weight of the crane hook, the stress induced in crane hook must be studied [4]. It is also mentioned that till date very few papers are published regarding the stress analysis of crane hook [6].

So, in this study, Design, Analysis and Optimization of EOT Crane Hook is carried out for 5 ton (50 kN) load lifting capacity. Pro-Engineer software is used for hook modeling and ANSYS software is used for analysis.

II. METHODOLOGY

In this project, design, modeling, analysis and optimization of EOT crane hook is carried out.

2.1 Phases of Project

This study contains, finding out dimensions of hook, theoretical stress calculation, calculating stress using ANSYS software, validation of theoretical stress with ANSYS results, modeling for different

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iterations to obtained optimized shape and finally manufacturing and testing.

2.1.1 Design of Hook

In this phase basic dimensions for crane hook are calculated like bed diameter, throat diameter, depth of crane hook. In this study, three type of cross-section for crane hook namely circular, rectangular and trapezoidal are considered. Area and depth are kept constant for all cross sections.

2.1.2 Modeling of Hook

As per dimensions calculated in above step, all three cross-sections are modeled in Pro-engineer software. Then, saving .igs file is used further for analysis.

2.1.3 Analysis of Hook

After modeling of above mentioned three types of crane hook cross-sections its .igs file which was saved in Pro-e is imported in ANSYS software and by applying load and proper boundary constraints its stresses and deformation are obtained. The result obtained in ANSYS are compared with theoretical calculations and based on the result section having least stress concentration is taken for further optimization.

2.1.4 Optimization of Hook

For performing optimization, shape optimization is used as a tool. And based on stress concentration the cross-sectional dimensions are changed i.e geometry is modified of the selected cross-section shape of crane hook. Here sections are created at twelve locations which are used for modifying dimensions as per stress concentration obtained. Six iterations are performed, compared with the basic case and the best optimized iteration is selected. After that best optimized cross-section is given for manufacturing and testing.

2.1.5 Manufacturing and Testing of Hook

The optimized shape obtained is manufactured and tested.

III. DESIGN OF EOT CRANE HOOK

3.1 Basic Dimensions of Crane Hook

Hook bed diameter (C) is given by the formula,

$C = \mu^1 \sqrt{P}$ mm ------- Eq. (1) [14],

Where,

W = Safe working or service load = W = 5.00 ton

P = Proof Load = (2.00 x W) = 2.00 x 5.00 = 10.00 ton = 100.00 kN,

W_L = Limit Load = (1.25 x W) = 1.25 x 5.00 = 6.25 ton = 62.50 kN,

μ^1 = factor (For economic design, value ranges between 12 to 36)

= 26.73 from IS code 3815-1969 (for economy of material),

Therefore, hook bed diameter (C), is calculated as,

$C = (26.73 \times \sqrt{10}) = 85$ mm

Throat of the hook (T) is calculated using empirical relation as,

T = (0.75 C) ----- Eq. (2)

= (0.75 x 85) = 64 mm

Depth of hook (d) is calculated using empirical relation as,

d = (0.82 C) -----Eq. (3)

= (0.82 x 85) = 70 mm

Radius of hook (r.), is given by,

r = (d/2) = (70/2) = 35 mm,

Area = A = $(3.1416 \times r^2) = 3848.45\ mm^2$

Now, keeping the values of area and depth as constant, dimensions for circular, rectangular and trapezoidal cross-sections are obtained.

3.2 Theoretical Stress Calculations

For simplifying the analysis, a crane hook is assumed to be a curved beam. In case of straight beams under bending, the neutral axis of the cross-section coincides with its centroidal axis and bending stress distribution in the beam is linear. But in case of the curved beams, the neutral axis of cross-section is located between centroidal axis and centre of curvature, and bending stress is nonlinear in nature.

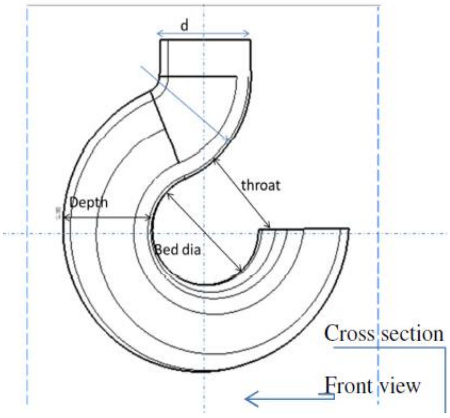

Figure 1. Sketch showing crane hook notations

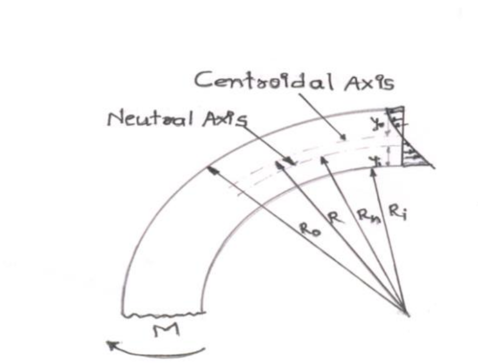

Figure 2. Hyperbolic stress distribution in curved beam

Figure 2 shows the hyperbolic stress distribution in curved beam. Stress distribution in a curved beam is useful in the design of crane hooks, frames of punches, presses, etc.

3.3 Bending Stress Calculations

In a curved beam, at any fibre at a distance y from the neutral axis,
Bending stress (σ_b) is given by,

$$\sigma_b = [\ (My) / (Ae(R_n - y))\ ] \text{ ------- Eq (4) [11]}$$

where,
M = Bending moment with respect to the centroidal axis
A = Area of cross-section
e = Eccentricity = distance between the centroidal axis to neutral axis
R_n = Radius of curvature of neutral axis to the fibre under consideration.
Resultant Stress (σ_r) = (Direct Stress + Bending Stress)

Resultant Stress (σ_r) is given by,

$$\sigma_r = [\ (W_L / A) + ((My) / (Ae(R_n - y)))] \text{ ------- Eq (5) [11]}$$

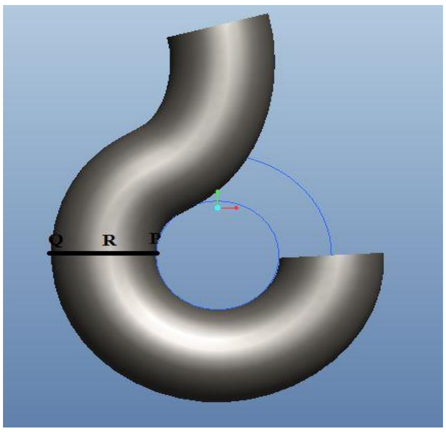

Figure 3. Sketch showing stress points P-Q-R

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Stress at outer face of hook (Q), middle face (R) and inner face of hook (P) are calculated theoretically. And results obtained for three cross-sections at three points are tabulated below.

From the table it is seen that, on the outer face of hook (at point Q) stress is minimum in trapezoidal cross-section as compared to circular cross-section, where as on the inner face of the hook (Point P) stress in minimum in trapezoidal cross-section as compared to rectangular and circular cross-section, which is about 40% less as compared to circular cross-section.

Table 1: **Theoretical Resultant Stress at points P-Q-R**

Type of Hook Cross-section	Outer Face of Hook Q (N/mm^2)	Mid Point of Hook R (N/mm^2)	Inner Face of Hook P (N/mm^2)
Circular	121.10	33.40	234.59
Rectangular	97.35	33.74	171.71
Trapezoidal	114.80	35.01	156.24

From the above comparison, it is seen that trapezoidal section has least bending stress as compared to circular and rectangular section, as stress coming at inner face of hook is of primary importance.

IV. VALIDATION OF STRESS CALCULATIONS

Material selected for crane hook is Structural Steel having following properties,

Modulus of elasticity (E) = 200000 N/mm^2 , Poisson's ratio (μ) = 0.30,
Density of steel = 7850 kg/m^3 = 78.50 kN/m^3, Tensile strength = 460 N/mm^2

Modeling of EOT crane hook was done in Pro-E Wild Fire 5.0 with the obtained dimensions. Then its .igs file was created and imported in ANSYS Workbench 11.0. Element type chosen was SOLI92 which is 3D 10-Noded tetrahedral structural solid.

4.1 Input Data- Boundary Conditions

The upper surface is fixed (all degrees of freedom are zero) shown by B and load is applied in negative Y- direction on selected surface shown by A. Applied Limit Load is W_L = 62.50 kN. Similarly, the boundary conditions are same for rectangular and trapezoidal cross-section of hook. After applying boundary conditions for all three cross-sections output obtained is shown below.

4.2 Output Results

4.2.1 Hook with Circular Cross-section

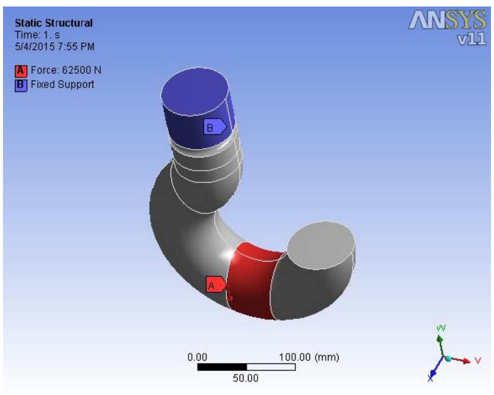


Figure 4. Sketch showing Boundary conditions for circular cross-section

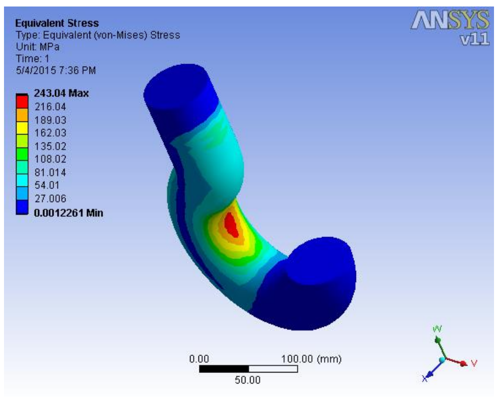


Figure 5. Stress pattern for circular cross-section
Maximum Value = 243.04 N/mm^2

4.2.2 Hook with Rectangular Cross-section

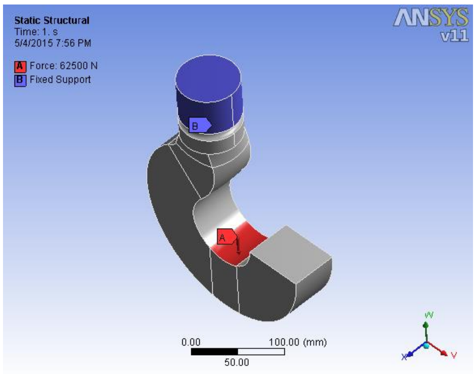


Figure 6. Sketch showing Boundary conditions for rectangular cross-section

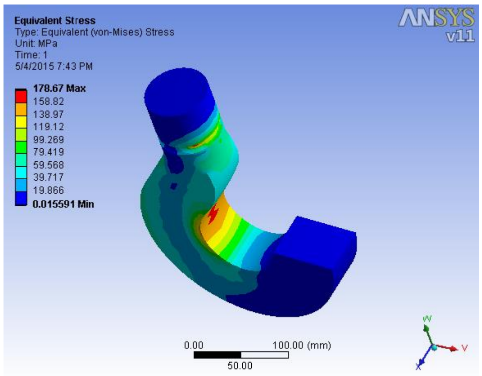


Figure 7. Stress pattern for rectangular cross-section

Maximum Value = 178.67 N/mm^2

4.2.3 Hook with Trapezoidal Cross-section

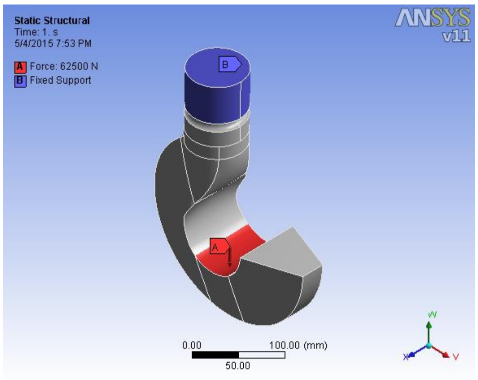


Figure 8. Sketch showing Boundary conditions for trapezoidal cross-section

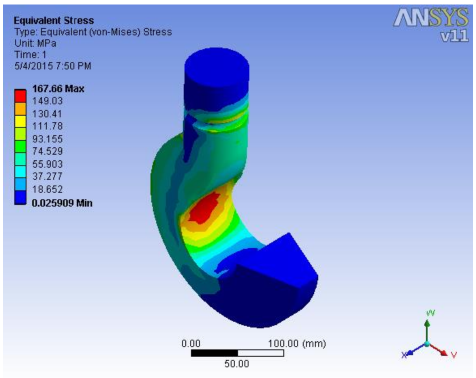


Figure 9. Stress pattern for trapezoidal cross-section

Maximum Value = 167.66 N/mm^2

Table 2. Comparison of Stress and total deformation

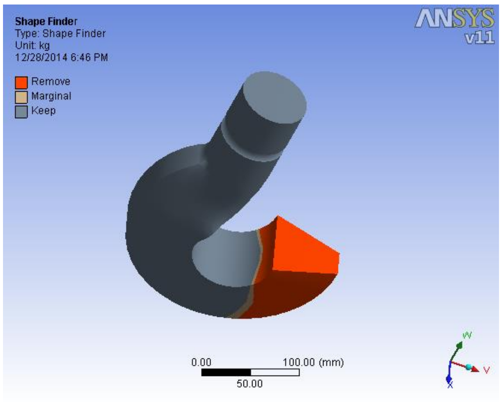
Type of Hook Cross-section	Theoretical Stress (N/mm^2)	Stress using ANSYS (N/mm^2)	Total Deformation (mm)
Circular	234.59	243.04	0.6484
Rectangular	171.71	178.67	0.5601
Trapezoidal	156.24	167.66	0.5829

From the above table, it is seen that stress in hook having trapezoidal cross-section is about 8% and 32% less as compared to rectangular and circular cross-section respectively. So considering all above three cross-section, trapezoidal cross-section is much better choice. Hence trapezoidal cross-section is selected for further optimization.

V. OPTIMIZATION OF HOOK CROSS-SECTION

For optimization main aim is to minimize volume and for this ANSYS Workbench 11.0 is used.

Shape optimization is the method used for optimizing hook and finding the best possible geometrical shape of hook with trapezoidal cross-section.



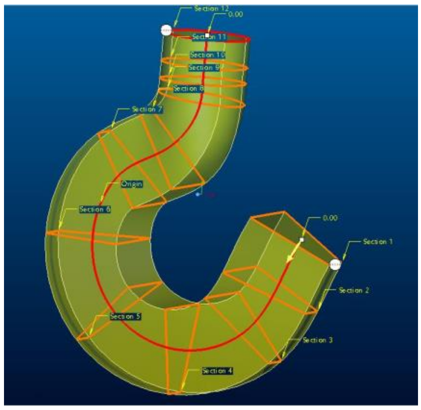


Figure 10. Sketch shows hook portion for shape optimization *Figure 11. Sketch showing location for twelve c/s*

From this result we come to know that material at the tip of hook can be removed to reduce volume. So based on this result further optimization process is carried out.

Above figure shows hook having trapezoidal cross-section. Twelve locations have been selected on this cross-section to study the stress pattern. Dimensions bet sections 9-9 to 12-12 kept same where as other dimensions modified. From the stress calculations, it is seen that stress at section 6-6 is more as compared to stresses at other sections, so the cross-section is not uniformly stressed. Now, we are taking the trapezoidal cross-section for further study of optimization. Hence, dimensions of the trapezoidal cross-section has been modified, such that sufficient cross-section is provided at section 6-6 to reduce the stress and extra sectional dimensions are reduced at other sections, where so much heavy cross-section is not required. This way stress at various locations has been calculated, so that section can be stressed uniformly and provided section is to be best utilized to its maximum permissible stress level. This way, optimization of hook cross-section can be achieved. Six iterations are carried out and analysis results are compared with the basic case of trapezoidal cross-section.

5.1 Basic Case and Iterations

Table 3. Change in cross-sectional area

Section No.	Change in Cross-sectional Area (%)						
	Basic Case	Iteration No. 1	Iteration No. 2	Iteration No. 3	Iteration No. 4	Iteration No. 5	Iteration No. 6
Section 1-1	0	20	35	70	70	70	72
Section 2-2	0	10	15	35	47	45	49
Section 3-3	0	10	15	35	37	40	48
Section 4-4	0	10	15	35	30	31	37
Section 5-5	0	5	10	35	30	30	37
Section 6-6	0	5	10	35	25	31	34
Section 7-7	0	5	10	35	30	30	34
Section 8-8	0	5	10	35	37	37	34
Section 9-9 to 12-12	0	5	10	10	37	37	37

For the basic case, all dimensions of the previous cross-section have been taken same, so that comparison can be carried out with reference to cross-section of basic case.

With the same basic values of parameters as used in previous analysis, analysis of basic case has been carried out using ANSYS 11.0 Workbench.

As shown in table 3, there are 12 sections showing changes in cross-sectional area at each section and after applying boundary conditions, results obtained are tabulated in table 4. Similarly six iterations are carried out by changing cross-sectional area at 12 sections.

Iteration No. 1

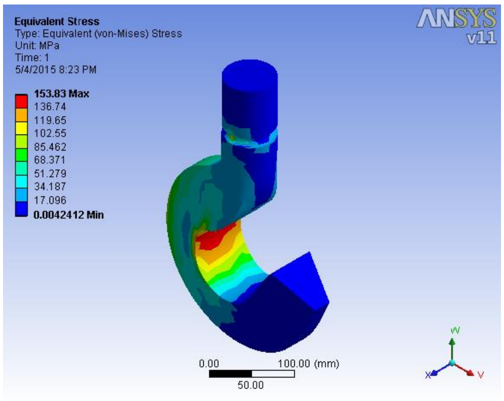


Figure 12. Stress pattern for iteration No. 1

Maximum Value= 153.83 N/mm^2

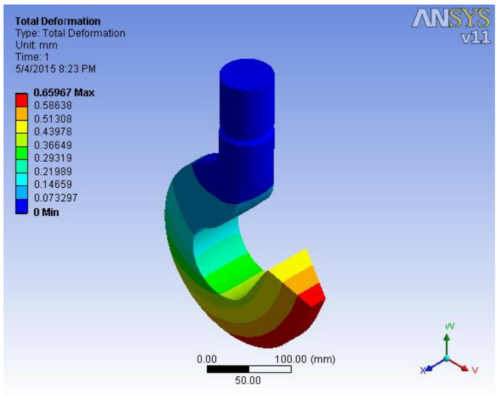


Figure 13. Total deformation values for iteration No. 1

Maximum Value= 0.6596 mm

Iteration No. 2

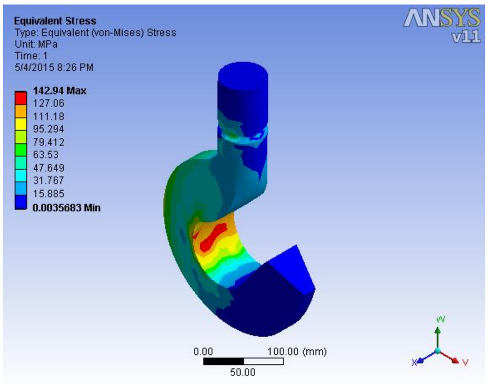


Figure 14. Stress pattern for iteration No. 2

Maximum Value= 142.94 N/mm^2

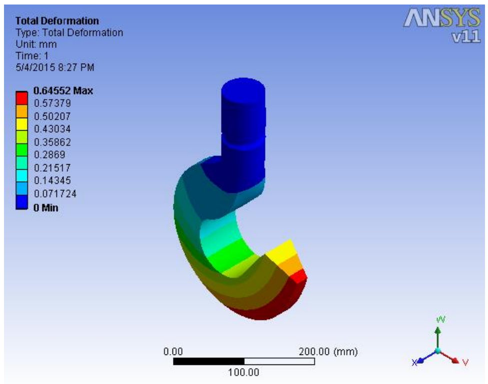


Figure 15. Total deformation pattern for iteration No. 2

Maximum Value= 0.6455 mm

Iteration No. 3

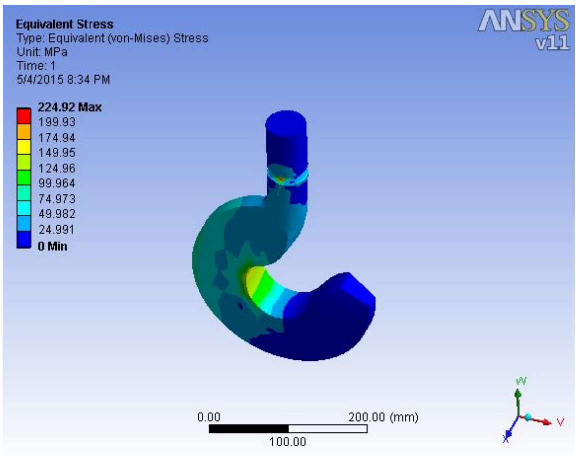


Figure 16. Stress pattern for iteration No. 3

Maximum Value= 224.92 N/mm^2

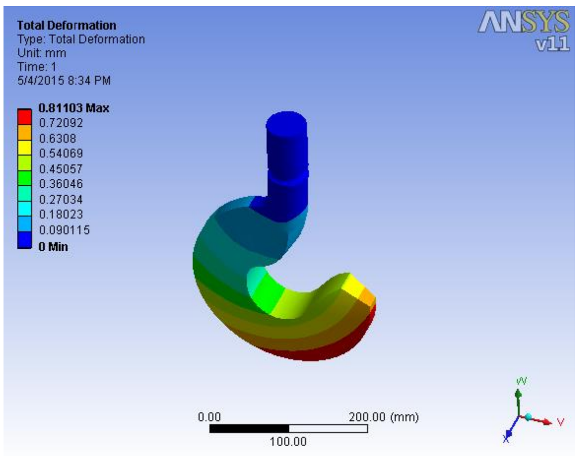


Figure 17. Total deformation pattern for iteration No. 3

Maximum Value= 0.8110 mm

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Iteration No. 4

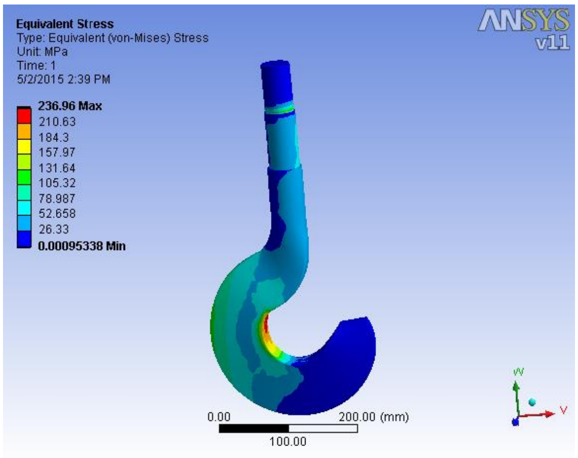

Figure 18. Stress pattern for iteration No. 4

Maximum Value= 236.96 N/mm^2

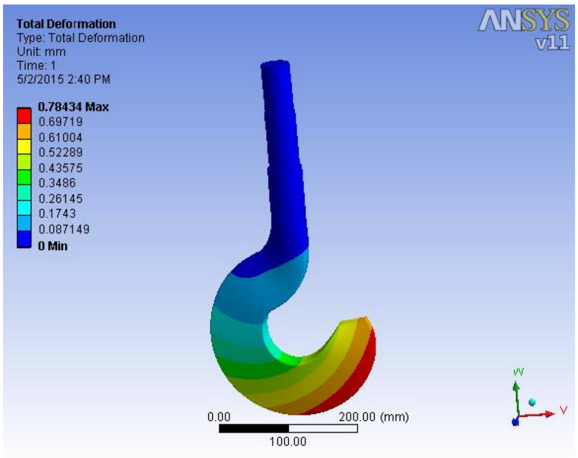

Figure 19. Total deformation pattern for iteration No. 4

Maximum Value= 0.7843 mm

Iteration No. 5

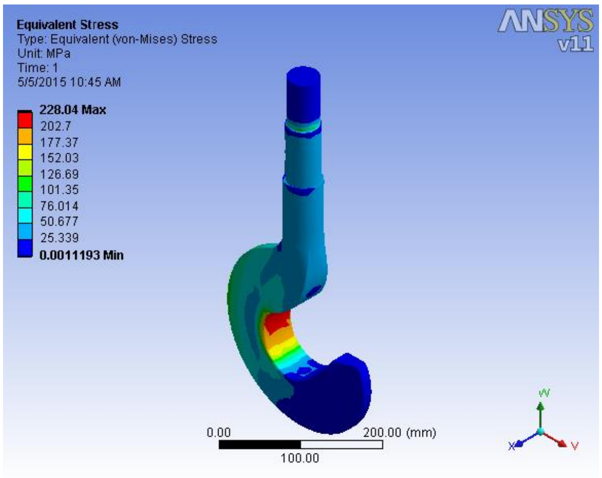

Figure 20. Stress pattern for iteration No. 5

Maximum Value= 228.04 N/mm^2

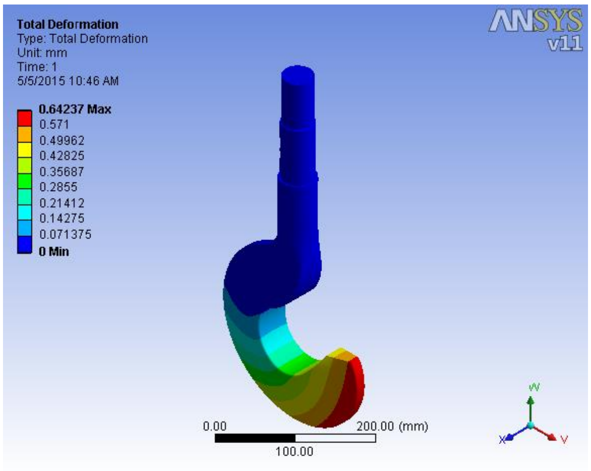

Figure 21. Total deformation pattern for iteration No. 5

Maximum Value= 0.6423 mm

The result obtained are compared with the basic case and tabulated as below.

Table 4. Comparison of results - Basic Case Vs All Iterations

Basic Case and Iteration No.	Volume (x 10^6 mm^3)	Volume Change in %	Stress (N/mm^2)	Stress Change in %	Total Deformation (mm)	Total Deformation Change in %
Basic Case	**2.10**	**00.00**	**167.66**	**00.00**	**0.5829**	**00.00**
1	1.93	-08.00	153.83	-09..00	0.6596	13.15
2	1.84	-12.38	142.94	-15.00	0.6455	10.00
3	1.63	-22.38	224.90	33.00	0.8110	31.00
4	1.45	-31.00	236.96	30.00	0.7853	26.50
5	1.44	-22.38	228.04	36.01	0.6423	10.19
6	**1.39**	**-34.00**	**239.13**	**40.00**	**0.5984**	**03.00**

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From the above table, it is seen that, section derived in iteration no. 6 gives section having less volume, stress and total deformation within permissible limit as compared to basic case.

VI. CONCLUSION

By comparing the results for basic cross-section and optimized cross-section, it is seen that, for the optimized cross-section, volume is reduced by 34.00 %, stress is increased by 40.00 % and deflection is increased by 3.00 %. Though stress and deformation is increased but it is still safe to carry load and values are within permissible limits. Hence section derived in iteration no. 6 is the best possible optimized cross-section of hook.

Table 5. Results for iteration No. 6

Parameter and Unit	Values for Basic Cross-section	Values for Optimized Cross-section	Change in Values
Volume (mm^3)	2.10 x 10^6	1.39 x 10^6	- 34.00 %
Stress (N/mm^2)	167.66	239.13	40.00 %
Total deformation (mm)	0.5829	0.5984	3.00 %

6.1 Comparison of Stress - Basic Case and Optimized Shape

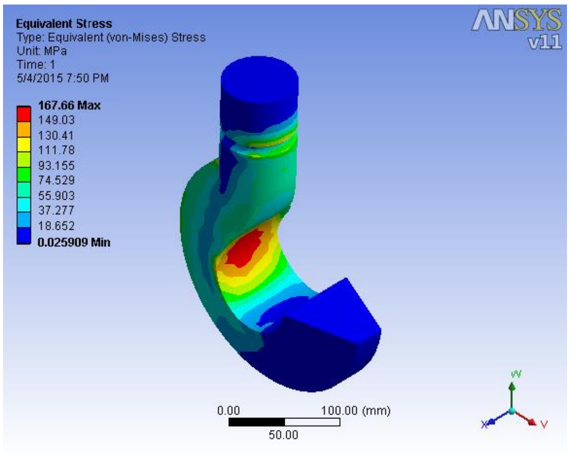


Figure 22. Stress pattern for basic cross-section
Maximum Value = 167.66 N/mm^2

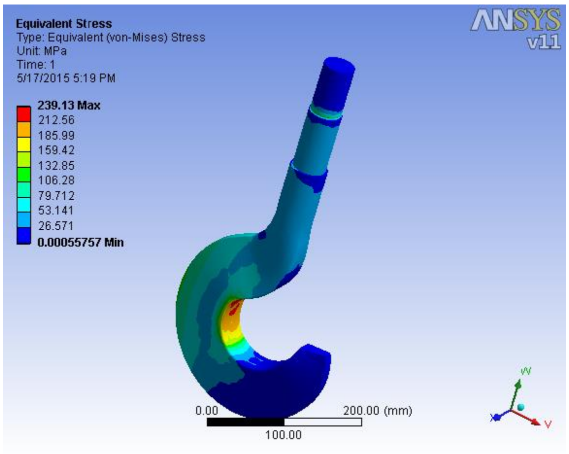
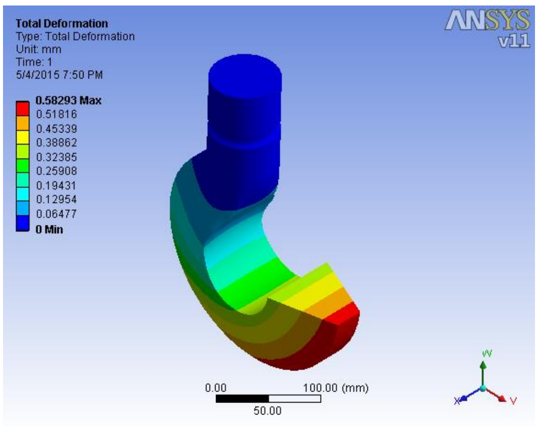


Figure 23. Stress pattern for optimized cross-section
Maximum Value = 239.13 N/mm^2

6.2 Comparison of Total Deformation - Basic Case and Optimized Shape



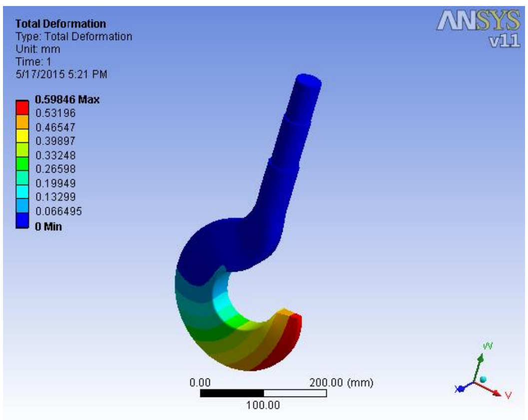


Figure 24. Total deformation plot for basic cross-section ***Figure 25. Total deformation plot for optimized cross-section***
Maximum Value = 0.5829 mm Maximum Value = 0.5984 mm

VII. FUTURE SCOPE OF STUDY

Literature available till date on this topic is very less and hence it has wide scope for carrying out analysis for hook with different cross sections. As it is mainly related to optimization hence the cross section which is to be optimized, should be so optimized that, the stability of structure and its function should not be affected.

VIII. ACKNOWLEDGEMENT

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