Finite Element Analysis Approach for Stress Analysis & Weight Optimization of Crankshaft

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Abstract: **In the Automotive Industry, Every day new developments are going on in the Engine domain. The most crucial component of Engine is Crankshaft as it is undergone through number of forces. Due to competitive market, all the OEMs now concentrating on overall vehicle weight optimization. The main objective of this paper is to optimize the weight of crankshaft using geometry & material optimization techniques. After optimized geometry, the FEA and experimental validation performed for analysis of the stress induced in the crankshaft during static condition. In this study, the crankshaft of two-wheeler 125 Access motorbike taken for study. The FEA analysis has been performed using ANSYS. In static condition bending and twisting forces applied on the crankshaft and Von mises stress is calculated and compared with experimental result.**

Index Terms-**Crankshaft, FEA, ANSYS, Experimental Validation, Bending, Strength Analysis.**

I. INTRODUCTION

In this study, as different forces acting on crankshaft, using FEA technique and Experimental validation results are obtained and it compared with allowable stresses. Crankshaft is complex element of Engine & due to its complexity classical methods used for calculation has some limitations on it so that why Finite Element Analysis method is used to analyze the complex problems. The forces applied at top of the piston, and it transmitted to crankshaft crankpin with the help of connecting rod. The Crankpin component is weakest part of crankshaft. That is why crankpin evaluated for safety. The CAD modeling of crankshaft was done using PRO-E creo 2.0 software. Modeling is done using worst-case geometry. The experimental validation done is Indoor Test lab of India's leading OEM.

II. OBJECTIVES

The objective of this study is to optimize the mass & geometry of the crankshaft and the result should be analyze by using FEA analysis and Experimental validation. FEA had done using ANSYS software. During FEA varies geometries created and prototype has been built using optimized FEA solution.

2.1 Mass reduction of crankshaft using material & shape optimization methods
2.2 FEA analysis of crankshaft
2.3 Experimental validation of optimized crankshaft
2.4 Performance improvement of vehicle by its mass reduction
2.5 Cost reduction of crankshaft by weight reduction

III. ANALYTICAL CALCULATIONS

3.1 Force Calculation on Piston:

Density of Petrol: 730×10^{-9} kg/mm^3
Operating temperature 25°C = 25+273.15= 298.15^{O}K

$$\text{Mass (m)} = \text{Density } (\rho) \times \text{Volume (v)} \qquad (3.1)$$

$$=730\times10^{-9} \text{ x } 125\text{x}10^3$$

$$= 0.09125 \text{ kg}$$

Molecular Weight of Petrol = 114.228 × 10-3 kg/mole

Gas constant for Petrol:

$$R = \frac{8314.3}{114.228 \times 10-3} \qquad (3.2)$$

$$R = 72.7868 \text{ x } 10^3 \text{ J/kg/mol K}$$

$$\text{As, } PV = mRT \qquad (3.3)$$

$$P\times 125 \times 10^3 = 0.09125 \times 72.7868 \times 10^3 \times 298.15$$

Thus,

$P = 15.8420\ \text{MPa} = 15.8420\ \text{N/mm}^2$

Hence, Gas Force (F_P):

F_P = Pressure (P) × Piston Cross section Area (A) (3.4)

Bore x Stroke = 52.5 x 57.4 [Piston Standard Dimension from vehicle specification]

$F_P = 15.8420 \times \frac{\pi}{4} \times (52.5)^2$

$F_P = 34.29402 \times 10^3\ \text{N}$

$F_P = 34.2940\ \text{KN}$

IV. FINITE ELEMENT ANALYSIS

Three Dimensional model created using PRO-E creo 2.0 software. The main components of the crankshaft are Webs, Crankpin, and Journals. The flywheel has not shown in the modeling. The dimensions for modeling taken from the existing available crankshaft in the market and based on that crankshaft modeling was done. The complete geometry of the crankshaft is solid. Crankshaft modeling is done using parametric design this technique is useful during the shape optimization.

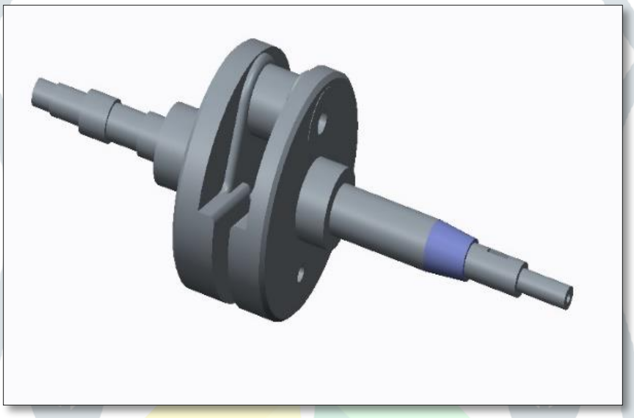


Fig. 4.1 Crankshaft CAD Model

4.1 Meshing:

Accuracy and precision of result depend on the meshing size. Mesh size is fine then result also very close to accurate hence, mesh size 2 was selected for the Analysis. Meshing type is tetrahedral element. Tetrahedral type was used for high quality meshing of boundary representation of solid structural components & the tetrahedral was found to be the best meshing technique.

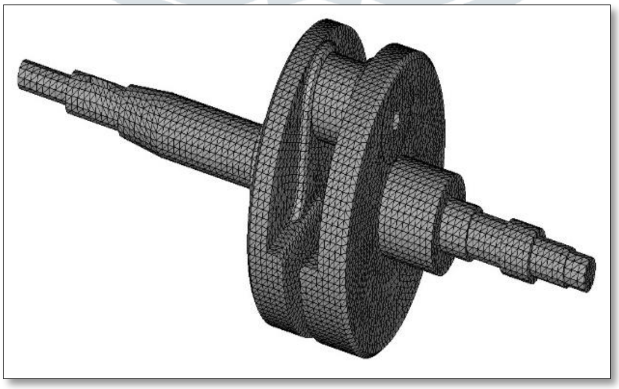


Fig. 4.2 Meshing

4.2 Loads and Boundary conditions:

Selection of boundary conditions drives the result of the FEA. In this study. Assumed that the crankshaft is stationary and performing the static analysis. Both the ends of crankshaft are fixed and point load of 35.23 KN applied at the center of crankpin.

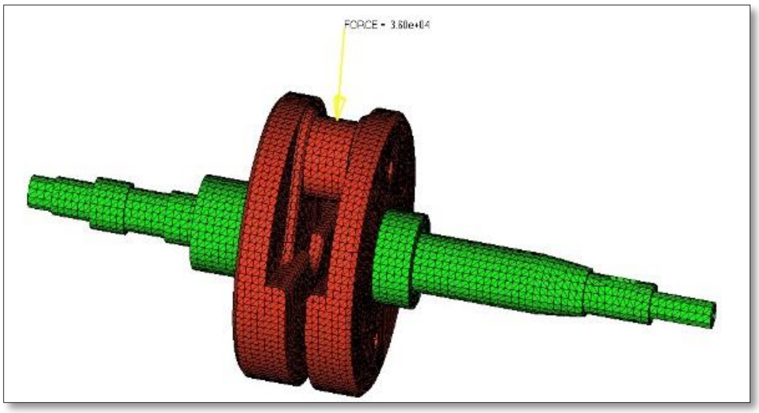


Fig. 4.3 Boundary conditions applied

The medium carbon steel properties as below:

Density	7.7 × 103kg/m3
Yield Tensile Strength	310 MPa
Ultimate Tensile Strength	565 MPa
Poisson’s ratio	0.29
Young’s modulus	200000 MPa

Table 4.1: Material Property

4.3 Meshing Solution:

The OptiStruct solver was used to solve linear static behavior problem. The Von-mises stress is measure in the crankshaft. Result obtained by FEA analysis with modified the dimensions shown as below figures. In iteration 1, 188.1MPa stress was generated in the crankpin, which is below the yield strength of material.

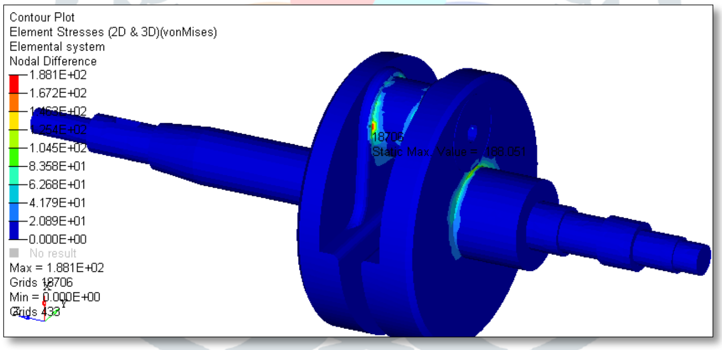


Fig. 4.4 Iteration-1

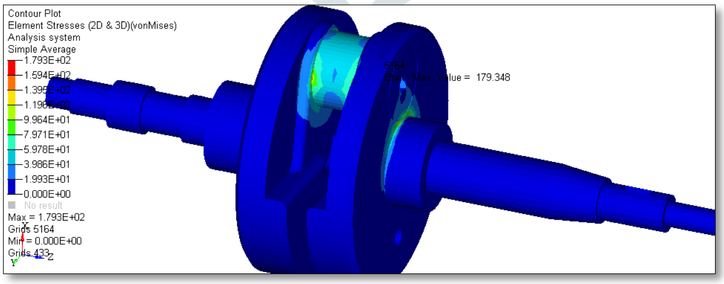


Fig. 4.5 Iteration-2

In the Iteration 2, 179.3 Mpa stress was developed in the specimen, which is below the yield strength of material hence design is safe. In Iteration 3, the stress developed is 197.1 MPa which was higher than the Iteration-1 and Iteration-2

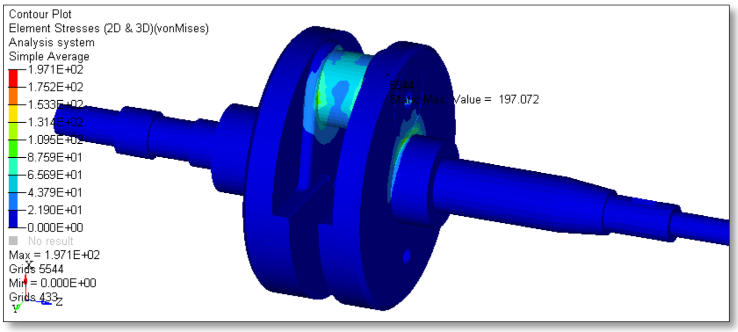


Fig. 4.6 Iteration-3

Iteration	**Web1 Thickness (mm)**	**Web2 thickness (mm)**	**Stress (MPa)**	**Mass (kg)**
1	18	21	188.1	2.934
2	**17**	**21**	**179.3**	**2.902**
3	16	20	197.1	2.840

Table 4.2: FEA Analysis Result

From all above analysis, it is observed that, Stress developed during Iteration 2 is minimum compared with other other two Iteration hence prototype built as per this dimensions.

V. EXPERIMENTAL VALIDATION

Validation of crankshaft with more practical sense the hydraulic press with load cell actuator was used from the Indoor-testing lab. The goal of testing is optimize the crankshaft with gradual application of load until the yield strength of crankshaft material. The experimental set-up is as shown in the fig. static as well as baseline deformation and fatigue properties of both materials were obtained. The load was applied with help of hydraulic actuator at the center of crankpin and all the reading has been taken.

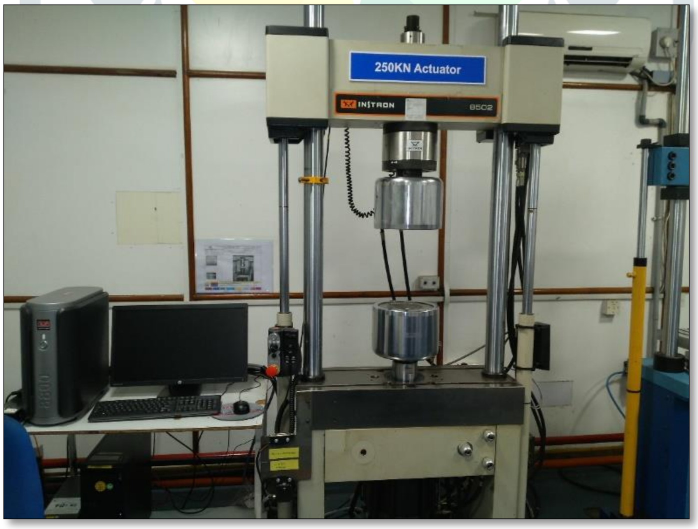


Fig. 5.1: Experimental set up- Intron 250KN Actuator

Machine Specifications	
Model	Dual Column Floor Models
Load capacity	250KN
Maximum Speed	508mm/min
Return Speed	600mm/min
Cross Head Travel	1830mm
Vertical Test Space	1930mm
Column Spacing	575mm
Weight	955kg

Table 5.1: Testing Machine specifications

5.1 Experimental Set Up:

The experimental set up to perform the given test is as shown in the Figure 5.1 to perform the test below steps were followed

5.1.1 Adjust the column structure of rig to achieve required distance for clamping of the crankshaft
5.1.2 The loading force should be should be equally distributed over the crank pin area
5.1.3 Place the crankshaft on the rig in the same orientation as mounted in the engine block and clamp it using fixtures
5.1.4 Mount the cylinder and prepare the hose connection from power pack
5.1.5 Mount the load cell at cylinder to cross verify the applied force
5.1.6 Check the electrical connection and timer settings
5.1.7 Conduct final check for fasteners and fasteners hydraulic connections
5.1.8 Load the axle as per specified load data sheet.
5.1.9 Record the data of for number of cycles
5.1.10 Record the data of defection of the crankshaft at the beginning to end of load cycle
5.1.11 Record the data of deformation at the end of load cycle.
5.1.12 Limit switch used to protect the actuator from damage, it will operated only when the deflection exceeds a set value and stop the rig
5.1.13 Cyclic Vertical load of 34 KN to be applied at center of the crank pin pads
5.1.14 Lateral load has to be applied through a suitable fixture in way that the loading point is 16mm away from crankshaft web 1

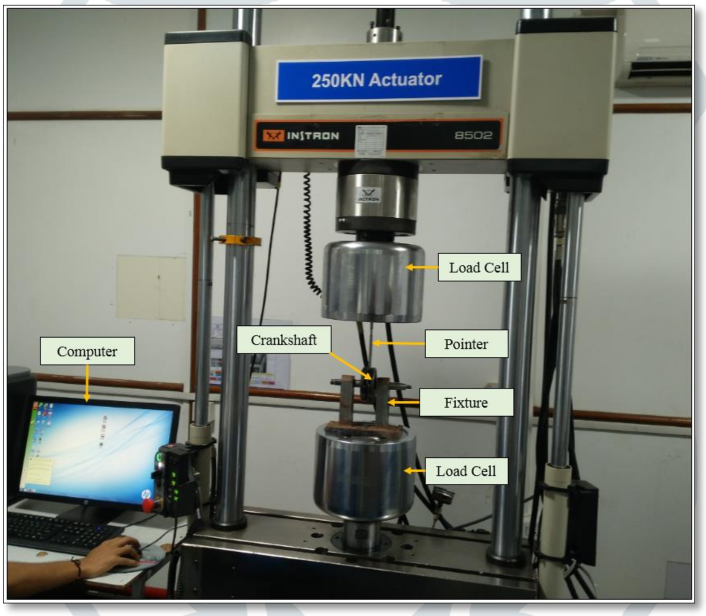
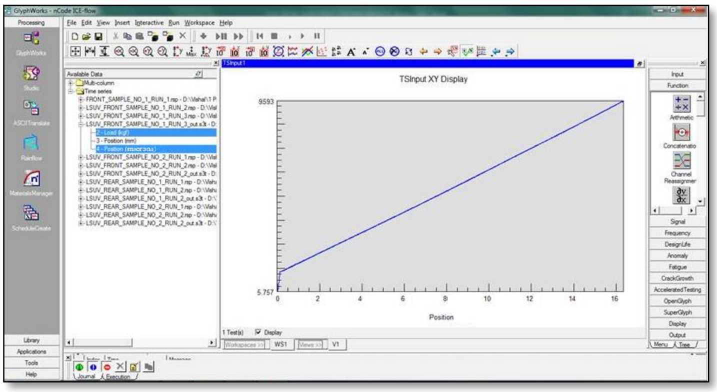
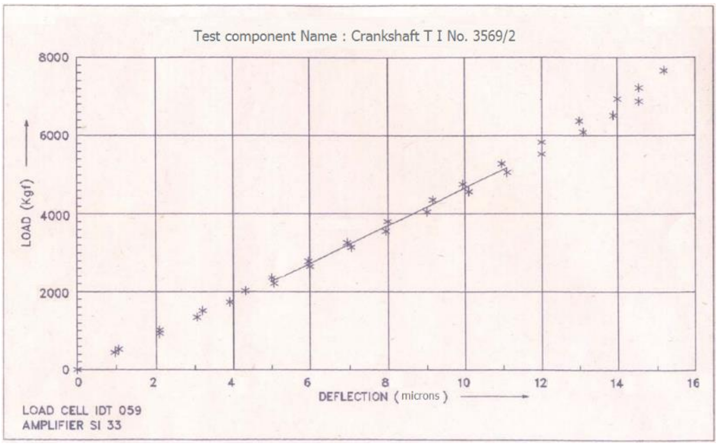


Fig. 5.2: Experimental Set up with Crankshaft

The software used for analysis of the result is Glyph Works. Code Glyph Works is a powerful data processing software system used for engineering test data analysis with specific application to durability and fatigue analysis. Designed to handle tremendous amounts of data, Glyph provides the graphical, process oriented data environment. Key Features of Glyph Works Durability and fatigue analysis. Specialized for damage calculations and test profile generation. Also integrates with Design Life to enable test and CAE fatigue in single conditions graphically develop analytical processes Intuitive and powerful. Intrinsically multi-file, multi-channel, multi-format-Optimized for complex analysis, and maximum file sizes. Wide range of functions for time, frequency, and statistical analysis AND video displays.



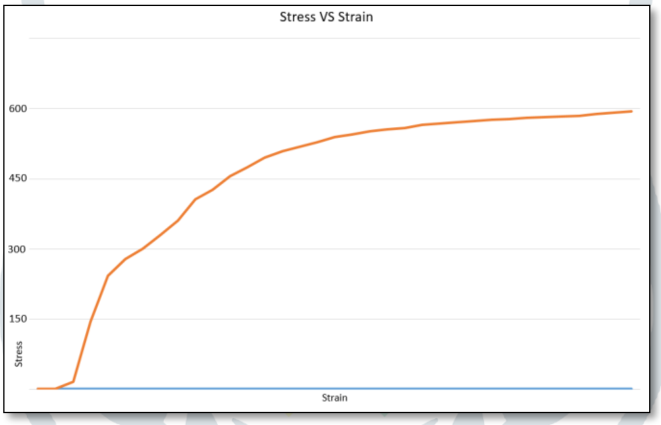
Graph 5.1: Graphical output from Glyph Works, Load vs Deformation



Graph 5.2: Load VS Deflection

5.2 Assumptions:

5.2.1 Assume that the crank pin acts as simply supported beam with both ends are fixed
5.2.2 The load is applied at the center of the beam (Crank Pin)
5.2.3 Material of beam is homogenous & isotropic
5.2.4 Each layer of the Specimen is free to expand or contract.
5.2.5 Young's modulus is constant in compression and tension
5.2.6 Beam is initially straight and all longitudinal filaments bend in circular arcs
5.2.7 The material of the beam is stressed within elastic limit and obeys Hooke's law



Graph 5.3: Stress VS Strain

Output received in the excel format after the experimental analysis as below:

The Graph was generated from the experimental readings obtained in the table 5.2. & it is seen that the nature of graph is similar to standard material.

Sr. No.	Time (sec)	Load (N)	Deflection (Micron)	Strain	Stress (Mpa)
1	0	2.2763	0.30	0.00000	0.0122
3	0.1664	24.0314	0.27	0.00000	0.1292
4	0.2912	972.5583	0.40	0.00002	5.2288
5	0.3744	8960.2697	1.02	0.00023	48.1735
6	0.4992	14993.3064	1.88	0.00038	80.6092
7	0.5824	17212.6889	1.86	0.00044	92.5413
8	0.6656	18652.2853	2.02	0.00048	100.2811
9	0.7904	20361.8670	2.36	0.00052	109.4724
10	0.8736	22371.4221	2.83	0.00057	120.2765
11	0.9984	25187.5579	3.21	0.00064	135.4170
12	1.0816	26459.2064	3.53	0.00068	142.2538

13	1.2064	28264.8683	4.03	0.00072	151.9617
14	1.2896	29401.8638	4.33	0.00075	158.0745
15	1.4144	30678.2687	4.60	0.00079	164.9369
16	1.5392	31591.5072	5.01	0.00081	169.8468
17	1.6224	32126.0190	5.29	0.00082	172.7205
18	1.7056	32756.2714	5.83	0.00084	176.1090
19	1.8304	33453.9747	6.21	0.00086	179.8601
20	1.9136	33798.6135	6.78	0.00087	181.7130
21	2.0384	34176.2531	7.12	0.00087	183.7433
22	2.1632	34461.0739	7.39	0.00088	185.2746
23	2.2464	34674.0270	7.65	0.00089	186.4195
24	2.4128	35081.6548	8.07	0.00090	188.6110
25	2.4544	35191.3249	8.32	0.00090	189.2007
26	2.5792	35435.4215	8.82	0.00091	190.5130
27	2.6624	35576.9598	9.14	0.00091	191.2740
28	2.7456	35707.6263	9.59	0.00091	191.9765
29	2.8704	35857.0016	10.00	0.00092	192.7796
30	2.9536	35957.8383	10.25	0.00092	193.3217
31	3.0784	36103.6801	10.54	0.00092	194.1058
32	3.1616	36171.8333	11.07	0.00093	194.4722
33	3.2864	36274.5500	11.40	0.00093	195.0245
34	3.7024	36552.6664	12.75	0.00094	196.5197
35	4.1184	36722.2226	13.91	0.00094	197.4313
36	4.5344	36826.1623	15.63	0.00094	197.9901

Table 5.2: Experimental Validation Results

After applying the axial point load on the crank pin the above shown reading are taken and it observed that the 183.7 MPa stress developed in the specimen at 34.17KN force, which very close to FEA result obtained in iteration-2.

VI. RESULT & CONCLUSION

Sr. No.	**Material**	**FEA Result**	**Experimental Validation result**	**Mass (kg)**
		Stress (Mpa)	**Stress(Mpa)**	
1	Medium Carbon Steel	179.3	183.7	2.902

Table 5.3: Comparison of FEA & Physical validation

From above comparison, it observed that:

- From Table 4.2, the optimized solution is Iteration-2 based on FEA result & stress in the specimen is 179.3MPa hence prototype was built based on Iteration-2 geometry and tested
- Table 5.2, Gives us the details of experimental analysis and stress developed at 34.17KN is 183.7MPa
- From Table 5.3, it observed that the difference between FEA result and Experimental result is very close. The percentage variation in the result is 2.35%
- From Table 5.3, It is observed that both the values of stress 179.3 MPa and 183.6MPa are below the yield strength of material hence the design is safe
- From Table 4.2, It is seen that 1.5% mass reduction obtained with newly proposed geometry i.e. iteration 2
- Mass reduction helpful for cost reduction as well as vehicle performance improvement
- Difference in Analytical, FEA & Experimental result occurred because the assumptions done while calculating the results

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