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MATERIAL SELECTION, DESIGN AND TOPOLOGY OPTIMIZATION OF BELL CRANK LEVER

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Abstract - *A bell crank lever is mostly characterized as a kind of lever which is used to alter the course of movement either through 90° or 180°. A bell crank lever is exposed to huge measure of stresses, so they are significant components in terms of safety. In this project Optimum Design of Bell Crank Lever was designed by considering some properties like Density, Young's modulus, Ultimate tensile strength, Yield Strength, Shear modulus, Cost. The material properties and costing of material was studied, and standard Bell Crank Lever materials were identified by using PSG Design Data Book. The selection of the materials is based on some multi criteria decision making methods (MCDM) like TOPSIS, VIKOR and COPRAS. The material has been ranked by using above mentioned criteria methods. Then virtual model of bell crank lever is designed with in allowable Bending stresses and shear stress. Modelling was done by using Catia. After that a Static Structural and modal analysis was done by using Ansys Software to find out stresses and deformation, and also Weight of the Bell Crank lever for the Selected Material are noted. Then I Perform Topology Optimization to Reduce Weight of Bell Crank Lever within The Allowable Limits.*

Keywords: *Bell Crank Lever, Materials, MCDM, Topology Optimization, Weight, Volume, Solid works.*

1. INTRODUCTION

Bell crank lever is a rigid bar or rod fixed about a point called fulcrum and capable of turning about this point. Also, it is used to lift the heavy load by applying small effort. The proportion of lifted burden to exertion is known as mechanical advantage. Stresses in the lever mainly due to bending and the design are also based on bending stress. Bell crank lever has many areas of application like automotive sector, production sector and household purposes, but mostly bell crank lever is used in automobile sector. Formula-style racer car mainly uses this type of lever in their suspension system in which their suspension control arms are exposed by protruding through the body panels. The spring and damper are relocated on vehicle within the bodywork due to aerodynamic reasons. This type of arrangement is different from standard setup as it needs push or pull rod and bell crank to control the suspension system. As bell crank lever is subjected to heavy loads and stresses, and it is necessary to find out the safe load and the best Material which under required conditions can fulfil the work criteria.

Figure 1.1 Formula-style racer car

The Bell crank lever is likely to wear and breakage during its normal working cycle by repetitive load in operations. So to oppose this loads the material ought to have some particular properties, in this project we consider four different material that is Cast steel, Forged steel, Stainless steel martensitic and structural steel for the material consider the properties like Density, Young's modulus, Yield Strength, Ultimate tensile strength, Shear strength and Cost of the material. Every material has distinctive execution for every property. Accordingly, it is important to choose the best elective material that has the most noteworthy level of fulfilment for all the applicable properties.

A multi criteria decision making methods is used to find out optimum material for that a weighting strategy, made out of the Analytic Hierarchy process(AHP) were utilized to decide the significance loads of assessment criteria, and afterward the elective materials were ranked by utilizing three MCDM techniques, i.e; TOPSIS,VIKOR and COPRAS strategies, so as to decide the best material for the Bell crank lever

Now we design bell crank lever and modelled using CREO software. Then we perform Static structural analysis and modal analysis to find out optimum material using ANSYS software, and also perform Topology optimization to reduce the weight of the bell crank lever within the allowable limits.

Figure 1.2 Bell crank lever Formula-style racer car

1.1 Problem statement

Bell crank lever should have some specific properties in order to maintain their function during working. In automobile various loads induced on the gears during working, These loads may cause failure to the gear, so to resist failure of gears the gear should meet the following requirements, i.e.; Young's modulus (YM) for high rigidity., Ultimate tensile strength (UT) to prevent failure against static loads., Yield strength (YS) to withstand dynamic loads, Density (D) and High shear strength (SM),there are some other property such as cost(C). The low value of which is desired in order to provide competitive advantage among manufactures. Four alternative lever materials were taken into consideration: Cast steel, Forged steel, Stainless steel martensitic and structural steel

However, none of the proposed materials met the previously referenced needs. Some material choice techniques have been immersed, so as to choose the best material that has most noteworthy level of fulfilment for all the significant properties. MCDM strategies, i.e; TOPSIS, VIKOR, COPRAS techniques were utilized in our investigation to assess conceivable material for gears. A traded off Weighing strategy made out of AHP were utilized to decide the criteria Weight.

Then Design a right angled bell crank lever having one arm 220 mm and the other 150 mm long. The load of 5 kN is to be raised acting on a pin at the end of 500 mm arm and the effort is applied at the end of 150 mm arm. The permissible stresses for the pin and lever are 84 MPa in tension and compression and 70MPa in shear. The bearing pressure on the pin is not to exceed 10 N/mm2.

Then we perform Static structural analysis, modal analysis to find out optimum material using ANSYS software, and also perform Topology optimization to reduce the weight of the bell crank lever with in the allowable limits
load. The bell crank lever was then fabricated using manual milling hand technique and 5-axis computer numerical control (CNC) machine.

2. MULTI-CRITERIA DECISION MAKING METHODS

Bell crank levers are utilized in different applications. These levers are in high demand for efficient manufacturing in advance industrial applications and automations such as power transmission in process equipment, material handling equipment, metal cutting and metal forming machineries etc.. In this paper we consider crane bell crank lever. The bell crank lever are probably going to wear and breakage amid its typical working cycle by repeated loads in activities. So to oppose this heaps the material ought to have some particular properties, for example, less Density, high Young's modulus, high Yield strength , high ultimate strength,. High shear strength and less cost There is no material which satisfies every one of these needs. Every material has distinctive execution for every property. Accordingly, it is important to choose the best elective material that has the most noteworthy level of fulfilment for all the applicable properties.

Material choice has extraordinary significance in plan and improvement of the items. The achievement and aggressiveness of the makers additionally relies upon the chose material. The destinations of execution, cost and ecological affectability drive building structure, and are commonly restricted by materials. Choice of the materials that best meet the prerequisites of the structure and give most extreme execution and least expense is the objective of ideal item plan . Nonetheless, some clashing circumstances are commonly seen between these destinations and criteria (for example Youngs modulus/cost, or durability/hardness) and there is a need to choose which property could easily compare to other people. Utilizing basic and intelligent techniques, the criteria that impact material determination for a given designing application must be recognized to kill inadmissible options and to choose the most suitable one. So as to explain the material choice issue of building parts and to expand the productivity in configuration process, a lot of materials choice strategies have been grown, for example, Ashby approach, TOPSIS (system for request execution by comparability to perfect arrangement), VIKOR (Vlse Kriterijumska Optimizacija Kompromisno Resenje, implies Multicriteria Optimization and Compromise Solution), ELECTRE (disposal and decision communicating the truth), PROMETHEE (inclination positioning association technique for improvement assessment), COPRAS (complex relative evaluation) ,Weighted Sum Method and COPRAS-G to expand the proficiency in configuration process. In this project, along these lines, a methodical assessment display was proposed to help the Bell crank lever generation for the choice of an ideal material among a lot of accessible options. A weighting strategy, made out of the Analytic Hierarchy process(AHP) were utilized to decide the significance loads of assessment criteria, and afterward the elective materials were ranked by utilizing three MCDM techniques, i.e; TOPSIS,VIKOR and COPRAS strategies, so as to decide the best material for the Bell crank lever , thinking about various material determination criteria. The properties desired for lever and materials with their quantities are tabulated in Table 2.1.

Table 2.1 The required properties for Bell crank lever and the Materials with their quantitative data

Material	Density (Kg/m^3)	Youngs Modulus(Pa)	Ultimate Tensile Strength(Pa)	Tensile Yield strength(Pa)	Shear Modulus (Pa)	Cost (Kg)
Forged Steel	8000	1.93E+11	5.86E+08	2.07E+08	7.37E+10	60
Cast Steel	7820	2.03E+11	5.05E+08	3.49E+08	7.81E+10	85
Stainless steel, martensitic	7750	2E+11	8.40E+08	7.62E+08	7.81E+10	160
Structural steel	7850	2E+11	2.50E+08	4.60E+08	7.69E+10	80

2.1 AHP Weighing strategy

The AHP strategy comprises of following advances

a. Developing a various levelled structure with an objective at the top dimension, the qualities/criteria at the second dimension and the choices at the third dimension

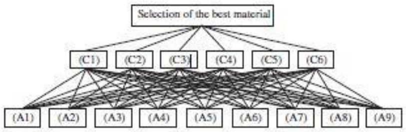

Figure 2.1 The decision hierarchy of material selection for the gears.

b. Decide the overall significance of various characteristics or criteria as for the objective, the pair insightful correlation framework is utilized and it tends to be made with the assistance of size of relative significance. 1 for "Equal importance", 3 for "moderate Importance", 5 for "Strong importance", 7 for "Very strong importance", 9 for "Extreme importance", and 2,4,6,8 for "Intermediate values",1/3,1/5,1/7,1/9 Values for inverse comparison The pair – wise comparison matrix for given criteria is appeared Table 2.2.

	D	YM	UT	YS	SM	C
D	1	0.2	0.2	0.2	0.2	0.3
YM	5	1	1	1	1	0.2
UT	5	1	1	1	1	0.2
YS	5	1	1	1	1	0.2
SM	5	1	1	1	1	0.2
C	3	5	5	5	5	1

Table 2.2 The pair –wise comparison matrix

c. Normalized pair wise matrix is determined by dividing each element by total sum of elements in that row Table 2.3.

	D	YM	UT	YS	SM	C
D	0.0417	0.0217	0.0217	0.0217	0.0217	0.1563
YM	0.2083	0.1087	0.1087	0.1087	0.1087	0.0938
UT	0.2083	0.1087	0.1087	0.1087	0.1087	0.0938
YS	0.2083	0.1087	0.1087	0.1087	0.1087	0.0938
SM	0.2083	0.1087	0.1087	0.1087	0.1087	0.0938
C	0.1250	0.5435	0.5435	0.5435	0.5435	0.4688

Table 2.3 Normalized pair wise matrix

d. Criteria weights are determined by averaging every one of the components in the column of the standardized pair savvy lattice. Criteria loads signified by "W" are appeared Table 2.4

Criteria Weights	D	YM	UT	YS	SM	C
W_j	0.0475	0.1228	0.1228	0.1228	0.1228	0.4613

Table 2.4 Criteria weighting by the AHP method.

e. In request to calculate the consistency of the abstract recognition and the exactness of the relative Weights, the consistency index (C.I) and consistency proportion (C.R) are determined. The consistency index(C.I) is
$C.I = (\lambda_{max}-n)/(n-1)$

Where n is number of thought about components. Λ_{max} is the proportion of weighted whole an incentive to criteria loads. The estimation of C.I ought to be lower than 0.1 for a sure outcomes. The consistency proportion (C.R) can be determined as

$C.R = (C.I)/(R.I)$

The R.I is resolved for various size frameworks, and its esteem is 1.25 for 6 x 6 network. The C.R ought to be under 0.1 for a solid outcome.

To find λ_{max} find wighted sum value by dividing each element in a row by the weight of that row

	D	YM	UT	YS	SM	C	Weighted Sum Value
D	0.0020	0.0027	0.0027	0.0027	0.0027	0.0721	0.0847
YM	0.0099	0.0133	0.0133	0.0133	0.0133	0.0432	0.1065
UT	0.0099	0.0133	0.0133	0.0133	0.0133	0.0938	0.1570
YS	0.0099	0.0133	0.0133	0.0133	0.0133	0.0938	0.1570
SM	0.0099	0.0133	0.0133	0.0133	0.0133	0.0938	0.1570
C	0.0059	0.0667	0.0667	0.0667	0.0667	0.2162	0.4891

Table 2.5 Weighted sum value

Then find out λ value by dividing weighted sum value by criteria weights

Weighted Sum Value	Criteria Weights	λ
0.0847	0.0138	6.1435
0.1065	0.0161	6.6144
0.1570	0.0245	6.4035
0.1570	0.0245	6.4035
0.1570	0.0245	6.4035
0.4891	0.0805	6.0737

Table 2.6 λ value

Select maximum value $\lambda_{max} = 6.340366$

The consistency index(C.I) is

$C.I = (\lambda_{max}-n)/(n-1)$

$= 0.068073$

The consistency proportion (C.R) can be determined is

$C.R = (C.I)/(R.I)$

$= 0.054898$

< 0.10

So our matrix is reasonably consistent so we use these weights for further calculations

2.2 TOPSIS Method

The TOPSIS strategy is utilized to get an answer, which is nearest to the perfect arrangement and most remote from the negative perfect arrangement. The technique needs data on relative significance of properties that are considered in choice process. The TOPSIS strategy comprises of the accompanying advances:

a. Normalization of data by using following equation

$$R_{ij}=\sqrt{\frac{Xij}{\sum_{i=1}^{m}(Xij)^{\wedge}2}}$$

The normalization decision matrix is shown in Table 2.7.

Material	**D**	**YM**	**UT**	**YS**	**SM**	**C**
Forged Steel	0.509	0.485	0.501	0.212	0.480	0.290
Cast Steel	0.498	0.510	0.432	0.357	0.509	0.411
Stainless steel, martensitic	0.493	0.502	0.719	0.779	0.509	0.773
Structural steel	0.500	0.502	0.214	0.470	0.501	0.387

Table 2.7 Normalization decision matrix

b. The columns of the normalized decision matrix are multiplied by the associated weights W_j obtained and the weighted normalized decision matrix is obtained by the following equation. And results shown in Table 3.8

$V_{ij} = R_{ij}W_j$ j=1,2…………n ; i=1,2…………..m

Material	D	YM	UT	YS	SM	C
Forged Steel	0.024	0.060	0.062	0.026	0.059	0.134
Cast Steel	0.024	0.063	0.053	0.044	0.062	0.189
Stainless steel, martensitic	0.023	0.062	0.088	0.096	0.063	0.357
Structural steel	0.024	0.062	0.026	0.058	0.062	0.178

Table 2.8. Weighted and Normalized decision matrix

c. Calculation of ideal and nadir ideal solution obtained by using following equations

$\{ V^+_1, V^+_2, \ldots\ldots\ldots V^+_n \} = \{(\max V_{ij}(j \in k) \,.\, (\min V_{ij})\, j \in k^I) \mid i=1,2,\ldots m\}$ (9)

$\{ V^-_1, V^-_2, \ldots\ldots\ldots V^-_n \} = \{(\max V_{ij}(j \in k) \,.\, (\min V_{ij})\, j \in k^I) \mid i=1,2,\ldots m\}$ (10)

Positive matrix is to be calculated for beneficial property take maximum value of weighted normalized matrix and minimum value for non-beneficial property. Similarly for negative matrix is to be calculated for beneficial property take minimum value of weighted normalized matrix and maximum value for non-beneficial property. The values of ideal and nadir ideal solution is shown in Table 2.9

	D	YM	UT	YS	SM	C
V_j^+	0.024	0.063	0.088	0.096	0.063	0.178
V_j^-	0.024	0.062	0.026	0.058	0.062	0.357

Table 2.9 The Positive ideal and Negative ideal solutions

d. The distances from the ideal and nadir solutions are measured. The two Euclidean distances for each alternative are computed as given in following equations:

$S^+_i = \{\sum_{j=1}^{n}(V_{ij} - V_j^+)^2\}^{0.5}$ j = 1,2……….n ; i= 1,2……….m. (11)

$S^-_i = \{\sum_{j=1}^{n}(V_{ij} - V_j^-)^2\}^{0.5}$ j = 1,2……….n ; i= 1,2……….m. (12)

The values of S^+_i , S^-_i are shown in Table 3.10.

e. The relative closeness to the ideal solution is calculated by using following equation

$C_i = (S^-_i)/ (S^+_i + S^-_i)$ i = 1,2,………..m ; $0 \le C_i \le 1$ (13)

The higher value of C_i gives the better rank. The values of C_i and ranking for the material are shown in Table 2.10.

Material	S^+_i	S^-_i	C_i	Rank
Forged Steel	0.087	0.228	0.724	2
Cast Steel	0.064	0.170	0.727	1
Stainless steel, martensitic	0.178	0.073	0.290	4
Structural steel	0.073	0.178	0.710	3

Table 2.10 S^+_i, S^-_i , C_i and Rank

2.3 VIKOR Method

The main procedure of the VIKOR method is described below

a. Identify beneficial and non-beneficial properties then the best, i.e. $(X_{ij})_{max}$ and the worst, i.e. $(X_{ij})_{min}$ values of all criteria are determined from decision matrix.

b. Find the values of S_i and R_i by the following equations and this values shown in Table 10.
$S_i = \sum_{j=1}^{n}\{ W_j[(X_{ij})_{max} - X_{ij}] / [(X_{ij})_{max} - (X_{ij})_{min}]\}$
(
$R_i = \max\{W_j[(X_{ij})_{max} - X_{ij}] / [(X_{ij})_{max} - (X_{ij})_{min}]\}$

c. Then find the values of S^*, S^-, R^*, R^- i.e; $S^* = \min(S_i)$; $S^- = \max(S_i)$; $R^* = \min(R_i)$;
$R^- = \max(R_i)$.

d. Now, we calculate value of Q_i by using following relation.
$Q_i = v[(S_i - S^*) / (S^- - S^*)] + (1-v)[(R_i - R^*) / (R^- - R^*)]$
The value of v is usually taken as 0.5 while it can take any value from 0 to 1. The values of Q_i is shown in Table 9 and The compromise ranking list is obtained by ranking according to Q_i measures. The best alternative is determined as the one with the minimum value of Q_i .and the ranking for the materials is shown in Table 2.11

Material	S_i	R_i	Q_i	Rank
Forged Steel	0.469	0.123	0.440	3
Cast Steel	0.291	0.115	0.000	1
Stainless steel, martensitic	0.498	0.461	1.000	4
Structural steel	0.371	0.123	0.203	2

Table 2.11 S_i, R_i, Q_i and Rank

2.4 COPRAS Method

The main procedure of the COPRAS method is described below

a. First step is to develop initial decision matrix that is in table 2.1

]

b. Nexst step is to normalize decision matrix by using the formula as shown below
$R_{ij} = \frac{Xij}{\sum_{i=1}^{m}(Xij)}$
The normalization matrix shown in table 2.12

Material	D	YM	UT	YS	SM	C
Forged Steel	0.255	0.242	0.269	0.116	0.240	0.156
Cast Steel	0.249	0.255	0.232	0.196	0.254	0.221
Stainless steel, martensitic	0.247	0.251	0.385	0.429	0.255	0.416
Structural steel	0.250	0.251	0.115	0.259	0.251	0.208

Table 2.12 Normalization decision matrix for COPRAS method

c. The columns of the normalized decision matrix are multiplied by the associated weights W_j obtained and the weighted normalized decision matrix is obtained by the following equation. And results shown in Table 2.13
$V_{ij} = R_{ij}W_j$ j=1,2…………n ; i=1,2…………..m

Material	D	YM	UT	YS	SM	C
Forged Steel	0.012	0.030	0.033	0.014	0.029	0.072
Cast Steel	0.012	0.031	0.028	0.024	0.031	0.102
Stainless steel, martensitic	0.012	0.031	0.047	0.053	0.031	0.192
Structural steel	0.012	0.031	0.014	0.032	0.031	0.096

Table 2.13 weighted normalized decision matrix for COPRAS method

d. Then sum of weighted normalized matrix. In this need to seprate beneficial and non- beneficial attributes
   $S_{+i} = \sum_{j=1}^{n} Y_{+ij}$; $S_{-i} = \sum_{j=1}^{n} Y_{-ij}$
   The result shown in table 2.14
e. Then determine relative significance of alternatives and then calculate the quantitative utility then give the rank based on quantitative utility high value gives top rank. The results shown in table 2.14
   $Q_i = S_{+i} + (S_{-min}\sum_{i=1}^{m} S_{-i})/(S_{-i}\sum_{i=1}^{m}(S_{-min}/S_{-i}))$

   $U_i = \left[\frac{Qi}{Qmax}\right] \text{x } 100$

S_+	S_-	Q_i	U_i	Rank
0.107	0.084	0.280	100.000	1
0.115	0.114	0.243	86.874	2
0.162	0.203	0.234	83.431	4
0.107	0.108	0.243	86.682	3

Table 2.14 S_+, S_-, Q_i, **U_i** and Rank

3. DESIGN OF BELL CRANK LEVER

Design a right angled bell crank lever having one arm 220 mm and the other 150 mm long. The load of 5 kN is to be raised acting on a pin at the end of 500 mm arm and the effort is applied at the end of 150 mm arm. The permissible stresses for the pin and lever are 84 MPa in tension and compression and 70MPa in shear. The bearing pressure on the pin is not to exceed 10 N/mm2.

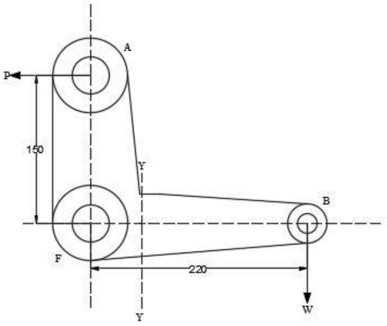

Figure 3.1 Problem statement

First of all, let us find the effort (*P*) required to raise the load (*W*). Taking moments about the fulcrum *F*, we have

$$W \times 500 = P \times 150$$

$$P = \frac{5000 \text{ X } 50}{150}$$

$$\therefore P = 16666.67 \text{ N}$$

and reaction at the fulcrum pin at *F*,

$R_F = \sqrt{W2 + P2} = \sqrt{(5000)2 + (16666.67)2} =$ 17400.51 N

3.1 Design for fulcrum pin

Let d = Diameter of the fulcrum pin, and
l = Length of the fulcrum pin.

Considering the fulcrum pin in bearing. We know that load on the fulcrum pin (R_F),
17400.51 = d × l × pb = d × 1.25 d × 10 = 12.5 d^2 ....(Assuming l = 1.25 d)
∴ d^2 = 17400.51 / 12.5 = 1392.04 or d = 37.31 say 38 mm
and l = 1.25 d = 1.25 × 38 = 47.5 mm say 48 mm

Let us now check for the shear stress induced in the fulcrum pin. Since the pin is in double shear, therefore load on the fulcrum pin (R_F),

$17400.51 = 2\times\frac{\pi}{4}\times(38)^2 \times \tau$

τ = 7.67 N/mm2 = 7.67 MPa

Since the shear stress induced in the fulcrum pin is less than the given value of 70 MPa, therefore
design for the fulcrum pin is safe.

A brass bush of 3 mm thickness is pressed into the boss of fulcrum as a bearing so that the renewal become simple when wear occurs.

∴ Diameter of hole in the lever
= d + 2 × 3
= 38 + 6 = 44 mm
and diameter of boss at fulcrum
= 2 d = 2 × 38 = 76 mm

Now let us check the bending stress induced in the lever arm at the fulcrum. The section of the fulcrum is shown in Fig. 3.2.

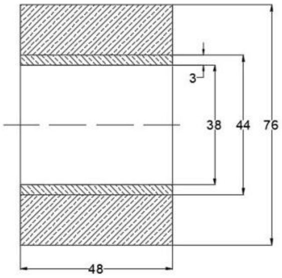

Figure 3.2 The section of the fulcrum

Bending moment at the fulcrum
M = W × FB = 5000 × 220 = 1100 × 10^3 N-mm
Section modulus,
Z = 37241.26 mm^3
∴ Bending stress,

$\sigma b = \frac{M}{Z}$

$= \frac{1100\times10^{3}}{37241.26}$

= 29.53 N/mm2 = 29.53 MPa

Since the bending stress induced in the lever arm at the fulcrum is less than the given value of
84 MPa, therefore it is safe.

3.2 Design for pin at A

Since the effort at A (which is 16666.67 N), is not very much different from the reaction at fulcrum (which is 17400.51 N), therefore the same dimensions for the pin and boss may be used as for fulcrum pin to reduce spares.

∴ Diameter of pin at A = 38 mm
Length of pin at A = 48 mm
and diameter of boss at A = 76 mm

3.3 Design for pin at B

Let d_1 = Diameter of the pin at B, and
l_1 = Length of the pin at B.

Considering the bearing of the pin at B. We know that load on the pin at B (W),

$5000 = d_1 \times l_1 \times p_b = d_1 \times 1.25\ d_1 \times 10 = 12.5\ (d1)2$... (Assuming $l_1 = 1.25\ d_1$)

∴ $(d_1)2 = 5000/12.5 = 400$ or d1 = 20 mm

and $l_1 = 1.25\ d_1 = 1.25 \times 20 = 25$ mm

Let us now check for the shear stress induced in the pin at B. Since the pin is in double shear, therefore load on the pin at B (W),

$5000 = 2\times\frac{\pi}{4}\times(20)^2 \times \tau$

τ = 7.95 N/mm2 = 7.95 MPa

Since the shear stress induced in the pin at B is within permissible limits, therefore the design is safe.

Since the end B is a forked end, therefore thickness of each eye,

$t_1 = \frac{l1}{2}$

t_1= 12.5 mm

In order to reduce wear, chilled phosphor bronze bushes of 3 mm thickness are provided in the eyes.

∴ Inner diameter of each eye
= d1 + 2 × 3 = 20 + 6 = 26 mm
and outer diameter of eye,
D = 2 d1 = 2 × 20 = 40 mm

Let us now check the induced bending stress in the pin. The pin is neither simply supported nor rigidly fixed at its ends. Therefore the common practice is to assume the load distribution as shown in Fig. 3.3 The maximum bending moment will occur at Y-Y.

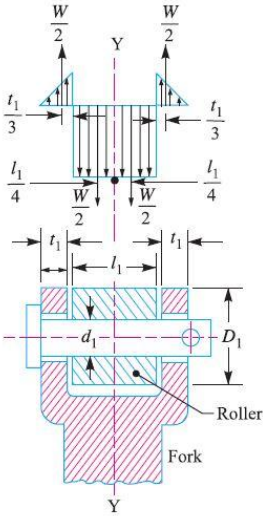

Figure 3.3 Load Distribution

∴ Maximum bending moment at Y-Y,

$M = \frac{W}{2}\frac{L1}{2} + \frac{W}{2}\frac{t1}{3} - \frac{W}{2}\frac{L1}{4}$

$= \frac{5Wl1}{24}$

= 26041.67 N-mm
and section modulus,
Z = 786 mm3
∴ Bending stress induced,

$\sigma b = \frac{M}{Z}$

= 33.13 N/mm2 = 33.13 MPa
This induced bending stress is within safe limits.

3.4 Design of lever

It is assumed that the lever extends up to the centre of the fulcrum from the point of application of the load. This assumption is commonly made and results in a slightly stronger section. Considering the weakest section of failure at Y-Y.

Let t = Thickness of the lever at Y-Y, and
b = Width or depth of the lever at Y-Y.

Taking distance from the centre of the fulcrum to Y-Y as 50 mm, therefore maximum bending moment at Y-Y,
= 5000 (220 – 50) = 85×10^4 N-mm
and section modulus, Z = 1.5 t3 .
We know that the bending stress (σb),

$\sigma b = \frac{M}{Z}$

$84 = \frac{85\times10^4}{1.5t3}$

t = 18.89mm say 20mm
and b = 3 t = 3 × 20 = 60 mm

4. MODELLING OF BELL CRANK LEVER USING CREO

- Open part modelling in creo, move to sketch window, draw fulcrum pin with outer diameter 76mm and inner diameter 38mm and extrude length 48mm.
- Now draw pin at point A at a distance 150mm from the center of fulcrum pin vertically. Draw a circle with outer diameter 76mm and inner diameter 38mm and extrude length 48mm.
- Then draw pin at point B at distance 220mm from the center of fulcrum pin vertically. Draw a circle with outer diameter 20 mm and inner diameter 40 mm and extrude length 25mm.
- Then combine these three pins with a rectangle pin of width 60mm and thickness 20mm at a distance of 50mm from fulcrum pin
- The model of bell crank lever is shown below 4.1

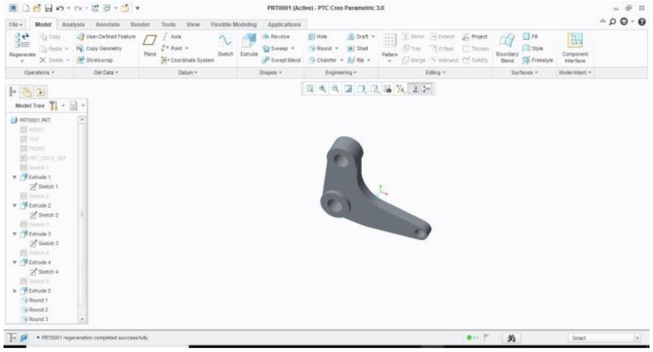

Figure 4.1 Bell crank lever modal

- Save the modal in IGES format for doing analysis in ANSYS work bench

5. ANALYSIS OF BELL CRANK LEVER

5.1.1 Static Structural Analysis on Forged steel bell crank lever

- Open Ansys Workbench select static structural analysis
- In engineering data add Forged steel material from the ansys material library
- Then import gemotry modal of bell crank lever which was drawn previously in creo

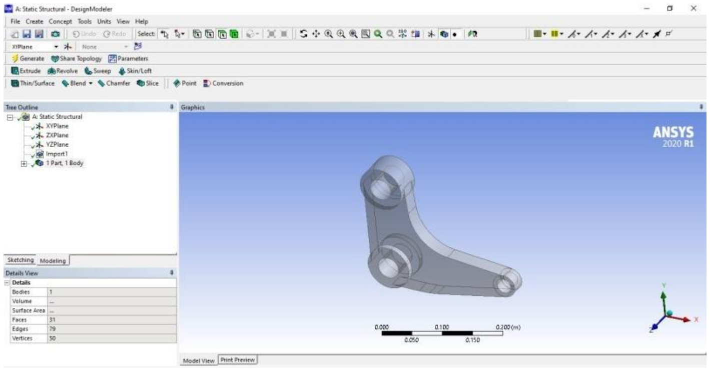

Figure 5.1 Imported geometry modal of bell crank lever

- In modal window generate mesh with face sizing to the inner diameters of the pins the meshed modal is shown in fig 5.2

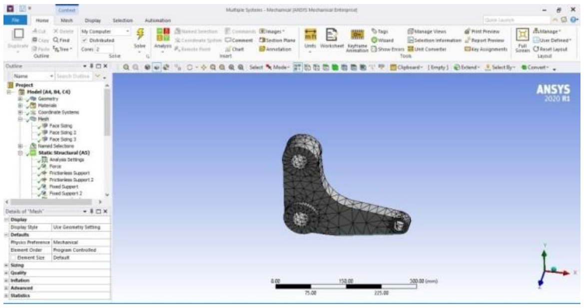

Figure 5.2 Meshed modal of bell crank lever

- Apply force of 5KNto the pin at point B in down ward direction, and apply frictionless supports to fulcrum pin and pin A
- Find out Total displacement, Equivalent stress and Maximum shear stress and also note down mass of the forged steel bell crank lever. the results shown in below figures

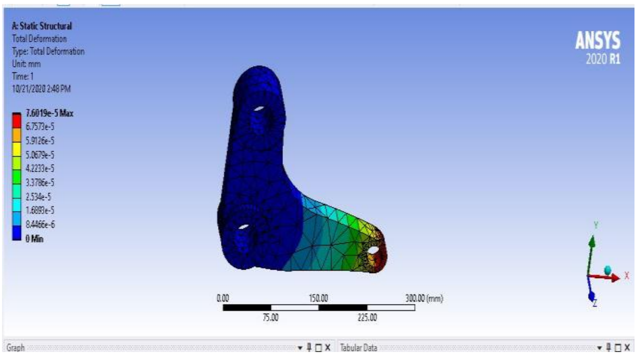

Figure 5.3 Total deformation for forged steel bell crank lever

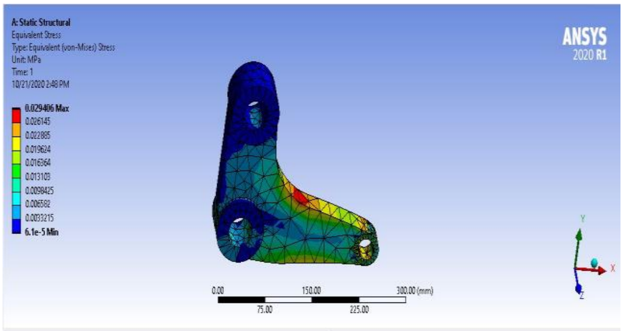

Figure 5.4 Equivalent stress for forged steel bell crank lever

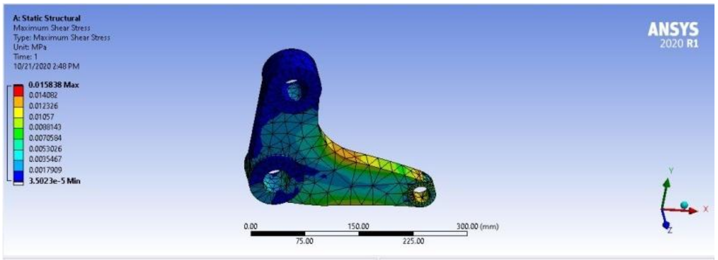

Figure 5.5 Maximum shear stress for forged steel bell crank lever

5.1.2 Static Structural Analysis on Cast steel bell crank lever

- In geometry window assign new material i.e; cat steel to the bell crank lever
- Click to solve
- Find out Total displacement, Equivalent stress and Maximum shear stress and also note down mass of the forged steel bell crank lever. the results shown in below figures

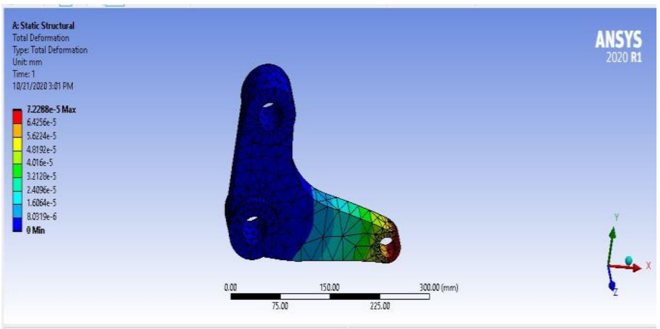

Figure 5.7 Total deformation for Cast steel bell crank lever

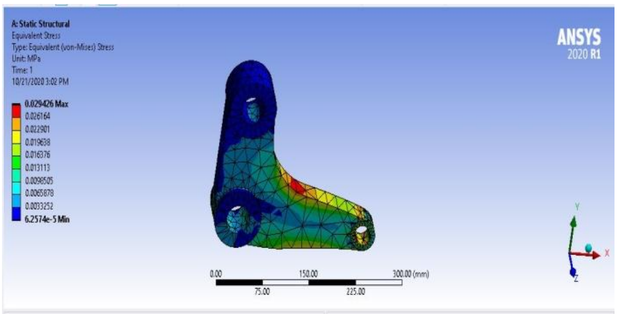

Figure 5.8 Equivalent stress for Cast steel bell crank lever

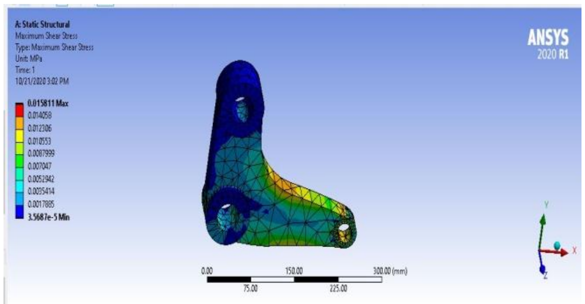

Figure 5.9 Maximum shear stress for Cast steel bell crank lever

5.1.3 Static Structural Analysis on Stainless steel, Martensitic bell crank lever

- In geometry window assign new material i.e; Stainless steel, Martensitic to the bell crank lever
- Click to solve
- Find out Total displacement, Equivalent stress and Maximum shear stress and also note down mass of the forged steel bell crank lever. the results shown in below figures

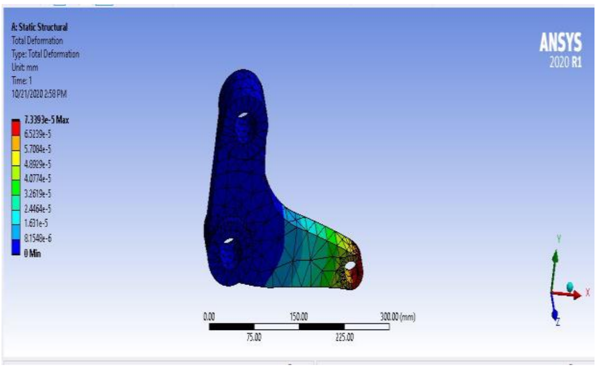

Figure 5.11 Total deformation for Stainless steel, Martensitic bell crank lever

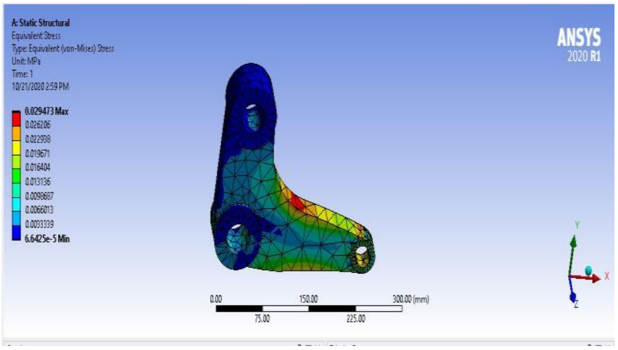

Figure 5.12 Equivalent stress for Stainless steel, Martensitic bell crank lever

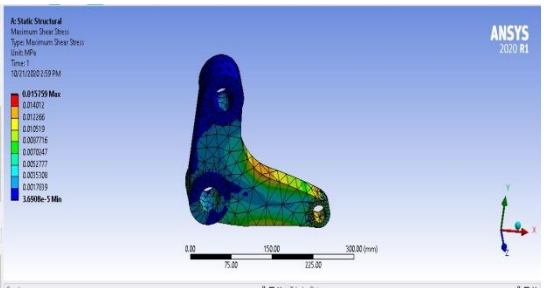

Figure 5.13 Maximum shear stress for Stainless steel, Martensitic bell crank lever

5.1.4 Static Structural Analysis on Structural steel crank lever

- In geometry window assign new material i.e; Structural steel to the bell crank lever
- Click to solve
- Find out Total displacement, Equivalent stress and Maximum shear stress and also note down mass of the forged steel bell crank lever. the results shown in below figures

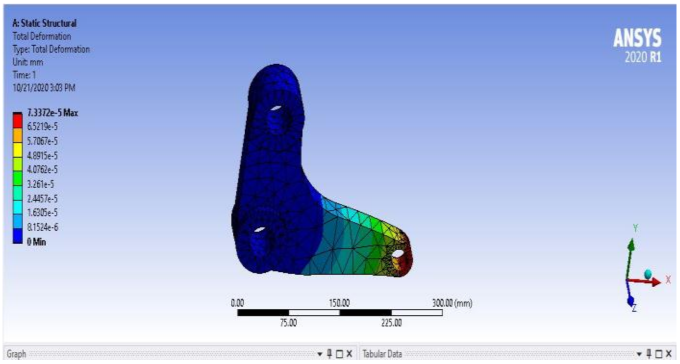

Figure 5.15 Total deformation for Structural steel crank lever

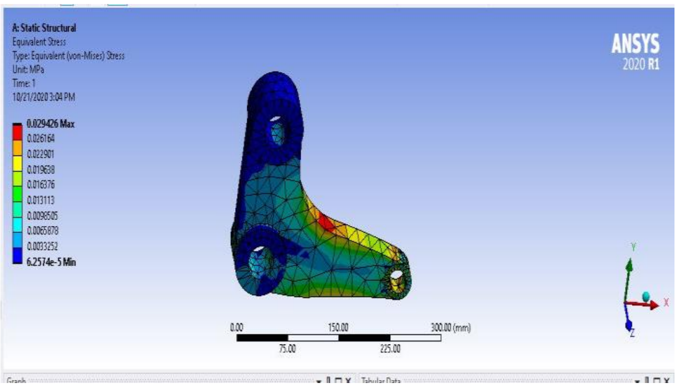

Figure 5.16 Equivalent stress for Structural steel bell crank lever

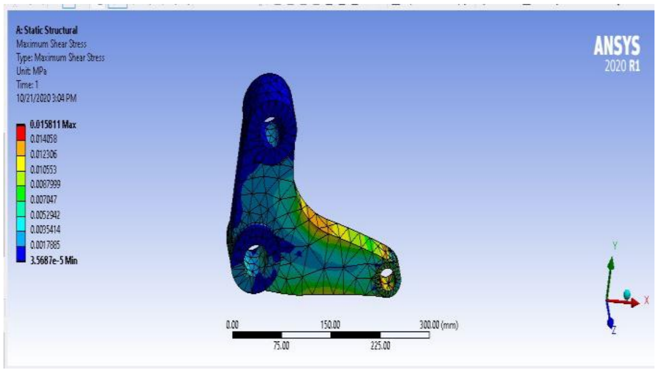

Figure 5.17 Maximum shear stress for Structural steel bell crank lever

5.2.1 Modal Analysis on Forged steel bell crank lever

- In Ansys Workbench from the static structural analysis results transfer data to modal analysis
- Caluclate total deformation with 6 mode shapes is shown below

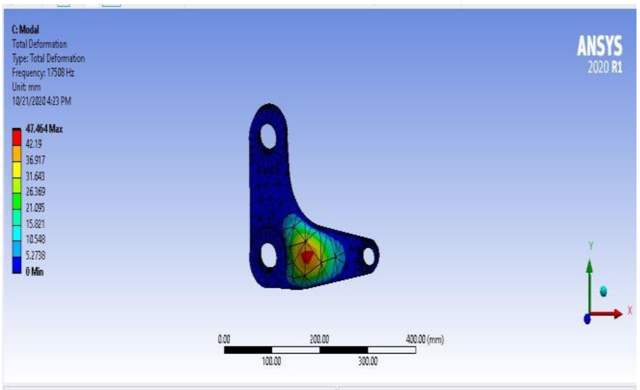

Figure 5.19 Mode Shape 1 for Forged steel bell crank lever

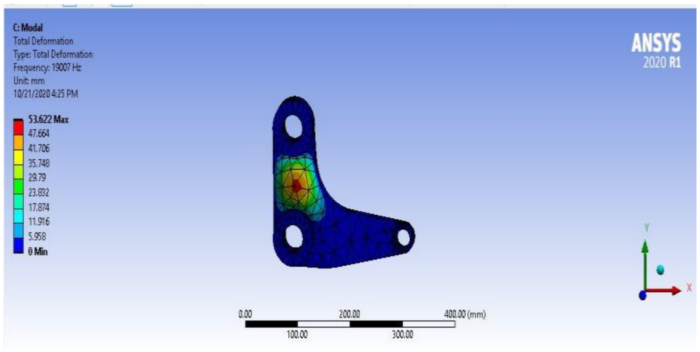

Figure 5.20 Mode Shape 2 for Forged steel bell crank lever

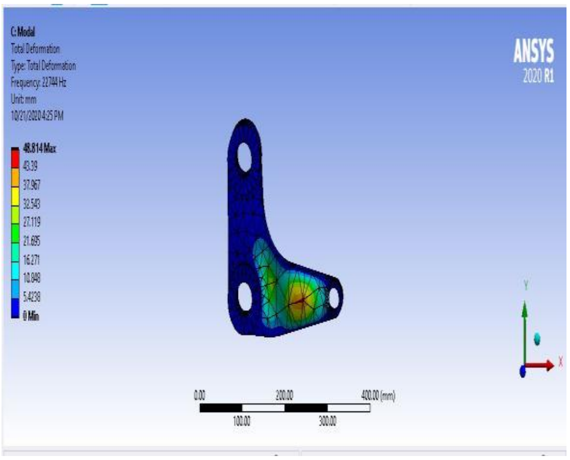

Figure 5.21 Mode Shape 3 for Forged steel bell crank lever

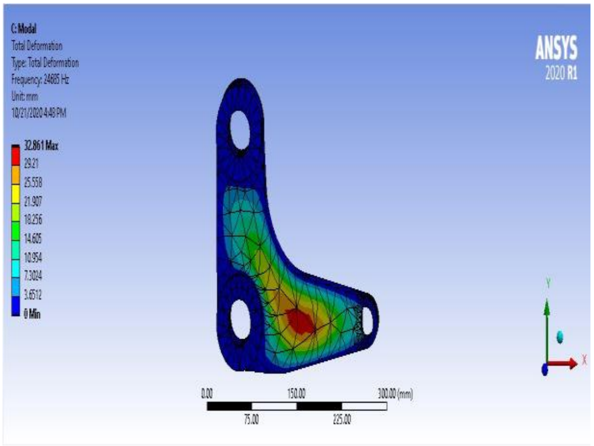

Figure 5.22 Mode Shape 4 for Forged steel bell crank lever

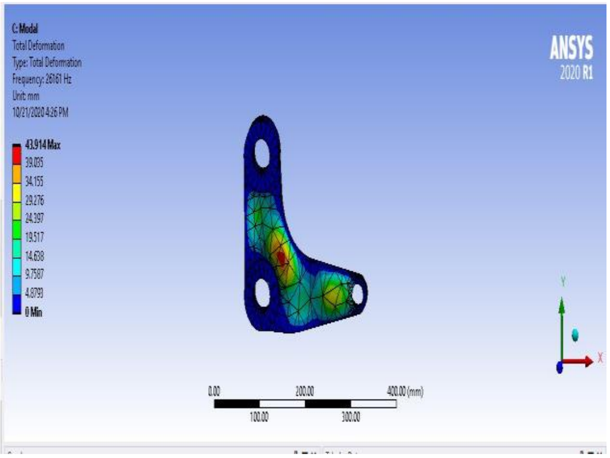

Figure 5.23 Mode Shape 5 for Forged steel bell crank lever

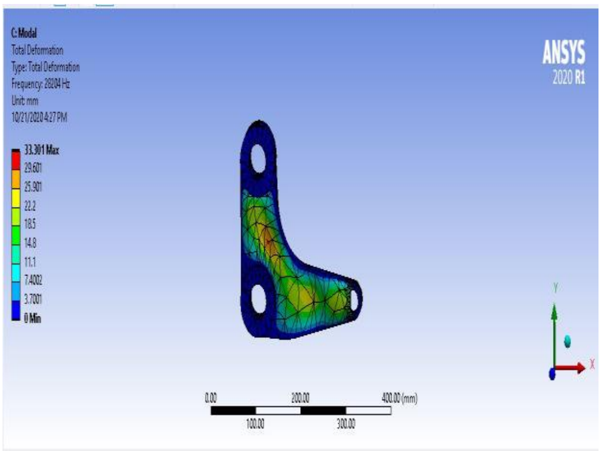

Figure 5.24 Mode Shape 6 for Forged steel bell crank lever

5.2.2 Modal Analysis on Cast steel bell crank lever

- The total deformation with 6 mode shapes is shown below

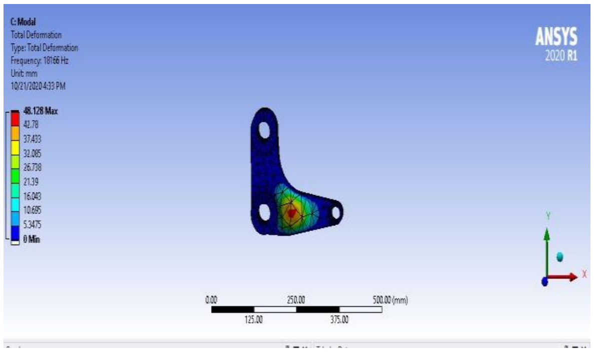

Figure 5.25 Mode Shape 1 for Cast steel bell crank lever

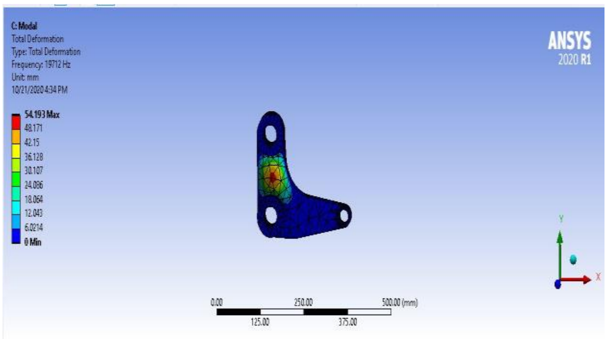

Figure 5.26 Mode Shape 2 for Cast steel bell crank lever

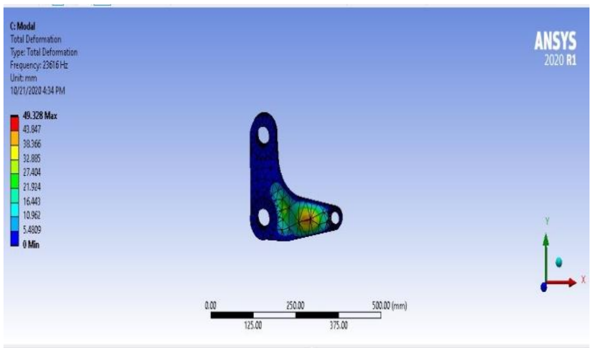

Figure 5.27 Mode Shape 3 for Cast steel bell crank lever

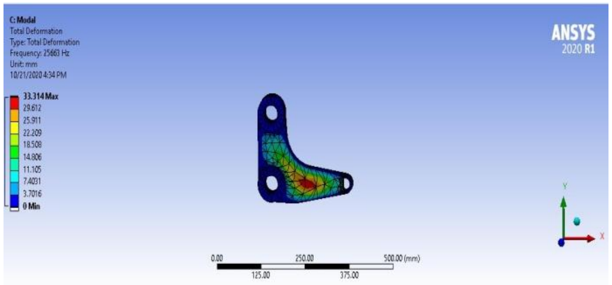

Figure 5.28 Mode Shape 4 for Cast steel bell crank lever

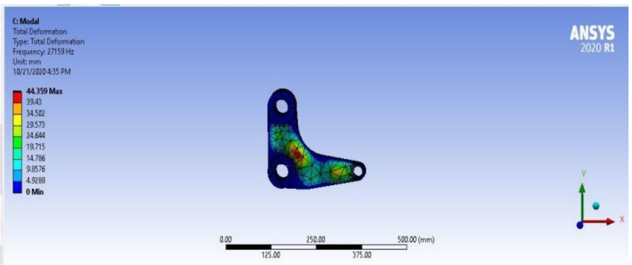

Figure 5.29 Mode Shape 5 for Cast steel bell crank lever

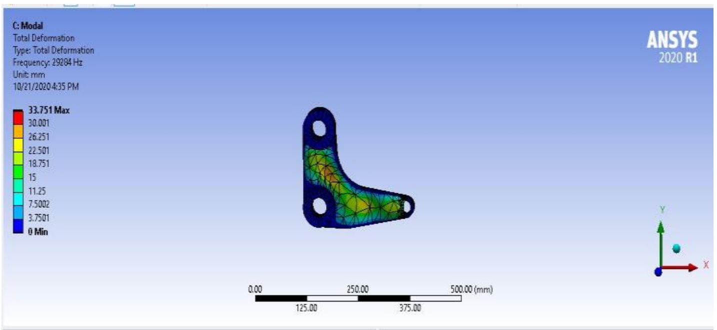

Figure 5.30 Mode Shape 6 for Cast steel bell crank lever

5.2.3 Modal Analysis on Stain less steel, martensitic bell crank lever

- The total deformation with 6 mode shapes is shown below

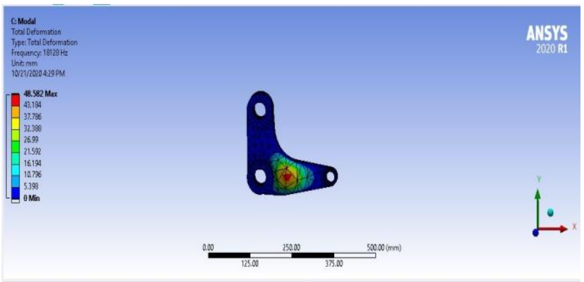

Figure 5.31 Mode Shape 1 for Stain less steel, martensitic bell crank lever

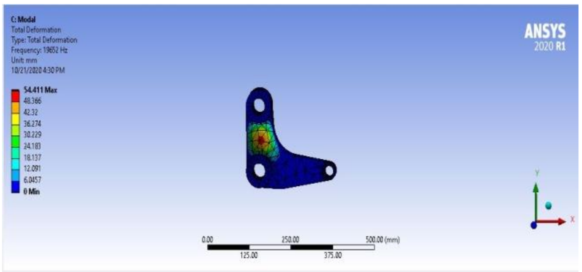

Figure 5.32 Mode Shape 2 for Stain less steel, martensitic bell crank lever

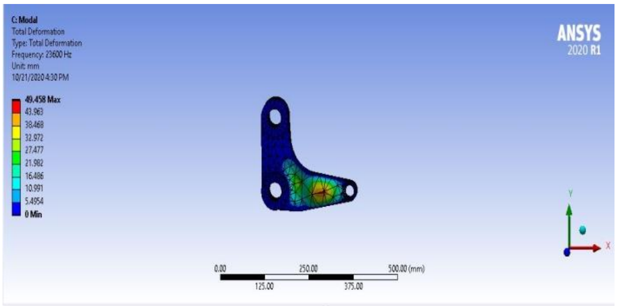

Figure 5.33 Mode Shape 3 for Stain less steel, martensitic bell crank lever

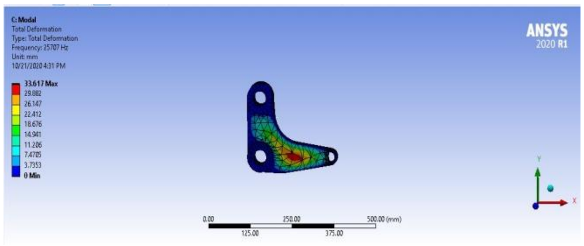

Figure 5.34 Mode Shape 4 for Stain less steel, martensitic bell crank lever

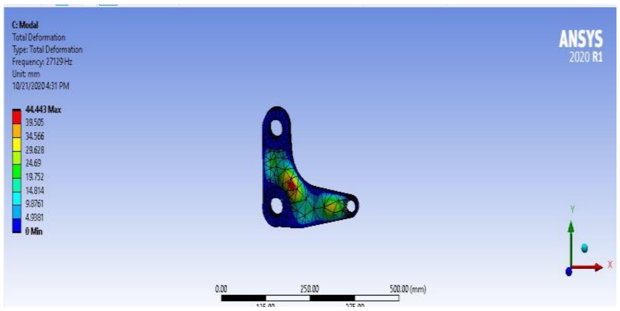

Figure 5.35 Mode Shape 5 for Stain less steel, martensitic bell crank lever

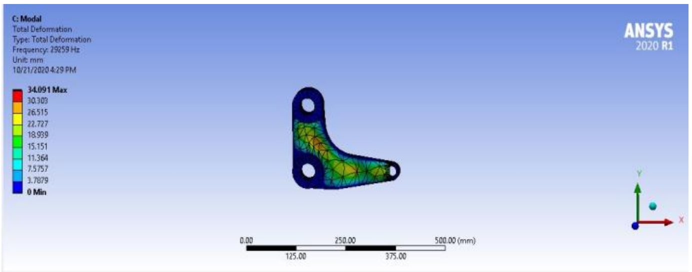

Figure 5.36 Mode Shape 6 for Stain less steel, martensitic bell crank lever

5.2.4 Modal Analysis on Structural steel bell crank lever

- The total deformation with 6 mode shapes is shown below

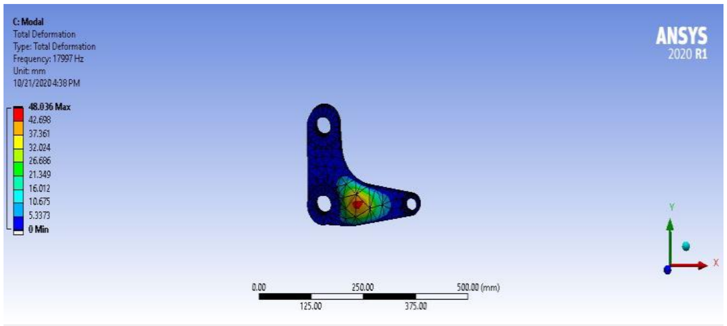

Figure 5.37 Mode Shape 1 for Structural steel bell crank lever

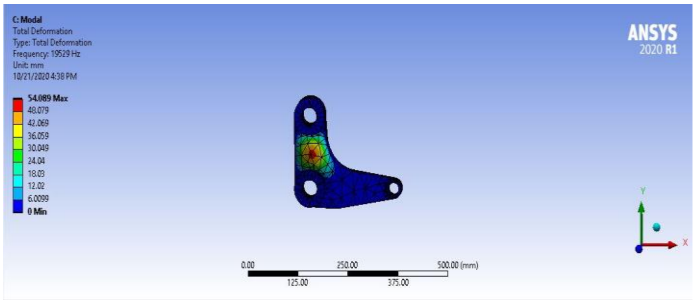

Figure 5.38 Mode Shape 2 for Structural steel bell crank lever

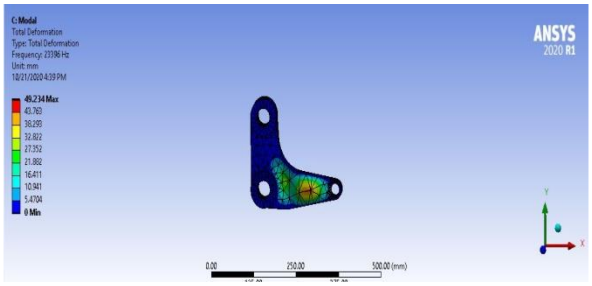

Figure 5.39 Mode Shape 3 for Structural steel bell crank lever

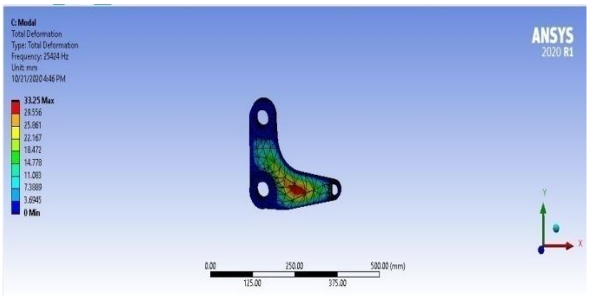

Figure 5.40 Mode Shape 4 for Structural steel bell crank lever

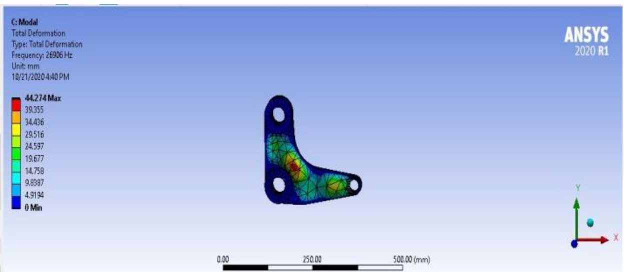

Figure 5.41 Mode Shape 5 for Structural steel bell crank lever

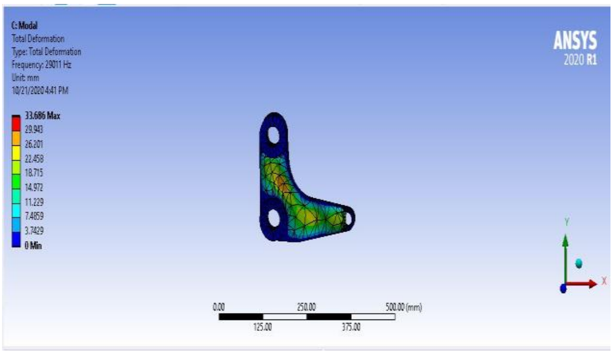

Figure 5.42 Mode Shape 6 for Structural steel bell crank lever

5.3 Topology Optimization

Transfer data from static starctural analysis to topology optimization to perform design optimization for the bell crank lever apply boundary conditions the optimized modal was shown in figure 6.43

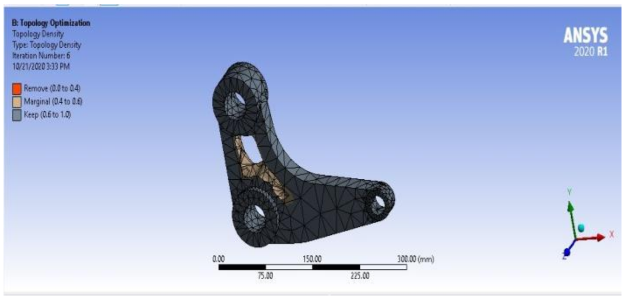

Figure 5.43 Topology optimization bell crank lever

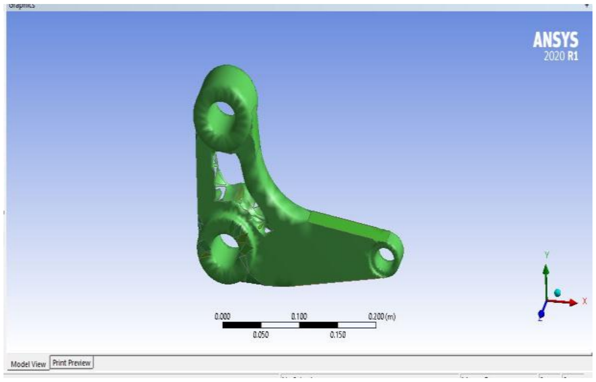

Figure 5.44 Topology Geometry of bell crank lever

Note down the mass of the each material bell crank lever was noted shown in Results and discussion. Table 6.4.

6.RESULTS AND DISCUSSION

6.1. Comparision of the MCDM methods and materials

Following Table demonstrates the rankings of the considerable number of materials determined utilizing the three MCDM techniques.

Material	TOPSIS	VIKOR	COPRAS
Forged Steel	2	3	1
Cast Steel	1	1	2
Stainless steel, martensitic	4	4	4
Structural steel	3	2	3

Table 6.1 Rankings of the alternatives.

6.2 Static Structural analysis of Bell crank lever

The results that is equivalent stress, displacement and maximum shear stress obtained in the static structural analysis is shown in following table 6.2

Table 6.2 Static Structural analysis results

Material	Total Deformation (mm)	Equivalent stress(Mpa)	Maximum Shear stress(Mpa)	Mass(Kg)
Forged Steel	7.60E-05	0.0294	0.0158	6.884
Cast Steel	7.23E-05	0.0294	0.0158	6.729
Stainless steel, martensitic	7.34E-05	0.0294	0.0157	6.669
Structural steel	7.34E-05	0.0294	0.0158	6.755

6.3 Modal analysis of Bell crank lever

Natural frequency obtained by modal analysis is shown in table 6.3

Table 6.3 Modal analysis results

Natural Frequency(Hz) obtained at each mode shape				
Mode Shape	Forged Steel	Cast Steel	Stainless steel, martensitic	Structural steel
1	17508	18166	18128	17997
2	19007	19712	19652	19529
3	22744	23616	23600	23396
4	24685	25663	25707	25424
5	26161	27159	27129	26906
6	28204	29284	29259	29011

6.4 Topology optimization of Bell crank lever

Optimized mass obtained by topology optimization analysis is shown in table 6.4

Table 6.4 Mass obtained by topology optimization

Material	Mass(Kg)
Forged Steel	5.9952
Cast Steel	5.8603
Stainless steel,martensitic	5.8103
Structural steel	5.8828

6.5 Mass savings after topology optimization

Table 6.5 Percentage of mass savings

Material	Mass(Kg)	Mass after Topology optimization (Kg)	Percentage of Savings
Forged Steel	6.8848	5.9952	12.92
Cast Steel	6.7299	5.8603	12.92
Stainless steel, martensitic	6.6697	5.8103	12.89
Structural steel	6.7557	5.8828	12.92

7. CONCLUSION AND FUTURE SCOPE

7.1 Conclusion

In this Project the detail explanation is given, how to resolve material choice issue for the Bell crank lever utilized in racer car through MCDM. The MCDM incorporates the TOPSIS, VIKOR and COPRAS techniques for the positioning of the elective materials as per decided criteria. The material weighting of the material properties was performed by utilizing the traded off weighting strategy that sorted out of AHP method.

The selection of material is considered through the ranking which has taken form comparison table(7.1). The table gives the Ranking of the materials. According to ranking the cast steel has selected for bell crank lever material. Then perform static structural analysis to find structural strength of the bell crank lever From table 7.2 cast steel has less deformation compared to others and also less mass compared to other materials. From modal analysis it was concluded that cast steel has to resist more vibrations compared to other materials. and finally we perform topology optimization from this analysis weight of the bell crank lever is reduced within the allowable limits of stress the percentage of saving of material is12.92.so it is concluded that cast steel is suitable for bell crank lever for this particular application. So it is shown that the optimum material obtained after design and analysis process is same that was selected by using MCDM technique, so i may concluded that the optimum material for any particular application is selected by using MCDM techniques before going to design stage.

7.2 Future Scope

- By using multi criteria decision making methods we consider maximum allowable materials for manufacturing bell crank lever including composites, alloys and metal find out optimized material for that particular application before moving to design phase.
- The material selection methods can be applied to other mechanical components for material selection problems.

REFERENCES

1. Soumya Sree Maravajjala1 , M Mohith23D Modelling and Analysis of Bell Crank Mechanism(2020)
2. Fornace, L.V.: Weight Reduction Techniques Applied to Formula SAE Vehicle Design: An Investigation in Topology Optimization (2006)
3. Muhammad Sahail, B. Zainol Abidin.: Design andDevelopment of a Bell Crank for Monoshock Front Suspension for Formula Varsity Race Car. Melaka, universiti teknikal malaysia Melaka
4. Borg, L.T., West, R.L., Ferris, J.B., Member, C., Merkle, M.A.: C.Member Borg_L_ETD_Copy_07-26-2009.pdf (2009)
5. Dange, M.M.M., Zaveri, S. R., Khamankar, S.D.: International Journal on Recent and Innovation Trends in Computing and Communication Stress Analysis of Bell Crank Lever (2014)
6. Zende, S.R., Shaikh, M.R.,Dolas,D.R.: International Journal of Modern Trends in Engineering and Research Fillet Radius Optimization of Bell Crank Lever (1947)
7. Halil Calıs_kan a,⇑, Bilal Kurs_uncu a, Material selection for the tool holder working under hard milling conditions using different multi criteria decision making methods
8. Rohit Saini, Gian Bhushan, and Pankaj Chandna Optimization of Design Parameters of a Bell Crank Lever Using CAE Tools