Topology Optimization of Bell Crank Lever

[1]Arnav Pande, [1]Om Ingole, [1]Dhairyashil Jadhav, [1]Deepak Dhamecha, [1]Aayush Dongre, [2]Ganesh Dongre, [2]Sachin Komble

[1] Student, Vishwakarma Institute of Technology, Pune,[2] Professor, Vishwakarma Institute of Technology, Pune
arnav.pande21@vit.edu, om.ingole21@vit.edu, dhairyashil.jadhav21@vit.edu, deepak.dhamecha21@vit.edu, aayush.dongre21@vit.edu, ganesh.dongre21@vit.edu, sachin.komble21@vit.edu

Abstract - A bell crank lever is used in a variety of applications and is subjected to a lot of tension. To examine the behavior of stresses and strains in the bell crank lever, numerical and analytical methodologies are used. To conduct research, a virtual model of a bell crank lever was created by gathering information from a design data book. The formula of lever in bending stresses was used to determine the stresses in the bell crank lever analytically. Fusion 360 was used to create the CAD model and numerical analysis of the bell crank lever, with FEA doing the stress analysis. Bell crank levers are designed by lowering weight in comparison to original bell crank levers and using topology optimization to achieve an optimum design. Fusion 360 was used for topology optimization, shape optimization, and static structural analysis. The plots of equivalent stress and % weight loss were then created. The outcome and conclusion are then drawn after a comparative analysis of the optimized and original bell crank levers.

Index Terms - Bell Crank Lever, Topology Optimization, Stress Analysis.

I. Introduction

A bell crank lever is a stiff bar or rod that is fixed around a fulcrum and can rotate around it. It can also be used to raise a heavy load with little effort. Mechanical advantage is defined as the load lifted divided by the effort applied. To avoid the failure of a part or component in any product that is to be manufactured, the most important responsibility for the design engineer is to keep the operating stresses below a predetermined specific limit. It is necessary to figure out the stresses in various elements in order to improve the product quality. A bell crank lever is first type of lever. Because of fulcrum is between the load and the effort applied. To predict the breakdown of a part, it is also vital to understand the stress and strain distribution. Today's product development presents a slew of obstacles, since intricate items must fulfil extraordinarily high standards.

II. Problem Statement

The balance of performance and weight is strongly linked in many sectors. Weight penalties can be significant in aerospace, for example, and there is a need to minimize them by experimenting with new materials, designs, and manufacturing processes can be a make-or-break issue. So, companies can use Topology optimization to experiment with new designs and shapes that result in high-performance solutions while lowering material costs and weight.

III. Literature survey

Suraj Vedpathak .et al [1] The bell crank lever is used to lift a load with a moderate amount of effort. When the load and force act at right angles to each other. Numerous studies were conducted and used various optimization strategies for mechanical linkages, such as numerical analysis, analytical methods, and stress patterns analysis. Despite the fact that numerous studies have been conducted on this topic, more study on weight-based optimization in the context of space constraints and weight reduction is still required. Static analysis of an existing bell crank lever was performed in this work to assess stresses and deformation. The topology optimization method is used to reduce weight. The red region in topology optimization denotes the material removal area where certain form areas are removed.
The existing bell crank lever had a mass of 0.38838 kg, which was decreased to 0.31442 kg following optimization. As a result, the amount of the material was decreased by 19.04 percent. As a result, the study's major goal of weight optimization has been reached, and this technique is practicable. As per the FEA results, the maximum deformation and von-Mises stress in the optimized bell crank lever are 0.100 mm and 24.151 MPa, resp. Since the strains induced in the optimized bell crank lever are nearly identical in both experimental and FEA analyses, the result is verified.
Toh Yen Pang .et al [2] The design optimization technique was used to reduce the structural weight of a sidecar suspension bell crank, which was then subjected to constraints such as volume, strain energy, and von Mises stress. A additive manufacturing technique was used to generate a 3D bell crank model, and the corresponding FE bell crank model was confirmed using laser vibrometer test results. The difference between the experimental and FE results of the natural frequency at the fourth mode was less than 5%, so it was considered valid for future studies.
However, with racing cars, it is necessary to reduce weight in order to achieve maximum speed in a smaller duration of time. As a result, there are restrictions on bell cranks due to their weight. A reduction in vehicle mass will also improve the performance component of a racing vehicle known as the power-to-weight ratio when there has been a limit in engine power capabilities. As a result, engineers are always working on improving the bell crank's performance by reducing its weight while retaining its structural integrity. Engineers have used the structural topology optimization method to pick the best material distribution in a structural design domain while considering an objective function and limitations. This is an important contribution to finding solutions to difficult designs without compromising quality and structural performance.
Jakub Mesicek .et al [3] The topological optimization of the Formula Student bell crank is the focus of this study. Weight reduction is a modern design trend, and as a consequence, fuel consumption is reduced. Topological optimization allows for changes to the component's shape in relation to the strength demand and component loading boundary conditions. In terms of computer approaches, topological optimization software is used. This software performs multiple interactions and determines which is the best. 3D printing is extensively used to generate topologically optimized components.

From the very first design to the final topologically optimized model, the authors track the development of a topologically optimal bell crank, the choice of printing material (metallic powder), and the description of its design evolution and geometrical shape smoothing step by step. The design also considers production technology such as metallic powder 3D printing and post-processing, which would be impossible to achieve without CNC machining and clamping jigs.

IV. METHODOLOGY

A. *Shape Optimization Study*

1. Design the model of bell crank lever on measurements
2. Go to simulation workbench.
3. Add constraints and loads
4. Preserve region of model and adjust simulation setting.
5. Solve the study on cloud and review the results
6. Promote result to design workspace and redesign the model based on shape optimization results.

B. *Modifying Model based on shape optimization study:*

1. Modify your CAD model. (Remove unnecessary material from the indicated areas)
2. Perform a stress analysis.
3. Review the structural results. (Review the stress, displacement, and safety factor results to ensure the suitability of the modified design to handle the applied loads.)

C. *3D printing of optimized model*

1. Export the STL File.
2. Choose the Materials.
3. Choose the Parameters.
4. Create the G code.

V. SOFTWARE USED

A. *For modelling and analysis- Fusion 360*

In Autodesk Fusion 360, Topology (or Shape) Optimization allows you to quickly generate an improved model based on a specified load and constraints. The Load Path Criticality metric is used by Fusion 360 to determine whether specific portions of material can handle the applied load. By removing material from less essential locations, the simulation generates an updated version of the part. Although the simulation does not guarantee that you will end up with a perfect model suited for production, it does show you how to keep updating and removing unnecessary material from your design.

B. *For slicing- Ultimaker Cura*

Ultimaker's Cura is a simple but powerful 3D slicing program. The print profiles are optimized for Ultimaker 3D printers; however, the software may slice 3D files for any brand/model of 3D printer. The software supports the 3D file formats STL, 3MF, and OBJ, as well as importing and converting 2D photos (.JPG,.PNG,.BMP, and.GIF) to 3D extruded models.

You'll be able to open and arrange several models on the print bed using the program (each with different slicing settings if required). This allows you to print numerous models at once, making the printing process easier to manage in the classroom. Cura is desktop software available for Windows, Mac, and Linux that can be downloaded for free from the Ultimaker website.

VI. METHOD USED FOR 3D PRINTING

Here, we are used FDM 3d printing process for printing the optimized Bell Crank Lever. Fused deposition modelling or FDM is an additive manufacturing technology that creates 3D parts using thermoplastic or composite filament wire. The plastic filament is extruded through nozzle, where it is heated and then selectively dropped on print bed surface layer by layer according to given CAD geometry.
In FDM 3D printer, the XYZ axis movement is done by extruders and the print bed surface. As we can see, in this figure, the extruder head moves along X & Y axis, and the print bed surface moves in Z-axis comes. In some versions of FDM, the print head moves along X and Z while the build platform of moves along Y axis.

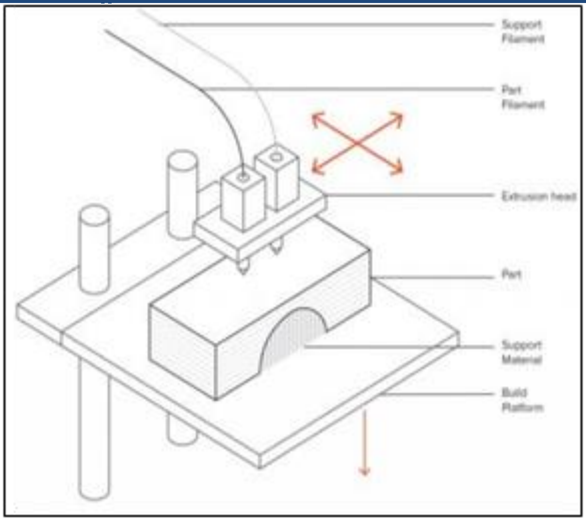

Figure 1: Fused Deposition Modelling

VII. RESULTS

The discrete variable called "load path criticality" has a range of 0 to 1. A region in the model with a value of 1 is one that must resist the applied load. A section in the model where resistance to the applied load is not crucial is represented by a value of 0. Shape Optimization attempts to remove the elements with the lowest Load Path Criticality values first in order to reach the target mass. To display the Load Path Criticality for each part of the model, move the sliders on the legend.

When the Shape Optimization Study is finished, the newly created reference shape is visible. The outcomes also display the approximate mass, mass ratio, and load path criticality. The mass ratio shows what portion of the original mass is still present. The Mass Ratio should be close to the Target Mass % indicated in the Shape Optimization Criteria when the results are first displayed. The mass of the remaining geometry is represented by the approximate mass. So, here for various mass ratio, the maximum mass for bell crank lever is evaluated and listed in Table 1.

Load path criticality	Max Mass (gm)	Mass Ratio
1	387	100%
0.2	284	73.55%
0.4	206	53.42%
0.5	174	44.92%

Table 1. Mass Ratio

Simulation Results

1. Mass Ratio= 100% & Max. Mass= 387 gm at 1 Load path criticality (Max.)

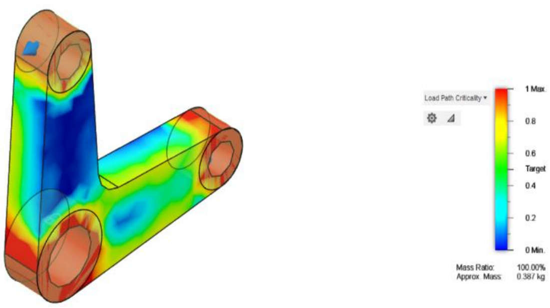

Figure 1: Fused Deposition Modelling at 1 Load path criticality

2. Mass Ratio= 73.55% & Max. Mass= 284 gm at 0.2 load path criticality

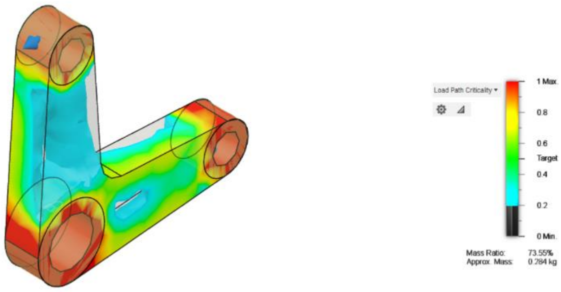

Figure 2: Fused Deposition Modelling at 0.2 Load path criticality

3. Mass Ratio= 53.42% & Max. Mass= 206 gm at 0.4 load path criticality

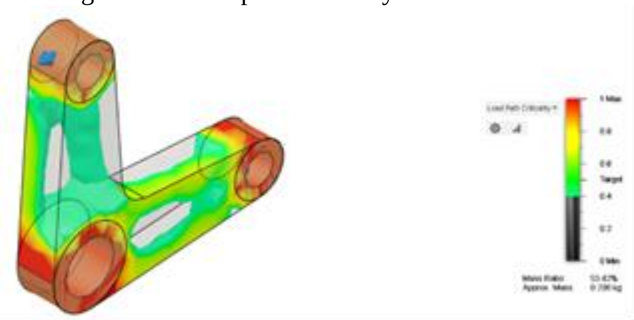

Figure 3: Fused Deposition Modelling at 0.4 Load path criticality

4. Mass Ratio= 44.92% & Max. Mass= 174 gm at 0.5 load path criticality (desired)

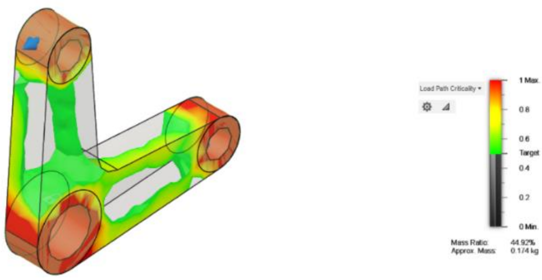

Figure 4: Fused Deposition Modelling at 0.5 Load path criticality

Comparison between actual and optimized bell crank lever:

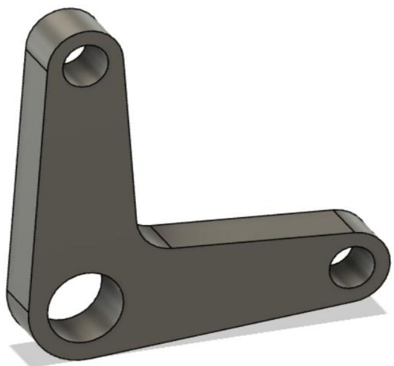

Figure 5: Bell crank lever CAD Model

Figure 6: Optimized Model

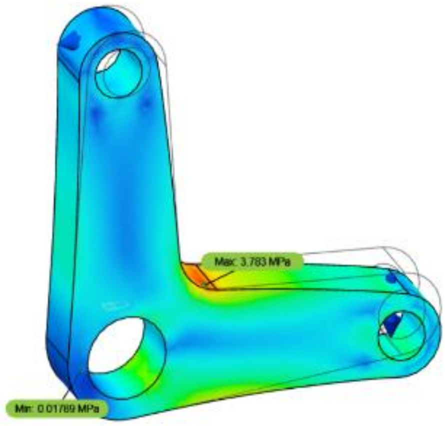

Fig 7. Stress distribution in Actual model

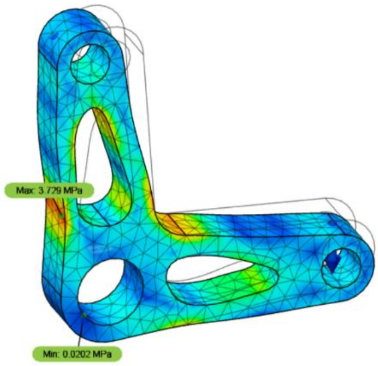

Figure 8: Stress distribution in Optimized mode

A. Stress Analysis:

From Stress analysis, it is found that in original bell crank lever, the maximum stress is induced at the junction of the horizontal and vertical lever hands. These stresses are generated due to the stress concentration. Stress under study is taken as von mises stress because the von Mises stress can be used to forecast how materials will behave under complicated loads. The value of maximum stress induced in Actual and optimized bell crank lever are 3.78 Mpa and 3.28 Mpa respectively. Also, the minimum stress induced in Actual and optimized bell crank lever are 0.018 Mpa and 0.02 Mpa respectively.

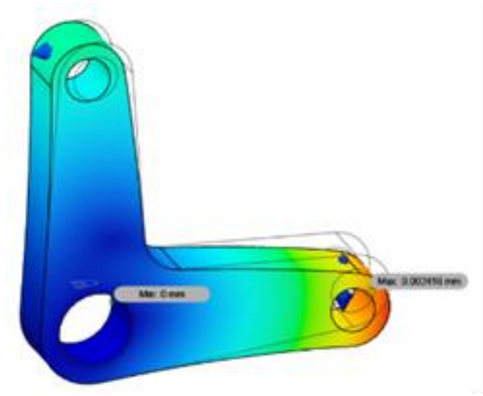

Fig 9. Displacement in Actual model

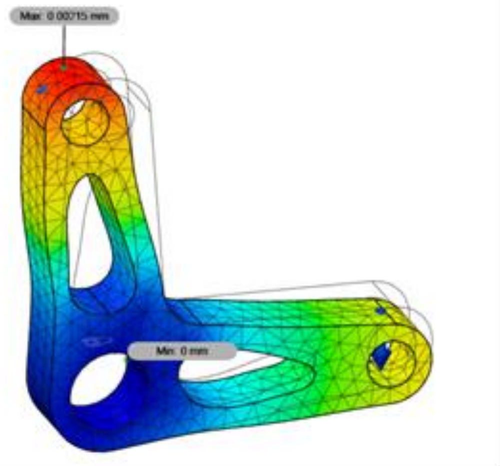

Fig 10. Displacement in Optimized model

B. Displacement Analysis:

When body is induced by applied loads cause the size and shape of a body to be altered, individual points of the body move relative to one another. So, it is necessary to find out the displacement formed due to applied loads. From Displacement analysis, it is found that in original bell crank lever, the maximum displacement is found at the top of the vertical lever hands. The displacement in lever is occurred due to the load coming at that point. The value of maximum displacement observed in Actual and optimized bell crank lever are 0.0024 mm and 0.0021mm respectively.

Fig 11. 3D Printed Model

VIII. INTERPRETATION OF RESULTS

From the results we interpreted that, at 100% mass ratio, bell crank lever has a mass of 387 gm. But After topology optimization, we get mass of bell crank lever as 174 kg at 44.92% mass ratio. From the stress analysis, it is shown that the stress induced in actual or normal bell crank lever is nearly equal to the stress induced in the optimized bell crank lever. Also, the maximum displacement in the actual bell crank lever and the optimized bell crank lever have displacements that are nearly identical. Here, we have reduced the mass from original bell crank lever without affecting the strength.

IX. CONCLUSIONS

Bell crank levers are employed to quickly and easily lift a load. when the load and the force interact at a straight angle. For mechanical linkages, numerous studies have been carried out using a variety of optimization techniques, including analytical approaches, numerical analysis, and stress pattern analysis. Despite the fact that there have been many studies on this subject, further research on weight-based optimization in the context of weight reduction and space restrictions is still needed. In order to assess stresses and deformation, the current study performed a static analysis of an existing bell crank lever. To reduce weight, the topology optimization method is applied. When creating low-mass components, topological optimization affords designers and technologists additional alternatives.

X. REFERENCES

[1] Suraj Vedpathak and Sandip Sarnobat, "*Analysis and Optimization of Bell Crank Lever*," ijates,volume no.9,issue no. 5,May 2021.

[2] Toh Yen Pang and Mohammad Fard, "*Reverse Engineering and Topology Optimization for Weight-Reduction of a Bell- Crank,*" Published: 30 November 2020.

[3 Jakub Mesicek, Marek Pagac, Jana Petru, Petr Novak, Jiri Hajnys, Kristyna Kutiova, "*topological optimization of the formula student bell crank".*

[4 Mr. M. M. Dange, Prof. S. R. Zaveri Prof.S. D. Khamankar,"*Stress Analysis of Bell Crank Lever by Optimising the Volume,*" IJERT Vol. 3 Issue 9, September- 2014.

[5] Tanmay Nandanwar, Keyour Waghela, Eshaan Gupta, Narendiranath ,Babu T, "*Topology optimization of the bell crank & brake pedal*" , IOP Conf. Ser.: Mater. Sci. Eng. 1123 012035 [6] Y. He, C. H. Chang, and J. Gu, "An area efficient 64-bit square root carry-select adder for lowpower applications," in Proc. IEEE Int. Symp. Circuits Syst., 2005, vol. 4, pp. 4082–4085.