Stress Analysis and Optimization of a Bicycle Crank

A. Nikhil Setty
Department of Mechanical Engineering
B.M.S College of Engineering, Bengaluru, Karnataka, INDIA

Abstract— Dynamic loading on the bicycle pedal cranks induce various changes in the geometry. The main objective of this study is to get the critical stress locations on the crank and develop a new improved design for minimizing the same. Therefore, this study consists of two major sections: (1) Finite Element and geometry modelling, (2) analysis and optimization by improved design. The crank was modeled using a modelling software and validation of model was done by using equivalent stresses and directional deflection of the crank and pedal. Refinement of geometry was done using the method of body sizing till convergent result of maximum stress was obtained. This research paper proposed improvements of designs with regard to minimize the weight, cost and optimum factor of safety.

Key words: Bicycle Pedal Cranks, Bicycle Crank

I. Introduction

Failure is the progressive or sudden deterioration of their mechanical strength due to various loading effects. Generally, cranks are manufactured of an aluminum alloy, titanium, carbon fiber, chromoly steel, or some less expensive steel in order to make the manufacturing costs economical as well as structurally stable. A paddle crank usually undergoes various types of loading. They include Tensile, Torsional, Shearing and Compressive. Due to these effects, it is possible for the crank to develop cracks at various critical places. As per general scrutiny, it is found that the cracks or failure most frequently happen near the crank mounting point or the spider arms. The consequences of loading in tension are that material defects and abrupt changes in the geometry may take place. Due to the fact that the crank undergoes dynamic cyclic loading, it is expected that the cyclic loading initiates brittle cracks which progress further to the step where failure occurs. In this study, an attempt is made to analyze and study the various dynamic loading patterns that the crank undergoes. It is done in two stages. The first study is made on the conventional crank design with the conventional material. The second study deals with the analysis of an improved version of the crank with various design changes, keeping in consideration of weight and stress reductions.

II. Methods applied

A. Input Parameters for Analysis

Since there is a dynamic loading taking place, it is understood that the pedal orientation and the forces applied on the pedal changes with motion. During the first half of the cycle, the pressure applied is positive while it is negative in the other half of the cycle. In a crank kinetics study conducted by [1], they have provided the loading patterns for different cycling positions which cyclists perform. The forces measured during uphill standing position is found to be maximum. The mass of the man was taken as 78.9 kg with a standard deviation of 5.3. It is observed that the maximum force which was acting on the pedal is in the downward direction with a magnitude of 1200 and a horizontal force of 100N with the cyclist standing while going uphill. It is also observed that a torque of 101 N-m is experienced by the crank in the clockwise direction. The study conducted also measured the angles of the crank where the peak forces occurred at it is observed that at an angle of 155(deg) and 131(deg), the max forces and torque are found to be acting on it respectively. The cadence rate of the cyclists is measured to be 64 with a standard deviation of 5.

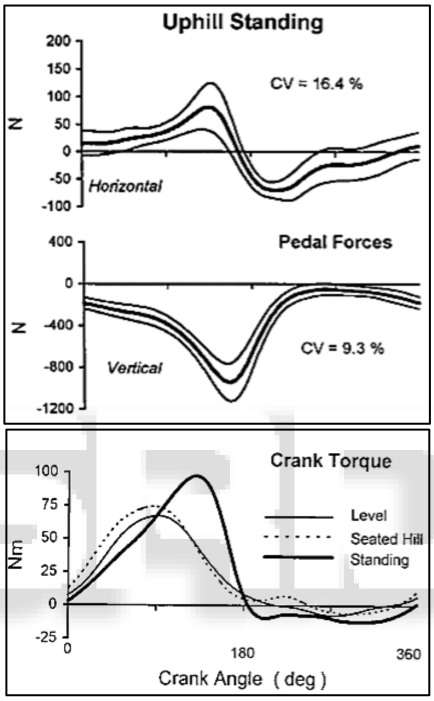

Fig. 1: Pedal forces and crank toque for uphill seated

The Fig above shows the pattern of the vertical, horizontal forces and the torque acting on the crank.

B. Finite Element and Geometry Modelling

Finite element modelling of any solid component is the generation of geometry, applying the components material properties using a simulation software, meshing the component by appropriate size, defining the load and boundary constraints. These steps will lead to the calculation of stresses and displacements in the component. The model for analysis is created using Solidworks, 3D modelling and simulation software by Dassault systemes. For the first part of the study, a conventional design was created in order to study the effects of dynamic loading on the crank and its behavior.

The image is shown above. Since the crank is fixed at the spider or crank mounting point, a fixture restraining all degrees-of-freedom is provided which is indicated by green markers. As mentioned above, the effect of the forces acting on the crank are depicted by providing a 1200 N force and 100N force in the vertically downward and horizontal direction respectively and is indicated by the violet markers. Due the above type of loading, torque is generated which is of the magnitude 101 N-m and is applied at the cylindrical face of the crank mounting point and is depicted in violet markers.

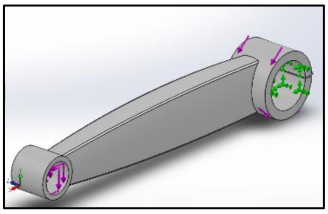

Fig. 2: Forces and constraints applied for conventional crank design

The material used here is Beralcast 363 and its properties applied to the material are listed in the form of a table.

Properties	Units
Density (g/cm3)	2.16
Modulus of Elasticity (Mpa)	202000
Poissons Ratio	0.2
Yeild Strength (Mpa)	213.7
Ultimate Tensile Srength (Mpa)	289.6
Specific Stiffness (Gpa-cm3/g)	93.5
Specific Strength (Mpa-c3/g)	134.1

Table 1: Material properties of Beralcast 363

C. Geometry modelling of the crank (Conventional design)

The 3d modelling and simulation software SOLIDWORKS by Dassault Systemes is used to create the model of the crank. The image of the profile of the crank is shown alongside.

The basic modelling tools like surface extrusion, loft and fillets were used in creating the model. The mass of the created geometry is obtained by using the software itself and it weighs at 111.01 grams after applying the following the respective material.

D. Mesh Generation and Convergence

FE analysis is performed on crank geometry for the dynamic load analysis. Quadratic tetrahedral elements are used to mesh the crankshaft finite element geometry. An important observation to be made is that decreasing the mesh size will increase the accuracy of the analysis and calculations done. But it comes at the cost of time taken to solve and solver resources. It is a general observation that after a particular mesh size, the values obtained post-Analysis do not differ much from its previous larger size mesh. Thus it is important to plot a convergence graph having the mesh size and maximum von-Miss stress on the axes. A curve is obtained where the stress developed saturates for a particular ballpark of mesh sizes. In this case, several iterations were done on the crank geometry to generate the graph.

Mesh Size	Max Von Mises Stress(Mpa)
5	137.9
4.5	139.7
4	143.8
3.5	139.7
3	140.7
2.5	141.5
2	141.7
1.5	141.71
1	141.7

Table 2: Variation of Von mises stress with mesh sizing

In this case, the meshing size is chosen to be 3 mm. The graph is shown alongside. A curvature based mesh is applied to the following geometry.

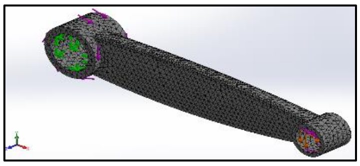

Fig. 3: Curvature meshing for conventional crank design

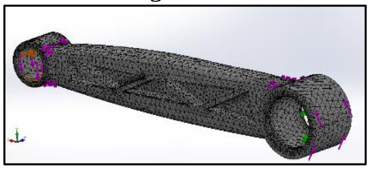

Fig. 4: Curvature meshing for new crank design

Considerations are made to eliminate any singularity points in the model as a result of which the max stress developed saturates after a number of iterations.

Since the critical areas where high stress developing regions were found to be near the contact vertice of the crank bar, crank mounting point and the pedal mounting point, a mesh control feature of mesh size 2 mm was applied at these faces in order to better capture the stress and displacement changes.

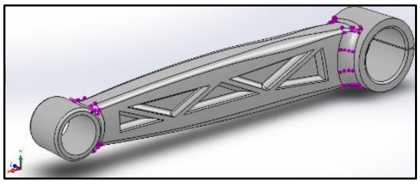

Fig. 5: Mesh control applied at critical areas

This is aptly illustrated in the above Fig by violet markers.

III. RESULTS

A. Conventional Design

After obtaining results of analysis of the conventional crank design, the maximum von-Mises stress developed is found to be 163.9Mpa and the minimum stress developed is found to be 2.13Mpa.

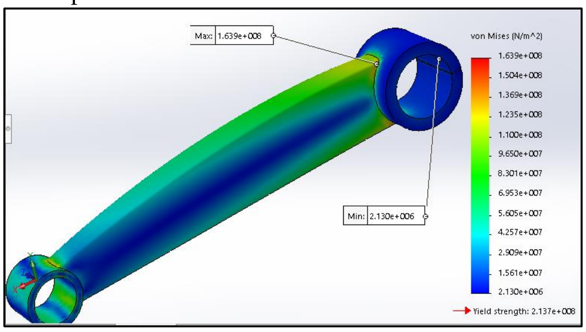

Fig. 6: Maximum stress in crank closer to the point of contact of crank bar and crank mounting point

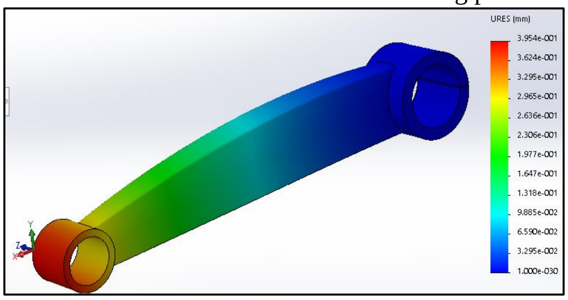

Fig. 7: Displacement in the conventional crank design

The maximum displacement is found to be 3.95E-001 mm. The high stresses are developed at the contact vertice of the crank bar, crank mounting point and on the cylindrical face of the crank mounting point respectively. The iso clipping feature in SOLIDWORKS is used to visualize the high stress developing areas by isolating it from the low stress developing regions.

B. Design Changes (New Design)

On analyzing the above results, it is found that fillets are required to be added near the high stress developing regions in order to distribute the stress developed to other areas. Variable fillet feature is used to provide fillet at the sharp edges of the crank. Moving from the crank mounting point towards the pedal mounting point, the order of the radius of fillet is 2, 4.5, 3, 2.5 mm.

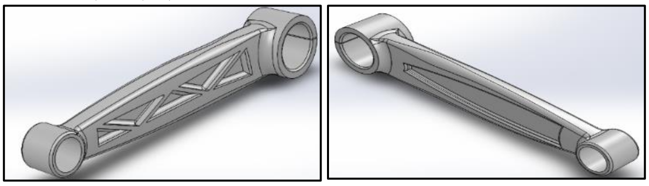

Fig. 8: New design with added fillets and cavity

A fillet of radius 5 mm is provided at the contact vertice of the crank bar and the crank mounting arm. In order to reduce the weight while maintaining the structural stability of the component, several extruded cuts were made on the crank geometry. On one side of the crank, a truss like sketch is made and extrusion cut is provided. On the other side, a small cavity is made thereby reducing the weight significantly.

The result due to the above changes turned out to be positive and is illustrated alongside with the images. The maximum and minimum stresses developed is found to be 140.7Mpa and 0.24Mpa.

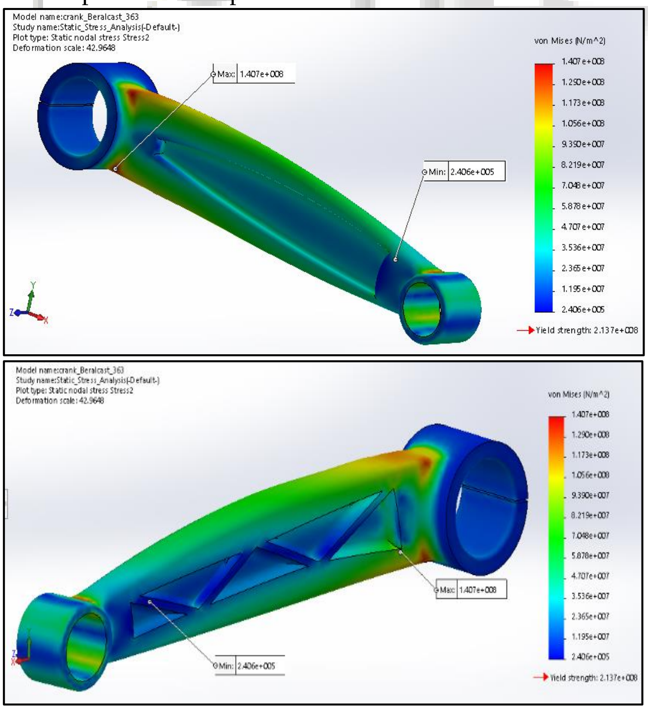

Fig. 9: Maximum stress in new crank design

The displacement is recorded to be 4.25E-001 mm.

An iso-clipping image is provided alongside to illustrate the high stress developing areas of the crank when dynamically loaded and is illustrated by colored regions.

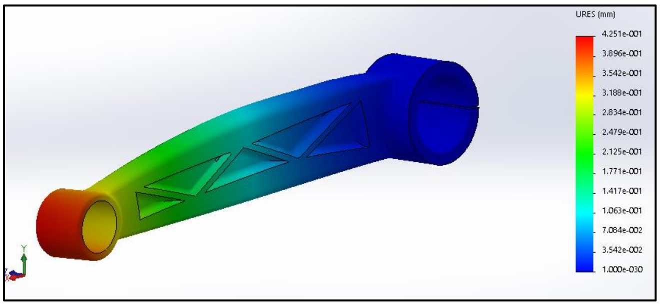

Fig. 10: Displacement in the new crank design

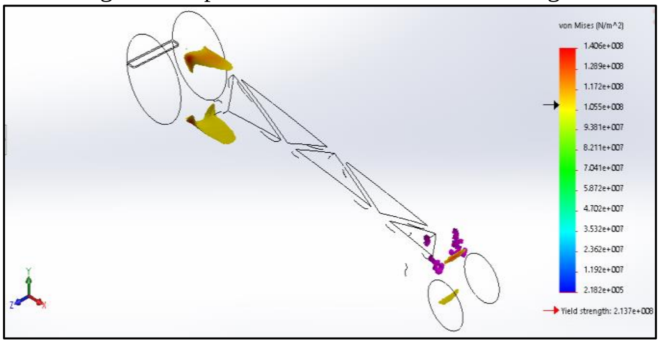

Fig. 11: Iso-clipping of high stress regions

The factor of safety is kept as 1.5 for the new design.

B. Effect of fillet radius

It is observed that the addition of fillets at the high stress developing point drastically reduced in accumulation of stress at a particular point.

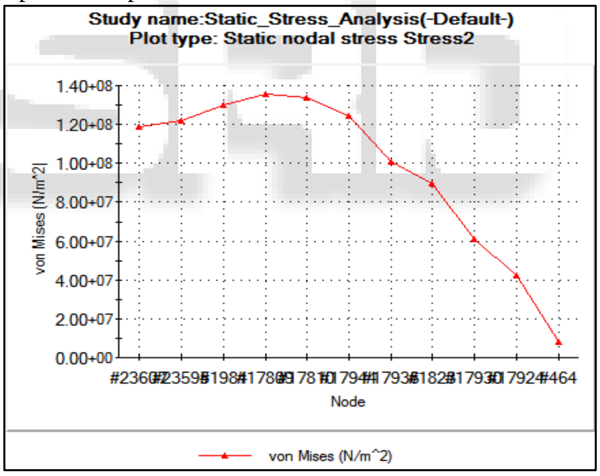

Fig. 12: Stress reductions due to added fillets at the contact of crank bar and crank mounting point

Criteria	Old Design	New Design
Max von-Mises Stress(Mpa)	163.9	140.7
Displacement(mm)	3.95E-01	4.25E-01
Factor Of Saftey	1.35	1.52
Mass(grams)	111.01	93.49
% Reduction in mass	N/A	15.7
%Reduction in stress	N/A	14.1

Table 3: Comparison between old and new design

This can be seen in the static nodal stress plot at the area where the max stress development takes place and is illustrated by the alongside Fig. It can be seen that it is seen that, fillet radius increases von mises stresses decreases.

IV. Discussion

Advancements and support to this study can be made by further researching on various lighter materials that can be implemented which can drastically cut down the cost on manufacturability also making the component as light as possible. Structural strength plays an important role here since various dynamic forces are acting on the crank at an instant of time.

V. CONCLUSION

Fatigue is the progressive structural damage that occurs when materials are subjected to cyclic loading. Stress due to load was increased to the maximum value and decreased to the minimum value. The equivalent stress should be reduced and it is to be kept in average for durability. High stress is the main factor causes to fail the component. If stress is high need to increase the area by adding material and reducing the load (Stress = Load/area).

There are various areas where low stresses are acting. Weight reduction can be made by removing some material from that which results in reduction of the cost as well as keeping the part light. There is a high stress region at the point of contact of the crank and the pedal mounting point. This can be lowered by providing tapering or by adding fillets. SOLIDWORKS was used to construct a 3D model of the Crank and results were obtained by performing iterations in order to get the converging values of equivalent stress and directional deformation. Finally, the high stress points were identified and the required design changes were made for durability, lightness, stiffness and reduction of cost. By working on the areas where the part or component can be made lighter, it reflects in positive outcome on the side of professional cyclists where the weight of the components are of great importance.

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