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Design Optimization of Bicycle Crank through FEA Analysis

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Abstract : *Bicycle is a one of most economical and popular transport mechanism in world. However Paddle crank failure was identified as a most critical failure point of bicycle. The bicycle crank is subjected to loads like weight of cycle as well as the rider pedalling forces static and dynamic. So this crank should have greater stiffness and more resistant to deformation., Generally used material for crank is mild steel, but if targeting weight reduction, the crank can be iterated in topology optimization without compromising the strength and under permissible stress and deformation limits. The analysis and optimization of a bicycle pedal crank using manual calculation and Finite Element Analysis (FEA) is a proposed procedure in this research. This research paper help to minimize the weight of crank, cost and optimum factor of safety.*
Keywords - *Bicycle crank, FEA, Optimization, Pedal Force, Stress*

I. Introduction

The bicycle market in the India and across the world is broken in to several different segments. Many recreational consumers are concerned primarily with cost and are not concerned about the weight of components. The serious cyclist, recreational racer, and professional racer are more concerned with weight of components than with the cost of components. The serious cyclist is also concerned with component performance characteristics as well. For example, a serious cyclist would want their crank and spider to be relatively stiff so there generated power translates to forward motion with the least amount of energy being wasted on deflecting the material.

However Paddle crank failure was identified as a most critical failure point of bicycle. The two cranks, one on each side and usually mounted 180° apart, connect the bottom bracket axle to the pedals. Bicycle cranks can vary in length to accommodate different sized riders and different types of cycling. Crank length can be measured from the center of the pedal spindle to the center of the bottom bracket spindle or axle.

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.

Fig. 1.1 Bicycle crank with chain sprocket

Crank arm play an important role of the transfers the force exerted on the pedals to the crank set.(Fig. 1.1) Therefore crank arms possible to crack in a number of places. In generally crack will develop at the crotch of the chaining-mounting arms or spider arms and the crank arm .However the effects of dynamic loading are most important of the strength of bicycle crank arm, regarding the problem of fatigue. Cyclic loading often initiates brittle cracks, which grow step by step until failure occurs. However, the most often refers to various methods of calculating stresses in crank paddle arm. We have used Hercules Atlas Roadster Bicycle and its crank component for research analysis. (Fig. 1.2)

Fig. 1.2 Existing Bicycle crank Component (Hercules Atlas Roadster Bicycle and crank component)

1.1 Problem Statement:

- As the prominent part of bicycle, optimization of the same reduces weight and in turn cost.
- The topology optimization of bicycle crank can make it perform well as compared to conventional model. The study is performed to reduce weight & improve strength.
- The redesign of bicycle crank is to verify by using customize package of Ansys, HYPERMESH to perform finite element analysis. The static stress analysis is performed and the results are compared with experimental results.
- The experimental analysis is to perform on redesign of bicycle crank and the results are obtained to find its performance.

1.2 Objectives:

- To analyze structural stability of existing and optimized bicycle crank by finite element analysis. Then, prediction of best fitting optimized crank for static loading condition.
- To reduce weight of component considerably by the application topology optimization in bicycle crank.
- Load carrying strength and weight optimization of bicycle crank by using iterative approach of material and topology methodology using FEA tools.
- Validation of optimized crank model with fabrication and experimental results.

II. Methodology

1.1 Literature Survey

In the research work the main focus in towards reduction of weight of the bicycle crank. The weight of the bicycle is going on increasing due to additional luxurious and safety features. The increasing weight of the bicycle affects the overall performance of the bicycle. Therefore the weight reduction of the bicycle is the real need of today's bicycle industry. Bicycle is one of critical component of bicycle. There is scope to reduce the un sprung weight. Weight reduction of bicycle crank is the objective of this exercise for optimization. Typically, the finite element software like OptiStruct (Hyper Works) is utilized to achieve this purpose. For optimization, FEA Ansys could also be utilized. The targeted weight or mass reduction for this exercise is about 10% without compromising on the structural strength. We will try to optimize the crank pedal by topology optimization or change in material like aluminium and composite if required ,adopted by iterative optimization technique.

1.2 Modeling and Analysis of Bicycle crank

The chapter Design and Analysis of bicycle crank includes design and analysis of existing crank. Dimensions of the existing crank have been measured and CAD model of a crank have been prepared in CATIA V5. The finite element analysis is carried out by using Hypermesh and ANSYS as post-processor.

1.2.1 2D Model :

Input parameter: 2 D drawing Dimension are required for calculating of boundary conditions for vehicle dynamics equations. Hence its CAD model is necessary. The conventional model used by Atlas roadster bicycle. Then .stp file of conventional CAD model, which is made by the commands in CATIA of Pad, pocket, fillet, and geometrical selections in part design module. Dimensional parametric model is generated in drafting module of CATIA having top, side and front view as given below. Parametric generation of drawings will help to get the dimensions useful in forces calculations in static and dynamic loading conditions on bicycle crank.

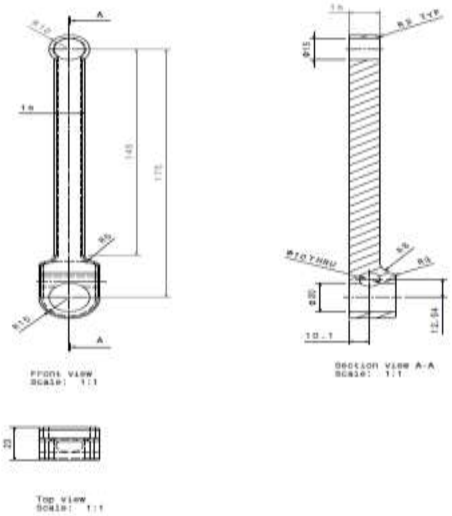

Fig. 2.1 2D Model of Bicycle Crank (All dimensions are in mm)

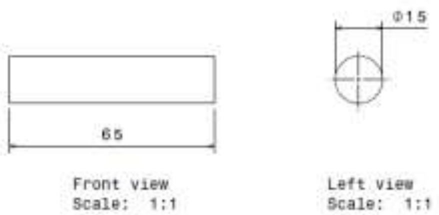

Fig. 2.2 2D Model of Bicycle pedal rod (All dimensions are in mm)

1.2.2 3D CAD Model :

We created the parametric model based off of the dimensions of an entry-level crank. We did not attempt to do any extra featuring of the model except to increase resemblance to the model. We chose to put fillets on all corners of 2 mm. This created a model (Fig. 2.3) that looked remarkably similar to the entry-level one.

Fig. 2.3 3D Model of Bicycle Crank and Pedal rod assembly

1.3 Pedal Force Analysis (Mathematical calculation):

The Fig. 2.4 below shows a bicycle going uphill at an angle of inclination Φ,and with a velocity V.

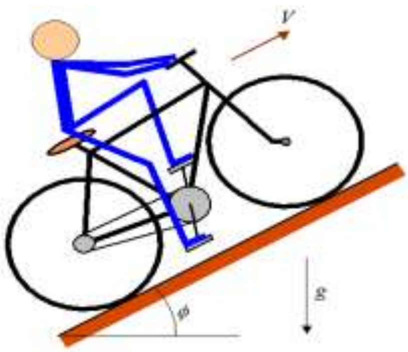

Fig. 2.4 Bicycle rider at uphill position

To propel the bicycle uphill the rider must push down on the pedals. The pedals are offset 180° which means that only one pedal can be pushed at a time, from the top position to the bottom position, and then switching to the other pedal. Given a force $F1$ acting on the pedal we can calculate the resulting force $F4$ between the rear wheel and ground. This is the force that propels the bicycle forward. Hence, we can treat this as a static problem.

Consider the figure below (Fig. 2.5), with forces and radial dimensions shown.

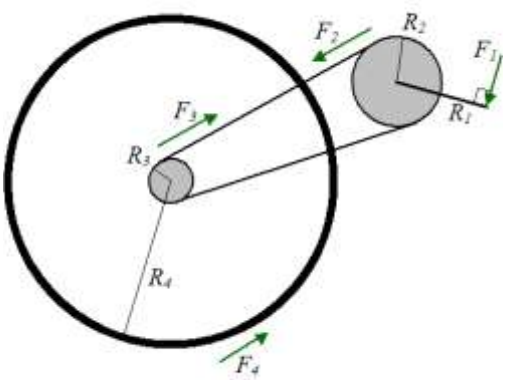

Fig. 2.5 Force Diagram

[For this project we take parameters from Hercules Atlas Roadster bicycle]

Where:

$F1$ is the force applied to the pedal

R1 is the pedal radius=180 mm
F2 is the force acting on the main crank, due to chain contact
R2 is the main crank radius=100 mm
F3 is the force acting on the rear gear, due to chain contact
R3 is the rear gear radius=50 mm
F4 is the force acting on the rear wheel, due to contact with the ground.
Note that the coefficient of static friction between wheel and ground must
be large enough to support this force, otherwise slipping occurs
R4 is the rear wheel radius=350 mm
Using the static equilibrium assumption, we can write the following torque equations:
F1*R1=F2*R2 (1)
and
F3*R3=F4*R4 (2)
Since F2 = F3, we can combine the above two equations to give an expression for *F4*:
F4= F1*R1*R3 / R2*R4 (3)

The force *F4* is what propels the bicycle forward. If we assume that the bicycle is moving at constant velocity (no acceleration) then the force *F4* must equal the resisting forces opposing the bicycle's motion. These resisting forces are gravity, rolling resistance, air drag, and internal bicycle friction. If we neglect the latter we can then write the following mathematical expression **[A]**:
Where:

$$F = mg\sin\phi + C_r mg(\cos\phi) + \frac{1}{2} C_d \rho A v^2 \qquad (4)$$

Where:
m= weight of rider=100kg
g=acceleration of gravity = 9.8 m/s2
F is the force propelling the bicycle forward. Note that *F* ≡ *F4*
Cr is the coefficient of rolling resistance, which can be 0.0022 to 0.005 for bicycle tires **[B]**
Cd is the drag coefficient=1.2 **[C]**
ρ is the density of the air through which the bicycle is moving=1.2 Kg/m^3
A is the projected cross-sectional area of the bicycle + rider perpendicular to the flow direction (that is, perpendicular to *v*) =0.5 m2 **[D]** and *v* is the speed of the bicycle relative to the air=18.5Km/h=5.1 m/s (Assuming real time)
The first term on the right side of the above equation is the gravity contribution. The second term is the rolling resistance contribution. The third term is the air drag contribution.
If we consider $\Phi = 4^0$[maxi. condition]
By putting all these values in formula (4), we get
F4= (100*9.8* sin 4^0)+ (0.005*100*9.8*cos4^0)+ (1/2*1.2*1.2*0.5*5.1*5.1)
F4=82.686 N (5)
We know that,
F4= F1*R1*R3 / R2*R4
We know values of F4, R1, R2, R3, and R4
From this we calculate F1 which is pedal force.
82.686=F1*180*50 / 100* 350
F1= 82.686*100*350 / 180*50
F1=321.6 N
(6)

1.4 Finite Element Analysis of Bicycle Crank :

The model was created and the boundary conditions were applied to the model. Maximum force is acting vertically downward to the end of the pedal. Force is 321.6N to vertically downward to pedal. Crank is fixed as fixed support to the chain of the bicycle. Crank and pedal are connected with contact bond.

A structure or component consists of infinite number of particles or points hence they must be divided in to some finite number of parts. In meshing we divide these components into finite numbers. Dividing helps us to carry out calculations on the meshed part. We divide the component by nodes and elements. We are going to mesh the components using 3D elements. As all dimension of bicycle crank are in proportion we use the tetra-hedral elements for meshing.(Fig. 2.6)

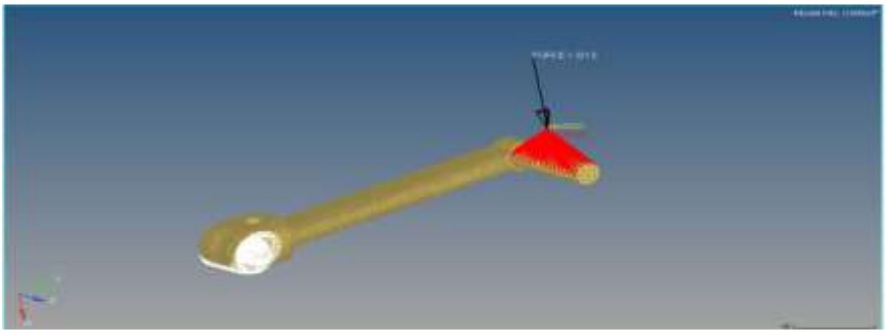

Fig. 2.6 : Meshed Bicycle crank model with applied boundary condition

1.4.1 FEA result:

During FEA solution phase we received deformation and stress plots as:

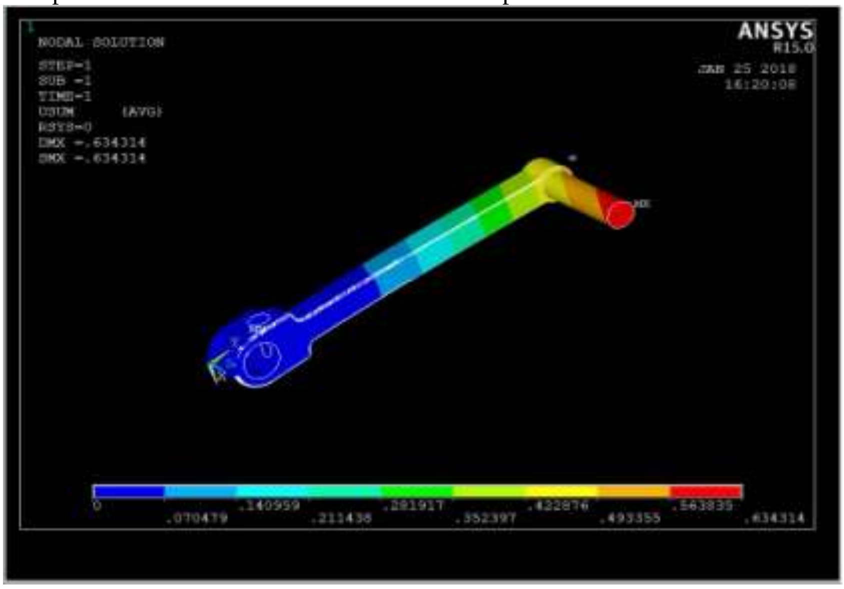

Fig. 2.7 Deformation Result

The maximum deformation is found to be 0.6343 which is very less.

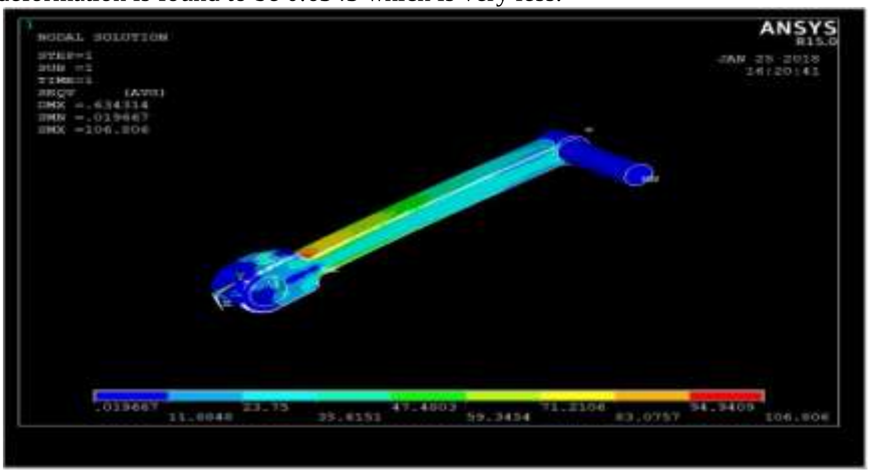

Fig. 2.7 Stress Result

The max stress obtained are 106.8 Mpa which means the design is safe.

As the design is safe, means the stresses are well within the yield stress 245 MPa, and deformation is much less there is a scope for optimization.

Summary:

As a part of research work, we have created 2D and 3D model of existing Bicycle Crank component using design tools. Calculated Peddling Force at bicycle rider at uphill position and applied boundry condition on crank component. FEA results shows stresses are well within the yield stress 245 MPa, and deformation is much less. So there is a scope for optimization. We will further do optimization by removing material by slots from bicycle crank. And if there is further scope for optimization by Ansys iteration then we will change material to aluminum.

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