STRESS ANALYSIS OF BICYCLE PADDLE AND OPTIMIZED BY FINITE ELEMENT METHOD

S. Abeygunasekara[1], T. M. M. Amarasekara[2]

1 Faculty of Engineering & Technology, Colombo International Nautical Engineering Collage (CINEC), Sri Lanka. Email: sampath@cinec.edu,
2. Undergraduate Student, Faculty of Engineering & Technology, Colombo International Nautical Engineering Collage (CINEC), Sri Lanka. Email:mihiran123@gmail.com

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 analysis and optimization of a bicycle pedal crank using manual calculation and Finite Element Analysis (FEA) is a proposed procedure in this research. All manual calculations based on applied mechanics for maximum load case from vertical direction and found greatest principal stress (Equivalent or Von-Mises) and total deflection. The pedal crank was modeled using design modeler and validation of model was done by using equivalent stresses and directional deflection of the crank and pedal. Geometry was refined by using method of body sizing till receive converged result of maximum stress. This research paper proposed improvements of designs with regard to minimize the weight, cost and optimum factor of safety.

***Keywords**:* Paddle crank, Stress, Paddle Geometry, FEM

1. INTRODUCTION

Failure of paddle crank means the progressive of sudden deterioration of their mechanical strength because of loadings effect. Paddle make materials shown different properties as a result many advantages as well as disadvantages. However material strength should have ability to withstand an applied stress without failure. Generally, cranks are manufactured of an aluminum alloy, titanium, carbon fiber, chromoly steel, or some less expensive steel.

The applied load may be tensile, compressive, or shear. Crank arm play an important role of the transfers the force exerted on the pedals to the crank set. 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 [4]. 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. Tensile load is caused by an applied load that tends to elongate the crank arm material which is bicycle crank arm in the axis of the applied load, on the other hand the stress caused by elongate the material. The strength of components of equal cross sectional area loaded in tension is independent of cross section geometry. Loaded in tension are susceptible to stress concentrations such as material defects or abrupt changes in geometry. However, such kind of materials exhibiting ductile behavior but can tolerate some defects while brittle materials structures subjected to fatigue load in metallic structure are a critical problem. It is of great importance for engineers the time a fatigue failure. Failures will occur without any early warning.

2. METHODOLOGY

2.1 Procedure for Analysis

The pedal force is changing every second in the process of turning the pedal and magnitude and direction of pedal force is different according to different riding posture. First half of the round pressure is positive and second half pressure is negative. Maximum load is coming vertically downward and magnitude is depending on the road condition, slope of the road and as well as weight of rider [5].

Here considered 95% man's weight of the population is about116Kg (1160N) [6]. This is the maximum load acting on pedal as well as crank in downward.

Due to this load bending stress in crank and it will create twisting of the crank. The maximum bending stress gives the load acting at the end of the pedal. Crank and pedal connected with threads and considered as two cantilever beams for calculation purposes.

When maximum force was acted on end of the pedal it causes bending and torsion of the crank. Total directional deformation was equal to deflection of pedal and crank with torsional deflection of pedal. For hand calculations made necessary assumption and simplification and geometry of the pedal considered as solid circular part and crank is rectangular part.

2.2 Finite Element Modeling

The model was created and the boundary conditions were applied to the model as shown in figure 01. Maximum force (95% man's Weight of the population) is acting vertically downward to the end of the pedal. Force is 1160N 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 [2].

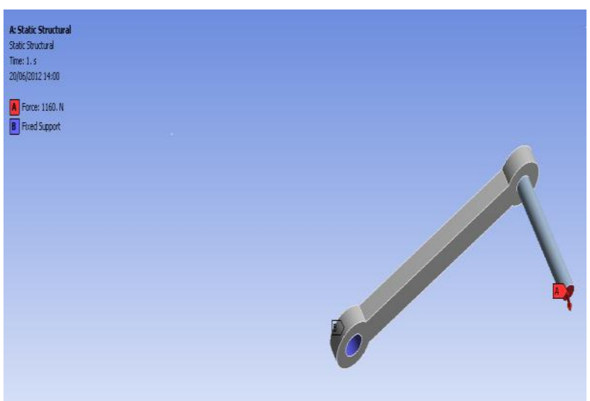

Figure 01: Boundary conditions of the bicycle pedal crank

According to default mesh equivalent stress (Von-Mises) of the crank and pedal (Fig 2 & 3) [3].

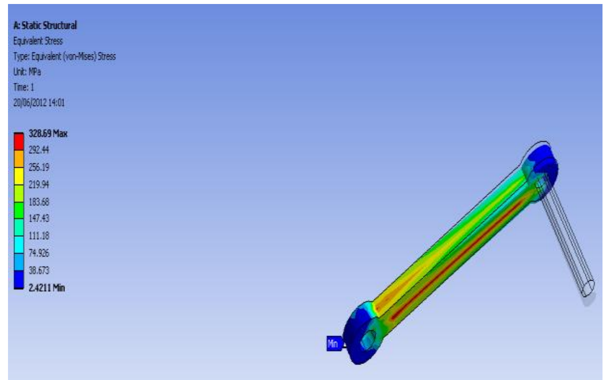

Figure 02: Equivalent stress of the crank for default mesh

2.3 Model Refinement

Refinement was done for crank of the bicycle till receive convergence value for maximum equivalent stress [3].

Table1: Variation of maximum equivalent stress with mesh sizing

Mesh size (mm)	maximum equivalent stress of crank(MPa)	maximum equivalent stress of pedal(MPa)
10.0	320.6	528.9
9.0	311.5	557.0
8.0	323.9	577.1
7.0	350.7	536.6
6.0	359.1	526.1
5.5	376.8	525.1
5.0	334.4	518.5
4.5	373.1	519.7
4.0	369.9	524.2
3.0	386.4	541.0

Table 2: Sphere influence to selected point (150mm)

After consideration of refinement values with 4mm refinment is the value that gives the convergent results of maximum euivalent stress.
Using that refinement model surface is applied with a sphere (stress gauge) 150mm from the end.

3. RESULTS

3.1 Application of Sphere (stress gauge) Influences to the Selected Point

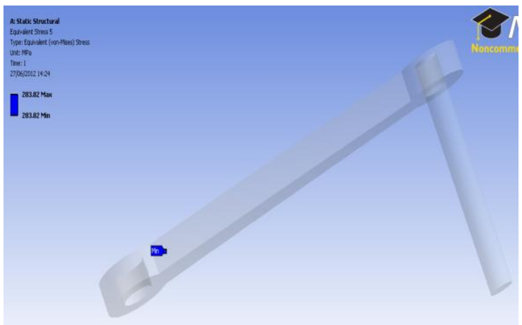

Figure 03: Equivalent stress from the point on the surface 150mm from the end.

For the validation considered equivalent stress(Von-Mises). Point was selected on the surface of the crank 150mm from the end point. For that point, equivalent stress(Von- Mises) was observed using FEA design modeller and hand calculation. Hand calculated value and FEA values were used to validate the model.

Default stress of that the selected point (150mm from end) is 283.8MPa. 5mm sphere was formed around the selected point and studied behavior of sphere influence. Selected 4mm,3mm,2mm,1mm and 0.5mm and refinement was done to find a convergence value if equivalent stress. Equivalent stress values were different with default mesh values for the validation.

Table 3: The equivalent stress values from hand Calculation and FEA

Sphere size(mm)	Rifinement	Von Mises stress(Mpa)
4	1	309
3	2	308
2	3	308
1	4	307
0.5	5	306

Parameter	part of the bicycle	Value received from Manual calculation	Value from FEA
Equivalent stress (Von-Mises) (Mpa)	**Crank**	224	308

From above graph selected **308MPa** as the convergence of Von-Mises or Equivalent stress.

3.2 Reasons for Deviations of Equivalent Stress:

The crank was considered as a beam with rectangular cross section. In real case it is not a rectangular and by the side there are two circular holes. For hand calculations those holes were neglected and considered both were filled with material. In hand calculation considered all edges were sharpen but in CAD model there were no sharp edges all are curved. Mass and volume of the two sections were different. Geometry was different in both cases. In hand calculation not considered any chamfers and curved surfaces but considered all in FEA.

3.3 Design Changes

According to above figure there is maximum stress in sharp edges in the crank near to fixed hole so need to apply some fillets on sharp edges and more thicken near to fixed hole than the pedal fixing hole by adding material (crank has a tapered shape).

Figure 04: The crank with minimize sharp edges

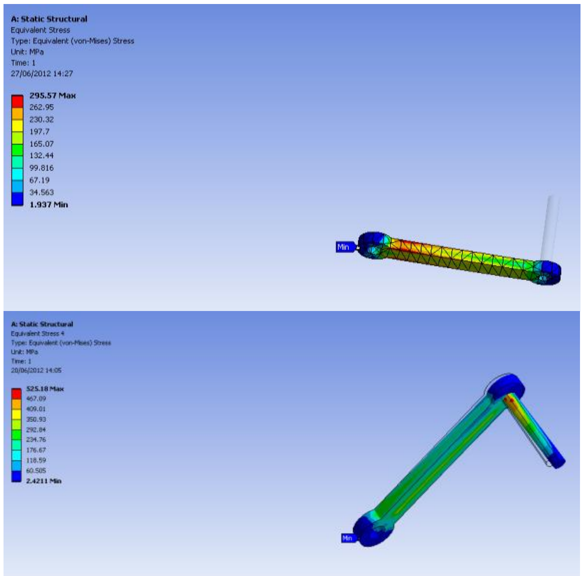

Figure 05: Maximum stress in pedal closer to contact point of crank and pedal.

In between crank and pedal, the contacting point there is also maximum stress. To reduce the stress need to increase the area of the shaft. So it can be tapered after passing that point. If not, weight of the crank will increase and it can be caused to increase the cost and finally need to have high cycling power.

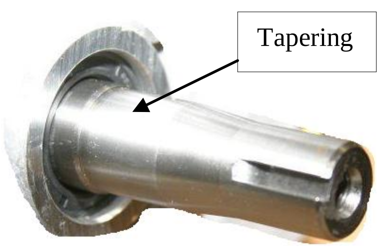

Figure 06: Tapered Shaft

At the end points of the crank and pedal there are sharp corners should be chamfered to reduce the stress.

Lightness and stiffness also important parameters should be controlled. Lightness of the crank is important. Materials can be reduced from bottom side of the crank. Then power required to cycling the bicycle is less. That is an advantage for patient who rides the bicycle.

4. CONCLUSION

Fatigue is the progressive structural damage that occurs when materials are subjected to cyclic loading. Stress due to load on the crank was increased to maximum and decreasing to minimum. Equivalent stress should be reduced and need to keep it in an average value for durability [1].

Always it is needed to keep equivalent stress (Von-Mises stress) as much as low. It will benefit to durability of component. 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 areas where low stresses are acting. For that area can reduce area by removing material. It will cause to reduce the cost as well as keeping lightness of the part.

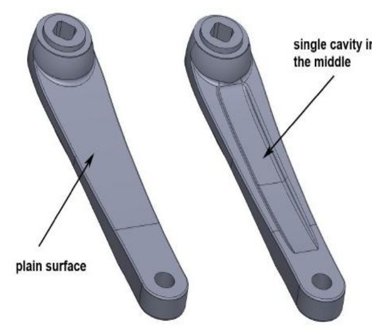

Figure 08: Reduction of materials to get lightness and cost reduction.

It can be used low strength material for low stress areas in a crank. So it will help to reduce the cost.

The FEA method and hand calculations activities done for the design to optimize the weight and cost while providing adequate factor of safety .Design modeler was used to construct a 3D model of the pedal crank and initially produced solution using simple representations of loads and restrains and default mesh produced. Model was solved until receive converged result of equivalent stress and directional deformation. Design was validated using hand calculated values and FEA values. There are some deviations only in equivalent stress and directional deformation was almost correct. Finally high stress points were identified and design changes/

improvements were proposed for durability, lightness, stiffness and reduction of cost.

5. REFERENCES

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