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Structural Analysis of Bicycle Structure and Improvement Analysis using Analytical and Finite Element Analysis

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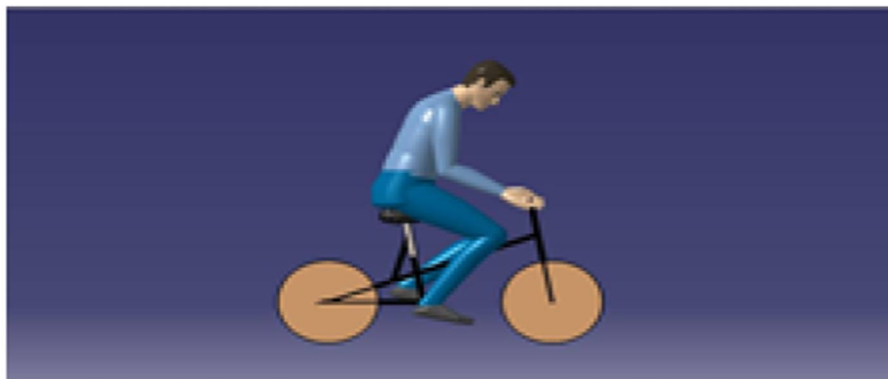
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Abstract—Bicycles are the common man mode of transportation for centuries. They are environmentally friendly and remote places can be easily accessed where road conditions are bad. Since it is essential member of common people, it has altered its shape, topology, design and mechanism for centuries. In the present work, a small effort is done to improve the frame structure and pedal design. Due to the advances in the numerical methods combined with high computing computers, virtual simulation is becoming alternative techniques for faster designs. In the present work, an existing bicycle structure is built using a three dimensional modeling software and drafted for dimensions. The individual members are exported to Hypermesh in 'step' file format for quality meshing which is not possible in Ansys software. The meshed geometry in 'inp' file format is again imported to Ansys for analysis. The analysis is carried out for the frame, fork and rim and results are captured for deformation and stress which are critical parameters of deciding the safety of the structural components. The result shows complete safety of the members for the given loading conditions. Both the stress and deformations are satisfying the functional requirements of safety. Finally a comparison is done for frame structure for weight, modal frequencies and stress conditions. The results shows new design has lesser weight and higher dynamic stability compared to the older or existing design. Similarly the pedal force requirements shows less pedal force with new design compared to the existing design which is based on sprocket type power transmission.

Key words—Pedal Arm, Bicycle Frame, Boundary Condition, Analytical analysis, Finite Element Analysis.

I. INTRODUCTION

Bicycles have remained a prominent part of society since their inception in the 1860s. The basic safety bicycle design has evolved in several directions which are commercially successful today. The market is dominated by road and track bikes, commuter bikes and mountain bikes. The handling properties of a bicycle are significant in how safe it is to ride, as well as how difficult it is to learn to ride on. While handling properties as felt by the rider are subjective, predictions may be made through knowledge of dynamic properties, particular those related to stability. Through more than a century of development, Successful bicycle configurations have been reached. However, much of this development has been through a process of evolution, rather than application of sound mathematic knowledge. While variations exist in modern bicycle design, basic layouts remain similar across popular styles.



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Fig.1.1: Virtual Model of a Bicycle

A virtual model created in the Catia software is shown **Fig.1.1** to show the working and physical appearance of bicycle. The stability, structural rigidity and mechanical advantages are the main feature of bicycle design.

II. PROBLEM DEFINITION

Analysis of existing and new chainless structural design using theoretical and finite element analysis is the main definition of the problem. The main objectives include,

- Finite element analysis of existing structure
- Theoretical calculations of the new frame structure
- Theoretical calculation of the chainless pivotal pedal Structure
- Comparison of existing and new structure.

III. MATERIAL

Material Name: SAILMA350 (Steel Authority of India Limited Manufactured)

Yield Stress: 350MPa

Factor of Safety = 6 (Considering the fluctuating loads) (CMTD reference)

Allowable Stress: $\frac{350}{6} = 58.33 \text{ MPa}$

Allowable Shear Stress = $\frac{58.33}{2} = 29.16 \text{ MPa}$

IV. EXISTING STRUCTURE

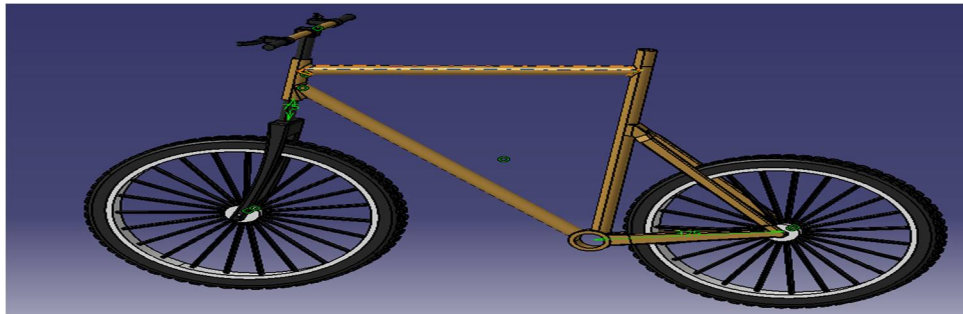


Fig.4.1: Existing Structural Design

The **Fig.4.1** shows modelling of the existing bicycle with frame structure. Since analysis is limited to frame, wheel, fork structure, other members are not modelled. Catia software is used to built the geometry. Tubed structures are used for building the bicycle geometry.

V. ANALYSIS OF THE EXISTING STRUCTURE

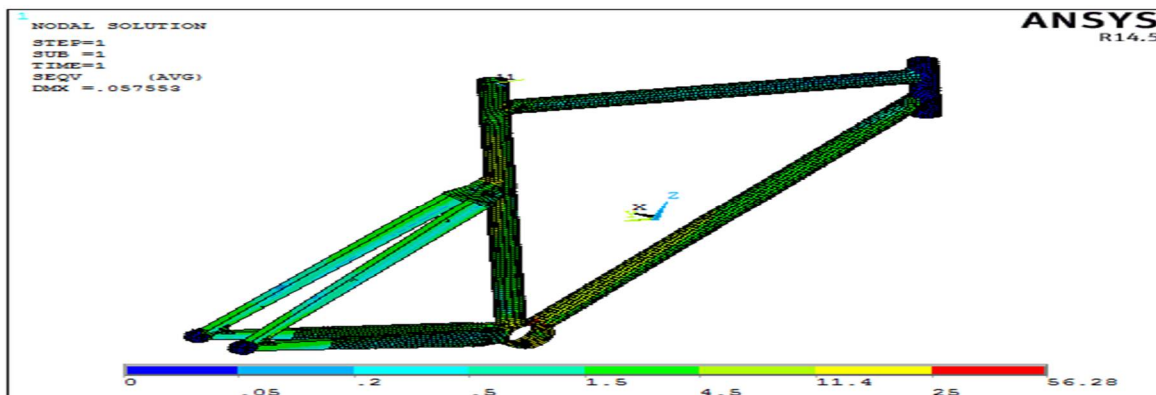


Fig.5.1 Vonmises Stress Plot

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The **Fig.5.1** shows vonmises stress development in the problem. Maximum vonmises stress is around 56.28MPa. The vonmises stress is the most important parameter to find the strength of the structure. Vonmises stress or equivalent stress is calculated as a results of all six stress components specified for any position. Vonmises stress in Ansys is represented as 'seqv' in the title bar. The results are averaged based on the nodal positions for uniform colour plots. Vonmises theory is the best applicable theory for ductile materials. It says the member fails if the vonmises stress calculated exceeds the allowable or yield stress of the material. Almost this theory has 90% acceptability in predicting the failure. This stress is also considered as stress corresponding to stored strain energy or distortion energy.

TABLE.5.1 First 5 Modal Frequencies

Set No	Modal Frequency (Hz)
1	79.594
2	126.04
3	244.08
4	280.74
5	281.81

The **TABLE.5.1** shows first 5 modal frequencies of the problem. The first frequency of 79.594 Hz is called fundamental natural frequency. Considering maximum velocity of cycle as 6m/sec from the literature, operational frequency of cycle for 450mm (0.45m) diameter.

$V = \pi dn$ where 'n' is revolutions per second

$$n = \frac{6}{3.14 \times 0.45} = 4.24 \text{ cycles/second}$$

Since the first fundamental frequency of 79.594 Hz is much higher than the maximum operational speed of 4.24 Hz. So the frame structure is stable for resonance.

VI. ASSUMPTIONS

- The analysis is done with in elastic limits.
- No yield point of the material is specified.
- Formulas based on simple bending, axial loads are used for calculations.
- Material is assumed to be homogeneous, continuous and free of voids and cracks.
- Pipe16, plane42 and solid45 elements are used for one dimensional, two dimensional and three dimensional problems.
- All approximation of finite element methods are equally applicable for the analysis
- Lower order elements are used with in the linear range.

VII. NEW STRUCTURAL DESIGN AND ANALYSIS

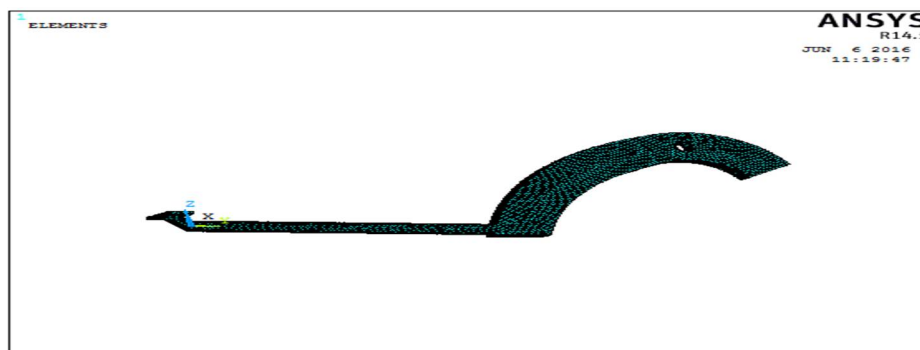


Fig.7.1 Basis for New Design (Chainless Transmission)

The old design will be modified to convert into chainless drive by pedal operation to obtain greater mechanical advantage. Only the

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frame and lever will be altered to obtain structural advantage. The design calculations and analysis procedures are represented in the following presentations.

VIII. TORQUE AND PEDAL FORCE REQUIREMENTS:

Total Load acting from the top: 1000 N.

Assuming the structural load of 30% total load.

Total load acting down ward direction $R_n = 1000 + (0.3 * 1000) = 1300 N$

Considering ground friction $\mu = 0.05$

Force required to slide the member: $F = \mu R_n = 0.05 \times 1300 = 65 N$

Considering the wheel diameter $d = 450 \text{ mm}$

Radius of the wheel = 225 mm

Torque generated $T = 225 \times 65 = 14625 N - mm$

Wind Load Estimations:

Assuming maximum velocity of design = 60 Km/h

Velocity, $v = 60000/3600 = 16.66 \text{ m/sec}$

Wind pressure $P = 0.5 \times \rho \times v^2 = 166.53 \text{ N/m}^2$.

Projected area from the neutral axis (hinge position) $A = 0.05 \times 1.8288 = 0.09144 \text{ m}^2$

On the assumption that 50 mm width and for 6 feet height $(6 \times 12 \times 25.4)$

Total drag load acting on the structure $F_d = 15.23N$

Considering one fourth load due to distributed condition is used for creating the torque load

Torque load to resist the wind load = $225 \times 15.23/4 = 856 \text{ N} - mm$

Considering frictional loads and inertia loads contributing 10% each

Total torque= drive torque + wind load torque + frictional torque + inertia torque

$M_t = 14625 + 856 + (0.1 \times 14625) + (0.1 \times 14625) = 18406N - mm$

So pedal torque should cross this load for giving rotation to the structure.

Assuming the pedal distance from the hinge location force required to operate the hinge = 650 mm

$$F \times L = 18406$$

$$F = \frac{18406}{650} = 28.32N$$

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or around 2.8 kg load need to be applied at the pedal from the user.

IX. PEDAL ARM DESIGN

Pedal arm length considered = 650 mm

Calculated force: 28.32 N

Considering load variation with shocks equal to 2

Total force applied $F = 28.32 \times 2 = 56.64 \text{ N}$

In case the pedal arm is struck at the hinge location, the load will be converted to bending. Otherwise it works like a shear load. For the worst condition of design, it is considered as bending load.

Moment at the fixed location $M = 56.64 \times 650 = 36816 \text{ N} - \text{mm}$

Considering a rectangular section with thickness 3 mm

$$\sigma = \frac{12 M}{b h^2}$$

$$58.33 = \frac{(12 \times 36816)}{(3 \times h^2)}$$

$h = 50.2 \text{ mm}$.

Since a hole is cut at the center of the rectangular plate, stress concentration effect should be considered by providing a boss which will increase the width at the hole region.

Moment of inertia required $I = \frac{(3 \times 50.522^3)}{12} = 32239 \text{ mm}^4$.

For circular geometry Moment of Inertia $I = \frac{(\pi \times d^4)}{64}$

If circular geometry is considered, diameter required, $d = 28.33 \text{ mm}$.

So a standard diameter of 30 mm can be considered.

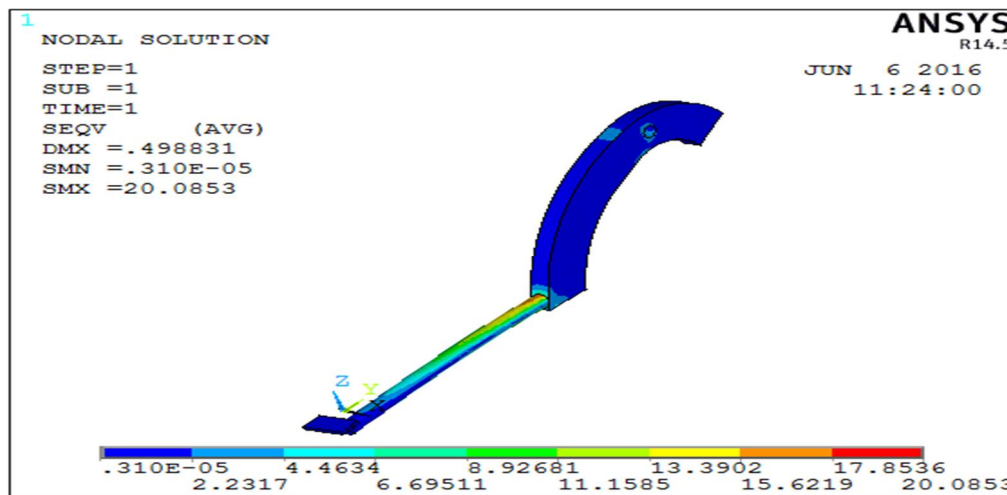


Fig.9.1 Vonmises stress in the Pedal arm

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Maximum stress of 20.08 MPa can be observed at the joining region due to stress concentration effect. Even this stress is less than the allowable stress of the problem. So structure is safe for the given load.

X. COMPARISON OF THE EXISTING AND NEW DESIGN

The comparison is mainly carried out for the frame structure and mechanical advantage. The comparison results are as follows.

Table.10.1 Comparison of original and New Design

	Displacement (mm)	Vonmises Stress (MPa)	Modal Frequency (Hz)	Weight (N)
Existing Frame	0.0575	56.28	79	70.5
New Design	1.2	58.2	164	43.6

XI. PEDAL FORCE REQUIREMENTS AND MECHANICAL ADVANTAGE:

Total torque required for the pedalling application: 18406 N-mm

Pedal force required from the new design: 28.32 N

Calculation for the old design for pedal force:

Considering the crank arm length = 150 mm

Mechanical advantage with the gearing: 3

$$\text{Pedal force required } F = \frac{18406}{(150 \times 3)} = 41 \text{ N}$$

Table 11.1 Force comparison

	Pedal Force (N)
Existing Frame	41
New Design	28.32

XII. RESULTS

The overall summary is as follows. Initially the existing structure is built using three dimensional software for virtual appearance and analysed for the loading conditions. Only major members are considered for modeling and analysis. Fork, rim, frame are extracted in step file format and exported to Hypermesh for meshing and analysis. The results are captured for stress and deformation. The result shows complete safety of the existing structure for the given loading conditions maintaining the stress and deformation with in the safe limits. New design is mainly considered to replace the frame structure and obtaining the mechanical advantage through chainless transmission or pedal operated level mechanism. Calculations are carried out for the worst loading and length conditions and structural design is done based on analytical formulas based on the type of load. The design for frame (Single cylindrical structure) is done by finding the shear force and bending moment diagrams. Section design is carried out based on simple bending formulas. Similarly the fork member cross section requirement is also carried out considering the member as strut.

XIII. CONCLUSION

Human trial is always for optimum design and this procedure is a never ending and always changes are required based on the requirements of the time. In the present work, an existing bicycle structure design is checked with finite element analysis and certain

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members are newly designed and compared with the existing structure. The results shows, both the designs are safe for deformation and stress conditions. But the weight is less with new design compared with the older design. Similarly more dynamic stability can be observed for the new frame compared to the older frame. Similarly mechanical advantage is better compared to the older design by observing the pedal force calculations and values. With the old design, a pedal force requirement of 41 N can be observed whereas only 28 N with new design. So efficiency of the system can be improved with the new design.

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