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Static and Vibration Analysis of Racing Bicycle Frame

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ABSTRACT

A Bicycle frame is prominent part in whole racing cycle system which is subjected to static and dynamic loads. The performance of frame is directly proportionate to weight of the cycle and frame structural design. The vibration occurs due to irregularities on the road surface. The frame behavior frame is most importance for the perception on comfort of the rider. Vibrations which are not absorbed by the bicycle frame must be absorbed by the rider and this causes fatigue of the muscles and thus diminished performance. This paper deals with the stress analysis and vibration analysis of bicycle frame by using Finite Element Method. In the analysis the frame is treated as truss like structure and the stresses in various members of frame like top tube, down tube, seat tube, chain stay and seat stay are determined, considering various static and dynamic loading conditions and calculating mode shapes, natural frequencies by using FEM software (ANSYS 15). The F.E.A. results are compared with the experimental results. The F.E.A. results are compared with the experimental results. The effects of stresses by static analysis and vibration responses are determined. Convergence study is also included for high accuracy of the results. Mode shapes and corresponding natural frequencies are studied for the bicycle frame.

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I. INTRODUCTION

The bicycle and the other single track vehicles are characterized by the problem of stability, which is tightly linked with safety: an unstable bicycle can be risky also for a well-trained rider running on a road with safe infrastructures. For this reason research in the field of bicycles dynamics, which started in the last years of 19th century, has principally addressed to the problems of auto-stabilization and rider control. The need for low weight coupled with high strength and stiffness has lead to continuing trail and development of high performance material for racing bicycles[1]. Thus, in trial and error method is costly and slow, and intuition does not always yield reliable results.The method used for modelling will be described and theoretical predictions of frame stresses will be compared with F.E.A result for some simple loading cases.This design has been the industry standard for bicycle frame design for over one hundred years. The head tube of the frame holds the sheerer tube of the fork, which in turn holds the front wheel. The top tube and down tube connect the head tube to the seat tube and bottom bracket. The seat tube holds the seat post, which holds the saddle. The bottom bracket holds the cranks, which hold the pedals. The seat stays and chain stays hold the rear dropouts, which connect the rear wheel to the frame[4],[5].

The safety framed road or bicycles, and wide range of specialist tools are now available to support bicycle development through analysis and iterative improvement. Performing Finite Element Analysis (FEA) on bicycle frames has become a common activity for bicycle designers and engineers in the hope of improving the performance of frames[2]. The most common material for the tubes of a bicycle frame has been steel. Steel frames can be very inexpensive carbon steel to highly specialize using high performance alloys. Frames can also be made from aluminium alloys, titanium, carbon fibre, and even bamboo and cardboard. Occasionally, diamond shaped frames have been formed from sections other than tubes[5]. Higher vibrations perceived mean an increase of discomfort at arms, legs and lumbar spine which affect the athletic performance of the cyclist. The entity of the vibration transmitted by the bicycle while cruising on irregular road surfaces depends on geometry, mass, inertia and structural characteristics of its components among which the wheels play a main role[3],[9].

Fig.1 Bicycle frame and components.

Depending on the used material for the frame, one or other aspect can be fulfilled better. Dynamic behaviosr means how the frame reacts when it is subjected to forces due to vibrations coming from the irregularities on the road surface[8]. The behavior of the frame is of big importance for the perception on the comfort of the rider. Because, the better vibrations coming from the road are absorbed by the frame, the better the rider will perform. The physical prototype will be to be tested to optimize the product[6]. Vibrations, which are not absorbed by the bicycle frame must be absorbed by the rider and this causes fatigue of the muscles and thus reduced performance.Nowadays various types of bicycles models have been developed, to improve the quality of results and the extend possibility of simulating racing bicycles running at high speed[1],[7].

II. LITERATURE REVIEW

A. Doria, L.Taraborrelli [1] On the structural vibrations of bicycles: influence of materials and construction technology on the modal properties, In this paper the modal analysis approach is used for identifying the out-of-plane modes of some bicycles with similar geometric properties: a utility bicycle with steel frame, a sport bicycle with Ergal frame and two sport bicycles in carbon.

Derek Covill, Steven Begg, Eddy Elton, Mark Milne, Richard Morris, Tim Katz [2] Parametric finite element analysis of bicycle frame geometries. This paper has outlined a FE model using beam elements to represent a standard road bicycle frame. The model simulates two standard loading conditions to understand the vertical compliance and lateral stiffness characteristics of 82 existing bicycle frames from the bicycle geometry project and compares these characteristics to an optimized solution in these conditions. Perhaps unsurprisingly smaller frames (490mm seat tube) behave the most favourable in terms of both vertical compliance and lateral stiffness, while the shorter top tube length (525mm) and larger head tube angle (74.5°) results in a laterally stiffer frame which corresponds with findings from literature. The optimized values show a considerable improvement over the best of the existing frames, with a 13% increase in vertical displacement and 15% decrease in lateral displacement when compared to the best of the analyzed frames.

Federico Giubilato, Nicola Petrone[3] A method for evaluating the vibrational response of racing bicycles wheels under road roughness excitationThe aim of the work was the development of a method for measuring and comparing the vibrational response of different racing rear wheels to the excitation caused by riding on irregular road surfaces.

M.V.Pazare [4] Stress Analysis of Bicycle Frame in this paper, he stuided stress analysis of bicycle frame by using Finite Element Method. The analysis is done in ANSYS, The F.E.A. results ware compared with theoretical results. For theoretical analysis the frame is considered as truss like structure and the stresses in various members of frame like top tube, down tube, seat tube, chain stay and seat stay are calculated, by co0nsidering static start up, steady state paddling, vertical impact, horizontal impact, rear wheel braking conditions. and FEA is done considering all these conditions.

Sagar Pardeshi [5] Design and Development of Effective Low Weight Racing Bicycle Frame this paper deals with study of static and dynamic loads. Optimization of weight and structure by using static and dynamic FEA Analysis of the frame gives better performance of the racing cycle.

III.FINITE ELEMENT MODEL DESCRIPTION

A general-purpose commercial finite element code, HyperMesh and Ansys are applied to conduct the static simulations. The FEA model of bicycle frame in this study is constructed based on the geometry.

A. CAD Model Design

The CAD is developed using 3-D modelling software. The cad geometry has basic requirements for Head tube, top tube, bottom tube, chain stays, seat stays, bottom bracket shell and the two triangles commonly says diamond frame[5]. This is the model of the bicycle frame. A bicycle frame is the main component of a bicycle, onto which wheels and other components are fitted.

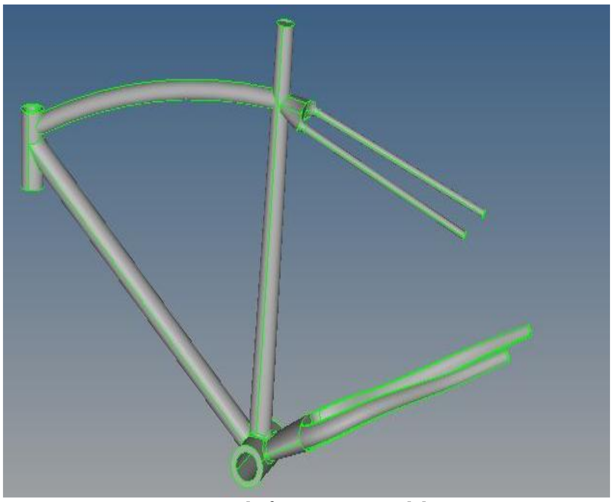

Fig.2 Bicycle frame CAD Model

B. Localized Meshing Control

Meshing for the model is done using the automated meshing refinement feature in Hyper Works can be seen in Figure 3.

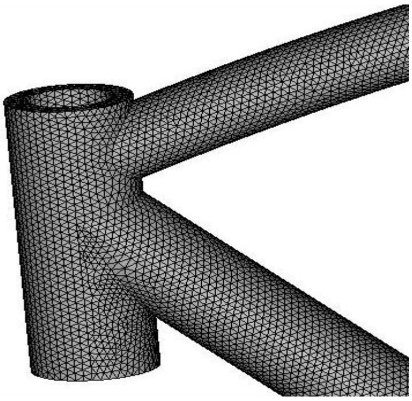

Fig.3 Meshed model with tetrahedral element

A full 3-D solid model is constructed for the static test simulation. The schematic of an FEA model used in static test simulations is shown in figure.The cad model in IGES format is imported in Hyper Works for the preparation of FE model. Then geometry cleanup was done by using options like ‘geom. Clean up’ and ‘defeature’ to modify the geometry data and prepare it for meshing operation. This process involves deletion of curvature of very small radius (less than 2mm) which has less structural significance. Mixed type of elements which contains quadrilateral as well as triangular elements, have been used in the analysis. These 2D elements are converted into 3D tetra elements. The sensitive regions have been re-meshed by manually considering the shape and size of the parts. Quality check of all the elements has been performed and mesh is accordingly optimized.

C. Material Selection

The aluminium alloy is chosen as the material for bicycle frame due to its low density and compatible yield strength. The best suited material is the aluminium alloy. This material is chosen for designing frame and comparing its results with different materials as mild steel, EN8 etc. The table 1 shows Comparison of properties of material.

Table.1Material Properties

Material	Density (Kg/m^3)	Modulus of Elasticity (Gpa)	Poisson's Ratio	Yield Strength (Mpa)
Alloy Steel	7850	210	0.3	450
Aluminium Alloy	2700	69	0.33	280

IV. STATIC ANALYSIS OF BICYCLE FRAME

A. Boundary Conditions

The boundary conditions and loads are applied to the frame in hyper mesh. Boundary conditions were then applied to chain steay, seat steay. At this location, we will constrain movement in all directions, setting the degrees of freedom in the X, Y, and Z direction to be zero. Creating this constraint will allow us to attain accurate results of the frame materials without the frame itself rotating Translational and rotational moments are not allowed.

B. Loading

For the design of Bicycle Frame following data is considered. The problem to be modelled in this example is a simple bicycle frame shown in the following figure[4]. The frame is to be built of hollow aluminium tubing having an outside diameter of 30mm a wall thickness of 7.5mm.

1) *Static start up:* A 700N rider is applying maximum effort to accelerate from a standing stop. Aerodynamic, rolling, and gyroscopic forces are assumed negligible. The bicycle is in vertical equilibrium with the front wheel pointed straight.

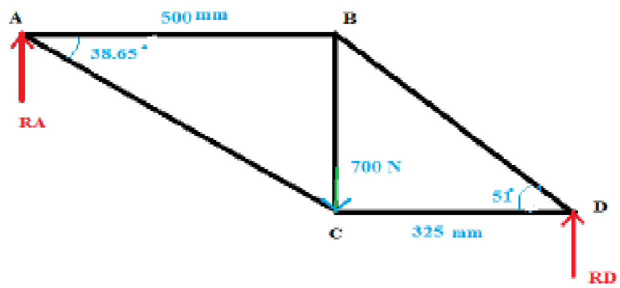

Fig.4 Static start up

2) *Static Pedalling:* A700N cyclist seated on a bicycle is assumed and due to leg dynamics 200N force is applied at pedal.

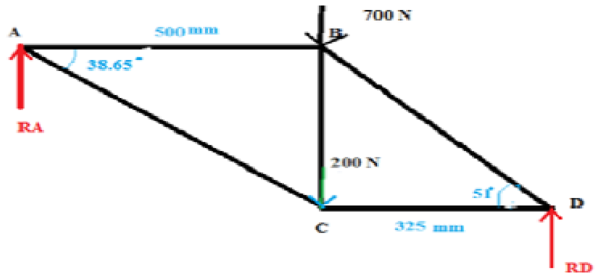

Fig.5 Static Pedalling

3) *Vertical Impact:* Vertical loads are considered by multiplying the rider's weight by "G factor". For this study

2G are used to simulate vibration effects in the absence of pedalling.

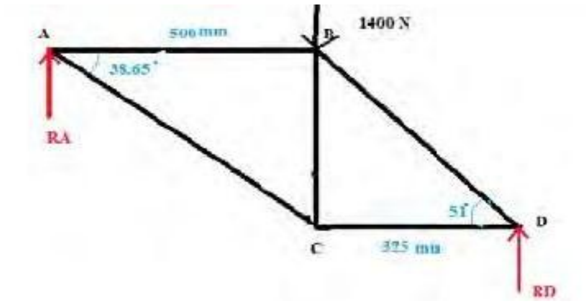

Fig.6 Vertical Impact

C. FEA Output Model

The analysis is based on the fact that areas with high levels of stress produce high levels of strain. The output from ANSYS can be seen below in Figures.

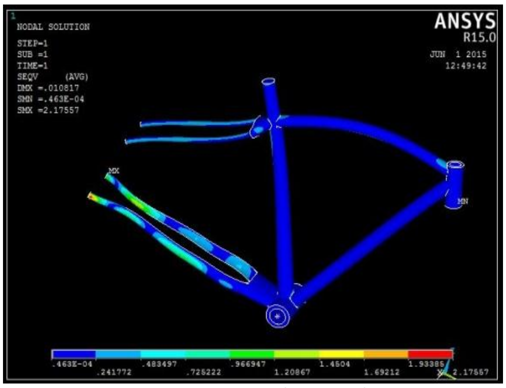

Fig.7 Stress analyses of bicycle frames

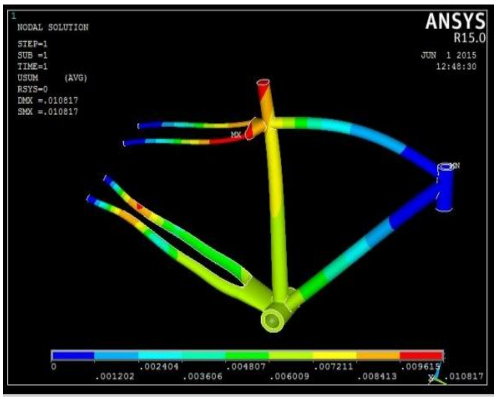

Fig.8 Displacement plot

V. MODAL ANALYSIS OF BICYCLE FRAME

To fully understand what is meant with vibration analysis, some theory about modal analysis is necessary. Modal analysis is a process whereby the structure is described in terms of its natural characteristics which are the frequency, damping and mode shapes. These three are called the dynamic properties from a structure.

A CAD model of frame is available. The frame is made of the thin-walled tubes; FE analysis was carried out in ANSYS 15.0 software. Modelling dimensions were in meters, and properties were given in GPa. Ttetrahedral elements are used to generate the mesh on the frame. Then boundary conditions are applied. As the isotropic material aluminium alloy is used for the simulation. The modal analysis was selected and its types were input. Then the solution was solved. The natural frequency is calculated when the simulation has finished, the mode shapes are made visible.

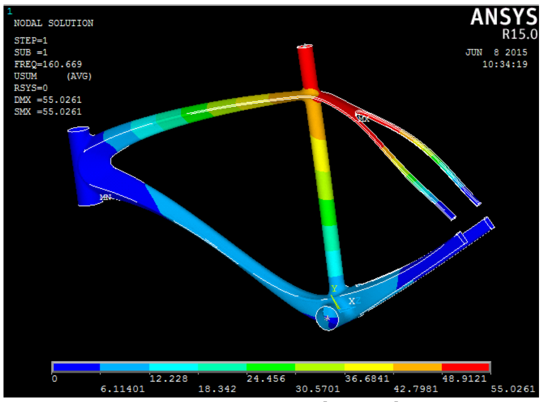

Fig.9 Frequency result at mode 1

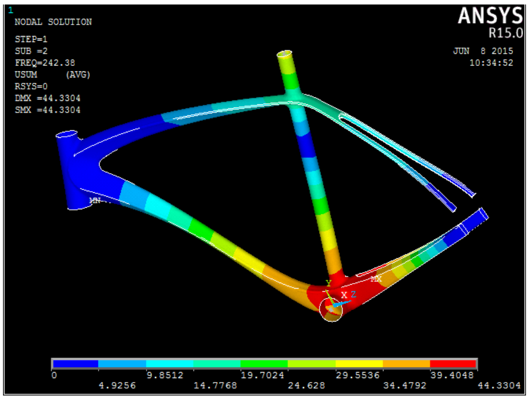

Fig.10 Frequency result at mode 2

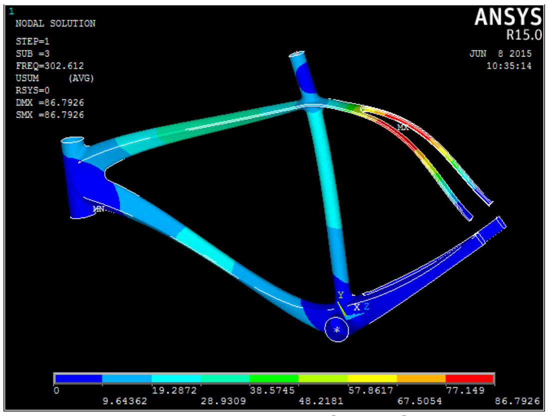

Fig.11 Frequency result at mode 3

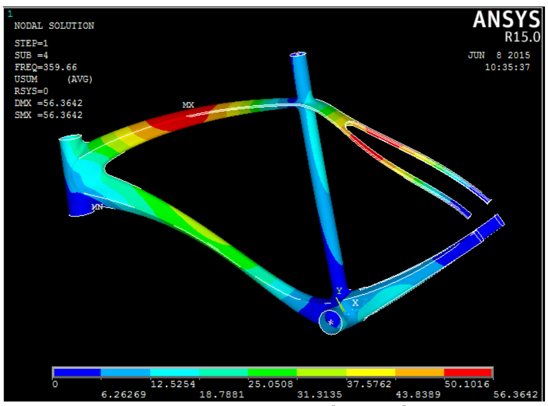

Fig.12 Frequency result at mode 4

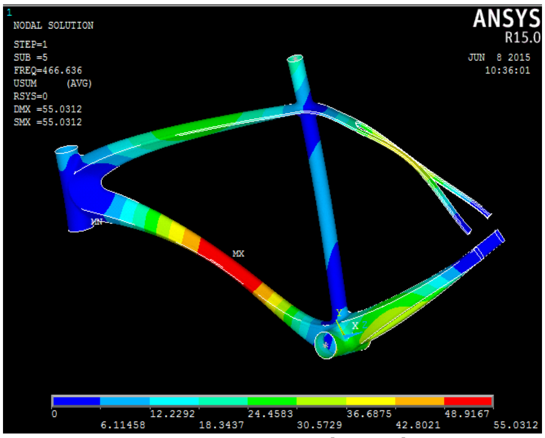
Fig.13 Frequency result at mode 5

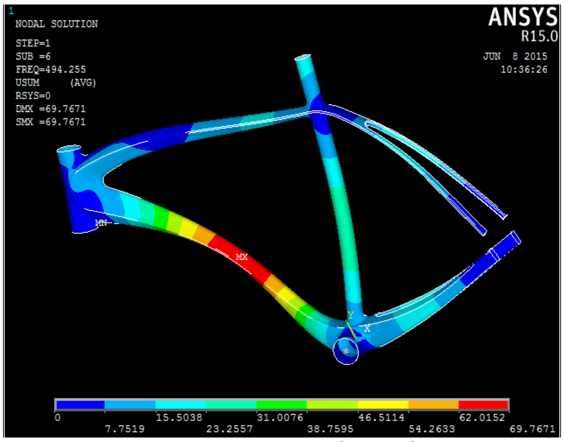
Fig.14 Frequency result at mode 6

VI. FINITE ELEMENT ANALYSIS RESULTS

Natural frequencies of bicycle frame by considering six modes. In table 2 shows the values of six natural frequencies of the bicycle frame of the FEM values with by the use of composite material.

Table.2 Bicycle frame frequency values

Mode Number	Natural Frequency Values Hz
1	160.67
2	242.38
3	302.61
4	359.66
5	466.64
6	494.26

VII. CONCLUSIONS

Through FEA of our bicycle frame, we were able to obtain stress and deflection results for the applied loads Results of all case reveals that the maximum stresses in the member of bicycle frame in seat stay is 21.92 and 21.75MPa for steel and aluminium respectively, which is less than yield strength in tension for the material selected.

Finite Element simulation can be implemented for free vibration analysis to predict the natural frequencies, and mode shapes of the bicycle frame. Two types of modes namely, flexural bending and torsional mode exists for vibrating bicycle frame irrespective of boundary condition.

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