Design and Optimization of Bicycle Frame for the Cyclist's Comfort

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Abstract— Bicycle plays an inherent role in our life. Bicycle riding is a globally popular sport and an economic transportation. The performance of frame is depends on the weight of the bicycle and frame design. Optimization of weight and structure of the bicycle frame is the best scope of optimizing the overall performance of the bicycle. When the rider ridding bicycle on rough surface, the induced vibrations will cause the fatigue of its rider and the fracture of its frame structure. This paper deals with the study of the structural design, modal analysis and optimization of bicycle frame by using composite material with help of FEA. Firstly structural analysis, numerical results obtained by applying dynamic loading condition. Secondly, the Modal analysis is used to identify modes of bicycle frame to calculate natural frequencies and mode shapes by using Finite Element Analysis. Finally, the analyzed frames are then optimized to reduce weight without affecting their capacity to be resistant to mechanical stresses.

Keywords- FEA, *composite material, Design Optimization, Modal Analysis.*

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I. INTRODUCTION

The one of the way of transport that doesn't consume any fuel, doesn't emit any pollution is a bicycle. It is a very popular form of transport as people make use of it to move from one destination to another whether it lie on map or not. While driving a bicycle, it uses maximum muscles of the body that provides a very good exercise, bicycling makes the rider to reach aerobic heart rates that drive up metabolism, and give a good workout and keep healthy. Bicycle has proved its importance in various fields as it is a popular form of recreation, and it is widely adapted as children's toys, fitness, courier services, and bicycle racing. Changes in bicycle frame are motivated by the weight and stiffness consideration and with the use of high performance engineering skills also it is influence by stability and handling characteristics. The handling properties of a bicycle are determined, by asking how safe it is to ride, also how difficult it is to learn to ride on. The main strength of frame construction is correct designing of a frame which is the most important part that ensures safe riding. The innovative ideas of the manufacturers and construction designers to minimize aerodynamic drag, to improve comfort, minimising the mass of the frame, maximising lateral stiffness in the load transfer from the hands and feet to the drive, maximising the strength capabilities of the frame to allow for a higher load capacity or better load distribution, and adjusting the vertical compliance of the frame to tune the softness of the ride that means comfort and safety ride. These are the reason of contribution in the development occurs in the design of bicycle frame and consequently the need of analysis of bicycle structure come to rise. The bicycles are popular sports equipments or traffic tools. The frame of the bicycle is the main structure to support the external loads [10].

Figure.1: Bicycle frame and components

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].

Depending on the used material for the frame, one or other aspect can be fulfilled better. Dynamic behaviour means how the frame reacts when it is subjected to forces due to vibrations coming from the irregularities on the road surface [8]. The behaviour 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 analysed frames. Federico Giubilato, Nicola Petrone[3] A method for evaluating the vibrational response of racing bicycles wheels under road roughness excitation The 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. 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. RIDER BODY VIBRATION

Every frame acts as a shock absorption system, the frame is placed between (i) the rider (who is connected to the frame by the hands, feet and the seat) and (ii) the vibration input of the road. Figure 2 shows a schematic of the frame as a shock-absorption device, which consists of an elastic element (spring) and a viscous element (damper).

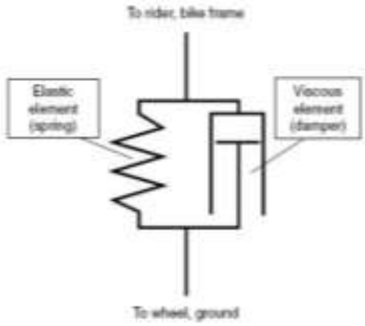

Figure 2: The frame as a shock-absorption device

The vibration input comes from the imperfection of the road surface. These imperfections are transmitted by the spokes to the shaft of each wheel; the shafts are connected with the frame so each vibration on the shaft is put directly to the frame. A part of the vibration is already absorbed by the tire, the rim and the spokes. These three parameters can be adapted to minimize the vibration (or maximize the comfort of the rider) due to the road roughness. However, a lot of vibration is still present at the point where shaft and frame are attached, so the vibration can now only be reduced by adjusting the frame.

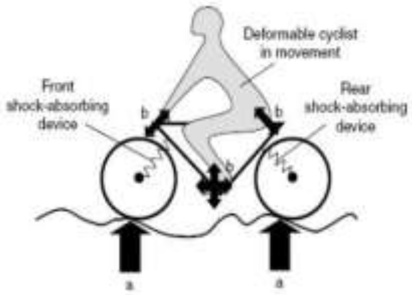

Figure 3: Forces transmitted to the frame

Figure 3 depicts the forces which interact with the frame. These can be classified in two categories ;(a) forces generated by the irregularities; and (b) forces generated by

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the movement of the cyclist which are applied to the handlebar, saddle and pedals.

IV. Finite Element Analysis

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.

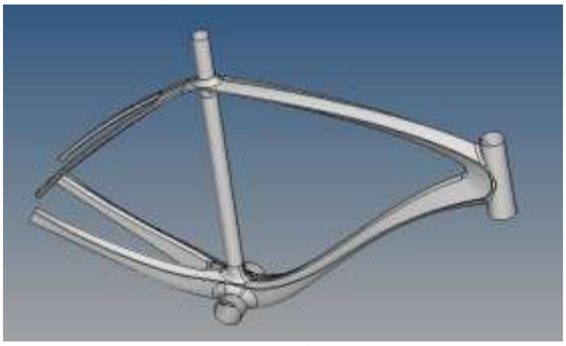

Figure 4: Bicycle frame CAD Model

B. Meshing

Meshing for the model is done using the automated meshing refinement feature in Hyper Works can be seen in Figure 5. 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.

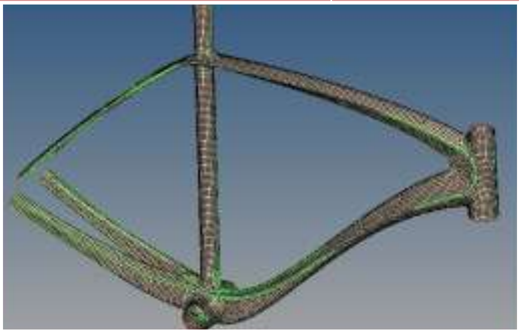

Figure 5: Meshed model with tetrahedral element

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 properties of material [11].

TABLE I. Material Properties

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

V. Modal Analysis

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 software. Modelling dimensions were in meters, and properties were given in GPa Tetrahedral 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.

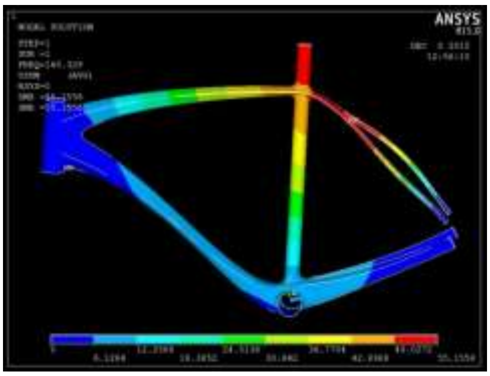

Figure 6: Frequency result at mode 1

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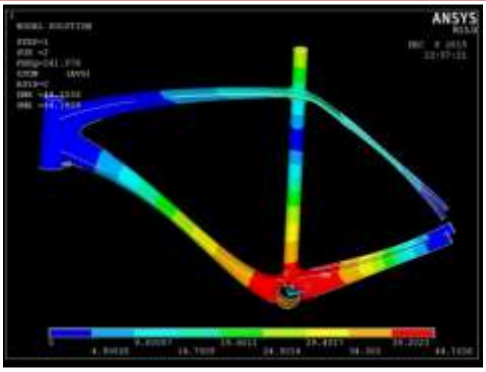

Figure 7: Frequency result at mode 2

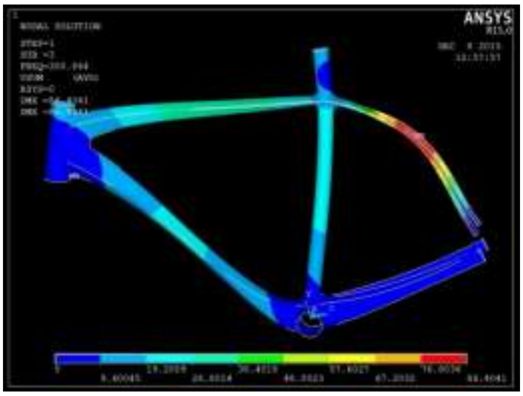

Figure 8: Frequency result at mode 3

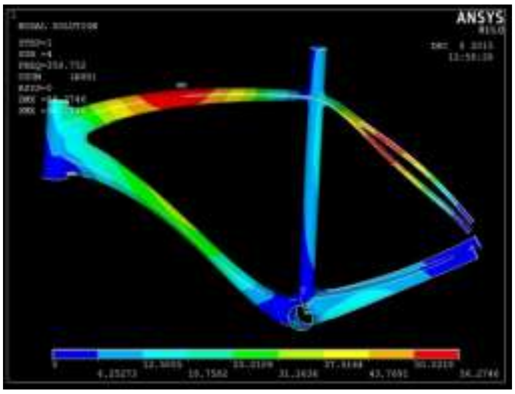

Figure 9: Frequency result at mode 4

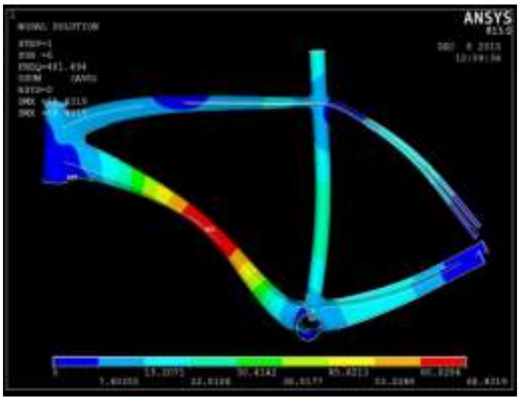

Figure 10: Frequency result at mode 5

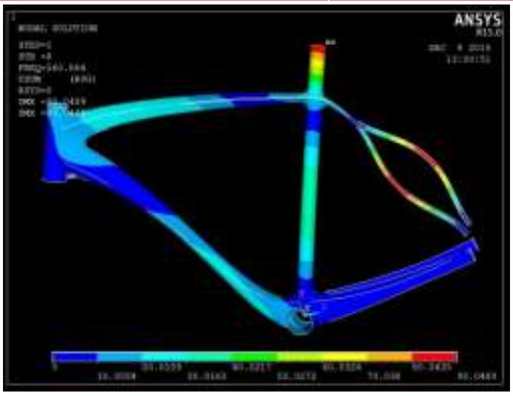

Figure 11: Frequency result at mode 6

VI. MANUFACTURING OF BICYCLE FRAME

Welding is the method of choice for most manufacturers to join frame tubes, as it provides high joint strength and is also affordable. TIG welding is the most common type of welding for 6063 bicycle frames, and was the joining method used for the donated frames. TIG Welding is an arc welding process in which heat is produced between a non-consumable tungsten electrode and the work metal. TIG welding is commonly chosen as the welding method for thin tubes and is desirable for the bicycle industry since it provides a high quality finish on the weld surface. Aluminium 4043 filler rod was used during TIG welding of the donated frames.

Figure12: Layout for experimental set up

VII. EXPERIMENTAL RESULTS

The natural frequencies obtained from the experimental analysis as follows.

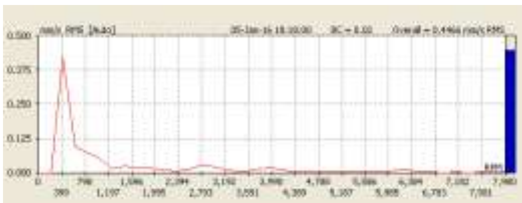

Figure 13: FRF of Forth Natural Frequency

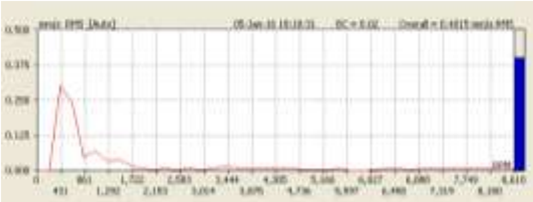

Figure 14: FRF of Fifth Natural Frequency

Figure 15: FRF of Sixth Natural Frequency

VIII. RESULTS AND DISCUSSIONS

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

TABLE II BICYCLE FRAME FREQUENCY VALUES

Mode Number	FEM (Hz)	Experimental (Hz)	% Error
4	359.66	399	9
5	481	431	10
6	560	550	2

IX. CONCULSION

Welding is the method of choice for most manufacturers to join frame tubes, as The FEM analysis of conventional bicycle frame of different material is carried out. The bicycle frame is optimised and FEM analysis of the frame with different materials is performed. Different mode shapes of the two frames are obtained and the comparison shows the satisfactory results for the frame with aluminium alloy. The optimised frame is fabricated and tested using FFT analyser for different mode shapes. The result shows the better convergence with the percentage error of approximately 7%.

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