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A COMPARATIVE STUDY ON STRUCTURAL HEALTH OF BICYCLE FRAME USING FINITE ELEMENT ANALYSIS- A REVIEW

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Abstract: Bicycle plays immanent role in our life. A bicycle frame is the important part of the bicycle, and on that frame, wheels and other components and accessories are mounted. Frames are need to be strong, stiff and light in weight, which is obtained by combining different materials and optimizing its shapes. The paper deals with the innovations occur in the design and material of bicycle frame i.e. its development over the time. The paper gives us the summary of work done on the bicycle frame related to the analysis work. The Theoratical Analysis, Finite Element Analysis, and Experimental Analysis are the various approaches considered in the analysis work. Using these approaches a lot of work is done on the bicycle frame. Thus we can say that this paper provide us a comparative study on structural health of bicycle frame.

Keywords: Innovations, Theoratical Analysis, Finite Element Analysis, Experimental

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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 [1]. 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 [2,3] 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. Traditional materials of the bicycle frame are the steel or aluminum alloy. For the purpose of reducing weight, the carbon/ epoxy composite materials are now widely used to make the bicycle frames [4]. Also there is use of eco-friendly material such as bamboo is observed. In the design process of the bicycle, the structural analysis of the frame or other parts is a very important stage. With the help of theoretical or numerical calculations, the strength and stiffness of the bicycle structures can be predicted and modified to the optimal design before the manufacture of the prototype and actual commercial products [4]. Trial and error method leads to increase in the production cost. It is slow and intuition does not always yield reliable result. A promising solution is provided by a tool of structural engineering; the Finite Element Analysis method. The finite element method is one of the numerical calculations applied in various physical problems. It usually plays a major role to calculate the stress and deformation of the structures. Through a century of development, several successful bicycles configurations have been reached. Thus, much of this development has been through a process of evolution, rather than application of sound mathematic knowledge. Variations exist in modern bicycle frame design but the basic layouts remain similar across popular styles. Variations in any of the components like top tube, down tube, seat tube, chain stay and seat stay will affect dynamics of the bicycle. Most lengths and angles in a frame are interdependent, that is, one variation in component design will necessitate another [1]. Nowadays situation came to know that the basic safety bicycle design has been evolved in several ways that are commercially successful in the market and the market is under the influence of road and track bikes, commuter bikes and mountain bikes.

II. **APPROACHES**

There are three approaches are used to analyze the bicycle frame, these approaches

are as follows:

2.1. Experimental Analysis.

2.2. Finite Element Analysis.

2.3. Theoratical Analysis

2.1 Experimental Analysis

In 1999, the paper titled Experimental analysis of hybrid bicycle frame was presented by D. Arola, P. G. Rainhall, M .G. Jenkins, S.C. Iverson. This paper described the method used for an experimental evaluation of unique Prototype Bicycle motocross (BMX) frame. The evaluation was used to find the critical service load within the frame relating to dynamic event which occur during competitive racing. Both Experimental and numerical calculation or evaluation are used in analyzing the frame and member geometry for design optimization. The prototype BMX frame evaluated in this study was made from combination of titanium and aluminum alloy. All the members of frame were constructed of Ti6Al4V.In the experimental set up, the bicycle frame was instrumented with fourteen three element rectangular rosetts. Strain guage locations were chosen to provide strain tensor for each structural member and specific details of strain distribution near the joints. Each joint was instrumented with two rectangular rosetts around the circumference of the tube which were aligned with the longitudinal/transverse axes. Two rectangular rosetts were used in the vicinity of each joint so that axial force, torsion, moments within the member could be extracted and used in experimental fatigue analysis. The strain measurements were firstly conducted with static loads of controlled magnitude and orientation to confirm linearity in gage response. In addition the results were compared with result from numerical model which was used for design optimization. Secondly the strain measurements were conducted for dynamic loading. Riding condition for dynamic testing included modest jump with rear tire landing, Large vertical height jump and front tire wall impact[5].The result of this experimental arrangement is that ,the strain in bicycle frame obtained in dynamic events are significantly greater than those obtained from static loading under controlled conditions[5].

2.2 Finite Element Analysis

Finite Element Analysis (FEA) is a computational technique used to obtain approximate solutions of boundary value problems in engineering. Simply, a boundary value problem is a mathematical problem in which one or more dependent variables must satisfy a differential equation everywhere within a known domain of independent variables and satisfy specific conditions on the boundary of the domain. Boundary value problems are also sometimes called field problems. The field is the domain of interest and most often represents a physical structure. The field variables are the dependent variables of interest governed by the differential equation. Depending on the type of physical problem being analyzed, the field variables may include physical displacement, temperature, heat flux, and fluid velocity to name only a few [6]. A lot of work is done on the analysis of bicycle frame; some of that work is presented here.

As far back as 1986, Peterson and Londry (1986) used FEA to fine-tube the design of the Trek 2000 aluminium frame using two other existing designs (one steel, aluminium) as performance benchmarks for mass, strength and stiffness characteristics. The model used beam elements to represent the tubular frame structure (excluding forks) with a variety of loading conditions to all frames to calculate their response characteristics. The identification of loading conditions are critical in the design, is decided in terms of undesirable responses (high stresses, high deflections, etc.) and establish which loads may be safely ignored. And finally the goal of paper is to look for relationships between strength, stiffness, and weight by studying (graphing, plotting, etc.) the output data from the previous steps. It seeks intuitive insights from the data about each frame's structural characters [7]. FE models using shell elements to model composite frames were developed by Lessard et al (1995), who also modelled tubular frames using beam elements. This study included a comparison of frame types and included some experimental validation of these models with load cases analysing vertical compliance and lateral stiffness [9].

In 2009, paper was published, in that paper the fiber direction and stacking sequence design for the bicycle frame is made of the carbon/epoxy composite laminates is discussed. Under three loading conditions that are torsional, frontal, and vertical loadings, the normal and shear stresses with respect to the principal material coordinate system of each ply will be obtained from the finite element analysis. The maximum stress theory is used to be the failure criterion. The strength-to-stress ratio R is defined as the design parameter for the optimal selection from 33 stacking sequences of laminates [4]. The methodology presented in the paper titled "Fatigue design of welded bicycle frames using a multi-axial criterion" has been validated on bicycle frames and the fatigue strength prediction is excellent when compared to the standard tests. The use of the Dang Van fatigue criterion is well adapted to the multi axial stress in critical areas of bicycle frames, and is easily characterized with simple fatigue tests. The paper concluded that the automatic meshing developed was proven to be accurate for an industrial application. As this is dependent on fusion penetration length, it gives a very powerful tool to link design and process. The methodology is now included in the reliability assessment procedure at Decathlon. Design and validation of frames are now realized in one way. It has a huge influence on the product quality, on the time to market and design cost [8].

The paper titled "Parametric finite element analysis of bicycle frame geometries" was presented by Derek Covill and his team, 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 quantify the vertical compliance and lateral stiffness characteristics of 82 existing bicycle frames from the bicycle geometry project and the comparison of these characteristics to an optimized solution in these conditions. The paper concluded that smaller frames (490mm seat tube) behave the most favourably 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. Also the optimised 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 [9]. Through FEA of sandwich composite model, obtain stress and deflection results for the applied loads and it make conclusions based on ply orientations. Generally a higher deflection tends to result in a higher stresses that has given the virtually unpredictable reaction of composite materials, one can assume this higher stress is due to a stress concentration at a corner or change in geometry. On a simple beam with a central loading, leads to higher stress concentrations at the fillets of the cross-section. Finally, verification of results using a simple beam section and three-point bending [2]. Recently in 2014, the paper titled, "The stress Analysis of bicycle frame" is published. This paper deals with the stress analysis of bicycle frame by using Finite Element Method. The analysis of frame is carried out in ANSYS software, and the F.E.A. results are compared with theoretical results. And it is found that there is good agreement between analytical and F.EA [10].

2.3. Theoratical Analysis

In the engineering design process, early design concepts are traditionally evaluated based on rough calculations, experience and eventually on costly prototypes. In order to perform more accurate analysis the bicycle is required to be divide into five portions: the bicycle chain, the chain/wheel connection, the pedal/crank assembly, the bicycle frame, and the handlebars. By treating the each portion as freebody diagram like structures, the forces acting on each portion were determined, and the stresses whether axial, shear, torsion, or bending moment were determined and calculated. After solving how the component of bicycle would act in the separate portions, then they needed to be assembled to gain a full analysis to ensure the exact behavior of bicycle is as that same which is required [11]. In theoretical analysis to calculated stresses in the frame member, 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 calculated, considering various conditions [10]. In 2010, the paper presented by David Lopez, Jovan May field, & Pierre Marc Paras, titled Stress Analysis of Bicycle, in that paper, there is complete theoretical analysis of bicycle is done and by that they concluded that breaking the bicycle into smaller portions of beams with stresses and moments to be the most effective way in constructing and designing the bicycle as a whole. They also realize the importance of yield, maximum, principle, and shear stresses as the maximum value are needed especially when provided with a factor safety in ensuring a low risk of failure. Also while designing, it is essential to understand that all parts are closely associated with each other along with that they came to conclusion that the type of material chosen makes a massive impact on the design as a whole [11].Recently in 2014, Mr. M. V. Pazare, a student presented paper titled Stress Analysis of Bicycle Frame, in that paper there is stress analysis of bicycle frame is done with the help of Finite Element Analysis and the result are validated by doing theoretical Analysis of bicycle frame. In theoretical 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 condition like, static start up, steady state paddling, vertical impact, horizontal impact, rear wheel braking. In the truss analysis, the assumption was made that all of the frame components were two-force members and that these members were attached at hinge joints that cannot apply any moments. The assumption was made that the material was linear elastic and isotropic [10].

CONCLUSION:

Bicycle had proved their contribution in various areas of transportation, sport, and fitness. The importance gives rise to its various innovations. In future bicycle provide a very great scope in the field of ecological, health challenges. Bicycle frame. The simplicity of the structure of bicycle frame allows loads to be monitored and the structure to be simulated on a numerical basis in terms of stress and strain distribution also helps in damage accumulation. The process of evolution of design occurs sometimes slowly and sometimes it is very rapid. The comparison between various analysis approaches came to conclusion that the use of new emerging technology that is finite Element Analysis thus proves its importance in upcoming days. Thus this paper will help to do comparative study on structural health of bicycle frame.

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