Ergonomical study and Vibrational analysis of Bicycle Chassis

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Abstract- *It is important to recognize that the design of any machine is an interdisciplinary process, involving aerodynamics, thermodynamics, fluid dynamics, stress analysis, vibration analysis, the selection of materials, and the requirements for manufacturing. The operation of any mechanical system will always produce some vibration. Our goal is to minimize the effect of these vibrations, because while it is undesirable, vibration is unavoidable. The result of excess vibration can vary from nuisance disturbance to a catastrophic failure. Bicycle chassis is a major component in a system. This work involves vibration analysis to determine the key characteristics of a bicycle chassis. The dynamic characteristics of bicycle chassis such as the natural frequency and mode shape were determined by using finite element (FE) method. Al alloy 6061 material will replace the conventional MS material. Experimental modal analysis was carried out to validate the FE models. Predicted natural frequency and mode shape were validated against the experimental results. Finally, the modification of the updated FE bicycle chassis model was proposed to reduce the vibration, improve the strength and optimize the weight of the bicycle chassis. Tools used are catiaV5 for 3D modelling, Hypermesh for meshing, and Ansys for post processing. Ergonomical study has been done on energy consumption and time required by using "MI FITNESS BAND" for aluminium alloy (6061) bicycle and mild steel bicycle in three different age group to complete 2 km distance.*

Keywords- Bicycle frame, weight Optimization, Design of frame, Alternate Material.

I. INTRODUCTION

Most modern bicycle frames have the simple form. This shape emerged in about 1895 following several decades of vigorous development and evolution and has remained basically unchanged since that time. 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. Thus in trial and error method is costly and slow, and intuition does not always yield reliable result. A promising solution is to turn a proven tool of structural engineering; the Finite Element Analysis method. 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 frame consists of a top tube, down tube, head tube, seat tube, seat stays, and chain stays. 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. [7]

Riding a bicycle, and mainly at professional level, goes hand in hand with the improvement of state of the art technology. For instance, during a time trial the position of the cyclist is of big importance. For this reason, it is important how air resistance can be reduced. Tests have already been done in wind tunnels to search for the best position on the bicycle, eventually also small adaptations at the frame is possible.[7] This is only one aspect, also research for better gears, brakes, tires, wheels, etc. makes progress. All these aspects cause the cyclist to achieve better results. The main component on a bicycle is still the frame itself. Even if all the other aspects of the bicycle are of top quality, no top performance will be achieved without a frame of the highest quality.[9] The cyclist wants his bicycle to be light, stiff, durable, strong, nice looking, weather resistant and it must also be comfortable. The developer of bicycle faces a great challenge, because designing a frame which meets all these requirements is barely impossible. For example, stiffness and comfort are each other's opposite, though a compromise between both must be found. Depending on the used material for the frame, one or other aspect can be fulfilled better. The behaviour of the frame is of big importance for the perception on comfort of the rider.[8] Because, the better vibrations coming from the road are absorbed by the frame, the better the rider will perform. 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. Research to the aspect of the dynamic behaviour eventually leads to a better frame, so one gets one step closer to the ideal bicycle frame.[9]

Ergonomical study Literature:[2-6]

Ergonomics helps to improve the output and the comfort of bicycle riding. When improving the comfort, you can use your power more for bike riding and not for struggling against pain. When you improve your output you get more comfort.It was observed that 80 to 90 % of the serious bicycle riders are suffering from pain in the neck, in the back, in the shoulders, in their wrists (hands) and in their bottom.Keeping in view of above facts, present study on "Ergonomicalevaluation of aluminium alloy (6061) bicycle'' on energy consumption and time required for taking 2 Km distance was undertaken specific objectives.Ergonomics can be defined simply as the study of work. More specifically, ergonomics is the science of designing the job to fit the worker, rather than physically forcing the worker's body to fit the job. Adapting tasks, work stations, tools, and equipment to fit the worker can help reduce physical stress on a worker's body and eliminate many potentially serious, disabling work-related musculoskeletal disorders (MSDs). Ergonomics draws on a number of scientific disciplines, including physiology, biomechanics, psychology, anthropometry, industrial hygiene, and kinesiology.

Components of Bicycle:

Fig.1 Bicycle frame and components [9]

However, the main component on a bicycle is still the frame itself. Even if all the other aspects of the bicycle are of top quality, no top performance will be achieved without a frame of the highest quality. The cyclist wants his bicycle to be light, stiff, durable, strong, nice looking, weather resistant and it must also be comfortable. The developer of bicycle faces a great challenge, because designing a frame which meets all these requirements is barely impossible. For example, stiffness and comfort are each other's opposite, though a compromise between both must be found.

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. The behaviour of the frame is of big importance for the perception on comfort of the rider. Because, the better vibrations coming from the road are absorbed by the frame, the better the rider will perform. 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. Research to the aspect of the dynamic behaviour eventually leads to a better frame, so one gets one step closer to the ideal bicycle frame.

II. CAD MODELLING

Dimensions are required for calculating of boundary conditions. Hence it's CAD (Computer-aided design) model is necessary. The conventional used.CAD model then is made by the commands in Catia V5 R19 of pad, pocket, fillet, stiffer.

Required CAD is developed using 3-D modelling software. The cad geometry has basic requirement for Head tube, top tube, bottom tube, chain stays, seat stays, bottom bracket shell and the two triangles commonly says diamond frame. 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. The modern and most common frame design for an upright bicycle is based on the safety bicycle, and consists of two triangles, a main triangle and a paired rear triangle. This is known as the diamond frame. Frames are required to be strong, stiff and light, which they do by combining different materials and shapes.

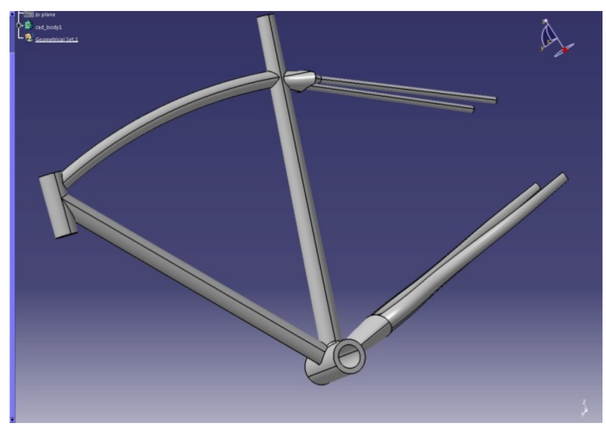


Fig.2 CAD model 1 of bicycle chassis

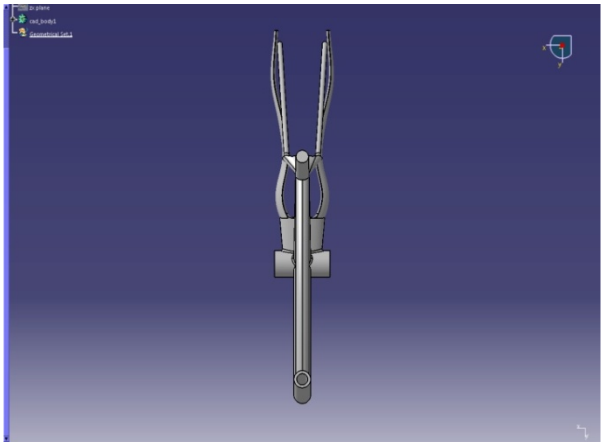


Fig.3 CAD model2 of bicycle chassis

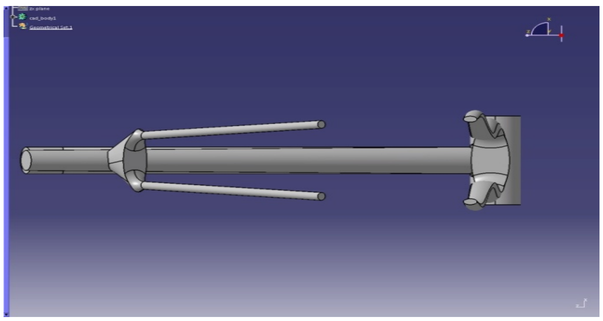


Fig.4 CAD model3 of bicycle chassis

Once the solid model of the donated frame and the test frame is created, an FEA is conducted with Hypermesh 12.0 using the solid model. An FEA is a computer based numerical method which models an object with a mesh of separate elements connected by nodes to determine stress, strain and a number of other properties.

III. MATERIALS FOR BICYCLE FRAME

The selection of material used for the manufacturing of bicycle frame depends upon the strength and service conditions. also involves the cost as well as the material performance required. The mild steel is widely used for the manufacturing of bicycle.

A. Mild Steel (MS)

At present bicycle frame is made of mild steel material. So, first analysis is done using MS as material. Steel is the traditional material for bicycle frame. Steel is easy to get. Machinery to manipulate steel is easy to get. Steel is easy and it's also cheap. This is the main reason that 99% of the bicycle frame are made from steel. Steel is stiff but dense (heavy). Steel rates well in terms of both yield strength and ultimate strength, particularly if it's carefully alloyed and processed. Steel also resists fatigue failure well which is extremely useful - even if theflexes under load, such flexing need not lead to a critical failure. [8]

The properties of mild steel are listed below ,

Structural Properties (MS):

Table 1: Material properties of mild steel [8]

Property	Value
Young's Modulus, E	2.1×10^5 MPa
Poisson's Ratio , ν	0.3
Density, ρ	7850 kg/m^3
Yield StrengthMPa	250 MPa

B. Aluminum alloy- (6061)

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

Table 2: Material properties of aluminium alloy [5]

Property	Value
Young's Modulus, E	69×10^3 MPa
Poisson's Ratio , ν	0.33
Density, ρ	2700kg/m^3
Yield StrengthMPa	290 MPa

Table 3: Chemical properties of AA 6061-T6 [5]

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Aluminium
Min.	0.40	0.0	0.15	0.0	0.8	0.04	0.0	0.0	98.61
Max.	0.8	0.7	0.40	0.15	1.2	0.35	0.25	0.15	95.8

IV. FINITE ELEMENT METHOD (FEM)

Required CAD is developed using 3-D modelling software. The cad geometry has basic requirement for Head tube, top tube, bottom tube, chain stays, seat stays, bottom bracket shell and the two triangles commonly says diamond frame. 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. The modern and most common frame design for an upright bicycle is based on the safety bicycle, and consists of two triangles, a main triangle and a paired rear triangle. This is known as the diamond frame. Frames are required to be strong, stiff and light, which they do by combining different materials and shapes. [7]

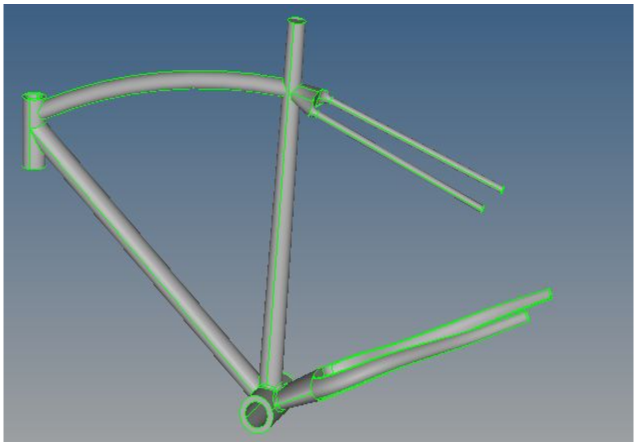


Fig.5 Bicycle cad model

Once the solid model of the donated frame and the test frame is created, an FEA is conducted with Hypermesh 12.0 using the solid model. An FEA is a computer based numerical method which models an object with a mesh of separate elements connected by nodes to determine stress, strain and a number of other properties.The decision is made to use Hypermesh 12.0 due to its ability to import solid models created in mechanical CAD Software and the software's ability to simulate static loading on the frame. The procedure for setting up the model in Hyper Works 12.0 is described in the following sections.

3.1 Localized Meshing Control

Meshing for the model is done using the automated meshing refinement feature in Hyper Works can be seen in Figure 3.2

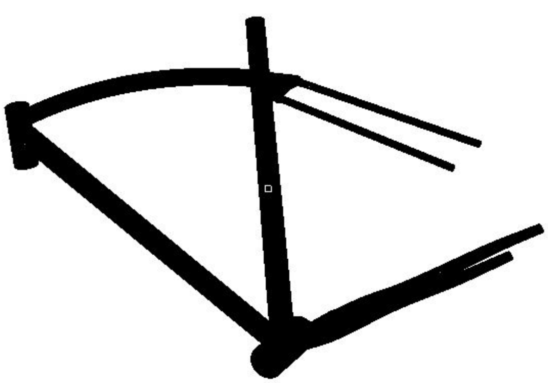


Fig.6 Full meshed model with tetrahedral element

Geometry clean up was performed prior to meshing the model. Finite element model is developed using HyperWorks. For better quality mesh combination of first and second order tetra elements are used. Surface meshing using triangular elements is performed to achieve better control on the meshing. Further this mesh is converted into a tetra mesh. Selective tetra elements are converted into second order and selective regions are finely meshed using first order elements controlling the number of nodes formed.

Mixed type of elements which contains quadrilateral as well as triangular elements, have been used in 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

Boundary Conditions and Loading

The boundary conditions and loads are applied to the frame in Hypermesh. Boundary conditions were then applied to handle, back seat. At this location, we will constrain movement in all directions, setting X, Y, and Z direction's degrees of freedom to zero. Creating this constraint will allow us to attain exact results of the frame materials without the frame itself rotating Translational and rotational moments are not approved.

A force of 700N is apply to vertical tube rider is applying maximum effort to accelerate from a standing stop. Aerodynamic, rolling, and gyroscopic forces are supposed negligible. The bicycle is in vertical equilibrium with the front wheel pointed straight. [7]

Loading:

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

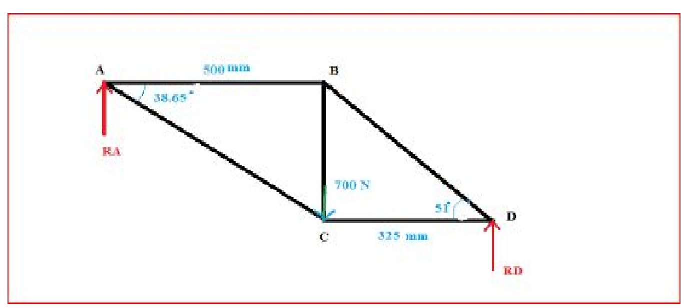


Fig.7 Static start up [7]

b) Static paddling: Assuming that 700N cyclist seating on bicycle the force of 200N is applied due to leg dynamics.

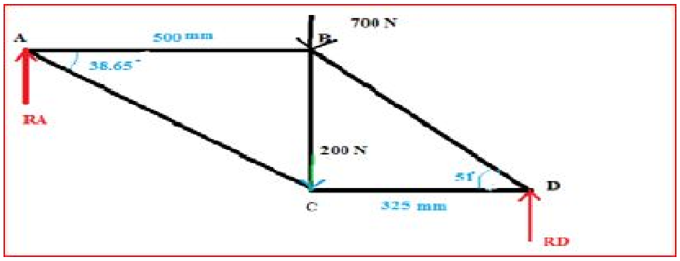


Fig.8 Static Pedalling [7]

c) Vertical Impact: Vertical impact loads are represented by, multiplying the rider's weight by a certain 'G' factor. As a interest, an object dropped from an infinitesimal height onto a rigid surface would exert a two G impact load, assuming total energy transfer.

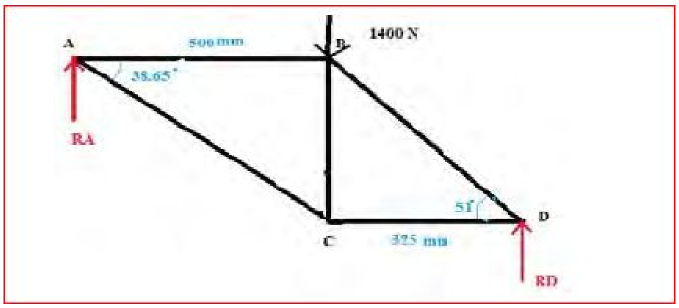


Fig.9 Vertical Impact [7]

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

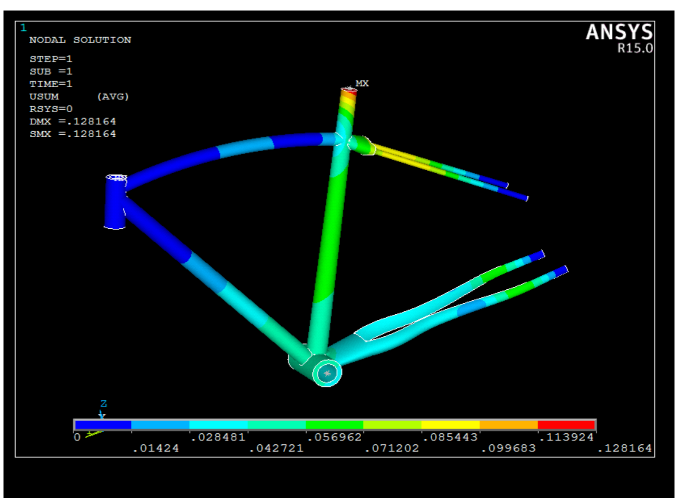


Fig.10 Displacement Plot for steel material

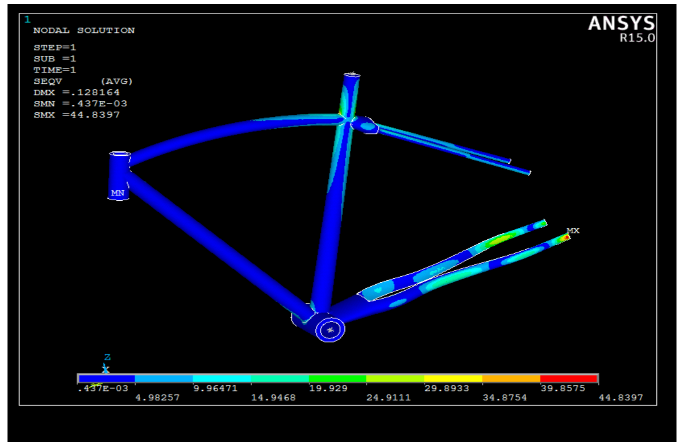


Fig.11 Stress Contour for steel material

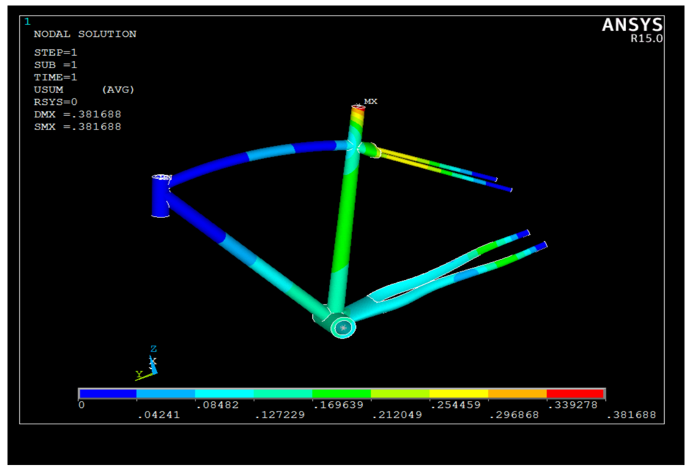


Fig.12 Displacement plot for aluminium material

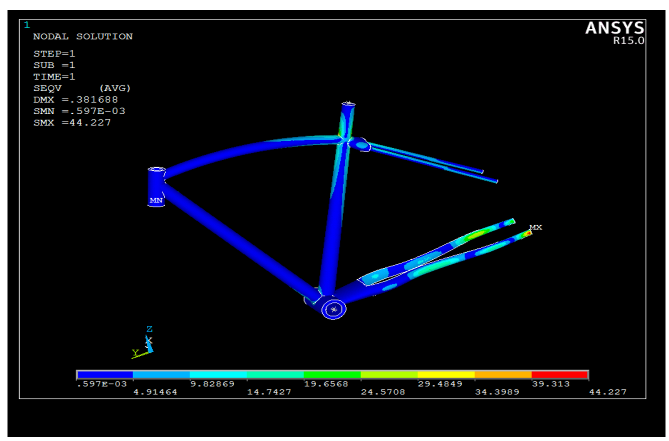


Fig.13 Stress Contour for aluminium material

MODAL ANALYSIS:

Modal analysis is the study of the dynamic properties of structures under vibrational excitation. Modal analysis is the field of measuring and analyzing the dynamic response of structures, when excited by an input. The modal analysis of the bicycle frame is performed using FEM technology to find the natural frequencies. [14]

In order to determine whether there is resonance or other vibration mode that against the operating of vehicles, we used the subspace iteration method provided by the ANSYS software to carry out the modal analysis on the frame. [14]
Modal analysis of bicycle chassis (MS):

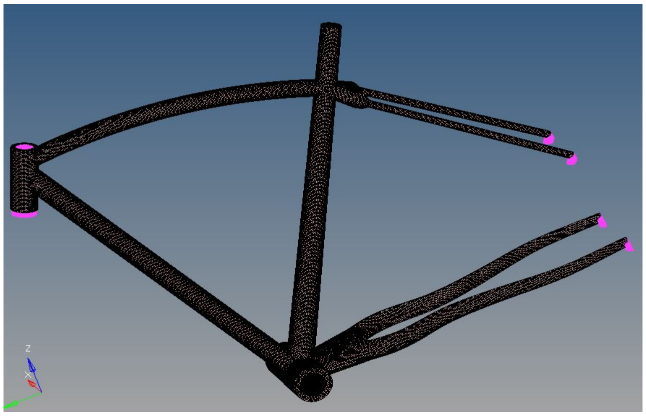


Fig.14 consytaints applied for modal analysis in hypermeshNo. of nodes: 106755No. of elements: 475921

Results for modal analysis:

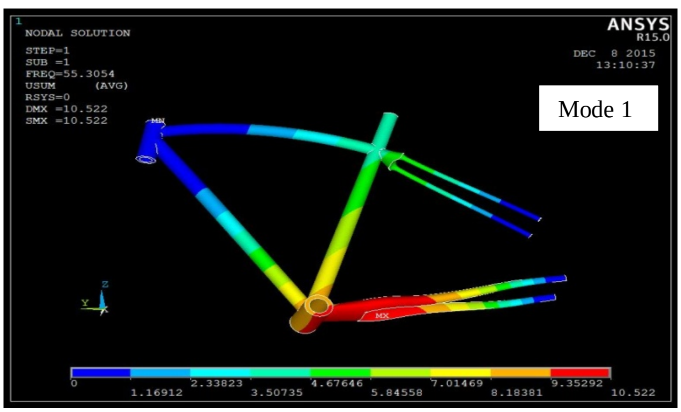


Fig.15 1st mode frequency of bicycle chassisthe frequency of 1st mode is 55.3 hz.

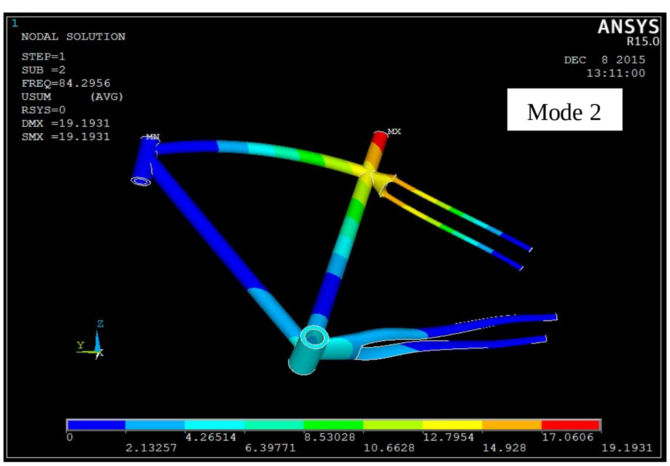


Fig.16 2nd mode frequency of bicycle chassisThe frequency of 2nd mode is **84.29** hz.

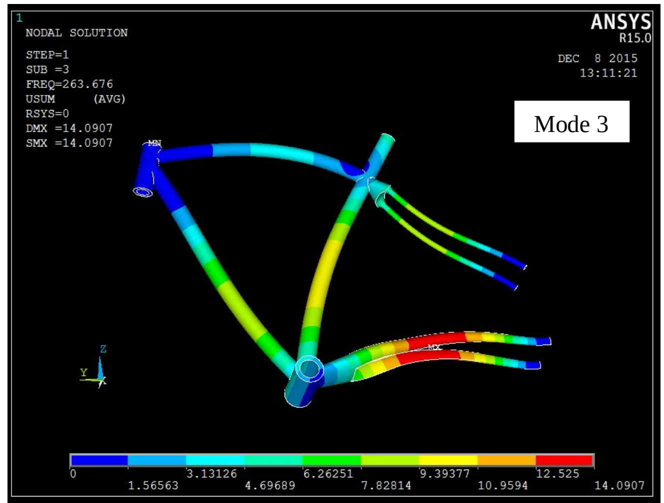


Fig.17 3rd mode frequency of bicycle chassisThe frequency of 3rd mode is **263.67**hz.

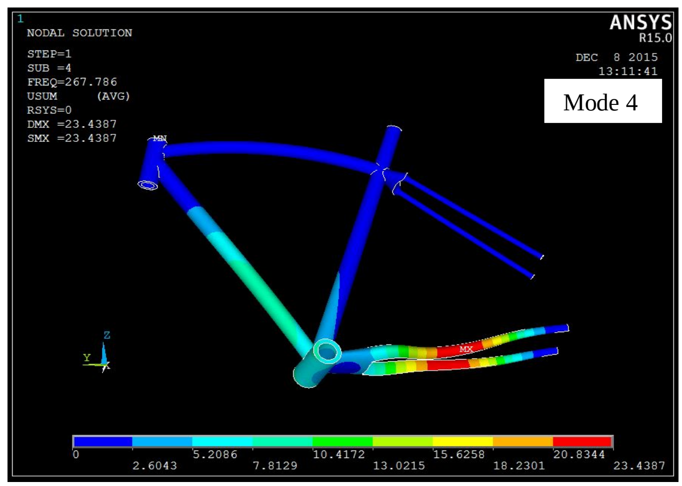


Fig.18 4th mode frequency of bicycle chassisthe frequency of 4th mode is **267.78**hz.

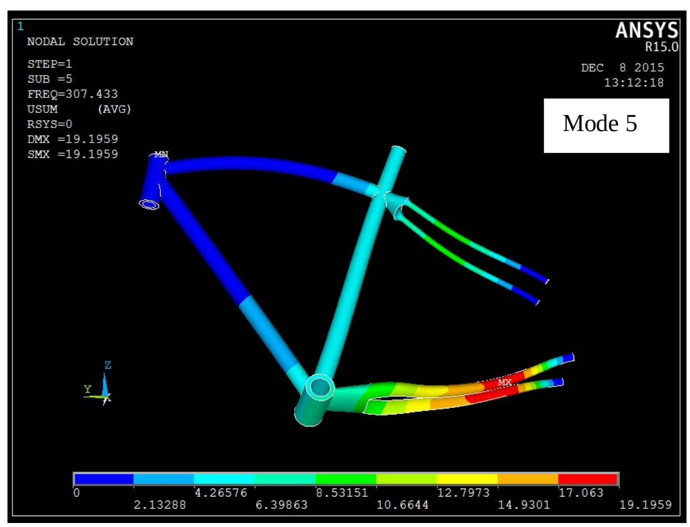


Fig.19 5th mode frequency of bicycle chassisThe frequency of 5th mode is **307.43hz.**

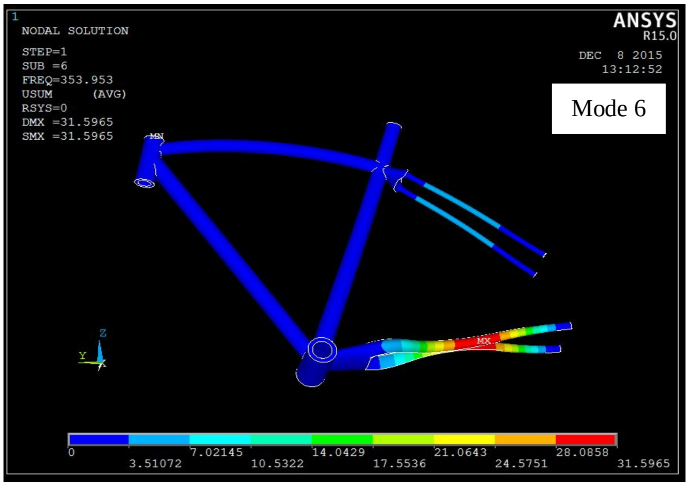


Fig.20 6th mode frequency of bicycle chassisThe frequency of 6th mode is **353.9** hz.

Modal analysis of bicycle chassis (Al):

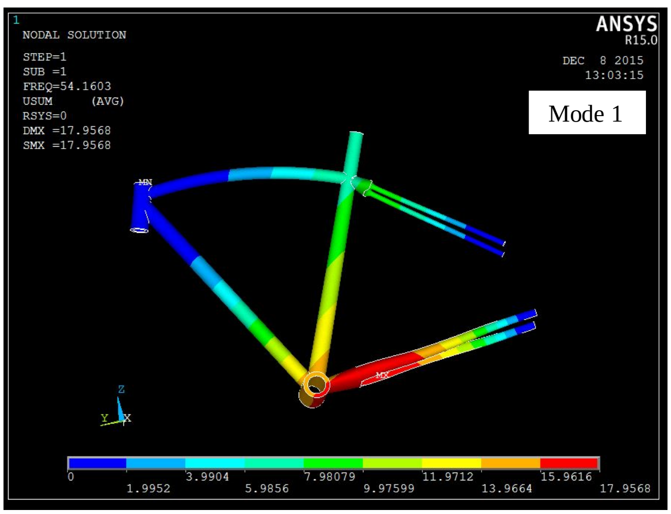


Fig.21 1st mode frequency of bicycle chassisThe frequency of 1st mode is **54.16**hz.

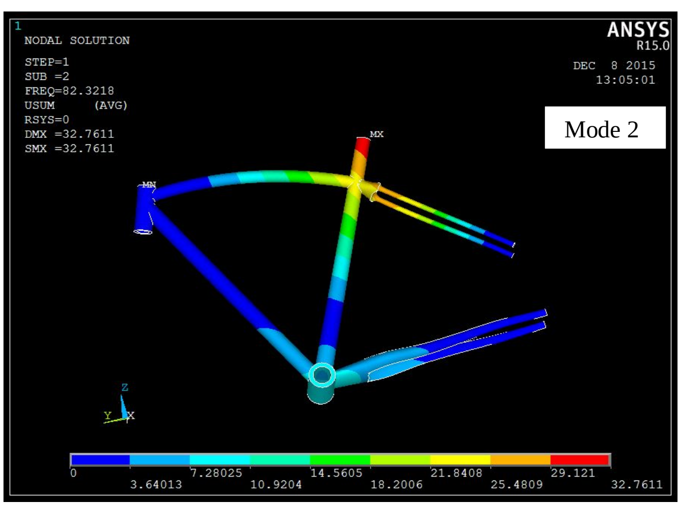


Fig.22 2nd mode frequency of bicycle chassisThe frequency of 2nd mode is **82.32**hz.

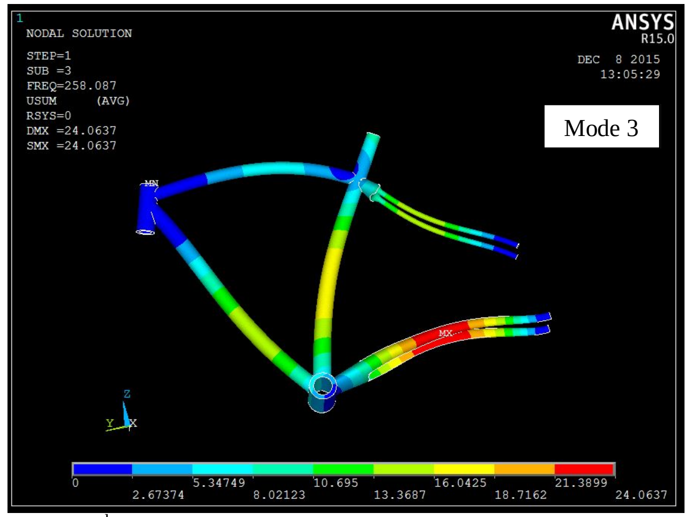


Fig.23 3rd mode frequency of bicycle chassis The frequency of 3rd mode is **258.08** hz.

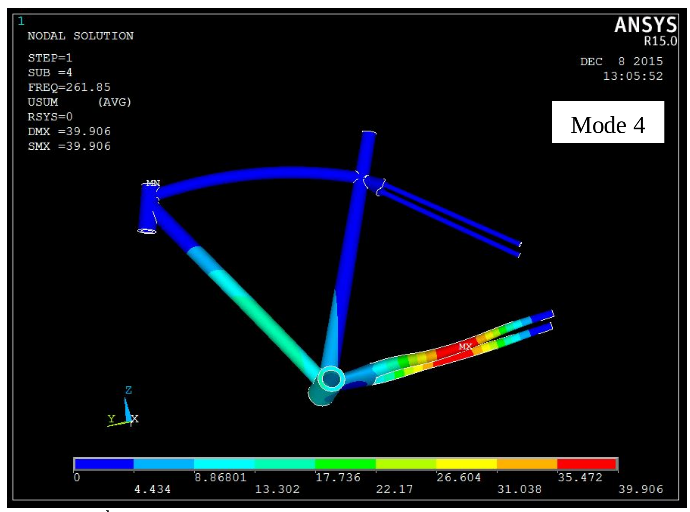


Fig.24 4th mode frequency of bicycle chassisThe frequency of 4th mode is **261.85**hz.

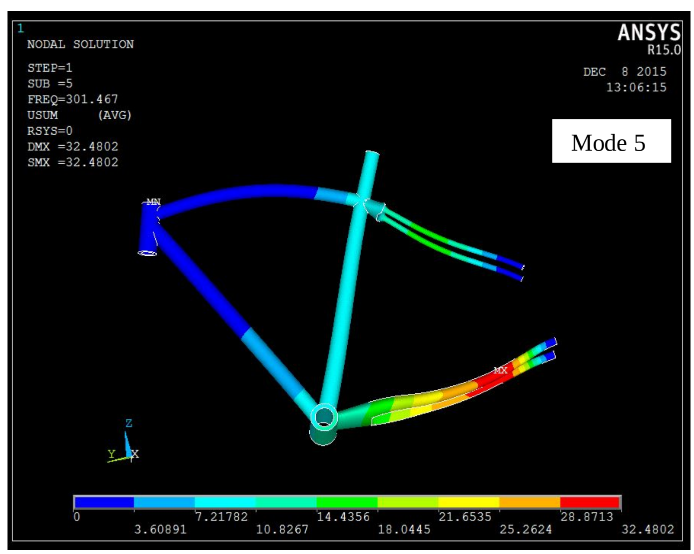


Fig.25 5th mode frequency of bicycle chassisThe frequency of 5th mode is **301.46**hz**.**

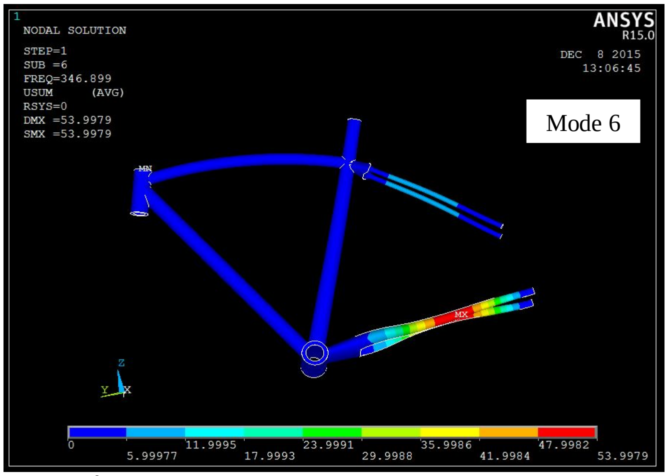


Fig.26 6th mode frequency of bicycle chassisThe frequency of 6th mode is **346.89** hz.

V. EXPERIMENTAL WORK

Fig.30 Experimental set up

Fig.31 FFT Analyser

1. An impact hammer with a load cell attached to its head to measure the input force.
2. An accelerometer to measure the response acceleration at a fixed point & direction.
3. A 2 or 4 channel FFT analyzer to compute FRFs.
4. Post-processing modal software for identifying modal parameters and displaying the mode shapes in animation.

- Bicycle chassis is mounted by using clamps on the bench to perform the testing. The hammering test is carried out.
- The FFT analyzer is connected to a sensor which reads the vibrations on the component.
- The bicycle chassis is hammered to give the vibrations by external means.
- As the vibrations flow in the chassis frame there will be peak amplitude which is the natural frequency of the component.
- Likewise the component is tested at three different points. Which the sensor is made to read and the readings are recorded in the FFT analyzer. Then the FFT analyzer is connected to data acquisition system and here the software is synced with FFT and the respective graphs are plotted.

VI. ERGONOMICALLY STUDY

Energy consumption result for mild steel bicycle and aluminum Alloy (6061) bicycle for different age group like 15 years,26 years, 62 years has been taken by using MI FITNESS BAND for 2Km distance. Same way was selected for all results, also find out time required for both bicycles.

Fig 30 Mifitness band

The Mi Band resembles a bracelet in its design, and can be worn on either hand, ankle or around the neck. The band's location can be set using the official Mi Band app called Mi Fit.

The band contains the core tracker which is around 9 mm thick, and 36 mm in length. It is inserted into a hypoallergenic TPSiV wristband, which has anti-UV and anti-microbal properties. The tracker is inserted into the charger module, which can be connected to a 5.0 V external power source. It is also called "Xiaomi Fit"

Fig.30 Experimental Set Up For aluminum Alloy (6061) bicycle on Ergonomic Study

VII. RESULTS

The analysis of bicycle chassis has been done for all two materials viz. steel, aluminium alloy (6061) analysis results are shown.

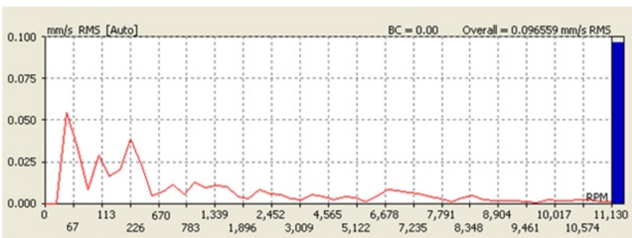


Fig. 27 Reading at point 1 from FFT

45Hz

Reading at point 2

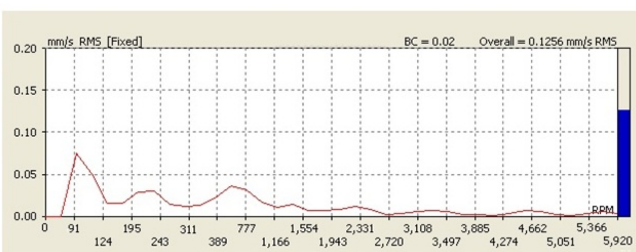


Fig. 28 Reading at point 2 from FFT

100Hz

Reading at point 3

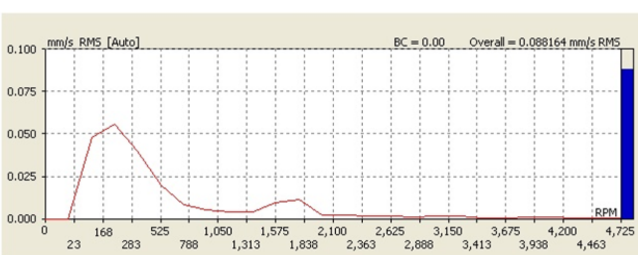


Fig. 29 Reading at point 3 from FFT

230Hz

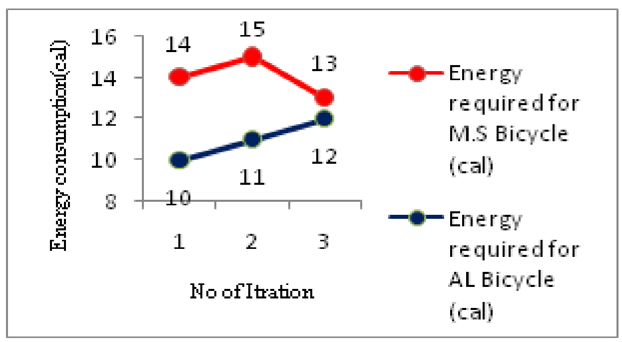
Table 3: Comparison of analysis results

Natural frequency (Hz)	Mild Steel	Aluminium
Mode1	55.3	54.16
Mode2	84.29	82.32
Mode3	263.67	258.08
Mode4	267.78	261.85
Mode5	307.43	301.46
Mode6	353.9	346.89

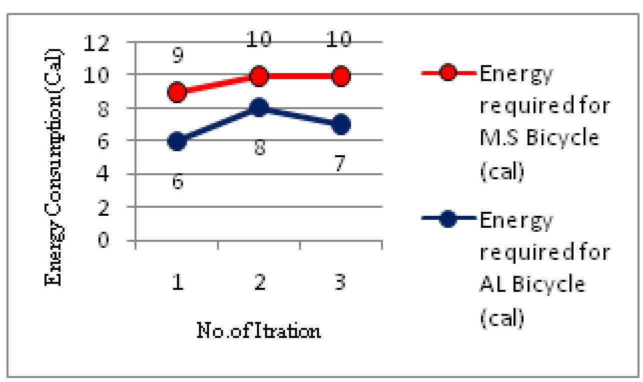
Table 4: Comparison Of Analysis Result And Experimental Result

Natural frequency (Hz)	FEA RESULT	EXPRIMENTL RESULT
Mode1	54.16	45
Mode2	82.32	100
Mode3	258.08	230

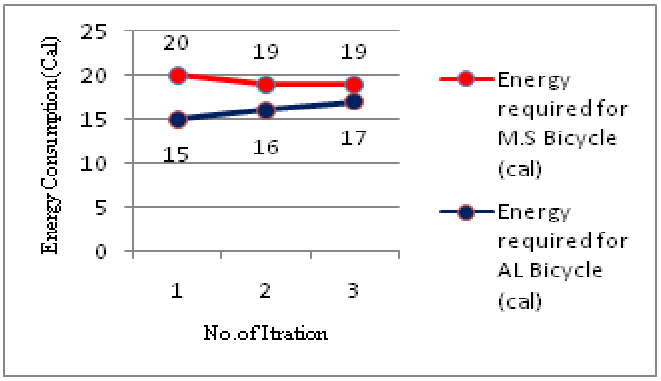
Ergonomically study results are as follows showing energy consumption for both aluminium alloy (6061) and mild steel bicycle for 2km distance with different group.



Result of energy consumption for 15 years group in cycling for AL and MS



Result of energy consumption in cycling for AL and MS For 26 years old



Result of energy consumption in cycling for AL and MS For 62 years old

VIII. CONCLUSION

The following conclusions were made from the above study.

1. From the result of finite element analysis maximum Stress value for aluminium alloy (6061) bicycle chassis is 44.22 N/mm^2 which is well below the critical value. Hence, design is safe.
2. From the result of finite element analysis maximum Stress value for mild steel bicycle chassis is 44.8397 N/mm^2 which is well below the critical value. Hence, design is safe.
3. Average 60 % Weight reduced by using aluminum alloy (6061) material for bicycle chassis as compared with mild steel bicycle.
4. Average time saved is about 60 sec for completing 2 Km distance by using aluminum alloy (6061) bicycle.
5. The maximum weight reduction noted in this study, hence average saved is about 3 to 4 cal.

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