Design of foldable bicycle with integral suspension wheel

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Abstract: In today's world, as we know that pollution is most probable criteria having issue with the lifetime of the earth, the surveys says that most of the pollution is done by the road transportation system. As well as nowadays one can't spare specific time for the health due to shortage of time and stressful life, Bicycle is the most suitable vehicle to avoid such situation as having 0% of generation of pollution. Among the several types of bicycle, the foldable bicycle has many practical and potential uses in recreation and daily life, and it may be the fastest growing category in the bicycle industry and the main idea of this project is to provide a bicycle which is sleek yet rigid and safe, easy to handle and easy to maintain and therefore we came up to the idea of folding bicycle. Since bicycle is foldable and compact in size, by introducing suspension system in the bicycle, itself provides more comfort and convenience to the rider than regular bicycle. In the suspension system spokes of the bicycle are replaced with the verities of leaf spring, also spring can be replaced with damper.

Keywords: Foldable bicycle, Integral suspension wheels, Damping, Leaf spring, Mid-frame horizontal fold, Deformation and Stress, Displacement.

1. INTRODUCTION

1.1. Foldable bicycle

Transport has been one of the major issues in developing cities or urbanization of country. With the petrol and diesel prices increasing day by day, almost all the modes of transport are becoming expensive and that increases pollution. Also It is difficult to reach the nearest public transport facility and in many cases the destination will be far from the main roads where the public transport might not be able to reach due to the small roads, to avoid which most people use vehicles of their own, which in turn leads to issues with parking, traffic, etc. With such issues in health, transport, space for parking, etc., one solution that comes to mind is bicycle. With the properties of cheapest mode of transportation, requires no fuel or source of energy and 0% pollution, bicycle is most suitable choice. A Folding Bicycle is defined as a two-wheeled vehicle, with pedals, which can be folded up or otherwise reduced into a more manageable shape/size package or set of packages for ease of storage or portage.[6][7]

Fig.1.1: Foldable bicycle

1.2. Integral suspension wheel

From many years' bicycle has used wire-spoke in wheel. It gives wheel to strength and durability. This wire-spoke carried load more than hundred times of their own weight. During off-road biking, it subjects more forces. To reduce this forces and impact on wheel we can use suspension in bicycle and now a day there are lots of researches carried on bicycle wheel, which lead us to introducing integral suspension wheel. In this type wheel wire-spokes was replaced by leaf spring which provide suspension effect and strength. Since bicycle is foldable and compact in size, by introducing suspension system in the bicycle, itself provides more comfort and convenience to the rider than regular bicycle. Since the design proposals exist for 'folding wheels' none are currently commercially available. Consequently, most folding bikes utilise small wheel diameters.[2][3][5]

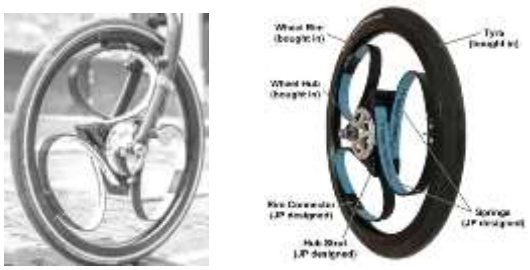

fig.1.2: Integral suspension wheel

2. METHODOLOGY

2.1. Foldable bicycle

There are many methods and mechanisms available in market to fold-unfold the bicycle, that were studied thoroughly. That gave us the way to change the design of frame and also folding mechanism by making it simple. After few sketches, we found that the one that has the proper ergonomics and easy to manufacture is mid-frame horizontal fold method, since it is convenient to the rider, retains strength of frame and very easy to fold the bicycle.it takes less than 5 seconds, bicycle to be folded and unfolded.[7]

fig.2.1 Mid-frame horizontal folded frame

- Types of methods of folding or unfolding the bicycle
  1. Mid-Frame horizontal fold
  2. Mid-Frame vertical fold
  3. Flip flop
  4. Telescope
  5. Take-apart at various places of the bike

2.2. Integral suspension wheel

When the design of wheel is came to mind, we thought to do something unique and we came up with the idea to make wheels which work as suspension system by itself. So we went through the research papers containing information about the studies of shock wheel, thus we decided to replace the wheel spokes with leaf spring which can absorb the sudden jerks and shocks come across the way. The material used for spring is having such type of properties that can provide damping effect also. This wheel also carried tangential forces, so it improves the life of bicycle wheel. In this type of wheel, the hub is floating type which displaced during the forces applied on it. It will provide comfort and smoothness to rider to ride the bicycle.[9]

fig.2.2 Integral suspension wheel assembly

3. DESIGN, MATERIAL AND STIMULATION

For better understanding and convenience, the cad models of wheel configuration and bicycle frame are made in Autodesk INVENTOR. Static analysis is used to determine the displacements stresses, strain and forces in structures and components due to load acting on the components. Steady loading in response condition are assumed. The kind of loadings that can be applied in static analysis include externally applied forces and pressure and steady state inertial force such as gravity. the static structure analysis was done in ANSYS Workbench.

3.1. Foldable bicycle

The bicycle frame concept developed is based on the ergonomics of the conventional bicycle frame. Also the concept designs were built with the reference to the following structure data:

table 3.1 Dimension of bicycle frame (STANDARD DATA)

Actual size	Head angle	Seat angle	Top tube	Head tube	Chain stay	Wheel base	Stand over height
	Degree	Degree	cm	cm	cm	cm	Inches
M	72.5	73	54.5	16.5	42	99	30.6
M/L	72.5	73	56	18.5	42	100.5	31.1
L	72.5	72	57.5	20.5	42	100.8	32
XL	72.5	72	59.5	22.5	42	102	32.8

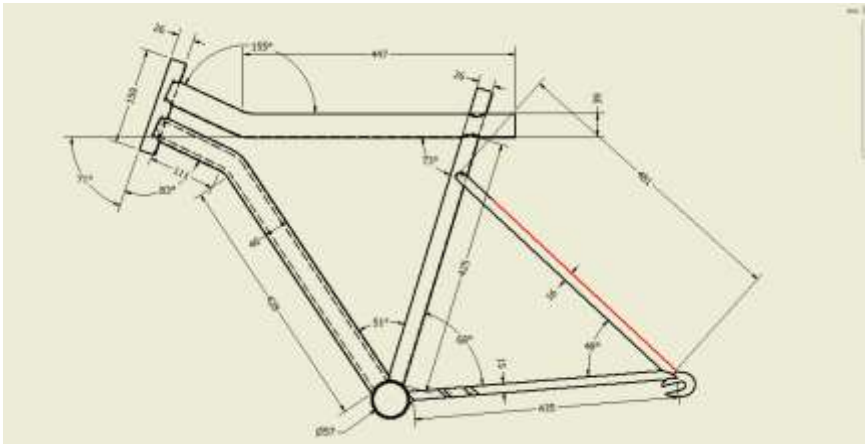

fig.3.1 CAD design of bicycle frame (All dimensions are in mm.)

As we know that the material, that has been used in bicycle is mild steel, the analysis has been done according to that in ANSYS Workbench. For the static analysis of bicycle frame the head tube and rear support at chain stay is considered as fixed. The force is defined at the top of seat tube and calculated deformation and stress and strain as below:

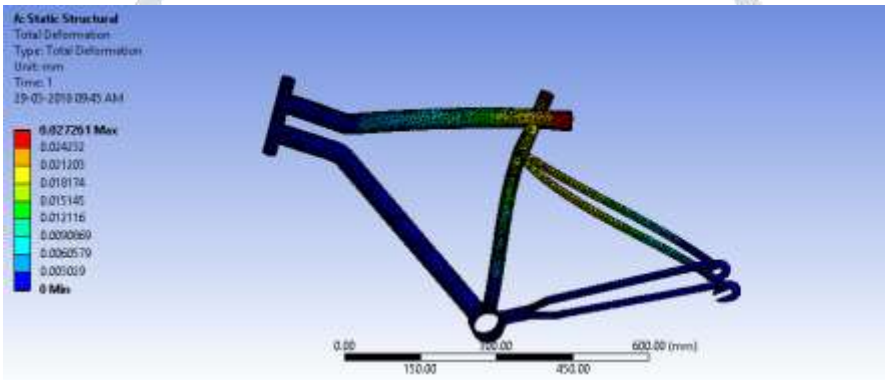

fig.3.2 deformation of frame

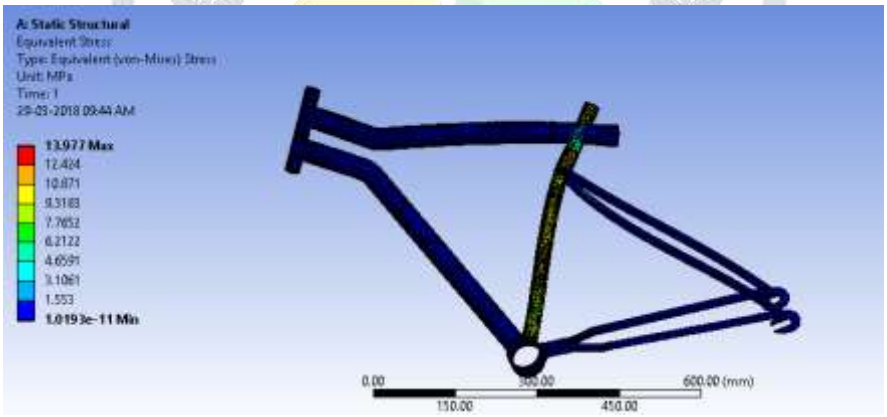

fig.3.3 stress analysis of frame

fig.3.4 strain analysis of frame

3.2. **Integral suspension wheel**

For the design of wheel, three configurations have been analysed. For 3 leaf, 4 leaf and 5 leaf configurations wheel hub is designed in triangular, square and pentagonal shape. For the static analysis for this geometry, rim was fixed and force is apllied on hub in steady condition and it is taken 1000N due to rider weight and bicycle weight. As for the selection of material, Carbon fibre is the best and most suitable for it. But as we know it is so expensive that the middle class people can't afford it. So after surveying we decided to go with the Spring steel EN 47 which has almost similar effect as the carbon fibre. [1][4][9] [10]

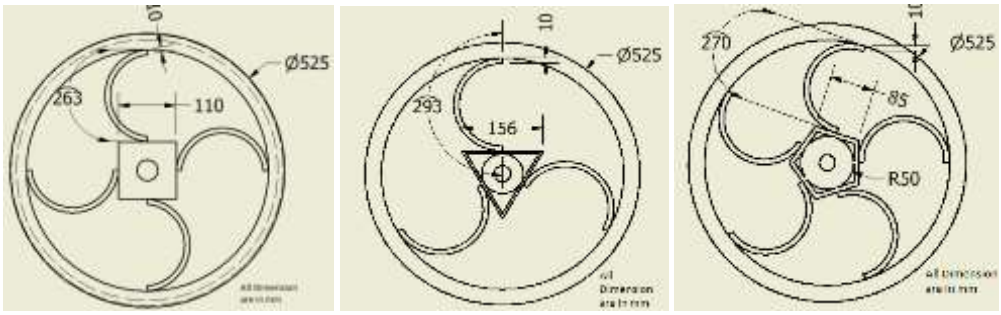

fig.3.5 CAD design of leaf configuration of suspension wheel (All dimensions are in mm.)

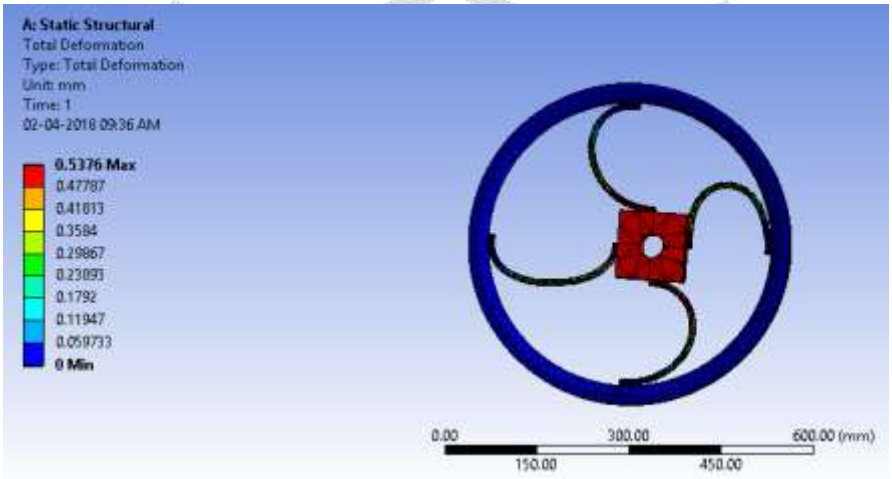

fig.3.6 4-leaf deformation

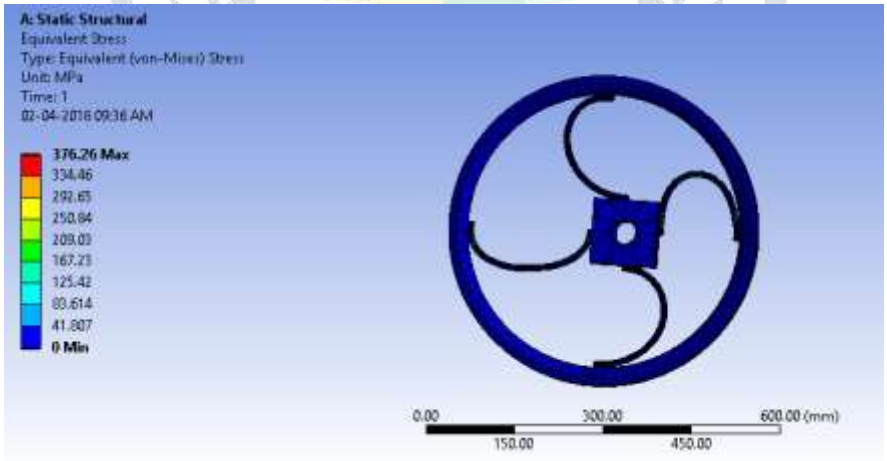

fig.3.6 4-leaf stress analysis

After analysing other configurations of the wheel we found the following data :

table 3.2 meshing of geometry

Parts	Nodes	Elements
3 Leaf	12351	3255
4 Leaf	23046	6553
5 Leaf	18036	8337

Table 3.3 results of analysis of other configurations

Geometry	Deformation	Von-misses Stress
3 leaf (Triangle hub)	1.286 mm	620.34 Pa
4 leaf (Square hub)	0.5374 mm	376.26 Pa
5 leaf (Pentagonal hub)	0.623 mm	468.35 Pa

- Calculation for the spring as in form of bar:
  - Material used: EN47 material
  - Material properties : Tensile strength (σ_{max})=820 $\frac{N}{mm^2}$
- Given data:

Length of leaf spring (L)=280 mm, diameter of rod (d) =? mm

Front impact test using impulse momentum theorem,

$F*T = m*v$

Let take,

Time of impact (T)= 1 sec

Mass of cycle with rider (m) = 100 kg

Maximum velocity of cycle (v) = 8.3 m/s

So,

$F = \frac{100*8.3}{1}$

F =830N~ 1000 N

Take leaf as cantilever beam,

$\sigma_{max} = \frac{16FL}{\pi D^3}$

$820 = 16*1000*280/(\pi*d^3)$

$d^3 = 1620.48$

d = 11.74 mm~ 10 mm

4. Merits and Demerits

4.1. Advantages

- Integral suspension wheel provides tangential suspension which works in every direction.
- Easy to park and carry with you anywhere compared to conventional one due to compactness.
- give you confidence in really smooth ride; people find they can tackle bumps, kerbs and cobbles much more easily on integral suspension wheels.

4.2. Disadvantages

- Design of wheel is complex
- Conventional bikes are usually cheaper than the folding bike
- You can get better fitting frame for conventional body

5. Conclusion

- From the analysis of different geometry of wheel by applying 1000 N force normal to the surface for each CAD model, it has found that the maximum deformation occurred on 3leaf wheel which is 1.286 mm and also maximum von-misses stress generated on it, and its value is 620.34 MPa.
- On 4leaf wheel the value of deformation is 0.5374 mm which is less compared to 3leaf and stress value is 376.26 MPa also less compared to 3leaf. So priority is given to 4leaf wheel.
- For selecting design, weight is also considered hence we can't select 5leaf spring because its weight is higher compared to other configurations of wheel. Also manufacturing the hub is hard task to deal with and making it for 3leaf and 5leaf configurations is even more complicated. So on the basis of that 4leaf wheel is considered as suitable for our bicycle.
- As for the analysis of bicycle frame, the values of stress and deformation are 13.977 MPa and 0.0267 mm respectively.

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