Rajkumar et al. 2014. *Int. J. Vehicle Structures & Systems*, 6(4), 115-119
ISSN: 0975-3060 (Print), 0975-3540 (Online)
doi: 10.4273/ijvss.6.4.06

International Journal of Vehicle Structures & Systems
Available online at www.maftree.org/eja

Conceptual Design of Shock Absorbing Bicycle Wheel

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ABSTRACT:

Bicycle suspension helps to cushion and insulate rider from the roughness of terrain. Till now fork suspension attached to the steering column is used to save the rider from impact. In this paper, a research involving the design of bicycle wheel that has a spring system between the hub and rim of wheel which provide tangential suspension to the rider from bumps and potholes on the road is reported. During this research, concept sketches for the proposed design were arrived from morphological chart and then Pugh chart was used for concept selection. Material indices were arrived for bow spoke that act as spring system and suitable material was suggested. Design Failure Mode and Effects Analysis was done for the proposed design concept and recommendations to reduce the risk priority number were discussed. Detailed design was carried out by considering factors that affect the stability of the bicycle.

KEYWORDS:

Hard tail bicycle; Bow spoke; Failure mode and effects analysis; Pugh chart; Tangential suspension

CITATION:

M. Rajkumar and R. Gandhinathan. 2014. Conceptual Design of Shock Absorbing Bicycle Wheel, *Int. J. Vehicle Structures & Systems*, 6(4), 115-119. doi:10.4273/ijvss.6.4.06.

1. Introduction

Mountain biking has become an important element of the sport of cycling in the last two decades. The Suspension system along with shock absorbers makes a significant distinction between competition bicycles. Bicycles with stronger frame structure and better suspension systems can effectively reduce vibration and increase comfort of the rider. This suspension system can be divided into three categories:

- A Rigid Frame (RF) bicycle that has no suspension;
- Hard Tail (HT) bicycle with only front suspension;
- Full Suspension (FS) bicycle that has both front and rear wheel suspension [1].

Many research studies indicated that FS type provides the potential benefit of better traction and reduced fatigue, but the rider's power output of FS bicycle is higher than that of HT bicycle. Riders average power output required by FS is about 80 W/min higher than HT type [2]. It is important to note that all the three categories of suspension cannot absorb tangential load. Telescopic forks are basically prismatic joints, thus the static friction between sliding parts cannot be eliminated and have poor response for small excitations [3-4]. Hence, tangential suspension that absorbs impact from all directions with better response to small excitations is required. In this background the research reported in this paper was carried out.

This research explored the design and development of HT type self-shock absorbing cycle wheel by creating the conceptual design of deflecting bow spoke. Five concepts were created and Pugh chart was used to select the suitable functional concept. A system with fork travel of 100 mm suspension, which was approaching the fork travel of HT bicycle, was used in this research.

The idea behind this research was to design a cycle wheel having the rider from bumps and potholes on the road. Bow spokes were used as spring system that compresses spring system between hubs and rim of the wheel to cushion on one side and expands in opposite side. This mechanism absorbs tangential load from any direction and reduce vibration of the frame into rider's arms. Because of providing suspension within the wheel, it is possible to use high-pressure or puncture-resist tires in the proposed concept. Schematic representation of the concept is shown in Fig. 1 [5].

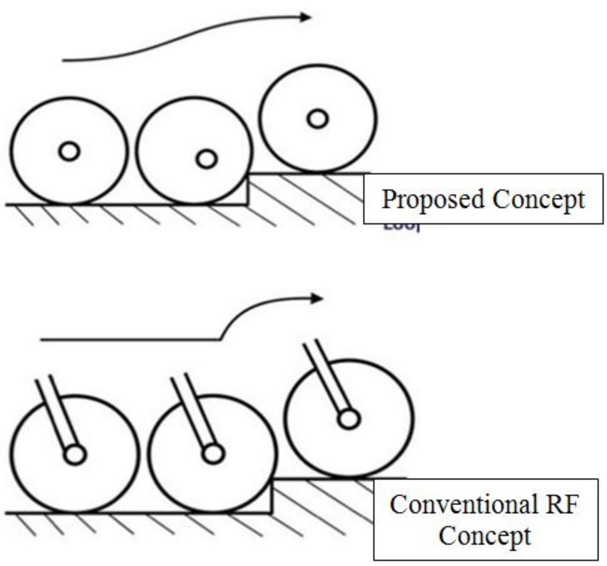
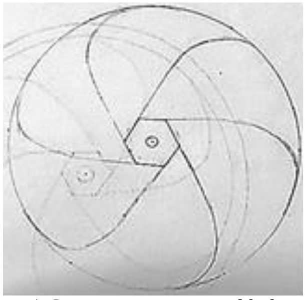


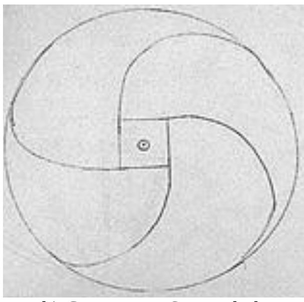
Fig. 1: Concept of shock absorbing system in cycle wheel

2. Design approach

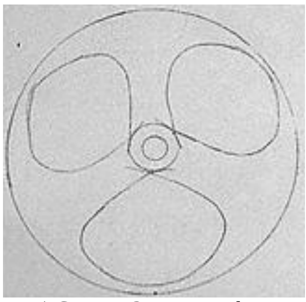
Concept drawings that function exactly similar to the proposed idea were drawn in free sketch. Design criterion for proposed concept was arrived and Pugh chart was used for identifying the most suited functional concepts. The force acting on front, rear and force due to pedalling was calculated as per ISO 4210:1996 standard [6]. Material indices that govern material selection of spring system for the proposed concept were predicted. Indian Standards that govern steering column alignment and trail were studied. Simulation of best and worst case design for the fork travel of 100 mm on spring system was analyzed according to BIS 10613:2004 standard [7]. In this research, design criterion for concept selection was obtained by conducting survey among 30 bicycle riders. Hand sketch of concept drawings that function as the proposed idea is shown in Figs. 2(a)-(d). Conventional tangential spoke bicycle wheel was taken as datum and all the concept drawings were compared against it. "+" indicates that the concept had better function and "-" indicates that the concept had poor function for the considered design criteria. "0" indicates that the concept had the same level of function as a datum. The representation of Pugh chart was shown in Table 1. According to this chart hexagonal hub bow spoke concept was selected and CAD model of this selected concept was shown in Fig. 3.



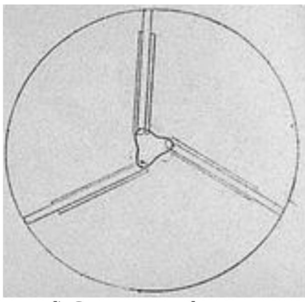
a) Concept 1: Hexagonal hub bow spoke



b) Concept 2: Square hub bow spoke [8]



c) Concept 3: Existing loop spoke wheel

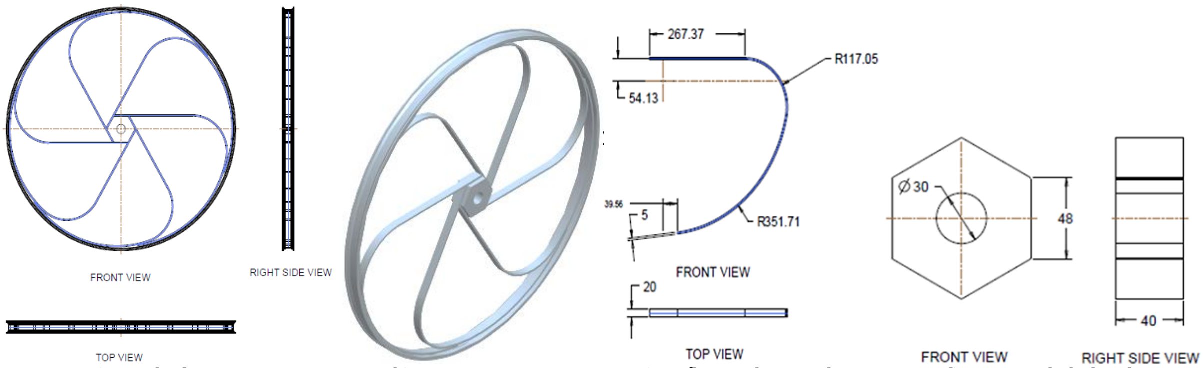


d) Concept 4: Telescopic spoke wheel

Fig. 2: Sketches of evolved concepts

Table 1: Concept selection Pugh chart

S.No	SELECTION CRITERIA	DATUM CONCEPT	CONCEPT SKETCH 1	CONCEPT SKETCH 2	CONCEPT SKETCH 3	CONCEPT SKETCH 4
1	Stability	**0**	+	-	+	-
2	Maintainability	**0**	+	+	-	-
3	Shock Absorbability	**0**	+	+	+	+
4	Reliability	**0**	-	-	-	-
5	Riding Comfort	**0**	+	+	+	+
6	Absorbing tangential load	**0**	+	+	+	+
7	Weight	**0**	**0**	**0**	-	-
8	Impact to axle	**0**	+	+	+	+
9	Cost	**0**	-	-	-	-
10	Ground clearance	**0**	-	-	-	**0**
11	Shock absorber Compression Length	**0**	+	+	+	+
Σ +			**7**	**6**	**6**	**5**
Σ -			**3**	**4**	**5**	**5**
Σ 0			**1**	**1**	**0**	**1**
RANK			**1**	**2**	**3**	**4**



a) Standard views b) Isometric view c) Deflecting bow spoke d) Hexagon hub details

Fig. 3: CAD model of hexagonal hub bow spoke

3. Variables affecting bicycle stability

3.1. Force acting on front and rear wheel

In order to calculate the force acting on the front and rear wheel of a bicycle, testing specifications from ISO 4210:1996 standard was adopted [6]. This standard prescribed the test velocity as 7 m/s for braking distance of 7 m. From the equation of motion,

$$v^2 - u^2 = 2as \quad (1)$$

Where initial velocity *u* taken as 7 m/s and final velocity *v* taken as 0 m/s. Deceleration from this equation was obtained as 3.5 m/s^2. Free body diagram of bicycle with forces acting in front and rear wheel was shown in Fig. 4 [9]. From this, the net force is calculated as,

$$F_{net} = Fz(rear) + Fz(front) \quad (2)$$

This net force for a given deceleration, *a*, equates as,

$$F_{net} = FOS * Mnet * a \quad (3)$$

Where FOS is factor of safety and *Mnet* is total mass of bicycle and rider.

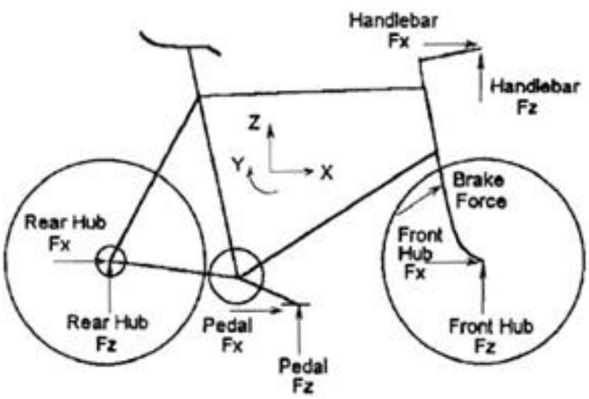


Fig. 4: FBD of force acting on a bicycle

New RF bicycle was hired for this research and weight of the bicycle was measured as 15 kg and maximum weight of the rider was taken as 80 kg. Hence, for calculating force acting on the front and rear wheel, total load of 95 kg was considered. With the factor of safety as 1.8, the calculated load using Eqn. (3) is 5872 N. The obtained result matched with field experiment by Lorenzo and Hull [9]. These authors measured maximum load acting in front and rear with the help of dynamo and observed maximum load acting on front wheel as 1900 N and maximum load acting on rear wheel as 4000 N. Hence, for this research, the force acting in front and rear wheel is taken as 1900 N and 4000 N respectively.

Field experiments on the effect of suspension system on rider's muscular stress, energy expenditure and time trial performance revealed muscular stress and average heart rate was higher for RF type bicycle. FS may not increase the riding performance because the pedalling efficiency was decreased due to rear suspension system; hence rider's power output had to be increased to overcome pedalling force [10]. To balance the pedalling efficiency proposed concept was designed for front wheel, thus acting like HT bike.

3.2. Material selection of deflecting bow spoke

The radial and tangential stiffness of spoke bicycle wheels, depend upon the spoke size, and the spoke geometry [11]. Since the design was HT bicycle, the proposed concept was deployed in front wheel. Hence, the load acting on front wheel 1900 N alone was considered for material selection of bow spoke. Bow spoke acts as a beam fixed at both ends. Length and shape were specified as geometric constraints and it should support bending load of 1900 N with 100 mm deflection. Thus the specified stiffness acts as functional constraint. In order to reduce rider's fatigue bow spoke should be light, hence minimizing mass becomes objective function. Cross section area and choice of material was free variable in material selection.

According to material selection Eqn. (4) by Ashby, the performance *P* of the element was described by an equation of the form:

$$P = f(F, G, M) \quad (4)$$

Where *F* represents functional requirements, *G* represents Geometric requirements and *M* represents material properties [12]. The suitable materials for a light, stiff bow spoke are those with the largest values of index M_b in Eqn. (5), where,

$$M_b = \sqrt{E} / \rho \quad (5)$$

From Ashby's Young's modulus and density chart, wood, CFRP, GFRP and ceramics have largest value of M_b. Among these toughness of ceramics was relatively low compared to other alternatives. Wood had natural variability and GFRP had low M_b value, but CFRP had an outstanding value of M_b [13]. Hence, CFRP was chosen as deflecting bow spoke material.

3.3. Bow spoke design

Wheel radius, head angle and fork offset separately, do not have an impact in the proposed concept. According to ISO 10613:2004 standard, steering axis intersects a line perpendicular to the ground line drawn through the wheel centre at a point should not be lower than 15% and higher than 60% of the wheel radius when measured from the ground line [7]. Hence the combined trail and steering axis should meet the wheel tolerance condition. The head angle of the bicycle was measured as 74° and fork offset was measured as 2.5”. The intersection point of steering axis and perpendicular line to ground had tolerance zone between 0.6 and 0.15 of wheel radius. For 100 mm deflection of bow spoke, hub axle can move inside a circle of 100 mm diameter. Shifting of the hub axle from its center would provide a shock absorbing effect to the cycle. When the hub center is shifted inside 50 mm, safe compression zone had larger area, this design was simulated in Fig. 5. When the hub center is shifted inside 100 mm, safe compression zone had larger area, this design was simulated in Fig. 6. This simulation helped in identifying the safe design limit for compression range that satisfying the standard.

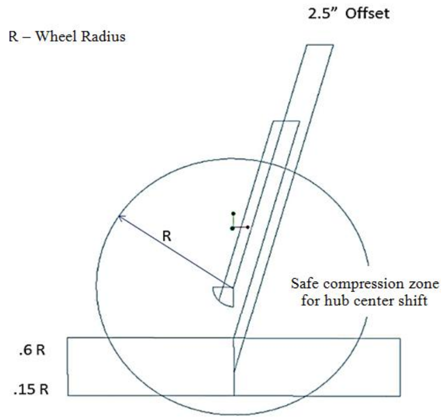


Fig. 5: Best case design of bow spoke

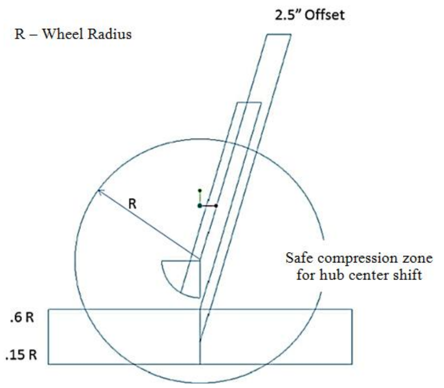


Fig. 6: Worst case design of deflecting bow spoke

Table 2: Design FMEA of bow spoke wheel

System : Bicycle			**Failure Mode and Effects Analysis (Design FMEA)**				**FMEA : 1**		
Component : Bicycle Wheel							**Prepared By : Rajkumar.M**		
S.NO	ITEM/FUNCTION	POTENTIAL FAILURE MODE	POTENTIAL EFFECTS OF FAILURE	SEVERITY	POTENTIAL CAUSES	CURRENT DESIGN	DETECTION	RPN	RECOMMENDED ACTION
1	Spoke	Breakage	Rider falls down may lead to accident	10	1. Incorrect Material Selection 2. Rider weight exceeding the design limit 3. Higher ir-regular terrain force	1. Design Failure criteria control using software 2. FOS of +10 Kg than rider weight should be given 3. Load test as cycle with rider	6 7 3	60 70 30	
		Fragile/Frequent buckling	Inconvinent riding	7	1. Deflection exceeding compression limit 2. Pedalling force exceeding the stiffness of material	1. Design Failure criteria control using software 2. Load test as cycle with rider	6 3	42 21	
2	Rim	Breakage	Rider falls down may lead to accident	10	1. Incorrect Material Selection 2. Rider weight exceeding the design limit 3. Higher ir-regular terrain force	1. Design Failure criteria control using software 2. Load test as cycle with rider	6 3	60 30	
		Crack	1. Reduction in life term of bicycle 2. Spoke may disassemble	6	1. Incorrect Method of Joint determination 2. Wheel crossed specified design rotations	1. Design Failure criteria control using software 2. Load test as cycle with rider 3. Testing the prototype for fatigue life	6 3 4	36 18 24	
3	Hub	Crack	1. Reduction in life term of bicycle 2. Spoke may disassemble	6	1. Incorrect Method of Joint determination 2. Wheel crossed specified design rotations	1. Design Failure criteria control using software 2. Load test as cycle with rider 3. Testing the prototype for fatigue life	6 3 4	36 18 24	

4. Design failure mode and effects analysis

Design Failure Mode and Effects Analysis (FMEA) was done to predict the possible failure modes in the proposed concept. FMEA is an analytical technique used to eliminate the potential failure mode of any product system [14]. The objective of FMEA in product design is to ensure that the reliability requirements are met for the product from its inception to obsolescence [15]. Design FMEA supports the product development process in reducing the risk of failure by evaluating the design requirements and alternatives. Potential failure modes that occurred in the proposed concept were represented in Table 2. Severity and detection rating were given according to quality assurance FMEA guidelines. Since this DFMEA was created for the new concept, number of defect occurrence rating was ignored. Spoke breakage failure mode observed to have high severity, since this failure mode had the potential to cause a sudden accident without warning. Spoke buckling failure makes the hub center to shift for each pedalling. The experimental test rig should be created with dynamometer to measure the force acting on the front wheel and pedal [16]. Bow spoke should not deflect due to pedalling or small terrain, hence loading by applying time varying force excitations should be tested [17].

5. Conclusions and further directions

A new concept of providing a shock absorbing mechanism in cycle wheel for smoother ride was proposed. Unlike suspension forks, bow spoke wheel provides tangential suspension, the suspension that works in every direction, hence their response obtained was same from any direction of force. Potential failure modes were captured using DFMEA and recommendations were discussed to enhance reliability of the concept. Fabrication of prototype with detailed design of concept can be done in future. Further experimental test rig that can simulate real off road environment can be created to test and prove the concept.

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EDITORIAL NOTES:

Edited paper from International Conference on Advanced Design and Manufacture, 5-7 December 2014, Tiruchirappalli, Tamil Nadu, India.

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