Design and Performance Evaluation of Chain Wheel Drive of Bicycle by Using Alternate Material

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Abstract*—Bicycles were introduced in the 19th century in Europe. A bicycle, often called a bike or cycle, is a human-powered, pedal-driven, single-track vehicle, having two wheels attached to a frame, one behind the other. A bicycle rider is called a cyclist, or bicyclist. The basic shape and configuration of a typical bicycle, has changed little since the first chain-driven model was developed around 1885. But many details have been improved, especially since the advent of modern materials and computer-aided design. Several components that eventually played a key role in the development of the bicycle, including ball bearings, pneumatic tires, chain-driven sprockets, and tension-spoke wheels. The sprocket is also called as chain wheel. The chain wheel is currently made up of hot rolled steel, aluminum alloy, forged steel, etc. which leads to increase product cost. The manufacturing cost is also high because it required a lot of machine operations. The selection of alternate material for chain wheel manufacturing will reduced the product cost and manufacturing cost. The alternate material is selected in such a way that which have high tensile strength and low weight than the conventional materials. The usage of alternate material reduces the weight of the component. The model of the chain wheel is developed for analysis. Analysis of a model is carried out to determine the functional parameters like deflection, stress and strain before developing the component. FEA is used to analyze the model. The chain wheel is manufactured by* Selective Laser Sintering *(SLS) rapid prototyping.

***Index Terms*—Chain wheel, Selective Laser Sintering (SLS) Rapid prototyping**

I. Introduction

A bicycle is a human-powered, pedal-driven, single-track vehicle, having two wheels attached to a frame, one behind the other. A bicycle rider is called a cyclist, or bicyclist. Bicycles were introduced in the 19th century in Europe and as of 2003. Bicycles have a fairly varied history. They have been around for almost two hundred years now, and they have evolved significantly during that time. The first bicycles were built completely different and were not nearly as comfortable as now. The bicycle's invention has had an enormous effect on society, both in terms of culture and of advancing modern industrial methods. Several components that eventually played a key role in the development of the automobile were initially invented for use in the bicycle, including ball bearings, pneumatic tires, chain-driven sprockets, and tension-spoke wheels. The basic shape and configuration of a typical upright, or safety bicycle, has changed little since the first chain-driven model was developed around 1885. But many details have been improved, especially since the advent of modern materials and computer-aided design. These have allowed for a proliferation of specialized designs for many types of cycling.

A bicycle is widely used for local means of transport. The demand of the bicycle has been increasing for new cycling methods and designs which optimize the human power input. Due to the increasing environmental concerns and the energy shortage in our society, there is a very strong incentive to find ways to use a non-polluting human power. Technology has led to the increased use of alternate materials like plastics as replacement to conventional materials in various sectors. Choosing alternate material for bicycle part allows manufacturing to adopt modular assembly practices, lower production costs, improve energy management, and use advanced styling techniques, more aerodynamic exteriors. The selection of alternate material overcome the limitations occurred by the conventional material.

This project is mainly focused on “Chain Wheel”, which is one of bicycle’s main components. Chain wheel is also called as sprocket. Chain wheel plays important role in running of bicycle. The chain wheel is currently made up of hot rolled steel, aluminium alloy, forged steel, etc. which leads to increase product cost. The manufacturing cost is also high because it required a lot of machine operations. The selection of alternate material for chain wheel manufacturing will reduced the product cost and manufacturing cost. The alternate material is selected in such a way that which have high tensile strength and low weight than the conventional materials. The usage of alternate material reduces the weight of the component.

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Williams S [1] had investigated on the sprocket. It is a very vital component in the transmission of power and motion in most motorcycle; there is always a pair (rear and front) in a motorcycle. The front sprocket drives the rear sprocket via chain connection. They exist in various dimensions, teeth number and are made of different materials. This study involves the fundamentals of sprocket design and manufacturing of a Yamaha CY80 motorcycle rear sprocket through reverse engineering approach. It had discusses dimensioning, drafting, chemical composition, material selection, choice of manufacturing process, heat treatment, surface finish and packaging as the eight steps that need to be followed sequentially in this reverse engineering approach. In this work, universal milling machine was used to produce the sprocket from the blanked medium carbon steel (AISI 1045) with chemical composition of C=0.45%, Mn=0.75%, P=0.03% max, S=0.04%. Induction heat treatment was applied to move the material hardness from 13 HRC to 45 HRC as shown by hardness test. Sprockets are of various designs, a maximum of efficiency being claimed for each by its originator. Sprockets typically do not have a flange. Some sprockets used with timing belts have flanges to keep the timing belt cantered. Sprockets and chains are also used for power transmission from one shaft to another where slippage is not admissible, sprocket chains being used instead of belts or ropes and sprocket-wheels instead of pulleys. They can be run at high speed and some forms of chain are so constructed as to be noiseless even at high speed. [2]

Rexnord (n.d.)[3] describes technical paper on chain drives is intended for illustrating the background and factors that affect the design of a chain drive in a comprehensive manner and for explaining the criteria that often go unnoticed. The systematic approach - or as we would put it – a guideline for your deliberations in calculating chain drives takes up the fore field of this paper.

The manual [4] provides a method for generating solid models of any standard sprocket, pitch, number of teeth, or configuration. This exercise also provides students and instructors with an excellent way to incorporate 8th and 9th grade algebra and geometry knowledge with engineering drawing skills to produce the design elements necessary to fully visualize their mechanical creations. The tooth form of a sprocket is derived from the geometric path described by the chain roller as it moves through the pitch line, and pitch circle for a given sprocket and chain pitch. The shape of the tooth form is mathematically related to the Chain Pitch (P), the Number of Teeth on the Sprocket (N), and the Diameter of the Roller (Dr). The formulas for the seating curve, radius R and the topping curve radius F include the clearances necessary to allow smooth engagement between the chain rollers and sprocket teeth.

Sagar Pardeshi [5] had created the design and development of Effective Low Weight Racing Bicycle Frame. A Bi-cycle frame is prominent part in whole racing cycle system which is subjected to static and dynamic loads. A monologue design is advisable in racing utility hence we are targeting towards composite design and how its frame can be optimizes by using static and dynamic FEA Analysis. A good result is found for the existing material. Results of all case reveals that the maximum stresses in the member of bicycle frame in top tube is which is less than yield strength in tension for the material selected i.e. Mild steel . So there is also scope to reduce the weight of the frame by considering the current stresses obtained.

M. D. Kidd [6] had carried out result of investigation, evaluating the forces present in statically loaded bicycle chain prior to and beyond sprocket engagement. Comparisons are made with the previous investigations that have been limited to industrial chains and sprockets. The chain drive system for a bicycle differs from the industrial standard types not only in its size but in its operations. A high degree of lateral flexibility is required in the bicycle chain for it to operate with non-coplanar sprockets having as effective misalignment of 3 deg or more. The experimental analysis considers chain load for a range of sprocket sizes and angles of misalignment. Result indicate that localized bending arising from misalignment between chain and sprocket can increase or decrease the strain on the side plates by a substantial fraction of the direct strain due to chain tension.

S. Vinodh [8] had describes the contemporary manufacturing organizations recognize sustainability as a vital concept for survival in the competitive scenario. The existing sprocket has been created using Computer Aided Design (CAD). Then, the sustainability analysis has been performed for determining the environmental impact. This is followed by the optimization of the sprocket design using Design Optimization. The environmental impact has been measured in terms of carbon footprint, energy consumption and air/water impacts. It has been found that the optimized sprocket design possess minimal environmental impact. The results of the case study indicated that CAD and Design Optimization could lead to the development of sustainable design with minimal impact to the environment. The results of the study had been practically as well as statistically validated.

From the above literature survey, there is scope for development in chain wheel. In this study, we had created the polymer chain wheel, as polymer is selected as alternate material for it. Finite element analysis was carried out for the both Steel and Polymer material. Also we had manufactured the experimental setup for the testing of it. And we are comparing the results of steel chain wheel and polymer chain wheel.

II. CHAIN WHEEL

A. Chain Wheel

Chain wheels are of various designs, a maximum of efficiency being claimed for each by its originator. It is also called as Sprockets. Chain wheels typically do not have a flange. Some chain wheels used with timing belts have flanges to keep the timing belt cantered. Chain wheels and chains are also used for power transmission from one shaft to another where slippage is not admissible; chain wheel chains being used instead of belts or ropes and sprocket-wheels instead of pulleys. They can be run at high speed and some forms of chain are so constructed as to be noiseless even at high speed.

The name 'Chain wheel' applies generally to any wheel upon which are radial projections that engage a chain passing over it. It is distinguished from a gear in that chain wheels are never meshed together directly, and differs from a pulley in that chain wheels have teeth and pulleys are smooth (Wikipedia). Chain wheels can be supplied in various materials and styles, depending upon the application and severity of service requirements.

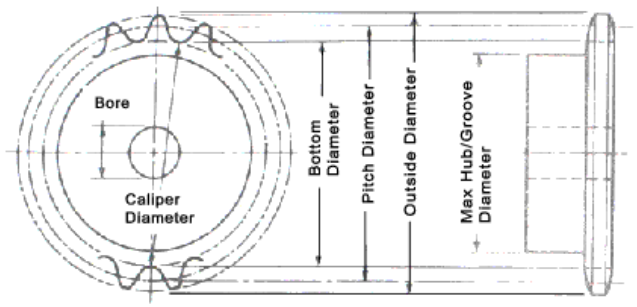

Fig.1 Chain wheel design

Fig. 1 shows the chain wheel design and its dimensions.

- **Chain Number** indicates the type and size of chain that will run on the Sprocket. For ANSI roller chain, the right hand number refers to the chain proportions. For example, 0 (zero) is for normal proportions. The numbers to the left of the right-hand digit denote the number of 1/8 inches in the pitch. The letter "H" following the chain number denotes heavy series. British Standard roller chain does not have a designation for the proportions of the chain. Instead, the first two digits of the chain number denote the number of 1/16 inches in the pitch.
- **Chain Pitch** is the distance between the pin centerlines in a link of chain. This distance is used to make the tooth profile of a sprocket, but cannot easily be measured on a finished sprocket. If the pitch of a sprocket is incorrect, the chain will not sit properly when wrapped around the teeth.
- **Pitch Diameter** is the diameter of the theoretical circle that passes through the centers of the link pins when the chain is wrapped around the sprocket. This can't be measured on the sprocket itself, since it is a dimension used to design to tooth profile.
- **Bottom Diameter** is the diameter of a circle tangent to the curve (called the seating curve) at the bottom of the tooth gaps. This immersion cannot be measured properly on odd-toothed sprockets, so the Caliper Diameter is used.
- **Caliper Diameter** is the same as the bottom diameter for a sprocket with an even number of teeth. For a sprocket with an odd number of teeth, it is the distance from the bottom of one tooth gap to the bottom of the nearest opposite tooth gap.
- **Outside Diameter** is the diameter over the tips of the sprocket teeth.

B. Chain Wheel Tooth Terminology

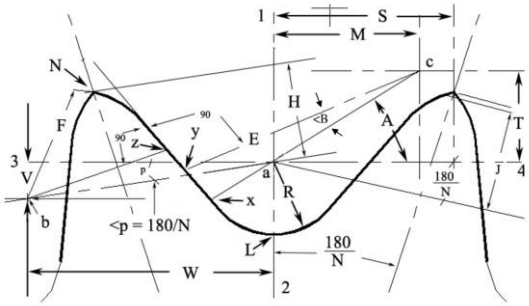

Fig.2 Chain wheel tooth terminology

The tooth form of a chain wheel is derived from the geometric path described by the chain roller as it moves through the pitch line, and pitch circle for a given sprocket and chain pitch. Fig.2 shows the chain wheel tooth terminology. The shape of the tooth form is mathematically related to the Chain Pitch (P), the Number of Teeth on the chain wheel (N), and the Diameter of the Roller (Dr). The formulas for the seating curve, radius R and the topping curve radius F include the clearances necessary to allow smooth engagement between the chain rollers and chain wheel teeth.

C. Problem Definition

The bicycle rider undergoes heavy physical stress during riding of bicycle due to heavy weight of bicycle parts. The weight of bicycle parts is reduced by using lightweight materials. In this paper, chain wheel of bicycle is replaced by alternate light weight material. The alternate material is selecting in such a way that which have high tensile strength and low weight. Theoretical design of the chain wheel is created [2]. The CAD model of chain wheel is developed for analysis [6]. Analysis of a model is carrying out to determine the functional parameters like deflection, stress and strain before developing the component. FEA is used for analyze the model. Rapid prototyping is selected for the manufacturing the component. CAD results and experimental results will be validating.

D. Material Selection

Selecting the right material for sprocket involves many factors, including the cost as well as the material performance required. Sprockets can also be supplied in various cast materials, with or without hardened teeth.

Table I Nylon 66 GF30 material properties [7]

Sr. No.	Property	Steel	Nylon 66 GF30
1	Hardness (HRC)	106.8	118-120
2	Tensile Strength (MPa)	67-70	186.158
3	Flexural Yield Strength (MPa)	40	145-310

4	Elongation at Break (%)	13	5-10
5	Melting Point (°C)	1470	260
6	Thermal Conductivity (W/m-K)	46	0.53
7	Tensile Modulus (MPa)	240	11170

The alternate material selected for chain wheels is "Nylon 66 GF30" [7]. Table I shows the mechanical properties of Steel and Nylon 66 GF30 material. Based on these properties the material is chosen. The properties of Nylon 66 GF30 is better than steel except for the thermal conductivity and melting point. Even though thermal conductivity and melting point is low for Nylon 66 GF30, this does not affect the dimension and function of the plastic chain wheel. Steel has 60-70 MPa tensile strength and selected material has 186.158 MPa, which is more than steel as shown in above table.

E. Methodology

Reverse engineering technique is one of the important parts of the product development cycle. With the help of reverse engineering (RE) technique surface models are generated by three-dimensional (3D)-scanning technique. The CAD model is created with using Pro-E software. The CAD model is converted to International Graphical Exchange Format (IGES) to suit the ANSYS environment. Analysis of CAD model is done with the help of FEA software. Chain wheel was manufactured by using Selective Laser Sintering (SLS) Rapid Prototyping. Experimental setup is manufactured and experimental testing is carried out for the both steel and nylon chain wheel assembly.

F. Engineering drawing of the Sprocket: Computer Aided Design (CAD)

Pro-E software is used for to create 3D model of the chain wheel and connecting rod. Fig.3 shows the 3D model of chain wheel. With the help of co-ordinate measuring machine dimensions of the chain wheel and connecting rod is taken. Form this measured dimensions 3D model in created as shown in Fig.3.

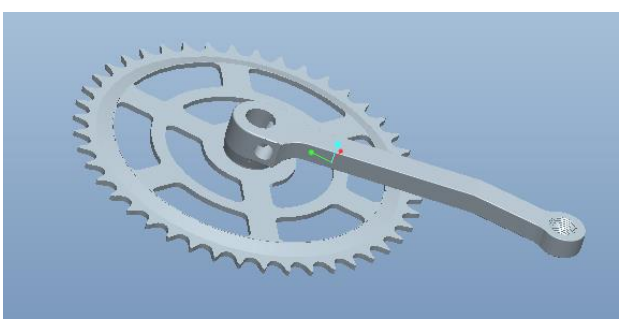

Fig.3 3D model of chain wheel assembly

III. Experimental Setup And Procedure

As shown in Fig.4, the experimental setup is designed and formed for the experimental testing of steel and nylon 66 chain wheel assembly. Chain wheel is mounted on the stand and one side of the chain is fixed and at other side of the chain various loads are applied as shown in fig. For loading the loads on other side of the chain, one rod is attached to the chain end. Number of 6kg and other weight combinations blocks are manufactured for the testing.

Fig.4 Experimental Setup

Fig.5 shows the close view of testing pointer location. This location is fixed by the FEA of the model. Digital Dial Indicator is used for measuring the displacement which is less than 1mm. Firstly pointer is set at zero deflection as shown in Fig.4. And then by applying 6 kg load displacement is measured and so on. Like this, with gradually increasing loads readings are taken. This procedure is done for both steel chain wheel assembly and nylon 66 chain wheel assembly.

Fig.5 Testing pointer location

IV. Finite Element Analysis

The Finite Element Analysis of chain wheel model is carried out with Steel and Nylon 66 material at 200kg load as shown in below Fig.6 and Fig.7 respectively. Stress is an important factor to determine the failure point of material.

ANSYS software is used for the structural analysis of the chain wheel assembly model. 3D chain wheel assembly which is created using the Pro-E software is used for the FEA in ANSYS.

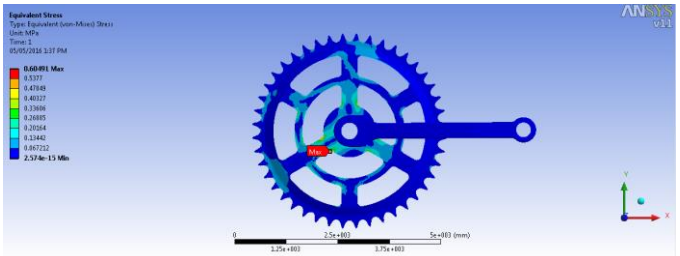

Fig.6 Steel Chain wheel Stress Analysis

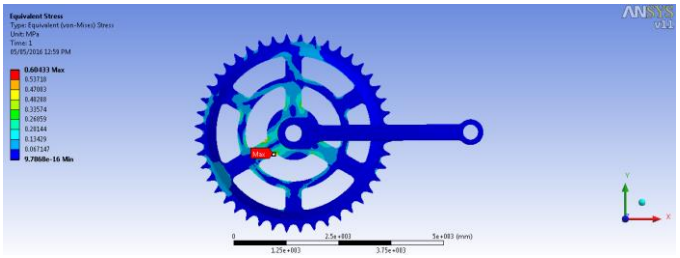

Fig.7 Nylon 66 Chain wheel Stress Analysis

For the stress and deflection analysis, half upper circle teeth are made constraint and load is applied on it. Fig.8 and Fig.9 shows the deflection analysis of the Steel and Nylon 66 chain wheel assembly respectively.

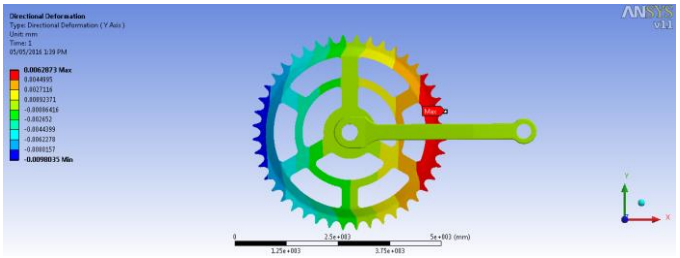

Fig.8 Steel Chain wheel Deflection Analysis

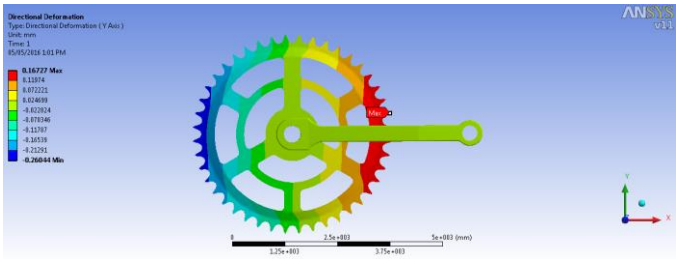

Fig.9 Nylon 66 Chain wheel Deflection Analysis

V. Results And Discussion

A. *Experimental Testing Results*

Table II shows the experimental testing readings for the Steel chain wheel and Table III shows the readings for the Nylon 66 chain wheel.

From the Table II and III, we can see that at 100N and 120N loads the displacement values for Nylon 66 chain wheel are more than the Steel chain wheel.

Table II Steel chain wheel readings

Load [N]	Displacement [mm]
20	0.065
40	0.095
60	0.125
80	0.15
100	0.18
120	0.205

Table III Nylon 66 chain wheel readings

Load [N]	Displacement [mm]
20	0.081
40	0.095
60	0.155
80	0.290
100	0.550
120	0.780

B. *Finite Element Analysis Results*

The results reveal higher stress point at the shown point in the fig and moderate stress at the other part of the chain wheel. The stress values from the Fig.7 for the propose design are well within the limits of tolerance when compared to the properties of the material used for the chain wheel assembly.

From the stress analysis, the component has suitable stress values as 0.60491 MPa for steel and 0.60433 MPa for Nylon 66 as shown in Fig.6 and Fig.7 respectively.

From the deflection analysis, the component found to have deflection values suitable for realizing. As seen from Fig.8, the maximum deflection of 0.006 for the steel and from Fig.9, 0.167 for the Nylon 66.

VI. Conclusion

The replacement of the conventional material with newer products for practical applications has reduced the pressure on non-renewable resources. Plastics though non-biodegradable, can be recycled to minimize the ill effects of non-decomposable nature of these polymers. The plastic material chosen is a composite of Nylon 66 and Glass filled. The model of the plastic wheel is developed using Pro/E and analyzed using the ANSYS software. The analysis shows that the physical and mechanical properties of the plastic chain wheel are comparable to a steel chain wheel and therefore, plastic can be used to replace steel.

From the obtained results we had conclude that, there is some dimensional changes and change in manufacturing process for Nylon 66 chain wheel as results shows more

displacement in Nylon 66 chain wheel than the Steel chain wheel. The Nylon 66 + glass filled chain wheel is manufactured by SLS Rapid prototyping process. With this manufacturing process, product is manufactured layer by layer form. So that, this Nylon 66 chain wheel shows the some more deflection. If we used molding manufacturing process for the same product then it will shows the more accurate results. Further if thickness of the plastic chain wheel is increased then it will show the less deflection.

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