DESIGN AND MATERIAL SELECTION OF HYDRAULIC WHEEL

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Abstract-The concept of hydraulic wheel will be discussed in this paper thoroughly. The hydraulic wheel seeks to eliminate the traditional wheel concept by using the hydraulics in place of air to change the radius of the wheel accordingly. The wheel is free from any rim thus making it the first of its kind. The whole paper consists of an overview of a hydraulic wheel which is designed with specific dimensions in accordance with SUV/Trucks vehicle. The material opted for this design purpose are assumptions based on their density, strength, elongation, physical properties of a material and grade of the material/liquid. Thus validating with the above assumptions to prove the consistency of this hydraulic wheel.

Index Terms- **Hydraulic Wheel, Design, Material Selection**

INTRODUCTION

The wheel of an automobile is one of the most integral parts of an automobile. The wheel is the part of the vehicle most responsible for acceleration and speed as it is the only one in contact with the road surface. The invention of wheel is considered to be one of the biggest milestones in human history. It started with a circular block of hard material with a hole at its central position from where it hinged to axle bearing through which it rotated, but with the course of time wheel evolution was a tremendous achievement. In today's time a wheel is classified as one of the integral part of any transportation vehicle with some extended changes to its integral structure as well as its aesthetic appearance. Even the motor vehicles produced now a days are strictly made to ensure the safety of its passengers. Likewise, its components such as wheel is also designed according to the international codes for safety of critical components.

Material selection for a wheel has become a concern topic for over a past few years. Difference in this aspect is based on type of material, properties of that material, resilience of material and adaptability of a material towards other material are considered to be some important sophisticated factors that are to be considered in material selection.

Tires are considered to be the outer most part of the wheel or the cover part of the wheel. There is a vast variety of tires that are been manufactured in the market, these are tube tires, tubeless tires and solid tires. In this paper the concept of solid tires is been implemented. The wheel consists of the hydraulic spokes on a hub. The materials considered for the different parts of the wheel are given as below: -

TYPES OF TIRE MATERIALS

Based on requirements of the above wheel three materials are selected for this design:

- **Natural Rubber**

Natural rubber is a rubber obtained from the latex sap of trees which belong to the genera hevea and ficus. It is an elastic hydrocarbon polymer. The poly-isoprene (natural rubber) has some specific properties such as

✓ Density (0.93* 10^3)
✓ Tensile Strength (20MPa)
✓ Elongation (800%)

(http://www.substech.com/dokuwiki/doku.php?id=elastomer_polyisoprene_natural_rubber)

The main advantage of Excellent abrasion resistance, Excellent tear strength, Excellent resilience, Excellent low temperature flexibility [1] and Excellent dielectric strength.

Applications: automobile tires, gaskets, hoses

- **Butyl Rubber**

Butyl rubber is a synthetic rubber or copolymer of isobutylene with isoprene. It is impermeable to gases [1] and thus used in many applications which have a requirement of airtight rubber. The synthetic rubber has some following properties over natural rubber

✓ Density (.92* 10^3)
✓ Tensile Strength (20MPa)
✓ Elongation (900%)

(http://www.substech.com/dokuwiki/doku.php?id=elastomer_butyl_isobutene-isoprene)

The main advantage of this rubber is that it has excellent resistance to acids and alkali [1], excellent heat resistance. But the major disadvantage is that it has very low permeability to air.

Applications: Inner lining of automobile tires, steam hoses and diaphragms.

- **Silicone Rubber**

Silicone or poly-siloxane is a polymer which include synthetic compound obtained from the repeating units of siloxane which contains a chain of alternating silicon and oxygen atoms [1] combined with carbon, hydrogen, and sometime other elements. This rubber has some following properties like

- ✓ Density (.98* 10^3)
- ✓ Tensile Strength (10MPa)
- ✓ Elongation (700%)

(http://www.substech.com/dokuwiki/doku.php?id=elastomer_silicone)

The main advantages of this rubber is that it has Excellent resistance to ozone and oxygen, Excellent resistance to heat and sunlight, Excellent Thermal Stability [1] Excellent weather resistance, Wide work temperature interval: -150ºF…600 ºF. Since this material has some disadvantages like Poor resistance to fuel, oil and hydrocarbons, Poor abrasion resistance, Poor tear resistance i.e. it not safe to make a whole rubber from it.

Application: high temperature sealant, adhesives, vibration damping components, types of fighter crafts [1].

TYPES OF HYDRAULICS AND HUB MATERIAL

Based on requirements of the above wheel three materials are selected for this design:

- **Stainless Steel Type 304**

Stainless Steel (type-304) is a combination of various material like chromium (18-20%), nickel (8-10%) as their major composition. These type of material is easy to machine since it has good weld ability and it is easy to form. It has a tensile strength of about 520-720MPa so it has good wear resistance. [2] Also it has excellent corrosion resistant [3] and quite good fluid handling durability. [2] According to the survey the cost of one ton of rolled steel is around $800-200 dollars with thickness of 0.3-60mm.

- **Titanium Grade 9**

Titanium (Grade 9) is a combination of various material with titanium as its major component along with vanadium (2-3%), aluminum (2.5-3.5%) and iron (below 0.25%). These type of material are easy to machine, weld and form, also due to presence of aluminum which is lightweight and excellent thermal conductivity. [2] [9] It has a tensile strength of 621MPa. It also has a good wear resistance and an excellent corrosion resistance. [2][4][9] Since its availability is very less it is very expensive. [2][4]

- **Cast Iron Grade 60-40-18**

Cast iron (Grade 60-40-18) is a combination of various material with iron (95%) as its major component along with carbon (3.5-3.9%), silicon (2.25-2.27%) and manganese (0.15-0.35%). This type of material is used where cost cutting is required but it is difficult to weld and solder. Although it has low cost of fabrication [2] and superior surface finish, [2] they are not quietly to be used near salt water and acidic environment. [2]

TYPE OF OIL/ FLUID IN HYDRAULICS

Based on the requirement for the hydraulic there are two oil/fluid which are suitable for this purpose:

- **Water Glycol Synthetic Hydraulic Oil/Fluid**

Water glycol based fluids has 35-60% of water in form of solution (not emulsion) and additives (anti-foam, anti-freeze, rust and corrosion inhibitors, anti-wear etc.). Water glycol based hydraulic fluids are used where excellent fire resistance is required. They are non-toxic and biodegradable. However, their temperature range is relatively low: 32°F - 120°F (0°C - 49°C). With the use of some additives they are used at higher temperature.

- **ISO VG 68 Hydraulic Oil/Fluid**

Hydraulic oil 68 is special type of oil mainly used in lifting heavy load efficiently. This type of oil is suitably used where lubricants with oxidation stability and performance is required. The main advantage of this oil is that it provides good anti-wear performance and prevent wearing of components. [6]

METHODOLOGY

- **Modelling in Solid works**

SolidWorks software is the standard in 3D product design used for representing 3D visualization of a product. The design built in this software are easy to process and requires less time. The below figure shows a solid model of a hydraulic wheel by using solid works. By taking the circular and tangential dimensions we have to draw a hydraulic wheel model in solid works.

Fig. A: Front View of Hydraulic Wheel

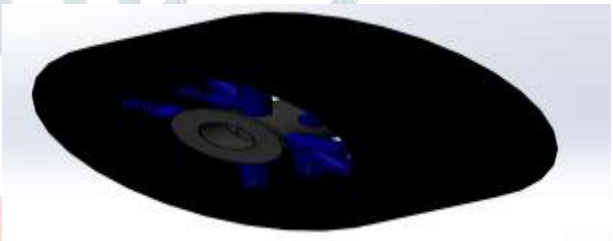

Fig. B: Isometric View of Hydraulic Wheel

Fig. C: View of Hydraulic

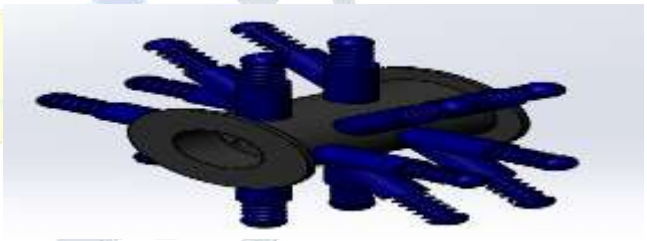

Fig. D: View of Hydraulics Integrated with Inner Part

The above shown figure is model drawn in the SOLIDWORKS software are by using the exact Dimensions of the hydraulic wheel with correct thickness and Dimensions.

- **Dimensions**

Outer Diameter of Hydraulic Wheel: 480mm [10]
Inner Diameter of Hydraulic Wheel: 315mm
Hole Size on Inner Wheel Surface: 25mm
Width of Inner Wheel: 170mm

Inner part

I. Inner Diameter: 100mm
II. Outer Diameter: 140mm
III. Length: 170mm
IV. Diameter of Hole on Surface: 30mm

Hydraulics

I. Total Length: 125mm
II. Base Diameter: 30mm
III. Diameter of Head: 25mm
IV. Oil Hole: 8mm

V.Diameter of spring: 20mm
VI.Pitch Length of Spring: 7.6mm
VII.No. of pitch: 5

- **Theoretical Analysis Based On Material Selection**

As a matter of facts and analysis on the following material, certain criteria are defined over the hydraulic wheel to determine the suitable material for its construction. Different selection is considered based on specifications provided on the material for determining the

❖ **For Tire Material**

Material	NATURAL RUBBER	BUTYL RUBBER	SILICONE RUBBER
Density (kg/m³)	0.93 *10³	0.92 *10³	0.98 *10³
Tensile strength (MPa)	20	20	10
Elongation (%)	800	900	700
Maximum work temperature (ºC)	80	100	300

In accordance with the above table, the values obtained in the table it is prove that butyl rubber is excellent in performance as compare to other two types of rubber. Also this rubber is used to make solid tires, therefore no permeability of air is seen. It has better elongation, maximum working temperature and less wear and tear.

❖ **For Hydraulics and Hub Material**

(a) To minimize the weight for a strength design

Performance index = Tensile Strength/Density

- Stainless steel 304 = 530/8 = 66.25 [3]
- Titanium grade 9 = 620/4.48 = 138.39 [4]
- Cast iron grade 60-40-18 = 414/7.1 = 58.31 [5]

(b) To minimize cost for a strength design

Performance index = Tensile Strength/Cost Per Kg

- Stainless steel 304 = 530/195 = 2.718 [3]
- Titanium grade 9 = 620/1500 = 0.413 [4]
- Cast iron 60-40-18 = 414/106.57 = 3.886 [5]

In the above cases, the material with the biggest result will perform better in the defined design criteria. Although, Titanium has the highest value when it is considered under minimum weight in a strength design and the lowest in cost reduction. [2] Ductile cast iron has lowest in weight but performs better in cost reduction for a strength design. [2] For the design criteria and for the purpose of hydraulic wheel we shall consider Stainless steel which has performed fairly well in minimum weight and cost for a strength limited design.

❖ **For Hydraulic oil/Fluid**

Parameter	ISO VG 68	Water Glycol
Viscosity @100^{0}C (10^{-6} m^2/s)	8.92 [10]	7.7
Density @ 75^{0}C, kg/m^3	864.2 [10]	1079.5
Oil Thermal Conductivity, W/(m.^{0}C)	0.097 [10]	0.09
Oil Specific Heat @ 40^{0}C , KJ/(kg.^{0}C)	2.062 [10]	0.815

From the above mentioned hydraulic fluids it has been seen that **ISO VG 68 Hydraulic Fluid** is better than Water Glycol Synthetic Hydraulic Oil/Fluid as it has better load lifting capacity. Also it prevents the component from wear and tear. Moreover, the cost of ISO VG 68 Hydraulic fluids is less in than that of Water Glycol Synthetic Hydraulic Oil.

LITERATURE REVIEW

- **Static Analysis of Wheel Rim Using CATIA/SOLIDWORKS and ANSYS16.0**

In this paper, analysis performed on wheel shows that the initiation of the cracks/fractures/deformation occurs at the places where the level of stresses is maximum as compare to whole wheel. The places where the level of stresses are maximum are the points where the discontinuity occurs in the wheel body i.e. holes for the bolts and air vents and these stress decreases as the distance from the discontinuity increases. This analysis has been done when the wheel is in static condition. For this a model of wheel is designed using software's **CATIA /SOLIDWORKS** and the analysis of the wheel is done by using a method called finite element analysis in a software called **ANSYS 16.0**. The diagram obtained for the deformity and stresses (von-misses diagram) of the wheel showed that out of aluminium, forged steel and titanium; titanium proved to be the best material for making of wheel, but due to excessive cost of titanium forged steel is preferred over other two. Also the different types of wheel and the different shapes of disc type wheels were discussed. [7]

- **Design and Weight Optimization of Aluminium Alloy Wheel**

In this paper an aluminum alloy wheel is designed in consideration with optimization of the mass of the wheel. Through finite element analysis the optimized mass of the wheel rim can be reduced up to 50% as compared to previous designs of the rim. During analysis of this wheel, only 36° circumference is taken for reflecting radial load at 0^0 and 36^0. Static analysis, structural analysis and fatigue analysis are measured with help of **ANSYS** where different load varying conditions are obtained on the basis of different stress that are been operated on the system. Fatigue analysis is performed where fatigue failure is being calculated according to S-N curve and on the basis of which the no. of cycles and maximum damage can be measured which is likely to be around 20 cycle and 0.2%. [8]

- **Stainless Steel as a Structural Material: State of Review**

This paper introduces stainless steel alloys and their properties relevant to structural designers. It also considers recent developments in this field with respect to stainless steel. Stainless steel has been indispensable due to its better corrosion resistance as compared to traditional steel. The toughness, stress strain and plasticity of the material has also been discussed in this paper. From the past research work, sustainability and material properties have been studied with reference to mechanical properties like corrosion resistance and cost. [3]

CONCLUSION

The theoretical aspect of hydraulic wheel based on design and material selection has been done by assuming the above parameters. Various materials like Stainless Steel Type 304, Titanium Grade 9 and Cast iron 60-140-18 are theoretically observed for the construction of hydraulics and hub of the wheel whereas, for Solid Tires materials like natural rubber, butyl rubber and silicone rubber are also observed. Variety of fluids are also taken into consideration and out of which water glycol synthetic fluid and ISO VG 68 hydraulic fluid are observed. With these materials and taking designing parameters into consideration a special wheel called hydraulic wheel is constructed.

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