DESIGN OF HYDRAULIC WHEEL

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Abstract - *There are many types of the wheel use in transportation and Exploration. Most of them are fixed diameter and not adjustable according to the type of obstacle. Hydraulic wheel is type of a wheel in which the diameter is adjusted with help of hydraulic pressure. The hydraulic wheel can be use in vehicle for collection of data, environment sample, picture of caves, terrain below the oceans, and in a surveillance robot. In this paper we have describe the working of hydraulic wheel and design various component used in hydraulic wheel.*

***Key Words*: Variable diameter wheel, Adjustable diameter wheel, Surveillance robot, Hydraulic wheel, Adaptive wheel, All terrain vehicle, Suspension wheel, Rover wheel.**

1. INTRODUCTION

Many types of the wheel are used in the vehicle for the transportation and exploration of new places. But most of the wheels are not adjustable according to the size of the obstacle. They have a definite diameter irrespective of the types of terrain and types of obstacle. Due to fixed diameter the vehicle can't be use in highly irregular terrain like rocky terrain, terrain present below the sea. The fixed diameter wheel has another disadvantage that we can't changed the height of the vehicle.

To overcome the above issues, we can implement hydraulic wheel in vehicle. The hydraulic wheel is adjustable diameter wheel in which driver can change the diameter of the wheel according to the terrain and size of the obstacle. Vehicle can cross high obstacle by increasing the diameter of the wheel. Similarly, vehicle can cross gap by decrease the diameter of the wheel so that the height of the vehicle decreases. The vehicle is also able to come out from pitting by increasing the diameter of the wheel. The hydraulic wheel is use in highly irregular and unpredictable terrain. The hydraulic wheel is also act as the suspension. Thus, it is not require to install suspension system separately. Hydraulic wheel absorb shock comes from irregular terrain Due to its motion and vehicle get less vibration.

2. CONSTRUCTION

In the hydraulic wheel six hydraulic cylinders are arrange at equal angle. The six hydraulic cylinders are welded on the steel plate. Each hydraulic cylinder consists of cylinder, piston and three spring of variable mean core diameter. A hole is drill on head of the cylinder. A distributor is connected with six cylinders.

A reservoir is used to store the hydraulic fluid. The reservoir is hydraulic cylinder in which pressure is changed by the movement of piston. A screw is attached with the piston by mean of bearing. The bearing is used to allow the rotation of the screw in the nut. The reservoir is connected with the distributor's input by mean of pressure vessel.

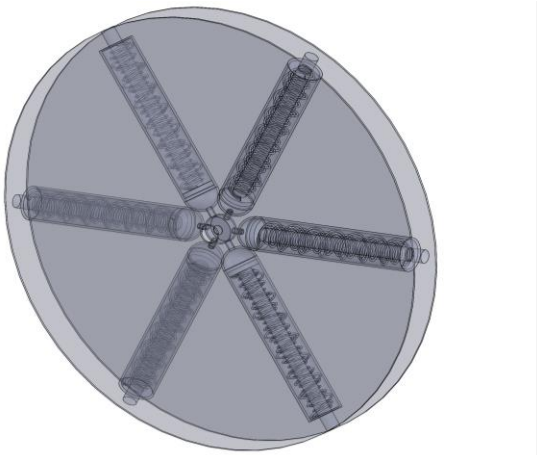

Fig -1: Hydraulic Wheel

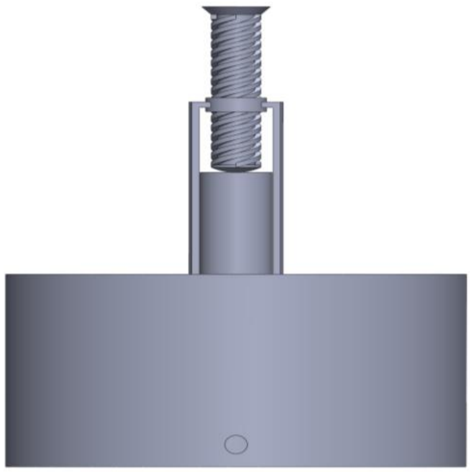

Fig -2: Reservoir

3. WORKING

When the screw is rotated clockwise either automatically or manually, the reservoir piston moves downward. The pressure of the hydraulic fluid increases. The high pressure hydraulic fluid is pass to the wheel cylinder through the vessel and distributor respectively. The volume of the fluid present in the wheel cylinder increases and push the wheel piston outward. The diameter of the wheel increases.

To reduce the diameter of the wheel the screw is rotated in anticlockwise direction. The piston moves upward. The pressure in the reservoir cylinder decreases. Thus, the hydraulic fluid present in the wheel cylinder come back to reservoir cylinder. The volume of the fluid present in the wheel cylinder decreases. The piston moves inward and the diameter of the wheel decreases.

For changed in diameter of the wheel driver has to only rotate the reservoir screw which is attached on the dashboard of the vehicle. The rotation of the screw may be automatic for the robot.

4. DESIGN OF COMPONENT

Hydraulic wheel is use in highly irregular and unpredictable terrain. Thus, it is designs based on the strength characteristic of the material and behavior of the material with the surrounding.

4.1 Wheel cylinder

Let the total weight of the vehicle is 40kg. The vehicle has 4 hydraulic wheels.

Vehicle weight = 400N

Weight on one wheel = $\frac{weight\ of\ vehicle}{no.of\ wheel\ in\ the\ vehicle} = \frac{400}{4} = 100N$

Let total displacement of the spring 100mm and driver can change the radius of the wheel by 90 mm. The 10mm spring displacement is reserve for working of absorption mechanism.

Force acting on the spring = 2* force acting on the one wheel = 200N

Spring stiffness(k) = $\frac{load}{displacement\ induced\ due\ to\ load} = \frac{200}{10} =$ 2 N/mm

According to IS 8208:2004 [1] the inside diameter of the cylinder is 32mm.

$$pressure = \frac{force}{area} = \frac{force\ acting\ on\ the\ piston\ head}{\frac{\pi}{4}{d_i}^2} = \frac{200}{\frac{\pi}{4}32^2} =$$ 0.25N/mm^2

Let we design the hydraulic wheel for collecting the data from the caves having acidic and humid environment. Mogbeyi [2] suggest material for cylinder as stainless steel 304 possess following properties.

1. Stainless steel 304 remain durable in acidic environment.
2. It has excellent durability in fuel and oil solvent.
3. It has ductility at lowest temperature.
4. It has high corrosion resistant.
5. It has good wear resistance.
6. It is easily available.
7. Stainless steel 304 is environment friendly.

The mechanical properties of stainless steel 304 are as follow [3].

$\rho = 8$ g/cc , σ_{ut} = 505MPa , σ_{yt} = 215MPa, E = 193GPa, μ = 0.29, G = 8.6GPa

Let factor of safety for the hydraulic wheel cylinder is 3.

$$\sigma_t = \frac{\sigma_{yt}}{FOS} = \frac{215}{3} = 71.67\ \text{N/mm}^2$$

The cylinder is close at both the end and made up of ductile material. According to V.B.Bhandari [4] the thickness of cylinder by clavarino's equation is given as

$$t = \frac{Di}{2}\left[\sqrt{\frac{\sigma_t+(1-2\mu)P_i}{\sigma_t-(1+\mu)P_i}} - 1\right] = 0.04786mm$$

Let thickness of cylinder is 2mm for increasing the rigidity of the cylinder.

$D_o = D_i + 2t$ = 36mm

4.2 Wheel piston

Mogbeyi [2] suggest material for piston rod as low alloy steel EN24T having following properties.

1. It has excellent machinability, formability and weldability.
2. Steel EN24T has good hardenability.
3. It has excellent toughness at minimum hardness.
4. It has high strength at ordinary temperature.
5. Steel EN24T has excellent corrosion resistance.
6. It has good wear and abrasive resistance.
7. It is durable in oil, fuel and solvent.
8. It is easily available.

9. It is cheap and Environment friendly.

σ_{ut} = 550 N/mm², σ_{yt} = 400MPa , E = 205GPa , σ_{yc} = 400MPa

Due to sudden applied load consider factor of safety is 5.

$\sigma_c = \frac{\sigma_{yc}}{FOS} = \frac{400}{5} = 80$ N/mm²

According to hpwizard [5] Co-efficient of friction between tire and dry earth road is 0.65 and between tire and wet earth road is 0.55.

Frictional force = μN = 130 N

$\sigma_c = \frac{F}{\frac{\pi}{4} * D_{PH}^2}$ = 0.25 N/mm²

The compressive stress induce in the piston head is less than 80 N/mm². Hence design of the piston head is safe against compressive load.

$\tau_{xy} = \frac{shear\ force}{shear\ area} = \frac{165.52}{d_p^2}$ N/mm²

$\sigma_y = \frac{compressive\ force}{cross-section\ area} = -\frac{254.65}{D_p^2}$ N/mm²

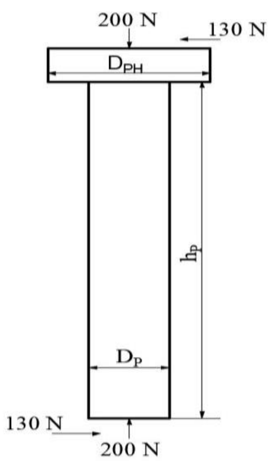

Fig -3: Forces on wheel piston

According to M.D.Dayal [6], the major and minor principle stress induce in a strained member is as follow.

$$P_1, P_2 = \frac{\sigma_y + \sigma_x}{2} \pm \frac{1}{2}\sqrt{(\sigma_y - \sigma_x)^2 + 4\tau_{xy}^2}$$

$$-\sigma_c = -\frac{254.65}{2d_p^2} - \frac{1}{2}\sqrt{\frac{254.65^2}{d_p^4} + 4\frac{165.52^2}{d_p^4}}$$

The diameter of piston is 2mm.

According to IS 8208:2004 [1] the diameter of piston is 14 mm.

$K = \sqrt{\frac{I}{A}} = 3.5mm$

According to M.D.Dayal [6], the rankine's formula for combined effect of bucking and crushing is as follow.

$$P_{rankine} = \frac{\sigma_c * A}{1 + \frac{\sigma_c * L_e^2}{\pi^2 E K^2}}$$

L_e= 6126.5mm

The maximum length of the bar is 6126.5mm to avoid buckling.

The maximum moment applied on a wheel piston of front wheel when vehicle tried to climb on obstacle is 200 * L Nmm.

$\frac{\sigma_c}{y} = \frac{M}{I} = \frac{E}{R}$

The maximum length of the piston is 215.5 mm to avoid bending failure.

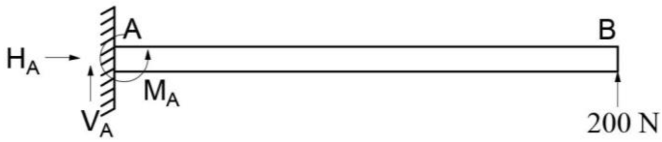

Fig -4: Moment analysis of wheel piston

4.3 Design of spring

V.B.Bhandari [4] suggest material for spring as high carbon hard drawn spring steel of Grade4 possess following properties.

1. It has high tensile strength.
2. It has high elastic limit.
3. It has ability to withstand high stresses under repeated loading.
4. It is least expensive of all spring material.

Properties of high tensile hard drawn spring steel (ASTM A679) given by [7].

E = 207*10³ MPa , G = 79.3*10³ MPa

Let three spring are in series with different mean core diameter.

So, K = 0.6667 N/mm

P = K*x = 66.67 N/mm^2

V.B.Bhandari [4] suggest the wire diameter of spring is 1.8 mm with ultimate tensile stress is 2190 N/mm^2.

$\tau_{max} = 0.5\sigma_{ut}$ = 1095 N/mm^2

Table -1: Design parameter of spring

Sr. No.	Parameter	$K_{17.6}$	K_{23}	$K_{28.4}$
1	$C = \frac{D}{d}$	9.78	12.78	15.78
2	$K = \frac{4C-1}{4C-4} + \frac{0.615}{C}$	1.148	1.11	1.09
3	$\tau = \frac{8KPD}{\pi d^3}$	588.2	743.2	901.1
4	$N = \frac{\delta G d^4}{8PD^3}$	29	13	7
5	Solid length (N*d)	52.2	23.4	12.6
6	Total gap = (N -1) * adjacent gap	14	6	3
7	Free length = solid length + total gap + δ	166.5	166.5	166.5
8	Pitch of coil = $\frac{free\ lenght}{(N-1)}$	5.94	13.87	27.75

4.4 Design of reservoir cylinder

Volume of the fluid require to move the piston up to 100 mm outside = $\frac{100*6*4*\pi d_i^2}{4}$ = 1.93*10^6 mm^3

Displacement of reservoir piston requires to move the wheel piston to its end = $\frac{1.93*10^6}{\frac{\pi}{4}D_{Ri}^2}$= 61.43mm

Let the material for wheel cylinder and reservoir cylinder is same and factor of safety for reservoir cylinder is 3.

Hence σ_t = 71.667 N/mm^2

$t = \frac{P_i D_i}{2\sigma_t}$ = 0.348 mm

Let thickness of the reservoir cylinder is 2 mm.

$D_{Ro} = D_{Ri} + 2t$ = 204 mm

4.5 Design of reservoir piston

F_{max} = P * A = 7853.98 N

Let the material for reservoir piston and wheel piston is same and factor of safety for reservoir piston is 3.

$d_p = \sqrt{\frac{4*7853.98}{\pi\sigma_c}}$ = 8.66 mm

According to IS 8208:2004 [1] the diameter of the reservoir piston is 32mm.

$K = \sqrt{\frac{I}{A}} = 8\ mm$

According to M.D.Dayal [6],the rankine's formula for combined effect of bucking and crushing is as follow.

$P_{rankine} = \frac{\sigma_c * A}{1+\frac{\sigma_c * L_e^2}{\pi^2 E K^2}}$

L_e= 4953.7mm

Assume length of the reservoir piston is 80mm.

4.6 Design of screw

Assume plain carbon steel 40C8 for design of the screw have following properties [8].

ρ = 7.85 g/cc , σ_{ut} = 660 MPa , σ_{yt} = 560 MPa , K = 140 GPa , G = 80 GPa , E = 190 MPa

μ = 0.27 , FOS = 2

$\sigma_c = \frac{\sigma_{ut}}{FOS}$ = 330 N/mm^2

$\tau = 0.5\ \sigma_c$ = 165 N/mm^2

$\sigma_c = \frac{W}{\frac{\pi}{4}d_c^2}$

The minimum core diameter of the screw is 5.5 mm.

V.B.Bhandari [4] suggest nominal diameter for screw is 22 mm with pitch 5 mm.

d_c = d – P = 17 mm > 5.5 mm

$d_m = \frac{d_c+d}{2} = 19.5\ mm$

For helix angle, $\tan\alpha = \frac{l}{\pi d} = 18.1°$

$\mu > \tan\alpha$

Let $\mu = 0.35$

$\varphi = \tan^{-1}\mu = 19.3$

According to V.B.Bhandari [4], the torque require to raise the load is given as

$M_t = \frac{Wd}{2}\tan(\varphi + \alpha) = 58.547\ kNmm$

$\tau = \frac{16M_t}{\pi d_c^3} = 60.69\ N/mm^2$

$\sigma_c = \frac{W}{A} = 34.6\ N/mm^2$

Principal shear stress (τ_{max}) = $\sqrt{\frac{\sigma_c^2}{4} + \tau^2} = 63.1\ N/mm^2$

The principal shear stress induce in the screw is less than 165 N/mm². Hence the design of the screw is safe.

$Z = \frac{maximum\ distance\ travel}{lead} = 3.072$

The designation of the screw is Sq 22 * 20 (P5)

The minimum number of the screw thread engaged with the nut is given as

$N = \frac{W}{\pi d_c t \tau} = 0.356$

Assume number of thread on nut is 1.

4.7 Design of bearing

V.B.Bhandari [4] guide deep groove ball bearing due to following properties.

1. High load carrying capacity.
2. It takes load in radial as well as axial direction.
3. Low frictional loss and temperature rise.
4. Create less noise.
5. It available with bore diameter from millimetre to 400 millimetres.

Table -2: Specification of deep groove ball bearing

Bearing no.	d (mm)	Static capacity (kgf)	Dynamic capacity (kgf)
6003	17	280	605
6203	17	460	956
6303	17	655	1250
6403	17	1180	2290

Select bearing number 6403 as static capacity is greater than 785.3 kgf.

4.8 Design of vessel

Assume the material for pressure vessel and wheel cylinder is same. The factor of safety for vessel is 4.

$\sigma_t = \frac{\sigma_{yt}}{FOS} = 53.75\ N/mm^2$

$t = \frac{Di}{2}\left[\sqrt{\frac{\sigma_t + (1-2\mu)P_i}{\sigma_t - (1+\mu)P_i}} - 1\right] = 0.0186\ mm$

Consider thickness of the pressure vessel is 1 mm.

$D_o = D_i + 2t = 10\ mm$

5. APPLICATIONS

1. Hydraulic wheel can be implements in vehicle use for mobility in rocky terrain.
2. It can be equip with robot that use to collect the picture, sample and other data from the caves and below the sea.
3. It can be use in surveillance robot to keep the track on activity of enemy.
4. It can be use in robot for research in highly irregular and unpredictable terrain.
5. It can be use in rescue robot for transportation of food and medicine in earthquake affected area.

6. CONCLUSIONS

The design of the hydraulic wheel is simple. The hydraulic wheel absorb vibration during its motion. So, it not necessary to install suspension system separately. It is easy to increase and decrease the diameter of the wheel. The driver has to rotate the reservoir screw attached on the dash board of the vehicle to change the diameter of the wheel. It neither have any folded part nor any complex mechanism like origami wheel. Thus, it is more feasible and has high service life. The hydraulic wheel act as a suspension system. It is well implement with the robot used for surveillance due to less vibration.

Thus, the hydraulic wheel aid in better mobility through different irregular and unpredictable terrain with simple construction and suitable to work in hazardous environment.

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