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# Design and Fabrication of Forklift with Multi-Directional Wheel

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**ABSTRACT:** This paper delves into the design and creation of the Multi directional wheels which offers a means to implement Omni-directional translational motion in a vehicle platform. To demonstrate technical contradiction that solve here shows the working of electric multi-direction forklift which is able to move single degree of freedom independently. To design a wheel which can take vehicle in multi-direction. Develop a low cost electric forklift model. As the wheel rotates, rollers around its circumference create a force directed at an angle relative to the plane of rotation. Various combinations of wheel rotational velocities can provide a net force in any direction. This provides enhanced manoeuvrability in close quarters, but is often limited to smoother surfaces as the wheels require many moving rollers that can become easily obstructed by debris. Applications of this model run from small hobby kits up to heavy duty industrial vehicles. This project used Multi directional wheel in forklift to make compact travel in industrial area. So that forklift move easily in any area of industrial store for material handling. In this project design and analysis the Multi directional wheel also check it directional stability for the given load condition and its sustainability.

**KEYWORDS:** Multi-directional wheel, Forklift, Mecanum wheel, manoeuvres, contradiction etc.

### I. INTRODUCTION

One of the common Omni-directional wheel designs is Mecanum Wheel or Ilon wheel. Mecanum wheel was design and invented in Sweden in 1975 by Bengt Ilon, an engineer with Swedish company Mecanum. Mecanum wheel is based on the principle of a central wheel with a number of roller placed at an angle around the periphery of the wheel. The angled peripheral roller translates a portion of the force in the rotational direction of the wheel to force normal to the wheel directional. [1] Depending on each individual wheel direction and speed, the resulting combination of all these forces produces a total force vector in any desired direction thus allowing the platform to move freely in direction of resulting force vector, without changing the direction of the wheel.

This design ensures that the rollers are always in contact with the work surface, thus allowing better performance on uneven surfaces. Using four of Mecanum wheels provides Omni-directional movement for a vehicle without needing a conventional steering system. Slipping is a common problem in the Mecanum wheel as it has only one roller with a single point of ground contact at any one time. Due to the dynamics of the Mecanum wheel, it can create force vectors in both the x and y direction while only being driven in the y-direction. [2] Positioning four Mecanum wheels, one at each corner of the chassis (two mirrored pairs), allows net forces to be formed in the x, y and rotational direction. A difficulty with this strategy is that there are four variables to control three degrees-of-freedom.

### II. OBJECTIVE

Technical contradiction that solve here, that make use of multidirectional wheeled forklift which has great advantages over conventional platform in term of moving tight areas as it scrub sideways, turn on path and follow complex trajectories. Vehicle are capable of easily performing task in environment with static and dynamic obstacles and narrow space. It run on electrical powertrain to get electrified handling equipment.

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1. To design and develop a wheel mechanism to achieved multi directional movement.
2. To design a mecanum wheel with regular concave rollers and rollers of different material other than regular plastic material to achieve better grip on surface to study performance of vehicle movement.
3. To fabricate low cost and low weight (10 Kg) forklift to study the performance.

## III. DESIGN PROCEDURE

**Force:-**A force is a push or pull upon an object resulting from the object's interaction with another object. Whenever there is an interaction between two objects, there is a force upon each of the objects. Force and velocity are vector quantities which means that they have both magnitude and direction. There are different types of forces which act on any object such as gravitational force and normal force. Gravitational force can be explained as attractive force which acts on two masses. [3] Normal force can be explained as the force which acts perpendicularly on given object due to sliding effect of one object on other surface.

**Motion:-**Forklift with Mecanum wheel assembly includes chassis and two wheels on each side. By use of these wheels as Omni-directional motion, it can drive the forklift without conventional steering system. This system makes robotic motion in any direction possible as forward, backward, sideways to left or right. This design can provide a great flexibility for company environment and work floor. [4]

**Analysis:-**The force vector analysis acting on right Mecanum wheel can be given in following format.

Table 1. Drive Mechanism for Mecanum Wheels [4]

Movement	Wheel rotations
Forward	All wheel moving forward with same speed
Reverse	Backward motion of wheels with same speed
Right Shift	2,3 backwards and 1,4 forward
Left Shift	1,4 backwards and 2,3 forward
Clockwise Turn	2,4 backwards and 1,3 forward
Counter Clockwise Turn	1,3 backwards and 2,4 forward

## Force Distribution on Mecanum Wheel Roller

Fig. 1.shows that the roller is attached to axle and plate at an angle of 45 degrees which is given by  $\alpha$ . FC is the reaction force of floor on bottom of roller. FC has two components named FS & Ff. FS gets counterbalanced by an equal but opposite force from wheel on other side of vehicle. [5] Ff is forward component which acts in the plane of Mecanum wheel. To counter balance the torque action on wheel, Fc must be equal to  $Ff / \cos(\alpha)$ .

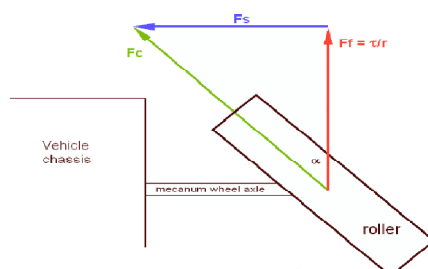


Fig. 1. Force Vectors on Single Roller. [5].

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## Material Selection

### • Material for roller

Rollers are manufactured with 75A – 85A polyurethane material. Polyurethane is a polymer with numerous industrial applications because of its properties. On the inner side of polyurethane wheel is the hard ABS material. These mecanum rollers are also made up of SBR rubber. But here we used light wood for roller material for ease of manufacturing and low cost. Acacia nilotica (babul) is a widely available wood in india. It is cost effective and also has good strength properties suitable for our mecanum wheel specification. Mechanical Properties of Acacia nilotica (babul) is given from reference [6].

### • Material Used to Manufacture Wheel Plate

Steel and Aluminum are two most economical material that can be used to manufacture the wheel plate. Looking from the designer's point of view both the materials are compatible but there are always some pros and cons related to the material.

Comparison between both Steel and Aluminum comes to conclusion that either of the material can be used to manufacture the wheel plate. Both have their own advantages and disadvantages. It now depends on the manufacturer and designer to decide on which material to be used depending on type of plate they need. Also, it depends on the load carrying capacity and size of the structure so as to decide which material to be used.

Therefore here we used Mild steel plate. Properties of steel C45 is given below.

Chemical composition [8]

- ✓ Carbon 0.4-0.5%
- ✓ Manganese 0.6-0.9%

Properties [8]

- ✓ It should have high tensile strength 710 N/mm<sup>2</sup>
- ✓ It should have high yield strength 630 N/mm<sup>2</sup>
- ✓ It should have high brinell hardness 265 HB.

## Catia design

### ❖ Design for mecanum wheel

The main idea behind designing the above Mecanum Wheel was to make sure that the roller contour was sticking out enough so that there could contact with the surface. But, for this wheel design also the rollers are assembled with the wheel plate to get a proper idea about the complete wheel structure. Also, this Mecanum Wheel is designed using both part design and generative sheet design. The bolts were implemented after placing the rollers at the desired location.

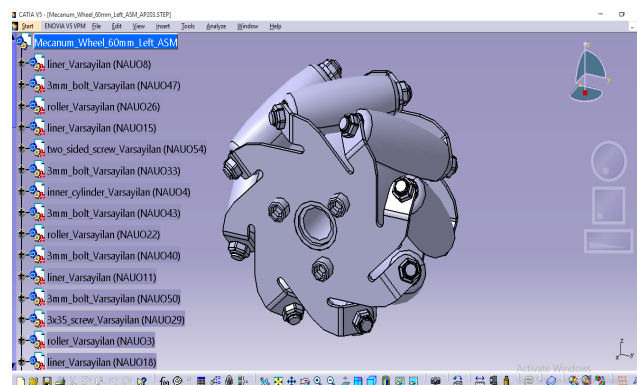


Fig. 2. Catia design of mecanum wheel

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For the design which is done in GSD workbench, rollers and plate are designed in part design while flanges are designed in GSD workbench. All this parts are assembled to get the full assembly.

## ❖ Design of fork frame

After selecting specific mechanism for forklift it is necessary to design basic frame of forklift to get basic idea about total span of lift. For the design which is done in structure design workbench, are assembled to get the full assembly.

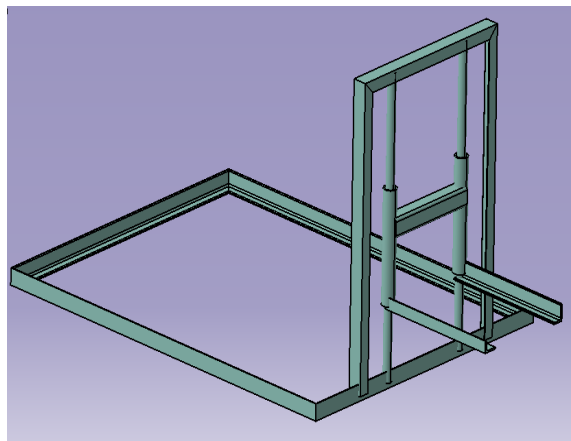


Fig.3. Catia design of forklift frame

## Analysis of Frame Structure:-

We have designed the frame to carry load of 10Kg approximately equal to 50N. as per boundary condition we have constraint the bottom part of the frame. After fixing the bottom part the next step to apply the force on the fork strips. So as the total weight is 50N so each fork strip is subjected to 25N force in downward direction. Fork is being pulled by the motor and sprocket arrangement through pulley and rope, so it is subjected to acceleration of 20 mm/sec. condition as applied to fork. Meshing of the Fork Frame. Element size chosen is 20mm. The Total deformation and stress coming on the fork frame considering all boundary condition is as shown in fig.4 (a) and (b). By considering the solution provided by the ansys we can conclude that our design of fork is safe.

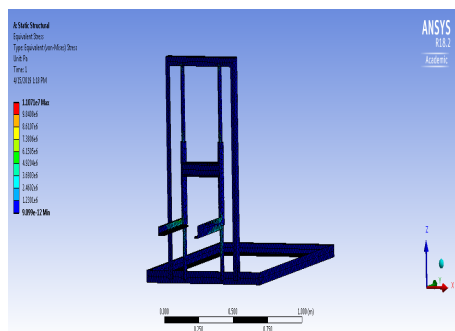


fig. 4 (a)

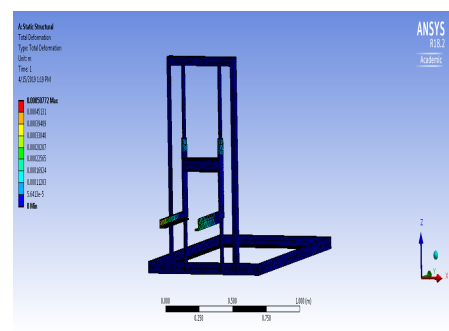


fig. 4 (b)

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## Analysis of Multi-directional Wheel:-

For analysing the wheel we have to constraint the some part of the wheel body. For that purpose a rectangular surface has been created using Ansys Design Modular. The force is given to the face of the hole considering all the forces are getting concentrated at the centre of the Mecanum Wheel. So here the application of the force at the five faces. Meshing of wheel. Element size taken as 10mm. For having the best result we have to use the finer mesh. For that purpose we have use body sizing and face meshing method. And resulting mesh is done. After solving the model the result provided by the Ansys is as shown in fig 5 (a) and (b). From the above analysis and our theoretical results we can conclude that the Design is safe.

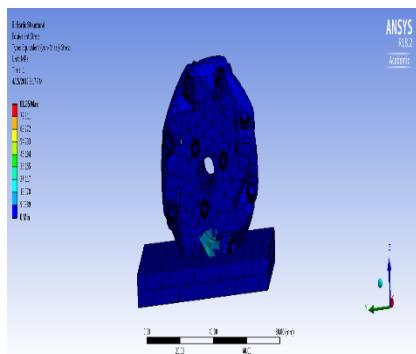


Fig 5 (a)

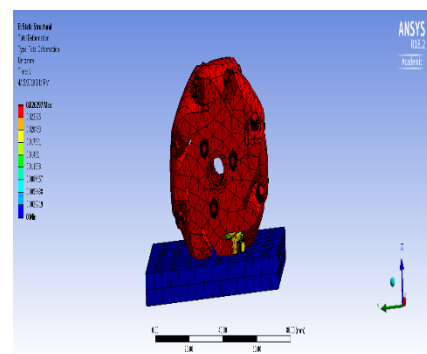


Fig 5 (b)

## Design Calculation for mecanum wheel

### 1) Design Calculations for motor shaft:-

#### a. Stress induced on roller pin:-

Total weight of machine is not to more than 20 kg. Weight distributed on all four wheel. So weight on each wheel is 5 kg is coming on roller pin so shaft will fail in bending. [1] We are using M4 bolts with 3 inch (75mm) length.

$$M = \frac{WL}{4} \text{ ----- as SSB}$$

$$M = \frac{5 \times 9.81 \times 75}{4} = 937.5 \text{ N.mm}$$

$$\text{And } Z = \frac{\pi}{32} * d^3 = (\pi/32) * 4^3 = 6.28 \text{ mm}^3$$

$$\sigma = (M/Z) = (937.5/6.28) = 149.28 \text{ N/mm}^2 = 150 \text{ N/mm}^2$$

As allowable bending stress for pin material (C45) is 730 N/mm<sup>2</sup>. So our design is safe.

#### b. Motor shaft diameter calculations:-

We are using motor having specifications

$$I = 3.5/5A$$

$$N = 40/60 \pm 5 \text{ rpm}$$

$$\text{Stall torque} = 29 \text{ N.m}$$

$$\text{Stall current} = 31A \text{ (max)}$$

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Motor power = VI = 3.5\*12 = 42 Watt ~ 50 Watt

$$P = \frac{2\pi NT}{60}$$

$$50 = \frac{2\pi * 45 * T}{60}$$

$$T = 10.61 \text{ Nm}$$

$$M = W * L = 5 * 9.81 * 65 = 3188.25 \text{ N.mm}$$

Therefore approx. torque on each wheel of forklift will be 10.61 Nm, also shaft undergoes both torsional and bending moment, So calculating equivalent torque for diameter calculation.

$$\text{Now, } T_e = \sqrt{M^2 + T^2} = \sqrt{(10610^2 + 3188.25^2)} = 11078.67 \text{ N.mm}$$

$$T_e = 11.078 \text{ N.m}$$

Now,

$$T_e = (\pi/16) * d^3 * \sigma_s$$

$$11078.67 = (\pi/16) * d^3 * 730$$

$$d = 4.26 \text{ mm}$$

As our motor shaft diameter is 10 mm so design is safe.

## 2) Roller Calculations :-

As per CATIA design select diameter of wheel as 150 mm and also roller with dimension. To check dimensional accuracy of mecanum wheel, Here use formula from reference [2], as improper selection of dimension of roller and wheel will lead to bumpiness in wheel. Bumpiness seen in mechanical wheel roller decrease efficiency of wheel if no. of roller not chosen properly it gives rise to bumpiness which is seen in roller. Increase in no. of roller decrease vibration. Selecting no. of rollers of certain size become important in mecanum wheel. Rollers are placed at  $45^\circ$ . Wheel is assumed to be lying in XX plane. Value of S varies from zero to half to length of roller axis. To calculate different values of other parameters some of derived formulas.

$$\begin{aligned} \alpha &= \tan^{-1} \frac{S/\sqrt{2}}{(R-r)} \\ d &= \frac{R-r}{\cos \alpha} \\ l &= R-d \\ \theta &= \cos^{-1} \left( \frac{\sin \alpha}{\sqrt{2}} \right) \\ h &= S + \frac{l \sin \alpha}{\sqrt{2}} \\ R_r &= l \sin \theta \end{aligned}$$

Where, R = wheel radius

S = distance measure along roller axis to intersection with L.

$\theta$  = angle between line L and roller axis

From all following equations the radius of roller which will best suit to avoid bumps can be found and will at a distance h from centre of roller. [2] So, from the above calculation conclude that roller with evaluate profit with diameter of 24mm at the end and diameter of 28 mm at the middle can reduce the bumpiness of mecanum wheel.

$$\begin{aligned} F &= \sqrt{2 * D^2 + S^2} & G &= \sqrt{(4 * D^2 + S^2)} T = \sqrt{2} * \frac{R}{F} \\ h &= (S/2) * (T+1) R_r = (G/2) * (T-1) D = R-r = 70-14 = 56 \end{aligned}$$

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Table 2. Different values of Mean radius from above derived Formulas

S	$\alpha$	d	l	$\theta$	h	Rr
1	0.0126	56.01	13.99	1.55	2.247	13.98
2	0.025	56.04	13.96	1.544	3.37	13.95
3	0.0378	56.07	13.93	1.535	4.49	13.92
4	0.0504	56.11	13.84	1.526	5.618	13.87
5	0.063	56.16	13.84	1.517	6.739	13.87
6	0.0756	56.21	13.79	1.508	7.856	13.81
7	0.088	56.28	13.72	1.5	8.96	13.82
8	0.1	56.35	13.65	1.49	10.08	13.76
9	0.113	56.44	13.56	1.48	11.2	13.69
10	0.1256	56.53	13.47	1.47	12.38	13.59
11	0.138	56.63	13.37	1.46	13.41	13.5
12	0.153	56.74	13.26	1.456	14.51	13.4
13	0.162	56.85	13.15	1.44	15.6	13.28
14	0.174	56.99	13.01	1.43	16.71	13.17
15	0.187	57.12	12.88	1.43	17.8	13.03
16	0.199	57.27	12.73	1.422	18.8	12.88
17	0.211	57.42	12.58	1.413	19.96	12.75
18	0.223	57.58	12.42	1.405	21	12.42
19	0.235	57.75	12.25	1.397	22.1	12.24
20	0.247	57.76	12.24	1.390	22.3	12.06

Table 3. Radius of roller which will best suit to avoid bumps can be found and will at a distance h from centre of roller.

S	F	G	T	h	Rr
1	79.20	112	1.25	1.1245	13.94
2	79.22	112.01	1.2496	2.2496	13.98
3	79.25	112.04	1.2491	3.3736	13.95
4	79.29	112.07	1.2485	4.497	13.92
5	79.35	112.11	1.2475	5.6187	13.87
6	79.42	112.16	1.2464	6.7392	13.81
7	79.50	112.21	1.2452	7.8582	13.75
8	79.59	112.38	1.2438	8.9752	13.68
9	79.70	112.36	1.2420	10.089	13.59
10	79.82	112.44	1.2402	11.201	13.5
11	79.95	112.53	1.2382	12.3101	13.4
12	80.09	112.64	1.2360	13.416	13.29
13	80.25	112.75	1.2335	14.517	13.16
14	80.42	112.87	1.2309	15.6163	13.03
15	80.60	113	1.2282	16.7115	12.89
16	80.79	113.13	1.2253	17.80	12.74
17	81	113.28	1.2221	18.8878	12.51
18	81.21	113.43	1.2189	19.9701	12.41
19	81.44	113.60	1.2155	21.047	12.24
20	81.68	113.77	1.2119	22.119	12.05

- 3) **Force Calculation:-**When calculating force for mecanum wheel the forward, strafe and diagonal force can be obtained by,[2]

$$F_F = \frac{4 * T}{r} = \frac{4 * 10.61 * 10^3}{14} = 3031.42 \text{ N}$$

$$F_r = \frac{4 * T}{r} = \frac{4 * 10.61 * 10^3}{14} = 3031.42 \text{ N}$$

$$F_D = \frac{2T * \sqrt{2}}{r} = \frac{2 * \sqrt{2} * 10.61 * 10^3}{14} = 2143.54 \text{ N}$$

- 4) **Calculating velocity for mecanum wheel:-**

For calculating forward velocity, strafe velocity and diagonal velocity equations are [2].

$$V_f = w * r = 4.71 * 14 = 65.97 \text{ mm/s}$$

$$V_r = w * r = 4.71 * 14 = 65.97 \text{ mm/s}$$

$$V_D = w * (r/\sqrt{2}) = 4.71 * (14/\sqrt{2}) = 46.65 \text{ mm/s}$$



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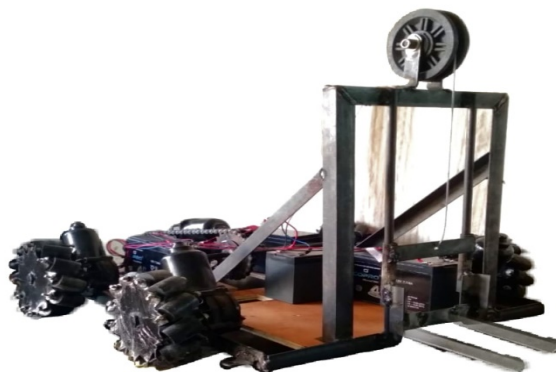
## IV. CONCLUSION

This paper reviewed study on multi-directional wheel and design and fabricate forklift with multi-directional wheels. Overall view over project shows that successfully achieved the objective of project such that fabrication of low cost loader vehicle model. With the help of proper selection of material for roller which has sufficient strength to carry required forces as well as reduce weight. Effective production of wheel plate by laser cutting lead to reduce overall cost of mecanum wheel. Also proper selection of mechanism for forklift lead to carry maximum weight for given power source. Here DC Lead Ion batteries are used that make use of electric energy which makes project go green and also model is portable that can be used in our small scale industry, in college workshop and also in many shop store in small scale application.

## V. ACKNOWLEDGEMENT

We take this opportunity to express our heartfelt gratitude towards the Department of Mechanical Engineering R. C. Patel Institute of Technology, Shirpur that gave us an opportunity for presentation of our project in their esteemed organization. It is a privilege for us to have been associated with Prof. P. L. Sarode, our guide during project work. We have been greatly benefited by his valuable suggestion and ideas. It is with great pleasure that we express our deep sense of gratitude to his for valuable guidance, constant encouragement and patience throughout this work.

### Final Modal of forklift with Multi-direction Mechanism



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