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Design and Development of Solar Assisted Electric Cart

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ABSTRACT

A cart is a vehicle designed for transport, using two wheels and normally pulled by one or a pair of draught animals. A solar vehicle is an electric vehicle which supplies all or most of its required power by converting solar radiation into electricity with the help of solar cells. The aim of this work is to design and develop a solar assisted electric cart that can be used for carrying loads and transporting people by villagers and farmers and also to reduce animal drudgery. As an initial investigation, the physical data of conventional cart used by farmers are collected based on which the motor and various parts of vehicle namely; Chain drive, Shaft, Suspension, Brakes etc. are selected for final development of cart. The FEM analysis is carried out to study the stress and displacements of the cart in order to ensure the safety. The basic performance of cart is evaluated in terms of its range, acceleration and maximum achievable speed. The final weight of cart so designed is 620 kg and load carrying capacity is found to be 800 kg. The achievable acceleration of cart is calculated as 1.2 m/s^2 with maximum achievable speed of 15 km/h with a power rating of about 1.5 kW out of which about 11.4% power is derived from solar radiation. The range of the cart is calculated as 44.75 km which seems to be reasonable for rural areas.

INTRODUCTION

While a majority of the world's current electricity supply is generated from fossil fuels such as coal, oil and natural gas, these traditional energy sources face a number of challenges including rising prices, security concerns over dependence on imports from a limited number of countries which have significant fossil fuel supplies, and growing environmental concerns over the climate change risks associated with power generation using fossil fuels. As a result of these and other challenges facing traditional energy sources, governments, businesses and consumers are increasingly supporting the development of alternative energy sources and new technologies for electricity generation. Renewable energy sources such as solar, biomass, geothermal, hydroelectric and wind power generation have emerged as potential alternatives which address some of these concerns. As opposed to fossil fuels, which draw on finite resources that may eventually become too expensive to retrieve, renewable energy sources are generally unlimited in availability [1-5].

Utilization of solar energy to power a vehicle has become an area of current research [6, 7]. It is worth to observe that development of solar assisted electric vehicles, auto rickshaw and golf cart have been reported in the literature [8-11], but the development of solar assisted cart to replace animal driven carts in rural areas in order to reduce animal drudgery is not traceable in the literature. Hence, the development of solar assisted electric cart which may prove to be a potential replacement of conventional animal driven cart which ultimately helps in reducing animal drudgery is the focus and scope of present work. The work of Raghavan and Rao [12] is taken as a base and after careful collection of data on recent bullock carts, a solar assisted electric cart is designed and developed wherein 11% of the power is derived from the sun. Dimensions and load capacity of the cart are selected based on the shape and functions of conventional cart. The FEM analysis is carried out to study the stress and displacements of the cart in order to ensure the safety. The basic performance of cart is evaluated in terms of its range, acceleration and maximum achievable speed.

DATA COLLECTION AND DESIGN

The physical data of conventional cart are collected based on which the motor and various parts of vehicle namely; Chain drive, Shaft, Suspension, Brakes etc. are selected for final development of cart. The following are the design considerations which are assumed for the Electric Cart based on study of existing carts and available literature [12] as given in **table 1**.

Table 1: Design Considerations for Electric Cart

Parameters	Case 1	Case 2
Load	1500 kg	1500 kg
Wheel Diameter	50 cm	60 cm
Maximum Velocity	10 kmph	10 kmph
Time required to attain maximum speed	40, 50, 60 seconds	40, 50, 60 seconds

The theoretical and actual power requirements of the electric cart is calculated for level road for selected configuration of cart considering aerodynamic and rolling resistances [13]. Based on power and speed requirements the key components are designed [14] and few are directly selected from available market keeping cost parameter in mind. The design calculations for few key components are given in **Appendix A**. The final specifications of designed and developed cart are given below in **table 2**.

Table 2: Final Specifications of the Cart

Parameters	Specifications	
Load on cart including self weight	1500 kg	
Wheel diameter	50 cm	
Maximum velocity	10 kmph	
Time required to attain maximum velocity	40 sec	
Acceleration	0.694 m/s^2	
Ideal power	1.219 hp	
Actual power	1.5049 hp	
Width of cart	140 cm	
Length of cart	300 cm	
Steering gear box	Rack and Pinion	
Chain drive	1500-375 rpm	375-125 rpm
Number of teeth on driving sprocket	23	25
Number of teeth on driven sprocket	92	75
Number of links	263	240
Centre distance	404.24 mm	604 mm
Pitch diameter of driving sprocket	69.95mm	75.99 mm
Pitch diameter of driven sprocket	278.98 mm	227.459 mm
Shaft material	50C4	
Inner diameter of hollow shaft	22.889 mm	
Outer diameter of hollow shaft	57.22 mm	
Bearing	Cylindrical roller bearing	
Bearing No.	NU 2212	

3D MODELLING AND STRESS ANALYSIS

3D MODELLING

3D modelling of the Cart is done using SOLIDWORKS. The model is designed such that the shape and functionality of conventional Cart should not be disturbed. Isometric view of the modeled cart is shown in the **figure 1**.

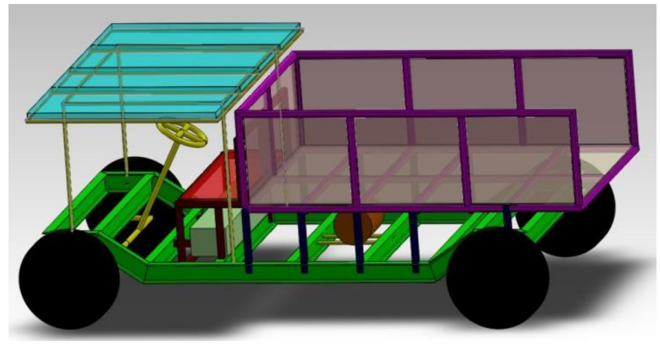

Figure 1 Isometric View of 3D Model

STRESS ANALYSIS

Stress analysis of different sections is carried out in order to know the strength of Carrier, Frame and Cart and to ensure its safety. The aim of the analysis is to determine whether the element or collection of elements, usually referred to as a structure, behaves as desired under the prescribed loading.

The stress analysis of different components of the cart is been done with the help of ANSYS 11.0 Software. The coordinates of the different elements was calculated from the design sketch of the model and the elements were appropriately connected to form the desired structure of the cart. The different components of the model are chassis, carrier and shaft. **Figure 2** shows the stress analysis of the cart.

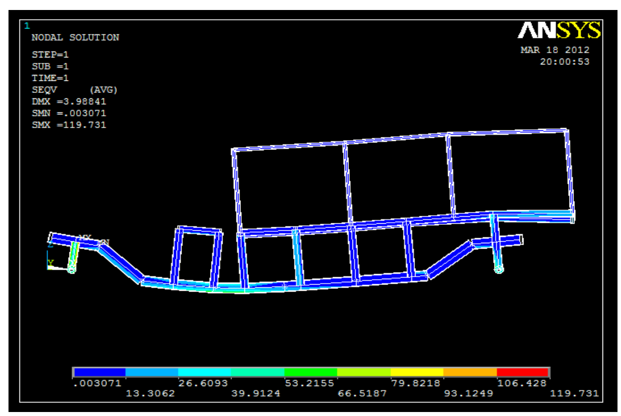

Figure 2 Stress Analysis of Combined Cart

Stress analysis of the Cart reveals that the maximum deflection is observed at a distance of 1.1 m from the front end of the frame which is 3.99 mm and the maximum stress is obtained as 119.731 N/mm^2 and minimum stress is 0.003071 N/mm^2 which is below the allowable Yield Strength of 380 N/mm^2 [14], hence the frame designed is appropriate.

This analysis allows us to use the parameters of frame and carrier for the fabrication of the Cart.

FABRICATION AND TESTING

The testing and fabrication of different components needed for the solar assisted electric cart have been done. The solar panel is tested on different days and time and the efficiency is calculated. The power supplied by the panel to the cart is calculated. RPM of the motor and shafts are measured under no load condition. Depending on the availability and access few modifications were made in the fabrication which are different from mathematical model.

Panel is tested for its efficiency as shown in the **Figure 3.** The ideal efficiency of panels which were used is 14.77% (at 25°C and 1000 W/m^2). Since, the panels were tested in the month of May when the temperature is in the range of 38-42°C and radiation is 600-1043 W/m^2, the actual efficiency was found to be 11.26% [4, 15]. Based on this the average percentage contribution of the power supplied to the motor by the panels throughout the year is found to be 11.44% [4, 15].

Appendix-B gives solar panel efficiency calculations.

Figure 3 Testing Panel under Variable Load

Finally the cart is fabricated as shown in the **Figure 4**.

Figure 4 Cart after Completion of Fabrication

Tests were conducted to calculate different performance parameters of the cart such as coefficient of static friction, rolling resistance and transmission efficiency, velocity, acceleration and range.

RESULTS

ROLLING RESISTANCE AND TRANSMISSION EFFICIENCY [13]

Rolling resistance, sometimes called rolling friction or rolling drag, is the force resisting the motion when a body (such as a ball, tire, or wheel) rolls on a surface. It is observed that the motor draws a current of 1A to rotate the wheels when held under no load. Based on this the power required to rotate the wheels under no load is calculated as:

Power = V*I = 220*1= 220 W

This value includes the efficiency of motor as well as transmission losses. Further, considering 220 W as a loss of power under no load and assuming it to remain constant, the overall transmission efficiency of the cart when motor derives the rated power of 1500 W may be obtained as 87%.

COEFFICIENT OF STATIC FRICTION [13, 14]

Static friction is friction between two or more solid objects that are not moving relative to each other. The coefficient of static friction, typically denoted as μ_s, is usually higher than the coefficient of kinematic friction. Static friction of the cart is tested in two different surface conditions. They are as follows:

a. Testing carried out in laboratory

b. Testing carried on road

The cart is tested for coefficient of friction under different load conditions and for self-weight of the cart, coefficient of static friction in laboratory and on road is found to be 0.0141 and 0.0183, respectively.

VELOCITY AND ACCELERATION [13, 14]

The acceleration of the cart is calculated based on the actual tests conducted on road. For a distance of every 5 m the time taken is measured. The average values of these measurements are selected to calculate the acceleration. On an average it is observed that the cart is reaching its maximum achievable acceleration as 1.2 m/s^2 and velocity as 15 km/h.

RANGE [16, 17]

It is observed that the overall voltage drop across the terminals is 2.6 Volts for a distance of 4.04 km as shown in the Fig 3. The maximum voltage that a 12.5 V lead acid battery can be discharged to is 10.9 V [17]. As the batteries are connected in series, the final voltage of the batteries after maximum allowable voltage drop is 196.2 V. Therefore the total distance that can be travelled when the cart is under continuous run is 44.75 km.

Overall specifications of cart after fabrication are given in the **table 3**.

Table 3: Specifications of Cart after Fabrication and Testing

Parameter	Value
Width	145 cm
Height	150 cm
Length	320 cm
Carrier	210*140*60 cm
Weight of the Cart	620 kg
Load capacity	800 kg
Power	1500 Watts

Acceleration	1.2 m/s^2
Speed	15 km/hr
Power required to overcome rolling resistance force under no load	220 Watts
Range- continuous run	44.75 km

CONCLUSIONS

The present work is towards the development of a solar assisted electric cart to replace the conventional animal driven carts used in rural areas in order to reduce animal drudgery. The approach adopted is based on survey of available draught animal driven carts based on which a basic configuration and load carrying capacity of the proposed cart is estimated. A self-weight of 620 kg and load caring capacity of 800 kg is finalized. Scientific approach of analysing the cart using FEM and designing the various components in a more systematic manner is highlighted. The complete development and testing of the vehicle is carried out based on available methodologies and constraints. The salient features of this journey are concluded below:

1. The FEM analysis of the cart indicates a maximum deflection of the chassis to be 3.59 mm and the stresses of the order of 119.73 N/mm^2 which is much below the allowable yield strength of 380 N/mm^2 and thus qualifies the design to be a safe one.
2. The power required to overcome the rolling resistance is observed to be 220 W for this cart which offers overall transmission efficiency as 87%.
3. The coefficient of static friction in laboratory and actual road condition is found to be 0.0141 and 0.0183, respectively.
4. The maximum achievable speed and acceleration of this cart is observed to be 15 km/h and 1.5 m/s^2 respectively.
5. The range of the cart in single charge is estimated as 44.75 km.
6. The average annual solar assistance which is derived from the panel is observed to be 11.4% for this cart.

In nutshell, the present work is a way forward to reduce animal drudgery and demonstrates an attempt towards development of an eco-friendly solar assisted electric cart suitable for rural applications.

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APPENDIX – A: DESIGN CALCULATIONS FOR FEW KEY COMPONENTS [13, 14]

Gear Design:

Gear is designed based on the torque transmission in the speed range of 750-250 rpm.

Table 4: Calculations for Gear Design

No.	Parameters	Values
1	Pinion Bending Endurance Strength , σ_{bp}	183.33 N/mm^2
2	Gear Beam Endurance Strength, σ_{bg}	183.33 N/mm^2
3.	Pinion Lewis Form Factor, Y_p	0.279
4.	Gear Lewis form factor , Y_g	0.4156
5.	Module, m	4 mm
6.	Beam Strength , F_b	511.49 * m^2 N
7.	Pitch Circle Diameter of Pinion, d_p	14 m
8.	Wear Strength, F_w	134.4 m^2
9.	Pitch line velocity, V	1.0995*m m/sec
10.	Effective load , F_{eff}	$\frac{397.908\,(6 + 1.0995 * m)}{m}$
11.	Centre Distance, a	112 mm
12.	Dynamic Load, F_d	59.010 N
13.	Effective load , F_{eff}	655.876 N
14.	Factor of Safety, N_f	3.278

Shaft Design

The material used for ordinary shafts is carbon steel of grades 40 C 8, 45 C 8, 50 C 4 and 50 C12. The mechanical properties of these grades of carbon steels are given below.

Table 5: Mechanical Properties of Steel Used for Shafts

Indian Standard Designations	Ultimate Tensile Strength, MPa	Yield Strength, MPa
40 C 8	560 – 670	320
45 C 8	610 – 700	350
50 C 4	640 - 760	370
50 C 12	700 Min	390

Based on the availability and mechanical properties, 50C4 is selected for the design.

Table 6: Calculated Values of Main Shaft Parameters.

Parameters	Values
Tangential strength T_1	752.54 N
Tangential Strength T_2	7.228 N
Maximum Bending Moment	1530 Nm
Design Torque	123 Nm
Equivalent Torque	3065.55 Nm
Material	50C4
Ultimate Strength S_{ut}	700 N/ mm^2
Yield Strength S_{yt}	380 N/ mm^2
Allowable Torque(min)	0.18*S_{yt} or 0.3*S_{ut}
Allowable Torque (keyway effect)	85.5 N/ mm^2
Solid Shaft diameter d	56.73 mm
Hollow outer diameter d_O	57.22 mm
Hollow inner diameter d_i	22.889 mm

Design Considerations for Bearings:

- Load on bearing F_r = 5000N
- Shaft Diameter d_s= 60mm
- No Axial Load
- Using trial and error method selecting Dynamic and static Load Capacity as C=29.60 KN and C_o=23.3 KN
- Machine for use 8hrs per day and not always fully utilized
- Life in hours L_H=15000
- Rotation factor V = 1(inner race rotating)
- Radial Factor X=1(single row)
- Load Factor K_a = 1.5 (machinery with moderate impact)

Table 7: Calculations of Bearing Parameters

Parameters	Values
Equivalent Dynamic Load P_e	7500 N
Life rating L_{10}	96.3 million revolution
Dynamic Load Capacity C	29.522 KN
Inner Diameter d	60 mm
Outer Diameter D	110 mm
Width B	28 mm
Thickness of outer radius r_o and inner radius r_i	2.5 mm , 2.5 mm
F=d+ 2r + clearance	73.5 mm

APPENDIX-B: SOLAR PANNEL EFFICIENCY CALCULATIONS [4, 15]

Given Specifications of panel:

a. Nominal Peak Power = 75W
b. Peak Power Voltage(V_{mp}) = 17V
c. Peak Power Current(I_{mp}) = 4.41A

For the given values the efficiency of the panel under standard conditions i.e. 1000W/m^2 Radiation and 25^{0}C is calculated as:

$$\eta = \left[\frac{Power}{Area * Input\ Power}\right]*100$$

$$= \left[\frac{75}{0.5077*1000}\right]*100$$

$$=14.77\%$$

The actual efficiency of the panel is different from its theoretical efficiency as the standard conditions do not remain same. Therefore the practical efficiency of panel is calculated by testing the panel under different loads at different times of a day. It is as given as below:

a. May 5th between 12-1 pm

$$\eta = \left[\frac{58.8528}{0.5077*1034.5188}\right]*100$$

$$= 11.21\%$$

b. May 6th between 10-11am

$$\eta = \left[\frac{45.549}{0.5077*837.4812}\right]*100$$

$$= 10.71\%$$

c. May 7th between 4-5pm

$$\eta = \left[\frac{32.7492}{0.5077*543.9378}\right]*100$$

$$= 11.87\%$$

Taking average of the above values, efficiency of the panel is taken as 11.26%.