Development and performance evaluation of a portable 50 kg capacity dc electrically powered shopping cart

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ABSTRACT

An improved direct current (DC) generic shopping cart with a maximum loading of 50 kg was developed to answer a long cry by retailers for improvement in the shopping cart and introducing innovation, improved ergonomics, stability, reduced cost and futurism to the shopping cart. Thus to achieve these, a DC electrical shopping cart was conceptualised. It incorporates an electrical motor, chain link transmission system, DC battery and switch, and utilizes all these components so as to eliminate the need of applying push for forward movement. To achieve the development of a number of activities, conceptualization, design, design analysis, static simulation, fabrication and testing, and performance evaluation were carried out. The capability of carrying 50 kg resulted in a 30% decrease in speed, revealing that the DC shopping cart though 100% efficient for the capability to carry its intended loading but its effectiveness is 70%. Upon testing, areas that need further development and improvement were identified.

Key words: Shopping cart, development, DC power, performance evaluation, cost analysis.

INTRODUCTION

The research was on the development and performance evaluation of a Direct Current (DC) electrical powered shopping cart. A DC electrical shopping cart is a device that is intended to be used in shopping malls for carrying the groceries of customers and help in loading and unloading of retailer's inventory. The D.C. powered shopping cart was re-imagined from a totally new perspective, thereby opening doors to numerous concepts and ideas.

Modern information is available in the public domain. Theoretical and methodological contributions that have been developed are intended to be used in the development and performance evaluation of the DC electrical shopping cart. Shopping is an activity in which a customer/consumer skims through the available goods, commodities such as appliances, food stuffs, clothing e.t.c or services rendered by a single of multiple suppliers with the intention of exchanging the goods or services for its equivalent monetary value (Wilson, 1978). The DC electrically powered shopping cart aims to knock off the bad qualities of the shopping experience, consequently improving the overall shopping experience and creating a larger customer base which will result in increased profit. Shopping Malls are destinations sometimes also referred to as shopping centres or arcade. The terms are used to refer to a massive building housing sub-units of shops all interconnected with walkways, escalator, elevators in order to allow visitors navigate through the entire building with ease and comfort as they search for items/services they are looking to purchase (Afis, 2017). This is the intended destination for possible implementation of the DC electrical shopping cart.

A Cart is a vehicle that is used in transporting items from one location to another when loaded. It is equipped with two or more wheels in order to achieve forward movement when mechanical force is applied to it parallel to the axis of the wheels (Dennis, 2017). A shopping cart is a kind of Cart that is supplied by a shop or supermarket to aid customer/consumers in manoeuvring their isles and to the check-out counter after they have selected all the items they are looking to buy and then to transfer the items to their vehicles (Bowman, 2012).
Nur Ain Izzati Binti Zainudin of the University of Malaysia Pahang, carried out the development of a foldable wet shopping cart. This is a device which users put their groceries in while shopping. The design considers durability, ease of use and ergonomics factor. The concept of the foldable wet shopping cart brought more innovation to the shopping cart with special consideration for the Asian user. The DC electrical Shopping cart differs from the foldable wet shopping cart in the sense that it utilises electrical motors and a motion transmission system to eliminate the need of applying force to initiate movement. This set it apart from the foldable wet shopping cart (Zainudin, 2016).

Robert Shultz and Sandor Imre of the BME Department of Telecommunication, carried out a project to summarize the problem that may arise in a so-called ‘intelligent shopping cart’. This is a special shopping cart that is capable of recognising the wares/groceries equipped with RFID tags. The intelligent shopping cart is able to register the wares collected in the cart with EPC standard tags and utilize wireless communication technology to have access to a central databases so that information about the ware is obtained. The intelligent shopping cart does not take into consideration improvements on mobility, design and ergonomics, the DC shopping cart does all this and implements electrical motors and motion transmission system to eliminate the need of actually pushing the shopping cart (Shulcz and Imre, 2008).

There has been a sizeable lack of innovation in the design of shopping carts to the extent that there was a large outcry by retailers in America requesting for innovations in the product, to the extent target multi-national conglomerate Target Hired Boston based Think-tank Continuum to re-invent the shopping cart (Cook, 2011).

Hence, The development and Performance evaluation of the 50 kg DC Electrical Shopping Cart that is ergonomically developed and aesthetically pleasing to sight

**METHODOLOGY**

The methodology involved component identification, design analysis, as well as the developed shopping cart performance evaluation.

**Design analysis of the DC shopping cart**

**Components used for the development**

The DC shopping cart contains the following components: Basket, Handle, Bottom Plate, Wheel shaft, Shaft connector, Load Platform, Chain Drive

**Design analysis of the basket**

This is the component that is responsible for holding the groceries of the shopper:

\[ V_{BCR} = A_{top} \times \text{Height of basket} \]  
\[ V_{BCR} = 0.315 \, m^3 \]

b). Hollow Column Tubes

\[ V_{tot} = 0.00048 \, m^3 \]

We need to total length of the beam.

Applying Pythagoras theorem:

\[ L = 1.08m \]

The total length of the trapezium bar is \( L_{TR} \):

\[ L_{TR} = 3.36m \]

\[ V_{PLATE} = A_{top} \times \text{Thickness} \]
\[ V_{PLATE} = 0.00504 \]

**Design analysis of the handle**

The handle is responsible for the mounting of the switch and making changes in direction of the shopping cart:

\[ V_{UP} = \pi \times (r_i^2 - r_o^2) \times h \]
\[ V_{UP} = 0.0000481 \, m^3 \]

Let the volume of the lower bar be \( V_{LOW} \):

\[ V_{LOW} = 0.00453 \, m^3 \]
Design analysis of the bottom plate

This will be the component of the frame to which the wheel shaft, the battery, electrical motor, wheels and charging ports will be hinged to.

Let \( A_R1 \) and \( A_R2 \) be the area of the first and second rectangle respectively:

\[
A_R1 = 0.075m^2; \quad A_R2 = 0.075m^2
\]  

**TOTAL TOP AREA (TTA)** = \( A_R1 + A_R2 \)

\[
TTA = 0.15m^2
\]  

\[
V_{BP} = TTA \times \text{thickness}
\]

\[
V_{BP} = 0.003m^3
\]

Design analysis of the wheel shaft

The wheel shaft is a hollow cylinder with a sprocket in the middle which will receive the rotary motion of the DC motor and transmit it to the wheels at the end of the shaft.

Let the volume be \( V_{ws} \) be the volume of the wheel shaft:

\[
V_{ws} = \pi \times (r_i^2 - r_o^2) \times h
\]

\[
V_{ws} = 8.82 \times 10^{-5}m^3
\]

Design analysis of the wheel shaft connector

This is the component that will be responsible in holding up the wheel shaft in place while it rotates:

\[
V_{sb} = \pi \times r^2 \times h
\]

\[
V_{sb} = 3.393 \times 10^{-6}m^3
\]

For the hollow cylinder:

\[
V_{HO} \approx 4 \times 10^{-7}m^3
\]
Table 1: Table for material selection for the DC shopping cart.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Component</th>
<th>Possible materials</th>
<th>Selected Material</th>
<th>Reason For Selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Basket</td>
<td>mild steel, aluminium, iron, titanium, zinc, stainless steel</td>
<td>Aluminium 2011</td>
<td>Aluminium has high abundance, this makes it cheaper; aluminium is light weight; aluminium has significant amount of strength</td>
</tr>
<tr>
<td>2</td>
<td>Handle</td>
<td>Stainless steel, aluminium 2011, tungsten, Inconel, Titanium, Carbon steel</td>
<td>Aluminium 2011</td>
<td>Aluminium 2011 has high corrosion resistance, Aluminium has sufficient strength to support the intended loading Aluminium is light weight</td>
</tr>
<tr>
<td>3</td>
<td>Bottom Plate</td>
<td>Aluminium 2011, Mild steel, Stainless steel</td>
<td>Aluminium 2011</td>
<td>Aluminium is light weight, Aluminium has great machinability, weldability</td>
</tr>
<tr>
<td>4</td>
<td>Tyre shaft</td>
<td>Aluminium 2011, Stainless steel, Titanium, Inconel</td>
<td>Aluminium 2011</td>
<td>Aluminium is light weight, thereby reducing inertia during spin by the rotor</td>
</tr>
<tr>
<td>5</td>
<td>Wheel Shaft</td>
<td>Mild steel, Aluminium 2011, Titanium, Stainless steel</td>
<td>Aluminium 2011</td>
<td>Aluminium has high strength to support the shaft, Aluminium has high availability</td>
</tr>
<tr>
<td>6</td>
<td>Bevel Gear</td>
<td>Cast Steel, Mild Steel, Stainless Steel, Carbon Steel</td>
<td>Mild Steel</td>
<td>Mild steel has the required sufficient strength, Mild steel has low wear rate, Mild steel is low cost</td>
</tr>
</tbody>
</table>

Table 2: Table of Mass estimate of the various components.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Component</th>
<th>Selected material</th>
<th>Component Volume (M³)</th>
<th>Density of selected material (Kg/M³)</th>
<th>Mass(Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Basket</td>
<td>Aluminium 2011</td>
<td>0.0029</td>
<td>2700</td>
<td>7.83</td>
</tr>
<tr>
<td>2</td>
<td>Handle</td>
<td>Aluminium 2011</td>
<td>0.0043331</td>
<td>2700</td>
<td>11.7</td>
</tr>
<tr>
<td>3</td>
<td>Bottom Plate</td>
<td>Aluminium 2011</td>
<td>0.003</td>
<td>2700</td>
<td>8.1</td>
</tr>
<tr>
<td>4</td>
<td>Tyre Shaft</td>
<td>Aluminium 2011</td>
<td>8.82 × 10⁻⁵</td>
<td>2700</td>
<td>0.23814</td>
</tr>
<tr>
<td>5</td>
<td>Shaft Holder</td>
<td>Aluminium 2011</td>
<td>7.586 × 10⁻⁶</td>
<td>2700</td>
<td>0.0205</td>
</tr>
<tr>
<td>6</td>
<td>Sprocket</td>
<td>Mild Steel</td>
<td>4.321 × 10⁻⁵</td>
<td>7700</td>
<td>0.3333</td>
</tr>
</tbody>
</table>

\[
\delta_{\text{MAX}} = 17.15 \times 10^{-9} m
\]

\[
\theta_{\text{MAX}} = \frac{WL^3}{6EI}
\]

\[
\theta_{\text{MAX}} = 22.45 \times 10^{-9}
\]

Design analysis for motor power

The selected motor has a rated torque of 100 kg.cm; the rated speed is 8 rpm which will be ideal for indoor use:

\[
\text{Power} = \text{Torque} \times \text{Angular Speed}
\]

\[
\omega = \frac{2 \times \pi \times N}{60}
\]

\[
\omega = 0.83776 \text{rad/s}
\]

\[
\text{Power} = 83.776 \text{ Watts}
\]

Design analysis for sprocket

The motor Sprocket diameter is \( D_M \); The shaft Sprocket diameter is \( D_S \):

\[
D_M = 50\text{mm}; \ D_S = 54\text{mm}
\]

\[
\omega_m = 0.83776 \text{ rad/s}
\]
Pitch Circle Diameter

\[ VR = \frac{N_{DR}}{N_{SH}} = \frac{T_{SH}}{T_{DR}} \]  

(17)

\[ N_{SH} = 1.25664 \text{rad/s} \]

\[ P.C.D. = \frac{D_{SH}}{D_{DR}} \]

(18)

\[ P.C.D. = 1.08 \]

Velocity of chain

\[ V_{CH} = \frac{\pi \times PCD \times P}{60} \]

\[ V_{CH} = 0.0017 \text{m/s} \]

(19)

Velocity Ratio

\[ VR = \frac{N_{DR}}{N_{SH}} = \frac{T_{SH}}{T_{DR}} \]

(20)

\[ VR = 1.5 \]

**Design analysis of the wheel shaft**

The power the shaft will be transmitting is \( P_s \):

\[ P_s = T \times \omega_s \]

(21)

\[ T = 9.81 \text{N.m} \]

Power = 8.870 Watts

\[ R = \left( \frac{6.5}{1000} \right) \]

Recall Classical Torsional Equation

\[ \frac{T}{I} = \frac{\tau_{MAX}}{R} \]

(22)

\[ 7.4 \text{ GN/m}^2 = \tau_{MAX} \]

**Design analysis for the bottom plate**

This can be modelled as a simply supported beam with a point load as shown in Figure 1.

Reaction at B,

\[ R_b = 392.83 \text{N} \]

Recall Classical Torsional Equation

\[ \frac{T}{J} = \frac{\tau_{MAX}}{R} \]

(22)

\[ 7.4 \text{ GN/m}^2 = \tau_{MAX} \]

**RESULTS AND DISCUSSION**

The results from the additive loading are shown in Tables 3 to 5

**Mass to time plot**

The graph of mass to time exhibits a direct proportional variability. The graph plotted is shown in Figure 5 and it resulted in the equation below:

\[ Y = 3.8x - 109.4 \]

(25)

Where \( Y \) is the Mass and \( x \) is the Time in seconds

**Mass to speed plot**

The graph of mass to speed exhibits inverse proportionality variability. The graph plotted resulted is shown in Figure 6 and the equation it exhibits is derived through least squares show as:

\[ Y = -832.5x + 168.2 \]

(26)

Where \( Y \) is the Mass and \( x \) is the Speed in Meters Per Seconds
Figure 1: Simply Supported loading of the DC shopping cart.

Figure 2: Isometric View of the DC electrical shopping cart.

Figure 3: Orthographic view of the DC electrical shopping cart.
**Figure 4:** Fabricated DC electrical shopping cart.

**Figure 5:** The graph of mass to time exhibiting a direct proportional variability.
Figure 6: The graph of mass to speed exhibiting inverse proportionality variability.

Figure 7: A graph exhibiting direct proportionality.
Mass to speed drop plot

The graph exhibits direct proportionality as shown in Figure 7. The obtained equation for the graph is shown below through least squares method:

\[ Y = 1.63x + 4.41 \]  
\[ \text{(27)} \]

Where \( Y \) is the Mass and \( x \) is the Speed Drop in percentage

For Stall Mass, this will be the greatest loading of the DC electrical shopping cart

\[ \text{when } x = 100 \]

\[ Y = 167.41kg \]

CONCLUSION AND RECOMMENDATIONS

The 50 kg capacity DC shopping cart was developed and its performance evaluation of a DC electrical shopping cart was carried out. Based on the activities carried out for the completion of the project spans from the conceptualization, design, design analysis, fabrication and testing of the DC shopping cart, the load designed for the DC shopping cart to carry is 50kg and this forms a part of the goals which is to be able to carry 50 kg. The DC electrical shopping cart was designed using solid works and proceeded to fabrication. As soon as the fabrication was completed, the DC electrical shopping cart was tested by additive loading at 8 kg steps and the time to cover a particular distance was measured alongside the mobility at each loading level. The DC electrical shopping cart effectively and efficiently carried a load of 50 kg with 30% speed drop at a speed of 0.140 m/s. Thus this speed is ideal for the intended indoor usage of a shopping mall and will allow the user to browse through items on the aisle with convenience.

1. Automatic follow: This is a feature that will require sensors that provide speed control to match the speed at which the shopper/user is moving at.
2. Baby carriage: The fabricated DC shopping cart does not have an allowance for babies considering that a major target audience of use is women
3. Two-way movement: The DC motor used allows for one way movement, that is, strictly forward. A two-way motor will allow for possible reversal of the shopping cart with relative ease without the round-about turn presently required.

REFERENCES


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