

Design and Fabrication of a Hydraulic Disc Brake Demonstration Apparatus

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ABSTRACT

This paper presents a detailed and fabrication of a low cost hydraulic disc brake demonstration apparatus. The paper shows the relevance of the apparatus for teaching in both schools and skill acquisition institutes on the working principles of a common hydraulic brake system. This was achieved by designing for the chain and gear drive, failure of the bolted and welded joints as well as the structural analysis. A simple hydraulic brake faults and diagnosis was presented. More than 85% of the materials used in the fabrication were locally sourced.

Key words: Hydraulic, Disc, Brake, Gear, Chain, Fabrication.

1.0 INTRODUCTION

Newton's first law of motion allows for a body at rest to continue at rest or that in motion to continue in motion. What this entails is that a moving car will continue moving unless its energy can be converted to another form, brakes serve this purpose (Khurmi et al, 2004). By definition, a brake is a device by means of which artificial frictional resistance is applied to a moving machine member, in order to retard its motion or stop the motion. In performing this function, brakes absorb the kinetic energy of the moving members or potential energy given up by the objects being lowered. The absorbed energy is dissipated in the form of heat to the surrounding air. Brakes are commonly classified according to the means by which they are actuated (Breuer et al, 2008):

- Mechanically actuated brakes
- Hydraulically actuated brakes
- Pneumatically actuated brakes.

Until 1917, brakes were mechanically actuated and operated (Breuer et al, 2008). Mechanically operated brakes were complex mechanical systems and as such turned out to be problematic in day-to-day use. Despite regular maintenance including careful lubrication and adjustment of all moving parts, influence from the environment and normal wear and tear regularly led to varying level of friction across the mechanical components of the transmission, ultimately leading to uneven braking forces at the wheel and eventually "brake pull" (Breuer et al,2008).

Braking is achieved by friction between a braking element and the moving machine element. The braking element may be divided into groups according to the direction of acting force; these are (Khurmi et al, 2004):

- Radial brakes
- Axial brakes

In the radial braking element, the force acting on the brake drum is radial in direction and they maybe sub-divided into external and internal brakes. Examples of external brakes are the block or shoe brakes and the band brakes. An example of the internal brake is the drum brake. Various arrangement of the drum brakes include:

- Leading and Trailing shoe (L&T)
- Two Leading shoe (2LS)
- Duo-Servo

For the axial braking element, the force acting on the brake system is in the axial direction. The axial brakes include the disc and cone brakes.

The hydraulic disc brake demonstration apparatus is one of those systems that can be used to understand the working principle of the brake system as well as to diagnose the system for possible faults and carry out repairs.

Hydraulic disc brake demonstration apparatus finds application in

- Schools and educational centres
- Skill acquisition centres.
- Automobile workshops.

3.0 DESIGN CONSIDERATIONS

The design and fabrication of a hydraulic brake system demonstration apparatus requires some considerations. These include:

1. **Feasibility / Viability**:
The question of whether the design and fabrication of the hydraulic brake system demonstration apparatus is possible and likely to be achieved is brought into view. The design and fabrication of the apparatus is practicable because there are various machines/systems that have put into use the hydraulic brake system.

2. **Cost:**
One of the objectives of this research is to design and fabricate a low-cost hydraulic brake system apparatus; hence the total cost of the project must be brought to a minimum to increase the chances of the product being highly marketable.
3. **Functionality:**
This has to do with whether or not the apparatus functions as it was intended to.
4. **Maintainability**:
One of the primary objectives of this apparatus is to simplify the diagnosis and maintenance of hydraulic brake systems; hence the apparatus should be designed to receive little or no secondary maintenance.
5. **Safety:**
The question of whether the object is safe to use, have only non-toxic and non-hazardous material, or whether the object conforms to standards and regulations is brought up. Although moving parts are exposed to allow natural convection and visibility to the users, they are constrained to enclosed sections to minimize accident. Non toxic and hazardous materials are used. Safety apparatus would be used in its fabrication and factor of safety will be highly emphasized in the design.
6. **Ergonomics:**
The apparatus will be operated by humans, hence the size, shape, weight and materials used must suit the user.
7. **Friction/wear and vibration/noise:** Moving parts introduces friction and vibration which results in wear and noise. Friction and vibration should hence be controlled to the minimum.
8. **Material Selection:**
The selection of materials for a project is often a careful compromise between the properties of the material (mechanical properties), the material reliability, the material efficiency and the material cost.
For the design and fabrication of a hydraulic brake system demonstration apparatus, the materials are selected based on:
    - Mechanical tendency of the material
    - Cost of the materials

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3.0 DESIGN CALCULATIONS

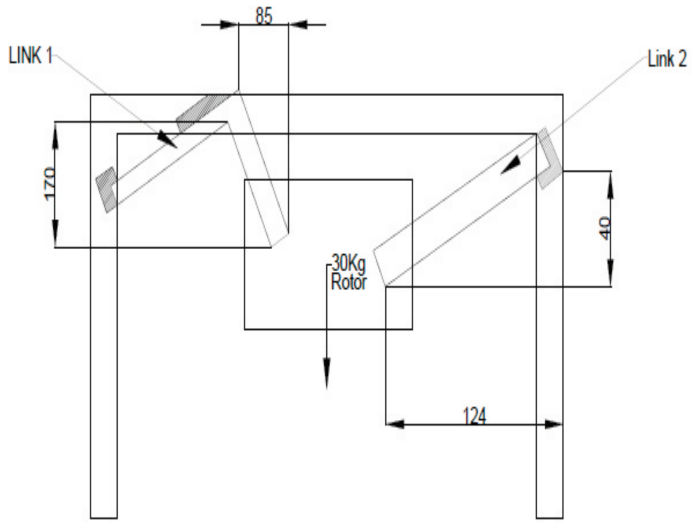


Fig 1.0

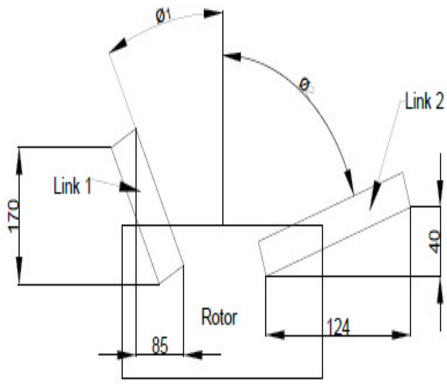


Fig. 2.0

3.1 Failure of Bolts Holding the Rotor and Caliper

Referring to Fig. 1.0 and Fig. 2.0

$\theta_1 = [90^\circ - (\tan^{-1}(17/8.5)]$; $\theta_1 = 90^\circ - 63.4 = 26.6^\circ$

$\theta_2 = [90^\circ - (\tan^{-1}(4/12.4)]$; $\theta 2 = 72.1^\circ$

Resolving T_1; we have, $T_1\cos\theta_1 = T_{y1}$; $T_{y1} = T_1\cos 26.6^\circ$

$T_{y1} = 0.89T_1$

$T_{x1} = T_1\sin 26.6^\circ$; $T_{x1} = 0.45T_1$

Resolving T_2; we have

$T_{y2} = T_2\cos\theta_2 = T_2\cos 72.1^\circ$; $T_{y2} = 0.31T_2$

And

$T_{x2} = T_2\sin 72.1^\circ$; $TX2 = 0.95T_2$

Weight of rotor and caliper = W_{RC}

$W_{RC} = 30kg * 9.81m/s^2 = 294.3N$

From $\sum F_x = 0$; $\sum F_y = 0$; $-T_{X1} + T_{X2} = 0 - 0.45T_1 + 0.95T_2 = 0$

$0.95\,T_2 = 0.45T_1$; $T_1/T_2 = 2.11$

$T_1 = 2.11T_2$ ………………………………… (i)

Again

$T_{y1} + T_{Y2} - W_{RC} = 0$

$0.89\,T_1 + 0.31T_2 - 294.3 = 0$

$0.89\,T_1 + 0.31T_2 = 294.3$

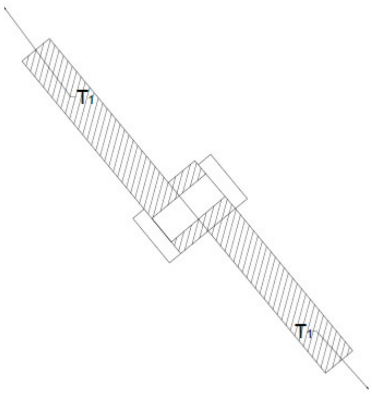
But $T_1 = 2.11T_2$; $0.89(2.11T_2) + 0.31T_2 = 294.3$

$1.88T_2 + 0.31T_2 = 294.3$

$2.19T_2 = 294.3$

$T_2 = 294.3/2.19 = 134.4N$

$T_1 = 2.11T_2$; $T_1 = 2.11(134.4)$; $T_1 = 283.6N$



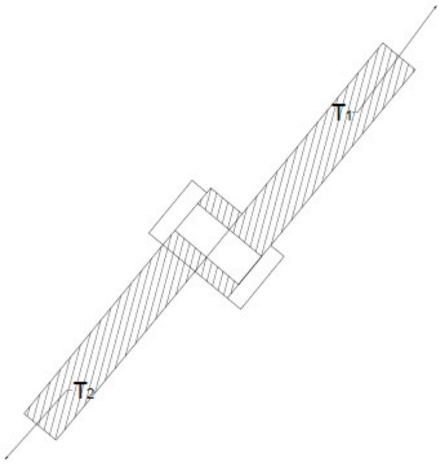


Fig. 3.0 Fig. 4.0

Bolts connecting rotor to the frame

For link 1, referring to Fig. 3.0

Shear stress on the bolt $\tau_{B1} = F_{B1}/A_{B1}$

Where F_{B1} = shear stress on bolt 1 = T_1 and
A_{B1} = cross sectional area of the shank of the bolt 1
$A_{B1} = \pi D_1^2/4$
$\tau_{B1} = T_1/\,(\pi D_1^2/4) = 361.3/D_1^2$

Shear stress of material of bolt (mild steel)

$\tau = 80N/mm^2$
$D_1^2 = (361.3/80) = 4.5mm$
$D_1 = 2.13mm$

For link 2; referring to Fig. 4.0

Shear stress on bolt $\tau_{B2} = F_{B2}/A_2$

$\tau_{B2} = T_2/\,(\,\pi D_2^2/4)$

$\tau_{B2} = 171.2/\,D_2^2$

From B.S. 499 and C.P 112, for mild steel single shear stress for bolt = $80N/mm^2$

$80 = 171.2/D_2^2$

$D_2^2 = \sqrt{2.14} = 1.46mm$; $D2 = 2mm$

Hence; for factor of safety to be greater than 1 F.S. > 1; $D_2 > 2mm$

3.2 Failure of Weldment

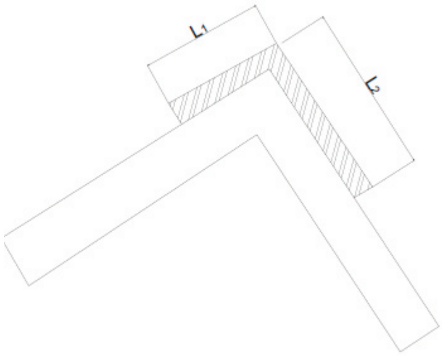


Fig. 5.0

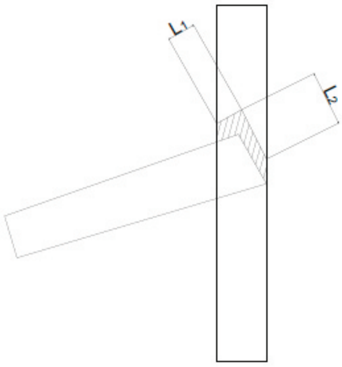


Fig. 6.0

Failure of welded joints

For link 1; referring to Fig. 5.0

It suffers an axial pull of $T_1 = 283.6N$

Using a single transverse and single parallel weld

$P = 0.707s * L_1 * \delta_1 + 0.707s * L_2 * \tau$

Where P = axial load

s = size of the weld = thickness of material

L_1 = length of the weld = L_2

τ = shear strength of weld/ material

P = 283.6N; s = 1.27mm for gauge 18 angle bar

$\tau = 115N/mm^2$, $\delta = 155N/mm^2$

Let $L_1 + L_2 = L$; and if $L_1 = L_2$;

$283.6 = 0.707(1.27) * L_1 *155 + 0.707(1.27) * L_2 * 115$

$283.6 = 139.2L_1 + 103.3\ L_2$; If $L_1 = L_2$;

$283.6 = 139.2L_1 + 103.3\ L_1$

$283.6 = 242.\ 5\ L_1$; $L_1 = 1.67mm$

$L = L_1 + L_2 = 1.67 + 1.67 = 3.34mm$

Length of weld $L \geq 3.34$

Or $L_1 + L_2 \geq 3.34mm$;

For link 2; referring to Fig. 6.0

Using a single transverse and double parallel weld

$P = 0.707s * L_1 * \delta_t + 0.707s * L_2 * \tau$

$L_1 = L_2$; $P = T_2 = 134.4N$

$134.4 = 0.707(1.27) * L_1 * 155 + 0.707(1.414) * L_2 * 115$

$134.4 = 139.2\ L_1 + 117.1L_2$, Where $L_1 = L_2$; $134.4 = 139.2\ L_1 + 117.1\ L_1$

$134.4 = 256.3\ L_1$; $L_1 = 0.52mm$

$L_1 + L_2 = 0.52 + 0.52 = 1.04$ mm; Length of weld $L > 1.04mm$

3.4 Design of the Chain Drive

The chain drive is used to drive the rotor. It is powered by a DC motor with specification

Power = 160 watt

Speed = 50 rpm

Voltage = 12 V DC

Torque = 11.5 Nm

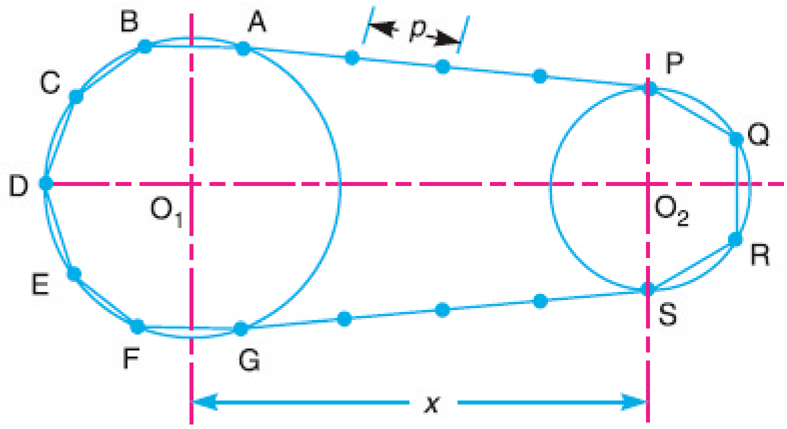


Fig. 7.0
Chain drive

Velocity ratio (V.R.) = $\frac{N_1}{N_2} = \frac{T_2}{T_1} = \frac{38}{15} = 2.53$

Where N_1 and T_1 = speed and number of teeth on small sprocket,

N_2 and T_2 = speed and number of teeth on big sprocket

$N_2 = \frac{N_1}{V.R.} = \frac{50}{2.53} = 19.8$ rpm

Design power = rated power * service factor (K_s)

Load factor (K_1) = 1 for constant load

Lubrication factor (K_2) = 1.5 for periodic lubrication

Rating factor (K_3) = 1, for 8 hours per day

Service factor $K_s = K_1 * K_2 * K_3 = 1 * 1.5 * 1 = 1.5$

Design power = 1.5 * 200 = 300watts

Using the British standard chain drive selection power rating graph

300watts = 0.3KW at 50 rpm corresponds to a 08B chain

A 08B chain has the following specification:

Pitch (p) = 12.7mm ≈ 13mm

Roller diameter (d_1) = 8.51mm ≈ 9mm

Breaking load for simple chain = 17.8KN

W_B = 17.8 KN = 1.78 * 10^3 N

Pitch circle diameter of the smaller sprocket d_1;

$d_1 = p \operatorname{cosec} (180/T_1) = 13 \operatorname{cosec} (180/15)$

d_1 = 62.5 mm ≈ 0.063m

Pitch circle diameter of the larger sprocket d_2;

$d_2 = p \operatorname{cosec} (180/T_2) = 13 \operatorname{cosec} (180/38)$

Pitch line velocity of the smaller sprocket

$V_1 = (\pi d_1 N_1)/ 60 = (3.14 * 0.063 * 50)/60 = 0.16$m/s

Load on the chain, W = Rated power / Pitch line velocity

W = 200/0.16 = 1.25 KN = 1250N

Factor of safety, n = W_B/W = (17.8/1.25) = 14.24 ≈ 14

From tables for factor of safety (n) for bush roller chain;

At 50 rpm for pinion speed, and pitch of chain 12-15mm; n= 7

This value is lower than the calculated factor of safety which is 14.

Minimum center distance between the smaller and larger sprockets should be 30-50 times the pitch

Using 30 times the pitch we have;

x = 30p = 30 * 13 = 390mm

In order to accommodate initial sag in the chain, the value of center distance is reduced by 2-5mm.

The correct center distance, x = 385mm

Length of chain L = KP

Where k = number of chain links

$k = (T_1 + T_2/2) + (2x/p) + [(T2 - T1)/2\pi]^2 \, p/x$

$k = (15 + 38/2) + (2*285/13) + [(38 - 15)/2* 3.14]^2\ 13/285$

$k = 70.9 \approx 71$ chain links

$L = KP = 71 * 13 = 923mm \approx 0.923m$

3.5 Design of Gear Drive for the Pump

A gear drive for the pump is required to reduce the speed while increasing the torque required to drive the alternator/vacuum pump assembly.

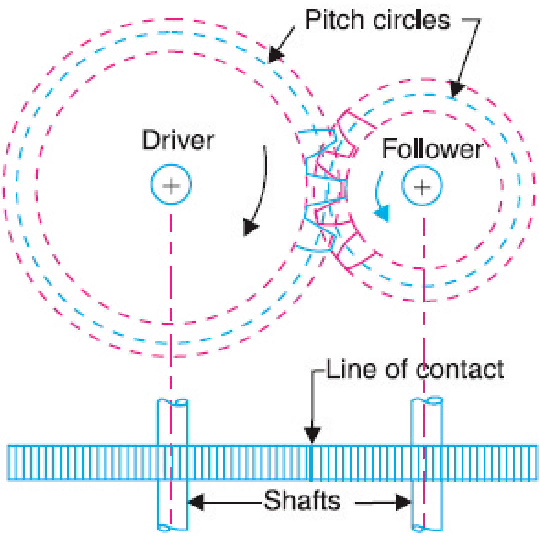


Fig. 8.0
Gear drive

The specifications for the motor are:
Power = 249W
Speed = 2650rpm
Voltage = 12V DC
Speed of gear 1, N_{G1} = speed of the motor = 2650rpm
The diameters of the gears are: $d_1 = 10$, $d_2 = 65$, $d_3 = 35$, $d_4 = 125$mm
$V.R = N_{G1}/N_{G2} = d_2/d_1$
$N_{G2} = N_{G1}d_1/d_2 = 2650(10/65) = 407.7$rpm
Since gear 2 and 3 are driven by a common shaft; $N_{G2} = N_{G3}$
Velocity Ratio = $N_{G3}/ N_{G4} = d_4/d_3$
$N_{G4} = N_{G3}d_3/d_4 = 407.7(35/125) = 114.2$rpm
The speed of the shaft carrying the alternator and pump is $N_{G4} = 114.2$rpm. Neglecting frictional losses and assuming the drive is 100% efficient, then;
Power output = power input = 249W
The power driving the shaft is 249W.
The torque required to drive the assembly;
$\omega = 2\pi N_{G4}/60 = (2*3.14*114.2)/60$
$\omega = 11.95 \approx 12$ rads/s
$T = P/\omega = 249/12$; $T = 20.75$Nm

4.0 FABRICATION AND ASSEMBLY OF PARTS.

Appropriate operational sequence was applied to produce each specific part of the apparatus to the desired dimensions. The production of the parts involves typical workshop operations like cutting, machining, drilling, shaping, welding, etc. The parts are arranged and assembled accordingly using the appropriate drawings provided. To give the demonstration apparatus an appealing look and to prevent corrosion of the mild steel parts, painting operation was carried out

5.0 DIAGNOSIS AND MAINTENANCE OF THE HYDRAULIC BRAKE DEMONSTRATION APPARATUS

The following faults could be detected using the hydraulic disc brake system demonstration apparatus.

FAULTS	CAUSES	REMEDY
Pedal requires pumping	Shoe requires adjustment.	Adjustments
Springy pedal	Air is present in the system.	Bleeding
Spongy pedal (pedal creeps downwards)	Leakage is present in the system.	Replace appropriate seal
Noise from the caliper-rotor assembly	Worn shoes or lining.	Replace
Fluid leaking from the caliper	Damaged or worn piston seal. Scores or corrosion on piston or in caliper bore.	Replace Service caliper
No braking when pedal is fully depressed	Air in hydraulic system Leak in hydraulic system. Damaged piston seal. Piston pushed back in caliper	Add fluid, bleed system Repair. Replace. Pump brake pedal, check shoe position.
Fluid level low in master cylinder	Leaks Worn linings	Repair, add fluid and bleed system. Replace.

5.1 BLEEDING THE BRAKES

Bleeding is necessary to remove air from the brake system whenever it enters. The main steps involved in the bleeding operation are as follows:

a) Ensure that the reservoir is filled with brake fluid.
b) Attach one end of a rubber tube to the bleed valve or nipple and immerse the other end in brake fluid placed in a jar.
c) Open the bleed valve slowly and slowly operate the brake pedal until air bubbles cease to appear. Close the bleed valve as the pedal is depressed.
d) Repeat the operation for the other wheel cylinders.
e) Top the reservoir with brake fluid up to the maximum mark.

6.0 CONCLUSION AND RECOMMENDATION

The ultimate aim of this work has been achieved by the detailed design and fabrication of a functional a hydraulic disc brake system demonstration apparatus. It was produced with locally sourced material at a very low cost of production. The work recommends as follows:

- Further works should include that of a complete brake circuit.
- The use of lighter materials should be encouraged to reduce the weight of the apparatus.
- Auxiliary systems such as anti-lock braking (ABS), electronic brake force distribution system (EBFD) and traction control system (TCS) should be incorporated in the design.
- Government and corporate organizations should encourage and assist prospective entrepreneurs by granting them to engage in the manufacture of such machines to aid ease of technical learning in schools and automobile workshops.

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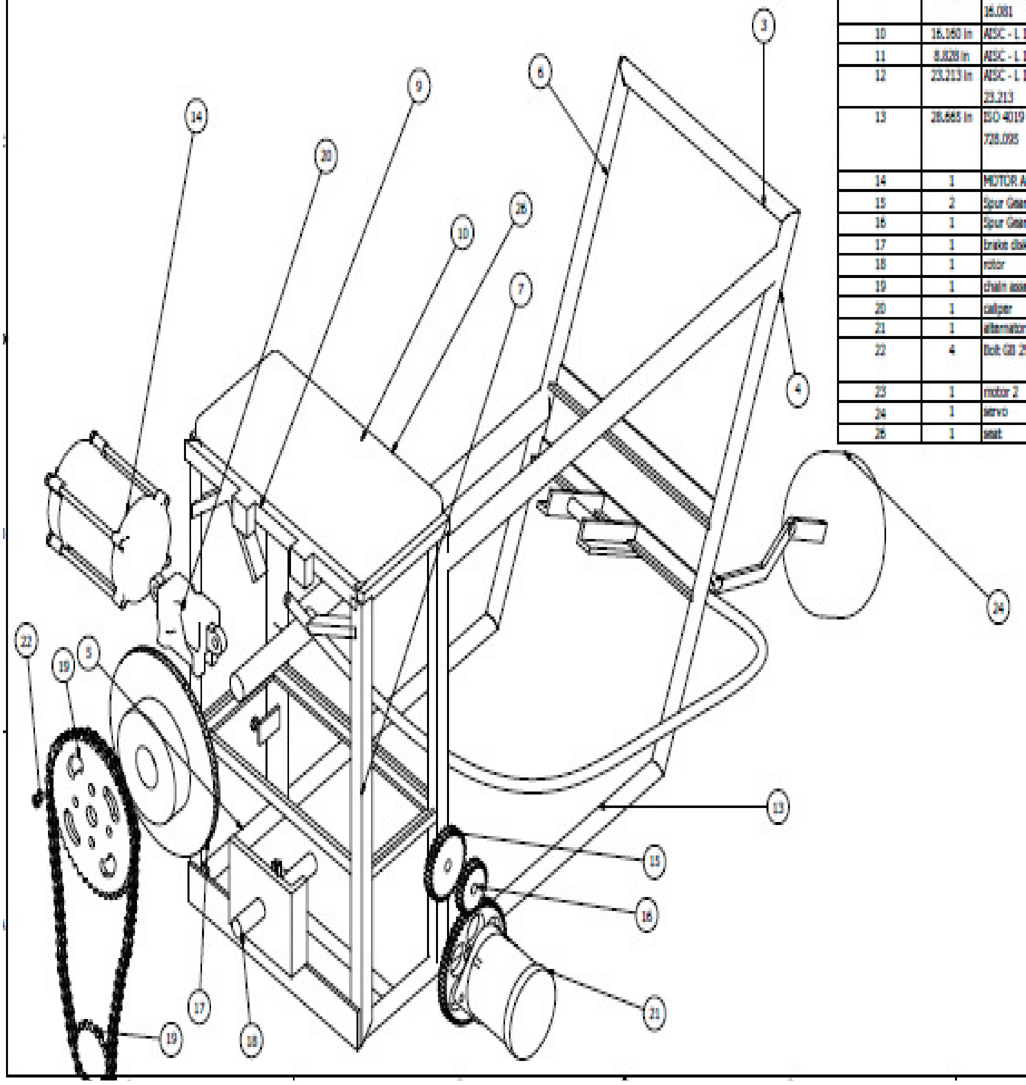
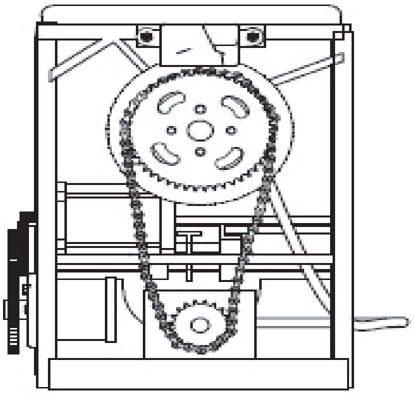
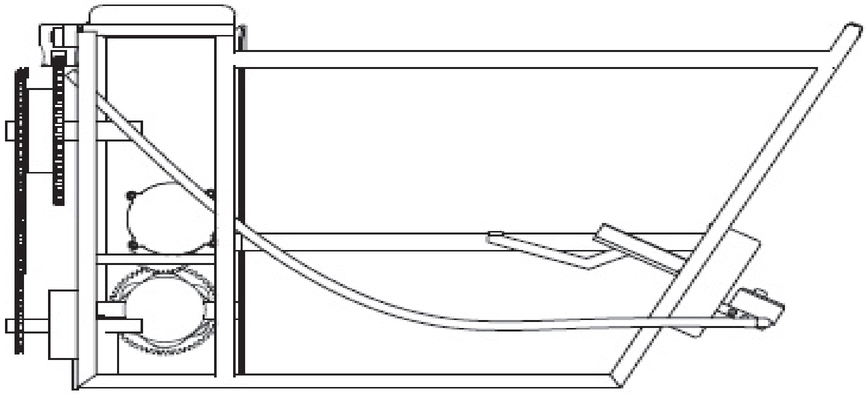
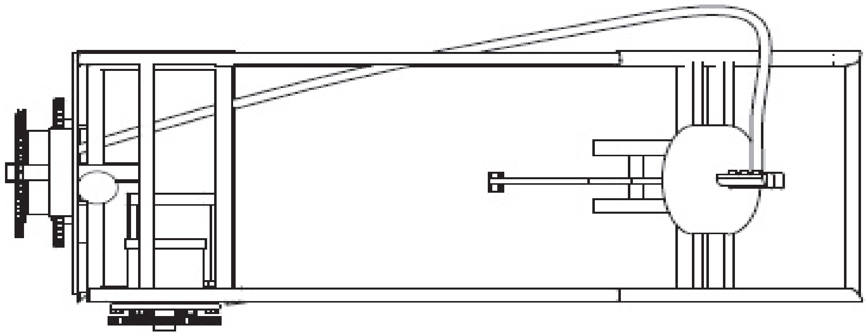
PARTS LIST

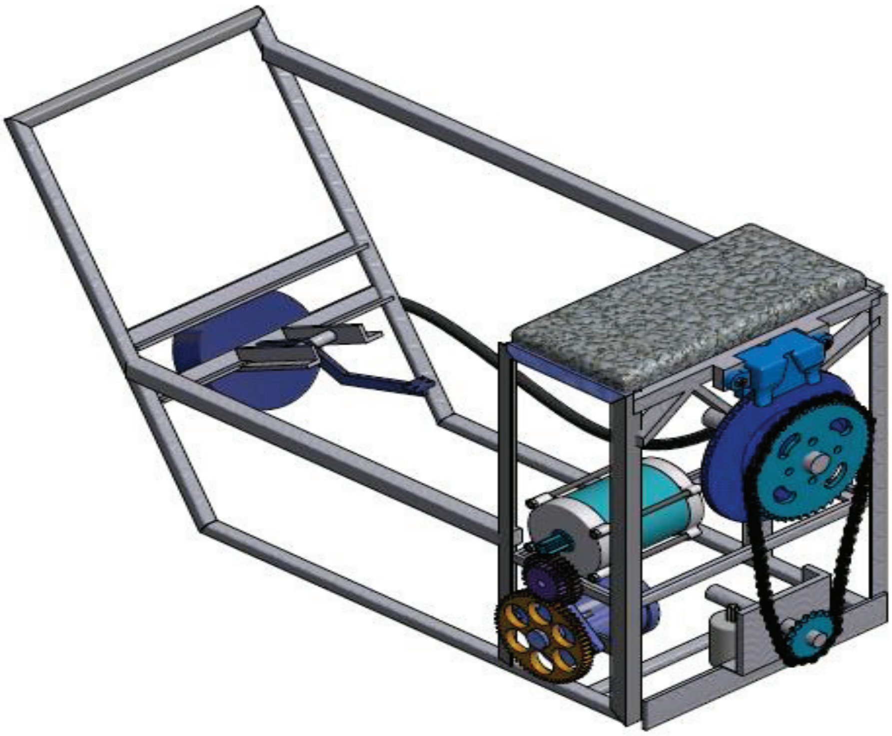
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	frame	
3	16.528 in	ISO 4019 - 20x20x2 - 419.816	Structural steels - Cold-formed, welded, structural hollow sections
4	26.979 in	ISO 4019 - 20x20x2 - 685.271	Structural steels - Cold-formed, welded, structural hollow sections
5	27.970 in	ISO 4019 - 20x20x2 - 710.445	Structural steels - Cold-formed, welded, structural hollow sections
6	26.910 in	ISO 4019 - 20x20x2 - 683.504	Structural steels - Cold-formed, welded, structural hollow sections
7	23.453 in	AISC - L 1 x 1 x 1/8 - 23.453	Angle Steel
8	24.000 in	AISC - L 1 x 1 x 1/8 - 24	Angle Steel
9	16.081 in	AISC - L 1 x 1 x 1/8 - 16.081	Angle Steel
10	16.160 in	AISC - L 1 x 1 x 1/8 - 16.16	Angle Steel
11	8.828 in	AISC - L 1 x 1 x 1/8 - 8.828	Angle Steel
12	23.213 in	AISC - L 1 x 1 x 1/8 - 23.213	Angle Steel
13	28.665 in	ISO 4019 - 20x20x2 - 728.095	Structural steels - Cold-formed, welded, structural hollow sections
14	1	MOTOR ASSEMBLY	
15	2	Spur Gear2	
16	1	Spur Gear1	
17	1	brake disk	
18	1	rotor	
19	1	chain assembly	
20	1	caliper	
21	1	alternator	
22	4	Bolt GB 29.2 M8 x 12	Cross recessed hexagon bolts with indentation
23	1	motor 2	
24	1	servo	
26	1	seat	











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