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Design and Fabrication of a Dual Power Water Pump

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ABSTRACT
The work is designed to alleviate the challenges inherent in pumping water from one particular place to another in the rural areas. It has great applicability in water borehole systems, irrigation, building and bricklaying activities, palm oil and groundnut oil industries and other industries that deal with fluid. The power for the pump can either come from manual pedaling or the dc motor. It incorporated a manual gear assembly which disengages from the pump by means of a clutch when the pump is powered by the dc motor.The major components of the machine include; centrifugal pump, dc motor, sprockets, chain drive, spur gears and angle bar. Testing the pump showed that it has a flow rate of 14litres per minute during manual operation and 24litres per minute during operation with the dc motor.
Keywords: Pump; Water-borehole; Manual-pedaling; dc-motor; sprocket; spur gear; chain-drive.

1.0 Introduction
The idea of pumping water has been in existence since the evolution of man. Pumping plays a very pivotal role in the day to day existence of mankind and as a result, different methods have evolved over the years to pump or displace water. Water supply has been a very critical issue, mostly affecting the rural areas. Water is one of nature's most important gifts to mankind. It is one of the most essential elements to good health and as such, it should be readily available to all and sundry. To address this problem, different methods and techniques have been used over the years ranging from man-powered operated ones down to the more efficient, but costly electrically and internal combustion engine powered pumps. This paper seeks to design and fabricate a novel product that will be:

- Completely independent of any engine or electrical power source.
- Easily affordable and available to the rural dwellers.
- Easily operated by all, children and women inclusive.
- Easily transported from one place to another.
- Easily set up without complication.
- Easily manufactured with available materials.
- Easily maintained.
- Easily adapted for irrigation purpose.
- Easily adapted for pumping of other liquids.
- Cost effective

1.1 Principles of lifting and moving water.
Water may be moved by the application of any one (or any combination) of five different mechanical principles, which are to a great extent independent of each other (Tuzson, 2000). The five principles are as follows:

I. **Direct lift -** this method of lifting water involves physically lifting water using a container. It is by far the most popular method of lifting water.
II. **Displacement -**this method of lifting water utilizes the fact that water is incompressible to an extent and as such, it can be effectively displaced.
III. **Creating a velocity head -**this method of pumping water utilizes the fact that when water is propelled to a high speed, the momentum can be used either to create a flow or to create a pressure.
IV. **Using the buoyancy of a gas -**this method of lifting water utilizes the fact that air or other gas bubbled through water will lift a proportion of the water.
V. **Gravity -**this method of lifting water utilizes the fact that water flows downward under the influence of gravity.

1.2Schematics ofthe methods of pumping water(www.fao.org).

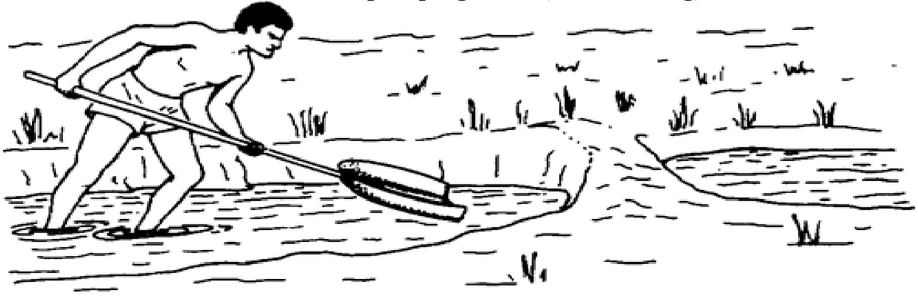


Fig. 1.0the scoop used as a simple hand tool

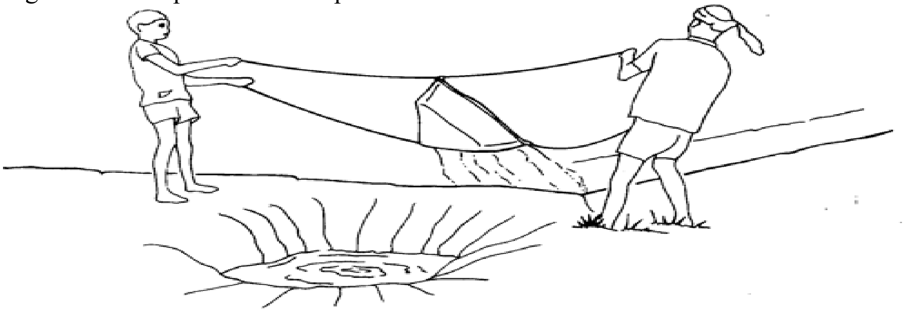


Fig. 1.2 the swing basket in use

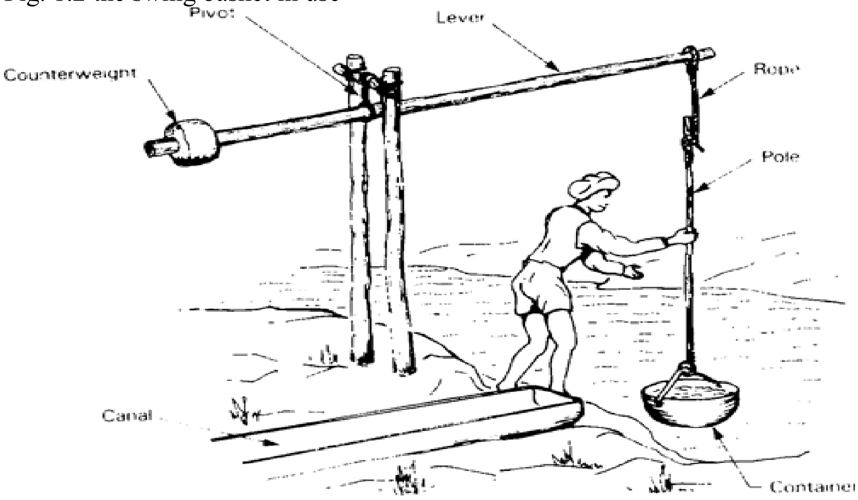


Fig.1.3 counterpoise lift

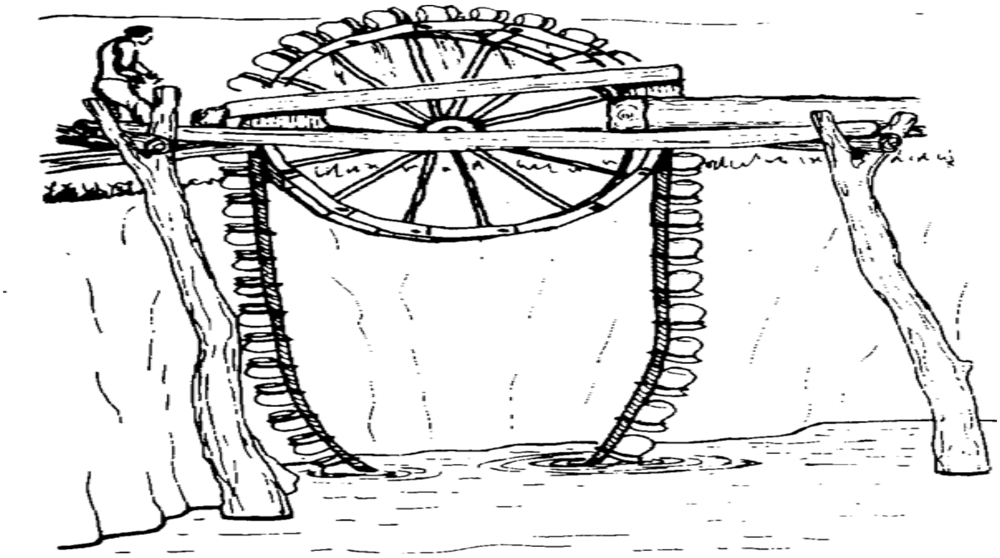


Fig. 1.4 Persian wheel

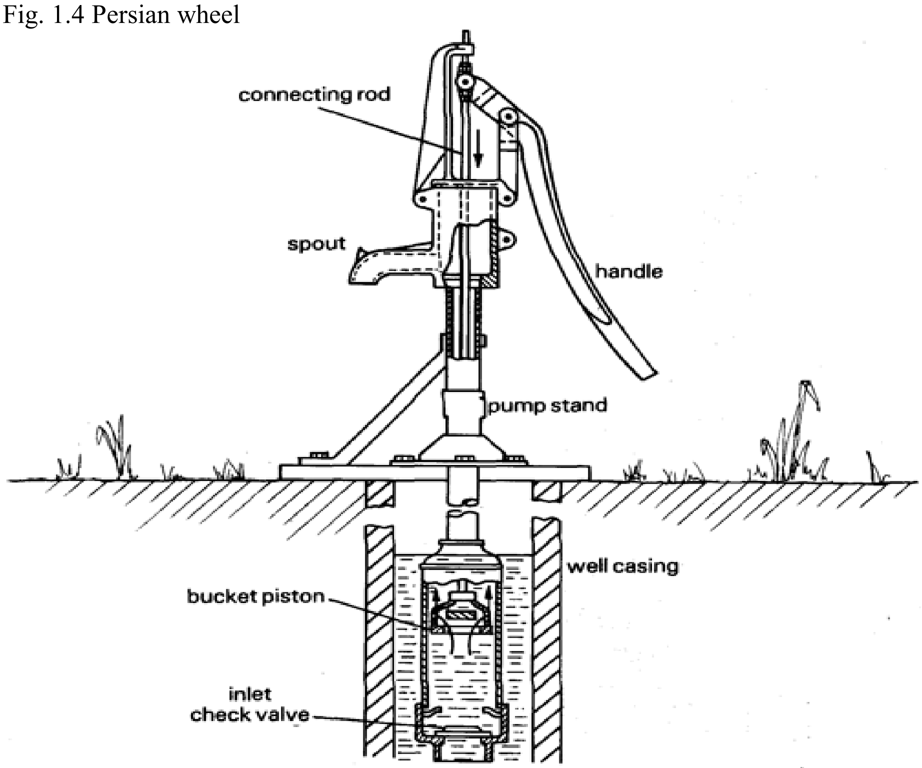


Fig.1.5 Hand pump

2.0 PROJECT DESIGN ANALYSIS

Design in engineering is simply the process in which a problem is recognized and appreciated according to the specifications and requirement made available from the feasibility studies of a creative design synthesis of the preliminary and detailed designing of the prototype for testing and production release (Khurmi and Gupta, 1979).

The design analysis is divided into different aspects based on the components used in the project. The major designs considered are;

I. Centrifugal pump design
II. DC motor design
III. Chain and sprocket design
IV. Gear design
V. Clutch system design
VI. Chassis design

2.1 Pump Selection

The performance of a centrifugal pump is governed by the impeller diameter, rotational speed, input power and the output piping system (En.wikipedia.org).

The main factors that affect the flow rate of a centrifugal pump are:

- Friction, which depends on the length of the pipe and the diameter.
- Static head, which depends on the difference of the pipe and discharge height versus the suction tank fluid level.
- Fluid viscosity, if the fluid is different than water.

In selecting the centrifugal pump, we followed the following selection criteria after due consideration with existing data for a standard pumping machine (Dixon and Hall, 1998):

I. Determine the flow rate; after due consideration, we estimated our maximum flow rate expected from any pump we are to use to be 50litres per minute, in order to provide for a good yield. To successfully build a good pumping machine, a flow rate of 40litres/minutes should be targeted.
II. Estimate the total head; the total head is the sum of the static head and the friction head. The total head was estimated to be 30metres.
III. Determine the maximum power consumption of the pump; the pump is expected to consume a maximum power of 800w.
IV. Estimate the average speed of the pump. The average speed of the pump is estimated to be 900rpm.

With these considerations, a pump with the following specifications was selected:

- Speed; 1000rpm
- Flow rate 45litres/minute
- Total head 30 m
- Maximum power 800w
- Volumetric flow rate, Q = $\frac{flowrate}{60} = \frac{45}{60}$

$= 0.75$litres/second

But 1litre = $0.01m^3$

$Q = 0.075 \times 0.01$

$Q = 7.5 \times 10^{-4} m^3/s$

- Mass flow rate, M = density × volumetric flow rate

Density of water, $\rho = 1000 kg/m^3$

∴Mass flow rate of the pump = $1000 \times 7.5 \times 10^{-4} = 0.75 kg/s$

2.2 Motor Selection;

This is based on the speed and power requirements of the centrifugal pump. The motor should supply a power of at least 1.5 to 2 times the desired output power at nominal voltage. Considering the fact that the speed of the pump is 1000rpm, and the power requirement is 800w, a motor of the following specifications was selected;

- Maximum speed: 1500rpm
- Maximum power: 1.5kw
- Voltage: 12volts DC

The electric motor supplies power to the centrifugal pump through series of gear trains.

Torque from Motor

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

Where p= power given by the motor manufacturer

N= speed of motor in rpm

T= Torque developed by motor

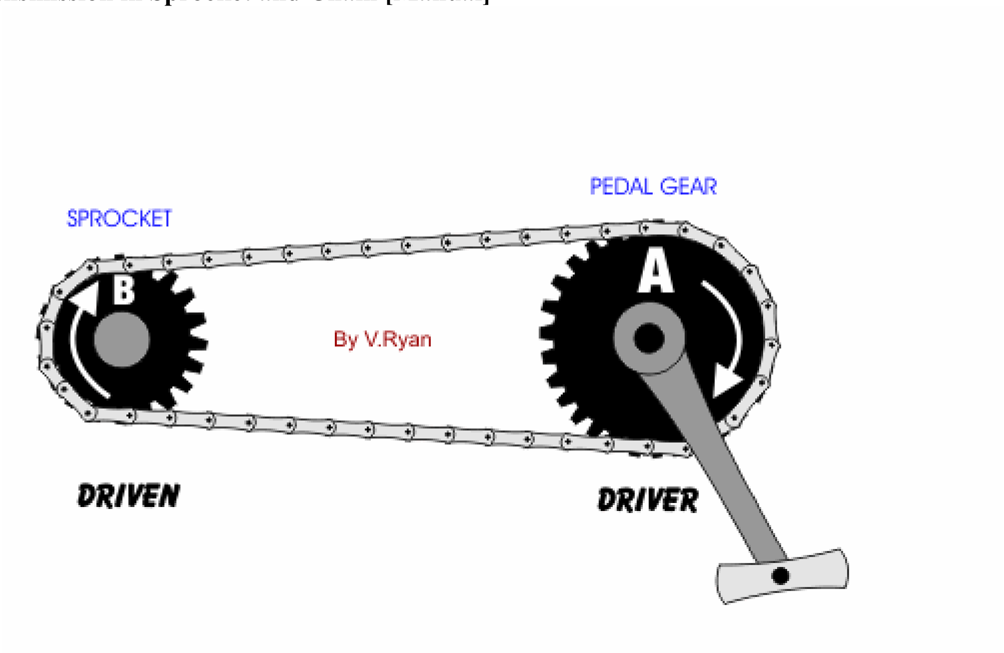
$T = \frac{60P}{2\pi N}$

$T = \frac{60 \times 1500}{2 \times 3.1428 \times 1500}$

$T = 9.55 Nm$

∴Torque from the motor is given by 9.55Nm

2.3 Transmission in Sprocket and Chain [Manual]



Rated power for a healthy human is approximately 250 watts. This gives the peddling power from the peddler. This is the power required to manually rotate the pump. Also the optimum pedaling speed for a healthy human is 80rpm. For comfortable pedaling, the pedaling speed should be as given above.

2.3.1 Design Parameters

From sprocket gear to rear gear
Diameter of driver pulley, D_1= 180mm
Pedaling speed, N_1= 80rpm
Number of teeth on sprocket 1, T_1 = 44
Number of teeth on sprocket 2, T_2= 20
Diameter of driven pulley, D_2= 88mm
Centre distance between the two sprocket, x= 51.7cm
Pitch of the chain, p= 1.27cm

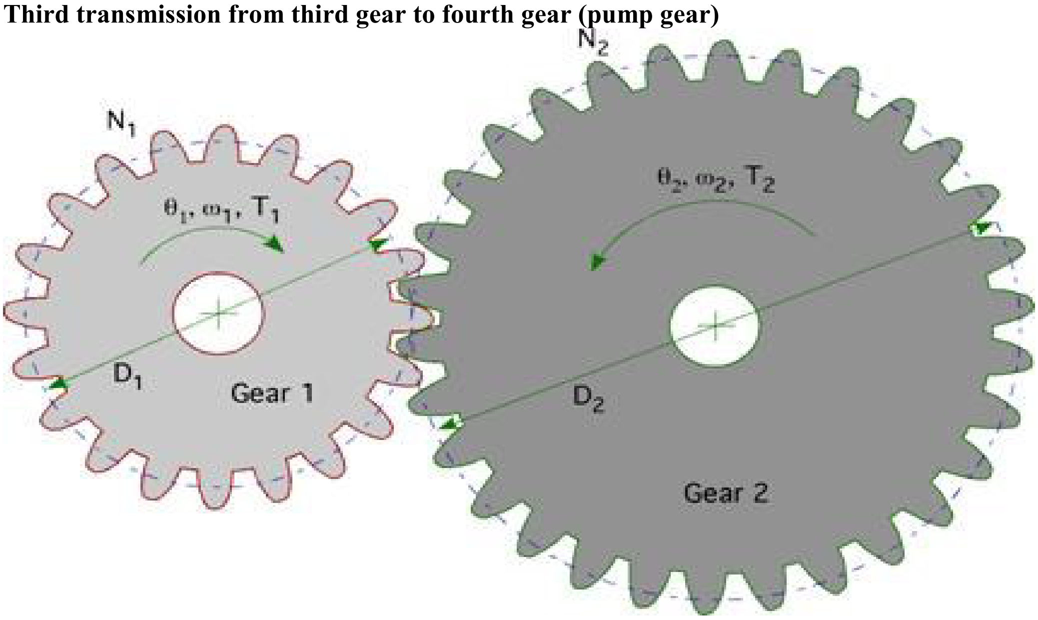
Determination of speed of driven pulley
For Gear drive,
$N_1D_1 = N_2D_2$
$N_2 = \frac{N1D1}{D2} = \frac{80 \times 180}{88} = 163.6\text{rpm}$
Diameter of driven pulley=163.6mm

Determination of average velocity
Average velocity of chain, $v = \frac{\pi D1N1}{60} = \frac{3.1428 \times 0.18 \times 80}{60} = \mathbf{0.754m/s}$

Number of chain links
Number of chain links is given by the expression,
$K = \frac{T1+T2}{2} + \frac{2x}{p} + \left(\frac{T1-T2}{2\pi}\right)^2 \frac{p}{x}$
$K = \frac{44+20}{2} + \frac{2 \times 51.7}{1.27} + \left(\frac{44-20}{2 \times 3.1428}\right)^2 \frac{1.27}{51.7}$
K = 32 + 81.4 + 0.358 = 113.8

Length of chain
The length of the chain is given by, $L = k \times p = 113.8 \times 1.27 = 144.5\text{mm}$
Second transmission from second gear to third gear
The second and the third gear are attached together, as such the third gear travel at the same speed with the second gear.
Speed of third gear $N_3 = N_2$ = 163.6rpm
Diameter of third gear, D_3 = 4.7cm
Number of teeth on third gear, T_3 = 22

Third transmission from third gear to fourth gear (pump gear)



Speed of third gear $N_3 = N_{2=}$ 163.6rpm
Diameter of third gear, D_3 = 47mm
Number of teeth on third gear, T_3 = 22
Speed of centrifugal pump, N_4=?
Pump pulley diameter, D_4 = 140mm
For two meshing gear, the velocity v of the point of contact on the pitch circles is the same on both gears and is given by;
$V = r_3\omega_3 = r_4\omega_4$
$\frac{\omega 3}{\omega 4} = \frac{D4}{D3} = \frac{N3}{N4}$
$N_4 = \frac{D3N3}{D4}$
$N_4 = \frac{47\times 163.6}{140}$
N_4= 55 rpm
Speed of the pump, N_4= 55 rpm

Torque required driving the pump during manual pumping

Power transmitted from pedaling to the pump is given by
$P = \frac{2\pi N4T}{60}$
Where P = power required to drive pump
N_4= speed of the pump during manual pedaling
T = Torque required to drive pump
$T = \frac{60P}{2\pi N4}$
$T = \frac{60\times 800}{2\times 3.1428\times 55}$
T = 138.8Nm
The possible torque required to drive the pump during manual operation is given by 138.8Nm.

Torque generated by human pedaling

$\mathbf{P = \frac{2\pi N1T}{60}}$
Where P = power developed by pedaling
N1= pedaling speed
T = torque developed by pedaling
$T = \frac{60P}{2\pi N1}$
$T = \frac{60\times 250}{2\times 3.1428\times 80}$
T = 29.8Nm
Comparing the torque developed by pedaling to the torque required by the pump during pedaling, it becomes imperative that we have to increase the torque generated during pedaling. This can be achieved by stepping down the pedaling speed at pump, by series of gear increment (Gorla and Khan, 2003).

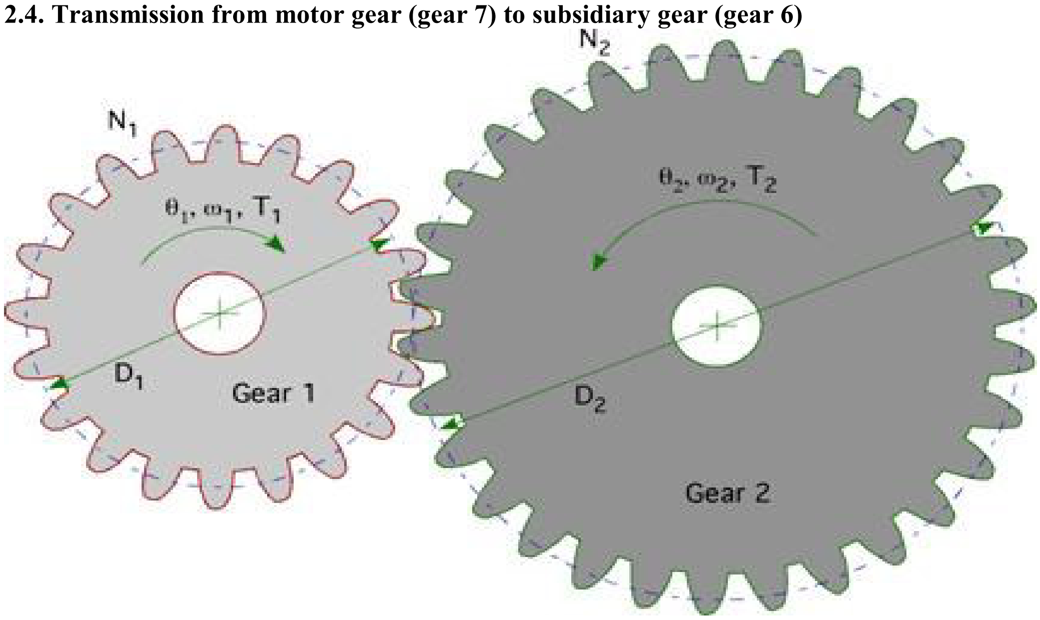
Linear speed of pump shaft

Linear speed, $v = \frac{\pi D4N4}{60}$

$V = \frac{3.1428 \times 0.14 \times 55}{60}$

V = 0.403 m/s

2.4. Transmission from motor gear (gear 7) to subsidiary gear (gear 6)



Maximum speed of pump N_7= 1500rpm

Rated power of pump = 1.5kw

Diameter of motor gear, D7 = 12mm

Number of teeth on motor gear, $T_7 = 9$

Number of teeth on driven gear, $T_6 = 63$

Diameter of driven gear, D_6 = 65mm

For two meshing gear, the velocity v of the point of contact on the pitch circles is the same on both gears and is given by;

$V = r_6\omega_6 = r_7\omega_7$

$\frac{\omega 6}{\omega 7} = \frac{D7}{D6} = \frac{N6}{N7}$

$N_6 = \frac{D7N7}{D6}$

$N_6 = \frac{12 \times 1500}{65}$

N_6= 278rpm

2.4.1 Transmission from subsidiary gear 6 to subsidiary gear 5

The sixth and the fifth gear are attached together, as such; they travel with the same speed.

Speed of fifth gear**,** $N_5 = N_6$ = 278rpm

Transmission between subsidiary gear (gear five) and the pump gear (gear 4)

Diameter of gear 5, D_5 = 38mm

Diameter of gear 4, D_4 = 140mm

Speed of gear 5, N_5 = 278rpm

Number of teeth of gear 5,$T_5 = 18$

Number of teeth of gear 4, $T_4 = 73$

Speed of pump gear, N_4**=?**

For two meshing gear, the velocity v of the point of contact on the pitch circles is the same on both gears and is given by;

$V = r_5\omega_5 = r_4\omega_4$

$\frac{\omega 5}{\omega 4} = \frac{D4}{D5} = \frac{N5}{N4}$

$N_4 = \frac{D5N5}{D4}$

$N_4 = \frac{38 \times 278}{140}$

N_4= 75.5rpm

Speed of pump during dc motor operation = 75.5rpm

Torque required to drive pump during motor operation

Power transmitted from motor to the pump is given by

$P = \frac{2\pi N4T}{60}$

$T = \frac{60P}{2\pi N4}$

$T = \frac{60\times800}{2\times3.142\times75.5}$

T = 101.2Nm

The possible torque required to drive the pump during manual operation is given by 101.2Nm.

Torque from Motor

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

Where p= power given by the motor manufacturer

N= speed of motor in rpm

T= Torque developed by motor

$T = \frac{60P}{2\pi N}$

$T = \frac{60\times1500}{2\times3.1428\times1500}$

T = 9.55Nm

∴Torque from the motor is given by 9.55Nm

Comparing the torque developed by motor to the torque required by the pump during motor operation, it becomes imperative that we have to increase the torque generated during motor operation. This can be achieved by stepping down the pedaling speed at pump, by series of gear increment.

2.5 Design of clutch

A clutch is a machine member used to connect a driving shaft to a driven shaft, so that the driven shaft may be started or stopped at will, without stopping the driving shaft (Black, 1996).

It is a mechanical device that provides for the transmission of power from one component to another, when engaged, but can be disengaged.

Clutches are used whenever the transmission of power or motion must be controlled.

In this design, the clutch is used to disengage the manual side of the pump while using the motor, to prevent the pedal from rotating alongside with the motor, which will lead to a loss of efficiency and a poor design.

2.5.1 Material selection for clutch

The material used in the design of the clutch should have the following characteristics;

- It should have a high and uniform coefficient of friction.
- It should not be affected by moisture and oil.
- It should have high resistance to wear and scoring

2.5.2 Considerations in designing a clutch

The following considerations must be kept in mind while designing a friction clutch;

- A suitable material should be chosen
- The moving parts of the clutch should have low weight in order to minimize the inertia load
- The clutch should not require any external force to maintain it
- It should have provision for facilitating repairs
- The provision for taking up wear must be provided.

2.6 Design of gear

A gear is a rotating machine part having cut teeth, which mesh with another toothed part in order to transmit torque, in most cases with teeth on both gears being of identical shape. Two or more gears working together are called a transmission. Geared devices can change the speed, torque and the direction of the power source (Sharma, P.C, 1982).

The most suitable gear for this work is the spur gear.

Spur gear

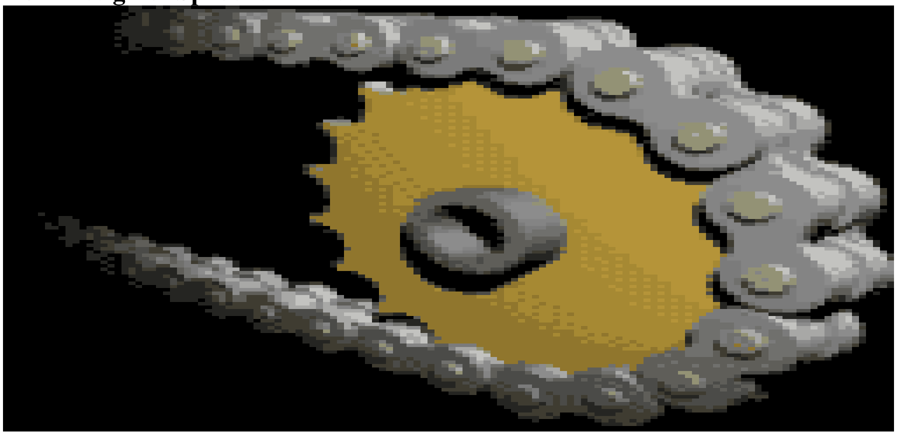
2.6.1 Advantages of spur gear over other gears

- It transmits exact velocity ratio
- It is used to transmit large power
- It is used for small center distances of shafts
- It has high efficiency
- It has reliable service
- It has a compact layout

2.6.2 Disadvantages of spur gears

- It is costly due to high machining cost.
- The error in cutting teeth causes vibrations and noise operation.
- It requires suitable lubricant.

2.7 Design of Sprocket and chain



A sprocket is a profiled wheel with teeth, cogs or even sprockets that mesh with a chain or track. It is distinguished from a gear in that sprockets are never meshed together directly, and differs from a pulley in that sprockets have teeth, but pulleys are smooth (Kumar, K.L(2000).

They are used when the distance between shafts is large as encountered in this work. Sprocket and chain is selected over pulley and chain, because of the high slippage in pulley and chain.

2.7.1 Design considerations for a sprocket and chain

Given that the rated power = 800W
Speed of bigger sprocket, N_1 = 80rpm
Speed of smaller sprocket, N_2 = 163.3rpm
Velocity ratio of chain drive =, V.R. = $\frac{N2}{N1} = \frac{163.3}{80}$ = 2.04
Design power = Rated power × service factor (Ks)
Load factor (K_1) = 1.5
Rating factor (K_2) = 1.25
Service factor, Ks = 1.5 × 1.25 = 1.875
Design power = 800 × 1.875 = 1.5kw
Checking the characteristics of the roller chains table according to ISO: 2403 – 1991
A chain with an ISO chain number of 08 B was selected with the following specifications,

- Roller diameter = 8.51mm
- Pitch, p = 12.7mm
- With between inner plates = 7.75
- Transverse pitch, p1 = 13.92
- Minimum breaking load = 17.8kN

Breaking strength of chain, $W_B = 106p^2 = 106 \times 12.7^2$
= 17.1KN

Pitch circle diameter of smaller sprocket; d1 = p cosec $\frac{180}{T1}$ =12.7 cosec$\frac{180}{20}$
= 81.2mm

Pitch circle diameter of larger sprocket, d2 = 12.7 cosec$\frac{180}{44}$ = 178mm

Pitch line velocity of smaller sprocket, v1 = $\frac{\pi d1N1}{60} = \frac{\pi \times 0.0812 \times 80}{60}$
= 0.34m/s

Load on chain, W = $\frac{Ratedpower}{pitchlinevelocity} = \frac{800}{0.34}$ = 2352N

Factor of safety = $\frac{breakingload}{loadonchain} = \frac{17800}{2352}$ = 7.56
Minimum center distance between smaller and larger sprocket = 30 p=
30 × 12.7 =381mm

2.7.2 Determination of average velocity

Average velocity of chain, v= $\frac{\pi D1N1}{60} = \frac{3.1428 \times 0.18 \times 80}{60}$ = 0.754m/s

2.7.3 Number of chain links

Number of chain links is given by the expression,

$$K = \frac{T1+T2}{2} + \frac{2x}{p} + \left(\frac{T1-T2}{2\pi}\right)^2 \frac{p}{x}$$

$$K = \frac{44+20}{2} + \frac{2\times 51.7}{1.27} + \left(\frac{44-20}{2\times 3.1428}\right)^2 \frac{1.27}{51.7}$$

K = 32 + 81.4 + 0.358 = 113.8

2.7.4 Length of chain

The length of the chain is given by, L = k× p = 113.8 ×1.27 = 144.5mm

3.0 MATERIALS AND DESIGN CONSIDERATIONS

The materials used for the various designs have been properly selected for the effective operation and long life span of the machine. In the design and fabrication of the dual power water pump, the following important factors were considered;

- Strength
- Maintainability
- Reliability
- Cost
- Serviceability
- Operational cost
- Weight and size
- Material availability
- Friction and wear
- Vibration and noise

3.1 GEAR TRAIN ANALYSIS

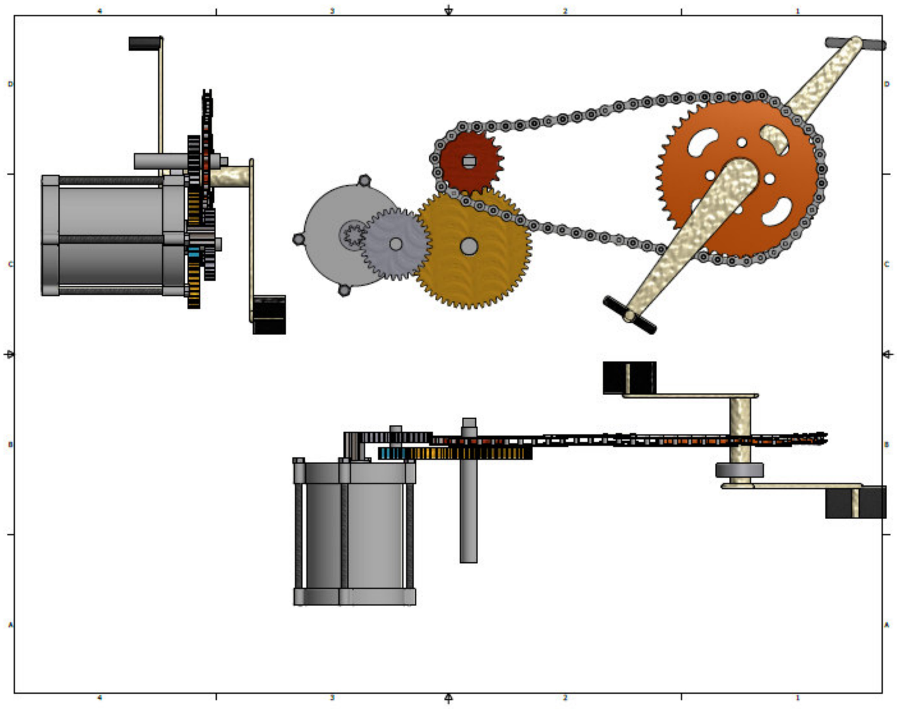


Fig 6.0 Drawing of the Gear Train Arrangement

3.2 DESIGN DIAGRAMS

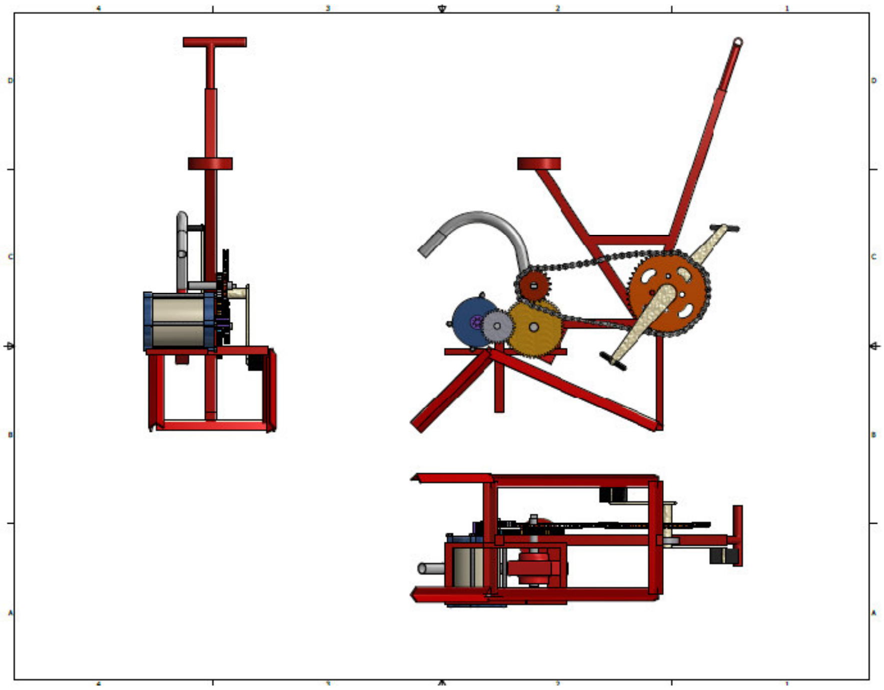


Fig 7.0 Drawings of the three different views of the Dual Powered Water Pump

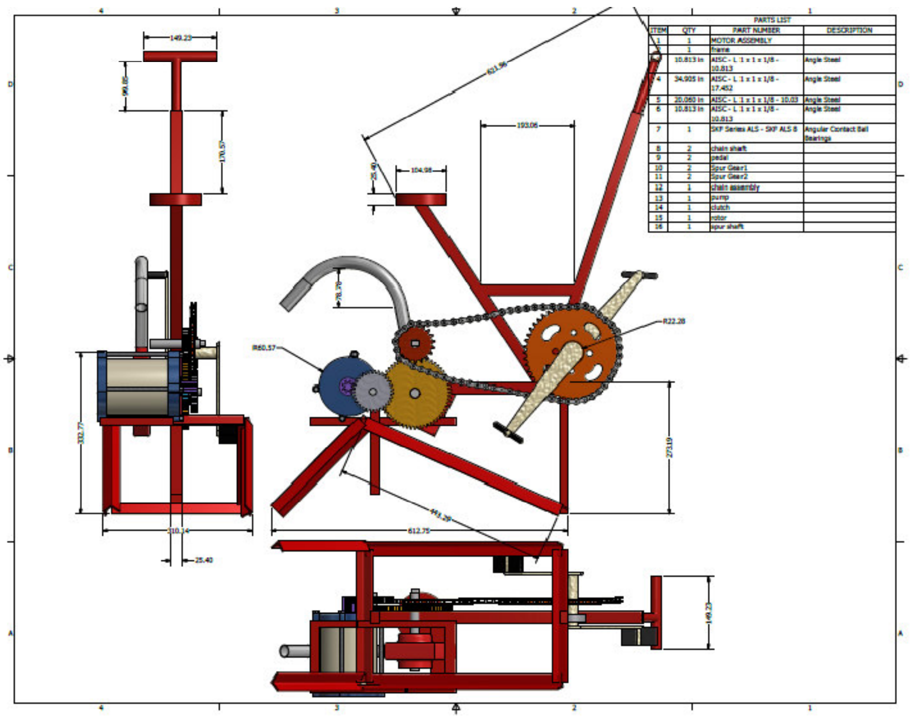


Fig 8.0 Dimensional Drawing of the three different views of the Pump

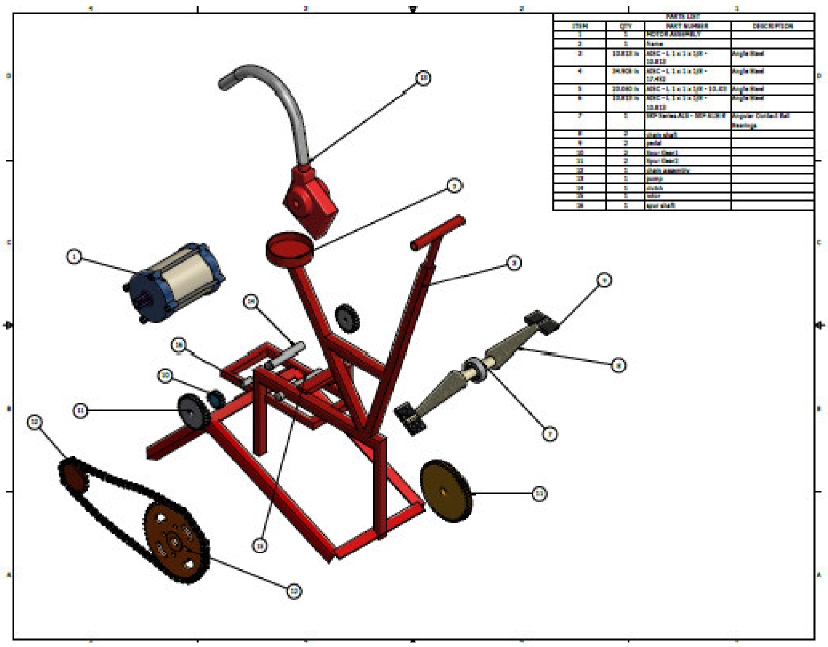


Fig 9.0 Disassembled drawing showing all the parts

Fig 10.0 Picture of the pump

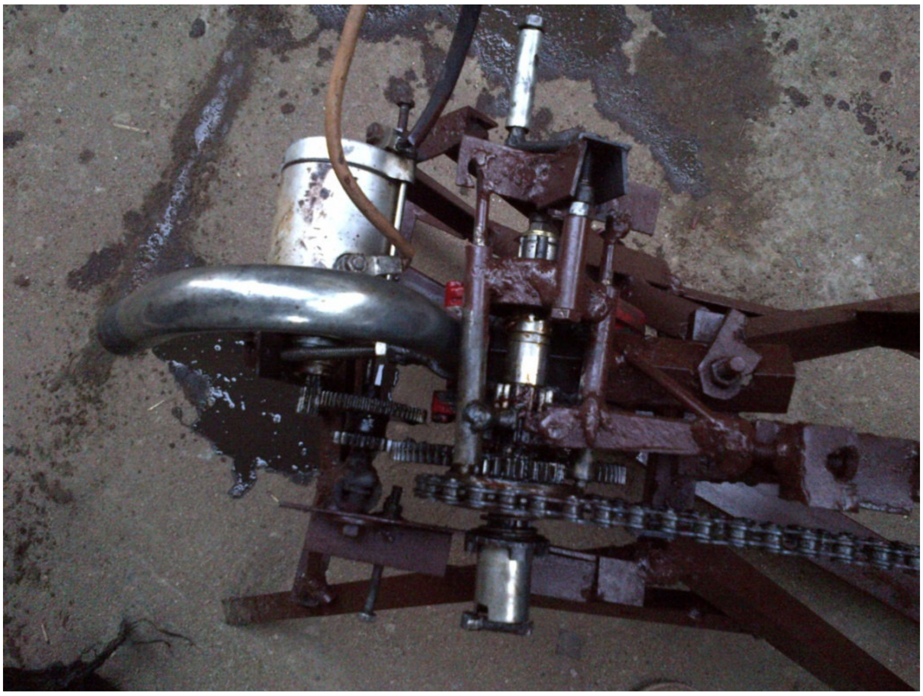


Fig 11.0 Picture of Pump showing detailed parts

4.0 CONCLUSION AND RECOMMENDATIONS

The ultimate aim of this work is the design and fabrication of a Dual Powered Water Pump. Our machine seeks to improve on the existing techniques for pumping water, basically the hand pump.

The project makes use of two power sources which are meant to complement each other. The two power sources are manually pedaling the system using the legs and by the use of dc motor.

The major parts of the project are the centrifugal pump, the motor, the gears, sprockets and chain. The machine was tested and from the testing, it was shown that the machine can pump water from a height of up to 5metres and could discharge the water to a depth of up to 6meters; giving the machine a total head of 10.1metres. Having completed the design and fabrication of the dual water pumping system, the following recommendations are applicable:

- In subsequent design, an alternator should be included in the design to charge the battery during pedaling action to conserve energy.
- In future design, a tyrecan be incorporated to make the machine moveable.

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