Improvisation of Reciprocating Pump Using Beam Engine

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Abstract— **In this we have used the reciprocating motion of the beam engine to drive the reciprocating pump to displace the hydraulic fluids, conventionally the beam engines are used to lift the water from the deep mines, it also finds wide range of application in the oil rig areas . Here the oscillating motion of the beam is used to operate two reciprocating pumps which is operated simultaneously giving maximum efficiency and the delivery stroke, it is designed to operate the pumps to give alternative stroke, by which the discharge capacity is increased. By using the beam engine the vibrations are reduced and pump setup is dynamically balanced. The main limitation of reciprocating pump is lower discharge capacity is been overcome by using the two pump setup under the same operating pressure and the input power.**

Index Terms —**Dynamically balanced, Hydraulic fluids, Oscillating, Reciprocating pumps.**

INTRODUCTION

A beam engine is a type of steam engine where a pivoted overhead beam is used to apply the force from a vertical piston to a vertical connecting rod. But instead power from piston and cylinder is replaced by a pump. So the direction of force applied is reversed from piston to crank. These input force applied on the crank is used to actuate the reciprocating pumps. The fuel efficiency of an engine was measured by its "duty", expressed in the work (in foot-pounds) generated by a bushel (94 pounds (43 kg)) of coal. Early Watt engines had a duty of 20 million, and later ones over 30 million.[2]

The reciprocating pumps have been around for over 2000 years, they did not gain wide popularity until 1840 when Henry R. Worthington invented the steam pump. These early, simple machines have evolved into the advanced reciprocating pumps in many industries. During the last 30 years technology improvements have allowed centrifugal and other pumps types to become more popular, and reciprocating pump have been marginalized. That being said, there are still many applications where reciprocating pump outperform their centrifugal pumps.

These dominance of these alternative pump types has lead to a knowledge gap for positive displacement machines. However , the positive displacement reciprocating pump is still a vital part of industry and will remain in use for the future.

1.1KINEMATICS:

Kinematics is the study of how things move .Understanding the following definitions and the principles will be both helpful and necessary for successfully answering the exercise in the section . This concept review is not meant to replace the full explanation of a textbook or lecture. If any of these principles are un familiar or confusing, please consult with an instructor or textbook before continuing with the warm-up exercises

1.2 FOUR BAR CHAIN:

A four-bar linkage, also called a four-bar, is the simplest movable closed chain linkage. It consists of four bodies, called bars or links, connected in a loop by four joints. Generally, the joints are configured so the links move in parallel planes, and the assembly is called a planar four-bar linkage.

A link can be defined as a member or a combination of members of a mechanism, connecting other members and having relative motion among them.

1.3 BEAM ENGINE:

It is the inversion of four bar chain mechanism (crank and lever mechanism). It converts the rotary motion into the reciprocating pump (oscillation of the beam). The engines were also used for powering man engines to assist the underground miners' journeys to and from their working levels, for winching materials into and out of the mine, and for powering on-site ore stamping machinery[1]

A beam engine is a type of steam engine where a pivoted overhead beam is used to apply the force from a vertical piston to a vertical connecting rod. This configuration, with the engine directly driving a pump, was first used by Thomas Newcomen around 1705 to remove water from mines in Cornwall. The efficiency of the engines was improved by engineers including James Watt who added a separate condenser, Jonathan Horn blower and Arthur Woolf who compounded the cylinders, and William McNaught (Glasgow) who devised a method of compounding an existing engine. Beam engines were first used to pump water out of mines or into canals, but could be used to pump water to supplement the flow for a waterwheel powering a mill.

The cast-iron beam of the 1812 Boulton & Watt engine at Crofton Pumping Station – the oldest working, in situ example in the world.

The rotative beam engine is a later design of beam engine where the connecting rod drives a flywheel, by means of a crank (or, historically, by means of a sun and planet gear). These beam engines could be used to directly power the line-shafting in a mill. They also could be used to power steam ships.

1.4 HISTORY OF BEAM ENGINE:

The first beam engines were water-powered, and used to pump water from mines. A preserved example may be seen at Wanlockhead in Scotland. Beam engines were extensively used to power pumps on the English canal system when it was expanded by means of locks early in the Industrial Revolution, and also to drain water from mines in the same period, and as winding engines.

The first steam-related beam engine was developed by Thomas Newcomen. This was not, strictly speaking, steam powered, as the steam introduced below the piston was condensed to create a partial vacuum thus allowing atmospheric pressure to push down the piston. It was therefore called an Atmospheric Engine. The Newcomen atmospheric engine was adopted by many mines in Cornwall and elsewhere, but it was relatively inefficient and consumed a large quantity of fuel. The engine was improved by John Smeaton but James Watt resolved the main inefficiencies of the Newcomen engine in his Watt steam engine by the addition of a separate condenser, thus allowing the cylinder to remain hot. Technically this was still an atmospheric engine until (under subsequent patents) he enclosed the upper part of the cylinder, introducing steam to also push the piston down. This made it a true steam engine and arguably confirms him as the inventor of the steam engine. He also patented the centrifugal governor and the parallel motion. the latter allowed the replacement of chains round an arch head and thus allowed its use as a rotative engine.

His patents remained in place until the start of the 19th Century and some say that this held back development. However, in reality development had been ongoing by others and at the end of the patent period there was an explosion of new ideas and improvements. Watt's beam engines were used commercially in much larger numbers and many continued to run for 100 years or more.

Watt held patents on key aspects of his engine's design, but his rotative engine was equally restricted by the patent by another of the simple crank. The beam engine went on to be considerably improved and enlarged in the tin- and copper-rich areas of south west England, which enabled the draining of the deep mines that existed there. Consequently, the Cornish beam engines became world famous, as they remain among the most massive beam engines ever constructed.

2.COMPONENTS OF BEAM ENGINE :

The main important components of beam engine setup is given below

1) Crank
2) Supporting column
3) Pivoted oscillating beam
4) Connecting rod
5) Piston and cylinder

2.1.1.Crank:

It is a link which rotate with the rotation of 360 degree at one end linked with connecting rod and to the fixed end. As the crank rotates and transmit the rotating power to the connecting link for the further transmission and give out an output.

2.1.2 Supporting column:

1. It is rigid supporting member in which the oscillating beam is supported.
2. This member is fixed at the frame setup**.**

2.1.3 Oscillating beam:

1. It is beam which is pivoted on the supporting column.
2. It transmits the rotary motion of the crank input into the reciprocating motion .

2.1.4 Connecting rod:

One end of the connecting rod is connected to the pivoted oscillating beam and the other end is connected to the piston of the pump.

2.1.5 Piston and cylinder:

A cylinder is the stationary part of reciprocating pump or engine, the space in piston travels. A piston is the component of reciprocating engines, reciprocating pumps ,gas compressors and pneumatic cylinders , among other similar mechanisms. It is the moving component that is contained by a cylinder and is made of gas tight by piston rings. In an engine, its purpose is transfer force from expanding gas in the cylinder to crankshaft via piston rod and connecting rod.

2.2 MAIN PARTS OF A RECIPROCATING PUMP:

The following are the main parts of a reciprocating pump as shown in figure.

1. A cylinder with a piston, piston rod, connecting rod and a crank
2. Suction pipe
3. Delivery pipe
4. Valve
    (a).Suction valve
    (b).Delivery valve
5. Air vessel

2.2.1Cylinder and piston:

A cylinder is the stationary part of reciprocating pump the space in piston travels. A piston is the component of reciprocating engines, reciprocating pumps ,gas compressors and pneumatic cylinders , among other similar mechanisms. It is the moving component that is contained by a cylinder and is made of gas tight by piston rings. In an engine, its purpose is transfer force from expanding gas in the cylinder to crankshaft via piston rod and connecting rod. In a pump, the function is reversed and force is transferred from the crankshaft to the piston for the purpose of compressing or ejecting the fluid in the cylinder.

2.2.2 Suction pipe:

The pipe which takes the liquid from the source and provide it to the cylinder of the pump is called suction pump.

2.2.3 Delivery pipe:

A pipe whose one end is connected to the outlet of the pump and the other end is delivers the water at a required height is known as delivery pipe.

2.2.4 Valves:

The most common type of valve used is a check valve, in which a movable element , shaped like a cone or ball is positioned opposite a cylindrical tube called a seat. Normally the movable element held away from the seat either by the force of gravity or by a spring. However, if the pressure force on the same side of the movable element exceeds that on the opposite side by more than the weight of spring force, the element is pushed against the seat, closing the valve, and blocking the flow of fluid through it. If the pressure force is greater on the opposite side, the element is forced back, and fluid can flow. Spring valves have the advantage that they can be used in any position, while gravity valves must be oriented downwards. So called flapper valves are also used in some cases (for example in toilet tanks), and have the advantage of being very simple. A disadvantage is that they tend to seal more slowly, and thus allow more fluid to leak through before sealing.

2.2.4.1 Suction valve:

It is the one way valve placed between suction pipe and cylinder of the pump. It is open when suction take place and closed when delivery of the water is taking place.

2.2.4.2 Delivery valve:

It is the one way valve and placed at the point of attachment of the delivery pipe with cylinder. It is open when delivery of the water is taking place and closed when suction of water in taking place.

2.2.5 Air vessel:

The air vessel is a cast iron chamber, which has opening at the base, through which water can flow, one chamber is fitted on the suction pipe just near to suction valve and one on the delivery pipe just near the delivery valves. Each channel is converted through a small length of pipe. For efficient working, vacuum vessels should be 3 to 5 times the discharge per stroke and the air vessel on the delivery side 6 to 10 times the discharge per stroke.

During the middle of delivery stroke, when pump is facing the water into the delivery pipe at a velocity greater than the average, excess water flows into the air vessel and compresses the tapped air in upper portion of the chamber. At the end of the stroke when water flows into the delivery pipe at a rate less than the average water flows out of air vessel from the excess amount of water already stored to keep the discharge more uniform. This fluctuating water column causes the acceleration head to be reduced that in between pump cylinder and the air vessel, which allows the pump to run at higher speeds. Thus in this way it saves large amount of power lost in developing accelerating heads on suction side, water first collects in the air vessel and then flows in cylinder on delivery side. Water first goes to air vessel and then flows with a uniform velocity. An air vessel provided in a reciprocating pump acts like a flywheel of an engine.

3.1 DESIGN SPECIFICATION OF BEAM ENGINE:

Average displacement calculated = 140mm (stroke length)

1. Diameter of the pump cylinder = 48mm
2. Crank length (r) = (L/2) = (140/2) = 70mm
3. Connecting Rod length = 505 mm
4. Beam length = 500mm

3.2 DISCHARGE OF RECIPROCATING PUMP:

D = Diameter of the cylinder m
A = Cross section area of the piston or cylinder m^2
L = Length of stroke=2×R m
H_S = Height of the horizontal axis of the cylinder from water surface in sump m
H_d = Height of the delivery outlet above the cylinder horizontal axis(also called delivery head) m
Q = Discharge of pump per second m^3/sec
W = Weight of the water delivered per second N
W_d = work done by reciprocating pump kW
P = Power required to drive the pump kW ρ=density of the water kg/m^3

$A = \pi D^2/4$

Volume of water delivered in one revolution = A×L

Number of revolutions per second = N/60

Q = ALN/60 for single acting

Q = 2ALN/60 for double acting

$W = \rho \times g \times Q = \frac{\rho \times g \times A \times L \times N}{60}$ for single acting

$W = 2\rho \times g \times Q = \frac{2\rho \times g \times A \times L \times N}{60}$ for double acting

3.3 WORK DONE BY RECIPROCATING PUMP:

Work done per second = weight of the water lifted per second x total height through which water is lifted

$$W_d = W \times (hs+hd)$$

$$W = \frac{2\rho \times g \times A \times L \times N}{60}$$

Work done per second $= \frac{\rho \times g \times A \times L \times N}{60} \times (h_s+h_d)$

$$P = \frac{Work\ done\ per\ second}{1000}$$

$$= \frac{\rho \times g \times A \times L \times N \times (h_s + h_d)}{60 \times 1000} \text{ KW}$$

3.4 DESIGN CALCULATIONS:

3.4.1 Design of beam:

Length of the beam = 500mm

Width of the beam = 20mm

Thickness of beam = 5mm

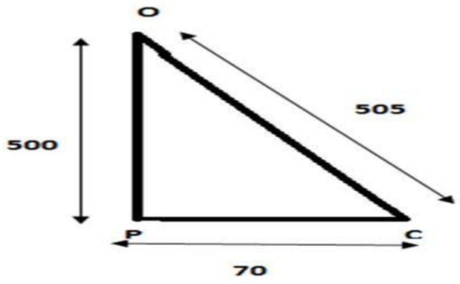


Fig 3.1 Beam

OP = line of stroke

OC = crank

From the triangle OPC

$$Sin\ \theta = \frac{70}{505}$$

$\theta = 8^{\circ}$ (At ideal condition)

3.4.2 Design of connecting rod:

Length of connecting rod = 505mm

Width of connecting rod = 18mm

Thickness of beam = 4mm

3.4.3 Design of crank:

$$Crank\ length = \frac{stroke\ length}{2} = \frac{l}{2} = \frac{140}{2}$$

Crank length = 70 mm

3.4.4 Design torque:

Torque T = force x radius

T = F x r

F = 4 x 9.81 (assume)

F = 40 N (approx)

$T = 40 \times 70 = 2.8 \times 10^3$ N-mm

T = 2.8 N-m

$$\text{Power input} = \frac{2\pi NT}{60}$$ if speed N = 30 rpm (manually)

$$\text{Power input} = \frac{2\pi \times 30 \times 2.8}{60}$$

P = 8.79 watts

3.4.5 Check for connecting rod in tensile and compressive loads:

Cross sectional area of connecting rod = b × t = 18 × 4 = 72 N mm^2

$$Tensile\ stress = \frac{force\ applied}{area} = \frac{40}{72} = 0.55\ N/mm^2$$

Maximum tensile stress for steel=320 (N/ mm^2) > Tensile stress, The Design is safe.

3.4.6 Check for beam in shear:

Shear area= 3×[πD×t] = 3×π×6×5 = 282.74 mm^2

$$Stress = \frac{force}{area} = \frac{40}{282.74} = 0.14147\ N/mm^2$$

3..4.7 Check for bolt:

Load acting = 40 N

$$Shear\ area = 2 \times \frac{\pi}{4} \times d^2$$

$$Shear\ area = 2 \times \frac{\pi}{4} \times 6^2 = 56.54\ mm^2$$

$$Shear\ stress = \frac{load\ acting}{shear\ area}$$

$$\text{Shear stress} = \frac{40}{56.54}$$

$= 0.707\ N/mm^2 < 180\ N/mm^2$, The design is safe.

3.4.8 Design of cylinder (pump):

Stroke volume = area ×stroke length

V = A×L

$$Area = \frac{\pi}{4} \times d^2$$

$$Area = \frac{\pi}{4} \times 48^2 = 1809.57\ mm^2$$

L = 140 mm

$V = 1809.577 \times 140 = 2.53 \times 10^6\ mm^3$

Clearance volume = Area× clearance length= $1809.577 \times 30 = 5.4 \times 10^3\ mm^3$

$$\text{Theoretical discharge Qth} = \frac{A \times L \times N}{60}$$ if N = 30 rpm (manually)

$$= \frac{1809.577 \times 140 \times 30}{60} \times 2 \text{ (two cylinders)}$$

$Q_{th} = 253.33 \times 10^3\ mm^3/sec = 2.5333 \times 10^{-4}\ m^3/sec$

Actual discharge $Q_{act} = 182.39\times10^3\ mm^3/sec$ (assume)

Slip = Qth - Qact = 253.33×10^3-182.39×10^3

Slip = $70.94\times10^3\ mm^3$ /sec

Percentage of slip = $(1-c_d)\times 100$

Where $c_d = \frac{Q_{act}}{Q_{th}} = 0.72$

% of slip = (1-0.72)×100 = 28%

Volumetric efficiency $= \frac{Q_{act}}{Q_{th}} \times 100 = 72\ \%$

Work done by pump = $\rho\times g\times Q(h_s + h_d)$

Where Density of water ρ =1000 kg/m^3 g = 9.81 m^2/sec h_s = 1 m(assume) h_d = 0.3m(assume)

$P = 1000\times9.81\times2.5333\times10^{-4}\times2.6 = 6.46$ Watts

Mechanical efficiency $= \frac{work\ done\ by\ pump}{power\ input} = \frac{6.46}{8.79} = 73.5\ \%$

The pressure head due to the acceleration in the suction pipe is given by the equation

$$h_{as} = \frac{l_s}{g} \times \frac{A}{a} \times \omega^2 r\ cos\ \theta$$

$$\omega = \frac{2\pi N}{60} = \frac{2\pi\times30}{60} = 3.141\ rad/sec$$

At beginning of the stroke $\theta = 0^O$ and hence $\cos\theta = 1$

h_s=suction head = h_s=1 m length of suction pipe ls=1m

Area of the cylinder A=1809.577 mm^2=$1.809\times10^{-3}\ m^2$

Area of the suction pipe A = $\frac{\pi}{4} \times d^2 = \frac{\pi}{4} \times (0.01)^2 = 7.85\times10^{-5}\ m^2$

$$h_{as} = \frac{1}{9.81} \times \frac{1.809\times10^{-3}}{7.85\times10^{-5}} \times 3.141^2 \times 0.07 = 1.649\ m$$

The pressure head in the cylinder at the beginning of the suction stroke = h_s+h_{as} = 2.649m

Absolute pressure head in the cylinder at the beginning of suction stroke

= atmosphere pressure head – 2.649

= 10.3 – 2.649

= 7.651 m of water

Similarly pressure head in cylinder at the end of the suction stroke= h_{as} - h_s

=1.649 - 1

= 0.649 m of water below atmospheric pressure head

=10.3 - 0.649

= 9.651 m of water

Pressure head due to acceleration at the beginning of delivery stroke $h_{ad} = \frac{l_s}{g} \times \frac{A}{a} \times \omega^2 r$

At beginning of the stroke $\theta = 0^O$ and hence $\cos\theta = 1$ and ld = 0.35 m

$$h_{ad} = \frac{0.35}{9.81} \times \frac{1.809\times10^{-3}}{7.85\times10^{-5}} \times 3.141^2 \times 0.07 = 0.567\ m$$

Pressure head in the cylinder at the beginning of the delivery stroke = h_d + h_{as}

= 0.867 m water above the atm

=10.3 + 0.867

=11.16 m

The pressure head in the cylinder at end of delivery = h_{ad} - h_d

= 0.267 +10.3

= 10.567 m

4.1 WORKING PRINCIPLE:

The main working principle of the beam engine is convert the rotatory motion into the reciprocating motion (oscillation of beam).In beam engine the pivoted overhead beam is used to apply the force by crank via connecting rod where one end of beam is connected to piston of the pump and the other end is connected to connecting rod. When the crank starts to rotate, the connecting rod is oscillated and also makes the over head beam to oscillate. This oscillation is transferred to the reciprocating motion of the piston by Lclamp linkages. The reciprocating pump has the two strokes one is suction stroke and delivery stroke. The working of the pump converts the reciprocating motion into the hydraulic energy in terms of pressure energy. For first half revolution of the crank (θ=0 to 180^{o}) the piston moves from the top dead center of the cylinder to bottom dead cylinder, is called as suction stroke.

In suction stroke the inlet valve open which allows the water only in the one direction .At the end of the suction stroke the inlet valve closes. For second half revolution (θ=180 to 360^{o}) the piston moves from top dead center to bottom dead center of the cylinder. It is called as delivery stroke. In delivery stroke the water is pressurized and water is passed through the outlet valve. By this either of the pump delivers fluid that i.e., if the pump1 delivers the fluid, then the pump 2 induces the fluid (suction).The discharge output of the pump is increased with same operating pressure. The pump uses the one way valve (spherical ball) to control the fluid flow according to the strokes involved. Thus the pumps are dynamically balanced and high discharge capacity is obtained which is the main limitation of the reciprocating pump is been overcome, by this design.

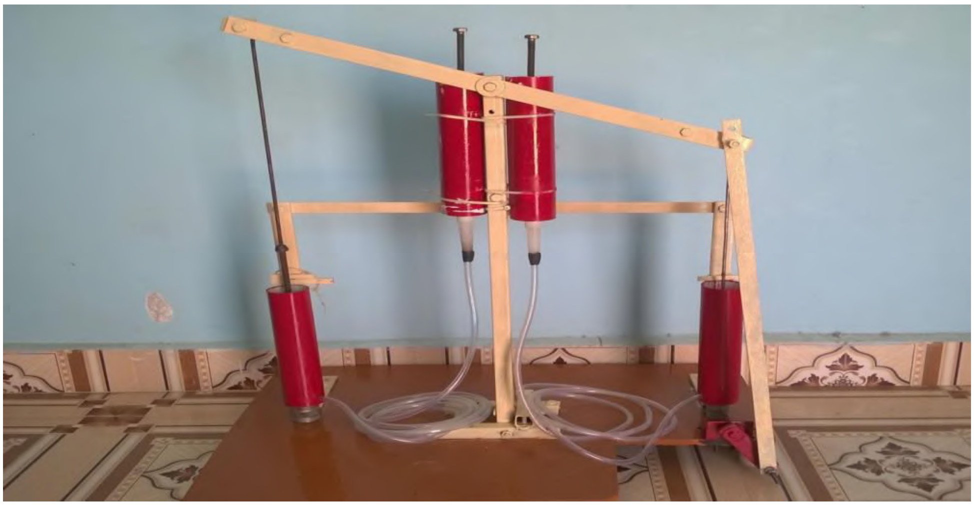


Fig .4.1 project model

4.2 ADVANTAGES:

- No priming needed for reciprocating pumps, because its self priming
- Higher efficiency
- High pressure water delivery
- Wide range pressure available

4.3 DISADVANTAGES:

- High maintenance cost
- High wear in the parts

4.4 APPLICATIONS:

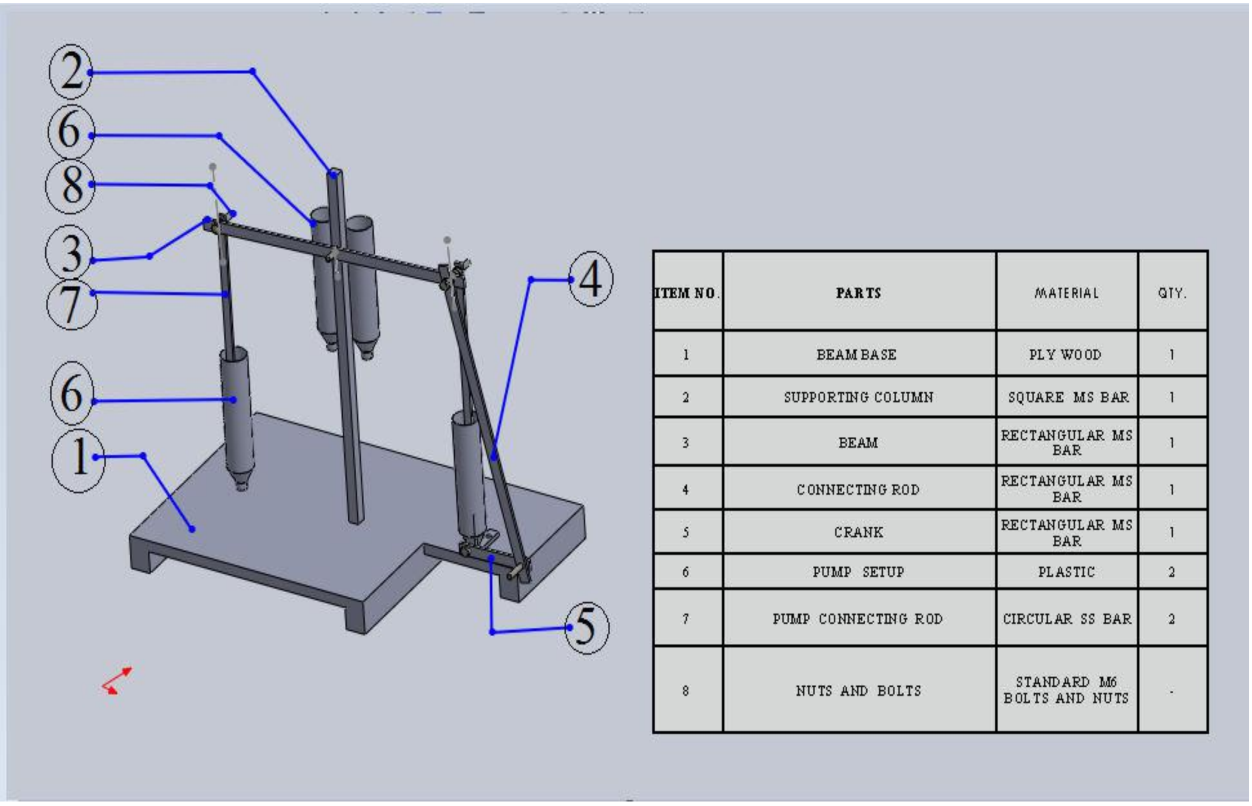
- This type of pumps are mainly used in the oil rig areas
- It is also used in the marine ships
- To displace the slurries or chemicals in industries
- It is also used in the agricultures(to lift the waters in conventional wells).

4.5 CONCLUSION:

We have developed the hydraulic pump powered by beam engine , which displaces fluid effectively. The usage of beam engine setup reduces vibrations and finds a wide range of application in mine sand oil rig areas.

The hydraulic pump and beam engine setup was designed and fabricated successfully taking into account in improving the discharge capacity by using two separate pumps and thereby overall efficiency.

5.1 APPENDIX:



ITEM NO.	PARTS	MATERIAL	QTY.
1	BEAM BASE	PLY WOOD	1
2	SUPPORTING COLUMN	SQUARE MS BAR	1
3	BEAM	RECTANGULAR MS BAR	1
4	CONNECTING ROD	RECTANGULAR MS BAR	1
5	CRANK	RECTANGULAR MS BAR	1
6	PUMP SETUP	PLASTIC	2
7	PUMP CONNECTING ROD	CIRCULAR SS BAR	2
8	NUTS AND BOLTS	STANDARD M6 BOLTS AND NUTS	-

Fig 5.1 3D Design

5.2 REFERENCE:

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