

# **“Computer Aided Design of Jaw crusher”**

Thesis Submitted in Partial Fulfillment of  
the Requirements for the Award of

**Bachelor of Technology**  
In  
**Mechanical Engineering**  
By

**Sobhan Kumar Garnaik**  
Roll No.: 10603013



**Department of Mechanical Engineering**  
**National Institute of technology**  
**Rourkela**  
**2010**

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Under guidance of  
**Prof. N. Kavi**



**Department of Mechanical Engineering**  
**National Institute of technology**  
**Rourkela**  
**2010**



# CERTIFICATE

This is to certify that the work in this Thesis Report entitled “**Computer Aided design of Jaw Crusher**” by **Sobhan Kumar Garnaik** has been carried out under my supervision in partial fulfillment of the requirements for the degree of **Bachelor of Technology in Mechanical Engineering** during the session 2009-10 in the Department of Mechanical Engineering, National Institute of Technology, Rourkela, and this work has not been submitted elsewhere for a degree.

To the best of my knowledge the matter embodied in this thesis has not been submitted elsewhere for the award of any degree/diploma.

**Dr. N. Kavi**

Professor

Department of Mechanical Engineering

National Institute of Technology

Rourkela – 769008

Date:

Place

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**Sobhan Kumar Garnaik**

Roll No.: 10603013

Department of Mechanical Engineering

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## **Abstract:**

Due to their simple design and easy maintainability jaw crushers are widely used as primary size reduction equipments in mechanical and mining industries. As jaw crushers break minerals & ores of high strength and the economy of many industries depends on its performance; it is essential to improve the efficiency of the present design. The kinematic analysis of single toggle jaw crusher shows that the forces on the moving jaw plate at different crank angle are different and hence power generated varies with crank angle. One way to increase the efficiency is to store the energy in a flywheel when the supply is more than the rate of consumption and to utilize the same when the supply falls down. Hence efforts are made to design a flywheel to minimize the wastage of power and to improve the performance parameters of single toggle jaw crusher.

Jaw plate wear has considerable affect on the life of jaw Crusher which is caused by the slipping motion between the fed material and the jaws. This wear is predominantly serious in the fixed plate and hence the liners of the fixed jaw should be properly chosen. In addition to this the toggle bar which acts as a safety lever has to be precisely designed. The design aspects of flywheel, spring of tension bar and toggle bar are discussed in this paper.

## Basics of Jaw Crusher

### **1.1 Introduction**

Crushing is the process of reducing the size of solid particles into definite smaller sizes. Jaw crushers are major size reduction machines used in mechanical, metallurgical and allied industries. The crusher crushes the feed by some moving units against a stationary unit or against another moving unit by the applied pressure, impact, and shearing or combine action on them. They are available in various sizes and capacities ranging from 0.3 ton/hr to 50 ton/hr. They are classified based on different factors like product size and mechanism used. Based on the mechanism used crushers are of three types namely Cone crusher, Jaw crusher and Impact crusher.

Fracture occurs in the feed material when the strain developed in it due to sufficiently applied impact forces, pressure or shearing effect exceeds the elastic limit .Generally crushers are very rugged, massive and heavy in design. The contact surfaces are equipped with replaceable liners made from high tensile manganese or other alloy steel sheet having either flat or corrugated surfaces. Shearing pins or nest in heavy coiled springs are provided in the crusher to guard against shock and over load.

A crusher may be considered as primary, secondary or fine crusher depending on the size reduction factor.

- a) Primary crusher – The raw material from mines is processed first in primary crushers..  
The input of such crushers is relatively wider and the output products are coarser in size.  
Example - Jaw crusher, Gyratory crusher.
- b) Secondary crusher- The crushed rocks from primary crusher are sent to secondary crusher for further size reduction. Example - Cone crusher, reduction gyratory crusher, spring rolls, disk crushers etc.
- c) Fine crushers- Fine crushers have relatively small openings, and are used to crush the feed material into more uniform and finer product. Example - Gravity stamp.

The material to be crushed is dropped between two rigid pieces of metal, one of which then move inwards towards the rock, and the rock is crushed as it has a lower breaking point than the opposing metal piece. Jaw crusher movement is guided by pivoting one end of the swinging jaw. and an eccentric motion located at the opposite end. [4] The size of a jaw crusher is designated by the rectangular or square opening at the top of the jaws .For instance, a 22 x 30 jaw crusher has an opening of 22" by 30", a 46 x 46 jaw crusher has a opening of 46" square. Generally primary jaw crushers have the square opening design, and secondary jaw crushers have rectangular opening design. Jaw crushers are used as primary crushers in a mine or ore processing plant or the first step in the process of reducing rock. They follow “crush using compression” mechanism.

## 1.2 Different Types of Jaw Crusher

According to the amplitude of motion of the moving face; Jaw crusher are classified as follows.

### a) Blake Type Jaw Crusher

Blake type jaw crusher, primary crushers in the mineral industry; attains maximum amplitude at the bottom of the crushing jaws as the swinging jaw is hinged at the top of the frame. These crushers are operated by and controlled by a pitman and a toggle. The feed opening is called *gape* and opening at the discharge end termed as the *set*. The Blake crushers may have single or double toggles. The toggle is used to guide the moving jaw. The retrieving motion of the jaw from its furthest end of travel is by springs for small crushers or by a pitman for larger crushers. During the reciprocating action, when the swinging jaw moves away from the fixed jaw the broken rock particles slip down and are again caught at the next movement of the pitman and are crushed again to even smaller size. This process continued till the particle sizes becomes smaller than *set*; the smallest opening at the bottom. For a smooth movement of the moving jaws, heavy flywheels are used.

. Blake type jaw crusher may be divided into two types. [4]

- (i) *Single toggle type*: - A single toggle bar is used in this type of crushers. Comparatively lighter jaw crushers use single toggle as they are cheap.

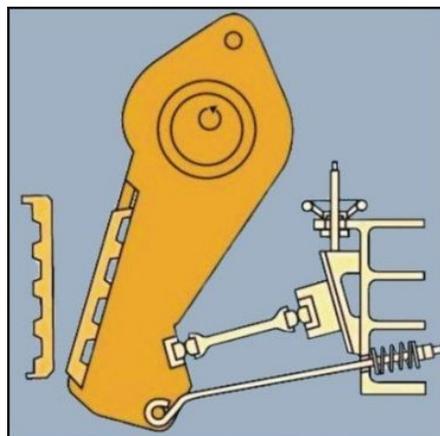


Figure 1.1

(ii) *Double toggle type*: - One extra toggle bar is attached here. Commonly used in mines as ability to crush materials is excellent, including tough and abrasive minerals. To crush larger material, Blake type jaw crushers are preferred. The characteristics of such crusher are:

1. Larger, rough, massive and sticky rocks can be crushed.
2. They are easy to maintain
3. It is very simple to adjust and prevent much of wear and are easy to repair,
4. Moving jaw can be reinforced with high tensile manganese to crush very hard rock.

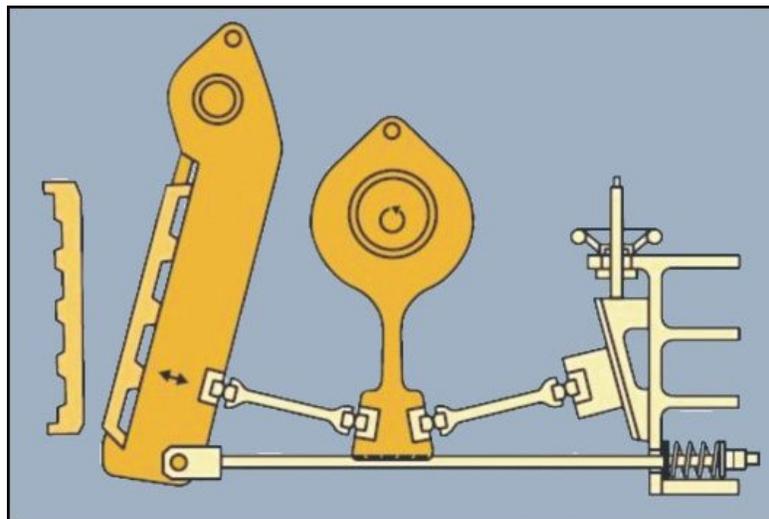


Figure 1.2

## 2) Dodge Type Jaw Crusher

The movable jaw is pivoted at the bottom and connected to an eccentric shaft. The universal crushers are pivoted in the middle so that the jaw can swing at the top and the bottom as well. Maximum amplitude of motion is obtained at the top of the crushing plates. Dodge type crushers are not used for heavy duty and commonly found in laboratories.

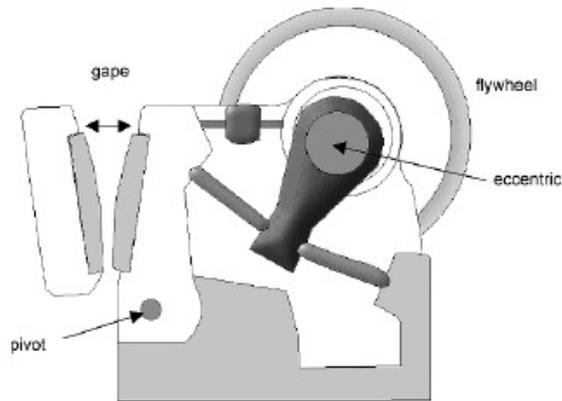


Figure 1.3

### 1.3 Working Principle:

The mechanism of jaw crusher is based on the concept “crushing without rubbing”. Jaw crushers consist of two jaws. One fixed and the other reciprocating. The opening between them is largest at the top and decreases towards the bottom. The pitman moves on an eccentric shaft and swing lever swings on centre pin. The rock is thrown between two jaws and crushed by mechanical pressure.

A belt pulley; which is driven by a motor drives the eccentric shaft to rotate. This makes the attached jaw to approach and leave the other jaw repeatedly, to crush, rub and grind the feed. Hence the material moves gradually towards the bottom and finally discharges from the discharge end. The fixed jaw mounted in a “V” alignment is the stationary breaking surface. The swinging jaw exerts impact force on the material by forcing it against the stationary plate. The space at the bottom of the “V” aligned jaw plates is the crusher product size gap or size of the crushed product from the jaw crusher. The remains until it is small enough to pass through the gap at the bottom of the jaws. [5]

The ores are fed to the machine from the top; where the jaws are maximum apart. As the jaws come closer the ores are crushed into smaller sizes and slip down the cavity in the return stroke. In following cycle, further reduction of size is experienced and the ore moves down further. The process is continued till particles size is reduced to less than the bottom opening. The toggle is used to guide the moving jaw. The retrieving motion of the jaw from its furthest end of travel is by springs for small crushers or by a pitman for larger crushers. For a smooth movement of the moving jaws, heavy flywheels are used.

### **1.4 Crusher Size and Power rating:**

The size of a jaw crusher is usually expressed as gape x width. The common crusher types, sizes and their performance is summarized in Table 1.1. Currently, the dimension of the largest Blake-type jaw crusher in use is 1600 mm x 2514 mm with motor ratings of 250-300 kW. Crushers of this size are manufactured by Locomo, Nordberg (Metso) and others. The Metso crusher is the C 200 series having dimensions 1600 x 2000 mm. driven by 400 kW motors. Various sizes of jaw crushers are available, even a crusher size of 160 x 2150 mm (1650 mm is the width of the maximum opening at the top and the jaws are 2150 mm in long) are not uncommon. The maximum diameter of the feed is ranged in 80 to 85% of the width of the maximum opening. Such a heavy crusher (16540x 2150mm) crushes rock, mineral or ore varying from 22.5 cm to 30cm with a capacity ranging from 420 to 630 ton per hour. The motor rpm and power are around 90 and 187.5 kW respectively. The jaw and the sides of the unit are lined with replaceable wear resistant plate liners. [4]

## **1.5 Components of a Jaw Crusher**

### **1.5.1 Crusher Frame:**

Crusher Frame is made of high welding. As a welding structure, it has been designed with every care so as to ensure that it is capable of resistant to bending stress even when crushing materials of extremely hard.

### **1.5.2 Jaw Stock:**

Jaw Stock is also completely welded and has renewable bushes, Particular importance has been given to jaw Stock of a design resistant to bending stresses. All jaw stocks are provided with a renewable steel Alloy or manganese steel toggle grooves.

### **1.5.3 Pitman:**

Pitman" means "connecting rod", but in a jaw crusher it doesn't connect two things. The pitman refers to the moving jaw in a jaw crusher. It achieves the reciprocating movement through the eccentric motion of the flywheel shaft. This creates enormous force in each stroke. Pitman is fabricated from high quality steel plates and stresses are removed after welding. The Pitman is fitted with two replaceable high strength steel Alloy or manganese steel toggle bar. Grooves housings for the bearings are accurately bored and faced to gauge.

### **1.5.4 Manganese Liners:**

The jaw crusher pitman is covered on the inward facing side with dies made of manganese, an extremely hard metal. These dies often have scalloped faces. The dies are usually symmetrical top to bottom and can be flipped over that way. This is handy as most wear

occurs at the bottom (closed side) of the jaw and flipping them over provides another equal period of use before they must be replaced.

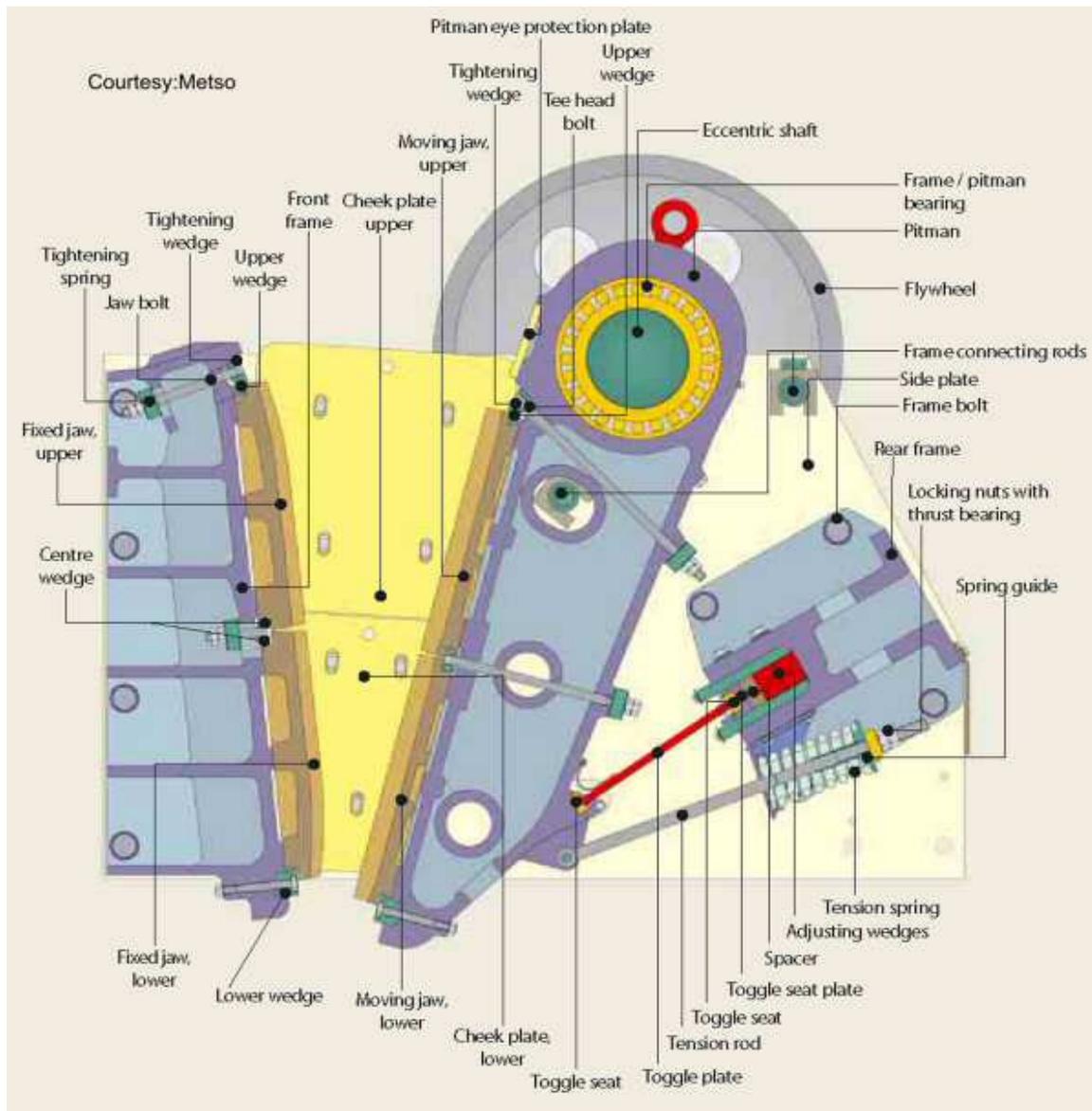


Figure 1.4

### **1.5.5 Jaw Crusher Fixed Jaw Face:**

The fixed jaw face is opposite the pitman face and is statically mounted. It is also covered with a manganese jaw die. Manganese liners which protect the frame from wear; these include the main jaw plates covering the frame opposite the moving jaw, the moving jaw, and the cheek plates which line the sides of the main frame within the crushing chamber.

### **1.5.6 Eccentric Shaft:**

The pitman is put in motion by the oscillation of an eccentric lobe on a shaft that goes through the pitman's entire length. This movement might total only 1 1/2" but produces substantial force to crush material. This force is also put on the shaft itself so they are constructed with large dimensions and of hardened steel. The main shaft that rotates and has a large flywheel mounted on each end. Its eccentric shape moves the moving jaw in and out. Eccentric Shaft is machined out of Alloy Steel Fitted with anti-friction bearings and is housed in pitman and dust proof housing.

Rotational energy is fed into the jaw crusher eccentric shaft by means of a sheave pulley which usually has multiple V-belt grooves. In addition to turning the pitman eccentric shaft it usually has substantial mass to help maintain rotational inertia as the jaw crushes material.

### **1.5.7 Toggle Plate Protecting the Jaw Crusher:**

The bottom of the pitman is supported by a reflex-curved piece of metal called the toggle plate. It serves the purpose of allowing the bottom of the pitman to move up and down with

the motion of the eccentric shaft as well as serve as a safety mechanism for the entire jaw. Should a piece of non-crushable material such as a steel loader tooth (sometimes called "tramp iron") enter the jaw and be larger than the closed side setting it can't be crushed nor pass through the jaw. In this case, the toggle plate will crush and prevent further damage.

#### **1.5.8 Tension Rod Retaining Toggle Plate:**

Without the tension rod & spring the bottom of the pitman would just flop around as it isn't connected to the toggle plate, rather just resting against it in the toggle seat. The tension rod system tensions the pitman to the toggle plate. The toggle plate and seats. The toggle plate provides a safety mechanism in case material goes into the crushing chamber that cannot be crusher. It is designed to fail before the jaw frame or shaft is damaged. The seats are the fixed points where the toggle plate contacts the moving jaw and the main frame.

#### **1.5.9 Jaw Crusher Eccentric Shaft Bearings:**

There are typically four bearings on the eccentric shaft: two on each side of the jaw frame supporting the shaft and two at each end of the pitman. These bearings are typically roller in style and usually have labyrinth seals and some are lubricated with an oil bath system. Bearings that support the main shaft. Normally they are spherical tapered roller bearings on an overhead eccentric jaw crusher.[10]

Anti-Friction Bearings are heavy duty double row self-aligned roller-bearings mounted in the frame and pitmans are properly protected against the ingress of dust and any foreign matter by carefully machined labyrinth seals. Crushing Jaws are castings of austenitic manganese steel conforming to IS 276 grade I & II. The real faces of the crushing

jaws are leveled by surface grinding in order to ensure that they fit snugly on the crusher frame and jaw stock. The crushing jaws are reversible to ensure uniform wear and tear of grooves.(sometimes implemented and a more adjustable or hydraulic fashion) allow for this adjustment. [6]

### 1.6 Material for components of jaw crusher.

Component	Material / Function
1. Body	Made from high quality steel plates and ribbed heavily in welded steel construction
2. Swing jaw Plate	Manganese steel
3. Fixed jaw plate	Manganese steel
4. Pitman	Crushers have a light weight pitman having white-metal lining for bearing surface
5. Toggle	Double toggles, for even the smallest size crushers give even distribution of load
6. Flywheel	high grade cast iron
7. Tension Rod	Pullback rods helps easy movement, reduces pressure on toggles and machine vibration
8. Hinge plate	Strong hinge pin made from steel are used for crushing without rubbing
9. Shaft and bearings	Massive rigid eccentric shafts made from steel along with roller bearing ensures smooth running.
10. Diaphragm	Flexible diaphragm seals opening in oil chamber and protects components from dust.

Table 1.1

### Kinamatic Analysis of Jaw Crusher

#### **2.1 Introduction:**

Due to its simple structure, easy maintainability jaw crushers are widely used for mining, mechanical and metallurgical industries. A lot of research work is going on over the world to improvise the performance of jaw crusher. The crushing mechanism is composed of series of single particle breakage. Once the particles are squeezed in the cavity and failed in tension stress, the resulting fragments move down before being crushed again. The movement of the swinging jaw is certainly a key factor to jaw crusher performance. In order to study the behavior of the moving jaw plate; a kinematic analysis of the same is being presented in this chapter.

The geometry of moving jaw results in the movement change, which has great effect on the crushing action and the particle breakage. At present, most of the research on the jaw plates wear is carried out from material science perspective on a microscopic level or to predict the jaw plates wear under the fine comminution condition. They are limited in helping designing the jaw crusher in use. Now the online monitoring to the wear is difficult [3]. In this paper the movement of the moving jaw is described in detail and the breakage squeezing process is also analyzed. The breakage force is measured and the test result is analyzed with the particle breakage character taken into consideration. Based on the analysis of the moving jaw movement, the squeezing process and the crushing force

distribution, the jaw plates wear on a macroscopic level is studied aiming to effectively predict the wear distribution on the jaw plates.

## 2.2 Swinging jaw movement

A schematic diagram of a single toggle jaw crusher is shown in figure 2.1. The reciprocating jaw MN driven by the eccentric shaft AB does a kind of periodic plain swing movement. Due to the importance and the complexity of the moving jaw movement, it is necessary to describe it in detail.

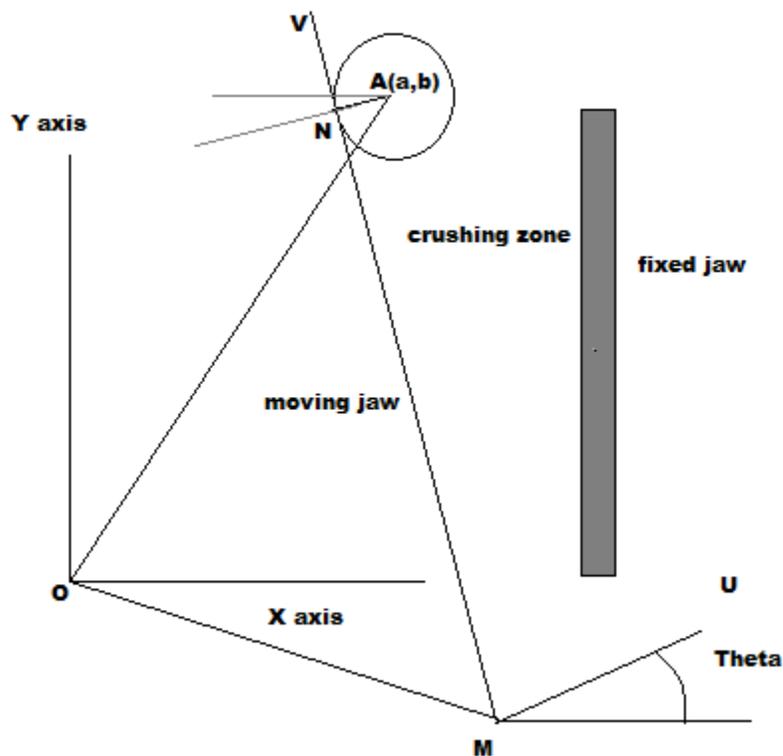


Figure 2.1

Jaw crusher can be considered as a four bar mechanism in which ,link AN is the crank and OA is the fixed link. MN is the moving jaw and OM is the toggle bar. In the kinematic analysis we are intend to find out the displacement, velocity and acceleration of various points on the swinging jaw

plate.

We consider the plane of moving jaw as v-axis which makes an angle “ $\alpha$ ” with the global co-ordinate “y-axis”. Similarly perpendicular to v-axis is u-axis which makes the same angle with x-axis of the global co-ordinate system.

From a standard jaw crusher following data is taken:

Length of AN =172 cm

Length of MN =1085 cm

Length of OM =455 cm

Co-ordinates of A (45.3 , 815.7)

The crank AN rotates from 0 to 360 anticlockwise. By designing the above mechanism in AUTO CAD 2007 for each 30 rotation of the crank we get the following angles made by the moving jaw with the y-axis.

<b>Crank angle (<math>\beta</math>) in degree</b>	<b>Angle b/w moving jaw and y axis (<math>\alpha</math>) in degree</b>
0	20.16
30	19.84
60	19.37
90	18.9
120	18.55
150	18.41
180	18.52
210	18.84
240	19.29
270	19.74
300	20.1
330	20.25
360	20.16

Table 2.1

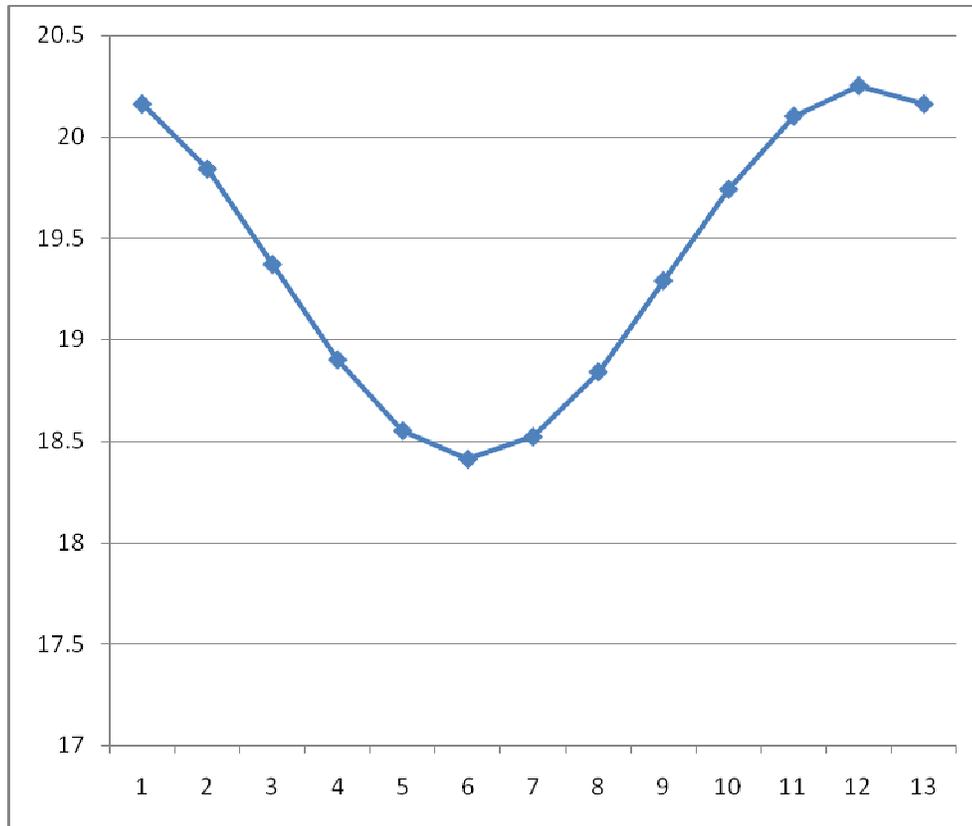


Figure 2.2

The graph shown above is crank angle v/s  $\alpha$  (angle between moving jaw and global y axis). The crank angle in x axis is taken  $30^\circ$  as 1 unit.

**Interpretation of the graph:**

The graph shows as the moving jaw approaches its counterpart which is stationary it tends to be vertical, i.e. the angle between y axis and the moving jaw decreases. As a result the crushed product slips downwards.

### 2.3 Derivation for Displacement of any point on the moving jaw plane:

We consider any point P (u,v) on the swinging jaw, On the moving jaw plate  $u=0$ . The coordinates p (u,v) can be represented in global axis in terms of x and y as below.

$$x = u \cos \alpha + (1 - v) \sin \alpha + a - r \sin \beta$$

$$y = u \sin \alpha + (1 - v) \cos \alpha + b - r \cos \beta$$

We take 11 sample points on the moving jaw plate at  $u=0$  and  $v=85, 185, 285, 385, 485, 585, 685, 785, 885, 985, 1085$  to study the kinematic behavior based on geometry.

A matlab program is written to find out the position of the above mentioned points and the following graphs are plotted from the output data.

1. Position of movable plate at different crank angle
2. Horizontal displacement of all 11 points v/s crank angle
3. Horizontal displacement and vertical displacement V/s crank angle for the 5<sup>th</sup> point.
4. The physical positions of the 5th point i.e. its vertical v/s horizontal displacement.

#### 2.3.1 Matlab program to find out displacement.

```
clc
clear
n=1;
l=1085;
a=45.3;
r=12;
u=0;
```

```

b=815.7;
i=1;
theta=[20.16 19.84 19.37 18.90 18.55 18.41 18.52 18.84 19.29 19.74 20.10 20.25 20.16];
for psi=0:30:360
    n=1;
    for v=85:100:1085
        x(i,n)=u*cos(theta(i)*pi/180)+(l-v)*sin(theta(i)*pi/180)+a-r*sin(psi*pi/180);
        y(i,n)=u*sin(theta(i)*pi/180)-(l-v)*cos(theta(i)*pi/180)+b-r*cos(psi*pi/180);
        n=n+1;
    end
    i=i+1;
end
psinew=0:30:360;
figure(1)
plot(x(1,:),y(1,:));
hold on
plot(x(4,:),y(4,:));
hold on
plot(x(7,:),y(7,:));
hold on
plot(x(10,:),y(10,:));
figure(2)
for i=1:1:11
    plot(psinew,x(:,i))
hold on
end
figure(3)
plot(psinew,y(:,5))
hold on
plot(psinew,x(:,5))
figure(4)
plot(y(:,5),x(:,5))
x;
y;

```

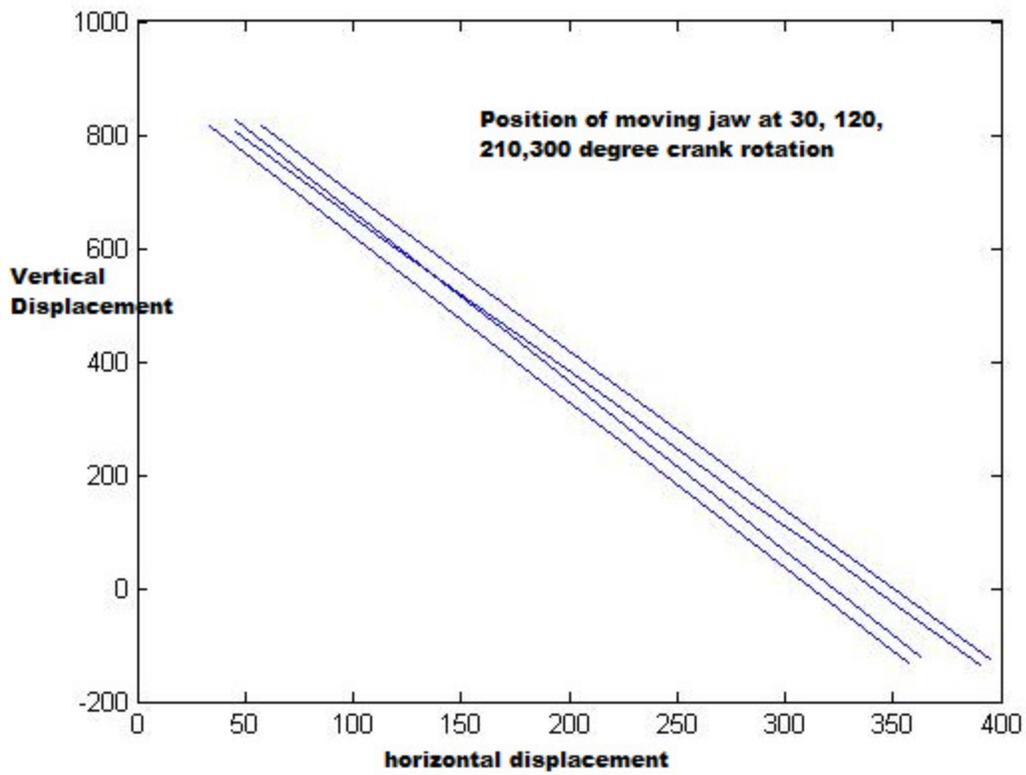


Fig.2.3

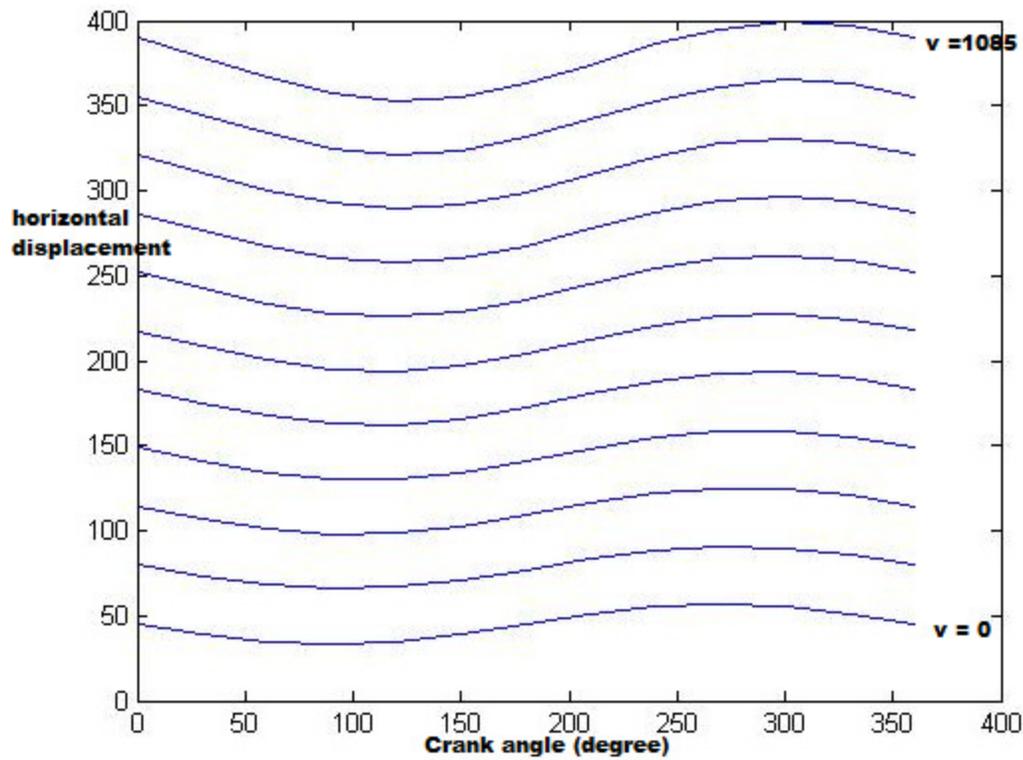


Figure 2.4

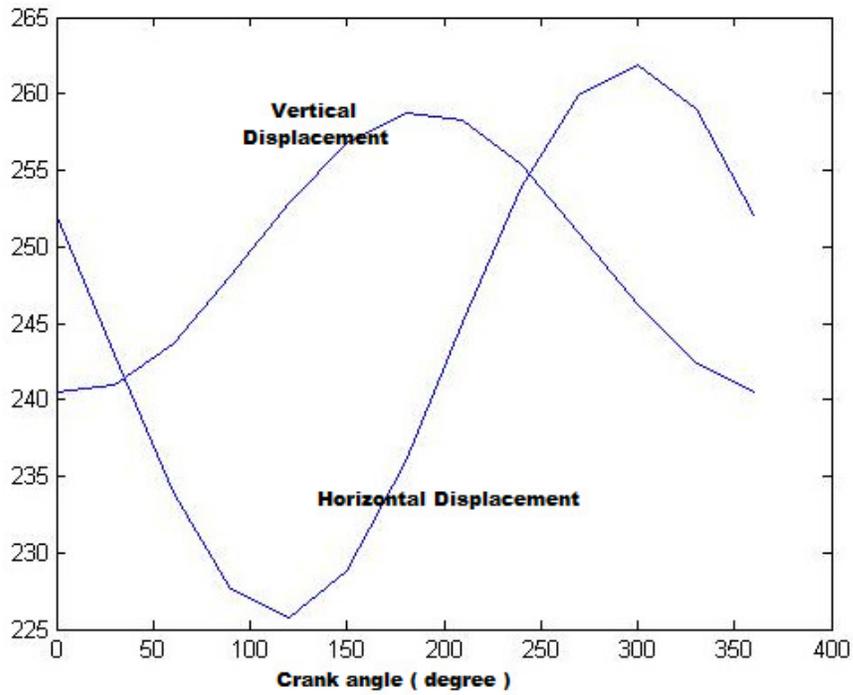


Figure2.5

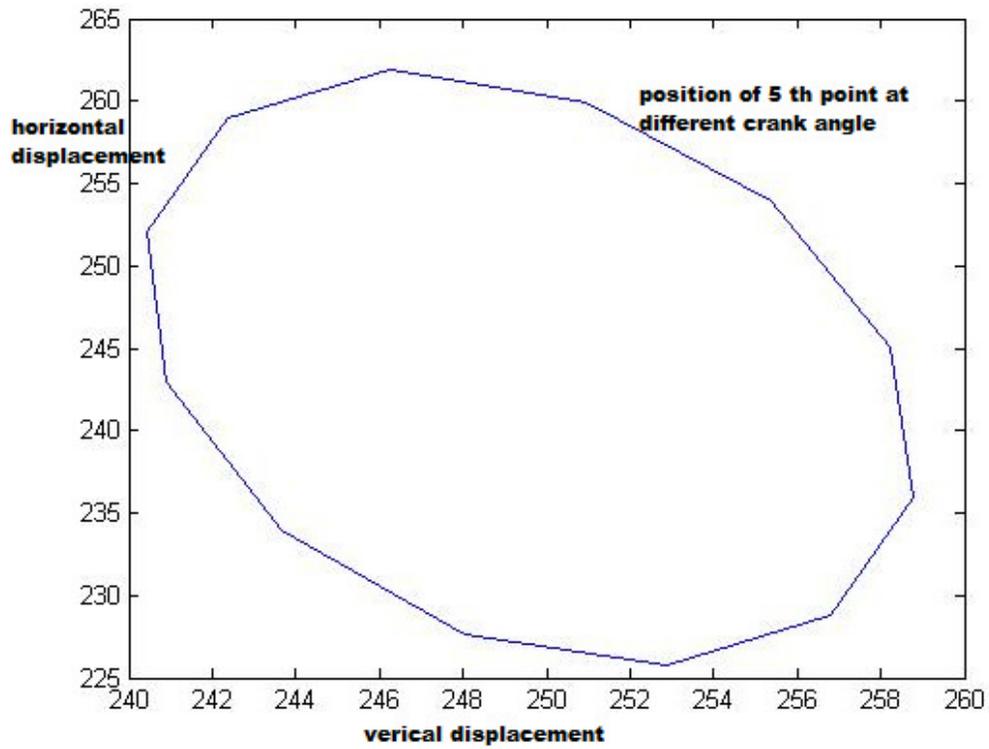


Figure 2.6

### 2.3.2 Interpretation of the graphs:

1. Every point on the moving jaw follows an elliptical path
2. When the moves towards the fixed jaw; it goes vertically down and in the return stroke it moves vertically up.

### 2.4 Derivation for Displacement of any point on the moving jaw plane:

By differentiating the position we get the equation to calculate the horizontal and vertical velocities. Expressions for horizontal and vertical velocities are given below:

$$V_x = (1 - v) \cos \alpha \left( \frac{d\alpha}{d\beta} \right) - r \cos \beta - u \sin \alpha \left( \frac{d\alpha}{d\beta} \right)$$

$$V_y = (1 - v) \sin \alpha \left( \frac{d\alpha}{d\beta} \right) + r \sin \beta + u \cos \alpha \left( \frac{d\alpha}{d\beta} \right)$$

A matlab program is written to find out the velocities of the mentioned points and the following graphs are plotted from the output data.

1. Horizontal velocity of all 11 points v/s crank angle
2. Vertical velocity of all 11 points v/s crank angle
3. Velocity V/s crank angle for all 11 points

#### 2.4.1 Matlab program to calculate and plot horizontal & vertical velocities.

```
clc
clear
n=1;
l=1085;
a=45.3;
r=12;
u=0;
```

```

b=815.7;
i=1;
theta=[20.16 19.84 19.37 18.90 18.55 18.41 18.52 18.84 19.29 19.74 20.10
20.25 20.16];
psi(1)=0;
m=0;
for i=1:1:13
    n=1;
    for v=85:100:1085
        vx(i,n)=(l-v)*cos(theta(i)*pi/180)*m-r*cos(psi(i)*pi/180)-
u*sin(theta(i)*pi/180)*m;
        vy(i,n)=(l-
v)*sin(theta(i)*pi/180)*m+r*sin(psi(i)*pi/180)+u*cos(theta(i)*pi/180)*m;
        n=n+1;
    end
    if(i<=12)
        psi(i+1)=psi(i)+30;
        m=(theta(i+1)-theta(i))/(psi(i+1)-psi(i));
    end
end
figure(1)
for i=1:1:11
    plot(psi,vx(:,i));
    hold on;
end
figure(2)
for i=1:1:11
    plot(psi,vy(:,i));
    hold on;
end
for i=1:1:13
    for j=1:1:11
        v(i,j)=sqrt(vx(i,j)^2+vy(i,j)^2);
    end
end
figure(3)
for i=1:1:11
    plot(psi,v(:,i))
    hold on;
end

```

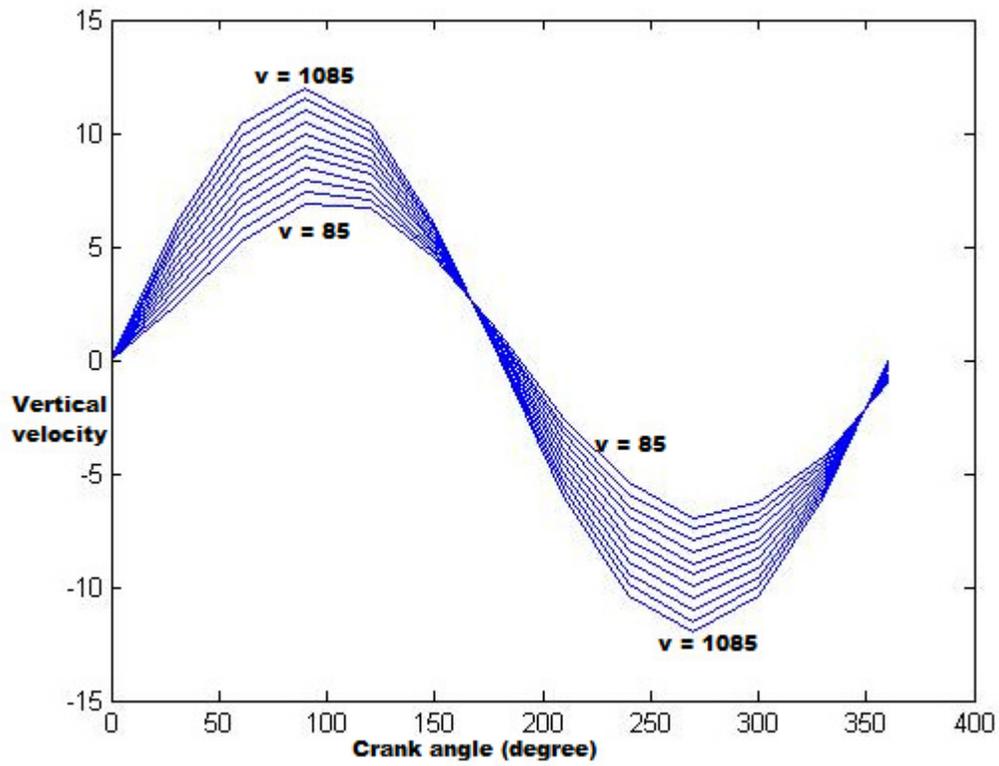


Figure2.7

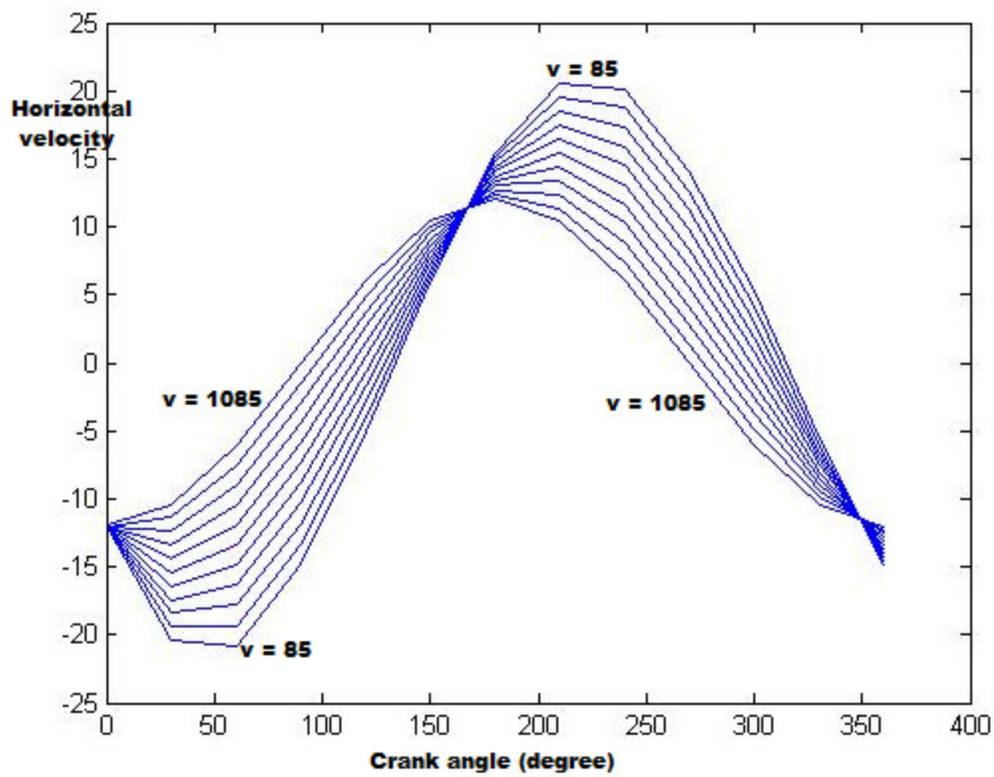


Figure 2.8

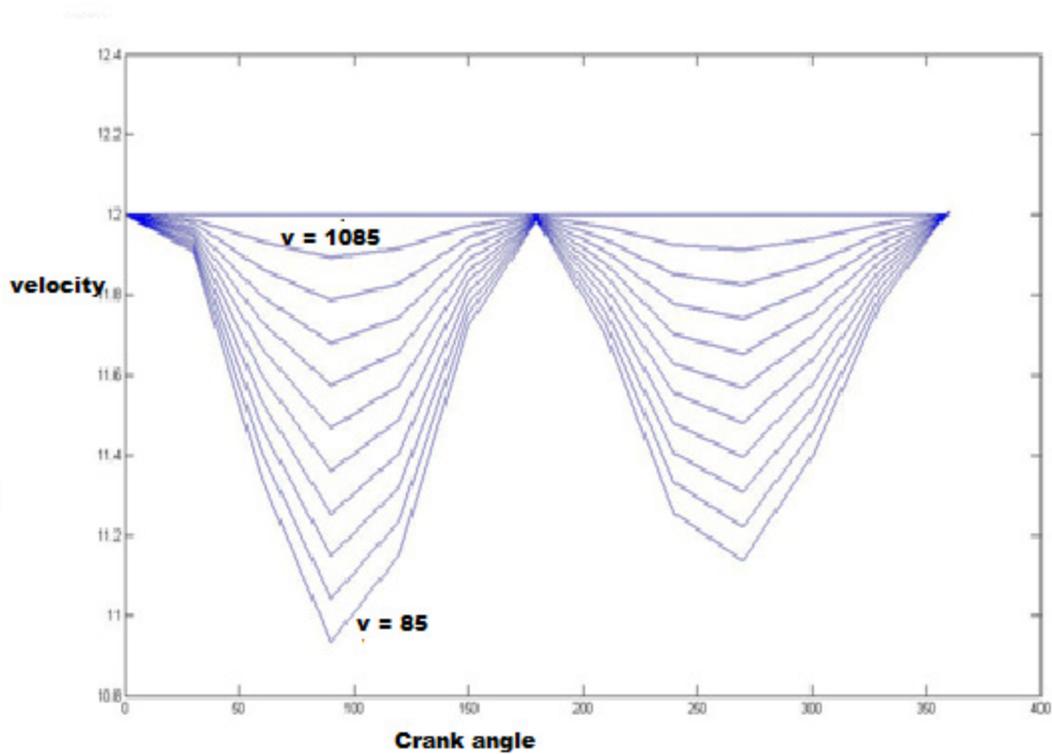


Figure 2.9

#### 2.4.2 Interpretation of the graphs:

1. The rate of change of vertical velocity is more for the top most point and decreases downwards.
2. The rate of change of horizontal velocity is more for the bottom most point and decreases upwards.
3. The maximum rate of change of final velocity is more for the points away from the crank.

## 2.5 Derivation for Displacement of any point on the moving jaw plane:

By differentiating the velocity we get the equation to calculate the horizontal and vertical accelerations. Expressions for horizontal and vertical accelerations are given below:

$$a_x = [(1 - v) \cos \alpha - u \sin \alpha] (d^2\alpha/d\beta^2) - (d\alpha/d\beta)^2 [(1 - v) \sin \alpha + u \cos \alpha] + r \sin \beta$$

$$a_y = [(1 - v) \sin \alpha + u \cos \alpha] (d^2\alpha/d\beta^2) + (d\alpha/d\beta)^2 [(1 - v) \cos \alpha - u \sin \alpha] + r \cos \beta$$

A matlab program is written to find out the acceleration of the mentioned points and the following graphs are plotted from the output data.

1. Horizontal acceleration of all 11 points v/s crank angle
2. Vertical acceleration of all 11 points v/s crank angle
3. Acceleration of all the 11 points V/s crank angle.

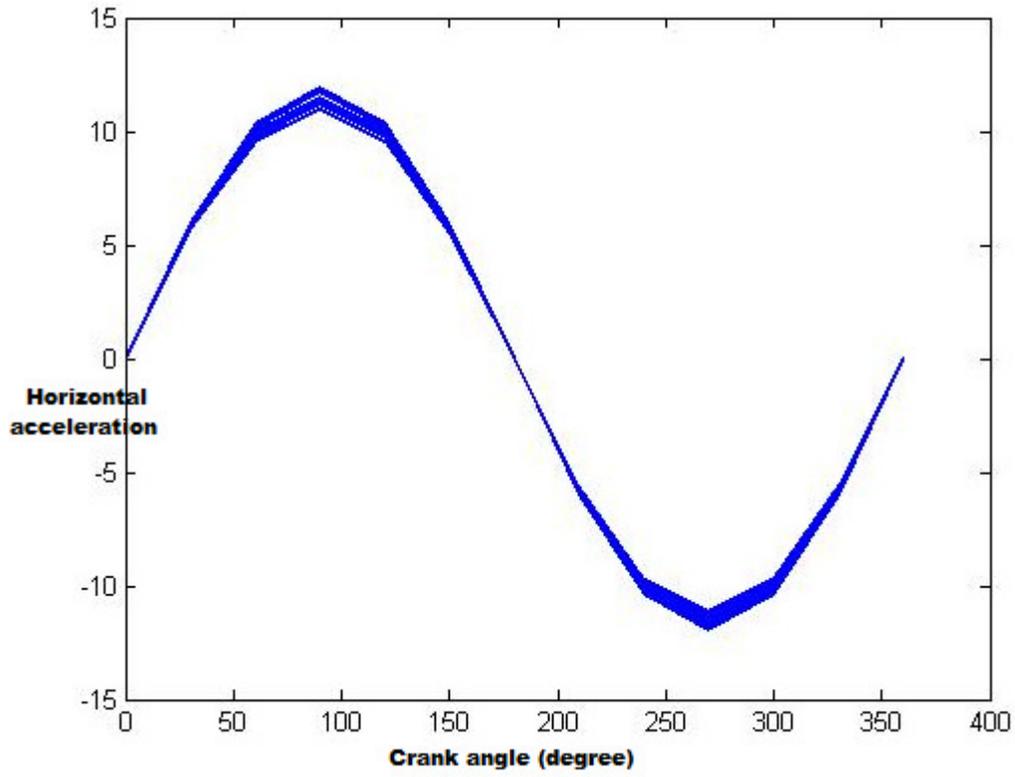
### 2.5.1 matlab program for acceleration of points on the moving jaw plate

```
dc
clear
n=1;
l=1085;
a=45.3;
r=12;
u=0;
b=815.7;
i=1;
theta=[20.16 19.84 19.37 18.90 18.55 18.41 18.52 18.84 19.29 19.74 20.10 20.25 20.16];
psi(1)=0;
m(1)=0;
dm(1)=0;
for i=1:1:13
    n=1;
    for v=85:100:1085
        ax(i,n)=[(1-v)*cos(theta(i)*pi/180)-u*sin(theta(i)*pi/180)]*dm(i)-m(i)^2*[(1-v)*sin(theta(i)*pi/180)+u*cos(theta(i)*pi/180)]+r*sin(psi(i)*pi/180);
```

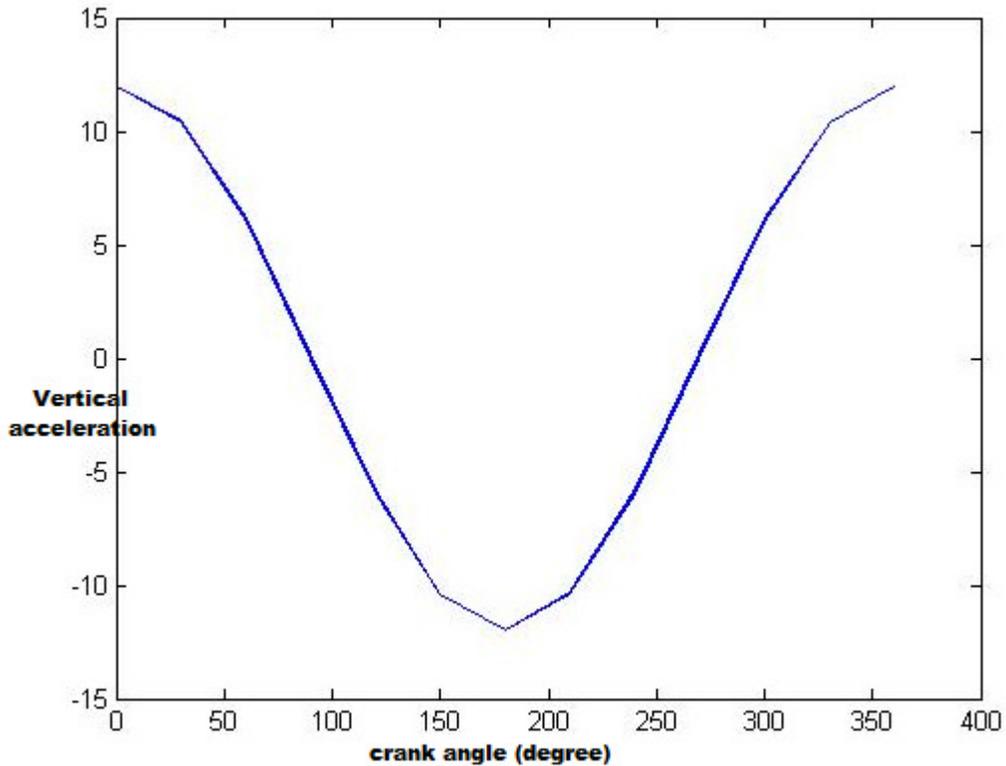
```

        ay(i,n)=(l-v)*cos(theta(i)*pi/180)-u*sin(theta(i)*pi/180))*m(i)^2+((l-
v)*sin(theta(i))*pi/180+u*cos(theta(i)*pi/180))*dm(i)+r*cos(psi(i)*pi/180);
        n=n+1;
    end
    if(i<=12)
        psi(i+1)=psi(i)+30;
        m(i+1)=(theta(i+1)-theta(i))/(psi(i+1)-psi(i));
        dm(i+1)=(m(i+1)+m(i))/(psi(i+1)-psi(i));
    end
end
figure(1)
for i=1:1:11
    plot(psi,ax(:,i));
    hold on;
end
figure(2)
for i=1:1:11
    plot(psi,ay(:,i));
    hold on;
end
for i=1:1:13
    for j=1:1:11
        a(i,j)=sqrt(ax(i,j)^2+ay(i,j)^2);
    end
end
figure(3)
for i=1:1:11
    plot(psi,a(:,i))
    hold on;
end
end

```



Figure



2.10

Figure

2.11

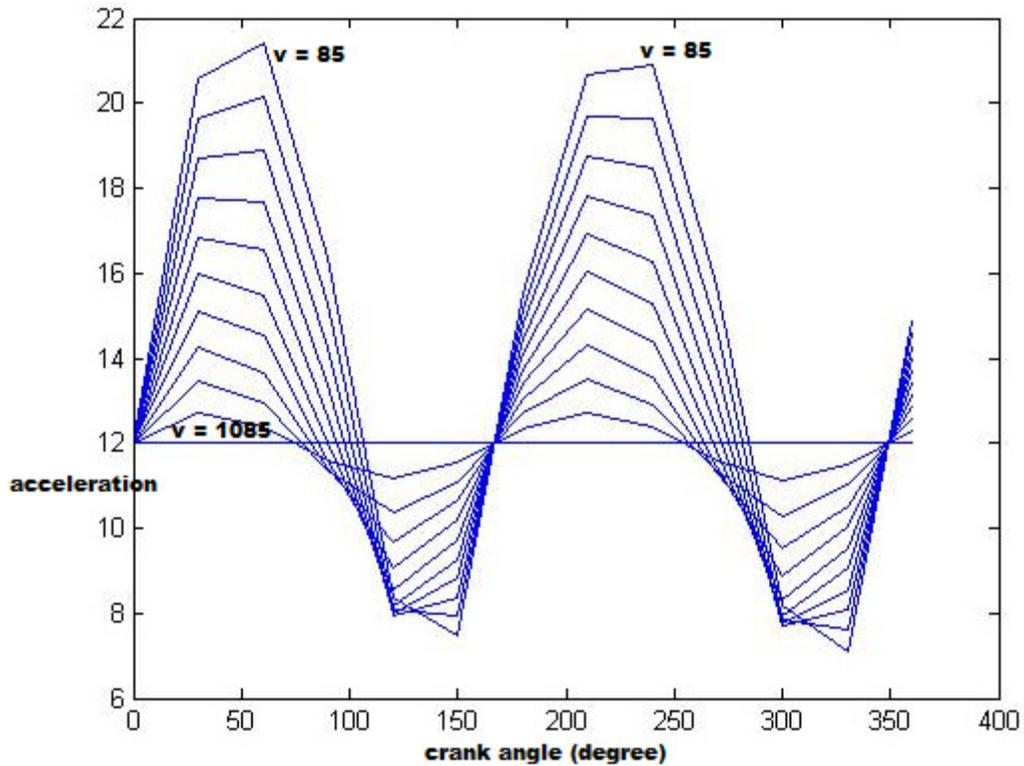


Figure 2.12

### 2.5.2 Interpretation of the graphs:

1. With progress from 0 to 360 degree crank rotation the horizontal acceleration first increases and then decreases.
2. With progress from 0 to 360 degree crank rotation the vertical acceleration first decrease and then increases .
3. The maximum acceleration is observed for the points farthest away from the crank.

**Effects of sliding motion on jaw plate wear**

**3.1 Breakage Analysis:**

Under compression as the energy intensity increases, there are three types of fracture mechanisms are observed as is illustrated in figure 3.1. The particle fracture mechanism in jaw crusher chamber is the mixture of the cleavage and the abrasion [7]. The abrasion fracture is caused with the localized too much energy input to the area directly under the loading points and the friction between the jaw plates and the particle. The induced tensile stress results in the cleavage fracture. The breakage process due to the point contact loading that occurs between the plates of a jaw crusher and a particle is shown in figure 3.2

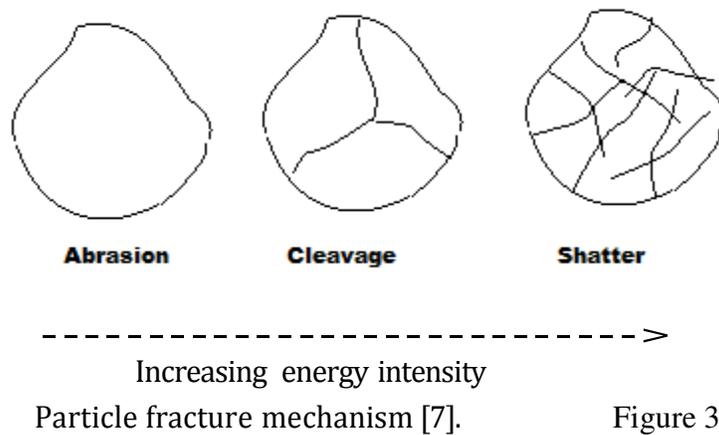
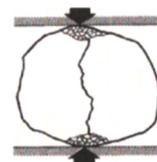


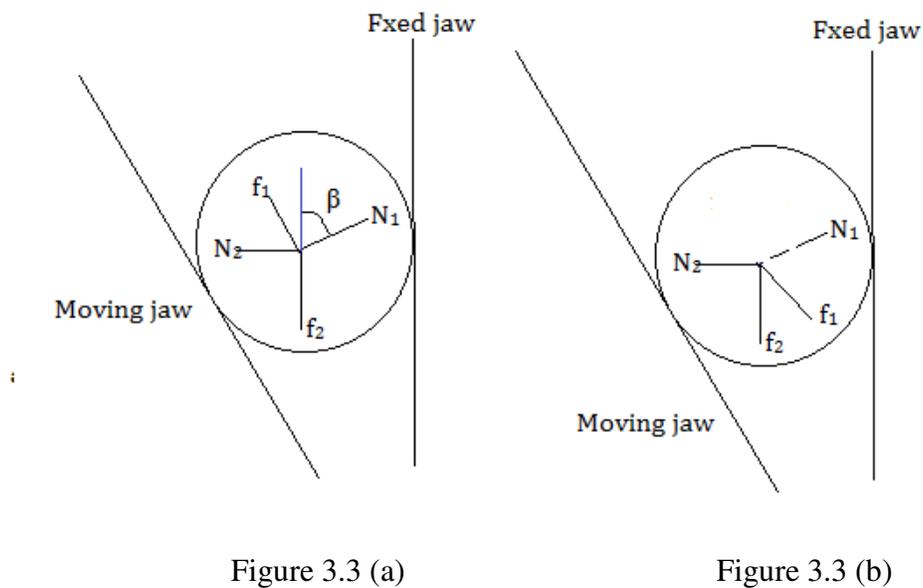
Figure 3

Figure 3.2, fracture caused by compression crushing [7].



### 3.2 Crushing Process

Theoretically a particle is crushed in side a crusher when it is compressed and fails in tensile stress. But in actual practice these particles also undergo slipping motion between the jaw plates . It is due to the vertical movement of the swinging during the working cycle. Sometimes the particles also exhibit rolling motion that depends on the the geometry of the fed material and the crushing zone. As the sliding motion between the jaw plates and the particle has considerable affect on the jaw plates wear, the consequences due to sliding motion is studied here.



The force acting on the element during the crushing process is shown in the Figure 3.3 As the horizontal and the vertical velocities of the moving jaw changes during the crushing process, the forces on the particle varies at different time. When the component of the vertical velocity in the moving jaw plate direction is bigger than that of the horizontal velocity in the same direction, the forces on the particle are shown in figure

3.3(a). When the component of the vertical velocity in the jaw plate direction is smaller than that of the horizon velocity, the forces on the particle are shown in figure 3.3(b). The magnitude of gravitational force is much smaller than others, it can be ignored.

Resolving forces in horizontal direction for figure 3.3(a)

for equilibrium 
$$N_1 \sin \beta - f_1 \cos \beta - N_2 = 0 \quad (\text{Equation 3.1})$$

Resolving forces in vertical direction for figure 3.3(a)

for equilibrium 
$$N_1 \cos \beta + f_1 \sin \beta - f_2 = 0 \quad (\text{Equation 3.2})$$

Let us assume slide takes place between the particle and the swinging jaw plate.

Coefficient of friction is taken as  $\mu_1$  between moving jaw and particle and  $\mu_2$  between fixed jaw and the particle under compression.

$$\mu_2 = (\cos \beta + \mu_1 \sin \beta) / (\sin \beta - \mu_1 \cos \beta) > 0 \quad (\text{Equation 3.3})$$

$$\mu_1 - \mu_2 = -\{(\mu_1)^2 \cos \beta - \cos \beta\} / (\sin \beta - \mu_1 \cos \beta) \quad (\text{Equation 3.4})$$

It is inconsistent to the assumption.

Now, Let us consider slide takes place between the particle and the fixed jaw plate.

$$f_2 = \mu_1 N_2$$

and 
$$\mu_2 = (\mu_1 \sin \beta + \cos \beta) / (\sin \beta + \mu_1 \cos \beta) \quad (\text{Equation 3.5})$$

$$\mu_1 - \mu_2 = -\{(\mu_1)^2 \cos \beta + \cos \beta\} / (\sin \beta + \mu_1 \cos \beta) > 0 \quad (\text{Equation 3.6})$$

Which is rational.

Hence from the above analysis for figure 3.3(b) it is proved that condition for the particle to slip against the fixed jaw plate is much easier than with the moving jaw plate. Under figure 3.3(b) condition the slide between the particle and the fixed plate is also unavoidable. So in either case the chance of the particle to slide with the fixed jaw is more as compared to

the moving jaw. In fact, due to the vertical motion and the irregular geometry of particles, a classification process before the particle fracture may exist during close process, in which the particle position adjustment takes place.

### **3.3 Wear analysis**

Squeezing and sliding are the two principal factors affecting the jaw plates wear. High manganese steel are widely used as the liner for moving jaw as it possesses excellent work hardening character. By scanning the worn jaw plates under the electron microscope, it is found that the sliding is the main factor to the jaw plates wear and the sufficient squeezing can even relieve the jaw plate wear [1]. Squeezing plays the main role at the top of the jaw crusher as the sliding is small at this area, the wear in this zone is small. As we move down the crusher, the probability to slip increases and the wear becomes more serious. While moving along the length, at the middle lower part of the crusher, the ratio of the vertical distance to the horizontal stroke reaches the maximal value resulting maximum wear in this region. Very few particles come in contact with the edge parts, so the wear at the lower parts is considerably small. For the same jaw crusher, the slide between the particle and the moving jaw plate, is more compared to the moving jaw plate and hence the wear is dominant in fixed jaw relative to its stationary counterpart.

### Design Of Flywheel

#### **4.1 Flywheel**

A flywheel is used as a reservoir of energy in machines. It stores the excess of energy when the supply is more than the requirement and utilizes the same when the rate of supply of energy falls. Basically it is used as a storage device for rotational energy. Flywheels help to stabilize the rotation of the shaft when a varying torque is exerted on it by its power source; by resisting changes in their rotational speed. Flywheels can be used to produce very high power pulses for experiments, where drawing the power from the public network would produce unacceptable spikes.

#### **4.2 Role of Flywheel in Jaw crusher**

From the study of kinematic behavior of jaw crushers it has been found that for one complete rotation of the crank the forces developed on the moving jaw plate varies. At some region this force is sufficiently large to crush the material and in some zone this force could produce a stress less than the ultimate stress of the fed material. Hence to get the fed crushed in a regular time the energy lost during over supply should be utilized when the supply value falls below the requirement mark. To produce this effect every jaw crusher is equipped with a heavy flywheel with significant moment of inertia.



Figure 4.1

Energy stored in a flywheel:

Let  $m$  = mass of the flywheel in Kg

$K$  = radius of gyration of the flywheel

$I$  = mass moment of inertia of the flywheel

$\omega_1$  and  $\omega_2$  = maximum and minimum angular speed during the cycle in rpm

$\omega$  = mean angular speed during the cycle in radian

$C_s$  = coefficient of fluctuation of speed =  $(\omega_1 - \omega_2) / \omega$

Maximum fluctuation of energy = maximum KE - Minimum KE

$$= \frac{1}{2} I (\omega_1)^2 - \frac{1}{2} I (\omega_2)^2 = I \omega^2 C_s = 2 E C_s$$

### 4.3 Stresses in a flywheel:

Assuming the rim is unstrained by the arms, the tensile stress in the rims due to centrifugal force is determined as a thin cylinder subjected to internal pressure.

- Let
- $w$  = Width of the rim
  - $d$  = thickness of the rim
  - $A$  = area of X-section of the rim =  $w \times d$
  - $D$  = mean diameter of the flywheel
  - $R$  = mean radius of the flywheel
  - $\rho$  = density of the flywheel
  - $\omega$  = angular speed of the flywheel
  - $\mu$  = linear velocity of the flywheel
  - $\sigma_t$  = tensile or hoop stress

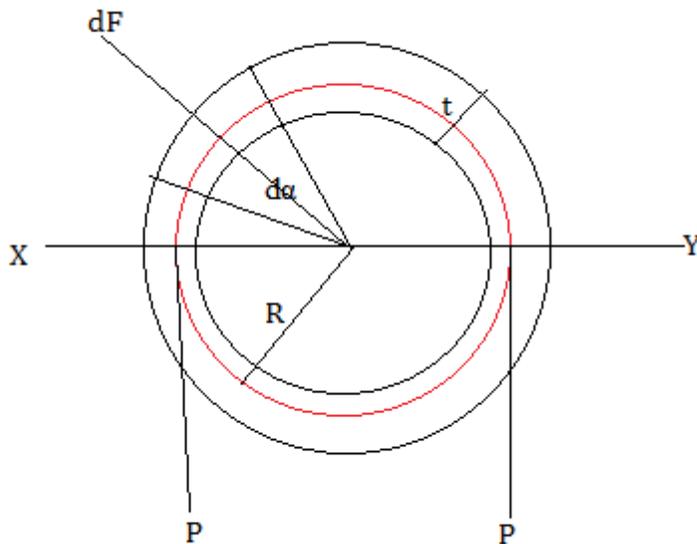


Figure 4.2

Considering a small element of the rim as shown in Figure 4.2; Let it makes an angle  $d\alpha$  at the centre of the flywheel.

Volume of this small element =  $A.R. d\alpha$

Mass of the element = volume x density =  $A.R. d\alpha \rho$

Centrifugal force on this element =  $dF = dm. \omega^2. R = \rho A.R^2. \omega^2. d\alpha$

Vertical component of  $dF = dF \sin \alpha = \rho A.R^2. \omega^2. d\alpha \sin \alpha$

Total vertical force across the rim diameter X-Y =  $\rho A.R^2. \omega^2. \int \sin \alpha d\alpha = 2 \rho A.R^2. \omega^2.$

This vertical force is restricted by a force  $2P$  such that

$$2P = 2\sigma_t \times A = 2 \rho A.R^2. \omega^2.$$

$$\sigma_t = \rho R^2. \omega^2 = \rho \mu^2$$

### **4.3.1 Tensile bending stress in the rim due to restrain of the arms**

Assumption: Each portion of the rim between a pair of arms behaves like a beam fixed at both ends and uniformly loaded.

Say, Length between fixed ends =  $\pi D/n = 2 \pi R/n$

The uniformly distributed load  $k$  per meter length shall be equal to the centrifugal force between pair of arms,

$$k = w .d. \rho R. \omega^2$$

The maximum bending moment,  $M = k l^2 / 12 = w .d. \rho R. \omega^2 (2 \pi R/n)^2 / 12$

Section modulus,  $Z = w d^2 / 6$

Bending stress,  $\sigma_b = M/Z = 6. w .d. \rho R. \omega^2 (2 \pi R/n)^2 / 12 w d^2$

$$= 19.74 \rho \mu^2 R/n^2 t$$

Total stress on the rim  $\sigma = \sigma_t + \sigma_b$

### 4.3.2 Torque v/s Crank angle graph

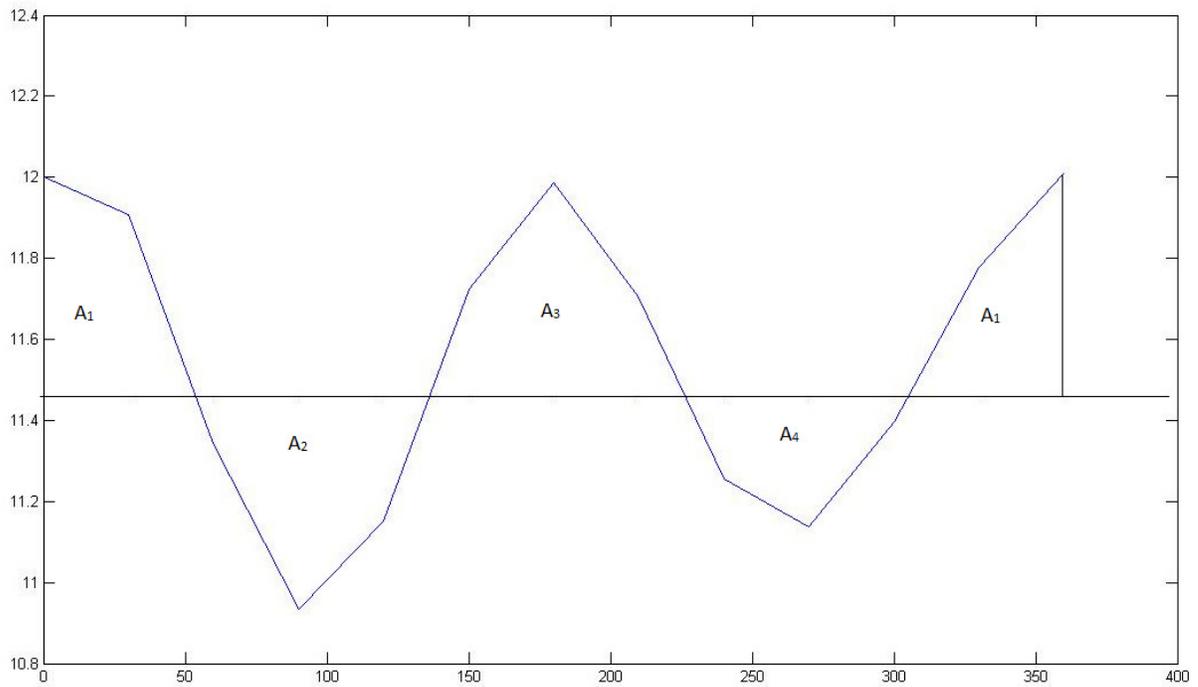


Figure 4.3

4.3.3 The following matlab program finds out the value of torque at different crank angles.

```
dc
clear
n=1;
l=1085;
a=45.3;
r=12;
u=0;
b=815.7;
i=1;
theta=[20.16 19.84 19.37 18.90 18.55 18.41 18.52 18.84 19.29 19.74 20.10 20.25 20.16];
psi(1)=0;
m(1)=0;
dm(1)=0;
for i=1:1:13
    n=1;
    for v=85:100:1085
```

```

        ax(i,n)=[(l-v)*cos(theta(i)*pi/180)-u*sin(theta(i)*pi/180)]*dm(i)-m(i)^2*((l-
v)*sin(theta(i)*pi/180)+u*cos(theta(i)*pi/180))+r*sin(psi(i)*pi/180);
        ay(i,n)=[(l-v)*cos(theta(i)*pi/180)-u*sin(theta(i)*pi/180)]*m(i)^2+((l-
v)*sin(theta(i)*pi/180)+u*cos(theta(i)*pi/180))*dm(i)+r*cos(psi(i)*pi/180);
        n=n+1;
    end
    if(i<=12)
        psi(i+1)=psi(i)+30;
        m(i+1)=(theta(i+1)-theta(i))/(psi(i+1)-psi(i));
        dm(i+1)=(m(i+1)+m(i))/(psi(i+1)-psi(i));
    end
end
figure(1)
for i=1:1:11
    plot(psi,ax(:,i));
    hold on;
end
figure(2)
for i=1:1:11
    plot(psi,ay(:,i));
    hold on;
end
for i=1:1:13
    for j=1:1:11
        a(i,j)=sqrt(ax(i,j)^2+ay(i,j)^2);
    end
end
figure(3)
for i=1:1:11
    plot(psi,a(:,i))
    hold on;
end
a(:,1)
mean(a(:,1))
figure(4)
plot(psi,a(:,1))
hold on;
plot(psi,11.46)
end

```

The numerical value of torque at different crank angle is tabled below

Crank angle (degree)	Torque (N-m)
0	12000.0
30	11907.5
60	11342.9
90	10934.8
120	11152.7
150	11725.2
180	11987.1
210	11703.1
240	11257.1
270	11137.0
300	11398.2
330	11776.6
360	12000.0

Table 4.1

**From the tabled data:**

The mean torque value is 11564 N-m .The T v/s  $\alpha$  curve has 4 segments . Maximum minus minimum of the area under these curves gives the maximum fluctuation of energy.

From calculation:

Area under  $A_1 = 18650$  Sq unit

Area under  $A_2 = 22850$  Sq unit

Area under  $A_3 = - 12850$  Sq unit

Area under  $A_4 = - 18000$  Sq unit

$$\text{Maximum fluctuation of energy} = 22850 - (- 18650) = 41500 \text{ J}$$

**4.4 Design calculations:**

Material of flywheel is cast iron

Density of flywheel = 7250 kg / m<sup>3</sup>

Ultimate stress of the material = 6 x 10<sup>8</sup> N/m<sup>2</sup>

Factor of safety = 2

Allowable stress= 3 x 10<sup>8</sup> N/m<sup>2</sup>

The mean angular velocity of the flywheel = 300 rpm =  $200 \times 2\pi / 60 = 31.42$  rad/s

Assuming fluctuation of speed is 20% of the mean speed;

$$\omega_1 - \omega_2 = .2 \omega$$

Coefficient of fluctuation of energy =  $C_s = (\omega_1 - \omega_2) / \omega = .2$

But,  $\Delta E = I \omega^2 C_s$

$$I = \Delta E / \omega^2 C_s = 41500 / (31.42)^2 \times .2 = 210.2 \text{ Kg m}^2$$

From basic design ,

$w =$  breadth of the flywheel rim =  $2 d = 2 \times$  (thickness of flywheel rim)

Induced tensile stress,  $= \sigma_t = \rho \mu^2$

$$\mu = \sqrt{(3 \times 10^8 / 7250)} = 20.34 \text{ m/s}$$

Peripheral velocity,  $\mu = \pi D N / 60$

$$D = (28.76 \times 60) / (\pi \times 300) = 1.295 \text{ m}$$

Total energy stored in fly wheel,  $E = \Delta E / 2 C_s = 41500 / 2 \times 0.2 = 103750 \text{ Nm}$

Energy of the fly wheel rim,  $E_{\text{rim}} = 0.92 E = 95450 \text{ Nm}$

But,  $E_{\text{rim}} = \frac{1}{2} m \mu^2$

$$m = 2 E_{\text{rim}} / \mu^2 = 2 \times 95450 / (20.34)^2 = 461.42 \text{ Kg}$$

also ;  $m = w \cdot d \cdot \pi D \cdot \rho = 2 d^2 \pi D \cdot \rho$

$$d = \sqrt{(m / 2 \pi D \cdot \rho)} = 78.22 \text{ mm}$$

$$w = 2 \times d = 156.4 \text{ mm}$$

## 4.5 Spring Design.

From experiment it is found that the energy required for breaking 1 ton Dehbeed Granite is 1696 Joule. Considering the jaw crusher under study is used to crush 1 ton such material per hour.

Power = Force X velocity

$$F_{MAX} = P / V_{min} = 1696 \times 1000 / (1.22 \times 3600) = 386.15 \text{ N}$$



Figure 4.4

$$W = \text{load on the spring} = T \cos 35^\circ = 386.15$$

$$T = 470.63 \text{ N}$$

### Maximum Spring deflection:

One end of the tension bar is attached to moving jaw and the other one is fixed with the column,  
Length of the tension rod = 1000 mm

Coordinate of the fixed end of the tension bar in global coordinate system = (-576.3 , 33.8)

Coordinate of the moving end (farthest point) = (428.72 , -219.66)

Distance between farthest point and fixed end = 1036.88 mm

Maximum deflection of spring = 36.88 mm

Spring material = carbon steel

Spring diameter,  $d = 12 \text{ mm}$

Ultimate stress = 294 MPa

Modulus of Rigidity =  $G = 80 \text{ KPa}$

Young's Modulus =  $E = 210 \text{ KPa}$

$D/d = 10$

Mean diameter,  $D = 120 \text{ mm}$

$\sigma_1 = 8 W D / (\pi d^3) = 83.22 \text{ MPa}$

$\sigma_2 = 4 W / (\pi d^2) = 4.1 \text{ MPa}$

$\sigma = \sigma_1 + \sigma_2 = 87.38 \text{ MPa}$

Factor of Safety =  $294 / 87.38 = 3.35$

#### 4.5 Final results

Material of flywheel is	cast iron
Density of flywheel =	$7250 \text{ kg / m}^3$
Ultimate stress of the material =	$6 \times 10^8 \text{ N/m}^2$
Allowable stress =	$3 \times 10^8 \text{ N/m}^2$
Mass of fly wheel =	461.42 Kg
Diameter of flywheel =	1.295 m
Thickness of rim of the flywheel =	78.22 mm
Width of rim of the flywheel =	156.4 mm

Table 4.2

## References:

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