OPTIMUM DESIGN AND ANALYSIS OF SINGLE TOGGLE JAW CRUSHER

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ABSTRACT

A jaw crusher is a kind of size reduction machine which is widely used in mineral, aggregates and metallurgy fields. The performance of jaw crusher is mainly determined by the kinematic features of the swing jaw during the crushing process. The practical kinematic characteristic of the points located along the swing jaw plate are computed and discussed. Based on the analysis of the liner movement and the crushing parameters, force distribution along the swing jaw plate is obtained. The job is helpful for a design of new prototype of this kind of machine on optimizing the frame, designing the chamber and recognizing the crushing character.The interaction between jaw plates and material particles brings the inevitable and serious wear to the jaw plates during the jaw crusher operation, which not only decreases the efficiency, but also increases the cost and the energy consumption of the jaw crusher. Obtained results from the kinematic analysis of the moving jaw and the crushing force distribution analysis, the jaw plates wear is analyzed on a macroscopic level. It is helpful to design the crusher for improved performance.Efforts to decrease energy consumed in crushing have lead to consideration of decreasing the weight of the swing plate of jaw crushers. Design of lighter weight jaw crusher will require a more precise accounting of the stress and deflections in the crushing plates than is available with traditional technique. The design of swing jaw plate is carried out by using CAD i.e., jaw plate has been solid modeled by using CATIAV5R20. FEA is applied to assembled structure of swinging jaw plate and lever to optimize the width and location of the toggle plate along the swinging lever. The different comparisons of swing jaw plates behaviour, calculated with the traditional and the new FEA failure models with stiffeners, shows that 24% savings in plate weight may be possible.

Keywords: Computer Aided Design (CAD), Jaw Crusher, Kinematic Features, Force Distribution, Wear Analysis.

I INTRODUCTION

The first stage of size reduction of hard and large a lump of run-of-mine (ROM) ore is to crush and reduce their size. Large scale crushing operations are generally performed by mechanically operated equipment like jaw crushers, gyratory crusher and roll crushers. The mechanism of crushing is either by applying impact force, pressure or a combination of both. The jaw crusher is primarily a compression crusher while the others operate primarily by the application of impact. The breakage mechanism of the jaw crusher is rather simple. The crushing process is composed of serials of single particle breakage. After a particle is nipped in the chamber and failed in tension stress, the resulting fragments drop down to new position before being nipped and squeezed. When particles meet the size demand, they leave the chamber from the outlet. It is obvious that the movement of the moving jaw is a key factor to jaw crusher performance. An accumulation of the jaw plates wear will change the crushing chamber geometry. At the same time, the geometry variation of moving jaw results in the movement change, which has great effect on the nipping action and the particle fracture. 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. Many engineering structures consist of stiffened thin plate elements to improve the strength/weight ratio. The stiffened plates subjected to impact or shock loads are of considerable importance to mechanical and structural engineers.

The main objective of the present work is to describe the movement of the moving jaw in detail and analyze the breakage squeezing process. Obtained results from the analysis of the moving jaw movement, the squeezing process, the crushing force distribution and the jaw plates wear on a macroscopic level is studied aiming to effectively predict the wear distribution on the jaw plates. And propose an efficient use of modeling in the connection between the plate and the stiffener has been described.

II THEORETICAL ANALYSIS AND DATA COLLECTION

Mechanism of a typical single toggle jaw crusher can be treated as a crank-rocker mechanism of a four-bar linkage having; frame as a fixed link, crank as an eccentric shaft, liner as coupler and toggle plate as follower as shown in the Fig 1

TABLE1 PE300*900 Jaw Crusher Calculation Parameters [12]

r(mm)	l(mm)	k(mm)
12	1085	455

The calculation parameters of the PE PE300*900 are shown in Table 1

AB = Crank (r), BC = Length of the liner (l), CO = toggle plate length (k), AO = frame or fixed link

Toggle plate one end is connected to frame (O) and other end is connected to the movable jaw(c) as shown in the Fig. 1. The angles Θ and Φ represents the angle of liner and crank making with vertical.

Dimensions and operating parameters when considering the jaw crusher of Fig. 1, there are variables of the feed that define the important machine dimensions.

The feed particle sizes of interest are:

1. The size of particle that enters the crusher
2. The size of particle that can be nipped
3. The size of particle that can fall through the chamber at any time
4. The size of particle that can fall through the chamber when the jaws are open as wide as possible.

The dimensions defined by those particle sizes are (Fig 1):

1. The gape - the distance between the jaws at the feed opening
2. The closed side set (CSS) - the minimum opening between the jaws during the crushing cycle (minimum discharge aperture)
3. The open side set (OSS) – the maximum discharge aperture
4. The throw – the stroke of the swing jaw and the difference between OSS and CSS.

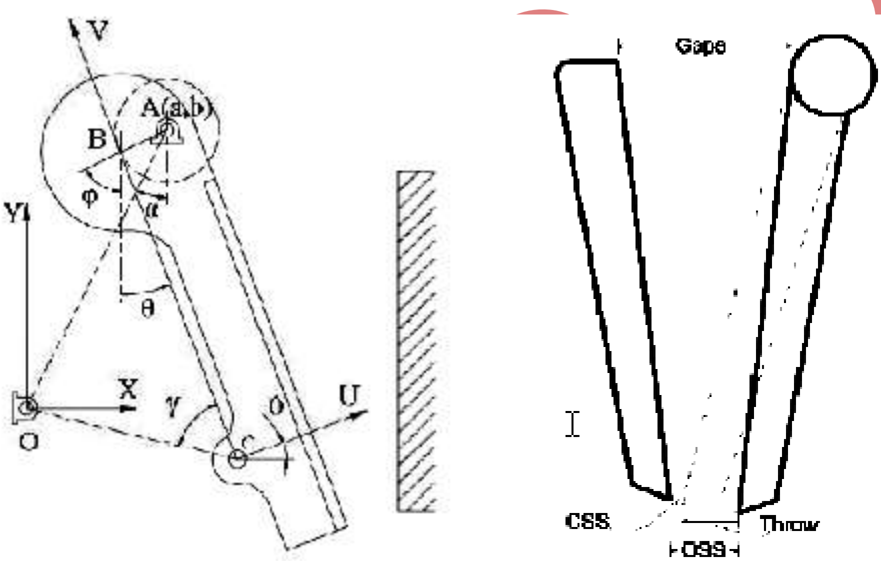

Fig 1 Jaw Crusher sketch [1]

III CHOOSING THE POINTS ALONG THE LINER FOR COMPUTING

A liner of jaw crusher is an interface for analyzing the crushing force, on which the crushing force occurs, in other words, the directly contact and the interaction between the material and the linear occur there. So the interface has great effect on the crushing feature of jaw crusher. The liner is one of the curves in the cross-section of the couple plane, which is also given a definition as one of the coupler curves in a four bar crank-rocker model. Since different positions of liners in the coupler plane have different moving features, the motion of points along the liners in the computing domain is quite different from that of them in the straight straight-line coupler of the simple four bar crank-rocker model. Therefore, it is necessary to consider motion differences caused by different liner positions and their motion features to select a coupler curve as the swing liner with good crushing character.

Based on the four bar crank-rocker model, the system sketch of jaw crusher for calculating is shown in Fig 2. The global static coordinate is XOY and the dynamic coordinate is UCV. Although a real shape and position of a fixed working liner is usually determined by a suspension point of the jaw crusher, computation of a liner will be done on the one of chosen curves in the liner domain. Thus with different position on the liner, each computing point on it liners will arrive at the limit position at different time. However it is well known that a practical crushing force exerted on fractured material is in the normal direction of the liner. The normal direction of each point in the liner changes in one operation cycle. So a distance between the limit positions in normal direction of those points is quite different from that of the displacement of horizontal motion.

In order to describe the kinematic characteristics of the points in the liner domain, the single toggle jaw crusher PE300*900 is taken as example to compute and analyze the distributed kinematic characteristic. The calculation parameters of the PE300*900 are shown in Table1. In order to illustrate the motion of the points in liner domain, it is needed to define the liner domain. One plane along the coupler BC is selected and is divided into 10 equal parts as shown in the Fig 2. So there are 11 points selected to be calculate in the V direction for a certain U and the eccentric shaft is rotating at a speed of 300rpm. The position of the eccentric shaft with respect to global co-ordinates XOY is A (a, b) is located at a=45.3 & b=815.7. With the points for computing and the liner domain chosen as above mentioned, computing results are shown in follows.

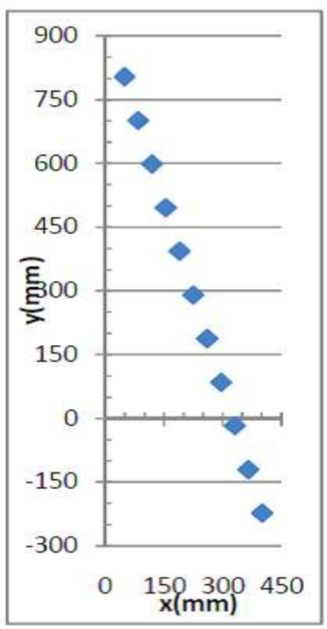

Fig. 2 Points track along the liner [2]

The mechanism of the jaw crusher is shown in Fig.3; given the rotation direction of the crank AB is clockwise.

Where Φ = Crank angle made by vertical

θ = Angle between two plates $\leq 90°$

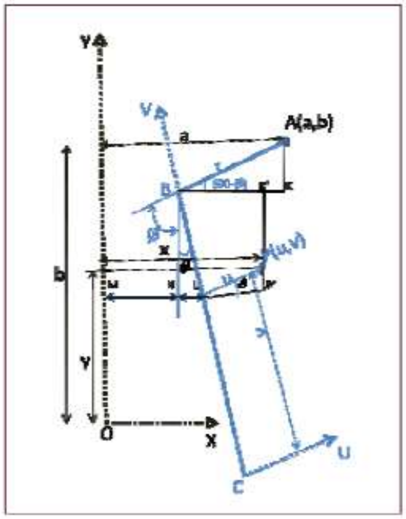

Fig.3 Point consideration in dynamic coordinate [2]

IV SOLID MODELING OF SWING JAW PLATE AND PITMAN USING CATIA

Engineering components can be of various forms (sizes and shapes) in three-dimensions. A Solid can be thought of as composed of a simple closed connected surface that encloses a finite volume. The closed surface may be conceived as an interweaved arrangement of constituent surface patches, which in turn, can be individually considered as composed of a group of curves. It then behooves to discuss the generic design of curves, surfaces and solids in that order. Even before, it may be essential to understand how three-dimensional objects or geometrical entities are represented on a two-dimensional display screen, and how such entities can be positioned with respect to each other for assembly purposes or construction operations. Engineers have converged to numerous standard ways of perceiving a three-dimensional component by way of engineering drawings depicted on a two-dimensional plane (conventionally blue prints, but for CAD's purpose, a display screen).

The Sketcher workbench is the basic 3D wireframe elements. In addition to the reference features and geometry creation, it is having sketch operations, constraints, and dimensions. The CATIA Part Design workbench is the modeling techniques used to create and edit designs and feature-based solids are explored. It includes sketch-based features, dress up features, and patterns. CATIA Assembly Design workbench describes the methods of building assemblies of the various parts of the system or structure. It also includes the assembly information, operations, tools, catalogs, analysis, parameters, formulas, and interpart links. 3D modeling of swinging jaw plate and swinging lever includes under the part design module and the tools required to model these include pads, pockets, holes, drafts, fillets, chamfers, threads, patterns, and mirror. Once modeling is complete it is needed to be assembled pitman with swinging jaw plate with the help of contact constraints and surface constraints. Fig 3 and Fig 4 shows the 3D modeling of swinging jaw plates with no stiffeners, one stiffener, two stiffeners, and three stiffeners,the conventional pitman or swinging lever and the assembled structure of the swinging jaw plate with pitman.

Dimensions of the swinging jaw plate: Dimensions of the stiffener:

I. Thickness = 140mm. I. Length= width of the jaw plate= 900mm

II. Length = 1200mm. II. Width of the stiffener = 100mm

III. Width = 900mm III. Height of the stiffener = 75mm

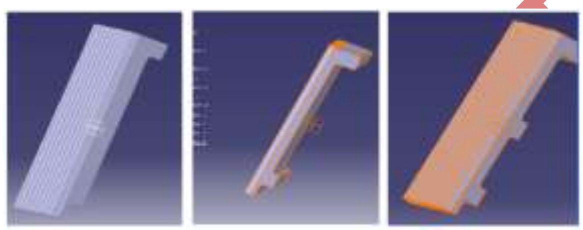

Fig 4: Sketching of swinging jaw plate with one, two and three stiffeners

Fig 5: Assembly of swinging jaw plate with pitman

V ANALYSIS BY CONSIDERING STIFFENERS TO THE SWINGING JAW PLATE

Many engineering structures consist of stiffened thin plate and shell elements to improve the strength to weight ratio. This analysis has performed attaching one stiffener, two stiffeners, and three stiffeners to the 140mm thick swinging jaw plate. During this analysis width of the toggle plate is considered as 800mm and toggle is located at 100mm from the bottom face of the pitman. Fig 5 shows the Von Misses stress and deformation of the structure when considering one stiffener, two stiffeners and three stiffeners.

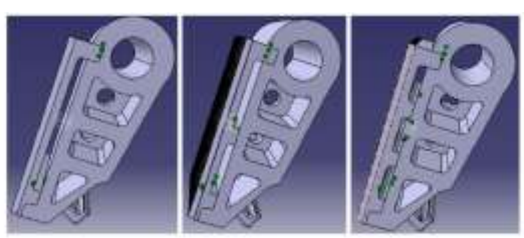

Fig 6 swinging jaw plate with one stiffener, two stiffeners, three stiffeners

TABLE 2 Von Misses stress and displacements with stiffeners

Number of stiffeners	VonMisses stress (N/mm^2)	Displacement (deformation) (mm)
1	158	0.836
2	68.3	0.145
3	53.9	0.0883

VI RESULTS AND DISCUSSION

6.1 Wear Analysis

Jaw plates wear is determined by the close process. Two key factors in this process affecting the jaw plates wear are squeezing and sliding. At present, the high manganese steel is widely used as the jaw plate material, which has the outstanding work hardening character. By scanning the worn jaw plates, 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.

Now, some of the phenomenon in practice can be explained. Since the sliding is small at the inlet part of the chamber and the squeezing plays the main role, the wear in this zone is small. With the horizontal stroke decreasing and the vertical distance increasing, the wear becomes more and more serious. Because fewer particles are crushed in the edge parts, the wear of the middle part in the same crushing zone is much serious comparing with the edge parts.

For the same jaw crusher, the slide between the particle and the fixed jaw plate is more than that between the particle and the moving jaw plate, so the wear of the fixed jaw plate is more serious relative to the moving jaw plate wear.

6.2 Optimization of Width and Location of Toggle Plate

While the material is nipping in the crushing chamber toggle supports the swinging lever at bottom end it means toggle plate is more affected during the crushing. So it is necessary to optimize the toggle plate dimensions and location of the toggle plate along the pitman.

By performing finite element analysis on the assembled system of swinging jaw plate and pitman for a typical PE 300*900 series type jaw crusher, it is found that the optimal value of the toggle width is 800mm at which the Von Misses stresses are approaching to asymptotic value at 98.6 N/mm^2 and the deformation is 0.164mm.

For a conventional PE 300*900 series type jaw crusher, toggle plate is located approximately at 300mm from the bottom of the pitman. But analysis gives the optimal value of toggle plate location is 100mm above form the bottom of the pitman and the Von Misses and deformation obtained are 54N/mm^2 and 0.0765mm.

6.3 Optimization of Mass of the Swinging Jaw Plate

Using stiffeners, strength to weight ratio of the jaw plate can be increased. Analysis has been performed on the assembled structure when swinging jaw plate is having without stiffener, one stiffener, two stiffeners and three stiffeners. Fig 7 to Fig 9 represents the mass of the stiffened jaw plates. The Von Misses and deformation are tabulated in the Table 3

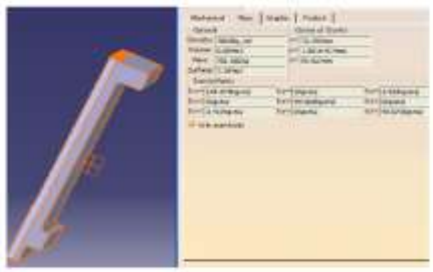

Fig 7 Mass of one stiffener jaw plate

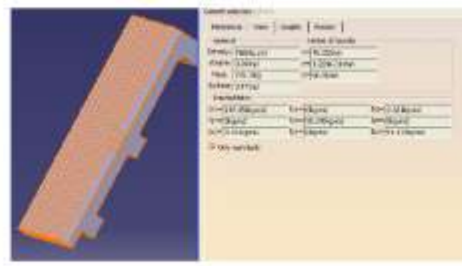

Fig 8 Mass of two stiffener jaw plate

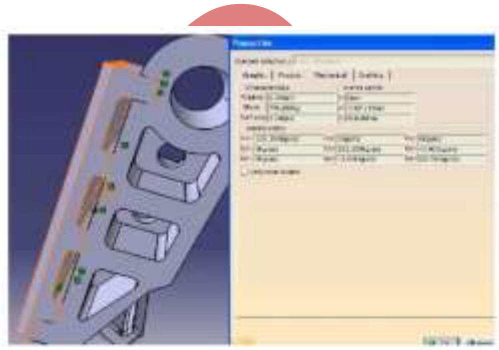

Fig 9 Mass of three stiffener jaw plate

TABLE 3 Von Misses stresses and deformation of the swinging jaw plates

No of Stiffeners	Von Misses stress(N/mm^2)	Deformation (mm)	Mass of the jaw plate(kg)
0	54	0.765	1018.314
1	158	0.836	701.882
2	68.3	0.145	739.683
3	53.9	0.0883	776.683

Table 3 shows that the Von Misses stresses and deformation of the swinging jaw plate without stiffeners are approximated to the jaw plate having three stiffeners. Therefore mass reduction of the jaw plate during the usage of stiffeners is

% of mass reduced = (mass of jaw plate without stiffeners- mass of jaw plate with three stiffeners) *100/ mass of jaw plate without stiffeners

= (1018.314776.683)*100/1018.314

= 23.73%

VII CONCLUSION

1. Results obtained from the movement analyses of the moving jaw and the crushing force distribution analysis, the jaw plates wear is analyzed. The relationship between the slide and the wear is reasonable and some results of the wear analysis are validated in practice. Predicting the jaw plates wear on a macroscopic level will be helpful to the jaw crusher design for better performance.
2. Finite element analysis of swing jaw plates is carried out, using four - nodded tetrahedral element to predict the optimized width and the location of the toggle plate, when it is subjected to point loading under simply supported boundary conditions.
3. The stiffened plate models which leads to reductions in plate weight and indicates that design of new energy-efficient systems of the crushed material.
4. In case stiffened jaw plates as the number of stiffener increases the strength/weight ratio of the jaw plate increases making it stronger than that of without stiffener.
5. The stiffened plate models which leads to 25% saving in energy, of course this 25% is an estimate for a typical 300*900 series jaw crusher.

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