HEBEI TOBEE PUMP CO.,LIMITED
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Procedia Earth and Planetary Science 1 (2009) 1532–1538

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The 6th International Conference on Mining Science & Technology

Finite element analysis of wear for centrifugal slurry pump

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Abstract

By applying theory of liquid-solid two-phase flow, the location and process of wear on pump are analyzed. The results are consistent with the real wear situation. On this basic, base on the geometry non-linear theory and material non-linear theory, the wear process on flow components was simulated by ANSYS. The simulation results showed that there will be pits on the surface of flow components due to the impacting of coal particles with certain diameter, shape, impacting velocity and invasive angle; and the largest Von Mises stress will be at the pits. The distortion degree of pits and the largest Von Mises stress will increase with the increasing of coal particle diameter, impacting velocity and invasive angle, and with the decreasing of tip angle. There will be some accumulation at the front-end of impacting when the invasive angle is small.

Keywords: centrifugal pump; slurry pump; wear parts; finite element

1. Introduction

In recent years, with unceasingly increase of quantity of cleaning and processing coal, the development of coal preparation process with dense medium in the coal preparation plant has been promoted. In dense medium cyclone coal preparation, centrifugal slurry pump must always be used for feeding materials[1]. When feeding materials with pump, the actuating medium is fluid-solid two-phase slurry which is a mixture of water, coal, gangue and magnet powdered ore. Because the working condition is very bad, serious partial wear to the flow components of pump is caused, which not only reduces the operational reliability of pump, but also reduces the service life of pump[2-4]. Therefore, besides energy saving and high efficiency, higher requirement to the operational reliability of pump is also proposed at coal preparation plants. There will be great significance for safe production to study the wear location and wear process of centrifugal slurry pump used in dense medium cyclone, and to reduce the wear degree of the slurry pump.

2. Wear location and wear process

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doi:10.1016/j.proeps.2009.09.236

2.1. Wear location

2.1.1. Wear location on impeller

The main location of wear on impeller is in turn the impeller vane outlet and inlet, the intersect point of the vane inlet with rear cover plate, internal surface of rear cover plate, and the middle of vane[5-9]. In the flow channel of axial surface of impeller, when solid particles enter the flow channel, the direction of motion of the particles from axial turns to the radial direction. Due to centrifugal force, the majority of solid particles are transferred to the rear cover plate, which results in the degree of wear at the rear cover plate larger than that at the front cover plate. Especially, the wear at the intersect point of vane inlet with rear cover plate is the most serious. In the plane flow channel of impeller, small solid particles have good characteristics of following with fluids due to their small inertia. Therefore, in the inlet of impeller vane, particles get into the flow channel of impeller along the direction which approaches the liquid flow angle at vane inlet with low impacting velocity and light wear on the vane inlet edge. In the flow channel of impeller, particles move along the vane working surface with a curvature of motion trace close to the vane type curvature, and their radial velocity and outlet liquid flow angle are small. As a result, wear on the outlet edge caused by small particles is more serious than that on the working surface. Large particles have bad characteristics of following with fluids due to their big inertia. Therefore, in the vane inlet, particles get into the flow channel of impeller with direction different from the liquid flow angle of vane inlet, so that many large particles impact on the vane inlet edge, and some of the big particles are pushed to the back of the vane, which results in wear on the vane inlet edge and the back of the vane outlet. In the flow channel of impeller, large particles loss momentum after impacting, there will exist three different situations: the first one is that the reflect velocity of particle is so large that the particle flows straightway out of impeller after impacting, without impact with vane again; the second one is that the reflect velocity of particle is relatively large, so that the particle does not flow out of the vane outlet immediately, and impacts with the vane working surface again (may be more than two times), which produces wear on the middle part and the outlet of vane working surface; the third one is that the reflect velocity of particle is so small or zero after impacting that particles will not bounce off from the vane surface, but rolls or glides along the vane surface, so that wear on the middle part and the outlet of vane working surface is produced.

2.1.2. Location of wear in discharge chamber

The main locations of wear in the discharge chamber are in turn the Ⅷ cross section, pump tongue, the I cross section and sidewall[8-10]. For small solid particle with small outlet liquid flow angle out of impeller, its motion trace is approximately a concentric circle in the discharge chamber. It forms circulation flow through the pump tongue, then the majority of solid particles are returned to the discharge chamber. Therefore, uniform wear on the discharge chamber sidewall and outer wall is produced. For large solid particles with large outlet liquid flow angle out of impeller, particles will impact on the outer wall of discharge chamber and move to diffusion tube along outer wall, and serious impact will be produced on the pump tongue. Therefore, it creates wear on the outer wall of discharge chamber and the pump tongue.

For example, a centrifugal slurry pump is used to supply material for dense medium cyclone in a coal preparation plant. There are three situations of wear on the impeller and discharge chamber. The first is wear on the impeller vane working surface outlet and back outlet, which makes the outlet edge became thin concave arc, and presents obvious trench at the outlet edge of working surface. Four outlet edges of the five vanes largely pell off because of wear (Figure 1). The second is that the inlet diameter of impeller becomes larger because of wear on the intersect point of the impeller vane inlet edge with the rear cover plate. The third is the VIII cross section region of the discharge chamber appears obviously linearity trench due to wear, the pump tongue becomes non-arc, and its length gets shorter (Figure 2).

2.2. Wear process

There are three stages in the process of wear on flow components of the centrifugal slurry pump:

The first is saturation wear stage: the flow components of the centrifugal slurry pump are founded; there is some roughness on the surface of components; the surface becomes smooth due to wear caused by particles after first running of the pump; and the process of wear gradually becomes steady from being faster at the beginning.

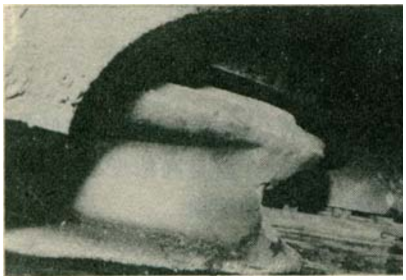

Fig. 1. Wear on outlet edge of the impeller vane working surface

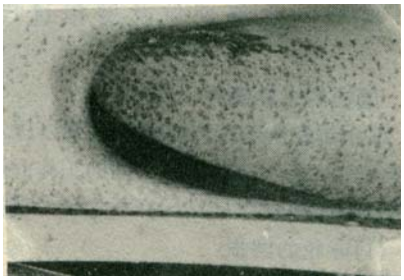

Fig. 2. Wear on VIII cross section of the discharge chamber and pump tongue

The second is steady wear stage: wear is relatively steady because the surface of flow components has been worn glossy at the first stage; this stage lasts for a longer time; it is the best stage for pump running.

The third is sharp wear stage: with long time of running, the size and angle of components may largely depart from designed hydraulic working conditions due to wear; particle impacting and medium flow separation vortex are intensified; the speed of wear increases sharply; the pump may not be able to run properly, and there exist hidden accidents.

In the above three stages of wear process, the main wear is micro-cutting wear when particles impact with small angle, while distortion wear is the main one when particles impact with large angle. In this paper, wear process caused by particle impacting is analyzed by numerical simulation method.

3. Basic model and calculation method

3.1. Geometry model

Geometry model adopts two-dimension plane model. Solid particles are chosen to simulate coal particles, supposing the shape of coal particle to be circle and equilateral triangle. The diameters of coal particles are 2.5mm and 10mm respectively. Because the character size of flow components is much larger than the size of coal particles, the surface of flow components impacted by coal particles is assumed as ideal plane. Taking a rectangle area as target, both of the width and height of the rectangle are 100mm. Due to the axial symmetry of physical model, a half of the model is analyzed (Figure 3). When coal particles impact target by certain invasion angle, the entire model is used.

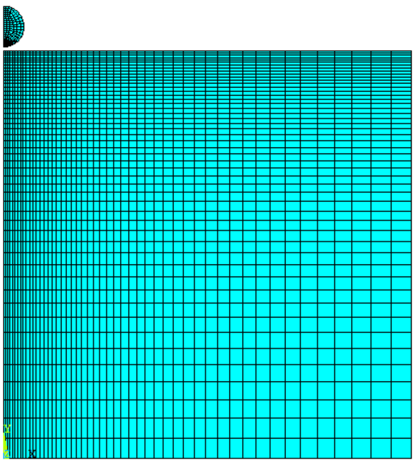

Fig. 3. Finite element model

3.2. Finite element model

In finite element model, both coal particles and target adopt two-dimension axial symmetry entity whose element number is 162. Manual grid partition is adopted. The grid shape for coal particles and target are rectangle. Local grid encryption is used at some local areas where coal particles impact the target, getting 181 elements with 209 nodes on coal particle, while 5625 elements with 5776 nodes on target (Figure 3). The boundary condition of model: coal particles impact on the top boundary of target along the direction of minus *y*. All nodes on the top boundary of target have the freedom in both *x* and *y*, without restriction in displacement. All nodes on the symmetry axis of target have no displacement in *x* direction. That is, all nodes on the symmetry axis have restricted displacement in *x* direction. The displacement is zero in both *x* direction and *y* direction for all nodes on the bottom boundary and right boundary of target model. That is, the displacement is restricted for all nodes in these two boundaries in both *x* direction and *y* direction.

3.3. Contact model

In ANSYS/LS-DYNA, the two-dimensional Lagrange law is used for analyzing; and dynamic contact symmetry penalty-function method is adopted for contact-impact finite element numerical value calculation; contact type chooses single contact arithmetic[11] which is COTACT_2D_AUTOMATIC_SINGLE_ SURFACE. The contacting dynamics friction coefficient of coal particles with component surface is 0.1, and static friction coefficient is 0.15.

3.4. Constitutive model

Target material is high chromium cast iron. The material constitutive model adopts Bilinear Isotropic hardening model which satisfies Von Mises yield rule. Elasticity module of the model parameter is 170GPa, the density is 7810kg/m^3, Poisson ratio is 0.3, yield limit is 396MPa, and the tangent module is 75GPa. Elasticity module of coal particle is 1.4GPa, Poisson ratio is 0.3, and density is 1500kg/m^3.

3.5. Calculation method

Central differential time integral explicit arithmetic is used. Load mode of model adopts velocity load of coal particles. Considering the actual impacting phenomenon of the coal particles in the pump, the load velocity of coal particles are defined as 3m/s and 5m/s, and the invasion angle is 90° and 15°, respectively. The artificial volume viscosity is 1.0, time step factor is 0.9, and calculation time is 3×10^{-6} s and 5×10^{-5} s, respectively.

4. Results and analysis

4.1. Influence of coal particle diameter

Figure 4 and 5 give the distortion in the material surface and the biggest Von Mises stress after loading by a sphere coal particle, with diameter *d* of 2.5mm and 10mm and velocity *v* of 3m/s, vertically impacts the material surface. It can be seen from Figure 4 (a) and 4 (b), there is obvious pit resulting from coal particles impacting on the material surface, and the depth and width of the pit increase along with coal particle diameter. It can be seen from Figure 5 (a) and 5 (b), the biggest Von Mises stress appears in the pit, and it increases along with the coal particle diameter. When the diameter is 10mm, the biggest Von Mises stress is 48.3MPa. Within material, distribution of Von Mises stress changes from approximately semicircle to circular with increase in depth. According to Mises yield rule, when the biggest Von Mises stress is larger than the yield stress of material, plastic flow will occur in this area first. Because the yield stress of high chromium cast iron is as high as 396MPa, the material has elastic deformation only. However, due to repeatedly impacting of coal particles in the centrifugal slurry pump for a long time, fatigue flake of the material occurs, and wear will happen.

4.2. Influence of coal particle velocity

Fig.6 shows the distortion in the material surface and the biggest Von Mises stress produced by coal particle, diameter 2.5mm and velocity 5m/s, vertically impacting on the surface of material. From Figure 4 (a), Figure 5 (a) and Figure 6 (a), 6 (b), it can be obviously seen that pit is produced by coal particle impacting on the material surface, and the biggest Von Mises stress appears in the pit. The depth and width of the pit and the biggest Von Mises stress increase along with the impacting speed of coal particles. When the impacting velocity is 5m/s, the biggest Von Mises stress is 79.3MPa.

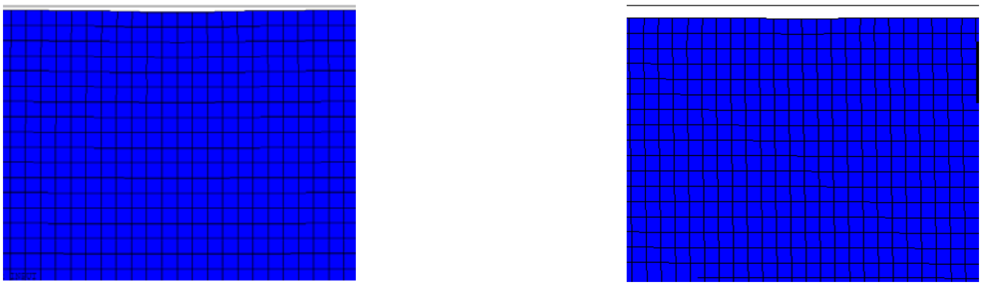

Fig. 4. Distortion on material surface by different diameters of coal particles (a) *d*=2.5mm, *v*=3m/s (b) *d*=10mm, *v*=3m/s

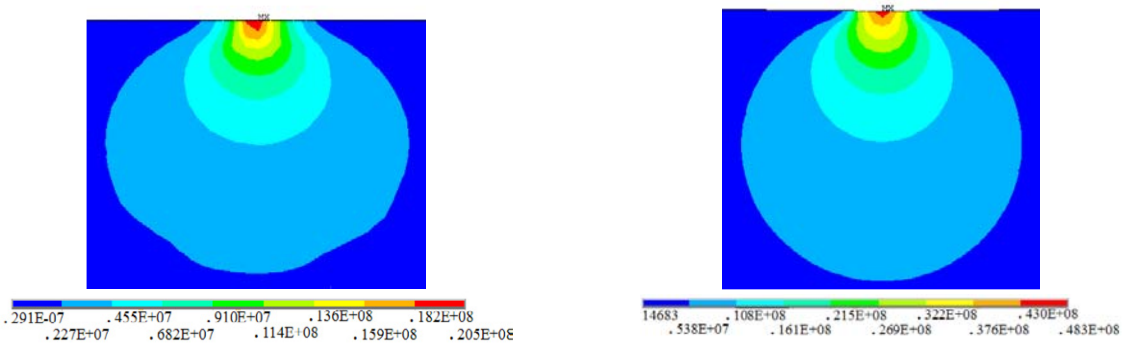

Fig. 5. The biggest Von Mises stress by different diameters of coal particles (unit: Pa) (a) *d*=2.5mm, *v*=3m/s; (b) *d*=10mm, *v*=3m/s

4.3. Influence of coal particle shape

Fig.7 gives the distortion on the material surface and the biggest Von Mises stress resulted from vertically impacting of angular coal particles with taper angle of 60˚ and impacting velocity 3m/s. From Figure 4 (a), Figure 5 (a) and Figure 7 (a), 7 (b), it can be seen that the biggest depth produced by angular particles with a taper angle of 60˚ is bigger than that produced by sphere particles with diameter of 2.5mm, and microscopic zigzag distortion is produced by angular coal particles impacting on the material surface. As a result of stress concentration at the zigzag root, the biggest Von Mises stress is obviously bigger than that produced by sphere particles with diameter of 2.5mm. Therefore, the shape of coal particle is also an important factor for wearing.

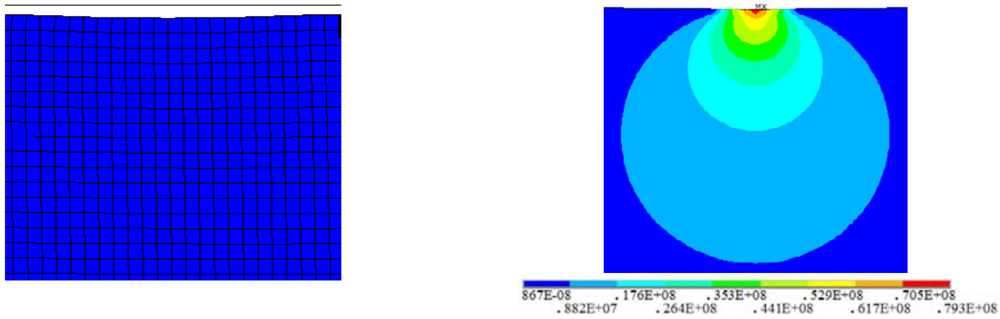

Fig. 6. The distortion and the biggest Von Mises stress by coal particles impacting on material surface (a) Distortion; (b) The biggest Von Mises stress (unit: Pa)

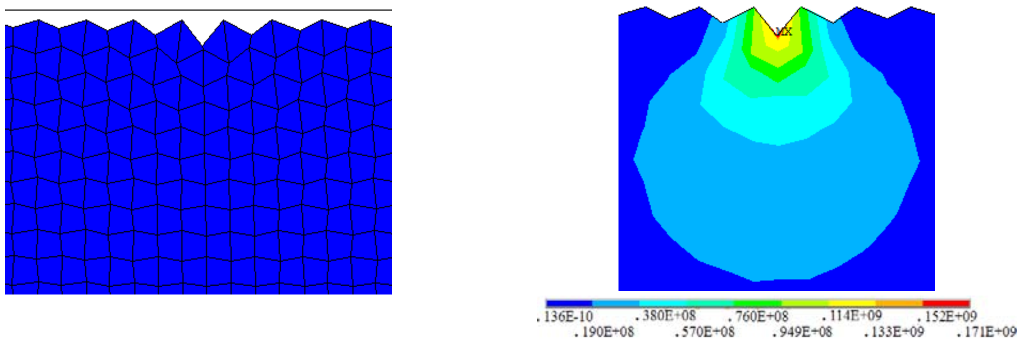

Fig. 7 The distortion and the biggest Von Mises stress by coal particles impacting on material surface (a) Distortion; (b) The biggest Von Mises stress (unit: Pa)

4.4. Influence of invasion angle of coal particles

Fig.8 gives the distortion which produces in the material surface and the biggest Von Mises stress produced by sphere coal particle with diameter 2.5mm and velocity 3m/s impacting on the material surface at an invasion angle of 15˚. It can be seen from Figure 4 (a), Figure 5 (a) and Figure 8 (a), 8 (b).

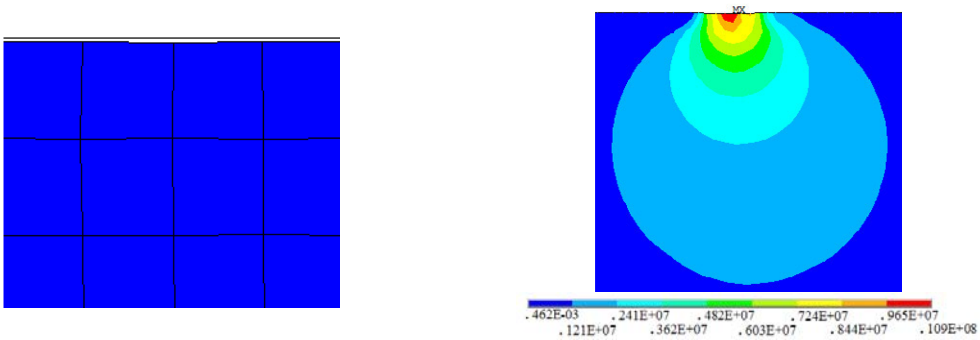

Fig. 8. Distortion and the biggest Von Mises stress by coal particles impacting on material surface at invasion angle of 15˚ (a) Distortion; (b)The biggest Von Mises stress (unit: Pa)

The distortion depth and the biggest Von Mises stress produced at the invasion angle of 15° is smaller than which produced by vertical impacting. And micro cutting is obvious when coal particles impact the material surface with an angle. There will be pushing phenomenon at the front-end of material surface, resulting in microscopic accumulation.

The data of coal particles impacting on material surface are given in Table 1.

Table 1. The data of coal particles impacting on material surface

Coal particle diameter (mm)	Coal particle angle (°)	Impacting velocity (m/s)	Impacting angle (°)	Depth of pit (μm)	Half width of pit (μm)	Biggest Von Mises stress (MPa)
2.5		3	90	0.18766	3.65852	20.5
10		3	90	0.88743	26.83523	48.3
2.5		5	90	0.31746	7.93654	79.3
	60	3	90	0.39953	4.48652	171
2.5		3	15	0.00213	0.15874	10.9

5. Conclusion

1) The main locations of wear on the impeller of centrifugal slurry pump are in turn the impeller vane outlet and inlet, the intersect point of vane inlet with the rear cover plate, internal surface of rear cover plate, the middle of vane. And the main locations of wear in discharge chamber are in turn the Ⅷ cross section, pump tongue, the I cross section and sidewall. The process of wear consists of saturation wear, steady wear and sharp wear.

2) Adopting dynamic contact symmetry penalty-function method as contact-impact finite element numerical value calculation method corresponds with the contact characteristics of the coal particles impacting on the flow components of centrifugal slurry pump, and good numerical simulation result could be gotten.

3) Pits will be produced when coal particles impacting on the surface of flow components. The biggest Von Mises stress appears at the pit. The distortion degree and the biggest Von Mises stress will increase along with the coal particle diameter, the velocity and the invasion angle, and increase with reducing of the taper angle of coal particle.

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