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Application of Computer Aided Engineering Tools in Performance Prediction and Fault Detection of Mechanical Equipment of Mining Process Line

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***Abstract*—**Nowadays, to decrease the number of downtimes in the industries such as metal mining, petroleum and chemical industries, predictive maintenance is crucial. In order to have efficient predictive maintenance, knowing the performance of critical equipment of production line such as pumps and hydro-cyclones under variable operating parameters, selecting best indicators of this equipment health situations, best locations for instrumentation, and also measuring of these indicators are very important. In this paper, computer aided engineering (CAE) tools are implemented to study some important elements of copper process line, namely slurry pumps and cyclone to predict the performance of these components under different working conditions. These modeling and simulations can be used in predicting, for example, the damage tolerance of the main shaft of the slurry pump or wear rate and location of cyclone wall or pump case and impeller. Also, the simulations can suggest best-measuring parameters, measuring intervals, and their locations.

***Keywords*—**Computer aided engineering, predictive maintenance, fault detection, mining process line, slurry pump, hydrocyclone.

I. Introduction

To extract minerals such as copper from ore in metal mining industry, usually concentrator process line is implemented. The concentrator typically consists of feeding and discharge pumps, grind circuit, and the flotation system [1]. After crushing ore in grinding system to an optimum particle size, the ground ore is passed as slurry to the flotation system to separate the mineral(s), of interest from the tails. A schematic of concentrator line before floatation section is presented in Fig. 1. After liberating minerals, the remaining slurry is transferred to disposal dam using tailing pumping system. Fig. 2 presents a typical tailing pumping system of a copper mine that consists of several in line centrifugal slurry pumps.

Stable working of each of the components and systems of concentrator process line and tailing pumping system (Figs. 1 and 2) is crucial to obtain reliable and economic production of valuable minerals such as copper. Good designing of production line, having good knowledge of operating parameters effect on the line's machinery condition, and a well-organized maintenance program can guarantee the good working condition for the machinery. Maintenance of machinery is a strategic tool for a production line to gain competitive advantages. It has been stated that only 10-20% of machines reach their design life, so there is plenty of scope for maintenance [2].

Even though, usually with considering the production targets, it is tried to select the efficient machinery and equipment in designing a mineral process lines; however, because of some market demands or mine field uncertainties such as unexpected variations in mineral deposit concentration, it may be need to use the installed machinery in design margins (under load or overload conditions) to maintain the demanded production level. Regular maintenance schedules usually do not cover these harsh conditions. So, the security of the machinery in these extreme limits may be unpredictable for the maintenance team.

CAE tools can be implemented to study the effect of deviated operational parameters (from the recommended or designed values) on the machines conditions before facing such situation in reality. Hence, based on this knowledge, maintenance team can provide suitable inspection and protection programs to detect the faults and prevent considerable or even catastrophic failures. In this paper some examples of predicting the failures and their effects for two critical components of a copper concentrator process line namely a slurry pump and a hydrocyclone is presented.

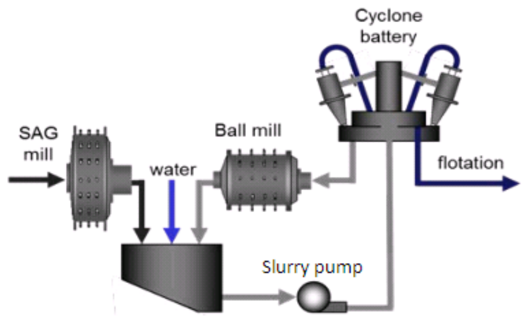

Fig. 1 A common grinding and solid-liquid hydrocyclone system [1]

II. Slurry Pump

Slurry pumps are used to feed the slurry to concentrator line and also send the waste material of this line to disposal dam. Consequently, failing of this slurry pump will lead to shutdown of the mineral production line. During operation, slurry pumps experience abrasive, corrosion, and cavitation

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wears. Any increase in operational parameters such as particle size, solid concentration, and slurry pressure will worsen. Case wear leads to the leakage of slurry around the pump and impellers wear cause to loss efficiency and also increases unbalance dynamic loads on other components such a bearings and main shaft. Therefore, it is valuable to study the effect of operating parameters on the wear of pump components such as case, impeller, and main shaft using CAE tools before deciding to allow any changes on the predesigned operational parameters. A 3-D model of a centrifugal slurry pump that has been modeled in SolidWorks software in this study is presented in Fig. 3 (b).

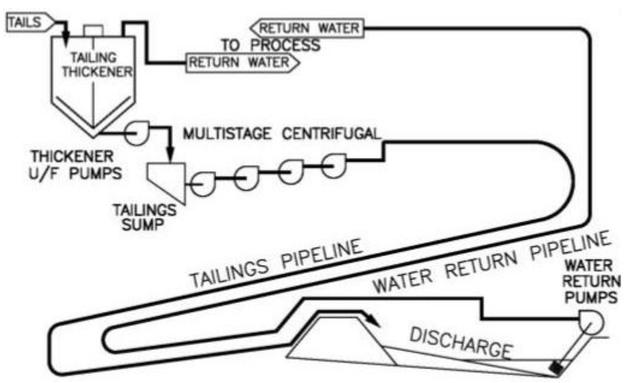

Fig. 2 typical tailing pumping system of a copper mine [3]

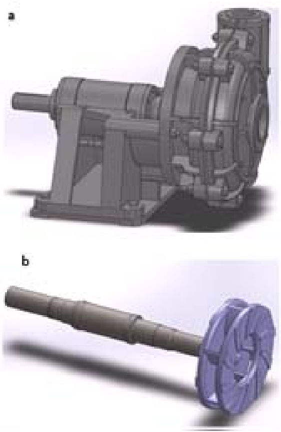

Fig. 3 Three-D model of a slurry pump: (a) pump; (b) impeller and main shaft

Any wear in impeller will change its rigidity and also will generate dynamic unbalance loads. These dynamic vibratory loads lead to fatigue failure in main shaft and its bearings. The abrasive wear pattern and its location can be estimated from fluid parameters by using fluid dynamic software such as Fluent. After that, by modeling the damaged impeller, one can simulate the effect of the worn impeller on the vibration level of the critical components such as bearings and main shaft by implementing finite element (FE) packages such as ANSYS, ABAQUS, and so on. Measuring Vibration levels of bearings is an efficient method to estimate the impellers wear.

With modeling different wear pattern and wear intensity of impeller in a FE package and simulating their vibratory effects on the bearing, it is possible to make a relation between the vibration levels and wear pattern and intensity. This relation can be developed by using computational tools such as artificial neural networks. After developing the trained neural network model, maintenance team can predict the wear situation by measuring the vibrations in bearings. Here, two common types of wear patterns of impeller, namely wear at tip of blades and wear at entrance region of the impeller are modeled by FE method, and their induced vibrations at bearings locations are estimated. FE models of these two types of wear are shown in Figs. 4 and 5 respectively. Induced vibrations due to impeller wears at front bearing location are presented in Fig. 6. As it is evident from this figure, local wear of impeller induced considerable vibration on the bearings and consequently on the main shaft, that will shorten the service life of these components.

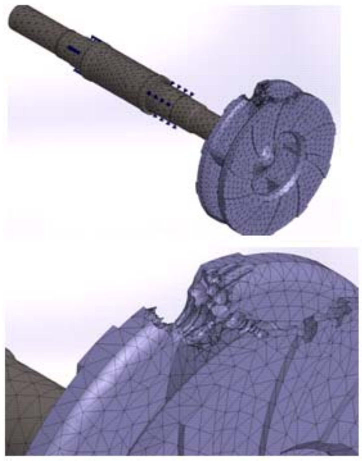

Fig. 4 FE model of wear at tip of impeller

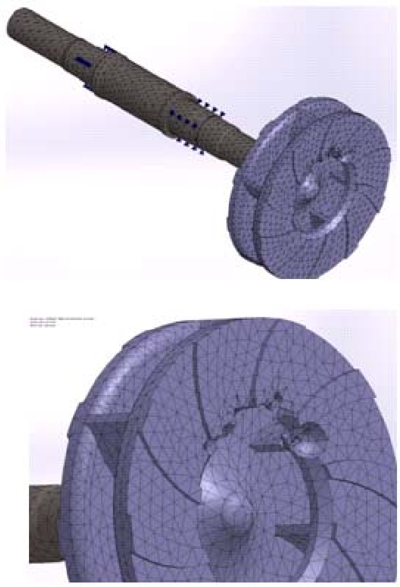

Fig. 5 FE model of wear at entrance region of impeller

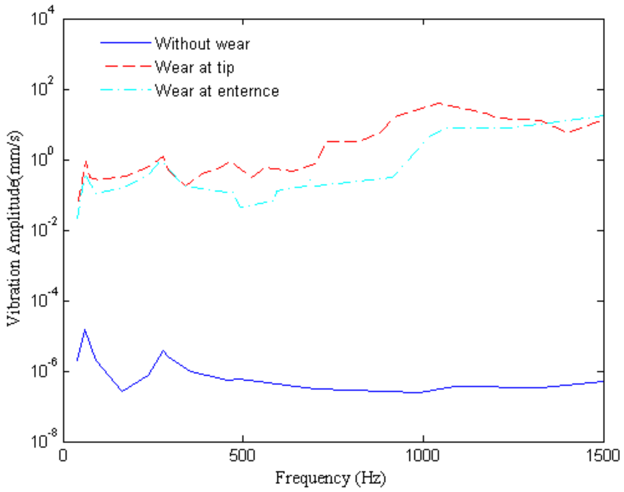

Fig. 6 Wear induced vibration in front bearing in vertical direction

III. Hydrocyclone

To efficiently liberate the minerals, the cyclone battery is designed, and its operating conditions are adjusted to separate the optimal size from the coarse material. The remaining coarse material is directed back to the grinding mills for further grinding.

Solid-liquid hydrocyclones are designed to separate solids in liquid suspension. Water is generally the main transport medium. In Fig. 7, a schematic of a hydrocyclone is presented. The slurry is introduced under pressure and tangentially into the upper cylindrical section of the hydrocyclone. This causes the slurry to spin inside the hydrocyclone, imparting centrifugal force on the suspended particles. The velocity at which the water flows through the hydrocyclone determines the efficiency at which the particles are separated from the water. Coarser particles with sufficient mass migrate toward the wall of the hydrocyclone. The particles then spiral downward, and the larger particles are transported down to the spigot of the hydrocyclone and are discharged out the bottom with a portion of the liquid. This stream is called the underflow. As the slurry moves downward through the narrowing cone section of the hydrocyclone, a large portion of the liquid turns inward and upward in a central vortex that discharges out the top of the hydrocyclone. Finer particles with insufficient mass to make it to the wall move to the inner section of the hydrocyclone, are entrained in this upward flow and discharge out the top. This stream is called the overflow [4].

The pressurized feed slurry containing solid particles with considerable sizes, from few microns to few millimeters and also swirling nature of flow in the cyclone lead to high abrasive wear of the cyclone walls and high noise [6]. The amount of abrasive wear and worse locations of wear depend on design parameters of cyclone and operational parameters of process line.

Using fluid dynamics software such as Gambit and Fluent, it is possible to simulate the effects of operational parameters such as feed pressure, solid particles size and percentage of solid on the dynamic of fluid within the cyclone for instance pattern of slurry swirl, pressure and velocity distribution of slurry in the cyclone. In the other words, the amount of abrasive wear of cyclone walls depend on the slurry velocity, slurry pressure and particle size. Therefore, the fluid dynamics can be used in the prediction of wear rate and location due to different operational conditions.

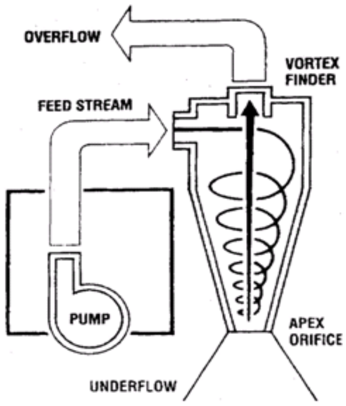

Fig. 7 Schematic of a hydrocyclone [5]

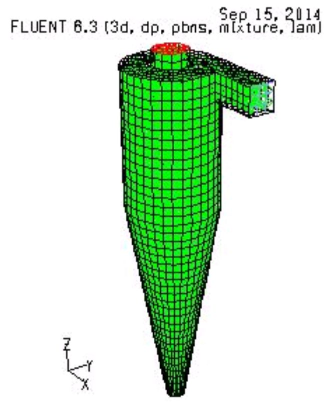

Fig. 8 Meshed 3-D model of cyclone in Gambit software

Here, an example of simulation of pressure and velocity distribution of slurry within a hydrocyclone is illustrated. The cyclone dimensions are as following: overflow duct's diameter: 190 mm; diameter of cylindrical section: 510 mm; length of cylindrical section: 760 mm; underflow duct's diameter: 90 mm, and length of conical section is 1193 mm. It is considered that the particle sizes with average sizes of 110 micron and speed of 3 m/s is fed to the cyclone by a slurry pump. The 3-D model of the investigated hydrocyclone is presented in Fig. 8. Distribution of pressure within the cyclone is presented in Fig. 9. Also, velocity direction and tangential velocity of fluid are illustrated in Figs. 10 and 11, respectively. As it is seen from these figures, the simulation predicts that in this case, the slurry in the upper section of the cyclone has high pressure and velocity. So, it is expected high wear rate in this region. Also, the flow path direction from the outer layer downward and from the core to upward has been demonstrated successfully.

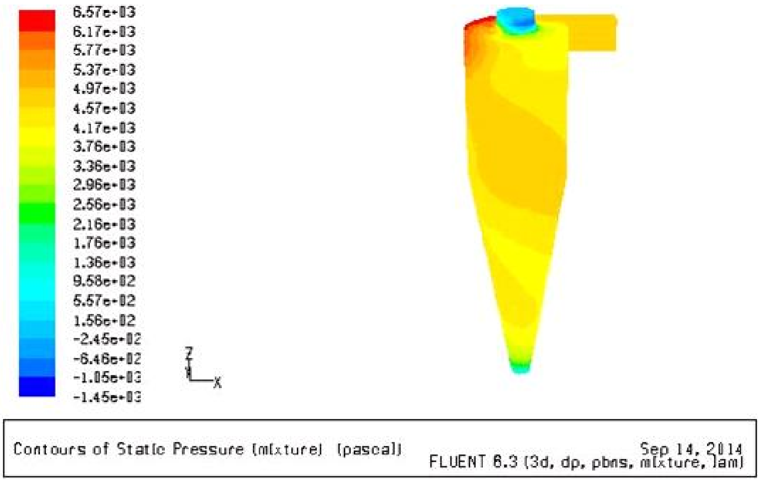

Fig. 9 Distribution of pressure inside the hydrocyclone

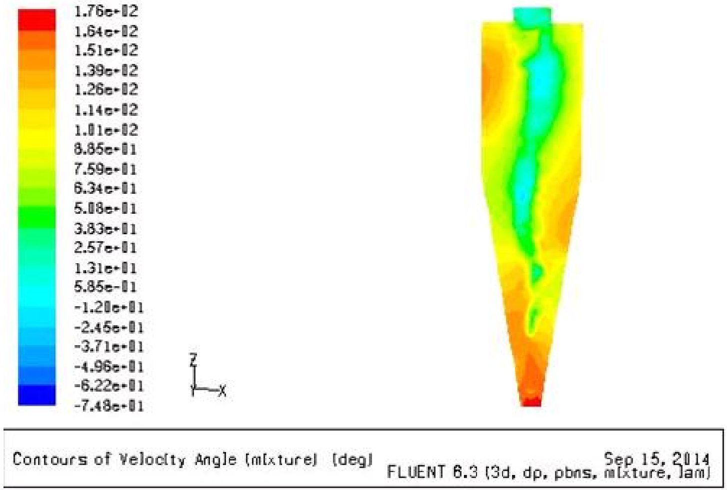

Fig. 10 Velocity direction within the hydrocyclone

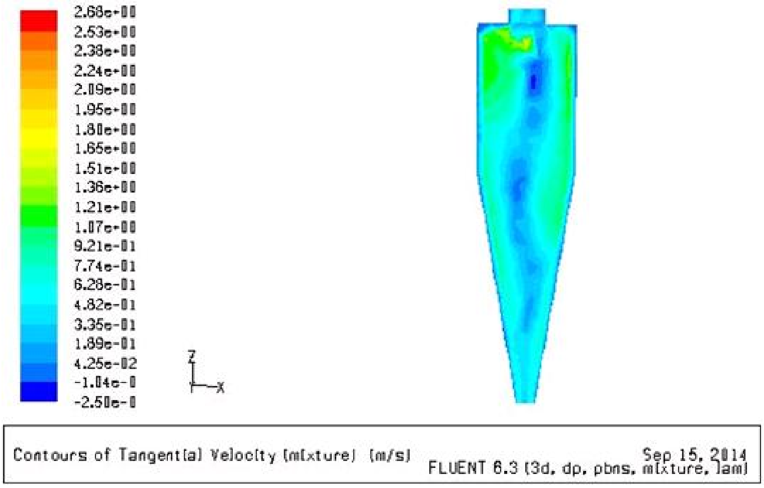

Fig. 11 Tangential velocity within the hydrocyclone

IV. Conclusion

In this paper, CAE tools were applied to simulate the working conditions of two critical components of a copper process line, namely a slurry pump and a hydrocyclone. In studying slurry pump, two common types of wear patterns of impeller; i.e. wear at tip of blades and wear at entrance region of the impeller, are modeled by FE method and their induced vibrations at bearings locations were estimated. The results showed that the local wear of impeller increases the vibration level on the bearings considerably and consequently on the main shaft. Thus, it will shorten the service life of these components. Simulating of a hydrocyclone by fluid dynamic software predicted high wear rate at the upper section of the hydrocyclone. Also, the flow path direction inside the investigated hydrocyclone was demonstrated successfully.

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