Dynamic Reliability Assessment of Slurry Pumps via Condition Monitoring

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Introduction

Time-based reliability models and tools have been widely used in design for reliability and for determining maintenance and replacement schedules of systems and components. Metrics such as mean time to failure (MTTF) and mission reliability have become common measuring sticks of the reliability performance of engineering systems. All reliability engineers are familiar with lifetime distributions like the exponential distribution and the Weibull distribution. These models and tools are very useful when the operating condition of the system can be well controlled.

The operating condition may include many factors such as the temperature and humidity levels in a room wherein telecommunications equipment is located; the ambient temperature, the humidity, precipitation condition, and wind velocity around a wind turbine; the road condition of automobiles; and the fluid medium of a pump. Some of these factors are easier to control than others; for example, room temperature, room humidity, paved road conditions, and pure liquid are controllable, while wind velocity and ice formation on wind turbine blades and the characteristics of the medium of a slurry pump used in the oil sands industry are impossible to control. Because time-based reliability models and tools are not very useful for systems working under such dynamic operating conditions, such as slurry pumps, it is more difficult to assess their reliability over time. In this case, instead of tracking the time or usage of the system, we must find a way to assess the health condition of the system over time. In this article, we describe a research project aiming to develop a dynamic reliability assessment tool for slurry pumps.

Slurry Pumps

Slurry pumps are used to pump a mixture of liquids and solids (called slurry). They are widely used in mining operations around the world and in oil sands operations in Alberta, Canada. For oil sands operations, the slurry to be pumped is composed of water, bitumen, and rocks. The rocks may be as large as several inches in diameter, and depending on the geographical locations, the hardness and abrasive properties of these rocks may be quite different. These rocks in the slurry cause severe wear of the wetted components, which are in contact with the pumped medium (the slurry). Wetted components include the impeller, casing, and suction liners. The diameter of the impeller may be as large as 60 inches. Once the amount of wear on a wetted component reaches a certain threshold level, it must be replaced with a new one; however, there are no well-established methods to determine the optimal time when the slurry pump should be shut down for replacement of its wetted components. Shutting down too early results in premature replacement of these components; if not shut down preventively in time, the pump will break down due to severe wearing of these components and this results in loss of production and economic loss. Developing a dynamic reliability assessment method for the wetted components of slurry pumps will enable full utilization of these expensive components while preventing unexpected downtime of the production system.

The Experimental System

To find out what metrics to observe as indicators of the wear status of the wetted components, we have designed a slurry pump test loop (See Fig. 1). Key components of this test loop are the slurry pump, 40HP drive motor, 3" diameter pipes, inlet pressure control tank, sand addition tank for creating a mixture of sand and water (simulated slurry), cooling tank to control the temperature of the medium, flow rate control valves, and measuring instruments for pump speed, motor current, pressure, slurry temperature, flow rate, slurry density, and vibration. The locations of the vibration accelerometers are shown in Fig. 2. Note that the pump to be studied in this pump loop is much smaller than the ones used in field oil sands operations.

Experiments Conducted

The focus of the study is on the impeller because it gets worn out much faster than other wetted components. The impeller of the pump test loop has five vanes. Based on the experience of engineers of field slurry pumps, one of the major locations of wear is the trailing edge of the vanes. Thus, we decided to run the pump loop using four different impellers each with one of the following wear conditions at the trailing edges of the vanes: no material loss (damage level 0), slight material loss (level 1), medium material loss (level 2), and severe material loss (level 3). The impeller at damage levels 0 and 1 is shown in Fig. 3. As shown in Fig. 3, at damage level 1, there is a vane length loss of about one inch.

For each impeller used (at a specific damage level), we ran the pump loop at several pump speeds (1600 revolutions per minute (rpm), 1800 rpm, 2000 rpm, 2200 rpm, and 2400 rpm) and several flow rates (70% of the best efficiency point flow rate (BEPQ), 85% BEPQ, 100% BEPQ, and 110% BEPQ). Vibration data from the three accelerometers and process data including inlet and outlet pressures, flow rate, density and motor current consumption were all collected with a data acquisition system.
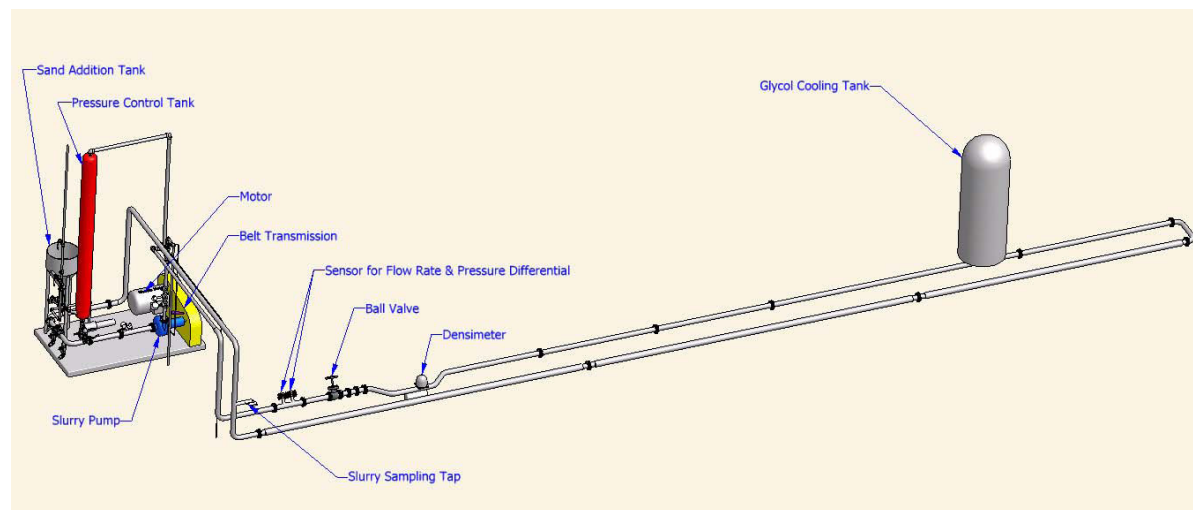

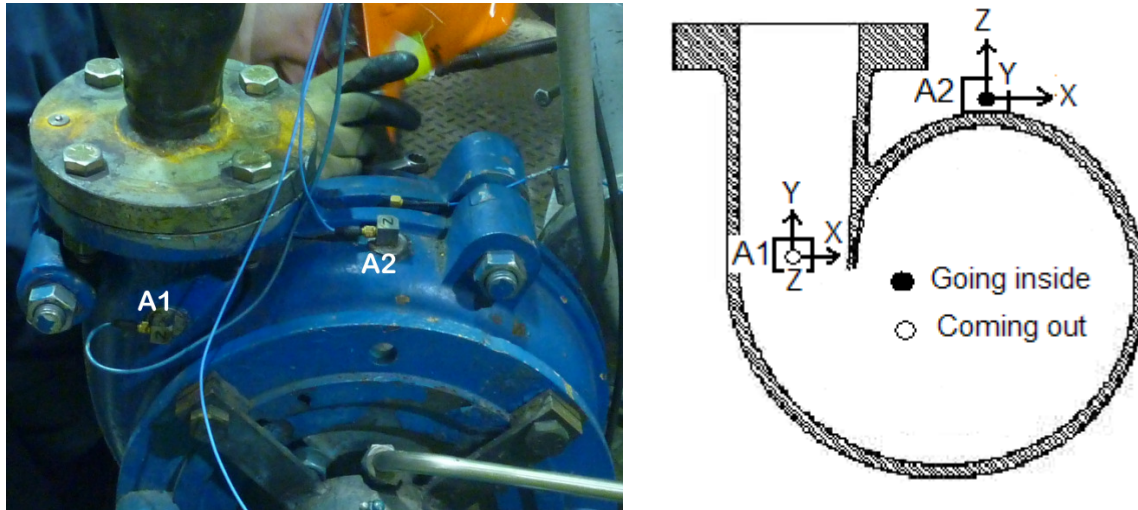Fig. 1 Schematic of the slurry pump test loop.

Fig. 2 Vibration accelerometer locations (left) and schematic for direction convention (right).
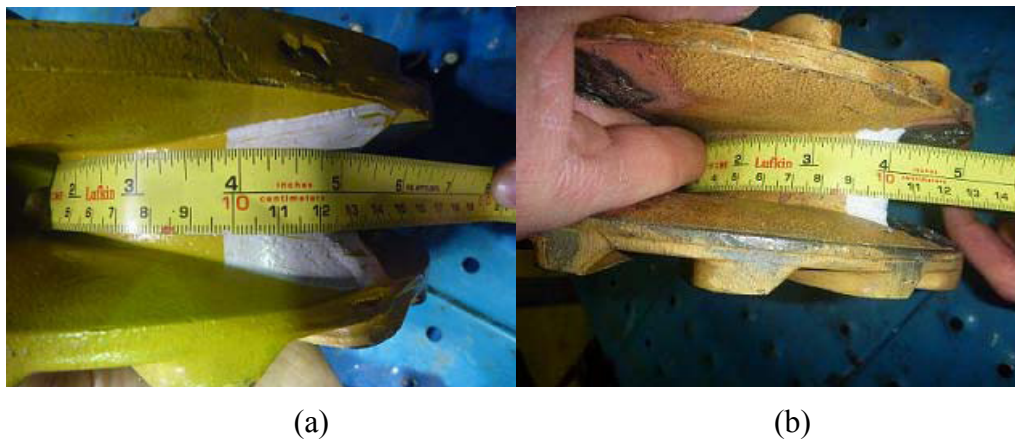

(a)   (b)

Fig. 3 (a) Impeller at damage level 0; (b) Impeller at damage level 1.

Data Analysis

Using the data collected, we examined many measures that potentially reflected the damage trend of the impeller. Based on the process data, we examined the trends of the head ratio (HR), the efficiency ratio (ER), and the power ratio (PR) versus the damage level. From the vibration data, we evaluated many time-domain features like root mean square (RMS), standard deviation, and kurtosis as well as many frequency-domain features like the amplitude at the blade passing frequency, its harmonics, and frequency centre. A fuzzy preference-based rough sets algorithm was used to select a subset of features that best reflected the damage trend.

Principal component analysis was then performed to generate the first principal component as the final indicator of the damage trend. An example plot of the generated first principal component from the process indicators is shown in Fig. 4. From these extensive data analyses of both process data and vibration data, we developed an algorithm to automatically generate the

appropriate metric to monitor. This metric provided effective indication of the damage level progression.

Future Work

Now that we have identified the appropriate metric to track as the indicator of impeller trailing edge damage progression, our next step is to test this metric using field data. This next step will identify the threshold level of this metric beyond which the pump is deemed failed and the impeller needs to be replaced. Data collected from multiple pumps will be used to identify the level of uncertainty when such a threshold is used. The information on the level of uncertainty provides a reliability measure of the running pumps. This dynamic information will provide field engineers with the knowledge that once such a threshold is reached, the engineers have a certain time window, say two weeks, to prepare for the impeller replacement.
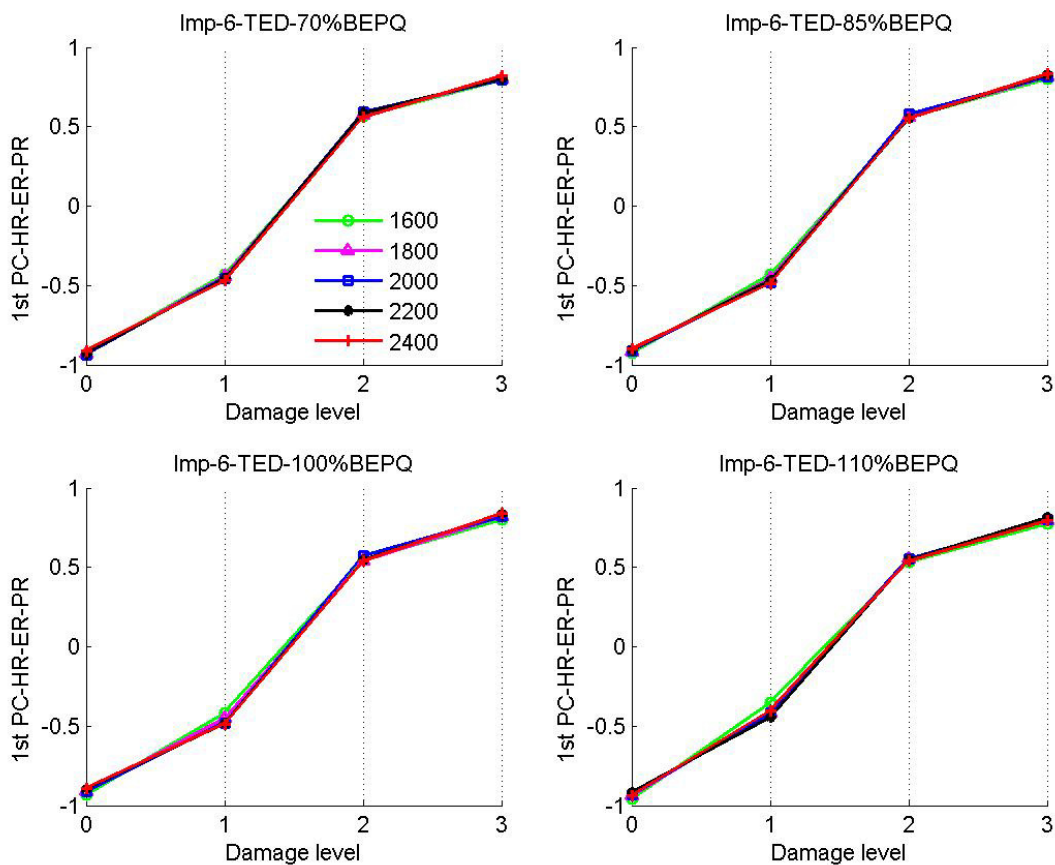

Fig. 4 The first principal component generated from process indicators versus the damage level.

Conclusion

When the operating condition is dynamic and thus impossible to control, it is much more difficult to develop effective reliability assessment methodology. Fortunately, many researchers are working in the area of diagnostics and prognostics which will generate useful results for condition based decision making in terms of reliability assurance and cost minimization.

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