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FAULT DIAGNOSIS OF ELECTRIC SUBMERSIBLE PUMPS USING AUDIO AND VIBRATION SIGNALS

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Abstract
The present work assesses the feasibility of using audio and vibration signals to establish correlations between different types of damage (a state) and related failure modes (an event) in centrifugal pumps. Most available diagnosis software strive to distinguishing between normal and abnormal conditions in centrifugal pumps, but are not capable of directly correlating a detected type of failure to an existing mechanical damage (injury or harm, the condition of something not being intact). In the present work, several types of controlled mechanical-damage are applied to a centrifugal pump as a means to univocally correlate via spectrum analysis typical signatures to given damage-failure pairs. Pressure and flowrate data together with vibration and audio signals were collected to detect the wear state and operational conditions of a known pump. Both acceleration and sound-wave data are analyzed using Fast Fourier Transform (FFT) and Power Spectral Density (PSD) techniques. This paper introduces an approach based on *random forests*, an algorithm that uses decision trees for classification and regression. Normal and defective pumps have different spectrum signatures, which allow for damage identification and classification.

Keywords
Pumps; monitoring; vibration; failure; prediction

Introduction
Electric submersible pumps (ESPs) are a popular artificial lift method, often resorted to in well production strategies. Depending on the particular design, ESPs are capable of surmounting great elevation differences in very compact configurations, but have been observed to be relatively sensitive to mishandling during transportation. ESPs consist of multiple centrifugal stages, arranged in series and connected through a shaft to a sealed electric motor. ESPs can be more than 30-m in length and operate in severe, hostile environments [4]. Since any intervention on ESP-based pumping systems is expensive and complex, a fast fault diagnosis would be of extreme importance for a reliable running of operations.
Unfortunately, commercial fault diagnosis software cannot directly correlate a detected fault to an existing mechanical damage. Alterations in pressure, flow rate, and elevation are normally detected by dedicated software through spectral analysis [1, 2, 5], but the type of mechanical damage that originally provoked the identified failure normally remains obscure. The purpose of the present work is to carry out controlled experiments and signal analysis as a means to establish a direct connection between different types of mechanical-damage and failure. In particular, given a typical failure signature, the purpose of the study is to develop the means to determine the type of mechanical damage that resulted in a particular failure. Thus, the work analyses the performance of ESPs before and after a controlled and known harm is caused to a particular mechanical component of the pump. Here, the main goal is to characterize the behavior of the pump though vibration and audio signals as a means to detect and classify any existing mechanical-damage.

Experimental Setup
The pumps were tested in the facility illustrated in Figure 1. Test benches were also used to generate controlled physical harm to the pumps and to simulate real impacts suffered by an ESP during transportation or operation. During the performance tests, the collected vibration and audio data were processed using Fast Fourier Transform (FFT) and spectrum analysis methods [3]. Pumps with a perceived altered spectrum signature allow for failure detection. One novelty of the present work relies on the considered method for prediction of the type of existing mechanical-damage. The method employs random forest (decision trees) classification algorithms instead of costly and time-consuming artificial neural networks.
The work imposed physical harm onto the shaft, bearings, casing and impellers. In fact, eleven

different types of damage were inflicted to pump components, including *mechanical* (impeller vane breakage, bending of the shaft to several different degrees of bend, journal bearing breakage, external impact from a pendulum and dropping the assembly from a known height), *hydraulic* (impeller vane blockage, both partial and complete, diffuser vane blockage, both partial and complete) and *electrical* (overheating the motor)

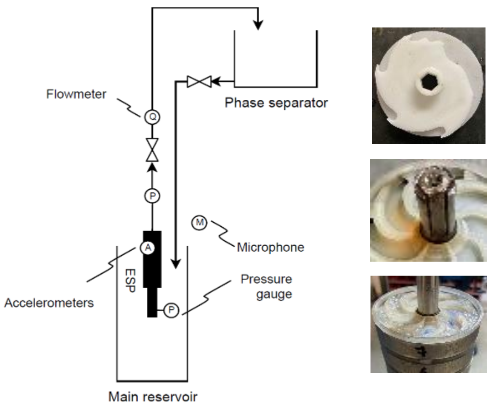

Fig. 1. Schematics of the experimental setup. Types of damage (impeller damage, journal-bearing damage, diffuser blockage).

Results and Discussion

The spectrum analysis of the vibration signals of healthy pumps (Fig. 2) shows that it is possible to assess that pumps have a distinct behavior for each different frequency that they operate. Distinct peaks are also easily identified due to the noise reduction obtained from the spectral density estimation using Welch's Method [6]. Similar results were observed in four additional measurements, carried out at different times. The tests used the same conditions to make sure that results could be repeated. Only off-the-shelf pumps were tested. Sound waves results are to be presented in the full paper.

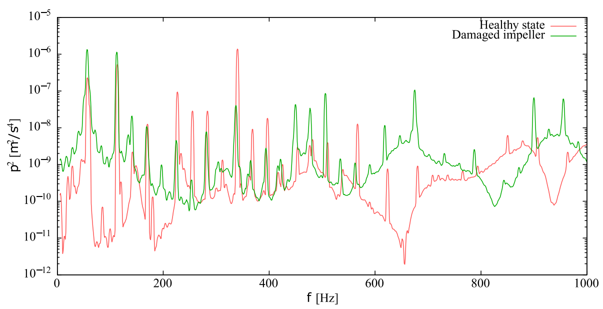

Fig. 2. Power spectral analysis of vibration signal from healthy (red) and damaged (green) ESP. Impeller damage.

Random forest classification works by generating a collection of decision trees based on a random sample of data, with possible repetition, from the training set [7, 8]. Each tree is then constructed considering only a random subset of the input variables. The output prediction is the class chosen by the majority of the decision trees. Initial results are shown in Fig. 3. Data from over 150 acquisitions were used, with a 75-25% training and testing split.

The parameters considered by the algorithm were the operational frequency of the motor and the amplitude at peaks near harmonic frequencies. As can be seen, the classifier was successful at determining the faulty states and differentiating between them. However, the classifier still has about 30% of false positive rate when the pumps are in health conditions. Further algorithm tuning and bigger training datasets are needed to improve the results.

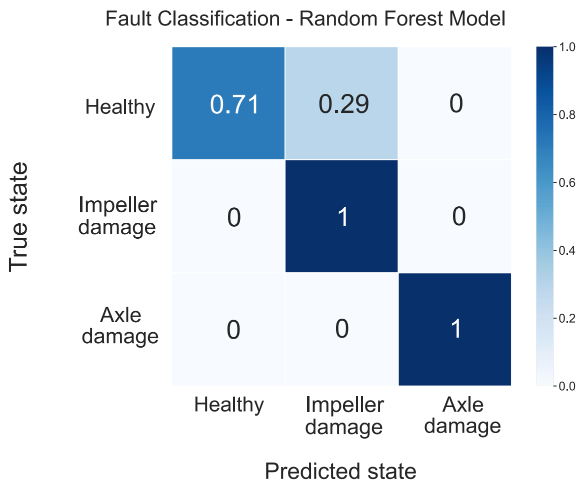

Fig. 3. Random Forest Classifier Prediction Matrix ("confusion matrix").

Conclusions

The present work presents an approach for testing, diagnosing and classifying failure modes of ESPs using flow-related (pressure and flowrate) and dynamics-related (vibration and sound waves) parameters.

The full version of this paper should include: the complete matrix of test conditions; spectral analysis of the sound data; implementation and validation of the proposed predictive model; and additional experimental results.

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Responsibility Notice

The authors are the only responsible for the paper content.

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