Detection of Ragging in Wastewater Pumps using Condition Monitoring

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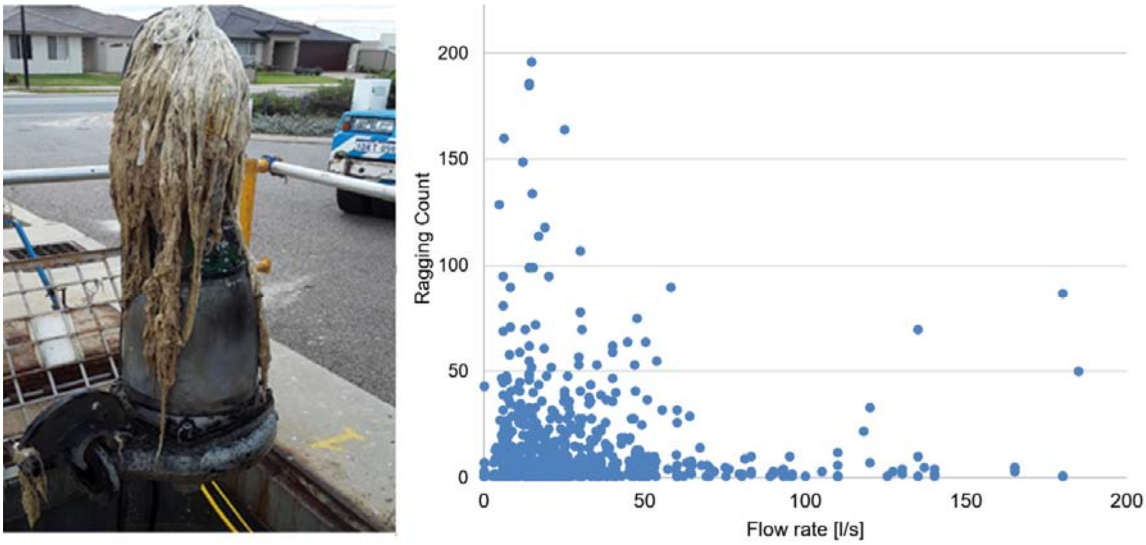
Abstract

The unexpected blockage of wastewater (WW) pumps caused by debris in wastewater is an ongoing challenge managed by the Water Corporation (WC). Removing rags and restoring pumps to service incurs significant labour costs and a risk of safety exposure because of the need to undertake entry to confined spaces to access dry well pumps. Ragging impedes pump performance and can result in damage to the pump's internal components. Currently there is no accepted method to predict ragging. This paper assesses the suitability of vibration and motor current for ragging event prediction. Vibration and pump motor current data were collected on 7 small WW pumps (<10 kW) in 6 different pump stations over 3 months. The set data includes 16 ragging events. Findings suggest that an increase in motor current is a reliable indicator of ragging. The vibration response of pumps to ragging is not consistent and it does not appear to be a reliable indicator. Preliminary statistical analysis suggests that motor current alone should be used for these small pumps and the additional costs involved in vibration data collection are not warranted.

1. Introduction

Water Corporation's wastewater network has 1,234 wastewater pump stations (817 Metro and 417 Regional) which operate to transfer wastewater collected from end-users via a network of gravity sewers to Wastewater Treatment Plants (WWTP) for treatment and eventual discharge to the ocean. The WWPS deals with both domestic and industrial waste entering the network and contains a varieties of waste including foreign objects which have the potential to damage or clog (rag) the wastewater pumps. Wastewater pumps are designed to transfer wastewater however based on WWPS design, pump specifications, impeller types and flow rate some pumps are more susceptible to ragging than others. Ragging is a functional failure of the pump due to accumulation of debris in WW pumps and various other factors explained in the study done in Water Corporation (Marinko, 2018). De-ragging is a reactive maintenance activity which always requires a team of technicians to be on standby to attend the site and clean the pumps in the event of an occurrence. Additionally, partial ragging of larger pumps results in increased energy consumption and if left unchecked, could reduce the pump life due to operating off Best Efficiency Point (BEP).

WWPSs are monitored through SCADA and Ademco communication systems at the Water Corporation Operations Centre (OC). Various measurement techniques (current, power, flow) to monitor pump performance are used by the Water Corporation, however this data is not currently used proactively to identify potential ragging events. Typically, ragging events are indicated by the activation of standby latch alarms. These are triggered when the pump cannot keep up with inflow and the wet well level reaches "Standby Alarm" level. This alarm triggers the control system to shut the operating pump down and start the second pump. Irrespective of the fault type, the OC will then call out the duty electrician to attend site to check the fault and identify the problem. If pump clogging is confirmed, additional mechanical team resources will attend site to perform a pump de-rag.



(a) (b)

Figure 1 Rags caught on pump body at a WWPS, Perth shown in (a). Ragging count from January 2016 to December 2019 shown in (b) where each dot represents a WWPS.

Figure 1 (a) show an example of the amount of debris caught on a pump body during a de-rag activity . Responding to these events is an around-the-clock requirement. Ragging events occur in all three types of WWPS designs: Dry well, Wet well and Vacuum WWPS. Historical data analysis of ragging history of all WWPSs from 2016 to 2019 was conducted to understand ragging frequency and identify candidate pumps for data collection, A plot of ragging counts vs pump flow rate (a proxy for size) is shown in Figure 1 (b). The diagram shows that smaller pumps have a much higher count than larger pumps with some WWPSs having over 150 events in the 4 years. The six most frequently ragging dry well stations were chosen to be a part of this project. All have a motor size of less than 10 kW and flow rate of less than 20 L/s.

1.1 Motivation

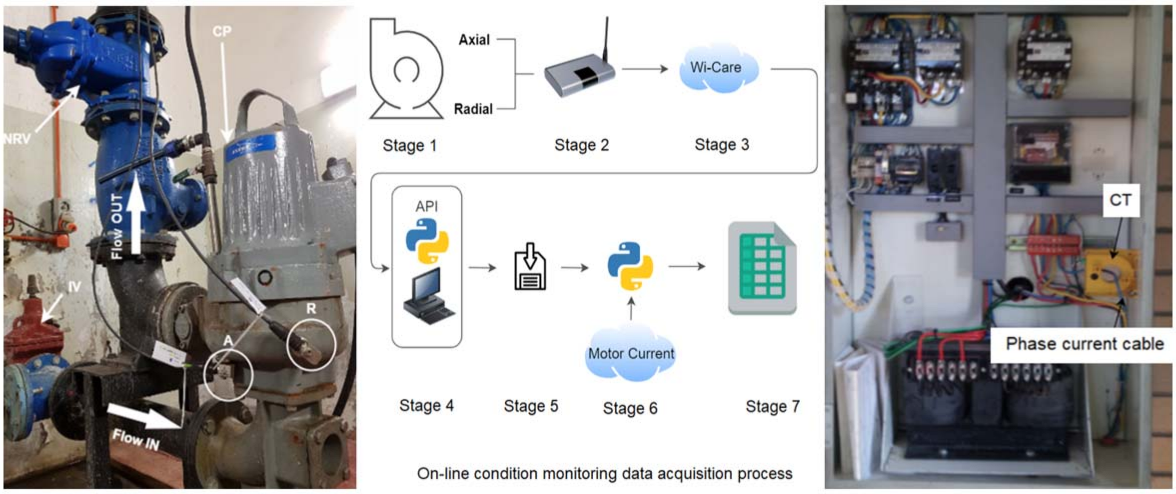
The objective of this project is to assess the suitability of two condition monitoring techniques, vibration, and motor current, to detect ragging in pumps. Early detection of ragging would help the planning team to better utilise their technicians and lower costs associated with this reactive work. The risks associated with de-ragging pumps would also be reduced if the pumps can be de-ragged during the day instead of night. The WWPS can be up to 15 m below ground level, therefore working inside requires a confined space entry permit. This is due to the potential presence of flammable gases above the lower explosive limit (LEL), toxic gases (H2S) and deficiency of oxygen. Other risks include that of skin contact with wastewater while dismantling, assembling, and cleaning the pump, engulfment because of failure of an isolation mechanism and falls from height. Activities during night is considered a high-risk activity and poses additional risks due to low visibility and security issues.

2. Process

The first stage of this project was to select the pumps for analysis and organise for the vibration sensors to be installed. Motor current data is readily available from the PI-Excel software which communicates to SCADA to access the motor current data collected from WWPS. Vibration data required the placement of accelerometers specially for these tests. Once in place, the sensors transmitted data to the cloud for remote access. Python scripts, developed in Jupyter environment by the author, were used to compile a set of vibration measures in the time and frequency domains. Data frames with motor current, vibration, calendar and running time, and the number of cycles were assessed statistically, and the results visualised using Python.

2.1 Condition Monitoring using Vibration Analysis

"Wi-Care 200" vibration condition monitoring system was installed at all selected dry-well WWPSs. Figure 2 (a) shows a typical installation of the vibration system at a WWPS in Perth with a complete schematic diagram outlining the process from collecting the raw vibration data from pumps to making a data frame in excel shown in Figure 2 (b). In Stage 1 two single-axis accelerometers are installed in axial and radial directions on both pumps of the WWPS (Hodkiewicz & Pan, 2003). Both accelerometers are powered by a 20 V DC cable from the data acquisition module (DAQ) module for live monitoring. The data is sampled at 4000 Hz and fed to Wi-care cloud server for remote access in Stage 2 using an integrated mobile network.



(a) (b) (c)

Figure 2 Accelerometers in Axial "A" and Radial "R" directions, Non-return Valve as "NRV", Isolation Valve as "IV" and Centrifugal Pump as "CP" shown in (a). Data management schematic diagram shown in (b) and installation of current transformers "CT" inside the control panel of pump stations to measure motor current shown in (c).

All WWPS vibration system installations were identical with regards to how the accelerometers were placed on the pump as shown in Figure 2 (a). The collected measurements stored on the cloud is in the JSON format in stage 3 which is converted into excel csv form by using the dedicated python script in Stage 4. The csv file is arranged and saved on the local computer in such a way that one Excel file contains all the measurements taken from the pump in the axial and radial direction in Stage 5.

2.2 Condition Monitoring using Motor Current Data

A significant change in motor current can be observed when the pump is clean in comparison to completely ragged pump (Hedes, Svoboda, Vitan, Muntian & Anton, 2018). Motor current is measured by current transformers (CT) installed at the majority of the WWPS through SCADA network as shown in Figure 2 (c). The motor current data can be extracted using PI-Excel software available on WC server. Each WWPS are defined by specific tags on PI-Excel which relate to the various measurements being recorded on SCADA. A tag for motor current is used to extract the data in Stage 6. Lastly, the vibration and the motor current data are merged into a single data frame for processing in Stage 7.

3. Results and Discussion

Although 6 WWPSs were included in the experiment only three stations had both vibration and motor current data for the analysis (two stations didn't have motor current data and one station had technical difficulties in obtaining enough vibration data). The steady state motor current drawn by the pump when it is clean is usually close to its rated current however as pump starts to rag the steady state current goes up due to motor requiring an additional torque to maintain its rated speed. Figure 3 (left) shows Pump no. 1 (2.5 kW, single vane impeller) from station "A" draws 3.5 A current when the pump starts after cleaning and the current goes up to 6.1 A before the over-current protection prevents it from running to avoid the risk of fire due to overheating. The graph in Figure 3 (right) shows Pump no. 2 (4.5 kW, single vane impeller) from station "B" draws 5 A when it is clean and goes up to 14 A before failing due to ragging (station B has larger pumps thus over-current protection threshold is set at higher ampere value).

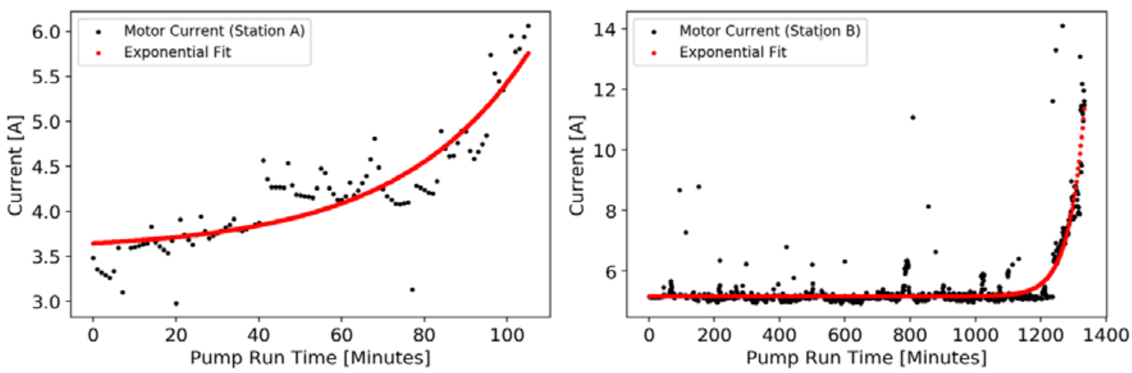


Figure 3 Motor Current trend shown by black dot of station A (left) and station B (right). An exponential fit made to data is shown in red line.

The horizontal axis on both graphs represents the 'total' pump run time in minutes from a clean to ragged condition. Our data suggests this 'total' run time of the pump varies considerably depending on several factors. Previous study within Water Corporation shows lack of awareness, societal attitude and inappropriate items entering the wastewater system are also the contributing factors which aggravates ragging (Marinko, 2018). Figure 4 (left) shows the exponential fits made to data representing the motor current trend of nine total failures of a same pump as a function of the pump's actual run time obtained from station A. Two features to notice are 1) an upward trend of motor current across, and 2) a wide variation in 'total' pump run time for the same pump. Figure 4 (right) shows the trend of motor current of 5 ragging cycles from a different pump (4.5 kW) of station B.

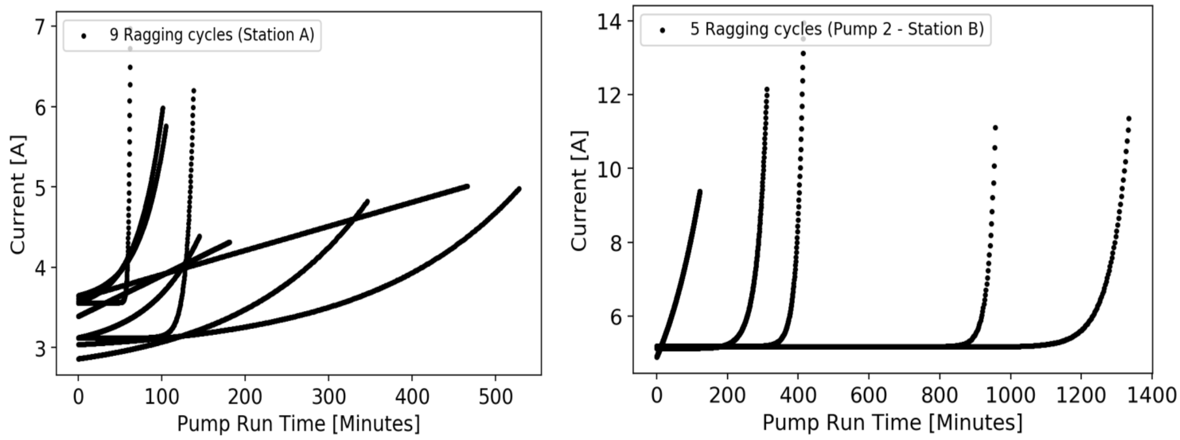


Figure 4 Superimposed 9 ragging cycles from pump 1 station A shown in graph on the left, 5 ragging cycles from pump 2 station B shown on the right

Vibration of the pump changes when the pump condition starts to deteriorate due to ragging. The vibration time waveform data collected from station A shows the difference in maximum amplitude of time waves of a clean and a ragged pump. Vibration response of the pump has been found to vary between pumps. Exponential fits made to vibration analysis variables such as RMS of time waves, running speed (1X) amplitude and running speed of the pump have been plotted as a function of total pump running time is shown figure 5. The change in vibration amplitude at running speed of the pump (24 Hz) of all 9 independent failure events is shown in (a), the Root Mean Square (RMS) of the time waves for all vibrations samples is shown in (b), and pump running speed approximated by a peak detection algorithm (FFT spectrum resolution is 1 Hz therefore the minimum change that can be detected is 60 RPM) can be seen decreasing towards the end of pump's life in (c).

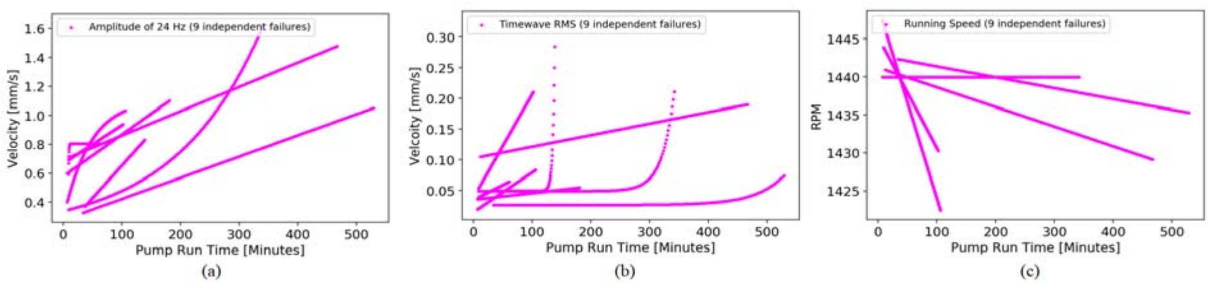


Figure 5 Trend (exponential fits) of 1X amplitude, RMS of time wave and RPM of pump from station A shown in (a), (b), and (c) respectively

The residual life of each ragging event of pump from station A is shown in figure 6 as a plot of Reliability R(t) against Run Time. An estimation of R(t) using motor current as an independent variable is shown in black, whereas the magenta triangle shows estimates of R(t) using both motor current and vibration parameters as independent variables. The blue line shows when pump ragged. The graphs show remarkably similar trends, notice the close similarity on trajectory for the motor current and vibration + motor current in the plot. This results are representation of 9 failure events from one pump and it suggests that the additional information obtained from vibration may not be worth the time and costs involved.

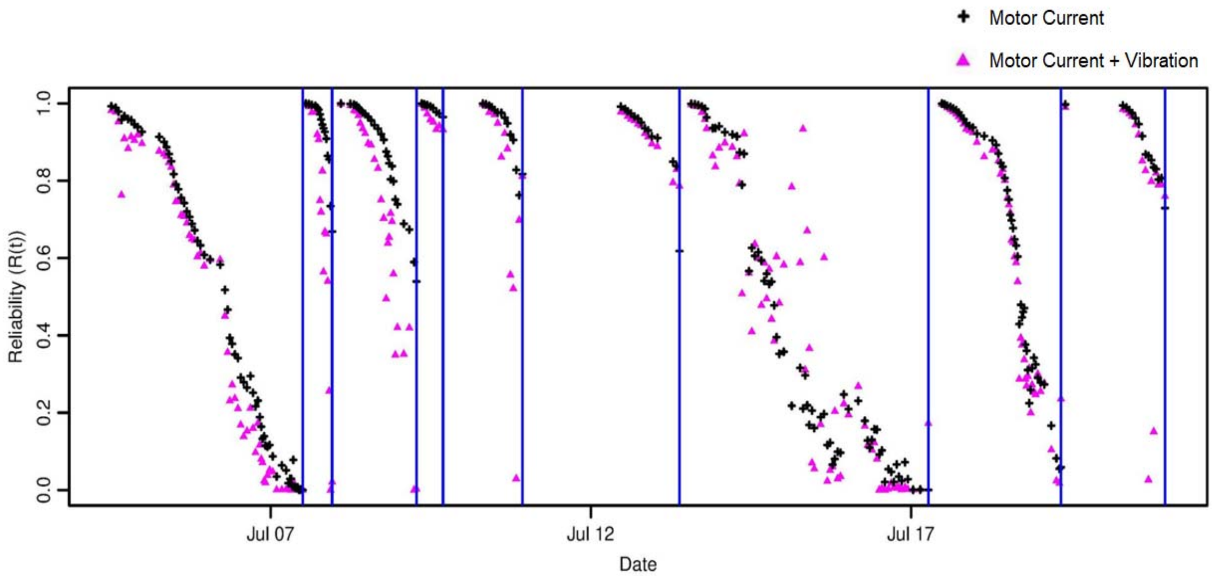


Figure 6 Residual life of pump (9 ragging events) of station A. Black represents reliability of pump using motor current as a covariate and, magenta represents motor current and vibration parameters obtained from timewave data as covariates

4. Conclusions and Future Work

Statistical analysis showed the parameters obtained using vibration data have lower statistical significance than that of motor current. A significant cost saving can be achieved by using SCADA motor current data at smaller pump stations to predict ragging. A long-term development could be building a website with real time monitoring dashboard which takes motor current data as its input and supported by Python scripts working in the backend to approximate when the next ragging event will occur.

5. Acknowledgements

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6. References

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