Downhole pump card approximation

using electrical signature analysis

Detecting mechanical faults on Sucker Rod Pumps at an early, developing stage benefits the reliability and performance of these pumps. In addition, it reduces the risks of environmental damage, as issues are remedied before they become a problem.

Traditionally, load cells have been installed to produce a dyno card. For this purpose, the load cell is installed either topside, or downhole. This is expensive, and error-prone, as sensitive sensor equipment is exposed to the harsh conditions in which the pump operates.

An alternative solution to produce a dyno card is to use electrical signature analysis (ESA). It is a technology that is based on the analysis of high-frequency electrical signals. An ESA-based monitoring systems:

- Produces a dyno card based on analysis of high-frequency electrical data
- Installs inside the motor control panel, and eliminates the need to install sensors in the field
- Offers real-time data about the performance and energy efficiency of Sucker Rod Pumps

At a trial in the United Kingdom, an ESA-based system was used to replicate the functions of the load cell by using 20kHz, 24-bit current and voltage data. The result is that the position of the pump can be estimated with 99,9% accuracy, and the associated load with 98%. This makes the system usable as an alternative to installing load cells. It is expected that the automated Sucker Rod Pump monitoring system will be available in Q2, 2023.

In this talk, Simon Jagers, founder of Samotics, presents the method, results, and future development steps.

Data received

Client has shared load cell data pertaining to two distinct assets, namely: A and B. Load cell data was gathered using the Echometer wired analyser kit, with the sampling rate configured to 30 Hz.

Asset	Sampling rate	Samples	Start time	Duration
A	30 Hz	53857	09:33:59 AM	~ 30 minutes
B	30 Hz	100254	11:52:53 AM	~ 56 minutes

The shared data consists of:

(A) The processed pump card data
(B) The underlying raw data
(C) The start time of data collection

The pump card data is in tabular .csv format, and contains 4 columns:

(1) Surface Card Position (SC_Pos)
(2) Surface Card Load (SC_Load)
(3) Pump Card Position (PC_Pos) ⟵ Down hole
(4) Pump Card Load (PC_Load) ⟵ Down hole

The raw data is in a proprietary binary format and can only be opened using Echometer software. It contains both static information about the asset (such as its dimensions and layout). as well as raw sensor data for load and acceleration.

Analysis goal

The goal of this analysis is to use SAM4 data to approximate the pump card position and load. The resulting approximation should be accurate enough to:

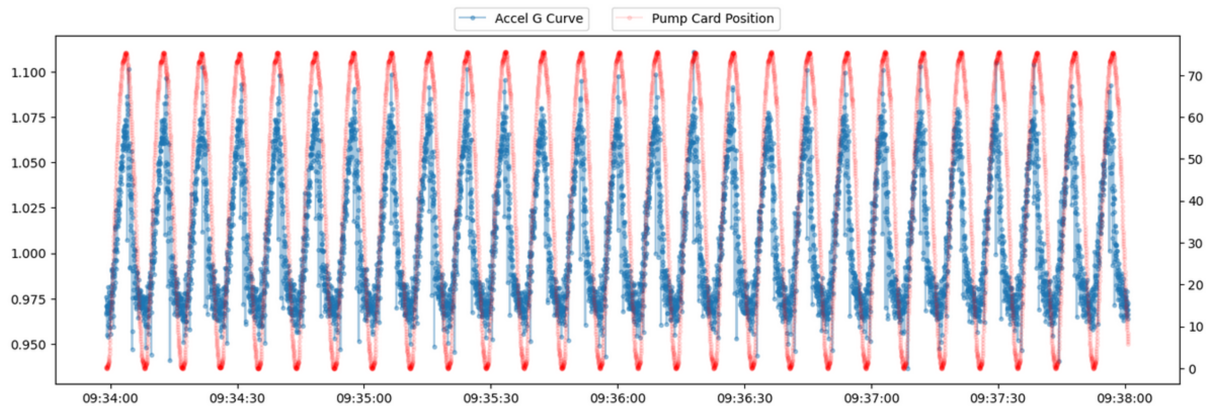
1. Aid in the diagnosis of failures and prevent unplanned downtime.
2. Assist with asset efficiency optimization: Maximising the output (measured in barrels per day), whilst minimising the input (i.e. operational / energy costs).

Analysis results

To summarise, The SAM4 sensor can be used to reliably approximate the pump card position with an accuracy of 99.99% or more. Based on early research results, it's possible to approximate the pump card load with an accuracy of around 95%. However, this accuracy is insufficient to fulfil the analysis goal. Improving load approximation is work in progress, with plenty of room for improvement.

From accelerometer to pump card position

The Echometer software uses an accelerometer to approximate the pump card position. This approximation is relatively straightforward. First, the local peaks in acceleration are detected. Secondly, a sine curve is superimposed on top of these peaks. Finally, the sine wave is scaled to match the maximum stroke height. The figure below shows both variables plotted on top of each other, the left y-axis corresponds to the acceleration (measured in G-force). The right y-axis corresponds to the pump card position (measured in inches).

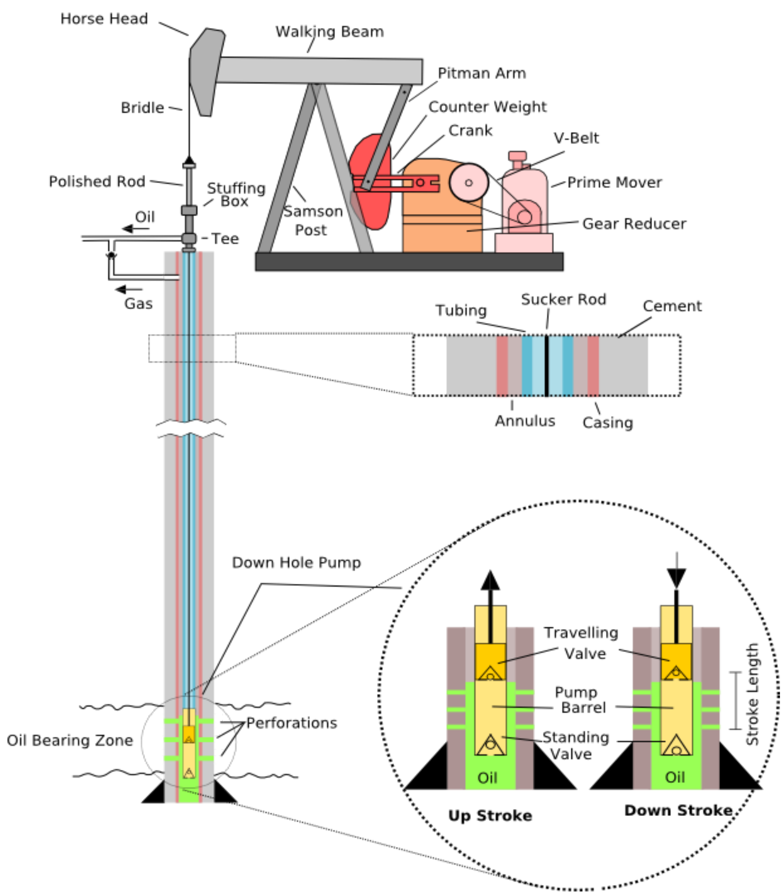


The sucker rod pump drive train

A sucker rod pump is powered by an electric motor. This motor uses a gearbox to drive a belt, which in turn drives a crank, which in turn moves the horse head, which in turn moves the rod, which in turn moves the pump. Even though this drive train is fairly complicated, the power consumption of the electric motor is highly correlated with position of the rod.

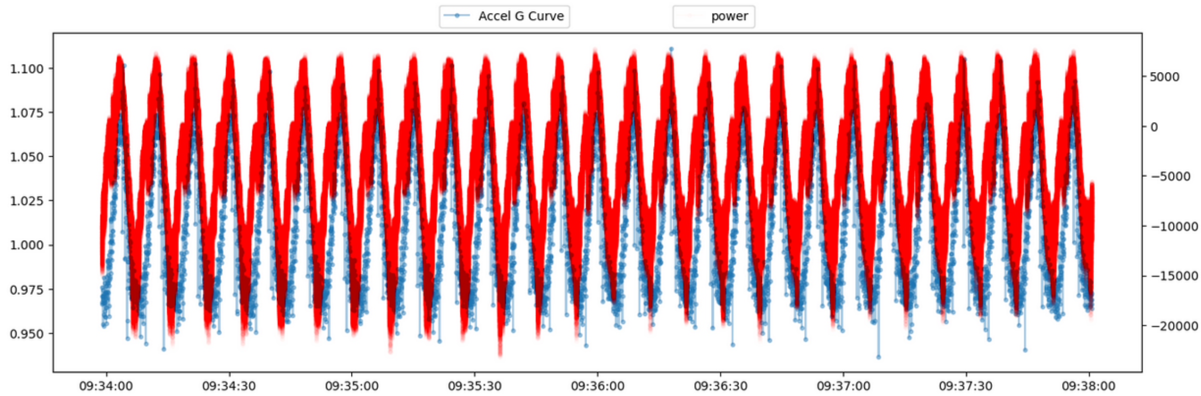
When the horse head is in free fall the rotor speeds up, resulting in power being produced. When the horse head is being lifted under load, power is consumed.

For more information about the drive train, see the figure on the right, or visit the source: link.



From electrical data to pump card position with 99,9% accuracy

By plotting the negative values of power on top of the acceleration G curve, you can see that all peaks line up. This allows SAM4 to accurately estimate the downhole pump card position. In other words, the accelerometer can be replaced by SAM4 without any loss in accuracy for estimating the pump card position.



The plot above was created without downsampling. Since SAM4 is sampled at 20 kHz, the red curve consists of nearly 5 million points being plotted across 4 minutes. This amount of plotting points is clearly overkill. The plot below shows the same information, but with SAM4 data downsampled at 30 Hz. The conclusion is still the same: blue and red peaks align perfectly (up to a margin of synchronisation error).

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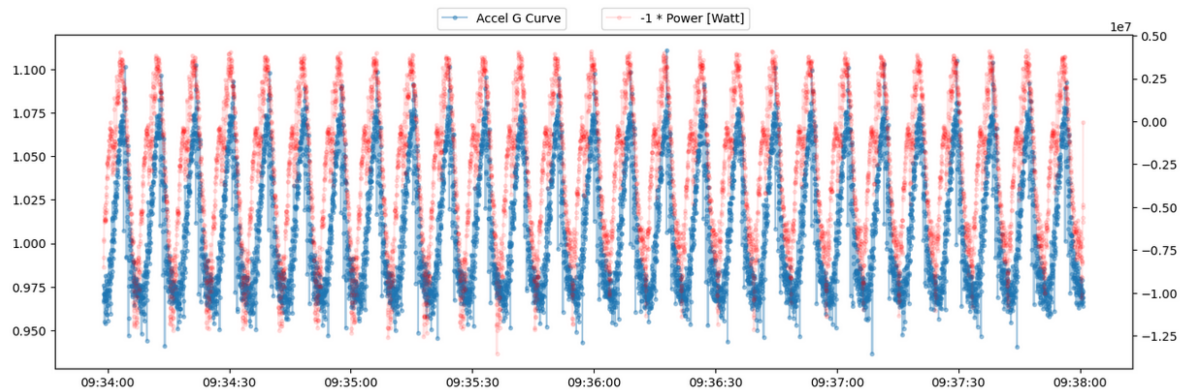
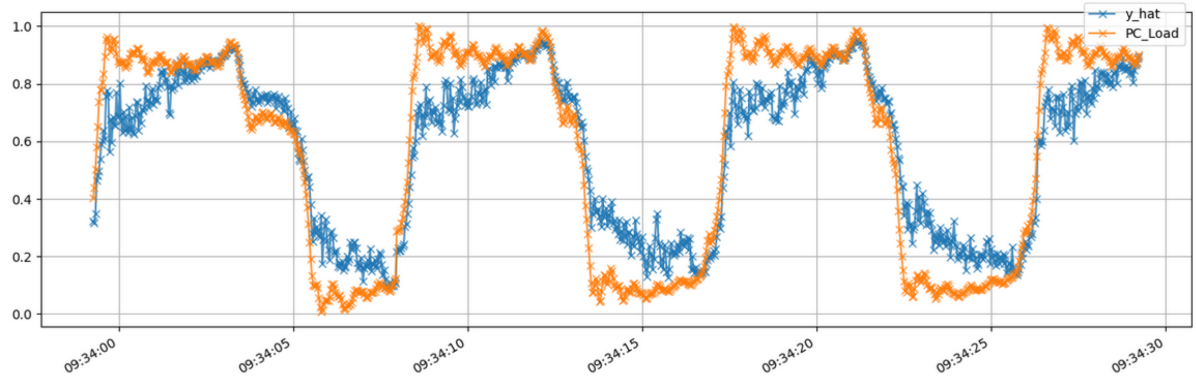


From SAM4 to pump card load

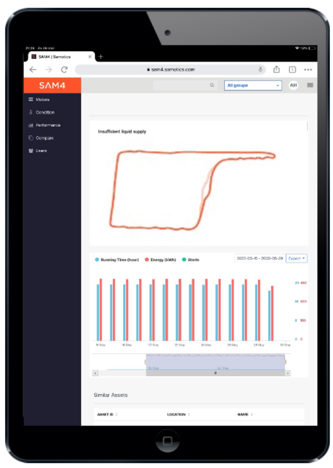
Analysis shows that it's possible to use SAM4 power data to estimate the pump card load. So far, the error of the best performing model is about +2%. Additional work is in progress to reduce the error further.

The figure below shows the estimated load (labelled y_hat) versus the actual load (labelled PC_Load). The model will be improved to reduce the error even further.



Dashboard

By calculating the position and the load of the pump, it is possible to reproduce a dyno card without the need to install a load cell in the field.



Next steps

It is possible to auto-diagnose the shape of the dyno card, as the basis for automating (some aspects of) pump operations. For instance, the system could shut down a pump or adjust the speed of the prime mover. This might be a useful feature for a limited number of observed faults. In principle, the tool will remain primarily a system that enables operators to make better decisions, by providing real-time information about the health, performance, and energy efficiency of pumps.

Conclusion

The accuracy of ESA-based systems in terms of determining position and load of the pump allow for the development of a dyno card-like feature. As such, they offer an alternative to load cell-based dyno card systems. This has 3 benefits:

- Sensors are installed inside the motor control cabinet, making it easier to install and more robust in terms of reliability of the sensor system.
- The costs of such a system are much lower, enabling permanent monitoring on pumps that produce 2+ barrels per day.
- Additional insights into the performance and energy efficiency of pumps add additional value of traditional systems.

Some additional development work is needed before the system is available to the public. This is expected to be completed by Q2, 2023. In addition, improvements in accuracy and automated classification of dyno cards might enable automating some operational decision-making in the future.