

The Role of High-Frequency

Automation and Predictive Maintenance



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1 Overview

The explosive growth in the field of IoT, the rapid development of cloud computing and the renewed interest in the use of Artificial Intelligence to process the massive volumes of data being produced by hundreds of thousands of sensors, coupled with the long downturn cycles in the O&G industry, has managed to elevate the value of data to the highest of levels. Organizations are increasingly turning to data to optimize operations and reduce cost of doing business in the face of vanishing margins. Automation at various levels of operation is gaining credence as the means of attaining efficiencies.

2 Glossary of terms

2.1 Stationary process

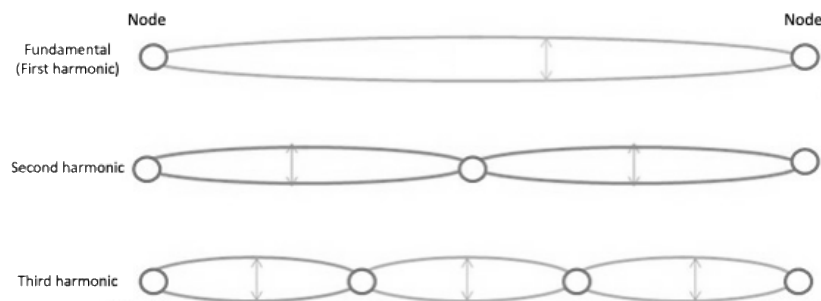
In mathematics and statistics, a stationary process (or a strict/strictly stationary process or strong/strongly stationary process) is a stochastic process whose unconditional joint probability distribution does not change when shifted in time. (Gagniuc, 2017). In other words, the process exhibits periodicity and repeatability. These are processes whose statistical characteristics do not change over time. The data inside a constant sized time window has the same distribution.

2.2 Non-stationary process

In contrast to a stationary process defined above, a non-stationary process has a variable variance. The data representing a non-stationary process, therefore, does not show a tendency of mean reversion.

2.3 Fundamental and harmonic frequencies

The vibration of an object, such as a string, happens at a certain frequency depending on the material composition and the physical construction of the object. The lowest frequency produced by an object is known as its *fundamental frequency* or its *first harmonic*. Constraints between the end points generate the second, third and other harmonics which are integer multiples of the fundamental frequency. The included graphic depicts this.



3 Data and high frequency data (HFD)

Systems can broadly fall into frequently and infrequently changing categories. The measurements of the quantities describing these systems can be similarly classified. The subject of the current document is data pertaining to frequently changing systems.

Measurements are taken at varying intervals. For the sake of the current discussion, data can be considered to be of high frequency only when at least one measurement is acquired every second. The domain of HFD stretches to multiple kilo hertz.

4 The automation and feedback control problem

One of the main drivers for the use of HFD is automation via feedback control using frequently changing measurements. Control is proportional to the deviation of the state of the system from the target. Inertia and time lag or latency between issuance of correcting directive and the accomplishment of the intended objective, has to be taken into consideration while designing a control. Delays are especially pernicious in feedback systems, and some form of modeling and prediction are invariably needed to overcome their effects. Prediction is either model or data driven. To accomplish a delay-free feedback control with little to no latency, signal synthesis adaptive control is a well-researched scheme (J. D. McDonald & A. T. Bahill, 1983). Synthesis connotes prediction and adaptive to keep the prediction in line with reality.

The time lag in latency-prone distant, distributed or centralized control processes can be broken down into the following components:

- Time for measurements to travel to control process
- Control process computation
- Time for correcting directive to travel to actuator (actuator delay)
- Actuator reaction
- Realization of course correction by physical object or plant

In general, the effects of delays in closed-loop feedback systems resemble the effects of lowering the sampling frequency. To make systems more responsive a two-pronged approach should be adopted; reduce the latencies and increase the sampling frequency or *HFD acquisition*.

4.1 Need for HFD in model driven predictions

A model driven approach heavily depends on a thorough understanding of the subject system from physical, spatial and temporal standpoints. Characteristics that adequately describe these aspects are invariably incomplete in extent. To predict states of fast-moving systems a balance has to be struck between how far into the future and the cost of prediction computation. A very tight, data dense time window is clearly preferable for reliable and timely predictions.

4.2 Need for HFD in data driven predictions

In data driven predictions the end goal, almost certainly, is pattern matching. If template patterns representing events (be it an anomaly signature or a vibration profile) have to match measurements in real-life, then the measurements have to be of sufficient density (number of data points per second). Otherwise, events end up slipping through the cracks.

4.2.1 Stationary vs non-stationary systems

The stationarity of systems stabilizes patterns allowing for successful matching of recurrent specimens in a streaming time-series data set to accomplish *feature extraction*. This allows for predictions using larger, sparsely populated time windows. Drilling operations, however, are non-stationary in nature and the hunt for recurrence of patterns is further complicated by the variability introduced by human actors (habits, drilling practices, procedures, etc.) and other extraneous factors. For instance, a Fourier Transform (FT) can no longer decompose the pure frequencies responsible for the measured signal. Decomposing a signal into the frequency domain (what an FT does) is no longer a viable path forward. A Continuous Wavelet Transform (CWT) that decomposes the signal into the *wavelet* domain, has to be employed to vectorize a signal that can provide frequency information *locally* as opposed to globally, across the whole signal. With wavelets, it is possible to model with a finite wave that can be *slid* along the time domain. Because *wavelets* are limited in time and frequency, applying a CWT to effectively match and extract frequency patterns obtained from training sessions, requires a very tight and data dense sliding time window.

4.3 Fundamental, harmonic and Nyquist frequencies

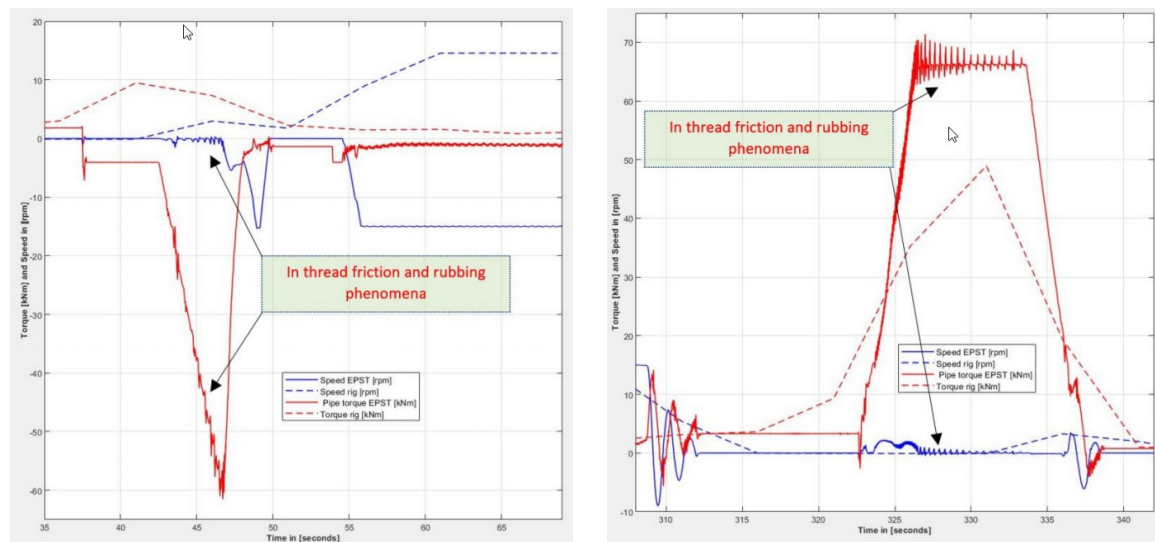
In a non-stationary world, transient events are very short-lived and appear not only in the first but also the second and third harmonics. To detect these events at higher harmonics and frequencies (4 – 10 Hz range), sampling has to be performed at a minimum of twice the frequency of the signal itself, what is prescribed by the Nyquist theorem or risk aliasing and loss of information. Discretization of data results in loss of data, especially, when performed at lower frequencies. The high frequency events end up getting discarded as noise.

5 Benefits of use of HFD

The previous sections have established the mathematical basis for the use of HFD to accomplish the twin goals of feedback control and automation. This section will dwell into the engineering and business benefits of HFD as it relates to the area of drilling in the Oil & Gas domain and as implemented within the context of the SigmaStream data platform. All of these use-cases presuppose the extensive utilization of AI algorithms using HFD.

5.1 Connection make-up and breakout torque (MUBO) detection

Torque and RPM channels from the top drive are available via the EDR at 1 Hz frequency. This sampling rate is not enough to capture, in sufficient detail, an event that lasts a few seconds. Iron Roughnecks and/or CRT (Casing Running Tool) should routinely collect HFD to fully and accurately capture connection and operating torque values. The included figures demonstrate the tremendous benefit of capturing torque and RPM at 250 Hz from the top drive (a SigmaStream Banyan platform capability via the DigiSub) over the traditional 1 Hz data available from the EDR. The red and blue dotted lines represent the EDR channels.



For instance, a best practice threshold of $\pm 10\%$ of full scale or ± 2000 ft-lb, whichever is less for Surface Rotary and Joint Makeup/Breakout Torque, would be virtually impossible without access to HFD.

5.2 Rig operation automation

The premise of automating rig operations is predicated upon the awareness of the current rig operational context. SigmaStream calls these Operational Events and offers the automated detection of 18 Basic, 7 Macro and the following Complex Operational events, all based on the use of HFD and low frequency data, by AI logic.

- Speed
 - Tripping In
 - Tripping Out

- Casing running
 - Liner Running
 - Open Hole
 - Cased hole
- Drag
 - Pick-up
 - Slack-off
- Friction factor (in development)
- Connection
 - Weight to weight
 - Weight to slips
 - In slips
 - Slips to weight
- Flat time per stand
- Drilling only time
- Bit-On-Bottom-Time (BOBT)
- Automatic WOB (in development)

The data channels used by these algorithms are listed below along with the desired frequency.

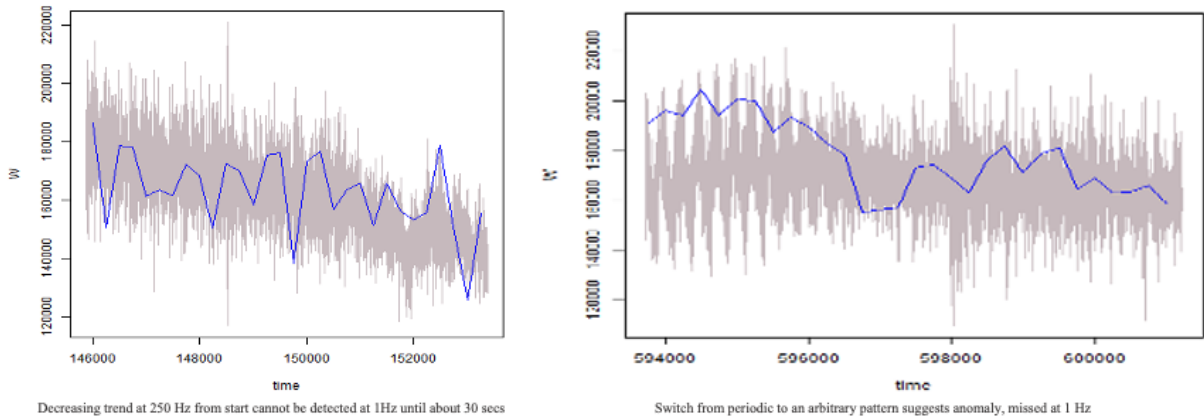
- EDR (1 Hz)
 - 30-40 channels
 - DD/MWD/LWD (optional)
 - Tool-face
 - Magnetic
 - Gravity
 - Survey
 - LWD – GR, Res, etc.
- Rig Operating System (~20 Hz)
 - Torque
 - Rotary Speed
 - Auto Driller
 - On/Off
 - Mode and Set Point
 - ROP
 - WOB
 - Delta T
 - Delta P
 - WOB
 - WOB set point
 - Rotary speed set point
 - TD RPM set point
- Surface Dynamic Sub (~100 Hz)
 - Tension (alternative to *deadline* measurement)
 - Torque
 - Acceleration
 - X axis
 - Y axis
 - Z axis
 - Battery life (voltage)

- Electropject DigiSub (250 Hz)
 - Tension
 - Torque
 - Current
 - Voltage
 - Downhole Observer (model)
 - Stick-Slip level
 - Along drill-string torque
 - Along drill-string RPM
 - At bit torque
 - At bit RPM
- Downhole Dynamic Sub* (~50 Hz)
 - Torque
 - Tension
 - Bending Moment
 - Acceleration
 - X axis
 - Y axis
 - Z axis
 - Temperature

**Downhole data will need to be manually aligned with surface data. 50 Hz was the maximum data rate selected to be recorded by the downhole tool based on tool memory and battery capacity considerations.*

5.3 Equipment Condition Monitoring, Anomaly Detection and Predictive Maintenance (PdM)

The fluctuations in the power consumption signal of the top drive, when collected at high and low frequencies offers a stark comparison of what is visible through each lens. The included graphic is a comparison of the same signal captured at 1Hz (blue) and 250 Hz.



The use of AI to accomplish PdM is the next frontier in the Equipment Condition Monitoring (ECM) space. The first step towards a PdM strategy is the detection of anomalies. If anomalies are discrete events or very short time-range events, it is not farfetched to postulate that certain precursors to a given anomaly can be predicted, giving engineers a chance to avert a catastrophic failure or an opportunity to schedule

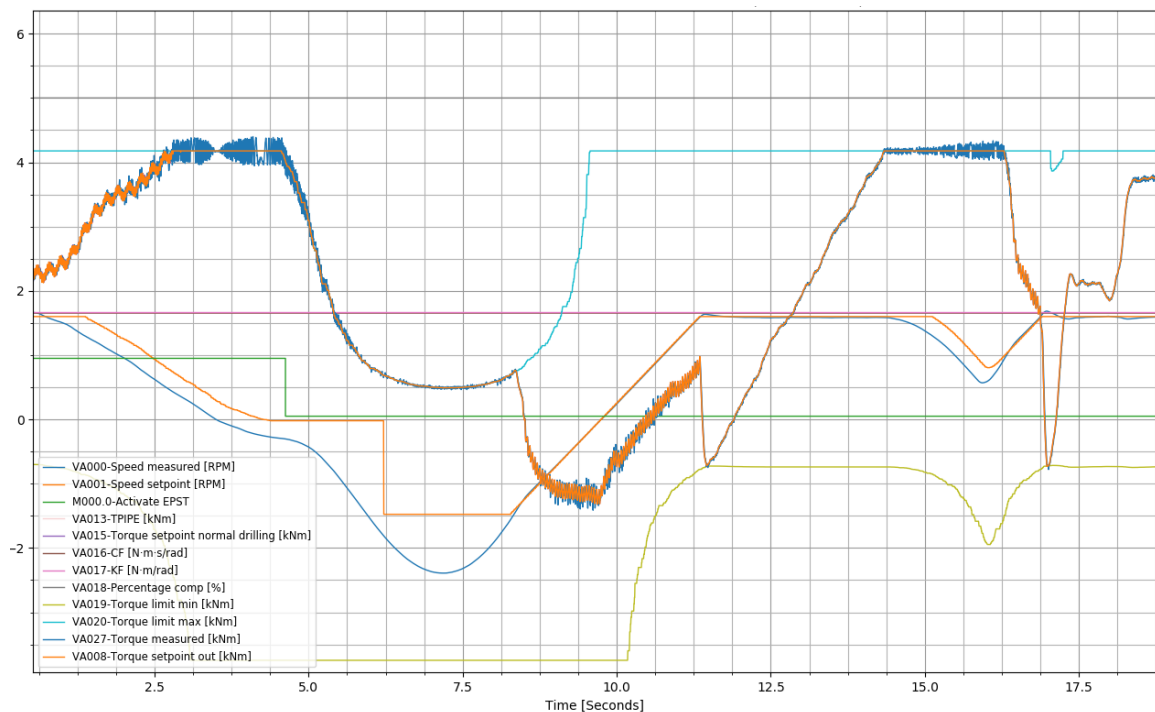
maintenance activities at an appropriate time. As shown in the figures above, anomalous behavior can be detected with a high degree of confidence using HFD.

5.4 Event detection and prevention

Drill string stall and twist off are both major events that bring rig operations to a halt and are responsible for significant expenditures of resources. SigmaStream's Banyan platform clearly demonstrates the value of HFD in the included figures where a *stall* leading up to a *twist off* are clearly visible.



Shown below is yet another example of a top drive stalling that can only be detected using HFD.



5.5 Mud pulse decoding

Despite pressure random noise and signal interferences, generated mud pump pressure fluctuations create notable signal amplitude and frequency variations within the frequency ranges 1–20Hz, commonly used for LWD data telemetry systems (Brackel 2016; Li and Reckmann 2009; Shen et al. 2013a, b). To detect signals at ~20 Hz in the frequency domain a time domain Standpipe Pressure (SPP) data frequency of ~200Hz is required. An advanced MWD/LWD mud telemetry technology that uses continuous pressure wave as opposed to discrete mud pulse, for greater telemetry speeds, will require higher speed time-based SPP (up to 1 kHz level).

6 Conclusion

To construct a digital twin of a system, data at the source has to be sampled at a sufficiently high rate. The more data that is left behind the more dissimilar the reproduced system will be to the original, the more fidelity is lost. Sensors deployed in the fields and at the plants are producing rich, information laden data. There's no dearth of compute or storage. When the directive is to *do more with less*, the industry just cannot afford to leave efficiencies on the table by ignoring HFD.

7 Bibliography

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