Wireless Sensor Technology to Monitor Rod Rotator Performance

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ABSTRACT

Mechanical rod rotators have been used as part of the beam lift artificial lift system since the concept was first patented in the 1930's. By rotating the rods, the frictional wear surface can be distributed around the circumference of the rod, versus on a single side of the rod. By distributing the wear surface, the rod life can be significantly extended. In the same way, the industry has used tubing rotators to derive this same benefit on the tubing, distributing the wear around the inner circumference of the tubing.

One of the biggest challenges associated with operating rotators is being able to confirm that proper rotation of the rods is taking place. The speed of rotation is very slow and is not easily observable without carefully watching the rods for several strokes, and often requires an observer to be very close to the rod string. Because of this challenge, the failure or malfunction of a rotator can go undetected for long periods of time, which often results in premature failure of the rod system, leading to excess cost and downtime.

This paper will explore some of the traditional methods that have been used to monitor rod rotators, including some of the advantages and disadvantages of these methods. It will also introduce a new wireless sensor that is capable of remotely reporting not only the proper operation of a rotator, but also the actual speed of rotation, which is very useful to understand the rotator's performance and to detect progressive failure. Field trial data was gathered as the algorithms were improved to eventually yield accurate monitoring capabilities. This data will be presented, along with several conclusions. This innovative sensor is adaptable to existing rotators and can be easily integrated into existing pump-off controllers, so it is agnostic with respect to the manufacturer of the equipment and will have broad application for rod pump wells in the industry.

INTRODUCTION

Reciprocating rod pumps have utilized mechanical rod rotators since they were first patented in the 1930's. The concept is that if the rod string is rotated during its operation, the wear surface will be distributed around the circumference of the rod, versus being isolated to one side of the rod, thereby extending the life of the rods. In theory, this could extend the life of the rods between 5 to 10 times just based on the expansion of the impacted area. In practice, this has been confirmed to extend rod life substantially as well. The low cost of a rotator compared to the high cost of a rod repair highly justifies its use, especially in wells where failures can be correlated to flat-spot wear areas in rod sections once the rod string is pulled. One of the primary problems with the operation of a rod rotator lies with confirming its proper ongoing operation. Rotator failure rates are quite high, with one California operator reporting that as many as 35% of their rotators are not functioning properly at any given time. Failures most often happen within the gearing and ratcheting mechanism, as well as the handle attachment. Efforts to detect these failures with visual surveillance is difficult, as the rods rotate slow enough to not be easily perceptible, and rod pumps with pump-off controllers are sometimes in an idle state where the operation of the rotator cannot be visually verified. An optimal solution is to employ electronic sensing of the rotation, and automatic reporting of the status through a host or SCADA system so that the rotator can be fixed and restored to proper operation within a reasonable timeframe.

THEORY: ROTATORS AND ROTATION SENSING

Rotators have been in use for many decades, with some progressive improvements, but based on similar methods of operation. The most common rotator used today employs an apparatus that mounts on the polished rod between the carrier bar and the rod clamp, with a pull handle attached by cable to a fixed location on the unit structure. Every downstroke of the polished rod will result in an upward pull on the handle that will employ gears to rotate a cap plate on the top of the rotator. The rod clamp on top of the plate has enough frictional force to also be rotated by the plate, hence turning the entire rod string. The direction of turn is in a clockwise direction (looking from above) so that the rod joints will not unscrew. Some recent improvements in design employ a notch in the rotating cap plate that the clamp fits into, thus engaging a mechanical method of rotating versus just a frictional force (see Figure 1).

Various methods have been used to monitor and detect a potential failure of the rotator. Visual surveillance is the oldest and most basic method, with some operators using a colored mark on the rods to make it easier to observe real-time rotation. As mentioned above, there are many limitations to this method, so electronic methods have been explored over the last decade. Some operators have employed magnets and switches with various mountings to send a wired signal to a pump-off controller at the well. This works much better for tubing rotators than rod rotators because of not having to accommodate anything mounted to a moving sucker rod. However, methods used so far result in tedious mountings and installations, as well as wiring to the sensors that are additional failure points. An integrated intelligent rotator was introduced to the market in the early 2010's that could send a wired signal back to a controller, but it still had the limitation of hard-wired communications as well as not being very economical.

A desired solution would have the following attributes: 1) wireless to remove cables and associated installation cost, 2) ease of installation, 3) adaptable to any manufacturer's rotator, 4) simple integration with existing pump-off controllers already existing at the well site, and 5) low cost so that the device could be widely employed, even on low-producing wells. The theory is that with the proper design, using modern motion sensing and wireless technologies, a "rod rotation sensor" could be designed and constructed. Another important design criteria is reduction of power consumption in a wireless sensor that could last several years between battery changes.

SENSOR PROTOTYPING EQUIPMENT AND TESTING PROCESS

Prototyping was done to meet the design objectives listed in the previous section. The focal point of the initial prototype was to understand how a motion chip could be employed to detect the presence or absence of rotation, and if low-power wireless communications would be reliable enough in the electrically noisy environment of a rod pumping system. Electronics were designed to be strapped to the sucker rod to allow logging of raw data via wireless communications. Several months were spent sampling data from a variety of different wells with different rotators. Because wells operate at different speeds, and rotators have various gearing that regulate how fast a rotator spins, it is important to sample enough data to produce a design that can accommodate these variables.

An interesting observation is that in the seven initial candidate wells that were chosen (across three different operators), three of the rotators were in a non-operational state upon arrival to install the sensors, without the operators having any knowledge of those failures. While this is a small sampling of wells, it does give credence to the high rotator failure rates that operators have cited. One of these original seven wells also had a rotator failure in the middle of the pilot.

One of the unexpected challenges is in the optimal way to mount the sensor to the polished rod. The sensor can really be mounted anywhere on the polished rod that would not have any mechanical interference, including above the rod clamp, or even below the carrier bar (see Figure 2). In field testing, plastic zip ties were used for ease of installation. U-bolts are another option but take much more time to install. For ease of installation, a quick clamp would be desirable, and more design iterations are underway to provide that.

After sampled data was studied, additional prototyping was done using a microprocessor in both a “sensor” that is attached to the polished rod, and a “receiver” component that is mounted inside the pump-off controller (POC) enclosure (see Figure 3). The sensor is able to process raw readings and communicate those wirelessly to the receiver for additional processing. The receiver then produces analog output signals that can easily be wired into the analog inputs of a pump-off controller. It was desirable to have an analog signal that could report the status of the system (rotation OK/Bad, communications OK/bad, etc), and another analog output that would indicate how fast the rods were rotating (degrees per minute). There is also a digital output in the receiver that can simply report an “OK” or “Bad” status if a spare analog input is not available in the POC. The states are described in Figure 4.

To preserve battery life, the sensor would wake up periodically to sense motion, report its findings, then go back to sleep. Design calculations confirmed that the sensor could do this reporting every 15 minutes and still have a 5-year battery life, meeting a key objective.

Final prototype units were built and installed on the original seven wells, with many field adjustments made to the firmware to provide reliable rotation detection and to eliminate false positives. The exact logic used to properly detect and calculate position and velocity is intellectual property and therefore outside the scope of this paper.

DATA AND RESULTS

After the basic operation of the sensor was established through prototyping, the focus shifted towards interfacing the equipment with the pump-off controller, and how the data being collected could be effectively shared with an operator, including indication of fault conditions. The sensor was interfaced with three leading manufacturers of controllers (ChampionX, Lufkin, and Weatherford), which all work in a very similar way. Once the analog signals were wired to the I/O terminals, proper scaling was configured in the controller.

Most SCADA systems will accommodate these inputs for trending and alarming to provide the full functionality needed to support the sensor. In our testing, we used XSPOC™ host software to trend the sensor data. Figure 4 shows the trends of sensor status and measured rotational speed. The state has different values to indicate the condition of the sensor at the time of the last sampling including vertical motion with rotational motion (value=30), no vertical motion but were rotating previously (value=28), vertical motion but no rotation motion (value=6; could indicate broken rotator), and no communications from sensor (value=0). These values give a full reporting on the health of both rotation and the sensor itself. The values can be associated with text in a host system, so the user receives a straightforward explanation of the condition.

The rotational speed is not absolutely necessary to report back to a host system and is considered auxiliary information. The state of the sensor will already indicate if rotational motion is detected, but the rotational speed could be useful to understand how many rotations are being made per time period, and could also help to determine if something is starting to degrade the rotator, such as the wearing of the gears. In this way, the rotator could be repaired or replaced before it completely fails.

In Figure 5, this is a well that cycles on and off via normal pump-off control operation. It can be observed that every time the well goes into an idle (off) state, the rod rotational velocity goes to 0, and the rotational state goes to 18. The state of 18 indicates that even though the rods are not rotating, that is OK because the rods are not moving vertically either. So this is not a state indicating any problem. Also noteworthy, there was a short time period where the state went to a value of 0, indicating there was an intermittent communication problem. Finally, noted in this graph is a rotational velocity that has lots of variation (reported in degrees per minute) between cycles. This variation was caused by some noise and some improved algorithms were later introduced to reduce this erroneous variability.

In Figure 6, it is observed that upon entering this time period there was a problem with communications (state of 0) due to a defective battery. Once that was addressed, proper operation of the sensor was restored. This is a well that normally runs 24 hours per day, but did have some manual shutdowns during the period which are easy to see in the graph. But the rotator is operating fine.

Finally, in Figure 7, we have an example of a failed rotator, so the state was 6. Once the rotator was repaired, the sensor indicated proper operation had been restored. Some time later, we see a value of 6 again, indicating that this rotator may be suffering from an intermittent issue and should be inspected.

CONCLUSIONS

The rotation sensor system proved that a wireless solution could be utilized to monitor and report the proper operation of a rod rotator. All of the other original design objectives listed earlier were all met as well. Packaging and deliver of a cost-effective production version of this sensor was made available to oil producers in 2022.

For future expansion of capabilities, other sensors in the vicinity of the wellhead could be incorporated into this same receiver to provide an array of wireless monitoring of critical components in the pumping system.

ACKNOWLEDGEMENTS

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REFERENCES

- Patent US1749722A, original rod rotator patent granted in 1930
- SPE 16198 A Study of the Methods for Preventing Rodwear Tubing Leaks in Sucker Rod Pumping Wells by K.P. McCaslin, Sun E&P Co.

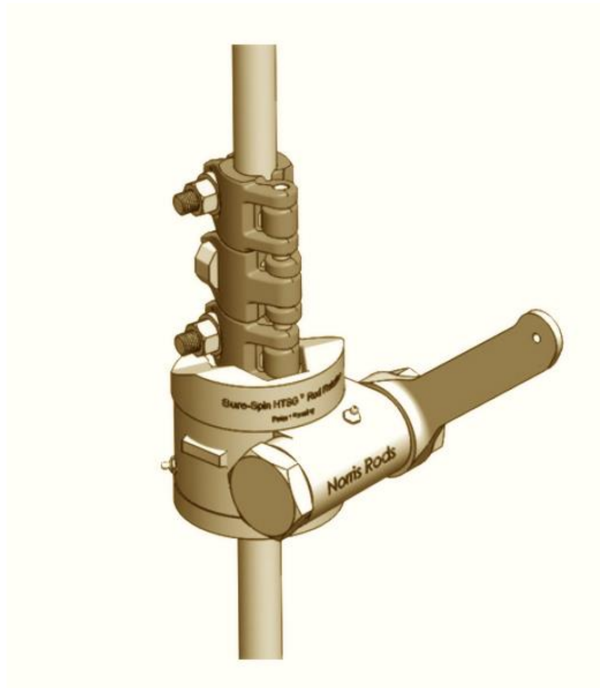

Figure 1. Rod Rotator and handle with rod clamp above

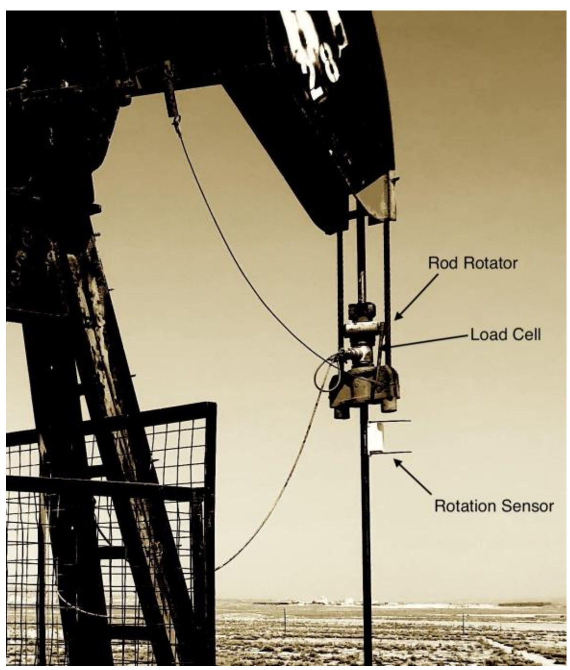

Figure 2. Rotation sensor installed on polished rod

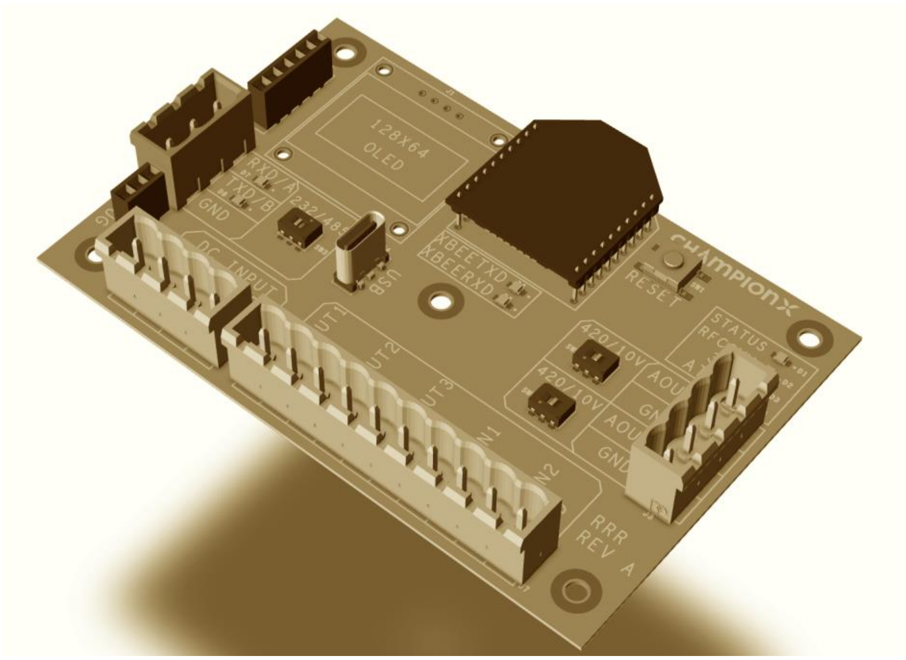

Figure 3. Rotation sensor receiver

Sensor Value	Rotation State Meaning
30	OK, well running, rods rotating
22	OK for now, well running, no rotation noted, but hasn't gone long enough to report it yet
18	OK, well is not running, but was rotating when last running (Any value less than 16 indicates a problem)
6	PROBLEM, well is running and no rotation is noted (but communications is OK)
2	PROBLEM, well is not running but no rotation was noted when it last ran (but communications is OK)
0	PROBLEM - communications is bad so rotation state is unknown, could be a bad battery or radio malfunction

Figure 4. Rotation state values and meanings

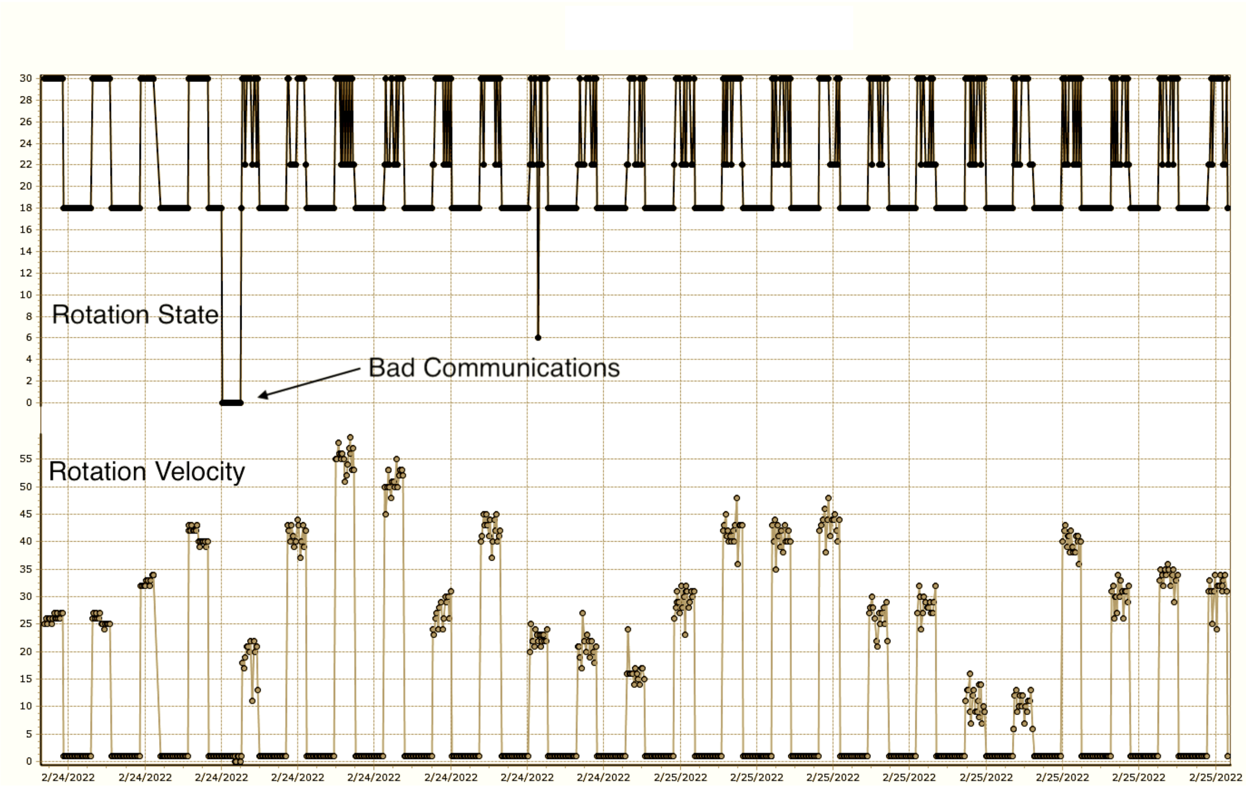

Figure 5. Rotation sensor data from XSPOC™ Host, cycling well

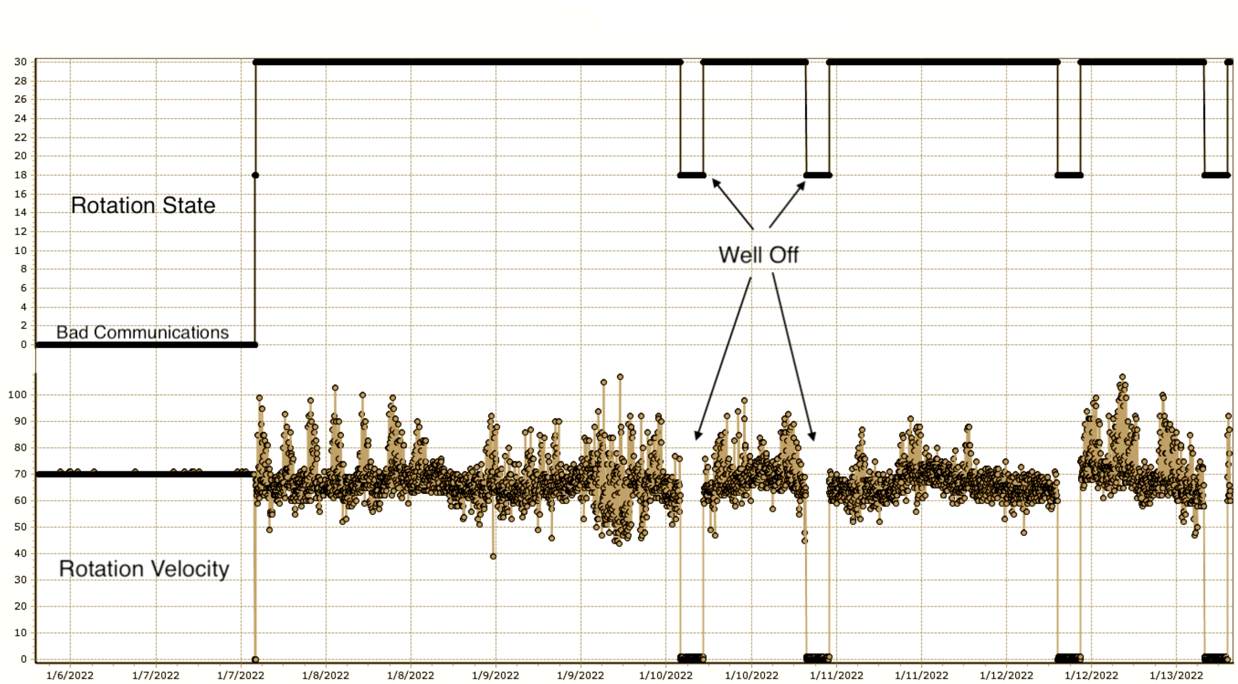

Figure 6. Rotation sensor data, well with intermittent shutdowns

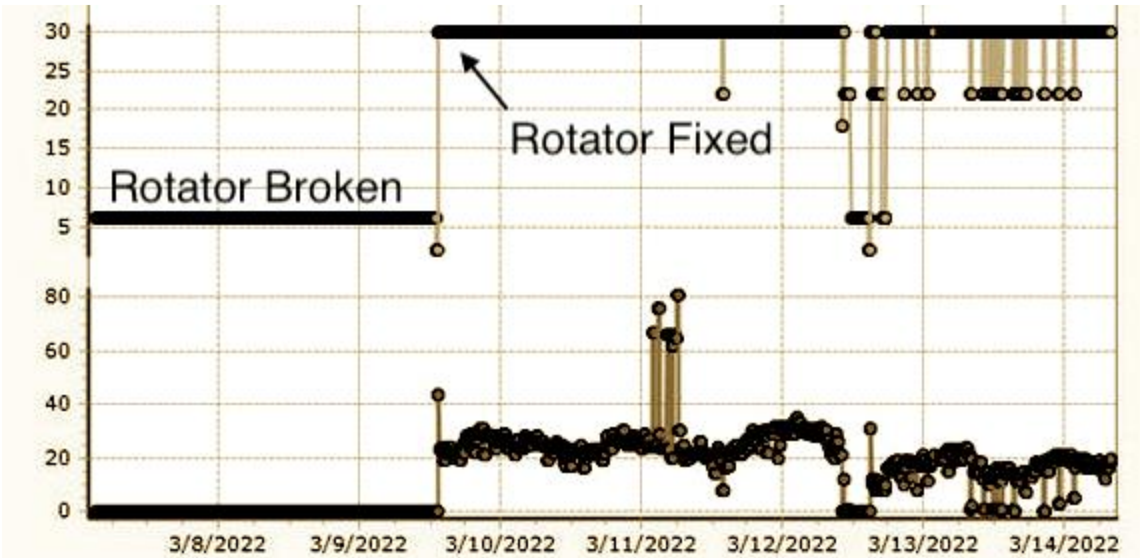

Figure 7. Rotation sensor data, rotator broken then fixed