Determination of lower sucker-rod breakage in wells equipped with sucker-rod pumps

A S Galeev, G I Bikbulatova, Y A Boltneva and S L Sabanov

Almetyevsk State Oil Institute, 2, Lenina Street, Almetyevsk, Republic of Tatarstan, 423450, Russia

E-mail: mailto:ssgaleev@mail.ru

Abstract. Development of mature oilfields of the Ural-Volga region is performed primarily by means of downhole sucker-rod pumping units (UShSN). The most characteristic failures of these installations are breakdowns and twist-offs and pump valve failures [1-5]. The ways of the elimination of these accidents vary significantly: rod breakage or twist-off implies pulling out of downhole equipment, and elimination of "sticking" of the pump's shut-off valve assembly requires rehabilitation of downhole equipment through flushing with water, hot petroleum or a solvent. Failure to identify a malfunction leads to incorrect planning of wellbore equipment rehabilitation activities and, eventually, to economic losses. The cause of downhole equipment malfunctions is usually determined through analysis of dynamometer cards (DC). However, in the majority of cases, the dynamometer cards do not allow to distinguish the rods' tail end twist-off from the rod pump valve failure. In the paper presented the method is considered for rapid detection of rod breakage and twist-offs (RBT) in the wellbore, which involves creation of an electrical circuit "rod string - tubing string" and monitoring of its integrity. To determine the failure type, the synchronization module measures the system's resistance on the dielectric coupling via an electromagnetic conduit. In case of RBT, the electrical resistance of "tubing - pump - rod string" circuit will be much higher (over 2 Ohm) than in case of absence of this failure (0...2 Ohm).

1. Introduction

Nowadays, sucker-rod pumps operate a significant part of oil-producing wells. These pumps can be divided into two parts: surface motor and downhole assembly.

Control on the technical condition of the surface part does not cause objective difficulties, at the same time, accuracy control of downhole equipment is usually realized indirectly. Such a situation occurs because of the impossibility of visual control, the inaccessibility of downhole equipment and difficult working conditions, for example, the cyclic load of the rod string. In addition, a significant proportion of emergency failures occur because of the rod breakage or back-off (RBB) [1-5].

2. Research objective

Monitoring the technical condition of the downhole equipment is usually carried out by analyzing dynographs (DG).

Dynamometry allows determining the majority types of emergency failures, comparing the received dynagraph with the reference one, and determining deviations in the SPR operation.
However, despite the known advantages of this method, there are also certain disadvantages, since the technical condition is evaluated using indirect parameters. One of the significant drawbacks is the practical difficulty of determining the lower RBB, which graphically coincides with the disrepair of the SPR valves.

The error in fault recognition results in incorrect planning of work to repair the downhole equipment. Thereby, there are extra costs associated with downhole equipment "recovery" (washing with water, hot oil, solvent).

3. Proposed solution

Figure 1. The lower RBB detection device. 1 - the source of the stabilized current, 2 - contact to surface part of string, 3 – metallic rod string, 4 - receiving electrode, 5 – tubing string, 6 - voltage change registration unit, 7 - separator of known electric resistance, 8 - well pump, 9 - dielectric material sealing, 10 – centralizing scraper from dielectric material; dash line shows the created electrical circuit.

For detecting the lower RBB, we suggest the following [6, 7] (Figure 1): at the wellhead, by using a stabilized current source the constant stabilized current $I_{stab}$ is delivered to the wellbore. The stabilized current source connected by one contact (with clasp) to the surface part of the rod string, and with other (with clasp) to the receiving electrode at the wellhead, for which a tubing string is used, that creates a potential difference $U_{divide}$ at the ends of the ohmic resistance, which separates the metallic electrical circuit and has a finite known resistance $R_{divide}$:

$$U_{divide.} = R_{divide} \cdot I_{divide}$$  \hspace{1cm} (1)

Herewith, the voltage at the wellhead $U_{downhole}$ (at the source of stabilized current) is equal to:

$$U_{downhole} = \left( \frac{R_{divide} \cdot R_{fluid}}{R_{divide} + R_{fluid} + R_{kko}} \right) \cdot I_{stab}.$$  \hspace{1cm} (2)

where $R_{kko}$ is the resistance of the rods string, pump, and tubing,
$R_{fluid}$ is the resistance of the reservoir fluid in annular space between the tubing string and the rod string:
where $\rho$ is the specific resistance of the formation fluid (oil+water), $D_{in}$ and $d_{out}$ are the diameters of the inner tubing string and the outer rod string, respectively, $H$ - the length of the rods string from wellhead to the pump.

Moreover, if there is no lower RBB, the resistance of the entire circuit is equal to:

$$U_{\text{downhole}} \approx R_{\text{divide}}$$

Since the $R_{\text{amount}}$ is small: $R_{\text{amount}} \ll R_{\text{divide}}$, and as the tubing and rod strings are metallic and have a larger cross-section (more than 150 mm sq.), also as the $R_{\text{fluid}}$ is large: $P_{\text{fluid}} >> R_{\text{divide}}$, since the resistivity of water-oil mixtures is close to oil conductivity and greater than 10 -10 (Ohm.m).

4. Experimental result
The purpose of current flow simulation through the "tubing-rod" channel was to justify the possibility of its use in wells equipped with SPR.

The unit consists of 4 coaxial conductor models, an analog of the "tubing - rod" channel which are metal tubes of a certain diameter and length.

Inside each tube (model), there is a coaxially installed metal (copper) wire of a certain diameter, centered with the use of dielectric centralizing plugs (Figure 2). Each tube has a rubber plug with a hole through which a wire passes and connects to give a signal.

Impulse registration was performed using a two-channel oscilloscope GW Instek gds-71042:
- channel A - signal control at the entrance to the tube,
- channel B – signal control at the exit from the tube.

To evaluate the wave resistance of a coaxial "cable" filled with air, the first series of tests were performed without filling the annular space. For convenience, the impulse frequencies were combined in the 1 . . . 5 GHz and 6 . . . 10 kHz lines.

It is found that at these frequencies the wave resistance does not affect the signal passing and the air is an ideal dielectric.

In the second part of the experiment, the pipes were filled with distilled water.
It is found that the conductivity of the distillate is significantly higher; accordingly, the output signal is ~20% less, regardless of the model number. Also, different frequency signals endure the same blanking (within the measurement error, 5%).

In the third part of the experiment, the pipes were filled with fresh water.
For freshwater, the complex resistance (ohmic + capacitive) is significant and there is a sizable signal blanking (from 3.5 times for model 1 to 11 times for model 4), regardless of the signal frequency. At the same time, we can see that the 6...10 kHz line is blanking more.
The experiments have shown the possibility of using a current flow through the "tubing-rod" channel to control the integrity of the electrical circuit and the rod string, respectively.

### Table 1. Experimental results

| Trial model No. | Pipe diameter, mm | The signal amplitude at the exit, B |
|-----------------|-------------------|-----------------------------------|
|                 | 6.2               | 10.3                              |
| Filled with air | 8.8               | 8.8                               |
| Line 1…5 GHz    | 8.8               | 8.8                               |
| Line 6…10 GHz   | 8.8               | 8.8                               |
| Filled with distilled water | 6.8 | 6.2 | 6.4 | 6.4 |
| Line 1…5 GHz    | 6.4               | 6.2                               |
| Line 6…10 GHz   | 6.4               | 6.2                               |
| Filled with fresh water | 2.4 | 1.2 | 2.2 | 1.0 |
| Line 1…5 GHz    | 2.2               | 2.2                               |
| Line 6…10 GHz   | 1.0               | 1.0                               |

5. **Results discussion**

When the lower RBB occurs, the electrical resistance of the "tubing-pump-separator-rod string" circuit will increase sharply, because at that moment:

\[
R_{amount} \rightarrow \infty
\]  

which will cause a synchronous increase at the \(U_{borehole}\) to maintain the \(I_{stab}\), that means:

\[
U_{borehole} \cdot I_{stab} \rightarrow R_{divide}.\]  

This will serve as a criterion for detecting the lower RBB.

Accidental closures of the rods string during bends (for example when going down), and consequently, the resistance drop to almost zero,

\[
R_{divide} \rightarrow 0
\]

do not affect the reliability of lower RBB determining by this method, since the synchronization block which is included in the wellhead block is configured to register an increase in resistance of the circuit quite more than \(R_{divide}\).

6. **Approval**

Practical tests were performed in 3 wells: 68A; 4051; 2823 of the Yelnikovsky oil field with a preliminary cause of failure-breakage of the rod.

Well 68A of the Yelnikovsky field. The operator found that there was no flow in the well. After the flow test (according to the dynagraph the loads were about 3 tons), it was decided to perform an unscheduled washing with hot oil. After flushing the flow at wellhead did not appear, the dynagraph also was showing non-working valves (loads after washing with hot oil were about 2.5 tons). It was quickly decided to invite a workover crew.
Before lifting the pump rods, the resistance of the rod string-pump-tubing string circuit was measured. For this, one of the contacts was fixed on the rod string, the other contact was attached to the BOP. The insulation resistance was 3.79 m\(\text{Ohm}\) which means a possible rod breakage.

During the lifting, a break on the joint between the 95 and 96 pump rods was found. The reason for the break was the high dogleg severity in this section. After lifting of downhole pump equipment, a pump of the previous standard size (H-57) was run in hole, and in the high dogleg severity interval was equipped pumping rods with centralizers. The economic costs associated with hot oil washing, as well as excessive downtime of the well could be avoided if the lower breakage of the rod was detected timely, which is impossible to determine from the dynagraph.

Well 4051 was stopped in February 2019 with no flow. According to the dynagraph (Figure 4) we can see that both valves are not working. After fracking in May 2018, well’s operating time was 212 days. After washing the well, the pump did not work, and it was decided to set-up a workover crew.

Well 4051 dynagraph
During measuring the isolation of the «tubing-pump-rod string» system, the isolation resistance was 0 Ohm which shows that there is no rod breakage. The lift of downhole equipment proved the absence of break.

Well 2823 was stopped with no flow in September 2018. According to the dynagraph, the pump valves were not working. The well was flushed with 30 m3 hot water. After flushing, the flow at the wellhead did not appear and it was decided to put the workover crew on this well.

During the measuring of the isolation resistance, it was close to 0 Ohm, which shows that there is no rod breakage. After lifting the downhole equipment, a break of the plunger was found at a distance of 50 cm from the discharge valve.

7. Conclusion
Today rod breakage and back-off (RBB) are the main problems of rod pumps. The reasons for this equipment failure may be different: abrasion of the rod string on the tubing string due to wellbore deviation, too large dynamic loads on the rod string for various reasons from deposits of asphalt, resins, and paraffin deposits before sticking of the plunger in the pump cylinder. All breakage failures of the rods are associated with an increase in the specific load per unit cross-section area of the pump rod.

All the "problems" of SPR downhole equipment can be easily recognized through dynamometry. However, it is difficult to determine the lower RBB from the dynagraph which almost does not differ from the non-working valve of the SRP. The error in fault recognition results in incorrect planning of work to repair the downhole equipment. Thereby, there are extra costs associated with downhole equipment "recovery" (washing with water, hot oil, solvent).

To determine the RBB via the electromagnetic channel, the synchronization unit measures the system resistance on the dielectric insert. In other words, if RBB is detected, the electrical resistance of the “tubing-pump-rod string” circuit will be much higher than in the absence of this failure.

The disadvantage of this method is that pumping rod string can contact the tubing string in the intervals high deviation which leads to the closure of the electric circuit “tubing-pump-rod string” before the dielectric separator. This significantly reduces the reliability of the channel, the solution to this problem can be the use of pumping rods with plastic scrapers.

This performing of RBB diagnosis will eliminate costs for "unnecessary" interventions of "well recovery" and lower downtime of well equipment due to the timely set-up of the workover crew if this problem occurs.

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