Simulation in the study of operating experience and application of the latest technology for the repair of rod plunger pumps

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Abstract. Insufficient attention has been paid to the issues of repair and increase of the service life of plunger borehole pumps used in the oil production industry. The oil company Bashneft aims to increase the life and the IRP of borehole pumps. For this purpose, a lot of work has been done to analyze downhole equipment failures across the entire stock of oil wells equipped with sucker rod pumps. To repair the plunger pair of sucker rod pumps, all the documents (a technical task and technical conditions for repairs) were developed and the technological process was prepared. For the fields NGDU Ufaneft and NGDU Krasnokholmneft, the best results were achieved by pumps with a landing group (0.06–0.11), and for NGDU Ishimbayneft - pumps with a landing group (0.03–0.06). When repairing a pump, one can choose a landing group (plunger-cylinder), which will increase the service life of a sucker rod pump that has previously worked out its service life.

1. Introduction
In the oil industry, the main stock of wells has been operated by sucker rod pumping units. The main operating element is a deep rod plunger pump. The economic efficiency of oil producing enterprises depends on the reliability of this unit. Therefore, improving the performance of downhole plunger pumps is a key task to reduce the cost of oil production [1].

2. Results
The reliability of borehole plunger pumps has increased over the past 10 years. If the inter-repair period t(IRP) did not exceed 300 days, currently it has reached 400 days or more. This is due to the use of advanced technologies in the manufacture of pumps and improvement of technology and quality of service during the operation of pumping units. Until now, insufficient attention has been paid to the issues of restoration and increase of the service life of plunger borehole pumps used in the oil production industry. The oil company Bashneft aims to increase the life and the IRP of borehole pumps. For this purpose, a lot of work has been done to analyze downhole equipment failures across the entire stock of oil wells equipped with sucker rod pumps. Data on failure modes of downhole equipment of one of the NGDU ANK "Bashneft" are summarized in Table 1 [2].
Table 1. Types of downhole equipment failures at NGDU "Tuimazanieft"

| Types of failures                                    | Number | %  |
|-----------------------------------------------------|--------|----|
| Broken rods                                         | 185    | 23.3|
| Lapel rods                                          | 259    | 31.3|
| Polished stem flap                                  | 84     | 10.1|
| Breakage of tubing                                  | 4      | 0.5 |
| Leakage of tubing                                   | 38     | 4.6 |
| Pump failures due to wear of valve pairs and wear of a plunger pair | 261    | 30.4|
| Well stock                                          | 831    | 100 |

Table 1 shows that pump failures account for 30.4% of the total number of failures. When considering the raised pumps, it was found that 72% of cases are worn or waxed valves and seized plungers, 18% - worn plunger pairs. Therefore, it was decided to repair pump plunger pairs (plunger-cylinder) and valve pairs (seat-ball) [3]. Economic calculations confirmed the inexpediency of repairing the valve pair, instead of replacing it with a new one. But a prerequisite for this is an incoming control and a tightness test on a vacuum tester. To organize the repair of the plunger pair of sucker rod pumps, all the documents (a technical task, technical conditions for repairs) were developed. To optimize repair costs, taking into account the large volume of accumulated pumps, RT-61701 high-performance machines for honing (mechanical processing of cylinders), a stand for straightening cylinders, a plunger with a force of Q = 60 kN, a washing unit, a shaft furnace SShTsN-10-60/9 for heat treatment of the cylinder, a machine for thermal spraying of the plunger, a pump test bench were installed [4].

Considering that the most critical unit of the pump is a plunger pair (cylinder-plunger), Tables 2, 3 show the technological processes of repairing the cylinder and plunger of a NN-44 submersible pump.

The sucker rod pump cylinder is one of the main parts that is of paramount importance. Therefore, operations 005, 006, 007 are performed on a unique honing machine with a bed length of 12 m, grade RT 6171. The final honing operation is performed with a honing head filled with 125×12×6 mm diamond stones LS6 80/63 100-M-2. The size of the allowance to be removed during finishing is 0.03 mm and the resulting roughness of the cylinder working surface is not less than R 0.32, which is checked with a special device manufactured by the Mitugoit company and by comparison with roughness samples [5].

Taking into account the 005 technological process, the honing operation restores the correct geometry (cylindricality) of the cylinder. In addition, there is a removal from its working surface along the entire length of ulcercative corrosion damage. Next, the thermal nitriding process is performed in the SShTsN10-60 / 9 shaft furnace. At the same time, 36 cylinders are nitride, and for quality control, witnesses are placed in each batch (metal samples from the same material); they are attached to the batch in three places along the length of the cylinders [6].

Nitriding is a process of chemical-thermal treatment, causing saturation of the metal surface with atomic nitrogen, which is formed during the dissociation of ammonia according to the scheme:

\[
2\text{NH}_3 = 2\text{N}+6\text{H}. \tag{1}
\]

The gas nitriding process can be carried out for parts made of structural and alloyed steels such as steel 40X, 40XH, 15XHMA, 38X2MYUA, 25X2M16, etc.

Nitriding is the final process of the heat treatment cycle used to increase the wear resistance and endurance limit of a rod pump cylinder.
Table 2. Technological process of sucker rod pump cylinder repair

| No of the operation | Name of the operation | Name of equipment | Number and short description of transitions |
|---------------------|-----------------------|-------------------|---------------------------------------------|
| 001                 | Detecting             | Detection table   | Reveal a cylinder defect in accordance with TU-366570-001356 45-2000; if there are cracks, washes, reject the cylinder on the working surface |
| 002                 | Washing               | Washing unit O.ADx013109.00.000 | Carry out a wash of the outer and inner surfaces of the cylinder until the complete removal of dirt and corrosion |
| 003                 | Adjusting             | Stand for straightening the cylinder ShGN 0595-158.000 | Adjust the cylinder until the curvature is no more than 0.125/1500 mm or 0.3 mm over the entire length of the cylinder |
| 004                 | Lathing               | Screw-Vintorez machine 1465-5 | Calibrate the thread M56x1.5-6 q at length L = 42s-2 sides |
|                     |                       |                   | 1 - honing a hole with a diameter of 44.45 without unclamping the stones at a length of L = 5530 mm |
|                     |                       |                   | 2 - measure the inner diameter of the cylinder from 2 sides |
|                     |                       |                   | 3 - honing a hole with a diameter of 44.49, ensure the cylindricity of the channel |
|                     |                       |                   | 1 - collect 30 cylinders in a cassette |
| 005                 | Honing                | Honing machine RT-61701 | 2 - measure the inner diameter of the cylinder from 2 sides |
|                     |                       |                   | 3 - honing a hole with a diameter of 44.49, ensure the cylindricity of the channel |
|                     |                       |                   | 1 - collect 30 cylinders in a cassette |
| 006                 | Heating               | Shaft furnace SShTsN-10-60 / 9 | 2 – nitride the surface "B" to a depth of h = 0.2-0.3 mm, achieve a hardness of 800 - 950 HV |
| 007                 | Honing                | Honing machine RT 61701 | 1 – honing the cylinder to a depth of h = 0.03 mm along the length L = 5530 m |
|                     |                       |                   | 2 – honing a hole 44.52 |
|                     |                       |                   | 1 - mark the font size PO-5 GOST 2930-82 by striking |
| 008                 | Locksmith             | Marking table     | 2 - cylinder serial number |
|                     |                       |                   | 3 - nominal cylinder diameter |
|                     |                       |                   | 4 - date of cylinder repair (month, year) |
|                     |                       |                   | 1 - control of dimensions according to drawings |
| 009                 | Controlling           | Control bench     | 2 - roughness control should be ≤ Ra 32 |
|                     |                       |                   | 3 - control of the hardness of the nitrided layer (on the sample) 800 - 980 HV |

Taking into account the experience of chemical-thermal treatment of tractor engine cylinder liners at NPO VNIITMASH, PO Chelyabinsk Tractor Plant, and the OZNPO ANK Bashneft plant, a cylinder working surface hardness of up to 1100 HV was achieved. These results were achieved by alternating saturation and diffusion holding cycles. Nitriding was carried out at a temperature of 510-530°C in a two-stage regime. The two-stage supply of ammonia made it possible to reduce the duration of the heat treatment process by 15% and the consumption of ammonia by 40%; the data are given in Table 3. Then the pump plunger is repaired. The technological process of plunger repair (Table 4) represents the classic sequence of operations, which are carried out with thermal spraying.
Table 3. Two-stage heat treatment mode

| Saturation period | Diffusion period | HV | Effective layer thickness $h_s$, mm | Total layer thickness $h_n$, mm |
|-------------------|------------------|----|-------------------------------------|-------------------------------|
| $\pi_n>1.5$       | $\pi_n<0.3$      |    |                                      |                               |
| 520 °C 6 hours    | 1103             | 0.25 | 0.4                               |
| 24 hours          | 1022             | 0.35 | 0.4                               |
| 520–560 °C        | 1066             | 0.45 | 0.5                               |
| 6–18 hours        | 1003             | 0.5  | 0.6                               |

Table 4. Technological process of sucker rod pump plunger repair

| Operation number | Operations            | equipment identification | Number and short description of transitions |
|------------------|-----------------------|--------------------------|---------------------------------------------|
| 005              | Blanking              | Control and location stand | Perform troubleshooting of the plunger according TU366570-00135645-2000. Reject in case of cracks of any nature and location, washing. |
| 010              | Adjusting             | Straightening stand Q = 6 t | Adjust the plunger until a curvature of no more than 0.05 / 1200 mm is obtained. 1. Calibrate the M38 x 1 thread. 5-6H with a tap along the length $L = 30$ from 2 sides $Dor = 37.026$ |
| 015              | Lathing               | Screw-cutting lathe CA562 C200 | 2. Grind the outer surface to Ø 42 along the length $L = 30$, clean. 3. Grind the outer surface to Ø 42. 4 at $L = 1140$ mm, clean. |
| 020              | Shot blasting         | Shot blasting machine OB-85 | Blast the outer surface of the plunger |
| 025              | Thermal spraying      | Spraying unit TRG-3, rotator | Spray the outer surface with powder PRNKh16SRZ TU14-1-3785-90 up to Ø 45.2 at $L = 1140$ mm |
| 030              | Floating              | Burner G-2-04 GOST1077-79 | Melt the sprayed surface to obtain the phenomenon of "fogging" |
|                  |                       | Screw-cutting universal lathe SA-5622S-200 | Groove 4 grooves keeping dimensions R 1; Ø39. 5; 5 and sizes 120; 320; 320 × 3 = 960 mm. |
| 035              | Lathing               | Round machine grinding 3M175 | Grind the outer surface to Ø 44.5 over $L = 1140$ mm. |
| 040              | Grinding              | Marking table            | Mark with the font size PO-3 GOST 2930-82, serial number, nominal diameter 1. Control the dimensions according to the drawing. 2. Surface roughness. 3. Control the hardness. |
| 045              | Locksmith             |                          |                                             |
| 050              | Controlling           | Control bench            |                                             |

Wear-resistant powder PNx16S4R brand is used as a spraying. The powder consists of nickel and contains 16% chromium, 4% silicon and boron. The spraying process is composed of two stages: coating spraying and fusing. As a result of spraying, a hard (900-1000 HV) wear-resistant coating is
formed on the plunger surface, which must be machined to obtain the required dimensions and roughness [7]. The technological process of plunger repair is completed by grinding the working surface of the plunger on a CA562C200 screw-cutting lathe for mating the plunger with the cylinder.

3. Discussion
The repaired parts, the cylinder and the plunger are subjected to the assembly operation, which is performed on a special stand (Fig. 1).

The assembled pump is delivered and placed for testing on a special bench. It is fixed with crimping yews in three places along the length of the pump, the piping of test pump 5 and the piping of receiving tank 9 are connected. The test is composed of three stages. At the first stage, the plunger is in position I, at the second stage - in position II and at the third stage in position III [8–10]. Using test pump 5, the pressure rises to \( P_{\text{init}} = 18.0 \, \text{MPa} \) and is maintained at \( t = 65 \, \text{s} \), while the pressure should decrease to \( P_{\text{fin}} = 9.0 \, \text{MPa} \); according to the volume of oil leakage through the annular gap (plunger-cylinder) at an oil temperature \( t = 20^\circ \text{C} \), the conjugation group is determined (Table 5).

![Figure 1. Test stand: 1 - test stand; 2 - sucker rod pump pump cylinder; 3 - container with oil M-10; 4, 8 - shut-off valves; 5 - LP pump for hydrotesting; 6 - manometer; 7 - safety valve; 9 - receiving container for oil; 10 - laboratory scales; I, II, III - the position of the plunger in the cylinder](image)

### Table 5. Parameters for determining the mating group of the sucker rod pump assembly during hydrotesting after overhaul

| Group | 1 | 2 |
|-------|---|---|
| Conditio... | | |
| P_{\text{in}} | P_{\text{fin}} | Test time | Leaking pump max – min, cm³/min at \( t=20^\circ \text{C} \) | P_{\text{in}} | P_{\text{fin}} | Test time, sec |
| P_{\text{in}} | P_{\text{fin}} | sec | [min] | [min] | [min] | [min] |
| 29 | 18.0 | 9.0 | 65 | 3.4–0.36 | 18.0 | 6.3 | 65 | 4.3–0.72 |
| 32 | 18.0 | 9.0 | 65 | 4.2–0.48 | 18.0 | 6.3 | 65 | 5.4–0.96 |
| 38 | 18.0 | 9.0 | 65 | 6.2–0.6 | 18.0 | 6.3 | 65 | 7.9–1.2 |
| 44 | 18.0 | 9.0 | 65 | 7.02–0.72 | 18.0 | 6.3 | 65 | 9.0–1.44 |
| 57 | 15.0 | 8.0 | 65 | 9.5–0.84 | 15.0 | 5.0 | 65 | 12.3–1.68 |
| 70 | 12.5 | 6.5 | 65 | 12.1–0.96 | 12.5 | 4.0 | 65 | 15.5–1.92 |
| 95 | - | - | - | - | - | - | - | - |


4. Conclusion
For the fields NGDU Ufaneft and NGDU Krasnokholmneft, the best results were achieved by pumps with a landing group (0.06–0.11), and for NGDU Ishimbayneft - pumps with a landing group (0.03–0.06). When repairing a pump, one can choose a landing group (plunger-cylinder), which will increase the service life of a sucker rod pump that has previously worked out its service life.

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