Compensator-vibration isolator

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Abstract. Nowadays electrical submersible pump (ESP) units remain the main type of formation fluid production equipment. There may be complicating factors during the operation of oil production wells equipped with such units. Complicating factors include the fall of the submersible unit downhole to the bottom of the production well. The damage from such falls is great. Despite the accumulated experience in this area, effective solutions need to be developed. In the work, the sources of vibration in the ESP are noted, and the places of breaks in the unit are indicated. The reasons for the occurrence of vibration processes in a submersible unit are summarized. The authors propose a design of a compensator intended for quenching vibration energy in a submersible unit. To evaluate the effectiveness of the compensator as part of an ESP unit, tests on industrial sites were conducted. At Open Joint-Stock Company Alnas, the test stand was a vertical well. Tests in Almetyevsk Central Base of Electric Submersible Production Service were carried out on a horizontal test stand section by section. Analysis of the results of the tests showed that the use of a compensator can reduce vibration levels.

1. Introduction

Quite often emergencies in electric submersible pump units (ESP) occur in oil production: SD-failures (spontaneous dismemberment) or "falls". This problem of the last decades has not yet been solved radically. The financial damage from the "falls" is great, so any possibility of solving this problem is justified. More than a thousand accidents occur in oil production regions. Even if the average amount of damage per accident is more than 500,000 rubles, the total losses per year will be more than 500 million rubles [1, 2]. At the present stage, some experience has been accumulated in dealing with emergencies, but discussions are still ongoing about the causes and measures to eliminate "falls".

2. Problem statement

The causes of SD-failures are not fully understood at the moment, but the available analysis of operational data suggests that they are mainly associated with vibration processes [3, 4].

Sources of vibration include [4, 5]:

1) the main sources of vibration processes that occur during the operation of equipment that contribute to the development of a critical level of vibration – the wrong choice, wear of working surfaces, the curvature of the wellbore, etc.;
2) additional vibration levels in the ESP unit that occur after repair and assembling works;
3) the permissible level of initial vibration, which is laid down in the unit design of 6.5 mm/s.

Note the places where most often there are breaks in the ESP units (Figure 1):
- connection between the module head and the upper section of the electrical submersible pump,
- connection between the compensator and the submersible motor,
- on the body part of the electric submersible pump,
- on the body part of the protector,
- by threaded connections of the check valve,
- for threaded connections of tubing,
- on flange connections.

The analysis of the operating history of submersible centrifugal units allowed establishing the relation between such indicators as the operating time between failures of submersible units and the distribution of vibration levels.

**Figure 1.** Places of possible breakages of the submersible unit

Many researchers have the same view that falls in the ESP occur as a result of processes such as pressure pulsation and increased vibration of a worn-out submersible pump. This leads to the destruction of the main fasteners and various weak points in the electric submersible pump unit [1]. Wear resistance and strength of the main components of the structure are the most important indicators of the resource and operation of the submersible unit. Structural x-ray analyses, fractographic and other studies of worn parts of details have shown the presence of almost all types of wear mechanisms in electric submersible pumps: abrasive, adhesive, erosive, fatigue and corrosive [6, 7].

To reduce the level of accidents in oil production wells, analysis of the operational history of submersible units indicates that it is necessary to develop devices that reduce vibration levels.

There are two ways to reduce harmful dynamic phenomena: vibration absorption and vibration isolation.

The use of vibration absorbers is one of the most common ways to reduce the level of vibration [8].

The friction element is the main part of any absorber. Friction contributes to the absorption of vibration energy and forced action oscillations are carried out with a smaller amplitude than in the absence of friction. This effect is most noticeable in the resonance area [9].

The units' vibration is common for the operation of oil production wells equipped with ESPs, namely the occurrence of oscillating waves of the longitudinal section in the lifting column of the tubing, which, having risen at the wellhead return to the submersible unit.

The overlap of oscillatory contours of forwarding and reverse waves is dangerous for the occurrence of resonant phenomena, which can contribute to the breakage of the main nodes of the ESP or the lifting column.
3. Research Results
The authors propose a specific design of the compensator installed at the outlet of the submersible unit to extinguish the vibration energy in the ESP and prevent dangerous vibrations in the lifting column.

The design of the compensator (Figure 2) includes housing, friction elements, fasteners. The compensator housing is connected to the tubing using a coupling and an adapter. In the inner part of the housing, there is an eccentric pipe with friction elements. The compensator is connected to the submersible pump unit by a branch pipe. The pipe is connected to the eccentric pipe using a thread. Friction elements are made in the form of cylindrical bushings. The material of these bushings is an oil-resistant rubber. The key locks the bushings from turning the bushings inside the housing. The contact surfaces of the eccentric pipe and the bush are coated with the appropriate lubricant. The presence of radial and longitudinal play of the eccentric pipe is not allowed. Axial play is eliminated by tightening the adapter with the ring until it stops. The presence of oil-resistant rubber rings helps to maintain tightness between the adapter and the eccentric pipe. It is possible to ensure the tightness of the compensator due to the own weight of the submersible unit and the presence of pressure in the ESP. The pressure drop is expected to be maintained at least 200 kgf/cm².

![Figure 2. Radial compensator design: 1 - housing, 2 - adapter, 3 - rings, 4 - rubber bushings, 5 - washers, 6 - eccentric pipe, 7 - connecting pipe, 8 - rings, 9 - coupling](image)

It is recommended to use the radial compensator with the ESP unit. As a drive, it is better to use submersible electric motors with a power of up to 40 kW. The surface area intended for compensation is 308 cm². The compensation torque is 14 kg·m. The axial load is allowed at a value of 2830 kg.

The compensator's principle of operation, designed to reduce the vibration level of the submersible unit, is as follows. During the start of the submersible pump unit's electric motor, a torque occurs. The starting torque is perceived by the friction elements and the eccentric pipe. This prevents twisting of the electric cable of the submersible unit, the possibility of limiting concentration stresses in the pipe column, their breakage, and the permissible limits of starting currents are not exceeded.

If the check valve is omitted due to contamination or de-energization of the electric pump unit, the friction elements and the eccentric pipe perceive the reverse torque that occurs from the rotating masses of the submersible pump unit and the inertial forces of the reservoir fluid column in the tubing column, which in turn prevents the tubing from turning.

To assess the effectiveness of the use (reduction of the vibration level of the submersible unit) of the radial compensator, tests were conducted in Open Joint-Stock Company Alnas and Almetyevsk Central Base of Electric Submersible Production Service in Almetyevsk, Republic of Tatarstan.

Tests at Open Joint-Stock Company Alnas of the compensator intended for lowering the vibration level of the submersible unit were carried out on a vertical automated stand of the VIG-98 series,
which externally simulates a well. During the tests, measurements of vibration, pressure, and energy parameters were made.

The results of the tests carried out on the test station of the Open Joint-Stock Company Alnas of the compensator for lowering the vibration levels of the submersible unit on the V1G series vertical well stand are shown in figures 3 and 4. A submersible sectional centrifugal pump Electric Centrifugal Pump A5-45-2050 type was selected for the experiments.

![Figure 3. Results of Electric Centrifugal Pump A5-45-2050 tests without using a compensator and measuring vibration levels (4.4067 mm/sec)](image)

![Figure 4. Results of Electric Centrifugal Pump tests A5-45-2050 using the compensator and measurement of vibration levels (2.9801 mm/sec)](image)

The following results were obtained during the tests: the vibration level of the submersible unit without the use of a compensator was 4.4067 mm/s (Figure 3), with the use of a compensator – 2.9801 mm/s (Figure 4).

The analysis of the results of measuring the vibration levels of the ESP unit shows that the use of a radial compensator makes it possible to reduce the value of vibration speed.

The deviation of the pressure characteristic of the submersible pump Electric Centrifugal Pump A5-45 during tests without the use of a compensator was mainly 2.73 m, with the use of a compensator - 1 m. A comparison of the results of deviations of the pump pressure characteristics showed that the use of the compensator contributed to the minimum head deviations in contrast to the passport data.

The power consumption of the submersible unit during tests without the use of a compensator was mainly 11.27 kW, with the use of a compensator-10.82 kW.

The efficiency of the submersible unit during tests without the use of a compensator was mainly 15.45 %, with the use of a compensator-15.64 %.
The analysis of the obtained results of energy characteristics showed that the use of the compensator together with the ESP increases the efficiency and reduces the power consumption of the unit.

Tests at the Almetyevsk Central Base of Electric Submersible Production Service of compensator units for lowering the vibration level were carried out on the horizontal test stand of the REDA company. Tests of electric submersible pumps were carried out in sections on a horizontal stand after washing (Figure 5).

During the tests, the pump section and the compensator for reducing the vibration of the submersible unit are installed horizontally on the stand, and the clamping chain devices are tightened to hold the nodes on the stand during the test period. The discharge adapter and the corresponding head are connected to the centrifugal pump. The personal computer is turned on, and the HPTS program is automatically loaded and started. This computer program makes it possible to test the entire range of commercially available electric submersible pumps. The colour printer displays test results with a graphic and tabular image of the power consumed by the unit, the Q-H characteristics, and the efficiency. A horizontal test bench records the vibration level and checks the tightness of the pump section. During steady-state operation of the pump section with a load when measuring vibration levels at three points: REDA company vibration analyzer is used on the base, in the middle of the section and on the head as shown in Figure 5.

![Figure 5. Horizontal test stand of REDA company](image)

The Electric Centrifugal Pump A5-125-1300 pump section, restored after repair work, was selected for testing. A number of stages in the pump's section 131.

The results of the tests on Almetyevsk Central Base of Electric Submersible Production Service of the compensator designed to reduce the vibration level of the submersible unit on the horizontal test stand of submersible pumps of REDA company are presented in tables 1 and 2.

**Table 1. Test results of the Electric Centrifugal Pump A5-125-1300 pump without the use of a compensator**

| Places for measuring vibration levels | Rotation speed of the shaft, amp. |
|--------------------------------------|----------------------------------|
| The head of the section              | 1.524                            |
| The middle of the section            | 2.102                            |
| The base of the section              | 1.452                            |
Table 2. Test results of the Electric Centrifugal Pump A5-125-1300 pump using a compensator

| Places for measuring vibration levels | Rotation speed of the shaft, amp. |
|--------------------------------------|----------------------------------|
| The head of the section               | 1.519                            |
| The middle of the section             | 2.098                            |
| The base of the section               | 1.441                            |

During the tests, the rotation frequency was 50 Hz. The vibration level of the pump section during the tests without the use of a compensator in general was 1.69 mm/s, with the use of a compensator – 1.68 mm/s. A comparative analysis of measuring the vibration levels results of the tested sections of the submersible pump allowed concluding that the use of a radial compensator can reduce the amount of vibration speed.

4. Conclusion

A radial compensator is proposed for the reduction of the vibration levels of the submersible unit and to absorb the vibration processes of the tubing lifting column. The tests of this compensator on the stand - on the well belonged to Open Joint-Stock Company Alnas has shown that the use of the compensator reduced the magnitude of the unit' vibration from 4.41 mm/s to 2.98 mm/s. A comparison of the energy characteristics' measurement results showed that the use of the compensator in conjunction with submersible units allowed reducing the consumed unit power capacity by 4%. The conducted tests of the compensator on the Almetyevsk Central Base of Electric Submersible Production Service horizontal test stand also showed that the use of the compensator reduced the values of the vibration speed of the pump section.

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