

Utilization of expert systems for screw pump sets with surface drive management

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Abstract—Here we deal with the current utilization of screw pump sets with surface drive management. The causes of rod string twisting off are analyzed. We study the mathematical model of functioning of the system “the screw – the rod string, dependence of torque inequality on the length of the rod strings, rod diameter, screw length, screw diameter, screw tightness, pump pressure and others. Also, we suggest using the designed apparatus set with sensors and a controlling system based on powerful, freely programmed panel controller with Linux operational system, that is the complex with expert systems. The control is fulfilled by connecting all sensors and a frequency converter to the soft-based controller, set in the control box. Connecting the soft-based controller to the computer is done through the protocol Modbus TCP. It has the Scada software for controlling screw set drives with the surface drive.

Keywords—screw pump sets, expert systems, modes of operation.

I. INTRODUCTION

Many Russian deposits are in the late or final stage of utilization. In these conditions bore hole fluid is highly viscous and contains asphaltene sediments. Highly viscous and non-Newtonian deposits with low pressure are being exploited. As a result a number of marginal wells increases constantly.

Screw pumps are widely used for utilizing marginal wells with highly viscous oil.

But the life time of screw pumps with submersible motors is short due to high speed of rotation, which leads to equipment wear. That is why screw rotating with the help of rod strings connected to the surface drive is more perspective.

Screw pump sets with the surface drive provide low frequency of screw rotation, which creates favorable conditions deposit utilization.

Also, the nature of exploitation wells crossections, due to the presence of high curve and inclination severely complicates mechanical exploitation. Tubing and rod strings wear in the parts with the highest curvature decreases the work over interval of wells.

II. MATERIALS AND METHODS

Analyzing field data of screw pump sets with the surface drive utilization at “Leninogorskneft”, “Tatneftebitum” the

following conclusions have been done. 12 wells were analyzed, with pumps type 40T-063 and 40T-025, drive rotation frequency 123 and 197 rot/min, exit pressure from 2 to 16 atm, average depth of pump suspension was 900 meters. The most frequent reason for installation default was rod string breakage at the top of the stem. It happens because the upper end of the string is tightly fixed in the drive cramps, that is why, the upper rods are more rigid and less tolerant to the fatigue. Let’s study this process in more details. During the operation of the screw pump set with the surface drive the torque vibration appears, from reductor to the rotor-screw due to the dropping friction coefficient depending on the speed of contacting rotor surfaces and rubber starter holder. Torsion vibrations of the system “screw – stem” cause early fatigue of screw surfaces and a rubber starter holder, fatigue rod breakage, tubing turn-away negatively influence the operation of the whole set in general. [1,2]

According to the results of the research, for reliability enhancement of screw pump sets with the surface drive they should be utilized with drive rotation frequency, exceeding critical speed of rotation, taking into the account that it is not equal for all arrangements of screw pump sets and utilization conditions, and depends on utilization parameters and sets parameters [3-5].

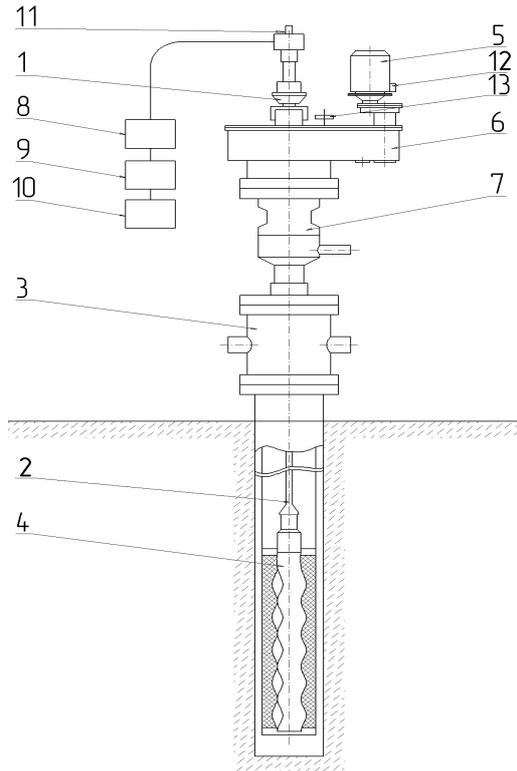
Also the productivity of screw pump sets depends on pumped fluid, whose characteristics can change during a short time.

To control screw pump sets with surface drive, a set with sensors and control system based on powerful, freely programmed panel controller with Linux operational system were designed.

A screw pump set has an electric motor with power 5 kWt, which drives the pump (picture 1). This motor takes power 380 W 50 Hertz. But the set does not have a gear box for speed change. A frequency converter was used to eliminate this drawback (further FC). Its function is to change frequency variation for speed reduction. Also FC has a possibility to control motor speed by sensing electro-motive intensity at one of the fazes. To exclude reductor jamming other function of FC is used – current control.

To control rotation of the polished rod a rotation sensor is used. This sensor is based on the device controlling metal approaching. The controller notes the time between the half

turns. Also, to control torsional vibrations a torquemeter with a pressure sensor was used [6].



1 – torquemeter; 2 – stem; 3 – landing head; 4 – screw pump; 5 – electric motor; 6 – reductor; 7 – stuffing-box preventer; 8 – booster; 9 – programmable controller; 10 – computer; 11 – pressure sensor; 12 – frequency converter with rotation calculation function; 13 – rotation sensor

Fig. 1. The unit to control screw pump sets with the surface drive

A flow-measuring set is on the blow line, as well as pressure and temperature sensors.

The control is fulfilled by connecting all the sensors and the FC to the soft ware controller (SWC) in the control box. Connecting the SWC to the computer is done through Modbus TCP. The computer is with Scada software to control operational modes of screw pump sets with the surface drive [7].

The operation modes are controlled by changing operation parameters of the set (motor rotational frequency, limit values of switching off and so on).

III. RESULTS AND DISCUSSIONS

This complex allows controlling and changing the operational regimes of screw pump set with the surface drive enhancing its productivity and reliability, switching it off in emergency situations, as well as allows controlling the parameters of the extracted fluid.

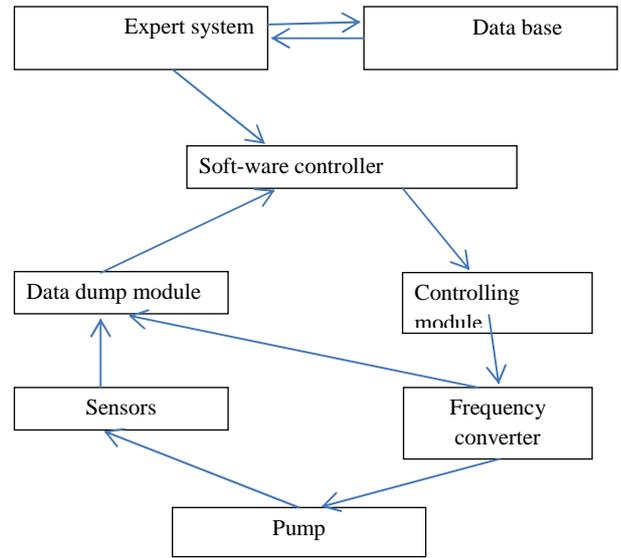


Fig. 2. Expert system

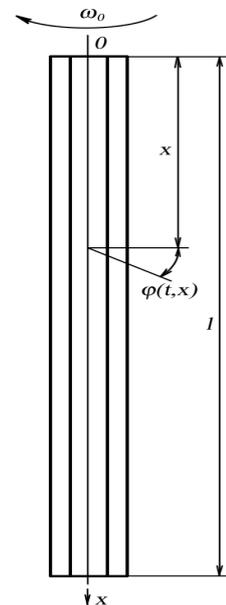


Fig. 3. Design scheme of screw pump set well equipment

The expert system can use the mathematical model of system operation “screw – stem”.

But even with the renewed arrangement a controlling operator is necessary.

For the set to function more effectively and autonomously it is suggested to use an expert system.

Expert systems are widely used nowadays. Fields of application of knowledge-based systems can be classified as follows: medical diagnostics, monitoring and control, fault diagnostics in mechanical and electrical devices, education [8].

The condition of any stem section as a distributed parameters system is determined by its three-dimensional position x , time variable t and angular motion speed of this cross-section $\frac{\partial \varphi}{\partial t}$. Dragging is taken as proportional to the motion speed that corresponds to Newton's law of viscous friction. The presence of lump masses in the form of the bell and spigot joint can be neglected.

Thus, the behavior of the stem can be described by non-uniform partial differential equation:

$$\frac{\partial^2 \varphi}{\partial t^2} = a^2 \frac{\partial^2 \varphi}{\partial x^2} - 2\nu \frac{\partial \varphi}{\partial t}, \quad (1)$$

where φ is stem torque angle, ν is an adduced ratio of viscous friction,

$a^2 = \frac{GI_p}{I}$ is speed of vibration propagation along the stem (G – rigidity of stem matter, I_p – polar moment of inertia of the cross section of rods, I – inertia moment of stem mass relative to the symmetry axis, reduced to the length unit).

The initial conditions are neglected because at the starting time the system “screw – stem” is idle:

$$\varphi(t, x)|_{t=0} = 0, \quad (2)$$

$$\frac{\partial \varphi}{\partial t}|_{t=0} = 0. \quad (3)$$

Limiting conditions:

$$\frac{\partial \varphi}{\partial t}|_{x=0} = \omega_0 = const, \quad (4)$$

$$GI_p \frac{\partial \varphi}{\partial x}|_{x=l} = -M_{kp}. \quad (5)$$

The last condition is based on the law of dependence between the torque M_t and the angle of shaft twisting φ .

The torque is determined by formula:

$$M_t = M_{friction} + M_{extracting}. \quad (6)$$

Frictional torque is determined by formula:

$$M_{friction} = \mu r_{sc} SP, \quad (7)$$

where μ is screw friction coefficient by rubber starter holder; r_{sc} is the radius of a screw section; S is friction area; P is pressure created by a pump.

The dependence is determined by approximating the graph of dependence of screw material friction coefficient over rubber on peripheral speed (picture 4).

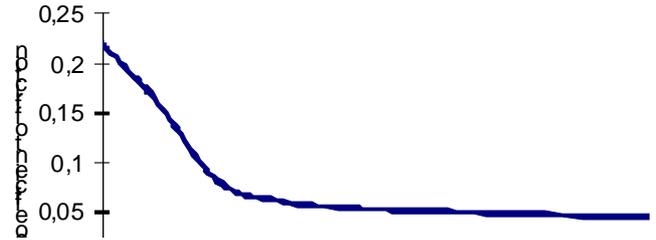


Fig. 4. Friction coefficient dependence on the peripheral speed

$$\mu = \frac{0,07}{\nu + 0,28} \quad (8)$$

$$\text{or: } \mu = \frac{0,07}{\frac{\partial \varphi}{\partial t} r_{screw} + 0,28}. \quad (9)$$

Friction area is equal to the screw surface area, scrubbing a starter rubber:

$$S = 4r_{screw} l_{screw} \arccos\left(\frac{r_{screw} - \delta}{r_{screw}}\right). \quad (10)$$

Substituting expressions (10) and (11) into (8) we receive the torque moment:

$$M_{friction} = 4r_{screw}^2 l_{screw} P \frac{0,07}{\frac{\partial \varphi}{\partial t} r_{screw} + 0,28} \arccos\left(\frac{r_{screw} - \delta}{r_{screw}}\right). \quad (11)$$

Fluid lifting torque is determined by formula:

$$M_{flt} = \frac{\rho_f g HQ}{\omega \eta_v \eta_h}, \quad (12)$$

where ρ_{fluid} is fluid density, m^3/s ; g is gravity acceleration, m/s^2 ; H is pump pressure, m ; Q is fluid pumping rate, m^3/s ; ω is angular propeller speed, rad/s ; η_v is pump volumetric efficiency; η_h is hydraulic efficiency.

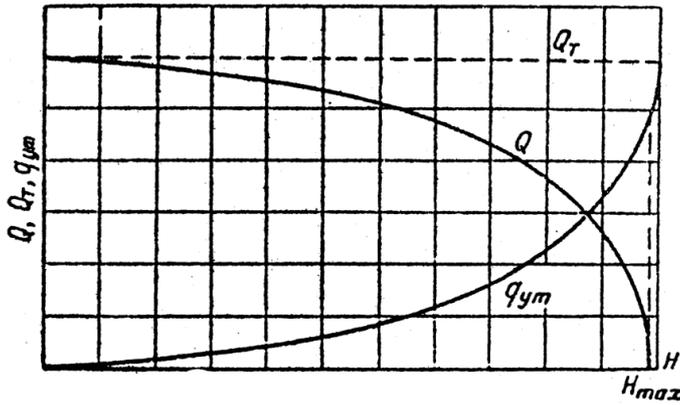


Fig. 5. Single screw pump characteristic

Thrust of pump and pumping capacity are connected by the dependence:

$$H = 4000 - 28Q^2. \quad (13)$$

Pumping capacity is determined by formula:

$$Q = 4eDTn, \quad (14)$$

where e is excentricity, m; D is screw crossection diameter, m; T is pump socket sleeve step, m; n is number of screw speed per second $\left(n = \frac{\omega}{2\pi}\right)$.
(15)

Applying (13), (14), (15) to (12) we get an equation to determine fluid lifting torque:

$$M_{lif} = \frac{\rho_f g [4000 - 28(2eDT\omega/\pi)^2] \cdot 2eDT\omega/\pi}{\omega\eta_v\eta_h}, \quad (16)$$

$$M_{lif} = \frac{32\rho_{fluid}geDT}{\pi^3\eta_h\eta_v} [250\pi^2 - 7\omega^2(eDT)^2]. \quad (17)$$

The final mathematical model of the system “screw – stem” is the following:

Stem motion equation

$$\frac{\partial^2\varphi}{\partial t^2} = a^2 \frac{\partial^2\varphi}{\partial x^2} - 2\nu \frac{\partial\varphi}{\partial t}, \quad (18)$$

Initial conditions

$$\varphi(t, x)|_{t=0} = 0, \quad (19)$$

$$\frac{\partial\varphi}{\partial t}|_{t=0} = 0. \quad (20)$$

Boundary conditions

$$\frac{\partial\varphi}{\partial t}|_{x=0} = \omega_0 = const, \quad (21)$$

$$GI_p \frac{\partial\varphi}{\partial x}|_{x=l} = -4r_{screw}^2 l_{screw} P \frac{0,07}{\frac{\partial\varphi}{\partial t} r_{screw} + 0,28} \arccos\left(\frac{r_{screw} - \delta}{r_{screw}}\right) - \frac{32\rho_{liquid}geDT}{\pi^3\eta_h\eta_v} \left[250\pi^2 - 7\left(\frac{\partial\varphi}{\partial t}\right)^2 (eDT)^2\right]. \quad (22)$$

The received equations are solved with the help of “grid method”, that is by substituting differential equations by corresponding difference equations, so we get a solution in a numerical view.

One of fluctuating data of system dynamic parameters is their inequality, that is relation of oscillation amplitude parameter to its mean value.

Torque inequality:

$$m = \frac{M_{max} - M_{min}}{M_{average}}, \quad (23)$$

$$M_{cp} = \frac{M_{max} + M_{min}}{2}, \quad (24)$$

where M_{max} , M_{min} , $M_{average}$ are maximal, minimal, and average torques.

Expert system is capable to use the received dependences torque inequality on stem length, rods diameter, screw length, screw diameter, screw tightness, pump pressure and others to control functional modes of the screw pump set [9-10].

For the accepted conditions of utilization (rodshear elasticity $G=8,05 \cdot 10^8$ N/m²; rod material density $\rho_r=7815$ kg/m³; screw tightness $\delta=0,1$ mm; rod diameter $d_r=0,022$ m; screw diameter $d_s=0,06$ m; stem length $l_r=1000$ m; screw length $l_s=2$ m; friction coefficient $\nu=2$; pumping pressure $P_p=6 \cdot 10^6$ Pa) the recommended driver speed with yield factor is ≈ 250 rot/min.

Using the expert system in apparatus complex allows controlling and managing operation modes of the screw pump set with the surface drive in the autonomous regime, enhancing its reliability and productivity, switching it off in emergency situations, and controlling the extracted fluid parameters.

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