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Professor Najafov Ali, botrn on 11.09.1961 in Tovuz, Azerbaijan. Head of departament for Machine Design of Azerbaijan Technical University. Author of more than 100 scientific works, incuding 8 patents and author's certificates. Since 1994 is chairman of the DAAD-Alumni in Azerbaijan

The scientic research of professor Najafov covers scientic areas such a strength calculations, scientific basis of design and construction, assessment of reliability and technical level of the machines, devices and equipment, the metods for the choice of the most appropriate materials for the machine parts and units providing technical requirements for their production and use, the search of selection methods of their shapes and sizes, the create and modernize of modern types of energy-efficient mechanical systems in accordance with environmental requirements and etc.

The results of some theoretical and experimental research of Professor A. Najafov were used in the oil-producing area "Absheronneft" of SOCAR. In 2013 his Eurasian patent "Three-stage double-flow cylindrical gear reducer" was awarded with the diploma of the 2nd degree in the first republican competition of the State Committee on Standardization, Metrology and Patent of Azerbaijan Republic

At the invitation of German Academic Exchange Service (DAAD), Professor A Najafov in different years worked as a researcher in some leading universities of Germany: in 1991-93 at the Ruhr-University Bochum, in 1996 and in 2005 at the Technical University of Karlsruhe, in 1999 at the Center for Nuclear Research in Karlsruhe. At the invitation of the Swiss Academy of Technical Sciences in 1996-97 he worked as a scientist-designer in MAAG Gear Co, in Zurich.

New Constructive Decision of a Mechanical Drive for Sucker-Rod Pumps for Oil Production

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Abstract
In this paper is new constructive decision of beamless pumping unit with new design of 3 stage package gear on only two shafts described.
Keywords: Sucker-Rod Pump, Beamless Pumping Unit, Package Gear.

Introduction

In oil-producing countries the sucker-rod pumps is one of the major aggregates for the mechanized way of an oil recovery on land.

The application of the method of oil pumping begins on the Baku oil fields since 1923. The history of development of pumping units is well recognized in stages to improve their standards. Without

considering the first samples, which had a wooden rocker and outdoor gear, it can be said that their development as a serious engineering products, began with the creation of the design, the parameters of which were regulated by the standard of "pumping unit" (GOST 5866). Worldwide the parameters of pumping units are regulated by the standard of the American Petroleum Institute Specification for Pumping Units Spec HE API. At present in Azerbaijan is valid the last edition of Interstate Standard developed by the Azerbaijan Scientific-Research and Design Institute of petroleum engineering (AzINMASH) in 1998 and harmonized with Spec HE API.

But in split of almost 90-year history of pumping unit is a fairly conservative set of equipment, the basic design elements of which are not changed for the past many ten years.

As in the time of the Nobel Brothers activity in Azerbaijan, which despite resistance from the conservative oil companies and dealers have implemented many of his revolutionary ideas such as pipeline transportation of oil, oil storage in steel tanks and many others, without modern oil industry is impossible and now has to contend with the still ongoing conservatism of oil companies who do not want to change anything in the equipment for the oil extraction.

Now issue of standard sucker-rod pumps makes several ten thousand a year and provides security of maintenance of all funds of oil wells. However the low efficiency, the big expenditure of the electric power, an incomplete construction of driving gear and reformative mechanisms, impossibility of use in existing aggregates of electric motors with a rotation high frequency lead to research of more perfect construction of a mechanical drive of sucker-rod pumps-MDSRP [1, 2].

One of essential deficiencies of known MDSRP (beam pumping unit) is that at the big traverse stroke, except increase in a dimension of the machine tool; raise as well the sizes of a beam head. At the usual beam with application of an arc beam head the span arrow in any position of the mechanism is organized.

Operation of the deep pump at each movement plunger up and downwards is accompanied by change of a direction of movement of pump rods and transition through some positions (dead points) with zero speed that should vary during one cycle of operation of machine on magnitude and a direction. As a result the "bifurcation" - an exit of the linkwork from a dead point has important value at start-up and machine stopping. At that dynamic loads on rods depend on magnitude of speed and acceleration which are drastic shown at descent of pumps to the big depths. As rods are set in motion by sucker-rod pump, operation of the deep pump essentially depends on the law of movement of a suspension bracket polished rod. Thus laws of movement of a suspension point of rods for an ideal case are simple harmonic functions accordingly for a path - a cosinusoid, speeds - a sinusoid, accelerations - a cosinusoid with amplitudes r, $r\omega$, $r\omega^2$. However, in an existing construction of the sucker-rod pump the real law of change of a path, speed and acceleration of suspension point of rods considerably differs from the simple harmonic.

Execution of a driving gear of an existing MDSRP with use of a double-reduction gear unit of classical execution demands application of electric motors of the big power with the lowest rotational speed and efficiency. It essentially augments its overall dimensions, reduces reliability and efficiency.

Method of solution

Department of «Machine parts» of Azerbaijan Technical University is developed, made and tested essentially new constructive decision of a mechanical drive for sucker-rod pumps (fig.1). Thus execution of the reformative mechanism as slide-crank mechanism with the embedded planetary gear, which has the changing laws of a path, speed and acceleration of suspension point of rods closest to theoretical laws and a bifurcation, allows reducing of the beam in this mechanical system having rather difficult construction, [3].

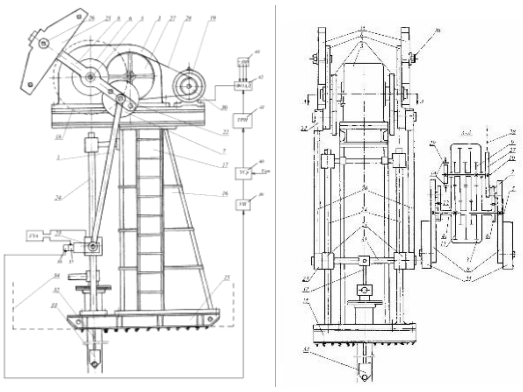


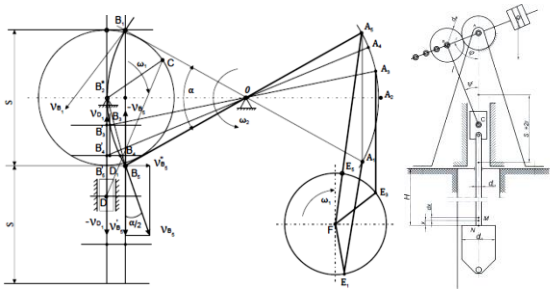
Fig. 1. The kinematic diagram of new constructive decision of a mechanical drive for sucker-rod pumps

It has been investigated the analytical kinematics of the geared linkage mechanism transforming a rotational motion of rod's suspension center of the new constructive decision of a mechanical drive for rod pumps into reciprocal , Fig.

2. It is made the estimation of deviation of the real maximum speeds and accelerations from the maximum speeds and accelerations of ideal harmonic motion of suspension center of rods of a mechanical drive for sucker-rod pumps.

By the kinematic calculation is determined a connection between displacement of an initial link - crank with the displacement, speed and acceleration of a driven link – suspension bracket of a rod of MDSRP [4, 5]. Here $s_c = s_0 / l$, $\lambda = r / l$ - are parameters of the transforming mechanism on which variable kinematic parameters of the given mechanical system depend. As an independent variable is set the rotation angle of the crank φ.

In the construction of modern beam-pumping units (fig. 2, a) the crank and the connecting rod on the both extreme positions lie on the straight line, that passes through the rotation center of the crank. However, the real displacement of the plunger of the deep-pump performed by the common pumping units, as a rule, does not correspond to the made demands. As a main cause for this are considered elastic deformations of the bars and rods, that are formed as a result of impose of variable in magnitude loads, influence of the inertial forces of flowing liquid masses and pumping bars, which substantially depend also on significant difference between laws of variations of way, velocity and acceleration of rod's suspension point in common beam-pumping units and simple harmonic laws.



a) b)

Fig. 2. Kinematics of the normal pumping unit a) and of the new constructive decision of a mechanical drive for sucker-rod pumps b)

And the execution of the transforming mechanism as a slide-crank mechanism in new constructive design of sucker-rod pumps (fig. 2, b) with the embedded planetary gear possessing the laws that are particularly close to the theoretic laws of variation of way, velocity and acceleration of rod's suspension point, and bifurcation enables to eliminate the beam in the present mechanical system, that has a relatively compound construction and leads to increase of the overall dimensions of the system. This way friction losses in kinematic pairs decrease, and stroke of wellhead rod's bracket by oil extraction takes place in a wide range due to theoretically derived laws of motion of rod's suspension point respectively co sinusoid - for way, sinusoid - for velocity and co sinusoid - for acceleration with the amplitudes r, $r\omega$ and $r\omega^2$ of mechanical drive of well pumps.

Compared with beam-pumping units the developed beamless pumping unit has more reliability and infallibility, because it lacks such weak links as swivel beam head and its supporting nodes. The pumping unit equipped with the developed transforming geared linkage mechanism has better dynamic behavior because the crank rotates uniformly, there are not significant unbalanced masses and acting on the base horizontally directed alternating forces that are characteristic for beam-pumping units. Since the beam head with the beam is replaced by the fixed base with the positioned guide gear wheel, better centering with the wellhead is ensured.

It is established, that dynamic loads in rods depend not only on value and the variation law of acceleration, but also on motion speed of suspension center of rods at the moment of motion of plunger up. Therefore it is necessary to find deviation of the kinematic parameters characterizing qualities of the new constructive decision of a MDSRP. In this connection as qualitative parameters of state of this mechanical system are accepted the deviations of the real maximum speeds and accelerations from the maximum speeds and accelerations at ideal harmonic motion [4]:

$$\chi_v = \frac{(v_c)_{\max}}{(v_c)_u} = \frac{\sin(\varphi+\psi)}{\sin\varphi\cos\psi}\,, \qquad (1)$$

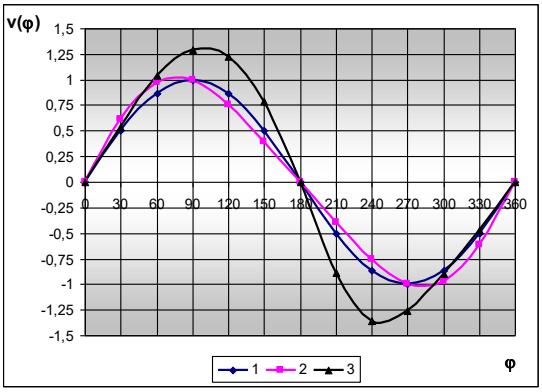
$$\chi_a = \frac{(a_c)_{\max}}{(a_c)_u} = \frac{1}{\cos\varphi}\left[\frac{\cos(\varphi+\psi)}{\cos\psi} + \lambda\frac{\cos^2\varphi}{\cos^3\psi}\right] \qquad (2)$$

here $(v_c)_u$, $(a_c)_u$ - are accordingly the maximum speed and the maximum acceleration at ideal harmonic motion of rod's suspension center of the given mechanical system.

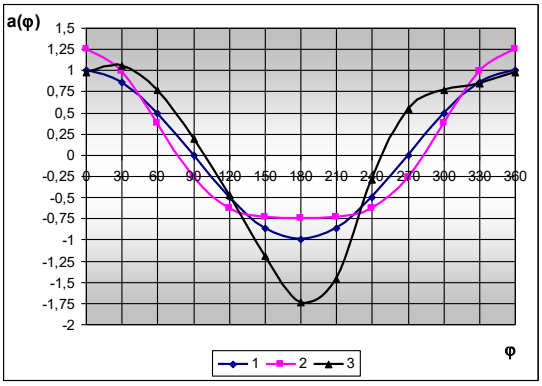
For definition of rotation angle of the crank corresponding to the maximum values of speed and acceleration of a suspension center of rod the derivative of the expressions (1) and (2) is equated to zero. The change pattern of speed and acceleration of suspension center of rod of sucker-rod pumps depending on rotation angle of crank is presented in the Fig. 3 [4].

It is established, that by using of the new constructive decision of a MDSRP the deviation of the real maximum speeds and accelerations from the maximum speeds and accelerations at ideal harmonic motion depending on a parameter value λ makes 2-7 %. That testifies expediency of use of the new constructive decision of a mechanical drive (sucker-rod pumps) at an oil recovery.

Thereby, comparing with the proposed construction of the new construction decision of mechanical drive for sucker rod pumps, plunger of the deep-well pump of common pumping units is staying at the lower and upper dead points longer for the time t^*, that can lead to the anticipatory deterioration of pump's plunger because of the ingress of big amount of sand into the cavity of pump's cylinder or incomplete use of whole capacity of the cylinder because of the ingress of condensate gases and oil displacement [5].



a)



b)

Fig. 3. Change pattern of speed (**a**) and acceleration (**b**) of suspension center of rod of sucker-rod pumps depending on **φ** : 1, 2, 3 – respectively for ideal harmonic motion, for new constructive decision, for existing construction

Approaching of the laws of variation of way, velocity and acceleration of rod's suspension point of new constructive decision of MDSRP to the harmonic laws decreases additional dynamic load caused by rods' vibrations and also inertial loads on the rods, which undoubtedly will increase their durability [6].

Use in the new constructive decision of a mechanical drive for sucker-rod pumps as a driving gear of AN-reducer diminishes its overall dimensions, friction losses in kinematic pairs, and allows receiving practically any quantity motion of a suspension bracket of a rod at an oil recovery [7].

During the full cycle of operation of the deep pump, the rod suspension point is loaded unevenly, which is accompanied by uneven energy consumption during each cycle. When the plunger moves upwards, work is done to raise the bars and liquid, and when the plunger moves down the bars are lowered by their own weight and, thus, the engine is unloaded. Such a load fluctuation requires the use of high power engines in the drives of sucker-rod pumps with extremely low efficiency.

One of the basic requirements that the kinematic scheme of the sucker-rod pumps must satisfy is to maintain the same average speed when the rod suspension point moves up and down. In other words, the time taken to move up and down should be the same. For this purpose, a normal crank-slider mechanism is used as the transforming mechanism in the new design solution of the beamless sucker-rod pump. Obviously, in this case, the rate of change of speed is equal to one, that is, it is ensured that the average velocity is maintained when the rod suspension point moves up and down. At the same time, the kinematic height - the distance from the center of the crank's rotation to the lower boom suspension point of the new design of the mechanical drive of rod pumps, is equal to the sum of the lengths of the crank and connecting rod, which depend on the stroke length S and λ.

In the sucker-rod pumps for oil production, applying an additional load of dynamic nature to the static load associated with the beginning of the movement of the liquid column and the lower end of the rod string at the end of the deformation period during the upward motion leads to the appearance of elastic oscillations in the rod string. In this case, the additional dynamic loads arising in each of the sections of the rod column vary with time according to a certain periodic law, and, owing to the resistances, the amplitude of these oscillations gradually decreases. The lower end of the rods is

driven by the finite speed of the rod suspension point with the end of the unloading period at the end of the deformation at the last downward stroke. There are elastic oscillations of the rod string. It is obvious that for a certain diameter of the pump and the depth of its descent, the maximum dynamic load depends on the speed and acceleration of the rod suspension point at the end of the initial rod deformation period for a certain pumping regime (stroke length and number of oscillations) dimensions of the crank and connecting rod.

The study and evaluation of the real values of the dynamic loads that take place under various operating conditions of a deep-well pump are of practical interest. A comparative evaluation of the output parameters of the SKD-7 rocking machine and the new design of the MDSRP is given in Table 1. In Fig. 4 shows the nomogram for determining the maximum dynamic load on the rods of borehole pumps, depending on the dimensionless parameters characterizing the ratio of the diameter of the plunger and the pipe to the diameter of the rod.

Table 1.

Name of the parameters	Name of the equipment	
	Sucker-rod pump SKD-7	New design of MDFSP
S_c, m	3	3
H, m	1345	1345
d_H, mm	56	56
F_{cT}, N	62000	62000
n, min^{-1}	12/9	12/9
υ_c, m/s	1.81/1.355	1.45/1.088
a_c, m/s^2	1.12/0.628	0.9116/0.5128
F_c^i, N	136,00	110,00
F_{vib}, N	1680,00	1085,00
F_g, N	1816,00	1195,00
F_{max}, N	8016,00	7395,00
F_g / F_{max}	0.227	0.1616

Currently the authors have designed sucker-rod pumps with transforming slide-crank mechanism with the embedded planetary gear (fig. 4), proposed various designs of beamless pumping units with toothed slide-crank transforming mechanism, carried out the industrial test of package gear in the oil fields of island “Pirallahy” near Baku (fig. 5).

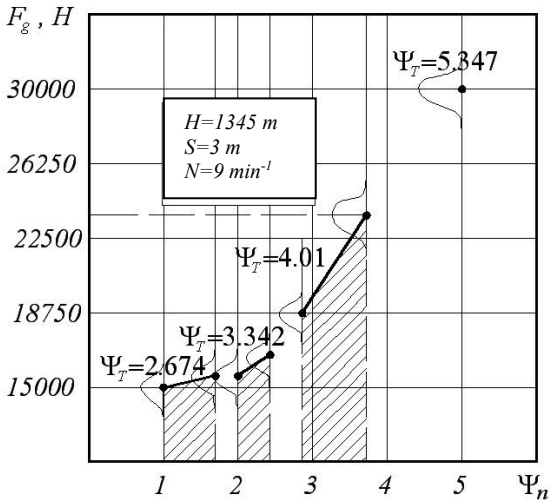


Fig. 4. Nomogram of determination of the maximum dynamic load on the rods of borehole pumps

Gear execution multistage, placed on two shafts practically with an unrestricted reduction ratio, gives the chance to diminish amount of belts, and also a reduction ratio of V-belt drive and by that overall dimensions, and consequently also metal consumption of plant at preservation of functionality of a mechanical drive rod pumps.

Fig. 4. A prototype of new constructive decision of a MDSRP with three stage package gear (U_Σ=64)

Fig. 5. Industrial test of sucker-rod pumps SKD 3-1.5-710 with three stage package gear (U_{Σ}=64) in the oil fields of island "Pirallahy" near Baku

Prominent feature of the last is that is ensured energy supply at the expense of use of electric motors of low power with the big rotational speed, the amount of constructive elements is diminished and by that reliability of the this mechanical system is augmented.

Comparing with classical multistage gears the AN-reducers have following specific advantages:

- possibility to getting very high gear-ratio;
- small dimensions;
- higher efficiency;
- high reliability and higher technical level;
- absence of countershafts;
- saving of energy supply.

As a basic kinematical schema of AN-reducer was chosen three- and fife-stage schemas where influence of rotation direction of double gear blocks are favorable for the loss of enhancements and increasing of efficiency of it [8].

Due to exclusion of countershafts on frictionless bearings the reliability level of AN-reducer in comparison with classical gears is higher up to 7.5 %.

Thanks to exclusion of pair of frictionless bearings the efficiency of AN-reducer increased up to 4.5 % [9].

Based on derived results was established, that the technical level of engineered AN-reducer is comply with the modern world gears models [10].

Conclusions and results

It is established, that by using of new design of beamless mechanical drive for sucker-rod pumps the deviation of the real maximum speeds and accelerations from the maximum speeds and accelerations at ideal harmonic motion makes 2-7 %.

With the use of a new design of beamless mechanical drive for sucker-rod pumps, the relative magnitude of the dynamic load (on average by 28.8%) and the maximum load at the suspension point of the rods are significantly reduced in comparison with the common beam-pumping units.

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