Research Concerning the Optimization of the Mechanism of the Conventional Sucker Rod Pumping Units

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Finding optimal solutions to design the mechanism of the conventional sucker rod pumping units is always present due to many problems that involve. The study in this case involves both the cinematic and dynamic analysis of the mechanism of the conventional pumping units, making sure that the optimization solution maintain unchanged certain operating parameters of the pumping equipment such as the stroke of the sucker rod column. In the paper is presented a method of determining the optimal dimensions of the structural elements of the mechanism of the conventional pumping units in order to reduce the maximum values of the connection forces in the bearings in the conditions of maintaining unchanged the stroke of the sucker rod column. The simulations have been performed in the case of a C-640D-305-120 pumping unit.

Keywords: sucker rod pumping unit, connection forces, optimization

The dimensional optimization of the structural elements that are parts of the conventional pumping units involves the realization of a highly complex study that includes both the kinematical and dynamic analysis of their mechanism [1-3]. For this purpose, an exact determination of the loads to which the component parts are subjected and the dynamic and cinematic modeling of the pumping unit mechanism plays an essential role [4-8]. On the other hand, it is well known that the bearings of the conventional pumping units are some of their most loaded components [5], so for increasing safety in operation a main objective in the optimization study is to reduce the maximum values of the connection forces.

In this paper is presented a method of determining the optimal dimensions of the structural elements of the mechanism of the conventional pumping units in order to reduce the values of the connection forces in the bearings in the conditions of maintaining unchanged the stroke of the sucker rod column. It is also analyzed the influence of the results obtained after the optimization process upon the variation of the motor moment at the crankshaft. Some significant results concerning the cinematic and dynamic analysis of the mechanisms in the perspective of their dimensional optimization that have strongly helped to the achievement of the research from this paper are presented in [9-22]. The optimization method has been transposed by the author into a computer program using Maple programming environment [23]. The experimental records have been processed with the program Total Well Management [24].

Experimental part
The program Total Well Management [24] has been used for processing the experimental records obtained in the case of a well that is serviced by a C-640D-305-120 pumping unit manufactured by Lufkin (fig. 1).

In establishing the connection forces acting on the bearings was used the record concerning the variation on a cinematic cycle beginning with the cranks angle corresponding to the upward movement of the rod column of the force at the polished rod for the stroke 50 (fig. 2).

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Fig. 1. Data concerning the analyzed well

Fig. 2. The variation of the force at the polished rod during the stroke 50

The simulation results obtained for the variation on a cinematic cycle beginning with the cranks angle corresponding to the upward movement of the rod column of the motor moment at the crankshaft have been
compared with the experimental records established for the stroke 50 (fig. 3).

In figure 5 are presented the load schemes of the rocker, of the connecting rods and of the cranks [5]. $G_j$, $j=1,3$, are the weight forces of the cranks, of the connecting rods and of the rocker, respectively; $G_{CG}$ is the weight force of the balancing counterweights; $G_{L1}$ is the weight force of the two crank pin bearings (it has been considered that half of the weight of these bearings is concentrated on the connecting rods, the rest remaining concentrated on the cranks); $G_{iCG}$ is the weight force of the equalizer bearing; $G_{i}$ is the weight force of the equalizer; $G_{h}$ is the weight force of the horsehead; $F_{ij}$, $j=1,3$, are the inertia forces corresponding to the cranks, connecting rods and to the rocker, respectively; $M_{ij}$, $j=1,3$, are the inertia moments corresponding to the connecting rods and to the rocker; $F_{iCG}$, $F_{iL1}$, $F_{iL2}$, $F_{itr}$, and $F_{iCB}$ are the inertia forces corresponding to the balancing counterweights, to the two crank pin bearings, equalizer bearing and equalizer and to the horsehead, respectively.

$F_{xy}$ and $F_{xy}$ represent the projections on x and y axes of the connection force from the centre bearing. Are also represented the projections on x and y axes of the connection forces: $F_{23}$ from the equalizer bearing acting on the rocker; $F_{32}$ from the equalizer bearing acting on the equalizer; $F_{12}$ from the two crank pin bearings acting on the connecting rods; $F_{21}$ from the two crank pin bearings acting on the cranks; $F_{01}$ from the two joints connecting the two cranks and the output shaft of the reducer.

The manner of determining of the connection forces and of the motor moment $M_m$ at the crankshaft is presented in [5]. A computer program that allow the determining of the optimal dimensions of the elements of the mechanism of the conventional pumping units in order to reduce the values of the connection forces in the bearings has been developed by the author using the powerful symbolic calculus functions included in Maple programming environment. For optimization calculus has been used the function NLPSolve included in the Optimization package of Maple [23]. In this way can be determined the dimensions of the component elements of the mechanism of the conventional pumping units that lead to minimizing of the maximum value of the connection force from the centre bearing that is the most loaded bearing during operation ($F_{GB}(O4,A,B,C,D,\varphi_{max},y_c)$), where $m_i$ and $y_c$ are the coordinates of the point C (fig. 4) and $\varphi_{max}$ represents the value of the angle $\varphi_1$ where the maximum of the force at the polished rod is reached.
Results and discussions

The simulations have been performed in the case of a C-640D-305-120 pumping unit produced by Lufkin [25], whose component elements have the following dimensions: OA = 30 in. (0.762 m); AB = 133.5 in. (3.3909 m); BC = 111.09 in. (2.8194 m) and the coordinates of the point C (fig. 4) are: xC = 111 in. (2.8194 m) and yC = 138 in. (3.5052 m). The values of the crank angle \( \phi_1 \) (fig. 4) corresponding to the beginning of the upward and downward movements of the sucker rod column are: \( \phi_{1a} = 88.976^\circ \) and \( \phi_{1d} = 266.929^\circ \), respectively [5].

The simulations have been accomplished by considering the following values of the other parameters involved in calculations: \( CD' = 140 \) in. (3.556 m); \( OA' = 54.5 \) in. (1.3843 m); \( mL_1 = 88 \) kg; \( mL_2 = 169 \) kg; \( m_{tr} = 580 \) kg; \( m_{CB} = 840 \) kg; \( q_1 = 722 \) kg/m; \( q_2 = 34 \) kg/m; \( q_3 = 300 \) kg/m (\( q_1, q_2 \) and \( q_3 \) are the linear masses of the cranks, connecting rods and of the rocker, respectively). The work angular speed of the cranks has been of 6.667 rot/min.

The variation on a cinematic cycle of the force \( F \) at the end of the polished rod (fig. 2) has been expressed according to the angle \( \phi_1 \) with a polynomial function whose coefficients have been calculated with the method of the least squares [26]:

\[
F(\phi_1) = c_0 + c_1 \phi_1 + c_2 \phi_1^2 + \ldots + c_m \phi_1^m
\]  

(1)

In figure 6 are presented the values of the coefficients \( c_i \), i=0, m, in the order in which they are found in the polynomial function (it has been consider \( m = 25 \)).

The variation of the force at the polished rod during a cinematic cycle beginning with the angle \( \phi_{1d} \) obtained using the polynomial function is represented by the curve 1 in figure 7 and the curve 2 corresponds to the variation of its measured values.

In figure 8 the curve 1 represents the variation on a cinematic cycle of the motor moment at the crankshaft beginning with the angle \( \phi_{1d} \) obtained after simulations and the curve 2 corresponds to the variation of its measured values for the stroke 50.

Figure 8 highlights a good accordance between the values of the motor moment at the crankshaft obtained with the simulation program and its measured values.

After performing the optimization calculation that aimed the minimization of the maximum value of the connection force \( (F_{c8}(OA, AB, BC, CD, x_C, y_C)) \), where in this case \( F_{c8}^{\text{max}} = 3.44 \) (fig. 7), have been obtained the following values for the dimensions of the component elements of the pumping unit mechanism: \( OA = 0.737 \) m; \( AB = 3.604 \) m; \( BC = 2.492 \) m; \( CD = 3.489 \) m; \( x_C = 2.396 \) and \( y_C = 2.979 \) m. In applying the function NLPSolve included in the Optimization package of Maple has been considered that the values for \( OA, AB, BC, CD, x \) and \( y \) can vary with ± 15% of their initial values. Also, it has been imposed the condition of maintaining unchanged the stroke of the sucker rod column.

In figures 9÷13 are presented the variation on a cinematic cycle beginning with the angle \( \phi_{1d} \) of the values of the connection forces \( F_01, F_12, F_23, F_03 \) and of the motor moment.
moment $M_m$ at the crankshaft. The curves 1 correspond to the simulation results obtained after performing the optimization calculation and the curves 2 correspond to the values of the connection forces and of the motor moment at the crankshaft obtained with the initial values of the dimensions of the component elements of the pumping unit mechanism.

Figures 9-12 highlight the extremely high values of the connection forces acting in the bearings of the analyzed pumping unit and the fact that by optimization their maximum values have decreased. Also, figure 13 highlights the decrease of the maximum values of motor moment at the crankshaft after optimization.
Conclusions

In this paper has been presented a method of determining the optimal dimensions of the structural elements of the mechanism of the conventional pumping units in order to reduce the maximum values of the connection forces in the bearings in the conditions of maintaining unchanged the stroke of the sucker rod column. The optimization method has been transposed by the author into a computer program using Maple programming environment. For optimization calculus has been used the Optimization package of Maple. It was also analyzed the influence of the results obtained after the optimization process upon the variation of the motor moment at the crankshaft. The simulations performed in the case of a C-640D-305-120 pumping unit highlighted the extremely high values of the connection forces acting in the bearings of the analyzed pumping unit and the fact that by optimization their maximum values have decreased. Also, the simulation results highlighted a significant decrease of the maximum values of motor moment at the crankshaft after optimization.

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