Research Concerning the Influence of Balancing the Conventional Pumping Units on their Dynamics

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Abstract: The paper analyses the influence of the rotary balancing and of the combined balancing (rotary and oscillating) on the variation of the motor torque at the crankshaft and on the variation of the connection forces acting in the joints of the mechanism of the conventional pumping units. For this purpose a computer program has been developed and a series of results in the case of a C-640D-305-120 pumping unit are presented.

1. Introduction

It is well known that for a good functioning of the sucker rod pumping installations the pumping units from their component must be correctly balanced. Balancing the pumping units represents the operation by which it is followed that the maximum values of the motor torque at the crankshaft corresponding to the ascending and descending strokes of the sucker rod column are equal [1,2]. The balancing of the conventional pumping units is achieved by adding counterweights in the extension of the cranks in the case of rotary balancing or by adding counterweights both in the extension of the cranks and in the extension of the rocker in the case of combined balancing (rotary and oscillating).

In the paper is analyzed the influence of the rotary balancing and of the combined balancing on the variation of the motor torque at the crankshaft and on the variation of the connection forces acting in the joints of the mechanism of the conventional pumping units. Starting from the calculation methodology a computer program has been developed which allows performing a comparative analysis of the influence of the rotary balancing and of the combined balancing on the variation of the mentioned parameters.

2. Materials and methods
2.1. Experimental part

For establishing the values of the connection forces acting on the joints of the pumping unit mechanism and of the motor torque at the crankshaft were analyzed several records concerning the variation of the force at the polished rod in the case of a C-640D-305-120 pumping unit to check that this one is in a stable operating condition. In Figure 1 is represented such a variation curve corresponding to the stroke 85. The processing of the records was done with the Total Well Management program [3].

2.2. Determining the connecting forces and the motor torque

Dynamics of the sucker rod pumping installations represents a topical field of research, some significant results regarding the dynamics of the conventional pumping units and of the sucker rod column being presented in [4-10].

In Figure 2 where is presented the mechanism of a conventional pumping unit the following notations were used: m_{CG1} is the mass of the counterweights mounted on the cranks; m_{CG2} represents the mass of the counterweights mounted on the extension of the rocker; M_m is the motor torque at the crankshaft and $\overline{F}$ is the force at the polished rod.

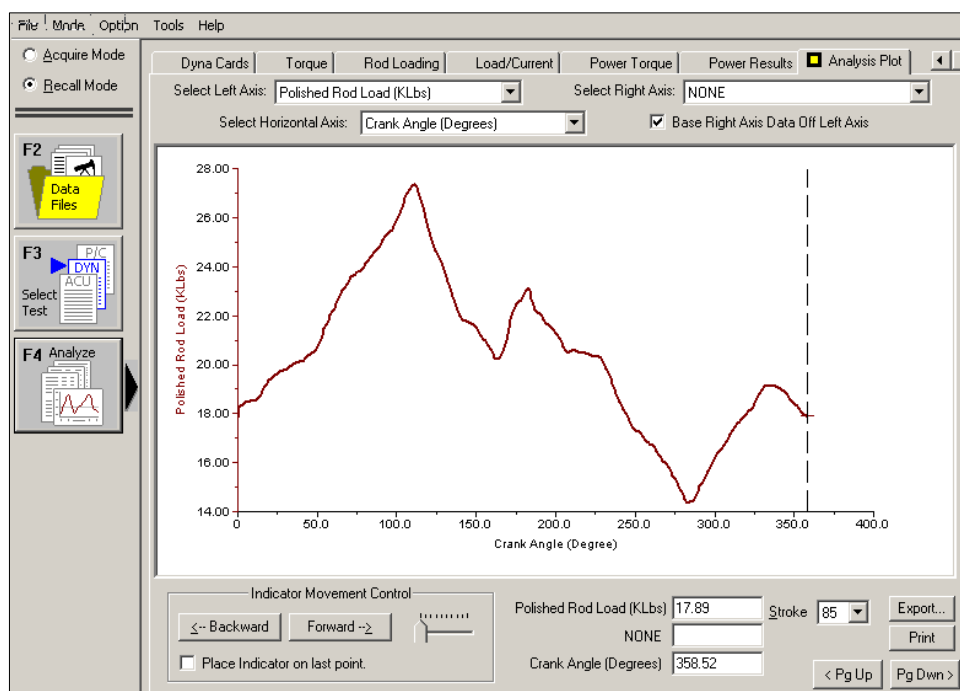*email: dorin.badoiu@gmail.com*

Figure 1. The variation curve during the stroke 85 of the force at the polished rod
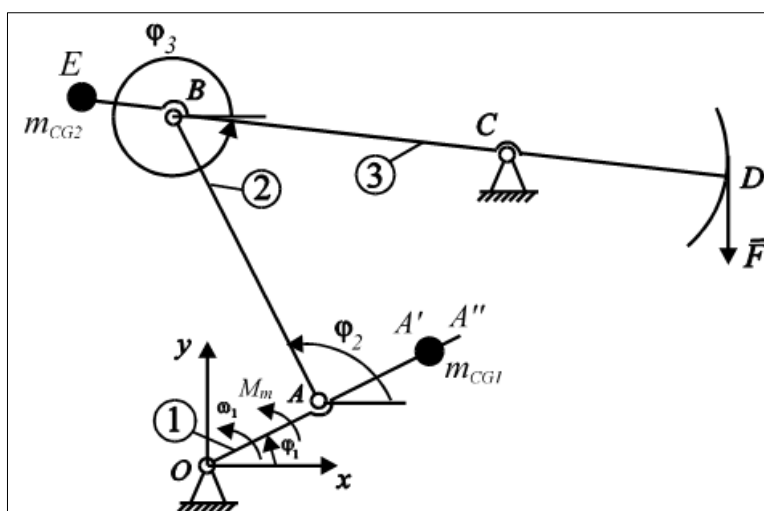

Figure 2. The cinematic scheme of a conventional
pumping unit mechanism

In Figure 3 and Figure 4 were represented the load schemes of the connecting rods and the rocker, which make up dyad (2-3) and of the cranks. $\overline{G}_1, \overline{G}_2$ and $\overline{G}_3$ are the weight forces of the two cranks, of the two connecting rods and of the rocker, respectively; $\overline{G}_{CG1}$ and $\overline{G}_{CG2}$ are the weight forces of the counterweights mounted on the cranks and on the rocker, respectively. Also, in Figure 3 and Figure 4 were represented the projections of the connection forces acting in the component bearings: $2\overline{F}_{12}$ from the two crank pin bearings acting on the connecting rods and $2\overline{F}_{21} = -2\overline{F}_{12}$ acting on the cranks; $2\overline{F}_{01}$ from the two joints connecting the two cranks and the output shaft of the reducer; $\overline{F}_{03}$ from the centre bearing.

Because the pumping units mechanism is very slow and in the case of a normal operation the shocks or vibrations that appear are very low, in the performed calculations the forces and the moments of inertia were neglected.
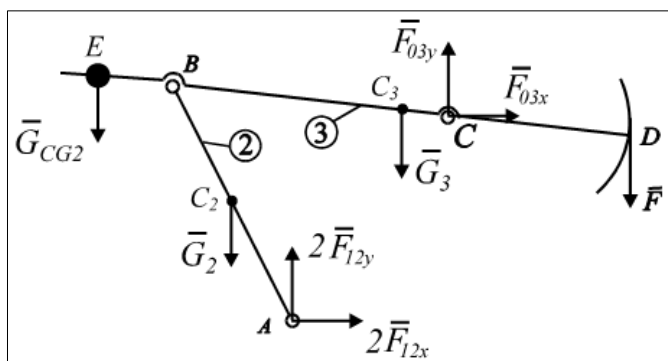
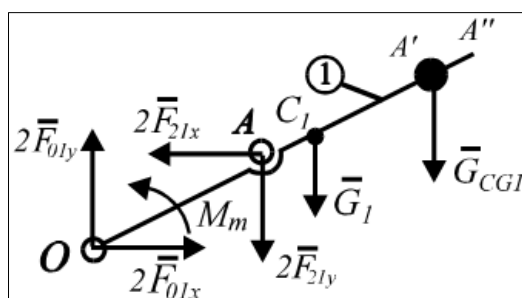**Figure 3.** Representation of loads on connecting rods and rocker

Figure 4. Representation of loads on cranks

From writing the equilibrium equations in forces in the case of the dyad (2-3) **(**Figure 3), it results:

$$\begin{cases} 2F_{12x} + F_{03x} = 0 \\ 2F_{12y} + F_{03y} - G_2 - G_{CG2} - G_3 - F = 0 \end{cases} \tag{1}$$

From the equation of equilibrium in moments on the whole dyad in relation to point *A* (Figure 3), it results:

$$(x_C - x_A) \cdot F_{03y} - (y_C - y_A) \cdot F_{03x} - (x_D - x_A) \cdot F - (x_{C_3} - x_A) \cdot G_3 - $$
$$- (x_E - x_A) \cdot G_{CG2} - (x_{C_2} - x_A) \cdot G_2 = 0 \tag{2}$$

Considering only the component *2* of the dyad (Figure 3), from the equilibrium equation in moments in relation to point *B* results:

$$2 \cdot (x_A - x_B) \cdot F_{12y} - 2 \cdot (y_A - y_B) \cdot F_{12x} - (x_{C_2} - x_B) \cdot G_2 = 0 \tag{3}$$

From the equilibrium equations in forces on the directions of the *x* and *y* axes in the case of the cranks (Figure 4) by considering that: $2\bar{F}_{21} = -2\bar{F}_{12}$, it results:

$$\begin{cases} 2F_{01x} - 2F_{12x} = 0 \\ 2F_{01y} - 2F_{12y} - G_1 - G_{CG1} = 0 \end{cases} \tag{4}$$

Then, from the equilibrium equation in moments in relation to point *O* (Figure 4) results:

$$M_m - 2 \cdot x_A \cdot F_{12y} + 2 \cdot y_A \cdot F_{12x} - x_{C_1} \cdot G_1 - x_{A'} \cdot G_{CG1} = 0 \tag{5}$$

From resolving the system composed of the equations 1÷5 it results: F_{03x}, F_{03y}, F_{12x}, F_{12y}, F_{01x}, F_{01y}, and the motor torque M_m.

For determining the connection force from the equalizer bearing $\bar{F}_{23}$ (Figure 5) were used the following equilibrium equations in forces:

$$\begin{cases} F_{23x} + F_{03x} = 0 \\ F_{23y} + F_{03y} - G_3 - G_{CG2} - F = 0 \end{cases} \tag{6}$$
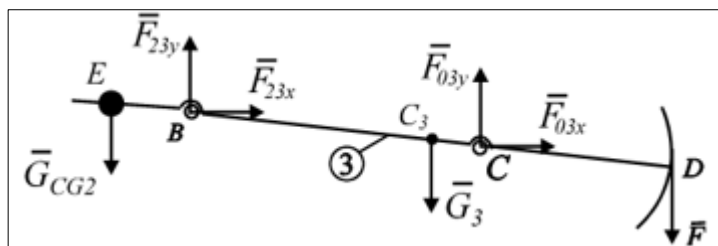

Figure 5. Load scheme of the rocker

The coordinates of the different points that appear in the equations of equilibrium 2,3 and 5 are determined following the positional analysis of the pumping units mechanism [11-13]. For this, the method of projection of closed and independent vector contours can be used [14,15].

The vector equation: $\overline{OA} + \overline{AB} + \overline{BC} + \overline{CO} = 0$ (Figure 2) projected on *x* and *y* axes leads to obtaining the following system of equations:

$$\begin{cases} OA \cdot \cos \varphi_1 + AB \cdot \cos \varphi_2 + BC \cdot \cos \varphi_3 - x_C = 0 \\ OA \cdot \sin \varphi_1 + AB \cdot \sin \varphi_2 + BC \cdot \sin \varphi_3 - y_C = 0 \end{cases} \tag{7}$$

Solving this system of equations it results the angles φ_2 and φ_3, and then knowing these angles we can determine the coordinates of any point on the mechanism of the pumping unit.

3. Results and discussions

Starting from the calculation methodology presented a computer program has been developed using Maple programming environment. It is presented below a series of results of the simulations realized in the case of a pumping installation serviced by a C-640D-305-120 pumping unit produced by *Lufkin* [17] for which are known: $OA = 0.762 \, \text{m}$; $AB = 3.391 \, \text{m}$; $BC = 2.822 \, \text{m}$; $CD = 3.937 \, \text{m}$; $OA'' = 2.413 \, \text{m}$; $x_C = 2.819 \, \text{m}$ and $y_C = 3.505 \, \text{m}$.

The values of the crank angles corresponding to the beginning of the ascending and descending strokes of the sucker rod column are: $88.976°$ and $266.929°$, respectively. A way to calculate these angles is presented in [16].

The linear masses of the cranks, connecting rods and of the rocker, denoted with: q_1, q_2 and q_3, respectively, have the following values: q_1=722kg/m; q_2=34kg/m; q_3=300kg/m.

The working angular speed of the cranks is: $6.6 \, \text{rot/min}$.

The simulations were performed considering the two balancing cases: rotary and combined (rotary and oscillating). For the case of rotary balancing it was considered that the counterweights of total mass equal to 4808 kg are mounted on the cranks so that $OA' = 1.6 \, \text{m}$ (Figure 2). In the case of combined balancing it was considered that the counterweights mounted on the cranks are of total mass equal to 2404 kg and $OA' = 2.032 \, \text{m}$ and the counterweights mounted on the rocker are of total mass equal to 2500 kg and $BE = 1.05 \, \text{m}$ (Figure 2).

In the following figures are represented the variations on a cinematic cycle beginning with the angle corresponding to the beginning of the ascending stroke of the sucker rod column of the values of the connection forces: $F_{01}, F_{12}, F_{23}, F_{03}$ and of the motor moment M_m by considering the variation of the force at the polished rod during the stroke 85 (Figure 1). The curves denoted with *1* correspond to the case of combined balancing and the curves denoted with *2* correspond to the case of rotary balancing.
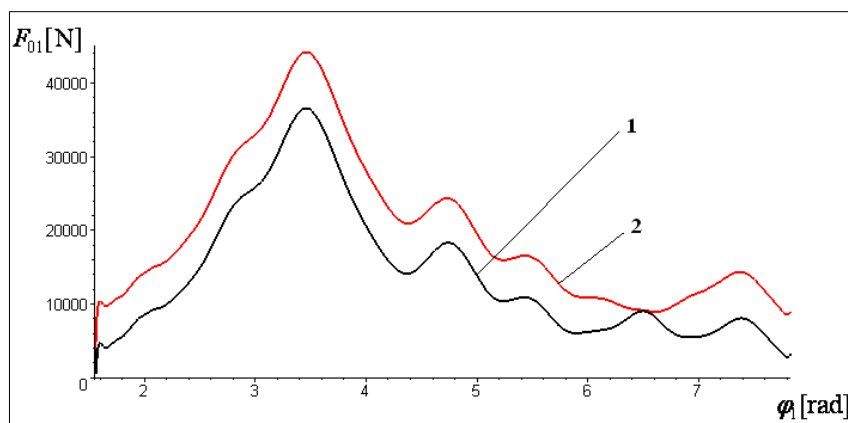
Figure 6. The variation of the connecting force F_{01}
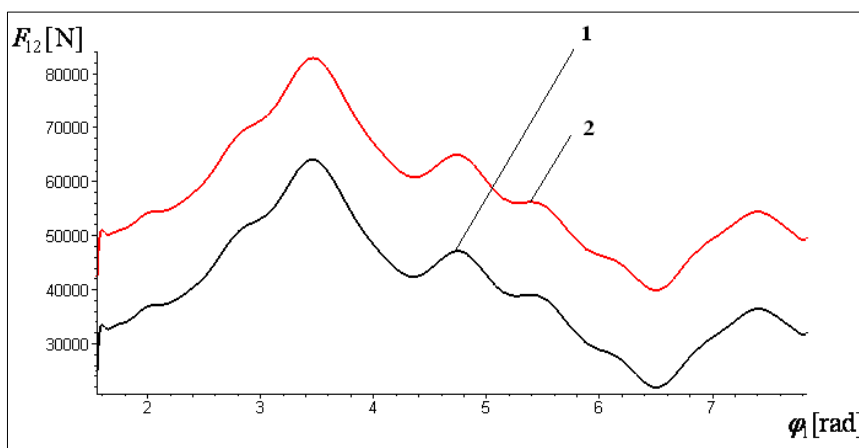(1 - combined balancing; 2 - rotary balancing)

Figure 7. The variation of the connecting force F_{12}
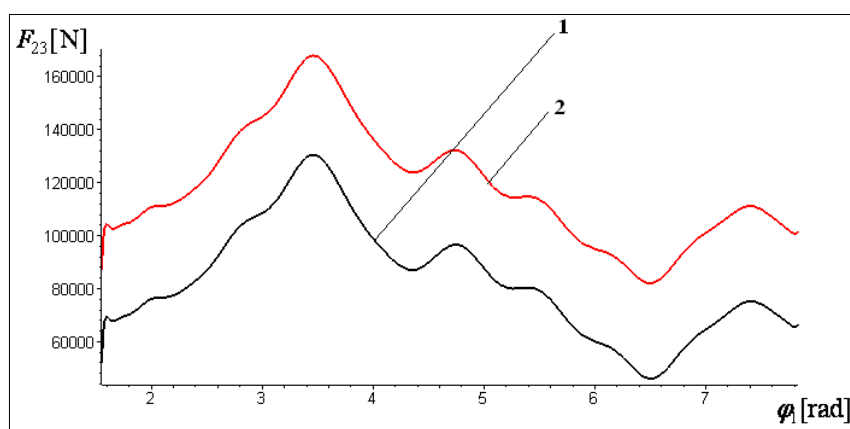(1 - combined balancing; 2 - rotary balancing)

Figure 8. The variation of the connecting force F_{23}
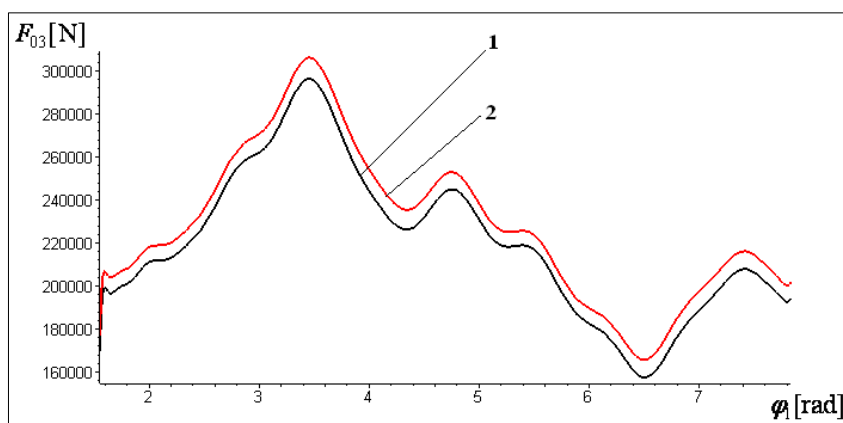(1 - combined balancing; 2 - rotary balancing)

Figure 9. The variation of the connecting force F_{03}
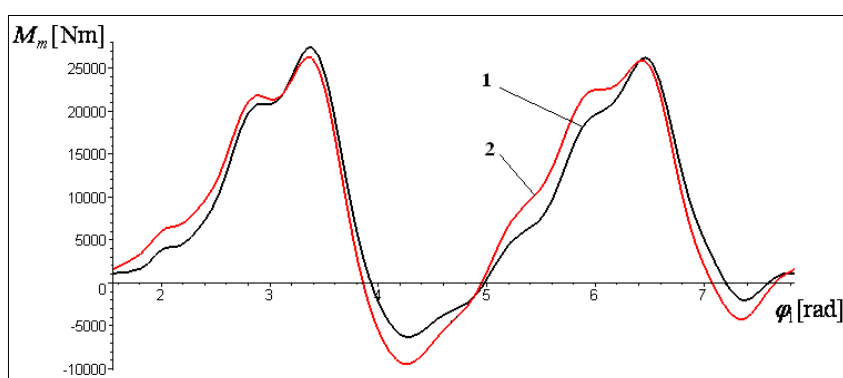(1 - combined balancing; 2 - rotary balancing)

Figure 10. The variation of the motor torque M_m
(1 - combined balancing; 2 - rotary balancing)

Figure 10 shows that the maximum values of the motor torque M_m corresponding to the ascending and descending strokes of the sucker rod column are very close, which shows that both balancing possibilities (rotary and combined) lead to a correct operation of the pumping installation. Moreover, the balancing solutions proposed for the analysis lead to close values of the motor torque M_m, with the observation that in the case of combined balancing there is a distribution of the mass of the counterweights on the structure of the pumping unit mechanism. This distribution of the mass of the counterweights leads to obtaining lower loads of the joints of the pumping unit as can be seen in Figures 6÷9.

4. Conclusions

In the paper has been analyzed the mechanism of conventional pumping units for determining the motor torque at the crankshaft and the connecting forces acting in the component joints. The simulation program developed using Maple programming environment allowed performing a comparative analysis of the influence of the rotary balancing and of the combined balancing on the variation of the motor torque at the crankshaft and on the variation of the connection forces acting in the joints. The obtained results highlighted that both balancing possibilities (rotary and combined) lead to a correct operation of the pumping installation, but the distribution of the mass of the counterweights corresponding the combined balancing leads to obtaining lower loads of the bearings of the pumping unit.

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