

Mechanics of a Grip System of Three-Key-Board Hydraulic Tongs Developed for Offshore Oil Pipe Lines

ZHAO Junyou^{*}, GUO Aiju^{**}, DING Keqin^{***} and LIU Chuntu^{****}

Abstract — This paper carries out the analysis of mechanics of a grip system of three-key-board hydraulic tongs developed for offshore oil pipe lines which has been successfully used in oil fields in China. The main improvement of this system is that a lever frame structure is used in the structural design, which reduces greatly the stresses of the major components of the oil pipe tongs. Theoretical analysis and numerical calculation based on thirteen basic equations developed show that the teeth board of the tongs is not easy to slip as frequently happens to other systems and is of higher reliability.

Key words: grip system; three-key-board hydraulic tongs; offshore oil pipe lines; stress analysis

1. Introduction

The oil pipe tongs are a special tool for screwing and unscrewing in the connection of oil pipes, especially used in repairing wells. Its function directly affects the efficiency and the quality of well repair. The two-key-board tong has been widely used in most oil fields in China. The application of the two-key-board tongs shows the following disadvantages: (1) the breach big gear in the grip system is easy to be out of shape and to break that the tongs have to be abandoned; (2) the gears of the tongs cannot tightly grip the outer surface of the oil pipe so that the pipe is easy to slip and the teeth of the tongs wear down quickly. Thus, the teeth board of the tongs must be replaced frequently during operation, otherwise, the working efficiency will be seriously affected and additional well-repair costs induced. If the tightening force (i. e. radial force) of the tongs is enhanced, the oil pipe will be deformed, and the size of the grip structures must be increased accordingly. To solve the above problems, a new type of grip system is designed, i. e. the evenly gripping system of three-key-board hydraulic tongs. This product has been successfully made in China and widely used in oil fields. This paper is to analyze the mechanics of this new type of hydraulic oil pipe tongs.

2. Load Analysis and Numerical Calculation of the Grip System

In the former design of the grip structures of the hydraulic tongs, graphic methods are often used to obtain the values of all the loading forces. Such kinds of methods are simple and easy to be put into practice but the results are not so accurate as to meet engineering requirements. For the new type of tongs, a lever frame structure is added to the tong mouth resulting in complexity of force analysis. The following is the process of load analysis of the grip system based on thirteen basic equations developed under the equilibrium conditions of the loading forces as shown

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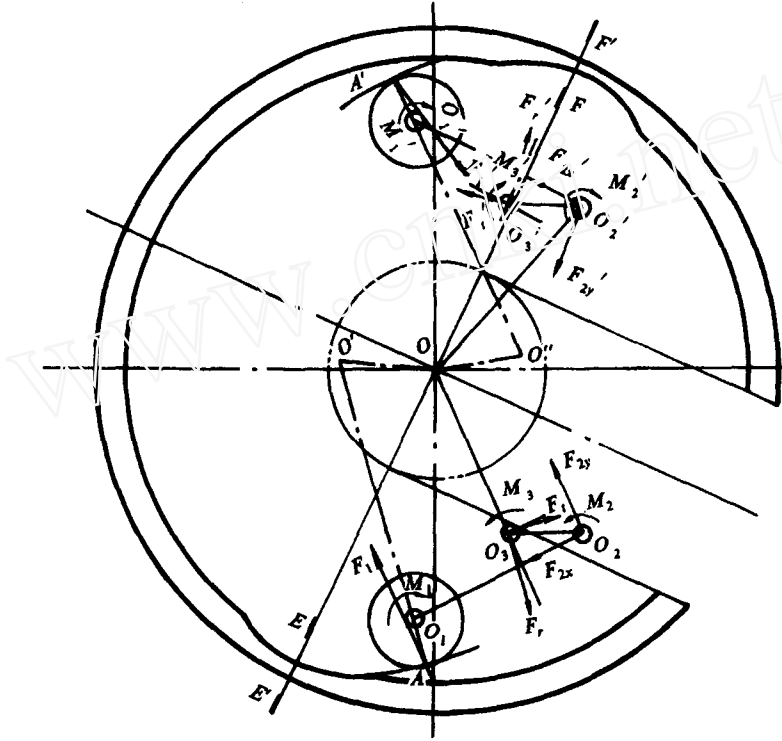


Fig. 1. The loading forces of the lever and gear wheel.

in Figs. 1, 2 and 3. Fig. 1 presents the loading force of the lever and the gear wheel, Fig. 2 shows the forces on the lever frame, and Fig. 3 schematically represents the force analysis of the key boards and the oil pipe.

(1) As shown in Fig. 1, the three key boards are connected on the same moon board, the ratio of the tangential force to the radial force should be equal, i. e., while one tooth begins to slip, the other two teeth slip too.

$$\frac{F_t}{F_r} = \frac{F'_t}{F'_r} = \frac{F''_t}{F''_r} = k \quad (1)$$

$$\left. \begin{aligned} F_t &= k \cdot F_r \\ F''_t &= k \cdot F''_r \end{aligned} \right\} \quad (2)$$

(2) According to the equilibrium conditions of the loading forces of the oil pipe, the following formulas can be obtained:

$$\sum F_x = 0, \quad F_r \sin 22.83^\circ + F'_r \sin 22.83^\circ - F''_r = 0 \quad (3)$$

$$\sum F_y = 0, \quad F_t \sin 22.83^\circ + F'_t \sin 22.83^\circ - F''_t = 0 \quad (4)$$

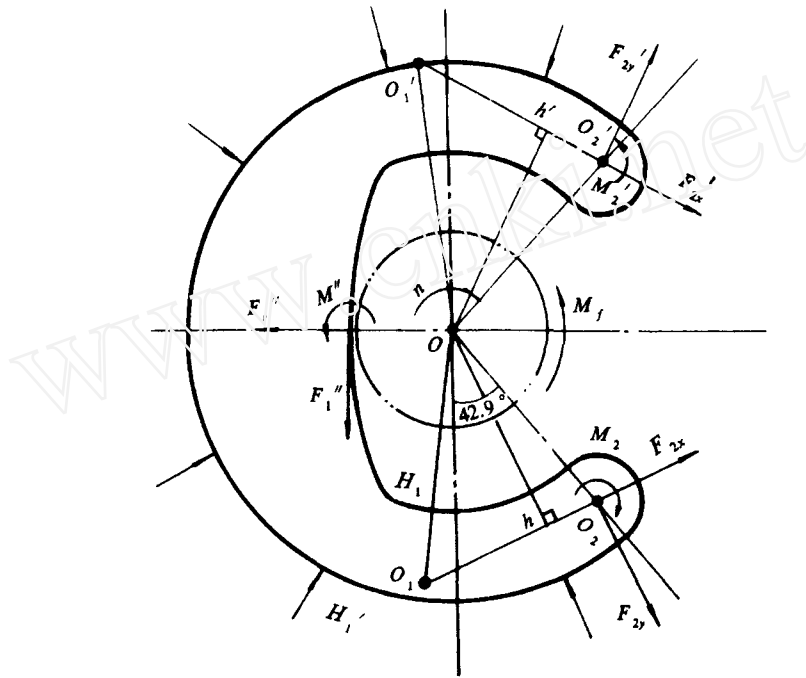


Fig. 2. The loading forces on the lever frame.

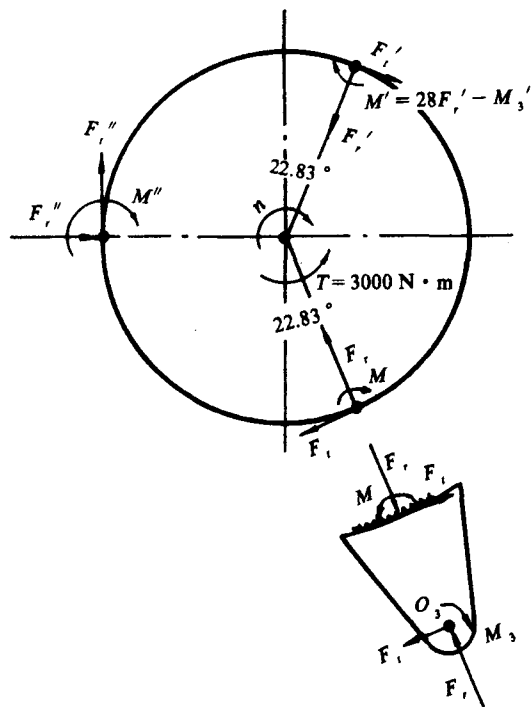


Fig. 3. The forces between the key board and the oil pipe.

$$\sum M_o = 0, \quad 45F_t'' + 45F_t + 45F_t' + M'' + M + M' = 3 \times 10^6 \text{ N} \cdot \text{mm} \quad (5)$$

where M and M' can be obtained from the torque equilibrium of the upper and lower key boards,

$$\begin{cases} M = 28F_t + M_3 \\ M' = 28F_t' - M_3' \end{cases}$$

and

$$M_3 = \sqrt{F_t^2 + F_r^2} (f \cdot R_3) = 1.35 \sqrt{F_t^2 + F_r^2}$$

$$M_3' = \sqrt{F_t'^2 + F_r'^2} (f \cdot R_3) = 1.35 \sqrt{F_t'^2 + F_r'^2}$$

in which f is the static friction factor, yielding a value of 0.15.

The ratios of the tangential force to the radial force for the three key boards are the same. Substituting

$$M'' = \sqrt{F_t''^2 + F_r''^2} \cdot 28k / \sqrt{1 + k^2}$$

into Eq. (5) gives

$$45F_t'' + 73F_t + 73F_t' = 3 \times 10^6 + (M_3' - M_3 - M''). \quad (5a)$$

In Eqs. (3) and (4) the value of 22.83° is calculated from the geometric triangle, and all the values of the angles and length can be calculated from the geometric relationship.

(3) According to the force equilibrium conditions of the lower lever (O_1, O_2, O_3), the following equations can be obtained:

$$\sum F_x = 0, \quad F_t \cos 2.7^\circ - F_r \sin 2.7^\circ + F_t \cos 84.35^\circ - F_{2x} = 0; \quad (6)$$

$$\sum F_y = 0, \quad -F_t \sin 2.7^\circ - F_r \cos 2.7^\circ + F_t \sin 84.35^\circ + F_{2y} = 0; \quad (7)$$

$$\begin{aligned} \sum M_{O_2} = 0, \quad & -F_t \cdot 35 \cdot (\cos 2.7^\circ \sin 2.7^\circ - \sin 2.7^\circ \cos 2.7^\circ) \\ & - F_r \cdot 35 \cdot (\sin 2.7^\circ \sin 27^\circ + \cos 2.7^\circ \cos 27^\circ) \\ & + F_{1y} \cdot 80 \cdot \sin 84.35^\circ = M_2 + M_3 - M_1. \end{aligned} \quad (8)$$

(4) The force equilibrium conditions of the upper lever (O_1', O_2', O_3') lead to the following equations

$$\sum F_x = 0, \quad F_1' \cos 2.7^\circ - F_r' \sin 2.7^\circ - F_r \cos 34.59^\circ + F_{2x}' = 0; \quad (9)$$

$$\sum F_y = 0, \quad -F_1' \sin 2.7^\circ + F_r' \cos 2.7^\circ - F_1' \sin 34.59^\circ - F_{2y}' = 0; \quad (10)$$

$$\begin{aligned} \sum M_{O_2'} = 0, \quad & -F_1' \cdot 35 \cdot (\sin 2.7^\circ \cos 2.7^\circ - \cos 2.7^\circ \sin 2.7^\circ) \\ & + F_r' \cdot 35 \cdot (\sin 2.7^\circ \sin 27^\circ + \cos 2.7^\circ \cos 27^\circ) \\ & - F_1' \cdot 80 \cdot \sin 34.59^\circ = -(M_1' + M_2' + M_3'). \end{aligned} \quad (11)$$

In Eqs. (8) and (11),

$$M_1 = F_1 \times 1.2;$$

$$M_2 = \sqrt{F_{2x}^2 + F_{2y}^2} \times 1.35;$$

$$M_1' = F_1' \times 1.2;$$

$$M_2' = \sqrt{F_{2x}'^2 + F_{2y}'^2} \times 1.35.$$

(5) The torque equilibrium conditions of the lever frame as shown in Fig. 3 can be expressed as

$$\sum M_0 = 0$$

or

$$88.88F_{2x}' + 27.75F_{2y}' - 27.75F_{2y}' - 88.88F_{2x}' - 45F_t'' = M_f + M'' + M_2' - M_2 \quad (12)$$

where M_f is a tested value, stands for the friction torque of the friction panel, and $M_f = 5 \times 10^5 \text{ N} \cdot \text{mm}$.

(6) The torque equilibrium conditions of the breach big pillar gear in Fig. 2 are in the following form

$$\sum M_0 = 0, \quad F_1 \sin(21.62^\circ) \cdot \overline{OA} + F_1' \sin(21.62^\circ) \cdot \overline{OA}' = 3 \times 10^6 + M_f.$$

Letting $\overline{OA} = \overline{OA}' = 120.98 \text{ mm}$, the above formula becomes

$$F_1 + F_1' = \frac{3 \times 10^6 + M_f}{44.575}. \quad (13)$$

(7) A FORTRAN program is given on the basis of the above thirteen equations and results of numerical calculation are listed in Tables 1 and 2. As shown in Table 2 where the joint forces and static friction torque at each action point are presented, the loading force of axle O_3 of the lower key board exhibits the maximum value.

Table 1 Calculation result of each force in the grip system ($\times 10^4$ N)

F_t	F_r	F_t'	F_r'	F_t''	F_r''	F_1	F_1'	F_{2x}	F_{2y}	F_{2x}'	F_{2y}'	k
1.772	8.437	1.149	5.469	1.133	5.396	3.251	4.602	1.693	5.276	2.383	2.796	0.21

Table 2 Calculation results of joint force and friction torque of each action point

Acting point	O_1	O_2	O_3	O_1'	O_2'	O_3'
Joint force ($\times 10^4$ N)	3.251	5.540	8.621	4.602	3.674	5.589
Friction torque ($\times 10^4$ N · mm)	3.901	7.480	11.64	5.522	4.960	7.545

3. Value of the Ratio of Tangential Force to Radial Force

Consider just one key board for the ratio analysis of tangential and radial forces. As shown in Fig. 4, the friction angle $\angle OBC = 19.47^\circ$ can be obtained from $\triangle OBO_3$, so the ratio of the tangential force to the radial force is calculated as

$$\frac{F_{tb}}{F_{rb}} = \text{tg } 19.47^\circ = 0.35.$$

The ratios for the other two plate teeth are the same as 0.35 by use of the same method. It is known that the ratio for two-key-board hydraulic tongs is in the range of 0.35~0.4, therefore, the values for the new tongs take the minimum indicating that the teeth board of the tongs is not easy to slip while the two-key-board tongs frequently happen.

4. Comparison of Loading Forces on Dangerous Sections of the New and Old Types of Tongs

For simplicity, suppose that the size and the transmitted torque of the gear drum for both the new and the old tongs are the same (take $T = 3 \text{ kN} \cdot \text{m}$) and the slope of the old tongs is 10° , then the reaction force on the gear drum from the rolling wheel when gripping tightly, can be calculated as $F_{\text{old}} = 7.14 \times 10^4 \text{ N}$.

As seen from Fig. 1, when the new tongs are gripping tightly, the dangerous sections of the gear angles go to the lower part (EE' section) and the supporting force around the pillar gear can be neglected, the reaction force of the rolling wheel against the gear drum being $F_{\text{new}} = 3.251 \times 10^4 \text{ N}$, and $F_{\text{old}} / F_{\text{new}} \approx 2.2$.

According to the above results, the pillar gear of the new tongs is not so easy to be out of shape and to break as frequently happens to the old tongs.

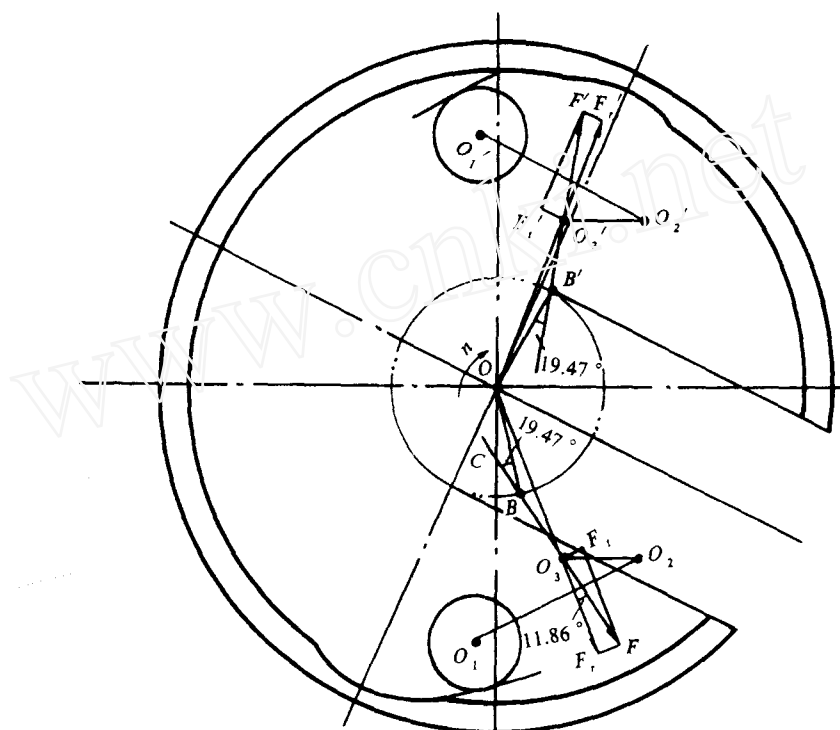


Fig. 4. Ratio of the tangential force to the radial force.

5. Conclusions

— An accurate quantitative method for analysis of the loading forces in the grip system in the key-board hydraulic tongs is proposed. The acting force at each point is calculated, with the maximum force of 8.621×10^4 N located on the connection axle between the key board and the lever, providing accurate and reliable data necessary for further strength check.

— The ratio of the tangential force to the radial force for the new oil pipe tongs is 0.35, which is smaller than that for the old tongs (0.35~0.40). So the teeth of the new tongs are not so easy to slip and the number of replacements of the teeth board can be largely reduced, increasing the well repairing efficiency and the economic efficiency accordingly.

— Since the lever and the lever frame have been added to the mouth of the new tongs, when the oil pipe is gripped tightly, part of the reaction forces of the oil pipe against the key board is received by the two ends of the lever frame, and the slope angle is increased from 10° to 18° , thus, the acting force of the rolling wheel against the gear drum is greatly reduced. A conclusion can be drawn from the numerical results that, on the dangerous sections of both the new tongs and the old tongs, the ratio of the largest acting forces for these two kinds of tongs is 2.2, and the mouth of the new tongs is not so easy to be out of shape and to break as frequently happens to the old tongs.

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