International Journal of Engineering and Manufacturing Science.
ISSN 2249-3115 Volume 7, Number 1 (2017), pp. 67-75

http://www.rfgindia.com

A New Energy-Efficient Pumping Unit Applied in the Oilfield

Juan Li

Periodical Office, China University of Petroleum (East China),

No.66 Changjiang West Road, Huangdao District

Qingdao City 266580, Shandong Province, China

Abstract

It is very significant for China to reduce the consumption of energy. In order to saving energy, a new pumping unit comes up. Design principle, structure and working theory of the new pumping unit are reported. The mathematic models of the unit are set up. Through the field test for industry application, it proved that the utilization rate of the motor is the good, and energy-saving effect is remarkable.

Significance: This paper reports a novel pumping unit based on a new energy-saving principle. The new unit is applied in the oilfield industry with an obvious good efficient.

Keywords: feedback torque and power, new pumping unit, design principle

1. INTRODUCTION

Conventional beam pumping units have been widely applied among oilfields in the world. There are more than 200,000 oil wells in the onshore of China; more than 55% of the wells make use of the conventional beam pumping unit. However, large energy and steel consumption come into being when applying the conventional beam pumping unit. In China, the conventional beam pumping unit uses up over 100 billion kWh electrical energy and over 1,650,000 tons of steel per annum; only an investment is over 21.24 billion USD.

Reducing energy consumption is a topic of worldwide concern. In China, if energy-saving two percentage points, it will be equivalent to the annual increase of 3 million tons of crude oil, reducing more than 400,000 tons of greenhouse-gas emissions. Many researchers focus on improving performance of the beam pumping unit. A variety of pumping units have been developed. However, the problem of feedback torque and power which waste energy is not resolved completely. For the sake of energy saving, the design principle of a new pumping unit comes up with. Field experiments show that the new unit achieves no feedback torque and power, and the unit utilization efficiency is improved.

2. DESIGN PRINCIPLE OF A NEW PUMPING UNIT

Regarding to the torque curves of the conventional beam pumping unit, as shown in Fig.1, there are negative and zero values nearby 0°, 180°, 360° in the net torque which is got by overlaying the suspension center load and balance torque. The negative and zero values mean that lost work and feedback power generation, which waste energy. And higher peak and deep valley in the net torque, on one hand cause the beam unit to shock and vibration, on the other hand, require choosing larger power rating, which reduce the motor utilization rate and increase energy consumption.

With the purpose of eliminating negative and zero, even out peak and valley values for the net torque, and improving the energy utilization rate, a new pumping unit is put forward [1]. By changing the work range of the suspension center load, the torque curve for the suspension center load has a certain offset, so that enlarge upstroke and lessen downstroke, and the net torque keeps the positive value throughout a work cycle.

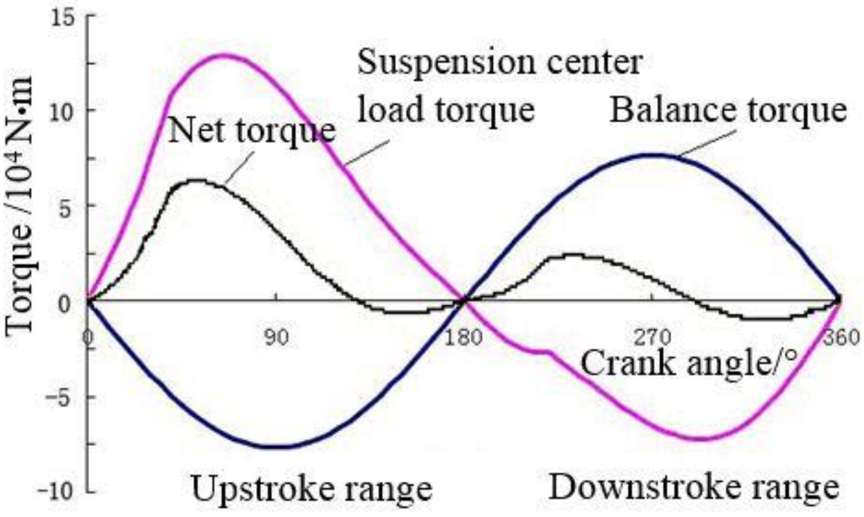

Fig.1 Torque curves of conventional beam pumping unit

3. STRUCTURE OF THE NEW PUMPING UNIT

The new pumping unit consists of electromotor, reducer, crown and traveling blocks, flexible rope and so on, shown in Fig.2. A balance crank AOB clockwise rotates as the driving arm mounted upon the reducer output shaft O. As a slave arm, the suspension center load crank $O'C$ driven by the pole BC connected with AOB rotates clockwise around an axis O'. A certain distance lies between the axis O and O'. From the fixed point D, the flexible rope around the travelling block C and two crown blocks E and F, pass the wellhead, and directly connect a plunger pump. The travelling block C drags the flexible rope to drive the plunger pump up and down reciprocating movement.

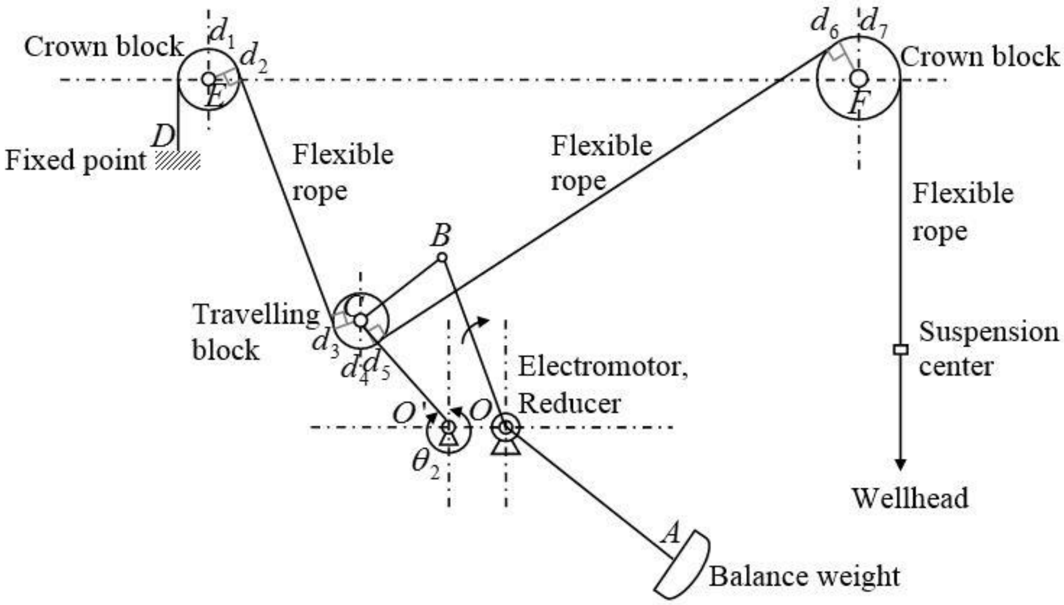

Fig.2 Schematic diagram of the new pumping unit

4. WORKING PRINCIPLE OF THE NEW PUMPING UNIT

With an eccentric distance between two rotating centers O and O', up-stroke interval range of the suspension center load is greater than 180°, and the down-stroke interval is less than 180°. In the case of stable rotational speed, the up-stroke time is longer than the down-stroke. The work characteristic of up fast down slow is good to balance the motor power.

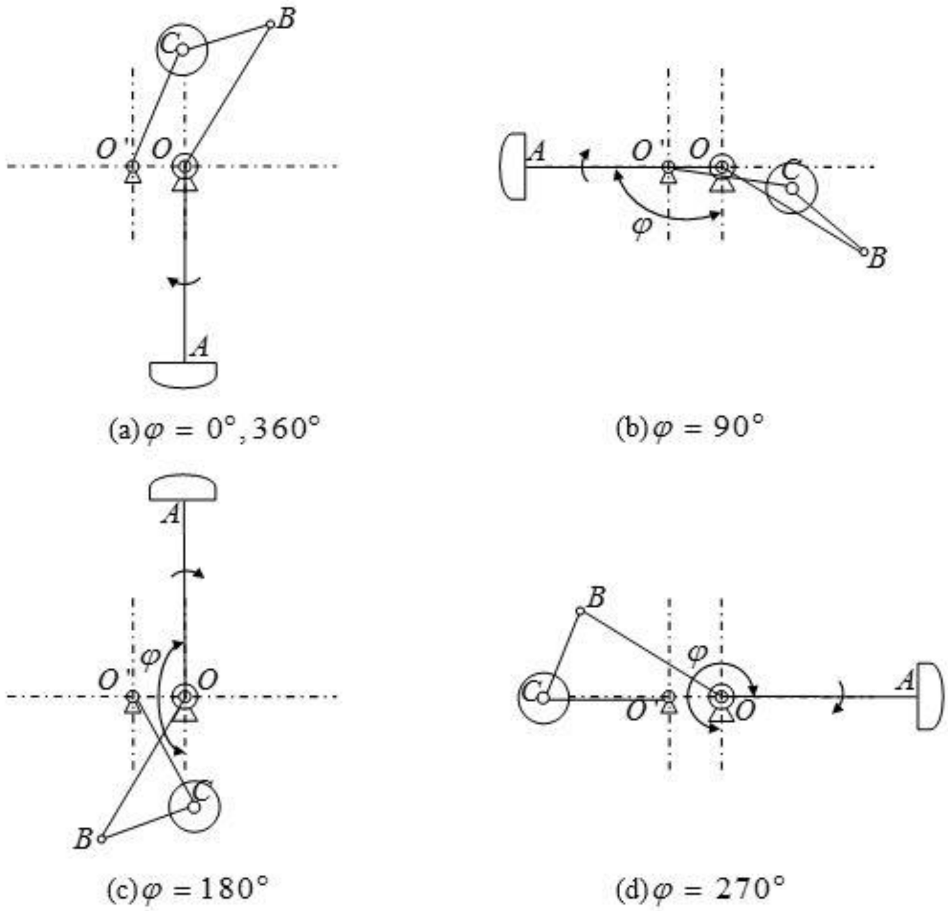

Fig.3 Working principle of the new pumping unit

As shown in Fig.3, the balance crank AOB begins to rotate clockwise when OA is in 6 o'clock position, an angle between OA and 6 o'clock position is φ. By comparing with the conventional beam pumping unit, the force status of the reducer output shaft O is improved mainly as follows. When the angle φ equal to 0° or 360°, the suspension center load does effective work in advance, the balance weight torque is zero, and the net torque is positive. When φ equal to 90°, the force arm of the travelling block C on the driving shaft O is smaller, the effective force of the balance weight on the travelling block is larger; meanwhile, the equivalent force of the shaft input torque on the travelling block also increases, making the net peak torque become smaller. When φ equal to 180°, the suspension center load does positive work, the balance weight torque is zero, and the net torque is positive. When φ equal to 270°, the radius of the travelling block on the shaft O increases, the effective force of the suspension center load increases, the required reducer input torque is reduced, effectively reducing the net torque peak.

In summary, the intersection of the torque curves of the balance weight and suspension center load deviate from 0°, 180°, 360° position, the net torque always is positive and the peak becomes smaller. Thus, the motion characteristics of the new pumping unit are superior to the conventional beam pumping unit, work characteristics of the new unit conducive to a balanced motor power, alternating amplitude of the net torque are small and uniform and remain in the positive range, and the required reducer torque and motor power are small.

5. THE MOTION MODEL OF THE SUSPENSION CENTER

According to the working principle of the new pumping unit, the travelling block makes a circular motion, use of the flexible rope to drive the pump for reciprocating movement. Assume that the flexible rope is uniform, and its deformation rate is same. As shown in Fig.2, the displacement from the suspension center connected with the flexible rope is the length variation between d_1 and d_7 points on the flexible rope, and can be expressed as the equation (1).

$$S = (d_1d_2 + \overline{d_2d_3} + d_3d_4d_5 + \overline{d_5d_6} + d_6d_7)\big|_{\theta_2,t} - (d_1d_2 + \overline{d_2d_3} + d_3d_4d_5 + \overline{d_5d_6} + d_6d_7)\big|_{\theta_2=0,t=0} = f(\theta_2) \quad (1)$$

Wherein, S is the suspension center displacement, m; d_1d_2 is the arc length between the d_1 and d_2 points on the crown block E, m; $\overline{d_2d_3}$ is the line length between the d_2 point on the crown block E and the d_3 point on the travelling block C, m; $d_3d_4d_5$ is the arc length among d_3, d_4 and d_5 points on the travelling block C, m; $\overline{d_5d_6}$ is the line length between the d_5 point on the travelling block C and the d_6 point on the crown block F, m; d_6d_7 is the arc length between the d_6 and d_7 points on the crown block F, m; θ_2 is any angle from 12 o'clock position clockwise to $O'C$ in any time, rad; t is time, s; $f(\theta_2)$ is a function of θ_2, m.

The suspension center velocity can be obtained from the equation (2).

$$v = \frac{dS}{dt} = \dot{f}(\theta_2) \quad \ldots \quad (2)$$

Wherein, v is the suspension center velocity, m/s; $\dot{f}(\theta_2)$ is the first time differential of $f(\theta_2)$, m/s.

The suspension center acceleration can be got by the equation (3).

$$a = \frac{d^2S}{dt^2} = \ddot{f}(\theta_2) \quad \ldots \quad (3)$$

Wherein, a is the suspension center acceleration, m/s^2; $\ddot{f}(\theta_2)$ is the second time differential of $f(\theta_2)$, m/s^2.

6. THE NET TORQUE OF THE REDUCER

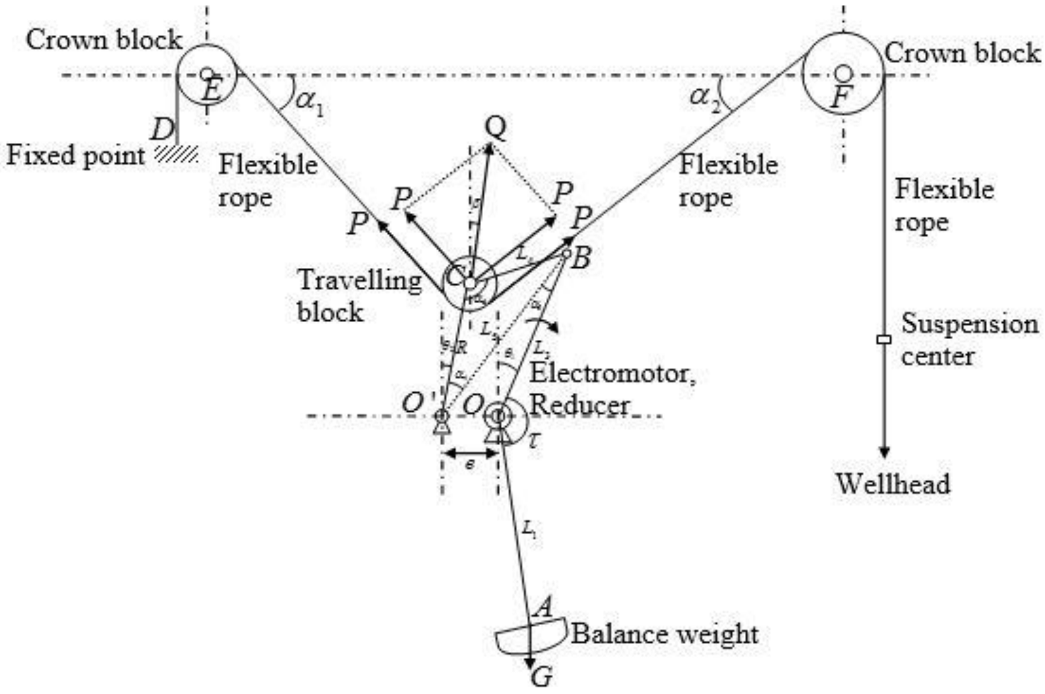

Fig.4 Force diagram of the new pumping

The force diagram of the new pumping unit is shown in Fig.4, L_4 is the length of CB, L_5 is the length of $O'B$, R is the length of $O'C$, e is the length of $O'O$, according to the principle of the moment equilibrium, the net torque on the reducer output shaft can be calculated from the equation (4).

$$M_n = \frac{2PL_3 \sin(\frac{\alpha_1+\alpha_2}{2})\sin(\theta_2-\beta)}{\sin\alpha_6}\sin(\pi-\alpha_4-\alpha_6+\alpha_5) - GL_1\sin(\theta_1+\tau) \quad \ldots \quad (4)$$

Wherein, M_n is the net torque on the reducer output shaft, $N \cdot m$; P is the suspension center load with relevance to the acceleration a, $N \cdot m$; L_3 is the length of OB, m; α_1 is an angle between the horizontal line and the flexible rope which lies the crown block E and the travelling block C, rad; α_2 is an angle between the horizontal line and the flexible rope which lies the crown block F and the travelling block C, rad; β is an angle between the vertical line and the CQ which is a resultant force of the suspension center load P on the travelling block C, rad; α_6 is the angle $\angle O'CB$ between the $O'C$ and the BC, rad; α_4 is the angle $\angle CO'B$ between the CO' and the BO', rad; α_5 is the angle $\angle O'B($ between the $O'B$ and the OB, rad; G is the balance weight, N; L_1 is the length of the OA, m; θ_1 is any angle from 12 o'clock position clockwise to the OB in any time, rad; τ is an angle from the OB clockwise to the OA, rad.

The root-mean-square torque of the net torque of the reducer output shaft can be calculated from the equation (5).

$$M_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} M_n{}^2 d\theta_1} \quad \cdots \quad (5)$$

Wherein, M_{rms} is the root-mean-square torque of the net torque of the reducer output shaft, $N \cdot m$.

7. EFFECTIVE OUTPUT POWER OF THE MOTOR

The effective output power of the motor can be calculated from the equation (6).

$$N_{eop} = \frac{\omega M_{rms}}{9549\eta} \quad \cdots \quad (6)$$

Wherein, N_{eop} is the motor effective output power, kW; ω is the angular velocity of the crank AOB, rad/s; η is the transmission efficiency.

8. FIELD TEST FOR INDUSTRY APPLICATION

The work operating conditions on a field test for industry application were as follows. The oil well depth of $2250m$, the pump stroke of $3.5m$, the stroke number of 4min^{-1}, the $70mm$ pump diameter of the hydraulic plunger pump[2]. Separately make use of the conventional beam pumping unit and the new pumping unit to suck out the underground oil, while the other conditions keep constant.

As shown in Fig.5 and Fig.6, compared with the conventional beam pumping unit, the net torque of the new pumping unit keeps always the positive value, namely no feedback torque, small fluctuation amplitude, so the heat loss of the motor is small.

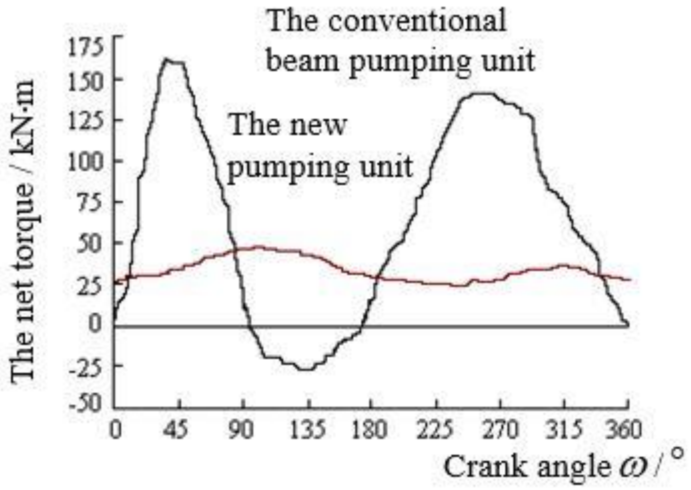

Fig.5 Field measuring curves of the net torque of the conventional beam pumping unit and the new pumping unit

Fig.6 Field test of the new pumping unit

CONCLUSIONS

In order to eliminate the feedback torque and power of the conventional beam pumping unit and reduce the consumption of the energy, a new pumping unit comes up.

The structure and the working principle of the new pumping unit are described. The motion and the torque and the power models are established.

The field tests show that the small fluctuation of the motor power, and the net torque of the new pumping unit is received, and no feedback power and torque exist during an entire pumping cycle.

ACKNOWLEDGEMENTS

This work was financially sponsored by the China Petroleum Science and Technology Foundation (dq2010-eyk008).

REFERENCES

[1] Han, X.T., Li, X.D., Xu, J.C. et al., 2010, "Power and Torque Balance Pumping Unit." China Patent No.201,010,258,217.4.

[2] Han, X.T., Wang, X.L., Hou, Y. et al., 2005, "Hydraulic Plunger Pump." China Patent No.200,510,082,603.1.