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Synchronization design of shape and structure of petroleum machinery and equipment

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Abstract. The purpose is to study the synchronous design of the form and structure of petroleum machinery equipment. The size of the four-bar mechanism of the conventional pumping unit determines its dynamic performance, kinematic performance and energy consumption. Based on the rated torque value of the reducer 1824 inlbs (210 kN.m), the suspension load value 427 1b (190 kN) and the maximum stroke length 240 in (6.09 m), the size of the four rod mechanism is optimized. The optimum performance of the four-bar mechanism size is studied. At the same time, according to the basic theory and installation dimensions, the size of the three bearing housings is designed. Its influence on the movement and force of the four-link structure of the pumping unit is discussed. The results show that this design can reduce the manufacturing cost of the product. In addition, it meets the demand of small quantity and specification. Therefore, it can be concluded that the design can meet the needs of production.

Key words. Pumping unit, four connecting rods, oil machinery, equipment.

1. Introduction

According to different working conditions of different oil wells, the requirements of the mechanical oil production methods for oil equipment technology are constantly improving. As a result, the design and manufacturing level of the oil recovery equipment has been greatly improved [1]. The pumping units also develop and innovate from their initial forms. In the process of continuous development, there are hundreds of technical inventions of pumping units [2]. In this paper, the model C1824D-427240 of the largest beam pumping unit in China is studied.

In recent years, the pumping unit industry has been developing in a new direction [3]. The main features of these new pumping units are the adoption of many modern technologies and advanced structural schemes, as well as new materials and processes [4]. The adaptability, economy, reliability, advancement and technical level of pumping units have reached the highest level ever. It has made outstanding

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contributions to the efficient, economical, safe and reliable exploitation of petroleum resources [5]. Here is a brief outline of the general development. It not only develops towards large pumping equipment and low energy consumption, but also develops towards automation and intelligence [6]. The high adaptability is very important. The special working condition pumping unit is developed [7]. The design concept of C1824D-427-240 pumping unit is designed strictly according to API standard. According to the domestic multinational mining units and the Middle East and other countries on the demand for pumping units, the production of API conventional pumping unit is imminent [8]. In this way, it is used to improve the series standards of API conventional pumping units. At the same time, the market competitiveness of pumping units in our country has been enhanced. It has important guiding significance for our occupation of the international market share [9].

The top drive rig was originally used for drilling in marine areas. At present, it is gradually applied to land drilling, desert areas and alpine regions. It evolved from conventional strata to more complex geological and stratigraphic structures. It should reduce the system height and save the cost of derrick reconstruction, so that the device can be effectively applied to various drilling systems. Although some of China's petroleum machinery plants have the ability to produce some types of top drive drilling equipment, the oil fields are gradually being popularized. However, due to the late start of China's top drive, it is still in the stage of development. Domestic top drive product model is relatively simple, which cannot meet the needs of China's offshore and land oil drilling rigs. It is still necessary to further strengthen the research of the top drive device, develop new products, increase specifications, and gradually form the top drive series in China, so as to realize the domestic production of top drive. At present, the development of top drive device has entered a mature stage. Its main features are as follows: first, the power motor (electric motor or liquid motor) with high power and large torque is adopted to achieve the torque speed characteristic suitable for drilling. Second, the drilling and unloading device is adopted, so that the drill string can be unloaded at any position in the derrick, thus giving prominence to the advantages of the top driving mode. Third, the rigid rail is added to the derrick to withstand the reverse torque of the derrick during drilling. The top drive drilling system is suitable for marine, desert, Arctic and other poor environmental conditions. The number of applications in foreign countries is more, and it accounts for more than 90 %.

2. Methodology

2.1. Determination of dimension of four connecting rods

The design of pumping unit type is discussed in C1824D-427-240 [10]. The size of the four bar linkage of the pumping unit is shown in Fig. 1. The height of the bottom plane of the pumping unit to the center of the support bearing is H. It is determined according to the maximum stroke length of the pumping unit. In addition, it also determines the height of the pumping unit. The specific calculation method of H is

$$H = s_{\max} + H_{\mathrm{h}} + 0.2 \sim 0.25\,\mathrm{m} \tag{1}$$

In the formula, $s_{\max}$ is the maximum stroke length (m), H_{c} denotes the wellhead height (m), which is generally 1.2–1.5 m and H_{h} is the height of the rope (m), which is generally 0.35–0.4 m.

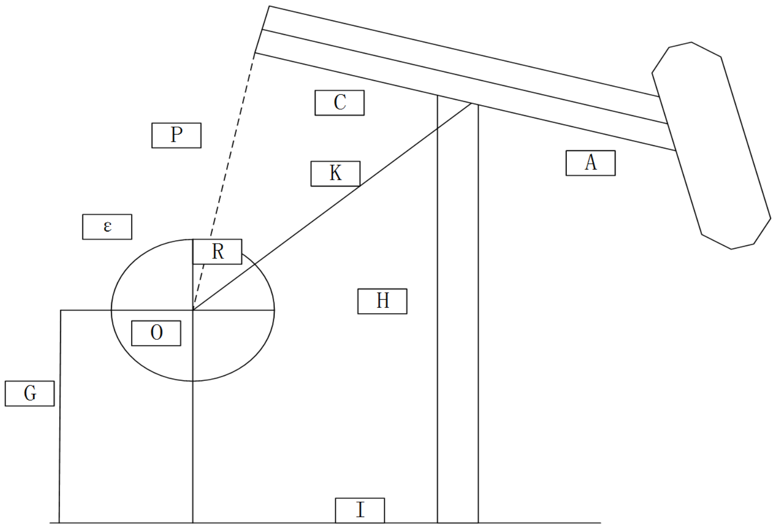

Fig. 1. Size diagram of four-bar linkage mechanism of beam-type pumping unit

The design of the "C" type pumping unit of the four linkage size of the beam, forearm length A is 6600 mm. The length of the rear arm of the beam is 3460 mm. The horizontal distance I of the center of the bracket bearing to the center of the output shaft of the gear unit is 3505 mm. The connecting rod length P is 5095 mm. The vertical distance (H–G) of the center of the bracket bearing to the center of the output shaft of the gear unit is 5080 mm. In addition, it was determined that the distance G between the center of the output shaft of the reducer and the bottom of the base was 3433 mm. The distance H from the center of the bracket bearing to the bottom of the base is 8515 mm.

2.2. Theoretical calculation of pumping unit

Figure 2 shows the mechanism of the conventional pumping unit.

The geometric calculation follows. According to the known condition and the triangular residual u theorem, the angle values are obtained, that is, the degrees of β, a, σ, θ', θ and the length of the pumping stroke [11]. The motion calculation: The velocity of the suspension point V_t and the acceleration point a_A are calculated. The process of calculation: under different pump diameters and different strokes, the maximum pump depth is calculated. The daily amount Q of fluid is calculated

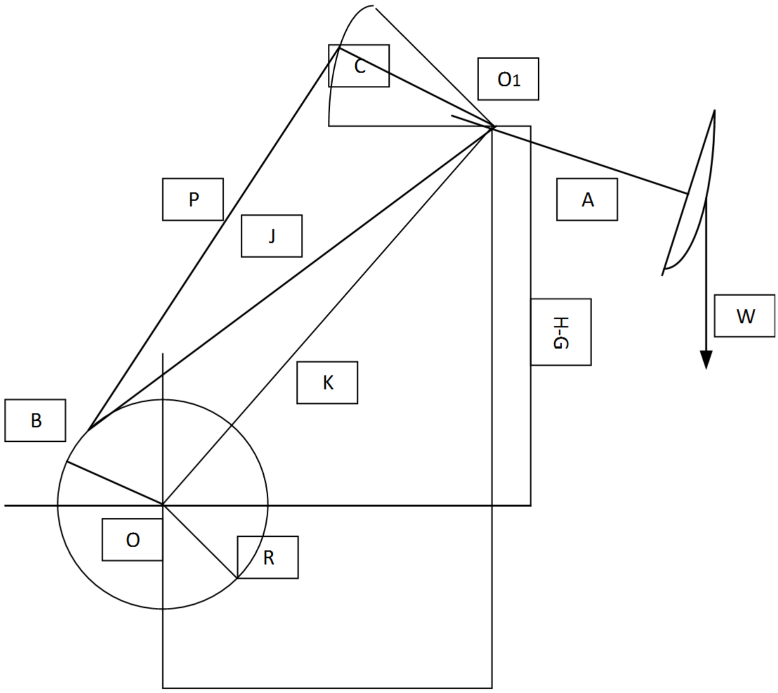

Fig. 2. Mechanism motion diagram of pumping unit

by the single well theory [12]. The working torque T_{W}, the balance torque T_{R}, the net torque T_{N} and the offset angle τ are calculated. The actual stroke length s_{i} and the actual output Q_1 are calculated. The power of the motor is calculated. The formulae for particular quantities are:

Connecting force:

$$F_{\mathrm{L}} = \frac{A}{C \sin\beta} W' . \tag{2}$$

Crank tangential force:

$$F_{\mathrm{ct}} = F_{\mathrm{L}} \sin\alpha . \tag{3}$$

Crank legality:

$$F_{\mathrm{cl}} = F_{\mathrm{L}} \cos\alpha . \tag{4}$$

Horizontal component of support:

$$F_x = F_{\mathrm{L}} \cos(\delta + \beta) . \tag{5}$$

Vertical component of support:

$$F_y = F_{\mathrm{L}} \sin(\alpha + \beta) + 1.15W . \tag{6}$$

Support force:

$$F_{\mathrm{s}} = \sqrt{F_x^2 + F_y^2}\,. \tag{7}$$

Stretch force direction:

$$\lambda = \arctan \frac{F_x}{F_y}\,. \tag{8}$$

Working torque:

$$T_{\mathrm{W}} = \frac{AR\sin\alpha}{C\sin\beta} W'\,. \tag{9}$$

2.3. Checking calculation of main bearing elements

The moving mechanism of a conventional pumping unit is a four-link mechanism. According to the foregoing, the main load-bearing components are: support, beam, beam, rod, crank and base. Then, there are support bearings, end bearings and crank pin bearings for connecting them. In addition, there are pins, bolts and other parts of the force. In the process of checking, the following calculation is carried out mainly: beam, beam, strength calculation, bearing, and strength and life calculation. The suspension load, the stroke and the strike stroke of the light rod are different. When checking calculation, the maximum load, maximum stroke and the maximum thrust are taken together. If the "three most important" conditions cannot be met at the same time, the calculation should be carried out in descending order.

The section size of the beam is 1050×350 mm, that is to say, the selected H-steel is made of 350×350 mm formed welding. The overall structure is welded by the upper and lower wings and the side plates. According to the loading condition of the traveling beam and the relevant knowledge of the mechanics of the material, the stress of the beam in the center section is the largest. When considering the role of the shim plate, it is safe to calculate the main body of the beam. In addition, the beam is a square structure. The flexibility of u is generally no more than 10, which does not require fatigue calculation and stability check. The beam is a H steel formed by welding, and the flexural modulus (S_x) of the section is 16804713 mm^3. From the above conditions, the maximum bending moment of the beam is calculated as

$$M_y = A \cdot W_{\max} = 6600 * 190000 = 1254000000(\mathrm{Nm}) \tag{10}$$

and the maximum stress of the beam is

$$\sigma_y(fcb) = \frac{M_y}{W_n(SX)} = 74.62\,\mathrm{MPa} < 74.62\,\mathrm{MPa} \sim 1000\psi\,. \tag{11}$$

By calculation, the beam meets the requirements specified by API and these requirements can be obtained. The strength of the beam is calculated. The transverse beam is connected to the connecting rod through the connecting rod pin and mainly bears the force of the connecting rod. Among them, the length of the transverse beam body is 2993 mm. The distance between the two pin holes is 2800 mm, and the span of the bolt hole is 592 mm. The main material of the cross element is H steel of cross section 606×201 mm. Its flexural rigidity is $W_n(Sx) = 3000000\,\mathrm{mm}^3$.

According to the force of the cross beam, the transverse beam can be simplified as simply bent beam with simply supported ends. The intermediate one is acted by pure bending moment. Through analysis, it can be seen that bolt hole is the most dangerous section. Its structure is checked and calculated. According to the load spectrum of the crossbeam in the schedule, it is known that the maximum load of the two center hole of the crossbeam is 202.247 kN. According to the stress analysis and the size of the structure, the maximum bending moment of the dangerous cross section of the beam is $M_y = 239258.201\,\mathrm{Nm}$. Therefore, the maximum bending stress of the cross section is

$$\sigma_y = \frac{M_y}{M_n} = \frac{239258.201}{3000} = 79.75\,\mathrm{MPa} > 77.4\,\mathrm{MPa}\,. \tag{12}$$

Since the calculation only considers the main body of the beam, and the effect of the strengthening plate is not considered, the strength of the girder can be considered sufficient. Similarly, the beam structure is not subjected to stability calculations and fatigue calculations. In the analysis of connecting rod of API conventional pumping unit with crank balance, the force of connecting rod can be simplified as two force pole, and the connecting rod is only subjected to pull force. In general, the size of the connecting rod is smaller than the size of the upper and lower connecting rod, and the strength is considered sufficient. Therefore, only the strength of the connecting rod can be calculated.

2.4. Checking of crank pin bearing

The crank pin bearing also rotates at low speed, which is subjected to unstable periodic variation load. According to the load spectrum, the maximum value $P_{\max}$ of the bearing force of the crank pin is 20224.7 kg, and the minimum force $P_{\min}$ is 12983 kg. According to the known conditions, it can be obtained

$$F_r = \frac{1}{3}(2P_{\max} + P_{\min}) = 17810.8\,\mathrm{kg}\,. \tag{13}$$

For the installation of a pair of bearings, the bearing force is $F_r = 17810.8\,\mathrm{kg}$. To check the "mechanical design manual", for the 22328 double row spherical roller bearing (53628) $C = 1040\,\mathrm{kN}$, $c_\mathrm{o} = 1770\,\mathrm{kN}$, $X = 1$, $Y = 1.8$ and $F_\mathrm{a} = 0$. Therefore, $P = F_\mathrm{r} + F_\mathrm{a} = F_\mathrm{r} = 178.11\,\mathrm{kN}$, $p_\mathrm{o} = XF_\mathrm{r} + YF_\mathrm{a} = Fr = 178.11\,\mathrm{kN}$.

The static strength check: according to its working characteristics, the instantaneous dynamic load factor is $\mu = 2.0$, and the static safety factor is $S_\mathrm{s} = 1.35$. It can be concluded that

$$S_\mathrm{o} = \frac{c_\mathrm{o}}{up_\mathrm{o}} = \frac{1770}{2 \cdot 178.11} = 4.79 > S_\mathrm{s}\,. \tag{14}$$

The process of life calculation is

$$L_\mathrm{H} = \frac{10^6}{60n}\left[\frac{f_\mathrm{T} C_\mathrm{r}}{F_\mathrm{f} p}\zeta\right]\,. \tag{15}$$

According to the working conditions of this bearing, check the "mechanical design manual", take $\varepsilon = 1.2$, $f_T = 1.0$, $F_f = 1.35$, $n = 4.0$, then, these parameters are brought into the formula. After calculation, it is obtained $L_H = 549321.14$ hours. It can be seen that the bearing life is sufficient.

2.5. General design structure diagram of pumping unit

Figure 3 shows the general design structure diagram of pumping unit

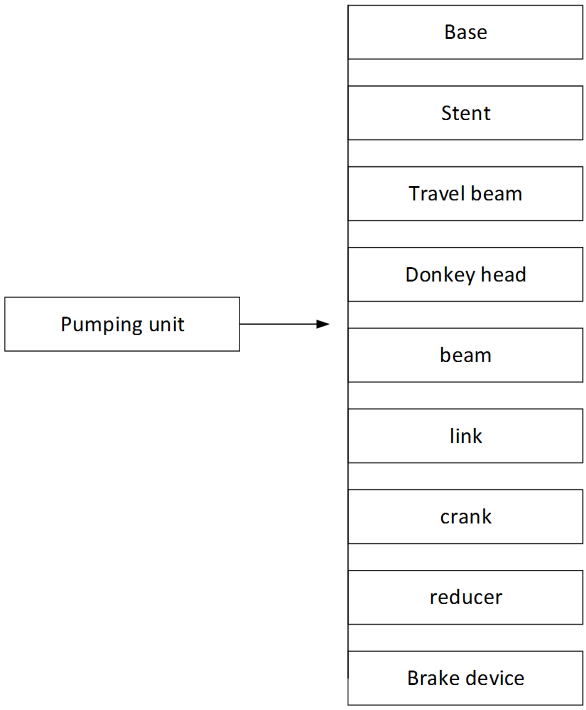

Fig. 3. General design structure diagram of pumping unit

3. Result analysis and discussion

The design dimensions of the pumping unit are shown in Table 1.

The specific data for designing other components are as follows. The total length of the transverse beam is 2993 mm. The distance between the two pin holes is , and the span of the bolt hole is 592 mm. The main material of the cross element is H steel of cross section 606×201. The connecting rod selection size is $102 \times 10\,\mathrm{mm}^2$ steel tubes. The maximum tensile force is 202.247 kN. The maximum value of the bearing capacity of the support shaft is 66641.63 kg, and the minimum force is 45110.96 kg. The maximum bearing capacity of the tail shaft is 40449 kg, and the minimum force is 25966 kg. The maximum value of the bearing force of the crank pin is 20224.7 kg, and the minimum force is 12983 kg. According to the data in the table, the maximum stress of the beam is 74.62 MPa, less than 77.4 MPa under the condition of maximum load, maximum stroke and maximum thrust. This calculation only considers the beam body, and does not consider the role of the enhanced version. Therefore, it can be considered that its strength is enough. The strength of the connecting rod meets the requirement of use and the size is reasonable. The static strength of the bracket bearing is greater than 2.1 S_s, and the service life is 14537.05 hours, and all the requirements are satisfied. The static strength of the tail bearing is greater than 4.5 S_s, and the life span is 274972 hours. Therefore, they meet the requirements. The static strength of crank pin bearing is greater than 4.97 S_s, and the life span is 549321.14 hours. All of these elements meet the requirements. All parts meet the requirements of stress and service life, so the design can meet the needs of production.

Table 1. Design of components of pumping unit

Pumping unit parts	Design dimension (mm)
Forearm length A	6600
The length of the rear arm of the beam C	3460
Bracket bearings to the horizontal distance of the reducer I	3505
Connecting rod length P	5095
The vertical distance of the support bearing to the reducer (H-G)	5080
Distance between the output shaft of the reducer and the base plane of the base G	3433
The distance between the center of the bearing and the base plane H	8515

4. Conclusion

The size of the four bar linkage of the beam pumping unit determines its movement performance, dynamic performance and energy consumption. According to the principle of determining the four link mechanism, the parameters of the four link structure are obtained. Through the determination of the size of the four connecting rod of the pumping unit and related theoretical calculations, structural design and verification, the size of C 1824D-427-240 pumping unit is determined. The structure design of the pumping unit is designed according to the standard of API. According to the size of the four link structure of the pumping unit, the structure size of the parts is determined, and the structure and size of the pumping unit are determined. According to the design theory of pumping unit, an analytical model of C 1824D-427-240 pumping unit is established. According to the standard of API and related theoretical calculation, the structure type and size parameter of pumping unit are obtained. The basic calculation of the model pumping unit is completed.

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