Processing capabilities of reducers with eccentric gearing for rotary drilling rigs

E A Petrovsky[1], **K A Bashmur**[1], **Yu A Geraschenko**[1], **E V Tsygankova**[1] **and V V Bukhtoyarov**[1,2]

[1]Siberian Federal University, 79, Svobodny Av., Krasnoyarsk, 660041, Russia
[2]Reshetnev Siberian State University of Science and Technology, 31 Krasnoyarsky Rabochy Av., Krasnoyarsk, 660037, Russia

E-mail: bashmur@bk.ru

Abstract. The present paper is dedicated to assessment of possibilities for using reducers with eccentric involute gearing in the system of the drilling rig top drive. Modern problems of top drive systems, in particular disadvantages of applied reducers are considered. The kinematics of eccentric gears is investigated; the main characteristics of the proposed gearing are calculated. High gear ratios and efficiency of the mechanism with its low weight and dimensions are revealed.

1. Introduction

The development of the oil and gas industry, in particular the introduction of new well construction technologies requires the development of drill string rotators installed in drilling rigs. At the present stage of well development power swivels as well as top drive systems (TDS) were developed as rotators [1], [2]. Existing TDS are divided into hydraulic and electric which are powered by direct or alternating current.

The main disadvantages of the known systems are the low power utilization coefficient, the impossibility of the output shaft rotation speed self-regulation depending on the required speed and load of the working tool [3]. Also it is the TDS torsional vibrations of large amplitude – drilling rig – drill string system which lead to wear of the system and adversely affect the drilling process which is caused by the presence of a large number of rotating parts, in particular, dimensional reducers used in the TDS [4]. There is a need to use reducers with the smallest possible number of stages which realize a large torque in the most ergonomic form which will increase the TDS reliability, increase the efficiency and the necessary torque when drilling hard rocks.

2. Types of reducers applied and their disadvantages

Planetary and cylindrical reducers are most often applied in modern drilling rig TDS. Each type of a reducer has the advantages and disadvantages. In particular, cylindrical reducers are quite massive and use of planetary gearing assumes high precision in the manufacture of the reducer and its installation. And with an increase in the gear ratio of the planetary reducer, its efficiency decreases [5].

One of kinds of tooth gearings which was planned to be applied in the oil and gas equipment is wave gearing [6]. Reducers with such gearings possess large gear ratios and practically zero play, but less torsional stiffness; there is a loss of efficiency for wheel deformation. The manufacture of flexible gears involves the use of expensive materials and high precision.

There are modern designs of reducers eliminated from the above disadvantages. This is the reducer using eccentric-cycloidal gearing, reducers with intermediate rolling elements, TwinSpin bearing reducer, cycloid speed reducers. However, these reducers are quite difficult to manufacture, special machines and high precision processing of the components are required. Bearing and cycloid speed reducers have a large number of parts subject to rapid wear [7].

Thus, there is a need for research and development of new types of gears and reducers for the TDS meeting all requirements of the oil and gas industry and are free from the mentioned disadvantages.

3. Eccentric involute gearing reducer for drilling rig rotators

The authors of the article proposed to use a reducer with eccentric involute gearing in the TDS (figure 1).

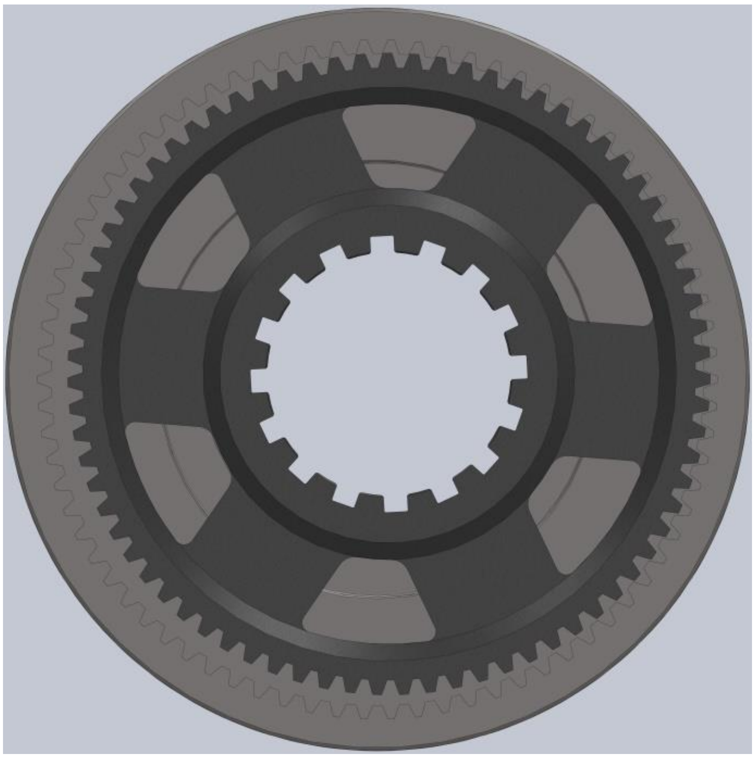

Figure 1. Eccentric involute gearing reducer mechanism.

This gearing type is based on the planetary K-H-V mechanism with internal gearing with a small difference in the number of wheels teeth [8]. According to the principle of action eccentric gears are close to wave ones, but they do not have a short-lived flexible wheel. Also one of the main features is its compactness and low weight compared to conventional planetary reducers with the ability to transmit high torques [9].

4. Kinematics of eccentric gearing reducer

To assess processing capabilities of the proposed reducer the main gearing characteristics were calculated for the drilling rig top drive systems (TDS). The design scheme of eccentric gearing is shown in figure 2.

The wheel 1 with internal teeth and radius r_1 is fixed. This wheel 1 is linked to satellite 2 with radius r_2. In view of a small difference in sizes of radiuses r_1 and r_2 carrier is executed in the form of eccentric with eccentricity $e = \varepsilon = \overline{OA}$. All gears with the difference in number of teeth equal to one are non-polar and have large gearing angles.

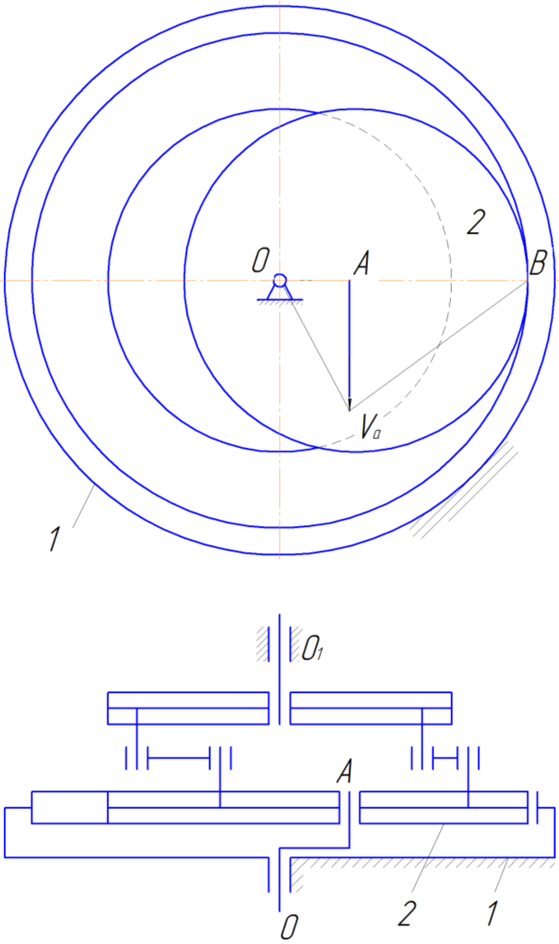

Figure 2. Design scheme of eccentric gearing: 1 – tooth-wheel with internal gearing; 2 – satellite.

Let's find angular speed ω_2 of satellite 2 at the angular speed ω_0 of their eccentric. As the gearing pole B is the instantaneous center, we find the angular speed ω_2 from a condition

$$\omega_2 = \frac{V_a}{r_2} \tag{1}$$

where V_a – linear speed at the point A.

As angular speed $\omega_0 = V_a / \overline{OA}$

$$\omega_2 = \frac{\overline{OA} \cdot \omega_0}{r_2} \tag{2}$$

As eccentricity is the difference of radiuses

$$\omega_2 = \left(\frac{r_1}{r_2} - 1 \right) \cdot \omega_0 = \left(\frac{z_1}{z_2} - 1 \right) \cdot \omega_0 \tag{3}$$

It is possible to define gearing of eccentric mechanisms, considering that $i = \omega_0 / \omega_2$, it is equal

$$i = \frac{1}{1 - \frac{z_1}{z_2}} \quad (4)$$

For example, at z_1 = 41 and z_2 = 40 we have i = -40. The minus sign specifies that the direction ω_2 back to the direction ω_0.

Let's find the efficiency of the considered reducer mechanism with eccentric gearing. We proceed from determination of efficiency as the relations of useful resistance power to the power of driving forces

$$\eta = \frac{M_2 \omega_2}{M_0 \omega_0} \quad (5)$$

From (3) it is easy to have

$$\frac{\omega_2}{\omega_0} = \frac{z_1}{z_2} - 1 \quad (6)$$

It is known that the moment on the carrier will be equal to the sum of the external moments on the axes of the gears, regardless of whether the mechanism is perfect or with friction losses

$$M_0 = M_1 + M_2 \quad (7)$$

Based on the law of transmission of moments

$$M_1 = \frac{r_1}{r_2} \frac{M_2}{\eta_{12}} \quad (8)$$

where η_{12} - the instant efficiency of links 1 and 2.

Having united results (6), (7) and (8), we have expression for the efficiency of eccentric gearing

$$\eta = \frac{\frac{z_1}{z_2} - 1}{\frac{z_1}{z_2} \frac{1}{\eta_{12}} - 1} \quad (9)$$

Taking into account that

$$\eta_{12} = 1 - \varphi = 1 - (\varphi_t + \varphi_s) \quad (10)$$

where φ – coefficient of losses (the sum of losses in teeth φ_t and supports φ_s).

Due to the small difference in the number of teeth $\eta_{12} \approx 0,998$, we obtain the value of the efficiency of the eccentric gearing

$$\eta = \frac{\frac{41}{40} - 1}{\frac{41}{40} \frac{1}{0,998} - 1} = 0,924 \quad (11)$$

If the reducer has two identical steps with the eccentric gearing, it is possible to obtain i^2 = 1600 at η = 0,85.

The obtained values indicate the efficiency use of the mechanism in the rotators of drilling rigs and not bad correlate with the data obtained in [10].

5. Model of the proposed reducer

The model of the drilling rig rotator with the eccentric reducer is shown in figure 3.

Such reducer has the smaller weight and dimensions in comparison with designs now in use. Besides, the use of a high-torque reducer (gearbox) based on eccentric motion will eliminate the torque amplifier from the top drive systems (TDS) as it is not needed. The basis of the proposed reducer (gearbox) configuration is the coaxial arrangement of the eccentric gear pair with the drive shaft, which allows not only to exclude the reaction of the bending moment relative to the shafts, but also to obtain internal gearing with a large gear ratio and guaranteed gearing of several involute teeth at the same time [7].

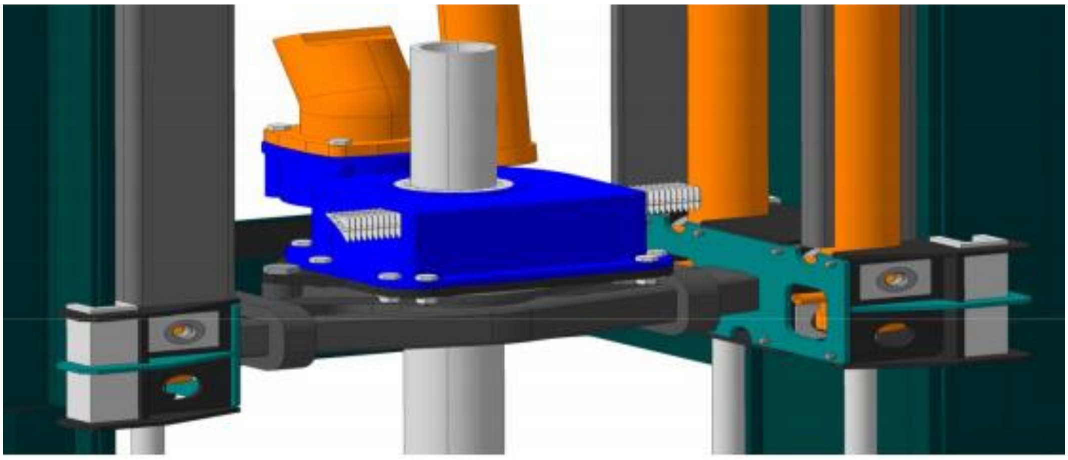

Figure 3. Model of the drilling rig rotator with the eccentric reducer.

This reducer (gearbox) can be used not only in the drilling rig top drive systems (TDS), but also in winches mechanisms of hoisting machines, rotators of construction machines, motor - wheels of heavy trucks, construction and road machines, passenger elevators and other units.

6. Conclusion

An analytical review of top drive systems and reducers (gearboxes) shows that the development of top drive systems (TDS) based on cylindrical, planetary and block-modular gears have certain difficulties in the design, since the structures have significant masses and dimensions. The use of gears with eccentric involute gearing is proposed. Their kinematics was studied; it indicates the effectiveness of using this mechanism in rotators of drilling rigs. In particular, when using two identical stages with an eccentric gearing in the reducer it is possible to obtain a gear ratio of 1600 with an efficiency of 0.85.

Thus, the use of the eccentric involute gearing reducer will allow the creation of compact reducers with large gear ratios, higher efficiency, high precision, and load and overload capabilities. The creation of an integrated system including the use of adjustable asynchronous electric drives will allow creating reliable and efficient top drive systems that meet the requirements of deep drilling.

References

[1] Shahin N, El Messiri A M, Haddad A H 2009 *Proc. of SPE Middle East Drilling Technology Conference & Exhibition* 125633

[2] Neason J R 2008 *Proc. of Offshore Technology Conference* **1** 1230–41

[3] Ashcheulov A V et al. 2015 *Chem. Petrol. Eng.* **51(1-2)** 94–100

[4] Bashmur K A, Petrovsky E A 2013 Equipment and Technologies for Oil and Gas Complex [in Russian – *Oborudovanie i tekhnologii dlya neftegazovogo kompleksa*] **5** 4–7

[5] Lin J, Parker R G 2002 *J. Sound Vib.* **249(1)** 129–45

[6] Repčić N, Pervan N, Šarić I 2011 *Proc. of 15th International Research/Expert Conference "Trends in the Development of Machinery and Associated Technology"* 765–8

[7] Privalikhin R S et al. 2015 *Drilling & Oil* [in Russian – *Burenie i neft'*] **3** 54–8

[8] Pechkovskaya O E, Pashkevich M F, Mashin Yu V 2012 *Bulletin of the Belarusian-Russian University* **1(34)** 81–90

[9] Liu D, Wang G, Ren T 2017 *Mech. Mach. Th.* **109** 51–64

[10] Sonoda K, Hirai H, Sonoda M, Takenouchi K 2017 *Proc. of The 4th International Conference on Design Engineering and Science* 161–4