

# Effect of Incorporated Pumping Station Weight on the Rotating Torque of Geokhod Transmission

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**Abstract.** The article describes the results of a theoretical research of installation of a pumping station into the tail section of a geokhod. It is considered how an increasing weight of the tail section influences power characteristics of geokhod transmission. The research is based on a mathematical model of geokhod's moving through the underground space.

## Introduction

High population density in metropolitan areas, intensive traffic on city roads as well as growth of house building and the necessity of underground utilities all encourage to develop cities' underground spaces. Every year the rate of underground workings increases more and more. In spite of the increase of drivage, rock tunneling is still a relatively labor-intensive and expensive process.

Currently, there are several drivage methods; one of them is shield tunneling. The need to increase the drilling rate and the performance of applied machines as well as the need to reduce the costs conditions such large number of research works on this topic.

The potentials of aspects of improvement of a traditional shield tunneling equipment are exhausted in the extension of its scope and the increase of its effectiveness [1].

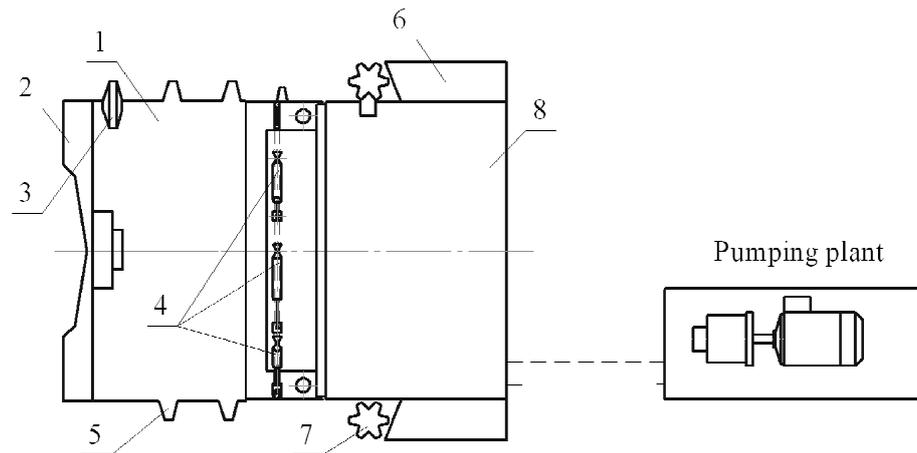
An alternative to the shield method is the geowinchester technology [1]. The main technological element of this promising technology is geokhod. A characteristic feature of this mining machine is that it uses the geological environment for moving in the underground space.

The geokhod is notable for an original layout scheme as well as the presence of new functional-in-design assembly parts. Besides, the geokhod construction includes elements which have never been used in mining machines before [2]. The geokhod is a machine built by the modular principle which means that there are several variants for each system or mechanism. Certain circuit designs and structural schemes are chosen depending on the exploitation conditions. It is convenient to chose using multi-criteria methods such as analytic hierarchy process [3].

The construction of a two-section geokhod (figure 1) includes head section 1 and tail section 8 connected with each other by a junction module through which the torque is transmitted. The torque is transmitted via hydraulic cylinders 4. Executive elements 2 that destroy the breast, the sinking system as well as executive elements of the propelling device 3 also possess a hydraulic drive. In general, hydraulic drives are widely used in mining machines because they have certain advantages. In works [4, 5], there are the particularities, the advantages and the disadvantages described concerning the use of hydraulic drives in geokhod transmissions. The main disadvantage of hydraulic transmission is



possible irregularity of the torque transfer from the tail section to the head section. Within the frames of experimental development, as an alternative transmission variant, there were geokhod transmission layout schemes suggested with harmonic drive with spacing rollers. The main advantages of such drives are the following: regular rotation of the output element, high torques at the output element, large overload reserve and high rigidity of kinematic elements, small size, high efficiency coefficient, low moment of inertia, high acceleration capacity level, high reliability rate and long life. You can find more information about the geokhod transmission with harmonic drive in work [6].



**Figure 1.** Layout scheme of geokhod.

1 – head section; 2 – actuating element; 3 – actuating element of the propelling device; 4 – hydraulic cylinder of revolution; 5 – helical blade (propelling device); 6 – counterrotation element; 7 – actuating element of the counterrotation element; 8 – tail section.

For the supply of all hydraulic systems of a geokhod, a pumping station is used. The pumping station is also built by the modular principle which means that every module or section supplies its own autonomous hydraulic circuit. This is necessary because geokhod systems work with different output and include hydraulic cylinders or hydraulic motors [7] that work in a simultaneous regime. Pumping station layout arrangements provide embedded schemes as well as mounting outside the tail section.

Up to the present moment, the produced prototype geokhod models had been equipped with a pumping station mounted outside the geokhod body. Of course, it clears some operating space inside the geokhod, however it results in the energy loss in hydraulic lines which can be very long. An alternative is a pumping station, the elements of which are located inside the tail section. Even though this idea has already been suggested, it has not yet been researched how power characteristics of the geokhod drive can change with the increase of the tail section weight by the value of pumping station. Moreover, the geokhods of different diameters have various weights of pumping stations, and the dependence of the pumping station weight on the geokhod diameter is nonlinear.

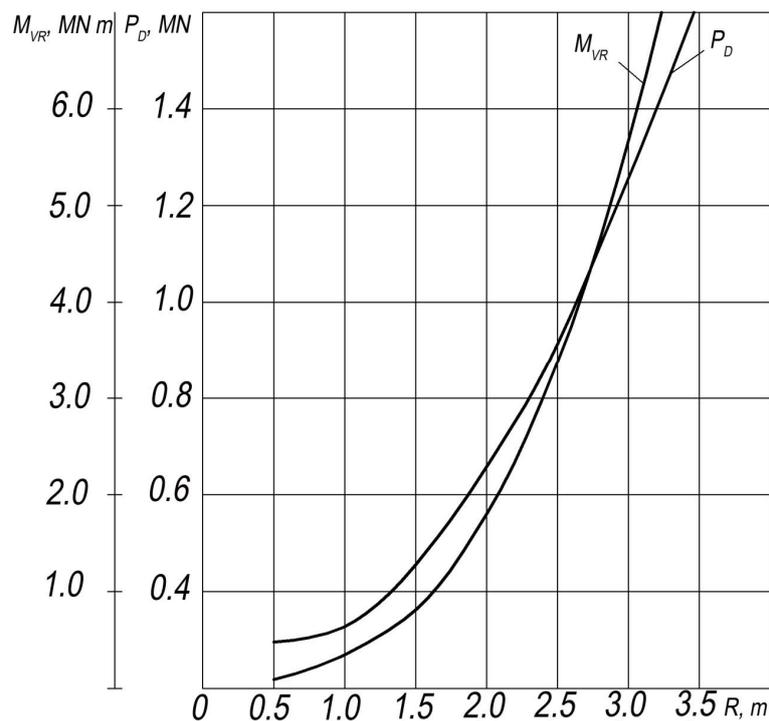
For now, a constraining factor for the installation of additional equipment, such as a hydraulic tank, on the inner shell of the geokhod consists in technological and economic problems [8, 9, 10].

## 1. Theoretical basis

The transmission is an important, inseparable part of the geokhod. As distinct from other mining machines, in geokhods, apart from the securing of the torque at the external propelling device and of

the moving force, the transmission creates the crowding power at the executive element. Besides, in case the pumping station is mounted "on board", it is the transmission that is loaded the most.

Currently, a new generation of geokhods is in development. In order to define the moving force for geokhods, in work [11] there was a mathematical model suggested of the interaction of geokhods with the geological environment. This mathematical model has been elaborated taking into account current transmissions with hydraulic cylinders. In this mathematical model, there are following main target values defined:  $P_D$  – force developed by all hydraulic cylinders of geokhod rotation, and  $M_{VR}$  – required torque. The calculated dependences allowed to estimate the values of forces and torques required for the moving of the geokhod (figure 2).



**Figure 2.** The dependence of moving forces of the geokhod  $P_D$  and rotating torque  $M_{VR}$  on the geokhod radius

This mathematical model was elaborated for a detached moving mode of the geokhod ELANG-3 (i. e. for the case when geokhod sections move in sequence) and does not count the necessity of continuous rotation of the head section as well as does not count a possible application of a mechanical transmission.

The mathematical interaction model of the hydraulic drive of a geokhod with the geological environment was developed in work [12]. In the improved mathematical model a coupled moving mode is taken into account (i. e. simultaneous moving of geokhod sections). The main target values of this mathematical model are the following:  $P_{GC}$  – integral force developed by hydraulic cylinders of rotation for the moving of sections, and  $M_{VR,TR}$  – required rotating torque developed by the hydraulic cylinders:

$$P_{GC} = \frac{\Sigma M + \Sigma P \cdot k_l + T_{G.OB} \cdot r_G \cdot \cos \beta + T_{OC} \cdot r_{OC}}{h_{GC} \cdot \left( 1 - \frac{k_l \cdot f_{TR}}{r_{EP}} \right)} \quad (1)$$

$\Sigma M$  – the sum of antitorque moments of geokhod, N·m;  $\Sigma P$  – the sum of motion resistance forces influencing the geokhod, N;  $k_l$  – frictional force and geokhod radius coefficient;  $T_{G,OB}$  – frictional force at the head section of the geokhod, N;  $r_G$  – geokhod radius, m;  $\beta$  – canting angle of the helical blade, degree;  $T_{OC}$  – frictional force from the section junction device, N;  $r_{OC}$  – radius of the section junction device, m;  $h_{GC}$  – distance from the center of the head section to the working line of the hydraulic cylinder rod, m;  $f_{TR}$  – factor of the steel friction against the ground;  $r_{EP}$  – radius of counterrotation elements, m.

Hereby, as for any other type of mining technique transmission, it necessary to define the following values: required rotating torque  $M_{VR}$  gained by the transmission as well as moving force  $P_T$  that is resulted from this torque, and  $R_{NAV}$  – reaction force at the propelling device:

$$M_{VR} = R_{NAV} \cdot \left( \sin\beta \cdot \left( r_G + \frac{h_L}{2} \right) + tg\varphi_{TR}^P \cdot \cos\beta \cdot \left( r_G + \frac{h_L}{2} \right) \right) - M_Z \quad (2)$$

$$P_T = R_{NAV} \cdot \cos\beta \quad (3)$$

$$R_{NAV} = \frac{-M_Z \cdot \frac{f_{TR}}{r_{EP}} - P_Z}{\cos\beta - tg\varphi_{TR}^P \cdot \sin\beta - \sin\beta \cdot \left( r_G + \frac{h_G}{2} \right) - tg\varphi_{TR}^P \cdot \cos\beta \cdot \left( r_G + \frac{h_L}{2} \right)} \quad (4)$$

$h_L$  is the height of the helical blade, m;  $\varphi_{TR}^P$  is the friction slope between the ground and the steel, degree;  $M_Z$  is the sum of antitorque moments of the geokhod, N·m;  $P_Z$  is the sum of motion resistance forces of the geokhod, N.

This mathematical model is an improved mathematical model of interaction of a two-section geokhod with the surrounding geological environment in the conditions of dry friction and of a continuous navigation mode. This mathematical model counts the continuous translational propeller-driven character of the moving of device sections and is true for all types of transmissions. The mathematical model helps follow the influence of dimensions of geokhods on the value of the required rotating torque with different working angles of gradient  $\alpha$ .

The disadvantage of this model consists in the fact that it does not take into account changing force characteristics in the process of exploitation of the geokhod. For instance, the metal body of the geokhod as well as its executive elements are corrodible and exposed to abrasive wear which inevitably affects the force characteristics and the efficiency of the whole machine in the same way as it happens to tunneling shields [13]. Body resistance to corrosion can be improved through the use of special covers described in work [14].

## 2. Results and discussion

In order to assess the impact of the weight on the rotating torque of geokhod transmission, the weight of the tail section must be increased by the pumping station weight. The weight of the in-built pumping station  $m_{PS}$  is calculated with the following equation:

$$m_{PS} = m_{ht} + m_l + \sum_{i=1}^n m_{ielm} + \sum_{i=1}^n m_{ip} + \sum_{i=1}^n m_{iapp} \quad (5)$$

$m_{ht}$  is the weight of the hydraulic tank;  $m_l$  is the weight of power fluid;  $m_{ielm}$  is the weight of electric motors;  $m_{ip}$  is the weight of pumps;  $m_{iapp}$  is the weight of equipment.

The weight of the hydraulic tank with power fluid, taking into account the tank charge level to 90 per cent, can be expressed in terms of the following equation:

$$m_{ht} + m_l = S_{surf} \cdot \delta \cdot \rho_{ht} + 0,9 \cdot V_{ht} \cdot \rho_l, \quad (6)$$

$S_{surf}$  is the surface area;  $\delta$  is the wall thickness of the hydraulic tank, for a steel tank  $\delta = 2..3$  mm;  $\rho_{ht}$  is the density of hydraulic tank material, for steel  $\rho_{ht} = 7,800$  kg/m<sup>3</sup>;  $\rho_l$  is the density of the power fluid, kg/m<sup>3</sup>.

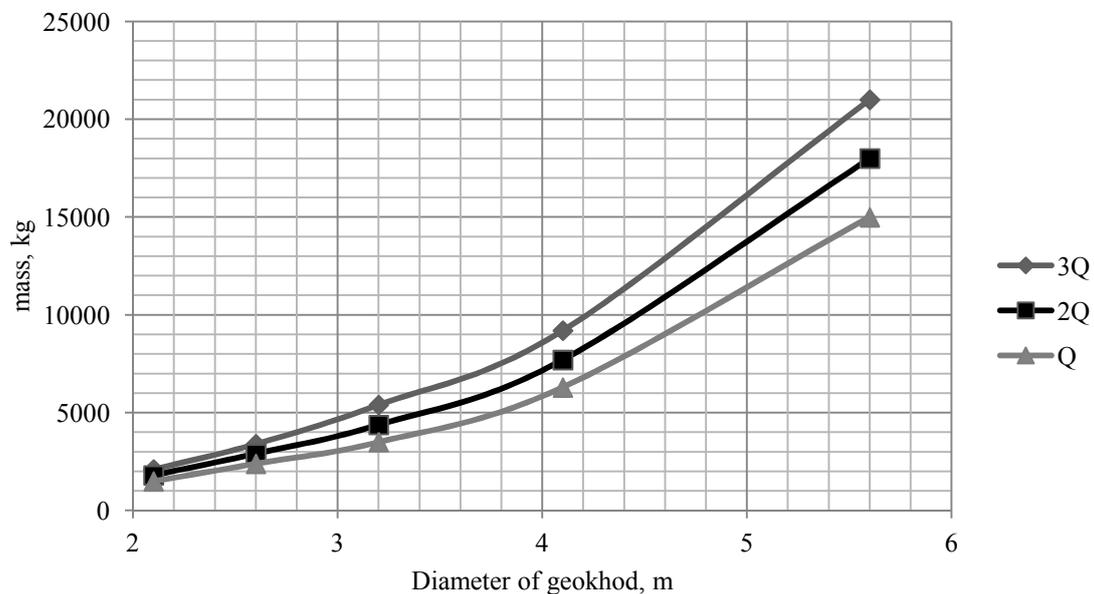
It should be noted that the weight of pumps and the equipment make only a small part of the cumulated weight of the pumping station, whereas the major part consists of the hydraulic tank with power fluid as well as of electric drive motors.

For geokhods with different diameters, there were dependency diagrams plotted of the pumping station weight and the diameter of the geokhod (figure 3) under the following conditions: the hydraulic tank of the type has a capacity that equals to one  $Q$ , two  $2Q$ , and three  $3Q$  cumulative momentary performances of all pumps. The metal wall thickness of the hydraulic tank equals to 2 mm, the density of the power fluid equals to  $\rho_l = 0.85$  kg/m<sup>3</sup>.

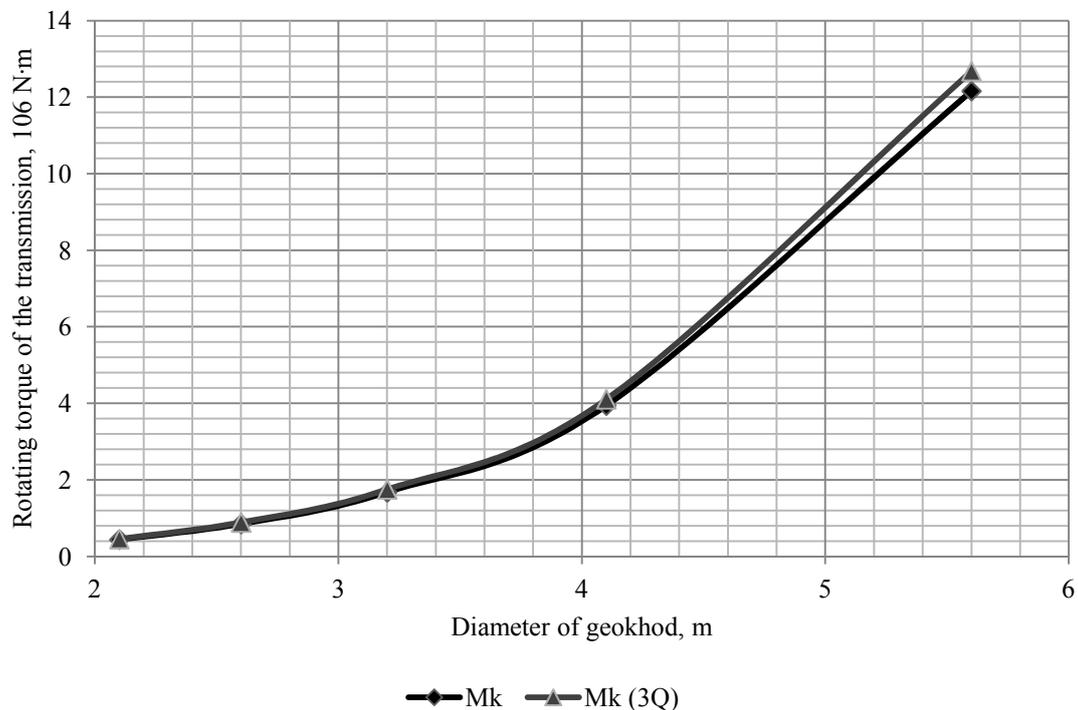
Analysis of dependence on figure 4 shows that the weight of the geokhod pumping station takes on large enough values, and in case it is mounted in the tail section, it can significantly affect the transmission parameters.

In equation (1), the weight of the tail section is included into the sum of motion resistance forces of the geokhod  $\Sigma P$ . If we add the weight of the pumping station into this equation, we can plot a dependency diagram of the rotating torque  $M_t$  on geokhod diameter. In practice, in equation (1), the dependence of the pumping station weight on geokhod diameter represented in figure 3 is inserted into the sum  $\Sigma P$ .

In figure 4, there is a dependency diagram of the rotating torque of the transmission taking into account the pumping station mounted "on board" (a) and without it (b).



**Figure 3.** Influence of the geokhod diameter on the weight of the pumping station with hydraulic tanks of the capacity  $Q$ ,  $2Q$ , and  $3Q$



**Figure 4.** Dependency diagram of the rotating torque of the transmission on geokhod diameter without pumping station Mk as well as with in-built pumping station Mk (3Q) with a hydraulic tank of the capacity equal to three cumulated performances of all pumps

The main factors of weight reducing of the pumping station of the geokhod are the volume reduction of the power fluid and the weight reduction of applied electric motors. The first variant inevitably results in the necessity of use of heat exchange devices in order to maintain the necessary thermal rate.

### 3. Conclusions

The analysis of the dependence in figure 4 shows that the increase of the rotating torque in the geokhod transmission is insignificant when the pumping station is mounted inside the tail section; the torque growth equals to 4.19-4.72%. It is explained by the fact that the main effort is given to the overcoming of friction forces of the helical blade as well as friction forces by the rotation of the head section against the tail section, while an additional load, i. e. additional weight of the pumping station, does not really affect the process. Thus, the mounting of the pumping station in the tail section does not appear to be any kind of a constraining factor. The impact is insignificant and can absolutely be compensated by means of the assurance factor in the designing process of geokhod transmission.

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