

Comparative Analysis of the Main Indicators You-Socioaffective Inertial Rotary Excavator

Zhussupov K.A¹, Kozbagarov R.A², Kunelbayev M.M³, Yesenaliyev M.N⁴, Taran M.V⁵, and Uskembraeva V.E⁶

Kazakh Academy of Transport and Communications^{1,2,4,5,6}, Republic of Kazakhstan, Almaty city
Kazakh State Women's Teacher Training University³, Republic of Kazakhstan, Almaty city

Abstract: According to the foreign and domestic practice one of the ways to improve the relationship of the efficiency of the process of excavation should be the application of the working bodies with increased force digging and greater transport capacity. The use of such high-performance equipment contributes to the progressive and effective technological schemes of work, allows existing government to improve conditions and increase productivity.

In the article, given the trend towards using bucket wheel excavators in the last century-dy and comparative analysis of key indicators inertial rotary-th excavator with high performance working bodies, operating at high speed. The authors developed the design of work equipment, allows full use of the advantages of inertial Roto-RA.

Keywords: excavation machine, rotary excavator, because my inertia rotor.

1. Introduction

Time-optimal motion planning for robotic machines has been the subject of research for a number of years. The focus has primarily been on open-chain manipulators driven by electric actuators, since they are the most commonly used class of robots. However, the range of robot applications has been steadily growing and other types of robotic machinery are emerging. Today, attention is being focused on machines used in outdoor field applications such as mass excavation and mining. The machines used in these applications are commonly driven by hydraulic actuators. A hydraulic excavator (HEX) is shown in Fig .1. It fills its bucket with material from a pile or a rock face, transports the bucket load to a waiting truck or conveyer belt, and dumps the load. Such tasks are ideal candidates for automation since they are repetitive and can reap huge benefits from increased productivity.



Fig. 1: A Caterpillar 325 Hydraulic Excavator (HEX)

Several researchers have used machine learning techniques to learn the robot linkage dynamics. In [1], [2], and [3], the authors use neural networks to learn the inverse dynamics of a robot manipulator. This learned model is then used in a model-based controller. In [4] the author uses a neural network to learn the error between an analytical dynamic model and actual robot behavior during operation of the controller. This learned error function is used to improve controller performance. In [5] the authors use an autoregressive time-series vector difference equation to model the input-output data of an excavator's motion, which is then used in a self-tuning controller. The advantage of using a data based model to learn the robot's dynamic model is that the model can adjust to the specific characteristics of a particular robot instead of having to rely on the parameters provided by the robot manufacturer which may be inaccurate due to robot wear or manufacturing variations.

Energy is consuming up and pollution is more and more serious nowadays, so research on energy saving of hydraulic excavators has great significance because of their large application quantities, high energy consumption and bad exhaust. The efficiency of hydraulic excavators is only 22% [6], because of the lower efficiency of the engine and hydraulic system. To raise the system efficiency of excavators, hybrid power system, which is successfully applied in automobile industry, has been already introduced into construction machinery. In construction machinery industry, researchers also actively developed various kinds of construction machines based on hybrid concept. KOMATSU construction machinery company is the first one which promoted hybrid excavator into the market in 2008.

A lot of research work has been conducted in automobile industry, but those research achievements cannot be directly applied in the development of hybrid excavators because of the difference of working condition and load. However, only a few literatures on hybrid excavators which focus on the research of power train system configuration [7], simulation research [8] and control strategy [9,10,11] can be retrieved. Few reports on the development rules of hybrid excavators can be found.

In this paper, the development rules of parameters design and control strategy in hybrid excavator are presented. A 20-ton hybrid excavator is the design target, in which a compound hybrid power configuration is applied, a negative flow hydraulic system is adopted, the hydraulic swing motor is substituted by an electric motor and the super capacitor pack is used as an energy accumulator. According to the typical work condition of heavy mode and the measured load profile, the key parameters design of the power train is proposed and a control strategy characterized by hierarchical structure is presented. Experiments show that the designed compound hybrid excavator can effectively reduce fuel consumption and emission.

Several kinds of power train architectures of hybrid excavator are presented in [8,9,10,11]. According to the power flow structure of drive train, the hybrid drive train can be classified into three categories such as parallel, series and compound type. The most popular structure is shown in fig. 1 and also adopted as the target excavator structure in this paper. The hybrid excavator includes an engine, a hydraulic pump connected to an output shaft

of the engine, hydraulic actuators (bucket cylinder, arm cylinder, boom cylinder and traveling motors) driven by the hydraulic pump, a generator motor connected in parallel to an output shaft of the engine to perform both a generator function and a motor function, a swing motor driving the upper structure of the hybrid excavator, an electric storage device (super capacitor pack) which supplies and receives electric power to and from the generator motor and the swing motor, and a hybrid power controller for coordinating the entire power train composed of the engine, the hydraulic pump, electric actuators and the capacitor pack. The engine, engine assist motor, pump and super capacitor constitutes the parallel hybrid power train; the engine assist motor, swing motor and capacitor constitutes the serial hybrid power train. So this kind of power train is called compound hybrid power system.

In development of the richest reserves of minerals of our republic the significant role belongs to rotor excavators and other cars of continuous action as forecasts show that further growth of mining will happen at primary application of an open way.

Development of economy of the Republic of Kazakhstan in many respects depends on growth rates of overall performance of the construction and extracting industries which can be provided only due to creation and introduction of own road-building, excavation cars and technologies of a modern technological level.

The industry of nonmetallic minerals, mountain chemistry, construction materials in the world almost for 100% is based already now on an open way of development. Now in the Republic of Kazakhstan about 40% of the reconnoitered coals, generally are got in the open way. Production of construction materials and minerals is conducted by means of the existing technologies based on use usual rotor and the one ladle of excavators, the drilling-and-blasting and to loosen the bulldozer equipment and which are characterized by irrational use of cars of big single power, recurrence and a the operational is much, thereby, causing to the state extensive economic damage and negatively having impact on environment.

The tendency of use of rotor excavators for development of stronger and frozen soil, strong breeds and coals is observed. Thus insufficiency of effort of digging and considerable dynamism of process of digging that conducts to decline in production and unstable operation of excavators is established. The aspiration to increase effort of digging and to lower dynamism involves strengthening of a metal construction and, as a result, progressive increase in mass of the car with an insufficient growth of productivity.

Development of designs and rotor excavators a number of research and design institutes and higher education institutions, plants and the operating organizations researches. These researches made a big contribution to creation of efficient and reliable designs of rotor excavators. At the same time the excavator applied now with gravitational rotors exhausted opportunities of further increase of their productivity and don't allow to increase effort of digging without increase of dynamism and mass of the car.

Recently in a rotor excavator building a number of highly effective workers of the bodies working at high speeds is created. Excavation by high-speed rotors finds broad application in mining branches and pits of building industry, and also in construction, loading and unloading and transport and warehouse works. Excavation process by high-speed rotors is characterized by intermittence of cutting and instantly changing cut thickness, and also low vibrato stability of a rotor, in view of insufficient rigidity and durability of an arrow on which end it is established. All this leads to emergence of fluctuations of force of cutting which, in turn, cause beats in dynamic system and complicate process of working off of a face.

From such positions the excavator of Kolbe firm (Fidelity's pit, the State of Illinois, the USA) [12] with working body of scraper and plow type which develops a face at rotation of a rotor "from top to down" is of interest. Refusal of ladles and their replacement by two rows of the cutting elements allowed to work at big speeds of rotation as unloading was carried out at the expense of centrifugal forces through open space between knives. Soil didn't rise ladles up, and on the contrary, fell down by gravity that gives decrease in power consumption of digging. The rotor had 8 couples knives, diameter was equal 5 m, its width - 1,5 m. Speed of

rotation of a rotor made 20 rpm (5,23 m/s). At all the merits this excavator was used short time. It was promoted by three reasons. First, the small quantity of the cutting elements with a big diameter of a rotor and considerable linear speed caused strong blows at an entrance of knives to soil that led to frequent breakages and increased idle times of the car. Secondly, because of an unreasonable choice of the sizes of shaving not decrease, but increase of power consumption of digging was observed. The third and main lack of this excavator was rigid fastening of an axis of a rotor on an arrow. It sharply limited possibilities of use of the excavator as such design allowed to work only at small corners is rejected soil spill out Infinite in a gap between the rotor and a reception tray having continuous situation concerning a rotor.

2. Theoretical analysis

Authors of article developed the design of the working equipment allowing to use completely advantages of an inertial rotor. The offered inertial rotor, unlike existing, rotating, cuts soil "from top to down", partially bringing down it. Under the influence of centrifugal force soil arrives on the tape conveyor located under a rotor. On the end of the conveyor the reception tray which is constantly adjoining to the developed face and preventing a soil spill out Infinite is established.

In an inertial rotor ladles are replaced in couple of knives located at an angle. It is necessary to carry to the main advantages of a new inertial rotor:

- possibility of implementation of working process in the big range of speeds and obtaining high efficiency;
- considerable reduction of specific power consumption of process of digging in which there is a slanting cutting to a chip and a partial collapse of the cut-off soil;
- the small weight of an inertial rotor and decrease in gross weight of the excavator (owing to change of the direction of reaction from cutting forces) that allows to reduce the overturning moment and the main loads of the excavator;
- automatic cleaning of knives with the cut-off soil;
- considerable initial speed of unloading of soil from a rotor in the direction of the movement of a tape of the reception conveyor.

Researches were conducted in sandy and clay soil II-III of category. Density of soil was measured by the drummer of at three levels on height of the developed layer. It averaged 12-16 blows in the top and 16-26 blows in lower layers. The cutting elements fixed to a rotor so that it was possible to change number of couples of knives (5, 8 and 10), distance between them (275, 310, 345 and 380 mm) and a corner of their installation concerning a rotor drum side (6-16 hail).

Experiments showed that transportation and unloading of all developed soil are provided at all accepted distances between knives, digging speeds $\vartheta \mathcal{G}_p = 2,0 \div 4,5$ m/s and 10 couples knives. Constructive data of the stand allowed to use only 90% of transport possibility of the studied rotor.

The maximum productivity of an inertial rotor at $\mathcal{G}_p = 4,1$ m/s made 256 m³/hour in a dense body that corresponds to settlement data.

Considering that the rotor has no traditional ladles, for the analysis of its parameters the conditional geometrical capacity of couple of knives (the volume concluded between two knives), and also the coefficient defining extent of filling of this volume in the course of work are entered.

The initial size for determination of parameters of an inertial rotor height of knives is.

In gravitational working bodies the relative height of ladles defining the rotor radius relation to ladle height has various values in limits and is defined by unloading conditions.

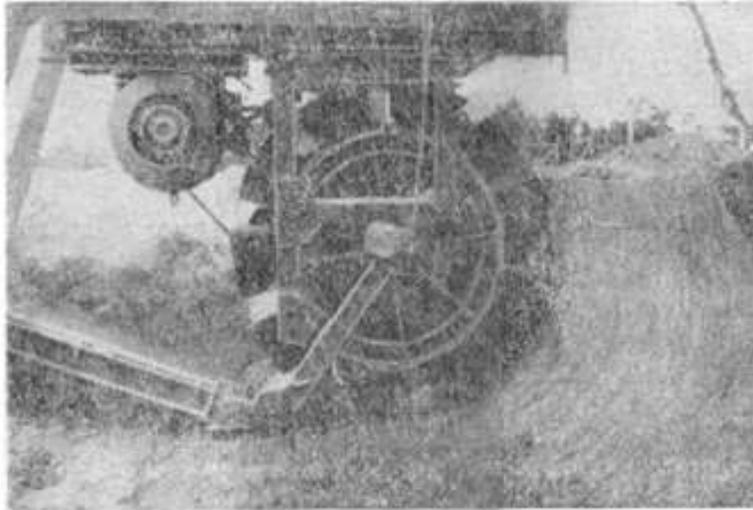


Fig. 2: Tests of an inertial rotor with a diameter of 1.54 m at the field stand

Soil supply by an inertial rotor on the conveyor happens under the influence of a body weight of soil and centrifugal forces that allows to make development of a face at big speeds of digging and to apply the cutting perimeters of considerable height.

Theoretical productivity of an inertial rotor in a dense body can be determined as

$$Q_T = 3600 \mathcal{G}_H h_C a_C, \quad (1)$$

where \mathcal{G}_H - the speed of face giving of a rotor;

h_C - shaving height;

a_C - shaving thickness.

$$\text{As } h_C = R_P \kappa_H, \quad \mathcal{G}_H = \mathcal{G}_P \text{tg } \tau_O \quad \text{и} \quad a_C = 0,09 h_H = 0,9 \frac{R_P}{\kappa_3}$$

(- h_H knife height), we will receive:

$$Q_T = 3240 \frac{R_P^2 \mathcal{G}_P \text{tg } \tau_O \kappa_H}{\kappa_3}, \quad (2)$$

where \mathcal{G}_P - cutting speed;

τ_O - kinematic corner of cutting;

κ_H and κ_3 - relative values of height of shaving and knives respectively.

For coherent soil it is possible to accept the relative height of the developed layer, and an optimum kinematic angle of cutting as it was established at field researches of an inertial rotor with a diameter of 1,54 m, the 7th hail is equal.

At these values κ_H and τ_O the formula (2) will assume an air (Taukelev R. N. formula):

$$Q_T = 110 \frac{D_P^2 \mathcal{G}_P}{\kappa_3}, \quad (3)$$

The analysis of this formula shows that productivity of the inertial worker of body depends on diameter of a rotor, speed of digging, height of the cutting elements and changes in wide productivity is counted on a formula [2]:

$$Q_T = \kappa D_p^{2,5}, m^3 / h, \tag{4}$$

where κ - productivity coefficient depending on properties of soil.

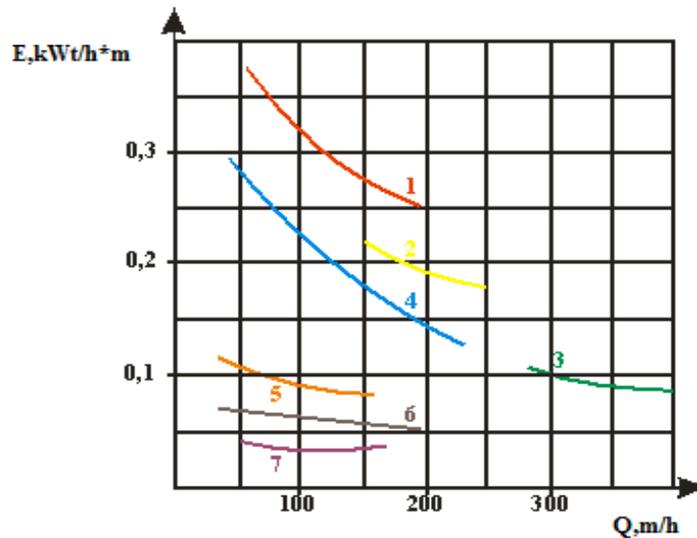


Fig. 3: Dependence of specific power consumption of digging by rotors from productivity

When developing incoherent soil the theoretical productivity of an inertial rotor is higher, than at gravitational the same parameters, for example, at and - by 1,5 times at and by 3 times at.

The increase in speed of digging to 4 m/s allows to increase productivity of an inertial rotor in comparison with productivity gravitational respectively in 3,0 and 6,2 times, and at in 4,7 and 9,4 times.

High efficiency of an inertial rotor is reached as a result of use of high speeds of digging and the good transport ability depending on number of couples and height of knives.

The increase in productivity at the expense of increase in height of knives can be defined through coefficient of transport ability of a rotor S_o , of the volume of the soil transported for one turn of working body determined by the relation (as a percentage) to the rotor W_p , volume counted on the greatest width of ladles or distance between knives

By pilot studies it is established that at 10 - 12 couples knives full transportation by a rotor of the cut-off soil is reached. Thus 100% filling of geometrical capacity of knives is observed and therefore at determination of distance between couple of knives it is possible to proceed from compliance of geometrical capacity of knives to volume of the cut-off shaving q_C :

$$q_C = a_C b_C h_C \kappa_P, \tag{5}$$

$$q_H = B_{CP} h_H l_H c_O, \tag{6}$$

where b_C - shaving width;

κ_P - loosening coefficient;

B_{CP} - average distance between couple of knives meeting at an angle 2 ;

l_H - knife length.

Comparing the right parts of the equations (5) and (6), accepting

$$h_C = 0,7D_P, \quad a_C = 0,9h_H, \quad b_C = \frac{\pi D_P}{z} \text{tg } \tau_O, \quad l_H = l_Z / \kappa_Z = \frac{\pi D_P}{z \kappa_Z}$$

(κ_Z - the distance relation between two interfaced points of knives to knife length; l_Z - distance between knives; z - number of knives) and having made transformations, we will receive:

$$B_{CP} = 0,63 \frac{\kappa_P \kappa_Z}{c_O} D_P \text{tg } \tau_O \quad (7)$$

At, $\kappa_P = 1,4$; $c_O = 1,0$, $\tau_O = 7^\circ$, $z = 10 \div 12$ and $\kappa_Z = 1,3 \div 1,4$ [2] maximum distance between knives

$$B_{\max} = (0,17 \div 0,2) D_P. \quad (8)$$

The received calculated values of coefficient S_O , for an inertial rotor were considerably big, than at domestic excavators, but experimental - it is less settlement. The last can be explained to that the distance between knives was accepted more settlement and only 90% of transport ability of the studied rotor were used.

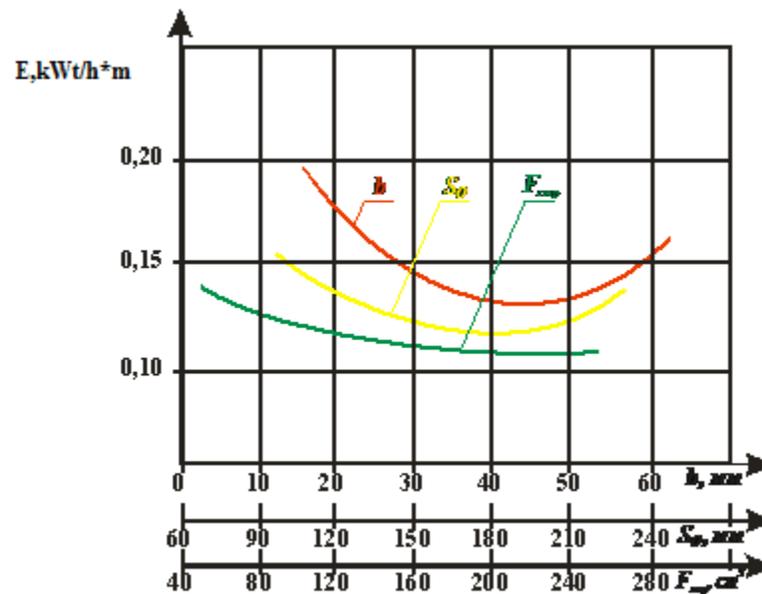


Fig. 5: Dependence of specific power consumption of digging by an inertial rotor from width in, thickness of S_o of the peeled shaving and the area of its section of F_{str} when cutting by one knife

The analysis of formulas (7) and (8) shows that distance between knives and consequently also the weight of the inertial worker of body, correspond to width and weight of a rotor of the same diameter of domestic excavators and practically remain constants with increase of transport ability of working body as a result of increase in thickness of the peeled shaving.

It is known that the weight of rotor excavators depends on character of the developed soil, the sizes of an arrow and diameter of a rotor.

Approximate comparison of weight of excavators to inertial and gravitational rotors can be received on the basis of geometrical similarity [13], accepting that cars work in different conditions and have arrows of one length.

Considering that the weight of geometrically similar bodies are proportional to a cube of the relations of their linear sizes (diameters) and accepting values of diameters of rotors from expressions (3) and (4), for rotors of one productivity we will receive:

$$\frac{G_r}{G_H} = \frac{Q_r^{0,3} \kappa_{\mathcal{E}}^{1,5}}{20g_p^{1,5}}, \quad (9)$$

Where G_H , G_r - weight of dredges with an inertial and gravitational rotor accordingly.

3. Conclusions

The materials stated in article show prospects of an inertial rotor capable to make development besides average and strong soil that is provided with process of digging and a without a ladle design of the cutting-transport elements of a rotor.

In general results of the carried-out experimental and settlement data of an inertial rotor show their high transport ability.

The carried-out analysis showed the high transport ability of an inertial rotor allowing to increase considerably its productivity.

Therefore, in general results of the analysis of experimental and settlement data of an inertial rotor of the lower unloading confirm its prospects for creation of highly effective excavation equipment of new type.

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