Algorithm for hydraulic system parameters of a dump truck

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Abstract. At the initial stage of designing a dump truck it is necessary to determine the main units and assemblies of the vehicle, their parameters and dimensions. One of the systems of the dump truck is the hydraulic system. When creating new dump trucks, there is a necessity to define parameters and characteristics of hydraulic system components. The peculiarity of quarry dump trucks, in contrast to dump trucks, which are used on public roads, is that the modes of their operation are different. Therefore, when creating new dump trucks, it is necessary to develop an algorithm for selecting and justifying the parameters of the hydraulic system at the early stages of design. The article substantiates the necessity of developing an algorithm for determining the parameters of the hydraulic system. The main hydraulic consumers are defined and the requirements of each of the consumers are presented. The algorithm of justification of the parameters of the hydraulic system of the quarry dump truck is described. Determination of the required pump capacity of the hydraulic system is described. The use of the described algorithm for justification of the hydraulic system parameters of the dump truck contributes to the reduction of terms of development of design documentation at the early stages of design.

1 Introduction

When designing a dump truck (DT), the parameters and characteristics of the components of the hydraulic system (HS) are to be determined [1-15]. The HS of a modern DT includes many elements, the characteristics of which are interrelated with each other. In HS DT it is possible to distinguish the following main consumers:

- hydraulic cylinders of lifting the load platform;
- hydraulic cylinders of steering wheels turning;
- brake mechanisms.

These consumers require different hydraulic pump capacities and do not operate simultaneously. When determining the required hydraulic pump capacity, it must be taken into account that during DT operation, the steering wheels are not turned while the load platform is being lifted. For this reason, the required flow rates of the hydraulic cylinders for

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lifting the load box and turning the wheels should not be summed up when determining the pump capacity.

DT operation modes differ from the operation modes of dump trucks used on public roads, therefore, the task of developing an algorithm to justify the parameters of the hydraulic components of DT is urgent.

The purpose of the work is to develop an algorithm to justify the parameters of the hydraulic system of a dump truck.

2 Materials and Methods

An algorithm for calculating the parameters of the hydraulic pump is proposed for selecting the parameters of hydraulic components DT, the block diagram is shown in Figure 1.

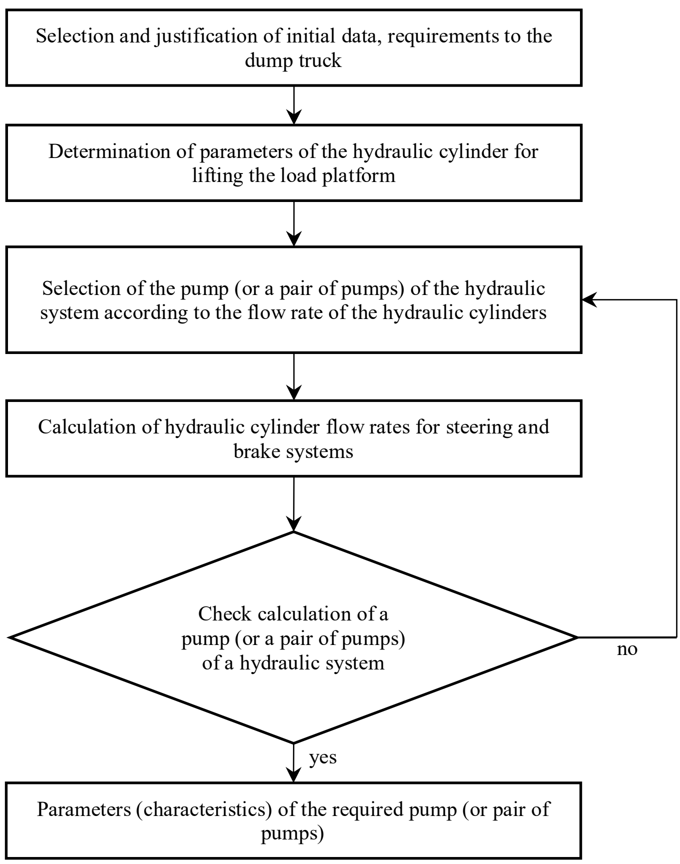


Fig. 1. Algorithm of justification of the parameters of the hydraulic system of the dump truck

The peculiarity of the algorithm is that the selection of the hydraulic pump is made first of all on the basis of the hydraulic fluid flow rate required for lifting the load platform, as it requires a higher capacity than turning the steered wheels. It is then checked that the pump capacity is sufficient for wheel turning and braking.

Determination of parameters of hydraulic cylinders for lifting the load platform begins with the construction of the kinematic scheme of lifting. At the first stage of the algorithm on the known positions of the axes of fixing the platform to the frame, fixing the hydraulic cylinders of lifting to the frame and to the cargo platform, as well as on the known geometry of the platform it is necessary to determine the maximum angle of lifting the platform and the lengths of hydraulic cylinders in the opened state.

The scheme of application of the gravity force of the load platform with the rock mass and the lifting force of the hydraulic cylinders is shown in Figure 2.

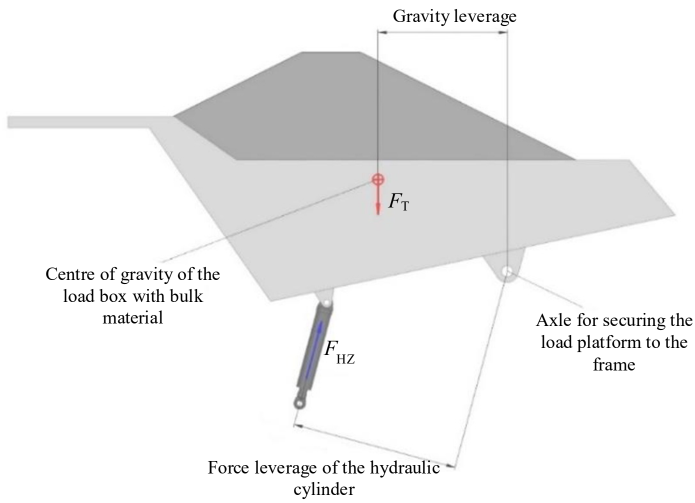


Fig. 2. Schematic diagram of forces in the calculation of the hydraulic cylinder for lifting the load platform

When constructing the dependence of the moment of gravity of the load platform with rock mass on the angle of elevation of the platform with bulk material, it is necessary to take into account that the rock mass in the process of lifting the load platform spills out, therefore, its mass and the position of the centre of mass change according to a complex nonlinear law.

There is a known method, when the loads from the action of dispersed bodies are determined in software systems using the discrete element method (DEM), and the loads in the joints - in the application for calculating the dynamics of solids [16-18]. Such approaches make it possible to realise high accuracy in determining the dependence of forces acting on the hydraulic cylinders of DT cargo platform lifting on the lifting angle, which is necessary for determining the hydraulic cylinder parameters. At the same time, this approach requires considerable time expenditure and a large amount of data on the designed DT.

In this paper it is proposed to exclude the simulation modelling of the process of bulk material ejection at the early stages of design to reduce the time spent, and to estimate the volume of hydraulic cylinders of lifting to be carried out using the kinematic scheme of lifting the cargo platform and CAD-model of the platform with bulk cargo.

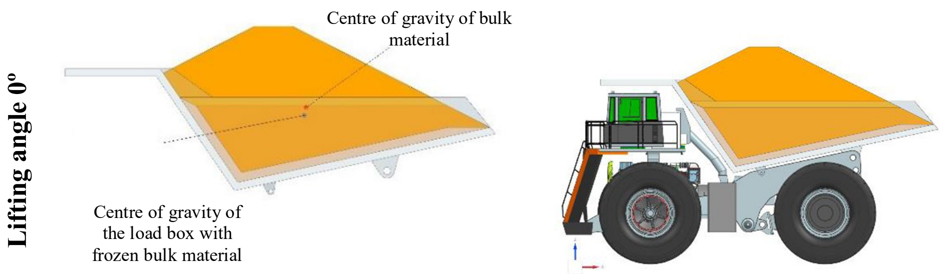
The following assumptions [19-21] are made for the calculation:

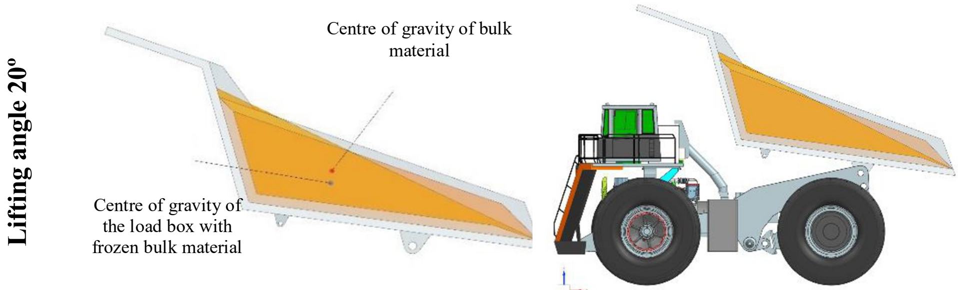
- bulk cargo is modelled as a volumetric body taking into account the "2:1 cap", according to GOST 27923-88;
- when unloading the platform, the cargo is dumped at an angle of 26.6º (according to GOST 27923-88, this angle of natural dumping is the closest to the angles formed by rocks and ordinary soils);
- part of the bulk cargo (15%) "freezes" to the bottom and side walls of the load box;
- the weight of the load box is evenly distributed between the hydraulic cylinders.

3 Research results

To build a graph of the dependence of forces arising from the mass of bulk cargo on the hydraulic cylinders of lifting, using the kinematic diagram (Fig. 2) determine the length of the arm of the hydraulic cylinder of lifting and the length of the arm of gravity of the body with the load in the lower and upper positions of the load platform, as well as in several intermediate positions. To determine the centre of gravity of the bulk cargo in intermediate positions, it is proposed to build a new model of the bulk cargo in each intermediate position, taking into account the angle of natural shrinkage.

Fig. 3 shows the developed models of the cargo platform DT with a load capacity of 240 tonnes with different degrees of lifting and different degrees of spilling of rock mass, and shows the images for the angles of lifting with respect to the bottom of the platform 0º, 20º and 40º, as well as the change of positions of the centres of gravity for the platform with a "stuck" load and for the loose load. At 40º angle of lift, the angle between the bottom of the platform and the horizontal plane exceeds 26.6º, which means that the load platform is completely empty of rock mass.





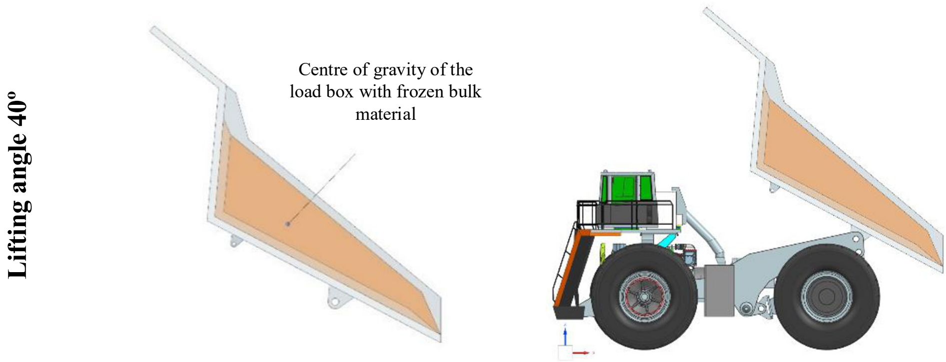


Fig. 3. Modelling of rock mass ejection from the loading platform of a dump truck

The force acting on one hydraulic cylinder of lifting from the platform with frozen rock and loose load is determined by formula 1:

$$F_{HC_i} = \frac{m_p \cdot g \cdot h_{p_i} + m_{c_i} \cdot g \cdot h_{c_i}}{2 \cdot h_{HC_i}} \tag{1}$$

here m_p – platform weight with frozen load; h_{p_i} – gravity arm of the platform with frozen load relative to the hinge of platform attachment to the frame in the i-th tilt position; m_{c_i} – mass of bulk cargo in i-th tilt position; h_{c_i} – arm force of the bulk cargo gravity relative to the hinge of the platform attachment to the frame in the i-th tilt position; h_{HC_i} – lever arm of the hydraulic lift cylinder relative to the hinge of the platform attachment to the frame in the i-th tilt position.

Fig. 4 shows the graph of force dependence F_{hc} per cylinder for lifting a platform with frozen rock and loose load from the platform lifting angle for a DT with a lifting capacity of 240 tonnes. Force F_{hc} is calculated by considering the equilibrium of the load platform in each of the positions and taking into account the changing mass and position of the centre of mass of the load platform.

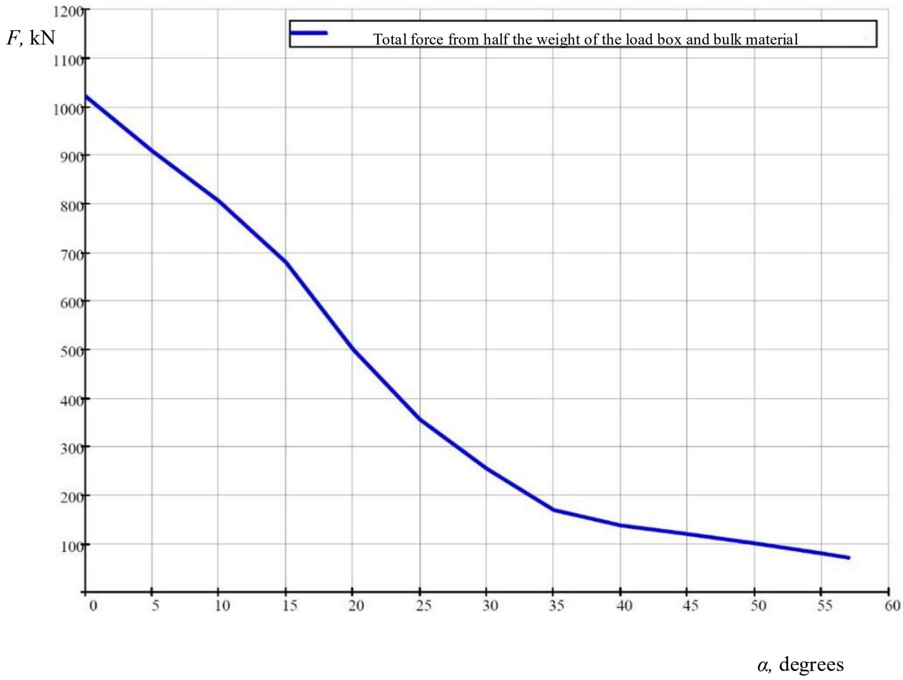


Fig. 4. Graph of dependence of the force on one hydraulic cylinder for lifting the load platform with frozen rock and loose load on its lifting angle

The force generated by the hydraulic cylinder should be selected so that it exceeds the force generated by the load platform with the rock mass by the value of the reserve coefficient. The reserve factor is selected depending on the permissible overload of the tipper and also depending on the types of bulk materials to be transported and their natural slope angles.

In DT, telescopic lifting cylinders are most often used. Due to their design features, it is necessary to take into account the reduction in force at the next step in the calculations. Based on the kinematic diagram, the length of each stage and the lifting angle at which the next stage will be operated can be determined from the known length of the hydraulic cylinder when folded and fully opened at the maximum tilt angle of the load platform.

Fig. 5 shows the graph of dependence of the force per one cylinder for lifting the cargo platform with frozen rock and loose cargo, and the graph of the force realised by one hydraulic cylinder on the angle of platform lifting for DT with payload capacity of 240 tonnes, obtained by multiplying the pressure provided by the pump and the piston area of each stage of the hydraulic cylinder.

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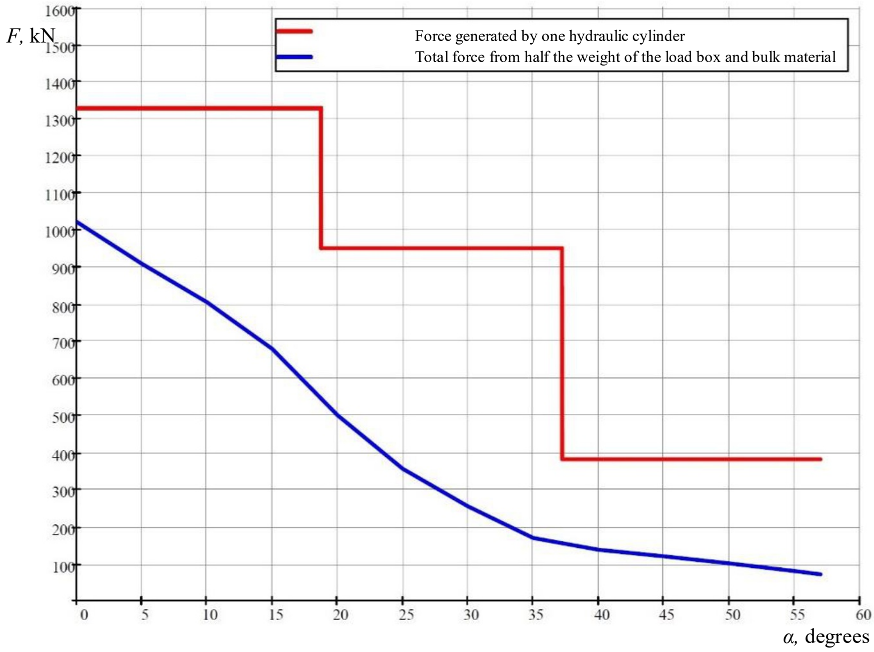

Fig. 5. Graph of forces generated by the hydraulic cylinder of lifting and half the weight of the load platform with bulk material from the angle of inclination of the load platform

We calculate the total volume of the DT load platform lifting cylinders according to expression 2.

$$V_{HC_{pl}} = 2 \cdot \sum_{n}^{j=1} l_j \frac{\pi \cdot d_j}{4} \tag{2}$$

here n is a number of hydraulic cylinder stages; l_j is the length of the j-th stage of the hydraulic cylinder; d_j is cylinder diameter of the j-th stage.

Based on the received volume of hydraulic cylinders of lifting, we estimate the required pump capacity by formula 3.

$$Q_0 = \frac{V_{HC_{pl}}}{\eta_{cap} \cdot t_l} \tag{3}$$

$here\ \eta_{cap}$ defines pump volumetric efficiency; t_l is the time required to lift the platform.

The time of lifting the load platform should be minimised, as the duration of DT unloading significantly affects the efficiency of the technological process of mineral extraction. For DT of large load capacity, the time spent for lifting the platform is on average 20 seconds [4].

The required working volume of the pump is defined by expression 4:

$$V_w = \frac{2 \cdot \pi \cdot Q_0}{n_{rev}} \tag{4}$$

here n_{rev} defines hydraulic pump shaft revolutions.

After the DT load platform lifting cylinders have been dimensioned, the wheel steering cylinders must be dimensioned. The wheel steering cylinders are the main component of the DT steering system and require a high hydraulic pump flow rate during operation. Knowing the volume of the wheel steering cylinders, the value of the wheel turning resistance torque and the time required to turn the wheels, the required working volume of the variable displacement pump can be determined and compared with the results obtained earlier.

We calculate the force on the rod using formula 5:

$$F_{rod} = \frac{T_{res}}{l_r} \tag{5}$$

here T_{res} – wheel turning resistance torque; l_r is the force leverage.

The working area of the piston in the rod end is calculated by formula 6:

$$S_{rod} = \frac{F_{rod}}{P_{max}} \tag{6}$$

where P_{max} is maximum cylinder pressure.

The piston area is calculated from expression 7 [19]:

$$S_p = S_{rod} + \frac{\pi \cdot {d_{rod}}^2}{4} \tag{7}$$

where d_{rod} is the rod diameter.

We calculate the piston diameter using formula 8:

$$d_p = \sqrt{\frac{4 \cdot S_p}{\pi}} \tag{8}$$

Knowing the area of the piston, by formula 9 we calculate the volume of working fluid required for one DT hydraulic steering cylinder:

$$V_{HC_{st}} = S_p \cdot l_x \tag{9}$$

here l_x is piston stroke.

The flow rate of the hydraulic cylinders of the steering system is estimated according to formula 10.

$$Q_{st} = \frac{2 \cdot V_{HC_{st}}}{t_{st}} \tag{10}$$

Here t_{st} is the time required to turn the steering wheels DT.

Turning the steering wheels from one end position to the other should be done in the time required for the driver to turn the steering wheel a full number of revolutions in one direction. For DT the recommended turning time is t_{st} for 4 revolutions of the steering wheel from one extreme position to the other - 4 seconds [21].

The brake system is also an important component of the HS DT. Although the hydraulic fluid consumption for the operation of this component is small compared to the hydraulic cylinders of the platform lift and steering, it should also be evaluated in the early stages of vehicle design.

The brake system flow rate is determined by formula 11:

$$Q_t = \frac{V_{fr} \cdot n_{fr}}{t_t} + \frac{V_{rear} \cdot n_{rear}}{t_t} \tag{11}$$

Here V_{fr} is front brake capacity; n_{fr} is the number of brakes on the front axle; V_{rear} is rear brake capacity; n_{rear} is the number of brakes on the rear axle; t_t is the actuator response time.

After determining the parameters of the steering and brake system, we compare the flow rates required for them with the pump capacity specified in formula 3.

Depending on the operating pressure and the required volume of liquid, one pump with variable flow can be selected, and two pumps can be selected: one with variable flow, the operation of which is aimed at supplying the steering units and other consumers with working fluid while the dump truck is moving, and the second with constant flow, which is connected during operation of hydraulic cylinders of platform lifting during unloading.

4 Conclusions

The developed algorithm allows to determine the characteristics of the main consumers (hydraulic cylinders of the load platform lifting and steering wheels turning, braking mechanisms) in HS DT, we calculate and select the hydraulic pump. The use of the algorithm of HS DT parameters justification contributes to the reduction of design documentation development terms at the early stages of DT design.

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