Development of the conceptual design of vehicles for off-road container transportation for mining applications

Kirill Evseev[1,*], *Boris* Kositsyn[1], *George* Kotiev[1], *Anton* Stadukhin[1] and *Igor* Smirnov[2]

[1]Bauman Moscow State Technical University, 5/1, 2-ya Baumanskaya, Moscow, 105005, Russia
[2]Moscow Polytechnic University, 38, Bolshaya Semyonovskaya, Moscow, 107023, Russia

Abstract. The article substantiates the relevance of off-road container transportation by ground railless transport vehicles and weight-size parameters of the transported cargo for the mining operations. A hierarchy of complex mobility properties is developed to investigate the significance of performance properties, which is divided into levels of properties. Taking into account the hierarchy of properties, the measuring instruments are determined, the indicators of which can be used to determine the priority technical solution for container and rock transportation vehicles. The article provides a classification of tracked vehicles and tracked trains with the analysis of their design and layout variants. As a result, variants of the concepts of vehicles for off-road container and rock transportation have been formed. Based on the analysis of the hierarchy of performance properties, design and layout variants of modern tracked vehicles and considering the selected objects of research, the conceptual design of a semi-trailer tracked train and a tracked train with a double-hinge fifth wheel coupling has been proposed.

1 INTRODUCTION

The container traffic is increasing every year worldwide, new terminal infrastructure facilities are being built to handle sea and rail transport in order to deliver containerized goods to the remote end user. Over the past 30 years there has been a significant growth in container transportation, more than 9 times and in relation to other types of transportation – more than 2.5 times [1]. Most often, the standard containers are used for freight transportation: 20, 40- and 45-footer containers conforming to the international standard ISO 668:1995 (GOST R 53350-2009). The designations of these containers and their mass-dimensional characteristics are given in Table 1.

Table 1. Container designations and their weight-size parameters.

Name	Designation	Overall dimensions (L x W x H), mm	Gross weight, kg
45-footer	1EEE	13716x2438x2896	30480
40-footer	1AAA	12192x2438x2896	30480
20-footer	1CC	6058x2438x2591	30480

Transportation of containers using a single multi-purpose high mobility vehicle which can transport both one 45-foot container and two 20-foot containers at the same time is the most economically feasible option. These containers can be transported off-road using high mobility vehicles with a payload capacity determined by the total gross weight of the two 20ft containers (61 tons) and the required dimensions of the transport platform determined by the overall dimensions of the 45ft container.

It is known that the use of modern multi-axle wheeled vehicles for off-road container transportation is limited [2], as they have insufficient cross-country capability, which does not allow them to carry out container transportation over unprepared ground surfaces.

Therefore, the use of tracked vehicles and combinations of tracked vehicles is appropriate for off-road container transportation, and, considering the length of the transported cargo and its mass parameters, it is advisable to use only specialized combinations of tracked vehicles.

In addition, one of the promising trends in the development of ground railless vehicles for container transportation is the transition to unmanned driving using a traction electric drive. The movement of the state of the art vehicles of this type is generally provided by the "Follow me" technology, when the trajectory is determined by the lead vehicle moving ahead of the unmanned tracked train which maintains the trajectory set by the lead vehicle via remote control and automated control.

In this context, the prediction of mobility [3-8] and analysis of the significance of the performance properties of vehicles for off-road container transportation during the research phase is an urgent problem.

* Corresponding author: kb_evseev@bmstu.ru

2 Materials and Methods

The special vehicle for off-road container transportation, like any other vehicle, is characterized by a set of different performance properties: mobility, reliability, technical and economic properties and others. Depending on the functional purpose of the vehicle, when assessing the effectiveness of the adopted technical solutions, a certain set of the most important properties, the significance of which is determined by operating conditions, must be considered. In order to determine the priorities of properties, a scientifically justified hierarchy of performance properties, characteristic for the vehicles under consideration, was developed [9].

The final hierarchical structure of the performance properties of vehicles for container transportation is presented in Figure 1. Two levels of criteria (properties) and a level of alternatives (design and layout options for vehicles for container transportation) have been selected to investigate the significance of performance properties. The study of the significance of performance properties can be carried out based on expert assessments using the method of hierarchy analysis [10].

From the list of basic indicators that reveal various properties, let us highlight those that are appropriate to use when comparing innovative tracked vehicles and combinations of tracked vehicles for container transportation, and identify the necessary values for indicators of individual properties that tracked vehicles and combinations of tracked vehicles must meet to ensure that their mobility is not worse than that of existing wheeled vehicles.

By analyzing existing wheeled vehicles with the required payload capacity, it is possible to determine some indicators that tracked vehicles and combinations of tracked vehicles should comply with, finally, when reviewing the significance of vehicle performance indicators, we will use only the metrics from Table 2.

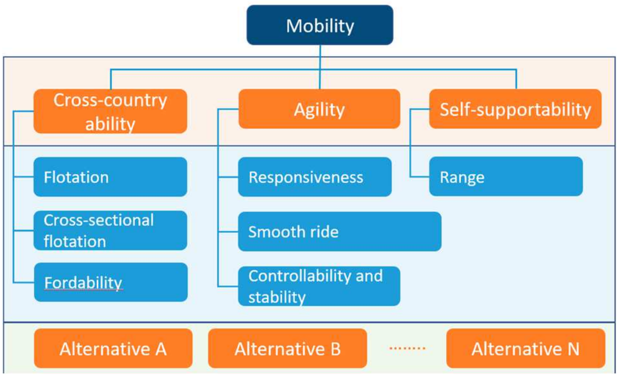


Fig. 1. Hierarchy of performance properties for the container transportation vehicles.

3 Results

It is economically efficient, as noted above, to provide for the off-road transportation of both one 45ft container and the simultaneous transportation of two 20ft containers, so that the carrying capacity of land vehicles should be at least 61 t and the length of the transportation platform should be sufficient to carry a container of at least 13716 mm length.

Among the existing multi-axle wheeled vehicles that can provide transportation of such cargoes are the following special wheeled chassis: MZKT-79221 and KAMAZ-7850 16x16 vehicles.

Table 2. Container designations and their weight-size parameters.

Measure
Cross-country ability
Mean contact pressure, kg/cm2
Maximum width of the canal to be crossed, m
Maximum height of escarpment (vertical wall) to be overcome, m
Maximum height of the counterscarp to be crossed, m
Maximum slope angle to be climbed, degrees
Maximum angle of the side slope to be crossed, degrees
Maximum slope angle when driving downslope, degrees
Minimum turning radius for the tracked vehicle (hauler), m
Overall driving range, m
Agility
Accelerating time from standstill to a specified travel speed, s
Average speed, km/h
Maximum speed, km/h
Critical speed for the turning maneuver, km/h
Critical speed for the lane change maneuver, km/h
Critical speed for S-turn maneuver, km/h
Self-supportability
Range, km

Such cargoes can also be transported by heavy duty wheeled vehicles and heavy road trains the appearance and technical characteristics of which are given in work [11], but the use of multi-axle wheeled vehicles for container transportation of heavy loads requires roads with a solid support base [2].

The work [2] gives the dependences reflecting the expedient scope of application of various ground railless vehicles with due regard to their gross weight and ground carrying capacity. Analyzing these dependences we established that a radical increase in the cross-country mobility of vehicles for off-road container transportation can only be achieved by using tracked vehicles or combinations of several tracked vehicles.

High container lengths and heavy loads limit the use of single tracked vehicles: it is necessary to use long wheelbase multi-roller tracked vehicles, whose turning capability is limited by the ratio of the length of the track surface to the track width (L/B) [12]. Thus, a cardinal increase in the cross-country mobility of vehicles for off-road container transportation can only be achieved through the use of multi-unit combinations of tracked vehicles.

We consider possible design and configuration solutions for tracked trains designed for container transportation and present their classification taking into account the existing classifications given in [7, 8].

Tracked trains for container transportation are classified as follows [13, 14]: by the number of movable units, by the number of articulated hitching points, by the location of articulated hitching points relative to movable units, by the method of turning and by the location of cargo.

Tracked trains are classified according to the number of moving units:

- two-unit vehicles (Figure 2 (a));
- three-unit vehicles (Figure 2 (b, c));
- multi-track vehicles (Figure 2 (d)).

Tracked trains are classified according to the location of coupling points relative to moving units [14, 15]:

- double jointed (Figure 2 (a));
- double jointed (Figure 2 (b, c));
- multi-joint (Figure 2 (d)).

Tracked trains are classified according to the location of coupling points relative to moving units [14, 15]:

- trailed (Figure 3 (a));
- semi-trailed (single jointed trains) (Figure 3 (b))
- wagons (double-jointed fifth wheels) (Figure 3 (c));
- trailed with an intermediate link (Figure 3 (d)).

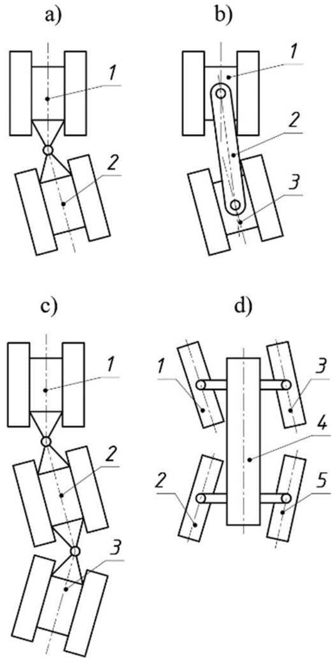


Fig. 2. Classification of tracked vehicles by the number of their moving units (by the number of the hitching points)

Tracked trains are classified according to the method of turning as follows:

- kinematic method, in which the units are forcibly folded relative to each other by means of actuators;
- power method, in which the curvilinear motion of the tracked train is the result of the difference in the applied moments to the drive wheels of the tracks of different sides;
- combined method combining the previous two.

Track trains are classified according to the arrangement of the load as follows:

- with a separate load arrangement on each unit of the tracked train (Figure 4 (a));
- with a monocargo arranged on the load platform of a double-jointed tracked train (Figure 4 (b));
- with a monocargo on the load platform of a trailed tracked train (Figure 4 (c));
- with a monocargo on the load platform of a semi-trailed tracked train (Figure 4 (d));
- with a monocargo on the load platform of a monocoque multi-track vehicle (Figure 4 (e)).

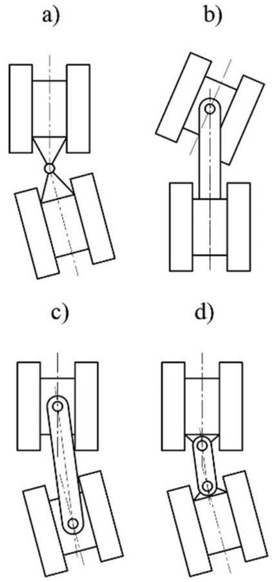


Fig. 3. Classification of tracked vehicles by location of coupling points in connection with the moving units

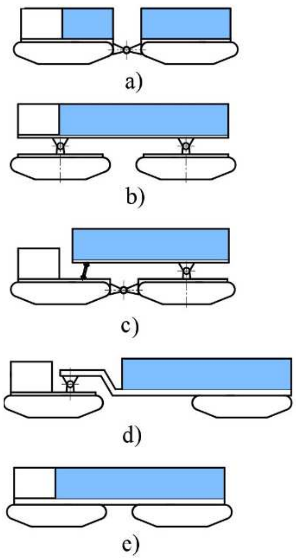


Fig. 4. Classification of tracked vehicles by the load arrangement

4 Discussion

Each of the possible design and layout variants of tracked trains has its advantages and disadvantages. However, it is possible to identify the variants that are not suitable for the container transportation under consideration, given the weight and dimensions of the cargo carried and the purpose of the vehicles.

The use of tracked trains with the trailing scheme with a separate arrangement of cargo on each unit of the tracked train (Fig. 4 (a)) does not allow for the transportation of indivisible cargo, which is a 45-foot container, so the tracked trains using this scheme will not be considered later on.

Trailing scheme tracked trains with an additionally mounted transport platform hinged to the units (Fig. 4 (c)) have redundant constraints which impose restrictions on the relative movement of the units and their articulation joint is a complicated assembly, so the use of this layout is not appropriate compared with the tracked train made according to the double hinged scheme (Fig. 4 (b)).

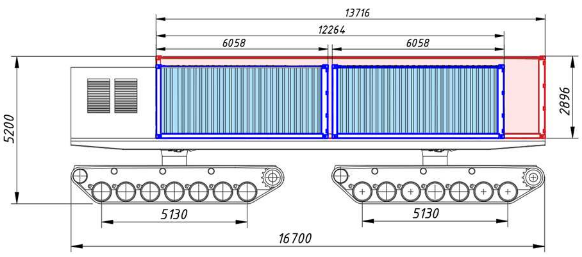
The existing designs of multi-track monocoque tracked trains (Fig. 4 (e)) have a low payload, this design and layout option is promising for mobile robots and agricultural machinery, such as the John Deere "8RX" four-crawler tractor, so the tracked trains made under this scheme will also not be considered further.

Tracked trains designed with a double hinged fifth wheel arrangement (Figure 4 (b)) and a semi-trailer arrangement (Figure 4 (d)) are promising in terms of their use for off-road container transportation and have no obvious drawbacks that would exclude them from further consideration. They can use different turning methods: kinematic, power and combined ones. Further research is required to determine the priority technical solution of the considered innovative variants of tracked trains.

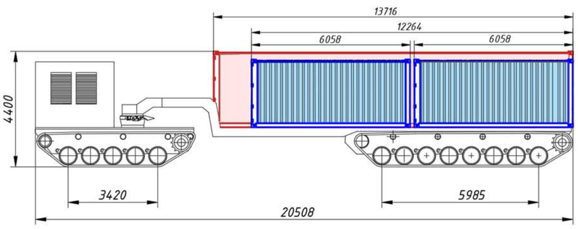
Thus, analyzing the developed classification and existing variants of designs and layouts, we select the following objects of research:

- a semi-trailer tracked train;
- a tracked train with a double-hinge fifth wheel coupling.

As a result of the analysis of the hierarchy of performance properties, design and layout variants of modern tracked vehicles and considering the selected objects of research, it is possible to form a concept of the studied vehicles. The conceptual design of a semi-trailer tracked train and a tracked train based on a double-hinge saddle arrangement are shown in Figures 5 (a) and 5 (b) respectively.



a)



b)

Fig. 5. Classification of tracked vehicles by the load arrangement

The second level of the hierarchy of properties of the complex mobility property for the tracked trains in question can be determined by means of mathematical simulation, which is an area for further research.

5 Conclusion

After development of the conceptual design of the vehicles for off-road container and rock transportation it is necessary to predict their mobility and analyze the significance of their performance properties at the stage of the research work. The developed hierarchy of performance properties is divided into two levels of properties to assess their significance. The measures of properties have been identified, which should be used in further research. Based on the analysis of the hierarchy of performance properties, design and layout variants of modern tracked vehicles and considering the selected objects of research, the conceptual design of a semi-trailer tracked train and a tracked train with a double-hinge fifth wheel coupling has been proposed.

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