Study of efficiency of a 6x6 all-terrain vehicle in coastal zone

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Abstract. In the paper, we consider relevance of autonomous mobile robotic system (AMRS) for coastal zones monitoring development. AMRS developed in Nizhny Novgorod State Technical University n.a. R.E. Alekseev is presented. General chassis characteristics are provided. The paper establishes four indicators of mobile chassis power efficiency: tractive force reserve under various operating conditions, tractive force for the certain probability of all soil surfaces, fuel consumption efficiency per 100 km, and the same indicator related to the carried load mass unit. Calculations based on the abovementioned indicators are made for 6x6 chassis, and for the track mover modification. The results show that on sand-gravel and sand roads power efficiency of wheeled chassis is 17-18% higher.

1. Introduction
The majority of people live near the coastal zones - along seas and oceans, lakes, reservoirs and large rivers. This is because water is an integral part of human life and activities. However, it is also a source of increased danger. Floods and storms cause substantial destruction and multiple deaths. That is why coastal zones are not just resorts, but sources of extreme danger. On the other hand, human activities considerably interfere with coastal ecosystem. Therefore, we need to monitor environmental situation in coastal zones.

Environmental monitoring solutions include fixed stations, or mobile complexes. The most rational solution currently is development of autonomous mobile robotic system (AMRS) for coastal zones monitoring. Application of specific chassis and robots for mobile measurements is quite promising.

Within the scope of works conducted by the authors of this paper, the following lines of research have been singled out:
1) specific operating conditions, which are non-relevant for general ground complexes, define methods and research performed to obtain characteristics of road and soil surfaces in coastal zones with regard to the season;
2) specifics of the equipment (its type and weight-dimension parameters) mounted on the mobile monitoring complex determine exterior design and chassis characterization methods;
3) continuous autonomous AMRS operation requires development of rational chassis design with regard to the coastal zone operating conditions, and power-efficient motion control.

The first issue was previously analyzed in papers [1-3], and the second one was considered in paper [1]. To evaluate validity of the selected design, we have developed an efficiency calculation method.
2. Selecting a power-efficient AMRS

2.1. Selecting a power-efficient AMRS

The subject of this research is an AMRS developed in Nizhny Novgorod State Technical University n.a. R.E. Alekseev. General view of the mobile complex is shown in Figure 1.

Figure 1. General view of AMRS. Pre-test.

A distinctive feature of this 6x6 mobile complex is possible installation of a removable track mover. General chassis characteristics are given in Table 1.

| Parameter                        | Value       |
|----------------------------------|-------------|
| Type of mover                    | Wheeled     | Track     |
| Full weight, kg                  | 2000        |           |
| Payload, kg                      | 500         |           |
| Dimensional length, mm           | 3800        |           |
| Dimensional body width, mm       | 2100        |           |
| Dimensional width                | 2100        | 2360      |
| Dimensional height (in transport position), mm | 3500 | 3690 |
| Dimensional height (in operating position), mm | 6400 | 6590 |
| Mover parameters                 | Tire size 33x12.5-15 | Track width, mm 400 |
| Clearance                        | 300         | 490       |
| Angle of approach at full load, deg. | 30       |           |
| Rolling angle (in transport position), deg. | 45       |           |
| Maximum speed                    | 45          | 35        |
| Engine type                      | Petrol      |           |
| Transmission type                | Manual      |           |
| Turning mode                     | Power turning |          |
2.2. Efficiency indicators

Mobility capability is determined by the correlation of tractive force $F_\varphi$ and motion resistance force $F_f$. A mobility capability criterion is presence of tractive force reserve, i.e.

$$\Delta F_\varphi = F_\varphi - F_f > 0.$$  \hspace{1cm} (1)

We suggest using this indicator for preliminary mobility capability evaluation.

In practice, we can sometimes consider only some operating conditions. It is enough to make sure chassis mobility is defined by a certain probability. If you try to design chassis with 100% cross-country capabilities, it will be too inefficient, large, heavy, and expensive to operate. Therefore, we shall define criterion (1) as follows:

$$P(\Delta F_\varphi > 0) \geq k_m,$$  \hspace{1cm} (2)

where $P(\Delta F_\varphi > 0)$ – accumulated probability of chassis tractive force exceeding zero under all operating conditions, $k_m$ – factor reflecting the value of such an event. $k_m = 0.95$ is enough for calculations, it means that chassis will be able to cross 95% of the surface.

If we select AMRS from different options, we need to ensure its power efficiency for maximum operation time. It means we need to evaluate fuel consumption in order to estimate autonomous operation time. Efficiency indicator for fuel consumption per 100 km shall be calculated according to the formula:

$$K_e^c = \int_\Lambda Q_s d\lambda,$$  \hspace{1cm} (3)

where $Q_s = f[F_f(\lambda)]$ – fuel consumption which depends on motion resistance force $F_f$ in certain operating conditions $\lambda$, $\Lambda$ – the whole range of operating conditions. $\Lambda = (\lambda_1, \lambda_2, ..., \lambda_n)$. Previous researches [1-3] conducted by the authors of this paper indicate the following main parameters which define operating conditions for sand-gravel surfaces in coastal zones: $\lambda = (\rho, E, c, \varphi)$, $\rho$ – soil bulk density, $E$ – modulus of elasticity, $c$ – internal soil traction, $\varphi$ – internal friction angle. Papers [1-3] also show that characteristics of coastal zone soil can be described by a statistical dependence, which is convenient for modeling.

To evaluate AMRS mobility and load-carrying efficiency, indicator (3) will be as follows:

$$K_e^m = K_e^c / m_c,$$  \hspace{1cm} (4)

where $m_c$ – weight of the load carried by chassis.

Criteria (3) and (4) are relevant in relative values when we compare several subjects of research, which comply with condition (1) or (2) under the whole range of operating conditions ($\Lambda$).

2.3. Efficiency calculation

The data we obtained previously will be used to calculate power efficiency of (1)-(4) 6x6 base chassis with respect to the above-mentioned criteria. To compare, for criteria (1) and (2) we shall use dependencies from papers [1, 5], and for criteria (3)-(4) we shall evaluate the effect of equipping AMRS with a track mover. The calculations will be based on the data provided in Table 1.

The results for base chassis with a wheeled mover show that probability of mobility with the same cross-country capabilities is 99% on sand-gravel and 98% on sand surface in the coastal zone. If we increase full chassis weight by 20%, loss-of-capability probability will be 4% higher for sand-gravel surface (if we increase the weight by 50% – by 14%) and 9% higher for sand surface (if we increase the weight by 50% – by 25%). 20%-lower weight ensures full chassis mobility with no loss-of-capability. If we reduce the radius by 20%, the cross-country capabilities will drop by 6% on sand-gravel and by 13% on sand surface. 20%-bigger radius ensures full chassis mobility with no loss-of-capability. If we decrease tire width by 20%, the cross-country capabilities will drop by 3% on sand-gravel and by 5% on sand surface. 20%-higher tire deflection ensures full chassis mobility with no loss-of-capability. The track mover modification has full chassis mobility with no loss-of-capability.
Therefore, if we consider base chassis, for criterion (1) wheeled chassis ensures mobility only under some operating conditions, but for criterion (2) wheeled and track mover modifications are equivalent provided that chassis mobility probability target is 95%.

The results of calculations for criteria (3) and (4) show that power efficiency of wheeled chassis is 17-18% higher on sand-gravel and sand surfaces, which also increases autonomous operation time.

3. Conclusions
The paper focuses on relevance of autonomous mobile robotic system (AMRS) for coastal zones monitoring development. We have established that for continuous autonomous operation of AMRS we need to develop rational chassis design with regard to the specific operating conditions in coastal zones, and power-efficient motion control.

The subject of this research is an AMRS developed in Nizhny Novgorod State Technical University n.a. R.E. Alekseev. General chassis characteristics are provided.

We have defined four power-efficiency indicators for mobile chassis: tractive force reserve under all operating conditions, tractive force for a specific certain probability of all soil surfaces, fuel consumption efficiency per 100 km, and the same indicator related to the carried load mass unit.

The results of calculations for 6x6 chassis and for the track mover modification show that both wheeled and track mover modifications have 98-99% mobility probability. On sand-gravel and sand surfaces, power efficiency of wheeled chassis is 17-18% higher. Therefore, the wheeled modification is more preferable if we consider motion resistance force on sand and sand-gravel surfaces of coastal zones.

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