THE STUDY OF MOTOR VEHICLES SUITABILITY FOR MOUNTING COMBAT SYSTEMS

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INTRODUCTION

The special-purpose modern combat systems perform complex functions in the extreme working conditions. In order to satisfy the users` requirements in the development process of these systems it is necessary to define the objective (aim) function of the system on the basis of the systemic approach and consequently on such defined objective function to set out concrete requirements for individual sub-systems. Considering that one of the basic requirements is the establishing of a quality system with the shortest development cycle period and minimal costs, the justified need presupposes that new systems be developed by the integration of existing sub-systems into development of which considerable know-how has been invested and which performed quite well in practice. This approach in development can ensure a considerable flexibility and the possibility to satisfy users` requirements, but can also be unsuccessful. The reasons for a possible development failure lie in the fact that the objective function need not secure the sub-systems of top quality characteristics that can in the best way contribute to the objective function as a whole [1]. Another reason, apart from the technological capabilities of the manufacturers that can always be a limiting factor, is related to the way in which the requirement has been defined, i.e., the objective function. Namely, the user frequently defines some requirements in general terms, and other requirements, however, in detail and strict way, so that, having in mind the fact that the requirements are almost in each case mutually confronted, there exists a genuine need to make correction in the course of their development. There is always evident interaction between the user (the customer) and the constructor, i.e., the manufacturer in developing the combat systems. It should appropriately ensure that the quality of the system be assessed in the right way only in the exploitation stage. On the other hand, one of the major characteristics of a combat system is its suitability for maintenance and modernization, which is at higher levels frequently entrusted to the manufacturer, so that the importance of interaction between the manufacturer and the user becomes quite significant.

One of the basic requirements related to the combat systems performances is their mobility, which presupposes that the systems have been mounted on the platforms of various motor vehicles, whereby this requirement has been satisfied. The motor vehicle onto which the combat systems are mounted (super-structured) apart from ensuring mobility should also meet a number of requirements which in the end should ensure that a combat system is not viewed separately from the platform, but that the term combat system presupposes a vehicle together with its superstructure. In order to accomplish this it must be ensured that the interaction of the combat system and the vehicle be such that it should secure functioning of the system in all conditions with accomplishment of all assigned performances. This paper

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represents an attempt to define general characteristics of vehicles as platforms for mounting combat systems, the superstructure characteristics and the way of its connectivity with the vehicle, as well as characteristics which describe the suitability of a specified category of a vehicle for mounting a special combat-purpose system.

THE BASIC CHARACTERISTICS OF VEHICLES AS PLATFORMS FOR COMBAT SYSTEMS BUILT-IN SUPERSTRUCTURE

When considering the possibility of vehicles selection for a combat system platform one should make the analysis in at least three fields – the analysis of the vehicle characteristics in terms of ensuring the mobility as a basic requirement for the integration of the combat platform, the analysis of the combat system purpose and the level of protection that the vehicle should ensure, as well as the analysis of the workloads of a vehicle which are the result of a combat system integration.

The mobility as one of the basic characteristics of the modern combat systems is ensured by different performances of a vehicle. Given the consideration of various vehicles types onto which a combat system can be mounted it is interesting to analyze the following characteristics of a vehicle: towing performances, possibilities of clearing obstacles (manoeuvrability), braking performances, steering capability and stability. While considering the towing performances the limiting criterion is not frequently the maximum speed, as in the case with transport and passenger vehicles, but the possibility of clearing an assigned steep terrain with a specified speed, medium or maximum movement speed outside the road network, the characteristics of acceleration, the minimal speed etc. The possibility of overcoming obstacles is also being analyzed from the aspect of the possibility of clearing obstacles of little volume, low coefficient of surface adherence and a high coefficient of rolling resistance, high obstacles (a vertical wall etc.), obstacles like ditches, water obstacles and so on. Considering the braking performances there are no specific requirements, except that the criteria for assessment of the efficiency of a braking system in certain segments can be more complex. The steering performances are very important, especially bearing in mind the fact that here we deal with the vehicles of large dimensions that are supposed to move across rough terrains or along the roads that have limited geometry. Stability is very significant and complex characteristic which has a major impact on the vehicle selection. It is important to note that the stability is analyzed as a static – through the analysis of the vehicle performance at acceleration stage, braking, moving round a bend and similar. It is especially interesting to consider the vehicle stability while accomplishing the objective function of a combat system.

The analysis of a combat system and the safety level that a vehicle should ensure gives the answer to a basic question – whether the combat armoured vehicle can be accepted as a platform or whether the platform can represent a highly manoeuvrable and passable all-terrain vehicle. In the category of combat armoured vehicles three types of vehicles are being considered – heavy combat vehicles based on the tank platform, light combat caterpillar-type vehicles based on the combat infantry vehicle and combat vehicles based on the platform of the armoured wheeled vehicle. In the category of the highly manoeuvrable all-terrain vehicles the all-terrain wheeled vehicles specially developed for applications in defence matters are being considered. These vehicles are different from commercial vehicles since their sub-systems have been so designed to ensure a high degree of manoeuvrability, and also have special sub-systems that ensure certain additional performances. Considering the fact that application of combat vehicles largely influences the safety level it is clear that the armoured platforms will be the candidates for those combat systems that are exposed to the direct enemy fire and the operation which can be accomplished if the crew is protected in the armoured section. Another major criterion for platforms selection is the unification of vehicles within a combat unit. This criterion can be even more important, so that, for instance, the tank platform is in most cases also used as a bridge pillar, that is to say, as a logistic vehicle in tank units because in this way the logistic support is simplified and the vehicle crews training is made easier in the process of combat systems exploitation. In figure 1 there is a tank as a basic combat weapon, as well as combat systems developed on the tank platform – bridge pillar and tow tank. The selection preference for a combat vehicle selection as a platform for a combat system can be also be related to an available contingent of armoured vehicles. Namely, of late many armies have at their disposal a larger number of tanks and armoured carriers of older generations which are no longer necessary for their basic use. There is a tendency to carry out the so-called conversion which encompasses also the modernization of a vehicle as a platform and in this way ensure vehicles that will be suitable for super-structured combat systems.

1a)

1b)

1c)

Figure 1: *The heavy tracked combat vehicle as a platform for different super-structured combat systems, a) tank, b) mechanised bridge, c) logistic vehicle*

The all-terrain vehicles of high manoeuvrability whose principal use is the transportation of troops and equipment are of major interest as the platforms of mounted combat systems. These vehicles are in most cases used for various mounted combat systems whose basic use is related to the operations outside the immediate combat contact. Since we deal here with vehicles whose manufacture price, as well as the costs of logistic support in the course of the life cycle are significantly lower than the price and the costs of the life cycle of armoured vehicles, of late there has been done significant research work in order to ensure the integration of different platforms onto the vehicle of this type. The unification as a major parameter for the selection of combat platforms also in the selection preference of this kind has a major impact. Thus, for instance, within artillery units, in case the artillery weapons are being mounted onto the vehicle, as a platform can be used a vehicle that can perform some other functions – transportation of ammunition, troops etc. In figure 2 is shown the vehicle with the variant of a built-in crate in case it is a transportation vehicle, as well as self-propelled multiple rocket launcher mounted onto the same vehicle.

2a)

2b)

Figure 2: *The all-terrain vehicle of high manoeuvrability as a platform for various mounted combat systems, a) transport vehicle, b) self-propelled multiple rocket launcher*

The analysis of the workloads of vehicles that are result of a mounted combat system has a great significance in the vehicle selection process. Apart from the mass and the superstructure mass centre of gravity position as a parameter for the vehicle selection that influence the performances of the vehicle itself, a great importance is also given to the way of establishing connectivity between the vehicle and superstructure, the way of distributing the load, the ratio of workloads in case the combat system does not perform its function and the case when the combat system performs its function, geometrical characteristics of a combat system in various situations and so on. An important element for analysis of workloads is also the fact that in case of armoured vehicles the connectivity between the superstructure and the vehicle is established through the armoured section, and in case with the all-terrain vehicles through a high manoeuvrability via the frame.

THE VISUALISATION OF A VEHICLE DESIGN CONCEPTION

The development of a combat system integrated onto the motor vehicle platform on the one hand presupposes the selection of the most suitable platform (of a vehicle), and on the other, the selection of the most suitable way to mount a combat system onto the platform. Both these tasks imply the analysis of a large number of possible variants which is not feasible without the application of modern methods and computer modelling techniques. The computer modelling is in this case a powerful tool for the analysis of a large number of solutions and the selected solution optimization.

Since the vehicle is an assembly of mutually interdependent integral parts, which accomplish the assigned objective by their joint operations, the systemic approach to the analysis of such a technical system enables us to analyze the characteristics of one section or a system from the aspect of its impact on other sections, i.e. on its place and role in the whole system. As the basic functions of a vehicle have in most cases mutually confronted requirements, it is necessary to achieve their mutual coordination, in other words their simultaneous satisfaction, so that it is necessary to start with the requirement for the whole vehicle, and then to make the analysis of the system impact on its component parts.

Systemic engineering is supposed, on the basis on the previously set requirements, to enable the production of specification of necessary operational characteristics of the technical system with the proposal of the most appropriate configuration and the organization of the major sections. In order to achieve this it is necessary to ensure a high degree of confidence in the results obtained without the prior production of the physical prototypes, that is, on the analysis of the virtual model. By applying the systemic approach we define not only the requirements in relation to the developed system, in other words its components, but the way in which to achieve their satisfaction.

In the course of the combat system designing integrated onto the vehicle the level of built-in characteristics should constantly be checked up and compared with the set requirements prior to the designing of the physical prototype. Thus the need arises to develop the appropriate methodology by which it is possible to design, simulate, check, and even test the system at the level of the virtual prototype.

Today the designers have at their disposal a large support and assistance in the modern development techniques of the so-called “virtual” models which make it possible to assess the requirements satisfaction of the monitored system prior to the completion of the first physical prototype. In this way the controlled virtual environment is established in which the preconditions for the meeting of basic requirements of the modern vehicle development are achieved.

A great advantage of designing by means of the virtual modelling process is reflected in the possibility to prevent human errors in the course of designing, which enable the simulated tests. These tests, considering that they are conducted on the virtual model, offer an objective assessment of the right and successful solution prior to the start of the physical model test.

In this way is also changed the role of tests which have so far been conducted exclusively on the physical model. These tests are now preceded by virtual tests. The visualization in essence represents a mediator between the monitored output characteristics of the system, that is being simulated and the constructor (designer). The software for visualization enables the designers to use the tri-dimensional visual data, creating by this the idea of the performance of a designed system or its components in real time, in the course of performing the objective function.

The designers have nowadays at their disposal a large number of a variety of programs from the virtual modelling domain. Software starts mainly from the 2D drawing, then through 3D parametric modelling to checking up of kinematics, dynamics, heat and other calculations and virtual tests of the 3 D models. In figure 3 is shown the 3 D model of the frame of an all-terrain vehicle [2] with the elements of an addition frame, stands (legs) and the elements of superstructure (mount structure).

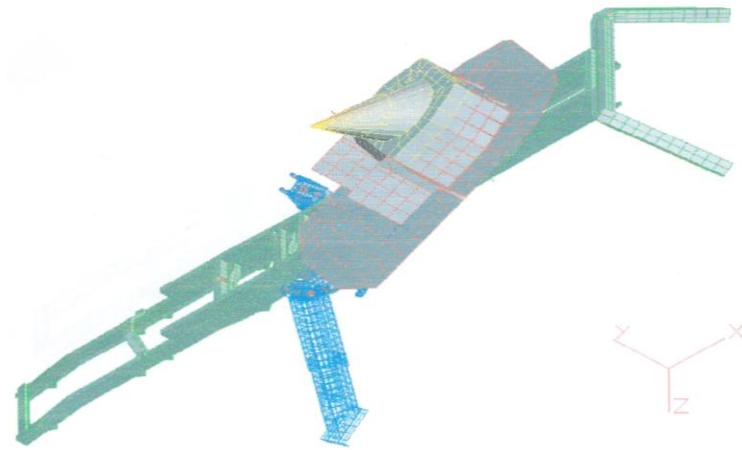

Figure 3: *3 D model of the frame of a measurement vehicle with the elements for superstructure construction*

THE ANALYSIS OF THE ALL-TERRAIN VEHICLE SUITABILITY FOR MOUNTED ARTILLERY SYSTEM

In the analysis of the conception of the special superstructure vehicle, from the aspect of suitability for superstructure construction (bearing in mind that it will carry powerful weapons) the initial criteria should be defined consequently leading to the designing conception. In case of the mounted artillery system onto the all-terrain vehicle it is important to consider the following:

- the barrel position of a weapon in the march formation (backwards or in the direction of moving),
- the barrel position in the combat position (most likely in the opposite direction from the moving, driving),
- the allowance of ammunition size (space),
- requirements in terms of building in accessory equipment,
- the number of the crew,
- requirements for an additional cabin for the crew,
- angle of fire in line, left and right of the vehicle longitudinal axis,
- necessary elevation,
- requirements for the ammunition magazine containing projectiles and
- requirements for existence of an electro-hydraulic system for the vehicle stabilization at a firing stage, movement of the weapon in assigned directions and elevation and loading of weapon.

Within the framework of development research [3, 4] which has been conducted in the Military Technical Institute the analysis of suitability of all-terrain vehicles for mounted artillery system has been made. The analysis has been made for two groups of vehicles:

- all-terrain vehicles of the drive formula 8x8 and
- all-terrain vehicles of the drive formula 6x6

To make the analysis of suitability of all-terrain vehicles for mounted artillery weapons a selection has also been made of the number of bridges and the number of drive bridges. The total number of bridges depends on the total mass of weapons and possible specific pressure onto ground. The specific pressure depends on the axis load and the contact surface between wheels and ground, and is conditioned by the ground capacity.

Considering that this weapon will be employed on the terrains and on the surfaces with little capacity, the axis load should be within the limits from 5.000 daN to 8.000 daN. Consequently, for the expected total mass of weapons of 25 000 kg to 30 000 kg, the total number of bridges should be from 3 to 4. If the maximum adhesion weight is planned to be achieved, it is necessary for all wheels to be drive wheels since in this case the adhesion weight equals the overall mass of the weapons, which is the main condition for ensuring the maximum mobility and manoeuvrability of a vehicle.

The analysis of positioning the weapon onto the all-terrain vehicle has been made for vehicles FAP 3032 BS/A 8x8; KAMAZ 63501, 8x8; TATRA 8x8; URAL 8x8; MZKAT 8x8; FAP 2026 6 t, 6x6; KAMAZ 43118, 6x6; TATRA 6x6; URAL 6x6 and MZKAT 6x6. Within the preliminary analysis of satisfying basic technical requirements the following activities have been carried out:

- measurements of masses and their positions aboard the vehicle – the coordinates of center of gravity have been defined,
- the towing-dynamic calculations have also been conducted - towing-dynamic characteristics have been thus calculated,
- axle load has been defined,
- parameters of the longitudinal static stability of a vehicle have been calculated,
- on the basis of static stability at the side camber the maximum angle of the side camber has been calculated and
- the analysis has been made for the tires capacity for each vehicle.

By this analysis a conclusion has been drawn that from the aspect of performances the most suitable vehicle for superstructure building is КАМАЗ 63501, 8x8.

The criteria for assessment of suitability for artillery systems superstructure

In order to obtain exact indicators on the vehicle suitability for artillery system superstructure in the research work [5] a detailed analysis has been made with the aim of identification of the parameters for the quantitative assessment of suitability from various aspects. In this regard the specific factors that ensure the afore-mentioned assessment have been introduced.

The criteria of suitability of an all-terrain vehicle with built-in superstructure can be defined in a variety of ways and a variety of viewpoints since the assessment criteria can also be different and depend on the purpose of a superstructure, that is, on the customer`s requirements.

The main criteria that will be applied to give the assessment of suitability for building superstructure should establish the capabilities of a vehicle to carry a load. The possibility of receiving a load depends on the resistance of the construction to bending and twisting of each concrete vehicle. This possibility depends on the geometrical characteristics of longitudinal and transversal frame supporters and on the character of their connection (riveting, total or partial welding, bolted joint etc) and the characteristics of the frame construction material. Since the geometrical characteristics of longitudinal supporters have the primary impact on the possibility of receiving a load, it has been established that the factor of the possibility of load receiving should equal the resistance moment of the vehicle frame. On the basis of calculations about the resistance moments the vehicle type ranging can be carried out and draw a conclusion on the vehicle suitability from the aspect of load receiving and the necessity of building an additional frame for receiving a load on the part of the superstructure. In the case study it was established that the vehicle frame from the family KAMAZ possesses two times larger resistance moment than the vehicle belonging to the family FAP, so that according to this criterion the advantage has been given to vehicle of the KAMAZ family.

The second criterion to assess the suitability of a vehicle for a superstructure building is the vehicle stability. The vehicle stability with mounted artillery weapons depends on the firing line elevation, the position of the system centre of gravity, overall system mass and the distance between the supporting points (with the vehicles these are wheels, if there are not any additional supporting legs or stands). From this it can be concluded that for the assigned firing line elevation and constant overall system mass, the vehicle stability at the moment of firing a projectile is subjected to both the centre of gravity position and the tires tracks. Thus it could be stated that the vehicle stability measurement represents the tires tracks and the elevation of the system`s centre of gravity. On the basis of such statement the factor of stability can be defined as:

The factor of stability at the moment of a projectile firing F_{st} can be defined as:

$$F_{st} = B \cdot h \tag{1}$$

where the following denotes:

- B – the width of the vehicle tracks,
- h – the height of the vehicle centre of gravity

By analyzing the value of the stability factor for different vehicles it has been concluded that there is not a significant difference, i.e. all analyzed vehicles have nearly the same suitability of being super-structured in terms of stability. It is the consequence of the law-regulated limitation of the maximum allowed vehicle width of up to 2.500 mm, which entails the tire tracks of almost 2000 mm, while the similar centre of gravity elevation with all vehicles is the result of the similar design. The absolute value of the stability factor with all vehicles was such that vehicles in this regard did not satisfy the stability requirements at the moment of projectile firing at all assigned angles. Thus it was defined that the meeting this requirement presupposes designing the additional supporters in the form of legs (stands) which should satisfy this requirement in all projected firing conditions.

The third criterion that can contribute to the assessment of the vehicle suitability for superstructure building is the possibility of maintenance. In the maintenance possibility analysis special attention has been paid to the superstructure impact on maintenance possibility of a basic vehicle. The maintenance possibility evaluation is a complex matter since it is difficult to define precise criteria for its presentation. Generally speaking, it is quite clear that the vehicles with the special superstructures have as a rule lesser maintenance possibility than the vehicles without superstructures.

Especially significant criterion for assessment of vehicles superstructure suitability is the additional load to vehicle structures as the consequence of the superstructure building. Within all vehicle structures, according to the previous experimental tests, it has been established that the largest loads occur on the vehicle frame, i.e. in the section where it joins the weapon junction. In order to more thoroughly evaluate the effect of successful mounting of weapon it is necessary to evaluate the additional load degree according to the adequate factors. In this case the additional load factor has been defined (F_{do}) which represents the ratio of weapon load in different conditions of exploitation. It has been considered in two characteristic cases:

- Additional load of the vehicle frame at projectile firing. Here the additional load factor is defined as the ratio of the vehicle frame strain at the moment of live projectile firing and the strain at the moment of the hydro shell firing. The hydro shell is used because the hydro shell tests can be conducted outside the test range (proving ground) which corresponds the firing range intended for concrete ballistic elements (since there is no projectile) and it is much cheaper because the projectile is not used. The recoil power effect with the hydro shell testing is nearly equivalent to the recoil power effect of the corresponding projectile. During these tests it has been concluded that the change of recoil effect in weapon with hydro shell and live shell is not equivalent although the recoil power effect in both cases is nearly equivalent.
- The additional vehicle frame load at the moment of projectile firing and in marching position. The additional load factor is here defined as the ratio of frame strain in case when the superstructure performs its purposeful function (in our case it is at the moment of projectile firing) and the strain in the case when the superstructure does not perform its function, i.e. in the course of movement (in concrete case it is in the marching position, when there is no projectile firing).

The addition load factor in the first specific case can be analytically shown in the following way:

$$F_{do} = \frac{\Phi_b}{\Phi_h} \tag{2}$$

where

- Φ_b – the vehicle frame strain in the moment of live projectile firing, at the observation place [$\frac{N}{mm^2}$],
- Φ_h – the vehicle frame strain in the moment of hydro shell firing, at the observation place [$\frac{N}{mm^2}$],

The additional load factor in the second specific case can be shown analytically in the following way:

$$F_{do} = \frac{\Phi_b}{\Phi_m} \tag{3}$$

where - Φ_m – the vehicle frame strain in the marching position, in the observation place [$\frac{N}{mm^2}$].

The analysis of the additional load factors shown in (2) and (3) points to the fact that the most influential parameters are the frame surface and the thickness of the frame wall. It is further noticed that the theoretical evaluation of the defined factors is significantly subjected to the hindering circumstances because of unknown influences of the simulation models on their value, and in the experimental part of the work, on the basis of measurement results, the concrete values of load factors have been established and they range from 1,36 to 2,38.

Figure 4: *The artillery system integrated onto the mobile platform*

By defining the factors of additional load explicitly the increase of load in the observation place for two specific conditions of performance has been shown and it has also enabled insight into the superstructure successfulness of this vehicle type. On the basis of defined criteria and methodology defined in [5] the vehicle selection was made with presentation of the prototype of the integrated combat platform shown in figure 4.

CONCLUSIONS

The integration of combat system onto the mobile platform in the form of a motor vehicle ensures better performance quality of the very system because the combat system in this case realize additional performances mostly in terms of its mobility. When evaluating the suitability of a vehicle for superstructure building it is necessary to pay attention to a large number of affecting parameters which should satisfy the criteria that lead to the evaluation of the system successfulness. Considering that the combat system being mounted does not itself perform the function, but that the term combat system indicates the integral construction consisting of a vehicle and a combat system it is obvious that the quality of this complex system will depend not only on the sub-system quality (a vehicle and superstructure) but also on the quality of realizing their connectivity. By introducing the criterion for assessment of vehicle suitability with built-in combat system superstructure, and also the factors which quantify individual criteria the systemic approach of analyzing this task is ensured and also conditions were obtained for the results to be satisfying, saving time and resources for construction and evaluation of the physical prototypes.

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